ELECTRICIAN

TRADE THEORY

NSQF LEVEL - 4.5

VOLUME - 2

HANDBOOK FOR CRAFTS INSTRUCTOR TRAINING SCHEME

Directorate General of Training

DIRECTORATE GENERAL OF TRAINING
MINISTRY OF SKILL DEVELOPMENT & ENTREPRENEURSHIP
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A Comprehensive Training Program
under Crafts Instructor Training Scheme (CITS)
for Instructors

HANDBOOK ON TECHNICAL INSTRUCTOR TRAINING MODULES

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सत्यमेव जयते

भारत सरकार
कौशल विकास एवं उद्यमिता मंत्रालय
GOVERNMENT OF INDIA
MINISTRY OF SKILL DEVELOPMENT
AND ENTREPRENEURSHIP

Foreword

In today's rapidly evolving world, the role of skilled craftsmen and women is more crucial than ever. The Craft Instructor Training Scheme (CITS) stands at the forefront of this transformation, shaping the educators who will train the next generation of artisans and technicians. This book aims to provide an in-depth understanding of the subject, exploring its significance, methodologies, and impact on vocational training.

The Craft Instructor Training Scheme was established with the objective of enhancing the quality of instruction in industrial training institutes and other vocational training institutions. By equipping instructors with advanced skills and knowledge, the scheme ensures that they are well-prepared to impart high-quality training to their students. This, in turn, contributes to the creation of a highly skilled workforce capable of meeting the demands of modern industry.

The initial chapters provide the importance of specialized instructor training. Following this, detailed chapters delve into the curriculum covering advanced techniques, safety protocols, and instructional strategies. Each section is designed to offer both theoretical insights and practical applications, ensuring a well-rounded understanding of the subject.

The book offers recommendations for overcoming obstacles and enhancing the effectiveness of the program, with the ultimate goal of producing highly skilled instructors capable of shaping the future workforce.

This book is intended for a diverse audience, including current and aspiring instructors, vocational training administrators, policymakers, and industry stakeholders. It serves as a valuable resource for understanding the intricacies of the subject and its pivotal role in vocational education.

I extend my heartfelt gratitude to all contributors who have shared their experiences and expertise, enriching this book with their valuable insights. Special thanks to the contribution of the development team, reviewers and NIMI that have supported this endeavor, providing essential data and resources.

It is my sincere hope that this book will inspire and guide readers in their efforts to enhance vocational training, ultimately contributing to the development of a skilled and competent workforce.

ATUL KUMAR TIWARI, I.A.S.
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GOVERNMENT OF INDIA
MINISTRY OF SKILL DEVELOPMENT & ENTREPRENEURSHIP
DIRECTORATE GENERAL OF TRAINING

FOREWORD

The Craftsmen Training Scheme (CTS) implemented by the Directorate General of Training (DGT) provides skill training to the youth and ensures a steady flow of skilled manpower for the industry. It aims to raise quantitatively and qualitatively the industrial production by systematic training, and to reduce unemployment among the youth by providing them with employable skills.

The Craft Instructor Training Scheme (CITS) is an indispensable part of the Craftsmen Training Scheme (CTS). It offers comprehensive training both in 'skills' and in 'training methodology' to the instructor trainees to make them conversant with techniques of transferring hands-on skills.

I congratulate NIMI for taking the initiative of preparation of the course content for CITS. This will help institutionalize the mechanism for imparting training to the trainers all across the ecosystem. I also extend my gratitude to the Instructors and Officials of National Skill Training Institutes (NSTIs) and the DGT for their invaluable contribution in preparation of the CITS course content.

As we navigate the complexities of a rapidly changing world and the technological disruptions, the significance of CTS and CITS has increased manifold. It not only empowers individuals with practical skills but also lays the foundation for a prosperous future. I am confident that this book will serve as a guiding light to all instructor trainees for skill development and nation-building.

(Trishaljit Sethi)

PREFACE

The Craft Instructor Training Scheme is an indispensable module of the Craftsmen Training Scheme, which has been an integral part of the Indian skill development industry since its inception. This program aims to equip instructors with the necessary skills and teaching methodology to effectively transfer hands-on skills to trainees and promote a holistic learning experience. The first Craft Instructor Training Institute was established in 1948, followed by six more institutes across India in 1960. Today, these institutes, including the National Skill Training Institute (formerly Central Training Institute for Instructors), offer the CITS course, which is mandated by the Directorate General of Training (DGT).

The Craft Instructor training program is designed to develop skilled manpower for industries. The course aims to offer instructors an opportunity to improve their instructional skills, engage learners effectively, offer impactful mentoring, and make efficient use of resources, leading to a more skilled workforce in various industries. The program emphasizes collaborative and innovative approaches to teaching, resulting in high-quality course delivery. Overall, the Craft Instructor Training Scheme is a pivotal program that helps instructors grow in their careers and make a significant contribution to society. This program is essential for developing skilled manpower and promoting a robust learning environment that benefits both trainees and instructors alike.

ACKNOWLEDGEMENT

National Instructional Media Institute (NIMI) sincerely acknowledges with thanks for the co-operation and contribution extended by the following experts to bring out this Instructional material **(Trade Theory)** for **CITS Electrician (Common for Wireman) (Volume - II of II) (NSQF Level - 4.5)** under the **Power** Sector for **Instructors**.

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NIMI records its appreciation of the Data Entry, CAD, DTP Operators for their excellent and devoted services in the process of development of this Instructional Material.

NIMI also acknowledges with thanks, the invaluable efforts rendered by all other staff who have contributed for the development of this Instructional Material.

NIMI is grateful to all others who have directly or indirectly helped in developing this IMP.

ABOUT THE TEXT BOOK

The Vocational Instructor Training Program is a comprehensive initiative designed to equip aspiring students with the necessary skills and knowledge to effectively teach in vocational education settings. This program encompasses a range of pedagogical strategies, instructional techniques, and subject-specific content tailored to the diverse vocational fields. Participants engage in coursework that covers curriculum development, assessment methods, classroom management, and the integration of industry-relevant technologies. Practical experience and hands-on training are emphasized, allowing participants to apply theoretical concepts in real-world teaching environments. Through collaborative learning experiences and mentorship opportunities, aspiring vocational instructors develop the confidence and competence to facilitate engaging and impactful learning experiences for their students. This training program aims to cultivate a new generation of educators who are not only proficient in their respective vocational fields but also adept at fostering the success and employability of their students in today's competitive workforce.

This text book covers communication, self-management, information and communication technology, entrepreneurial and green skills. It has been developed as per the learning outcome-based curriculum.

G C Rama Murthy,
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CONTENT

MODULE 11 : Electronics

LESSON 60-69: Resistors, Colour code, types and characteristics

Objectives

At the end of this lesson you shall be able to

- explain construction, types, colour coding and application of resistors in circuits.

Resistors: These are the most common passive component used in electronic circuits. A resistor is manufactured with a specific value of ohms (resistance). The purpose of using a resistor in circuit is either to limit the current to a specific value or to provide a desired voltage drop (IR). The power rating of resistors may be from 0.1 W. to hundreds of Watts.

There are four types of resistors

1 Wire-wound resistors

2 Carbon composition resistors

3 Metal film resistors

4 Carbon film resistors

1 Wire-wound resistors

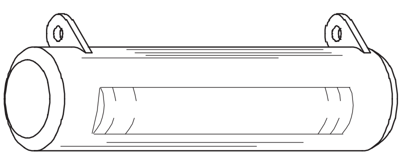
Wire-wound resistors are manufactured by using resistance wire (nickel-chrome alloy called Nichrome) wrapped around an insulating core, such as ceramic porcelain, bakelite pressed paper etc. Fig 1 shows this type of resistor.

2 Carbon composition resistors

These are made of fine carbon or graphite mixed with powdered insulating material as a binder in the proportion needed for the desired resistance value. Carbon-resistance elements are fixed with metal caps with leads of tinned copper wire for soldering the connection into a circuit. Fig 2 shows the construction of carbon composition resistor.

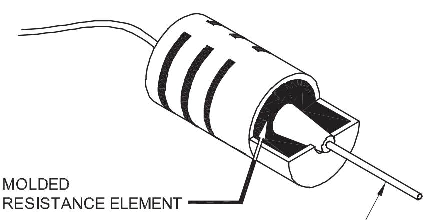
Carbon resistor are available in values of 1 ohm to 22 megohms and of different power ratings, generally 0.1, 0.125, 0.25, 0.5 and 2 watts.

Fig 1



WIRE-WOUND FIXED RESISTOR

Fig 2



CARBON COMPOSITION RESISTOR

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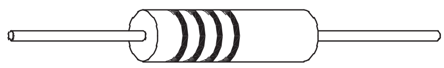
3 Metal film resistors (Fig 3)

Thin film resistors are processed by depositing a metal vapour on a ceramic base. Metal film resistors are available from 1 ohm to 10 MW, upto 1W. Metal film resistors can work from 120°C to 175°C.

4 Carbon film resistors (Fig 4)

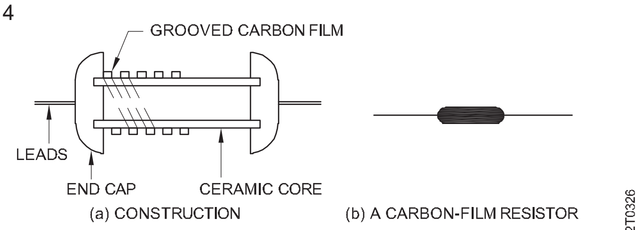
In this type, a thin layer of carbon film is deposited on the ceramic base/tube. A spiral groove is cut over the surface to increase the length of the foil by a specialised process.

Fig 3



METAL FILM RESISTOR

Fig 4



CARBON – FILM RESISTOR

Carbon film resistors are available from 1 ohm to few Meg ohm and up to 2W and can work from 85°C to 155°C.

Specification of resistors: Resistors are specified normally with the four important parameters

1 Type of resistor
2 Nominal value of the resistors in ohm (or) kilo ohm (or) mega ohm.
3 Tolerance limit for the resistance value in percentage.
4 Loading capacity of the components in wattage

Example

100 ± 10% , 1W, where as nominal value of resistance is 100Ω.

The actual value of resistance may be between 90 Ω to 110 Ω, and the loading capacity is maximum 1 watt.

The resistors can also be classified with respect to their function as

1 Fixed resistors
2 Variable resistors

Fixed resistors : The fixed resistors is one in which the nominal value of resistance is fixed. These resistors are provided with pair of leads. (Fig 2 to 4)

Variable resistors (Fig 5) : Variable resistors are those whose values can be changed. Variable resistors includes those components in which the resistance value can be set at the different levels with the help of sliding contacts. These are known as potentiometer resistors or simply as a potentiometers.

It is provided with 3 terminals as shown in Fig 5 and 6. They are available with carbon tracks (Fig 6) and wire wound (Fig 6) types. Trimmer potentiometers (or) resistor which can be adjusted with the help of a small screw driver. (Fig 7).

Resistance depends upon temperature, voltage, light: Special resistors are also produced whose resistance varies with temperature, voltage, and light.

Light dependent resistor (LDR): The LDRs are also known as photo- conductors. In LDRs the resistance falls with increase in intensity of illumination. The phenomena is explained as the light energy frees some electron in the materials of the resistors, which are then available as extra conducting electrons. The LDR shall have exposed surface to sense the light. These are used for light barriers in operating relays. These are also used for measuring the intensity of light.

Marking codes for resistors

Commercially, the value of resistance and tolerance value are marked over the resistors by colour codes (or) letter and digital codes.

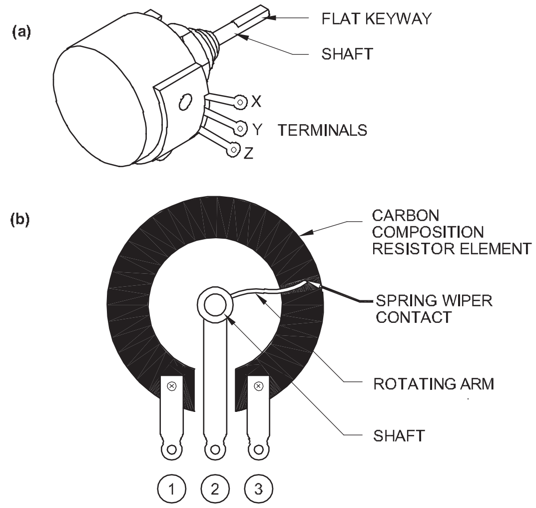
Resistance and tolerance value of colour coded resistors.

The colour codes for indicating the values to two significant figure and tolerances are given in Table 1 as per IS:8186.

The two significant figures and tolerances colour coded resistors have 4 bands of colours coated on the body as in Fig 8.

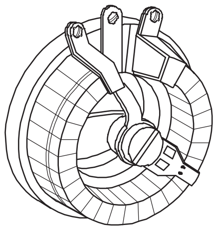
The first band shall be the one nearest to one end of the component resistor. The second, third and four colourbands are shown in Fig 8.

Fig 5



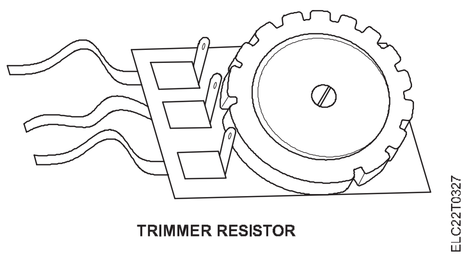
VARIABLE CARBON-RESISTANCE (a) EXTERNAL VIEW
(b) INTERNAL VIEW OF CIRCULAR RESISTANCE ELEMENT

Fig 6



WIRE-WOUND VARIABLE RESISTOR

Fig 7



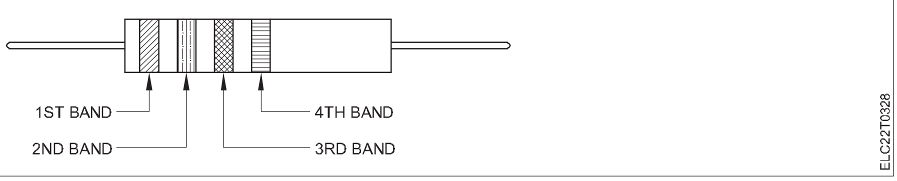
TRIMMER RESISTOR

Table 1

Values to two significant figures and tolerances corresponding to colours

Colour	First Band/ Dot	Second Band/ Dot	Third Band/ Dot	Fourth Band/ Dot
	First Figure	Second Figure	Multiplier	Tolerance
Silver	—	—	10^{-2}	± 10 %
Gold	—	—	10^{-1}	± 5 %
Black	—	0	1	—
Brown	1	1	10	± 1 %
Red	2	2	10^{2}	± 2 %
Orange	3	3	10^{3}	—
Yellow	4	4	10^{4}	—
Green	5	5	10^{5}	—
Blue	6	6	10^{6}	—
Violet	7	7	10^{7}	—
Grey	8	8	10^{8}	—
White	9	9	10^{9}	—
None	—	—	—	± 20 %

Fig 8



The first two colour bands indicate the first two digits in the numeric value of resistance. The third colour band indicates the multiplier. The first two digits are multiplied by the multiplier to obtain the actual resistance value. The forth colour band indicates the tolerance in percentage.

Example

Resistance value : If the colour band on a resistor are in the order- Red, Violet, Orange and Gold, then the value of the resistor is 27,000 ohms with +5% tolerance.

First colour	Second colour	Third colour	Fourth colour
Red	Violet	Orange	Gold
2	7	1000(10^3)	±5%

Tolerance value: The fourth band (tolerance) indicates the resistance range within which is the actual value falls. In the above example, the tolerance is ±5%. ±5% of 27000 is 1350 ohms. Therefore, the value of the resistor is any value between 25650 ohms and 28350 ohms. The resistors with lower value of tolerance (precision) are costlier than normal value of resistors.

For less than ten ohms, the third band will be either golden or silver.

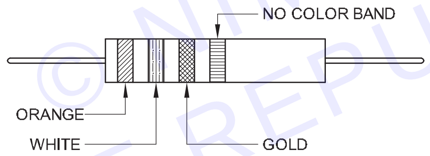
The colours are,

Gold - 10-1 = 1/10 = 0.1

Silver - 10-2 = 1/100 = 0.01

Example (Refer Fig 9)

Fig 9



Colour of 1st Band	Colour of 2nd Band	Colour of 3rd Band
Orange	White	Gold
3	9	1/10

thus, the value of resistor is 39/10 or 3.9 ohms.

Large value resistances are expressed in kilo ohms and megohms. Letter 'k' stands for kilo and M stands for mega. One kilo equals 1000 (103) and one mega equals 1000000 (106). The resistance values are expressed as

1000 ohms	=	1 k
1800 ohms	=	1k 8
100 ohms	=	0.1 k
10000 ohms	=	0.1 M
1500000 ohms	=	1 M 5.

Semiconductor theory-Active and passive components

Objectives: At the end of this lesson you shall be able to

- explain atom conductor, semiconductor, insulator and atomic structure
- state the function of N and P type semiconductor, PN junction, depletion region
- state the coding of semiconductor devices and its meaning
- explain active and passive components, symbols - uses.

Atom

The very tiny fundamental unit of an element which is capable of independent existence is the atom. An atom of any element consists of a central core called Nucleus. A number of small particles called electrons move around the central core.

The nucleus contains protons and neutrons. A proton in the nucleus possess a positive electrical charge. An electron in an atom possess negative electrical charge. In normal state, the atom is electrically neutral, that is the number of electrons is equal to the number of protons in the nucleus.

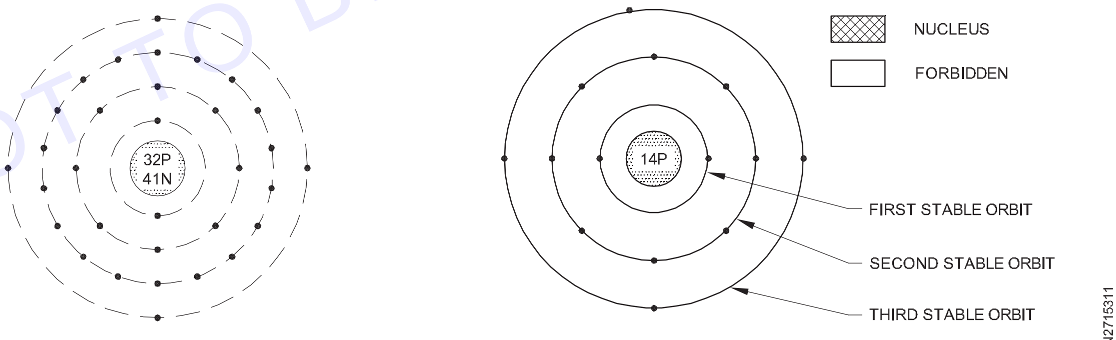
Difference between conductors insulators and semi conductors: We are familiar with conducting and insulating materials. Conducting materials are good conductors of electricity. Insulating materials are bad conductors of electricity. There is another group of materials called as semiconductors, such as germanium and silicon. These are neither good conductors nor good insulators.

The conductors on valence electrons are always free. In an insulator the valence electrons are always bound. Whereas in semi conductors the valence electrons are normally bound but can be set free by supplying a small amount of energy. Several electronic devices are made using semi conductor materials.

Semi conductors - Atomic structure: Germanium (Ge) and silicon (Si) are examples of semi conductors. Fig 1a shows a germanium atom. In the centre is a nucleus with 32 protons. 32 revolving electrons are distributed themselves in different orbits. There are 2 electrons in the first orbit, 8 electrons in the second orbit, and 18 electrons in the third orbit. The fourth orbit is the outer or valence orbit which contains 4 electrons.

Fig 1b shows a silicon atom. It has 14 protons in the nucleus and 14 electrons in 3 orbits. There are 2 electrons in the first orbit and 8 in the second orbit. The remaining 4 electrons are in the outer or valence orbit.

Fig 1



(a) GERMANIUM ATOM (32) (b) SILICON ATOM (14)

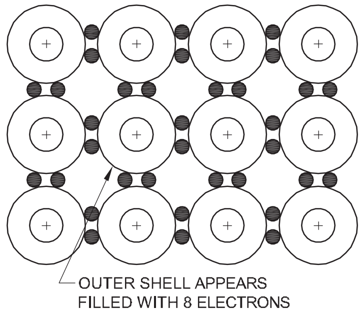
In semiconductor materials, the atoms are arranged in an orderly pattern called a crystal lattice structure. If a pure silicon crystal is examined we find that the four electrons in the outer (valence) shell of an atom is shared by the neighbouring atoms as in Fig 2.

The union of atoms sharing the valence electrons is called a covalent band. That means a valence electron being shared by two adjacent atoms. Each atom appears to have a full outer shell of eight electrons.

Types of semiconductors : A pure semiconductor is called an intrinsic semiconductor. For example, a silicon crystal is an intrinsic semiconductor because every atom in the crystal is a silicon atom. One way to increase conductivity in a semiconductor is by ‘doping’. This means adding impurity atoms to an intrinsic semiconductor. The doped semi-conductor is known as an extrinsic semiconductor.

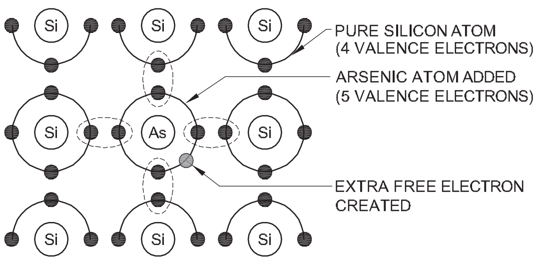
N - type semiconductor : A semiconductor with excess of electrons is called N-type. To obtain excess free electrons the element doped with the semiconductor material is arsenic, or antimony or phosphorus. Each of these atoms has five electrons in its outer orbit. (Fig 3)

Fig 2



CRYSTAL LATTICE STRUCTURE OF SILICON ATOMS

Fig 3



FORMATION OF 'N' TYPE SEMICONDUCTOR

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Because the outer orbits of the atoms can hold eight electrons, no hole is available for the fifth electron in the arsenic atoms to move into. It, therefore, becomes a free electron. The number of such free electrons is controlled by the amount of arsenic added to the crystals.

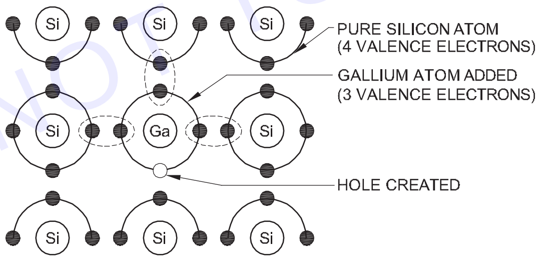
In N-type, the free electrons are called the majority carriers, and the holes minority carriers.

P-type semiconductor : To obtain more holes, a pure silicon crystal is doped with elements such as aluminum or boron or gallium. The atoms of each of these elements have three electrons only in their outer orbit. Adding gallium to pure silicon crystals allows the atoms of the two elements to share seven electrons. (Fig 4)

A hole is created in the place of the eighth electron. Now that the number of holes exceeds the number of free electrons the substance becomes 'P' type material. The holes in P-type are the majority carriers, and the free electrons are the minority carriers.

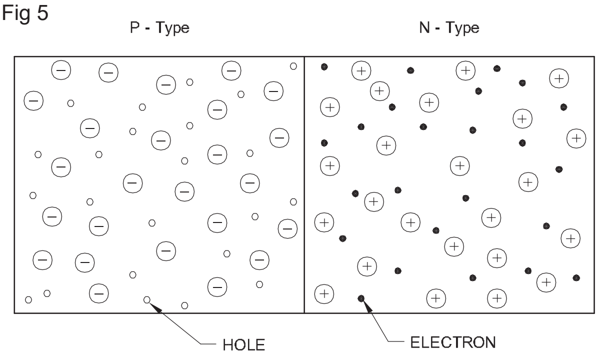
PN Junction : A PN junction is formed by combining P and N type materials. The surface where they meet is called the PN junction. A PN junction is illustrated in Fig 5.

Fig 4



FORMATION OF 'P' TYPE SEMICONDUCTOR

Fig 5



P – N JUNCTION

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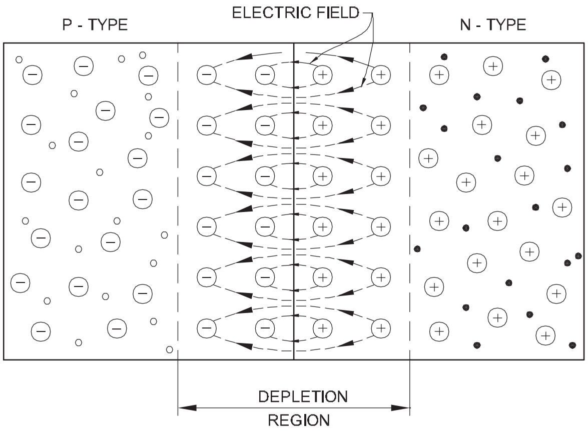
The ions in the crystal structure are fixed and cannot move. Thus, a layer of fixed charges is formed on the two sides of the junctions. This is shown in Fig 6.

There is a layer of positively charged ions on the N-side and on the P-side of the junction there is a layer of negatively charged ions. An electric field is created across the junction between the oppositely charged ions. This is called a junction field. The junction field is also known as 'barrier'. The distance between the sides of the barrier is the 'width' of the barrier.

Depletion region : The carrier in the vicinity of the junction are involved in forming the junction. Once the junction field is established, no carriers can move through the junction. Hence the junction field is called 'depletion region' or 'space charge region'. This layer is called the depletion layer, because there are neither free electrons nor holes present. This depletion region prevents further movement of electrons from the N-material to the P-material and thus an equilibrium is reached.

Fig 6



The intensity of the field is known as 'barrier height' or 'potential' hill'. The internal voltage set up due to positive and negative ions at the junction is called barrier potential. If any more electrons have to go over from the N-side to

P-side, they have to over come this barrier potential. This means, only when the electrons on the N-side are supplied with energy to overcome the barrier potential they can go over to the P-side.

In order to cancel the barrier potential and the electrons to cross over a potential difference of 0.7 V is required for a silicon diode and 0.3 V for a germanium diode. The barrier voltage is more for silicon because its lower atomic number allows more stability in the covalent bonds. The barrier potential decreases at higher temperatures.

Old system : Some earlier semiconductor diodes and transistors have type numbers, consisting of two or three letters followed by group of one, two or three figures. The first letter is always 'O', indicating a semi-conductor device.

The second (and third) letter(s) indicate the general class of the device.

A – diode or rectifier

AP– photo-diode

AZ– voltage regulator diode

C – transistor

CP– phototransistor

The group of figures in a serial number indicating a particular design or development.

Present system : This system consists of two letters followed by a serial number. The serial number may consists of three figures of one letter and two figures depending on the main application of the device.

The first letter indicates the semiconductor material used.

A Germanium

B Silicon

C Compound materials such as gallium arsenide

R Compound materials such as cadmium sulphide

The second letter indicates the general function of the device.

A detection diode, high speed diode, mixer diode

B variable capacitance diode

C transistor for I.F. applications (not power types)

D power transistor for A.F. applications (not power types)

E tunnel diode

F transistor for A.F. applications (not power types)

G multiple of dissimilar devices, miscellaneous devices

L power transistor for a.f. applications

N photo-coupler

P radiation sensitive device such as photo-diode, photo-transistor, photo-conducive cell, or radiation detector diode

Q radiation generating device such as light-emitting diode

R controlling and switching devices (e.g. thyristor) having a specified breakdown characteristic (not power types)

S transistor for switching applications (not power types)

T controlling and switching power device (e.g. thyristor) having a specified breakdown characteristic.

U power transistor for switching applications

X multiplier diode such as varactor or step recovery diode

Y rectifier diode, booster diode, efficiency diode

Z voltage reference or voltage regulator diode, transient suppressor diode.

The remainder of the type number is a serial number indicating a particular design or development, and is in one of the following two groups.

a Devices intended primarily for use in consumer applications (radio and television receivers, audio-amplifiers, tape recorders, domestic appliances, etc.) The serial number consists of three figures.

b Devices intended mainly for applications other than (a) e.g. industrial, professional and transmitting equipments.

The serial number consists of one letter (Z,Y,X,W etc) followed by two numbers (digits)

The International System follows letters 1N, 2N, 3N etc followed by four numbers.

1N indicates single junction

2N indicates two junction

3N indicates three junctions.

The number indicates internationally agreed manufacturer's code e.g. 1N 4007, 2N 3055, 3N 2000.

Again, manufacturers use their own codes for semiconductor devices. Manufacturers in Japan use 2SA, 2SB, 2SC, 2SD etc. followed by a group of numbers e.g. 2SC 1061, 2SA 934, 2SB 77. Indian manufacturers have their own codes too.

Passive and active electronic components

Introduction: The Components used in electronic circuits can broadly grouped under two headings.

– passive components

– active components

Passive components: Components like resistors, capacitors, and inductors used in electronic circuit are called as passive components. These components by themselves are not capable of amplifying or processing an electrical signal. However these components are equally important in electronic circuit as that of active components, without the aid of passive components, a transistor (active components) cannot be made to amplify electrical signal.

Circuits formed with passive components obey the electrical circuits laws such as ohm's law, Kirchoff's Laws etc.,

Resistors: The components whose purpose to introduce resistance in the circuit is called as resistors. Other details of resistors are dealt in earlier lessons.

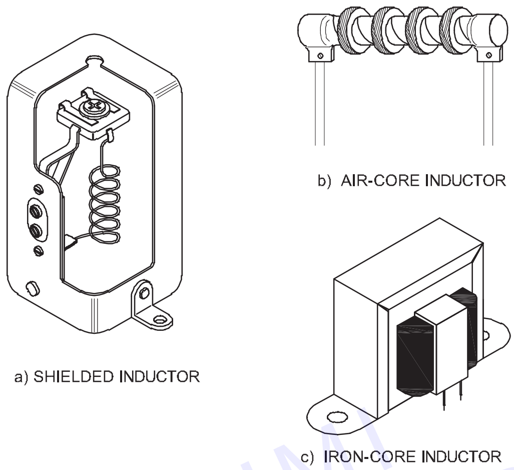
Capacitor: The components whose purpose to introduce capacitance in the circuit is called as capacitor. The unit of capacitance is 'FARAD'. Commercially capacitors are available in Microfarad (mF), Nanofarad (nF) and Picofarads (pF).

The colour coding of capacitors and resistors are same. Where as, in the case of fixed capacitors, the colour coded unit shall be in Picofarads.

For letter coding, incase of capacitor, the letter ‘p’, ‘n’, ‘m’ shall be used as multipliers. Where p = 10-12, n= 10-9 and m = 10-6 farads, and letter code for tolerance on capacitor is the same as in resistor.

Inductor: The ability of the conductor to induce voltage in itself, when the current changes in it is called as self inductance (or) simply inductance. A coil introduced in a circuit to have inductance is called as inductor. Different type of inductors are shown in Fig 7. The unit of inductance is “Henry”. Commercially a coil may have inductance in Millihenry (10-3H), or in Microhenry (10-6H).

Fig 7



TYPES OF INDUCTORS

ELC22T0334

While specifying the inductance the following factors to be considered

- nominal value of inductance in Henry / Millihenry / Microhenry.
- tolerance in percentage (±5/10/20%)
- type of winding like single layer, double layer, multilayer and pie (p) etc.
- type of core like air core, iron core, ferrite core
- type of application like audio frequency (AF), Radio frequency (RF) coupling coil, filter coil etc.,

In an electronic circuit some time, it is also required to vary the inductance.

The inductance of a coil can be varied by:-

- providing tapped inductive coil, as in Fig 8 or
- adjusting the core of a coil as in Fig 9.

However, all inductor coils have inherent resistance due to the resistance of the winding wire in the coil. Further the maximum current that can be safely carried by an inductor depends upon the size of the winding wire used.

Active components

In electronic circuit, the components, other than passive are known as active components. Namely, transistors, diodes, SCRs Vacuum tubes etc.,

Active components : In electronic circuits, components other than resistors, capacitors and inductors are also used. Namely, transistors, diodes, vacuum tubes, SCRs, diacs, zener-diode (Fig 10) etc. The application of electrical circuit laws (Ohm’s law etc.) in the circuit containing the above components will not give correct results. i.e. these components do not obey. Ohm’s law, Kirchoff’s law etc. These components are called active components.

The different active components and the method of representing them by symbols in the circuit diagram are given below (Fig 10)

The different types of diodes (Fig 11) used for specific purposes are represented by the symbols given.

Fig 8

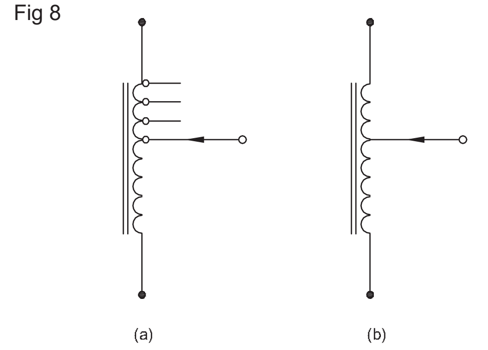


Fig 9

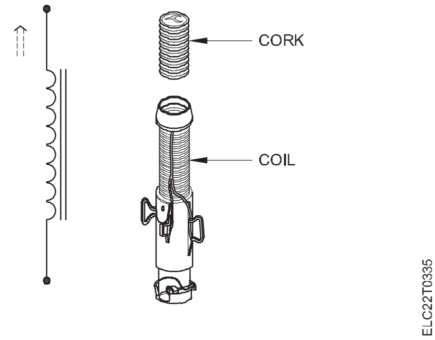
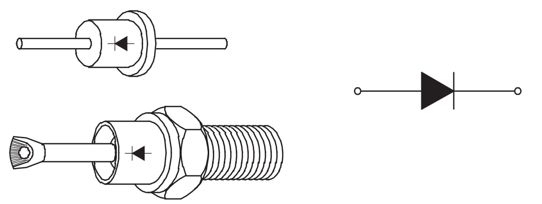


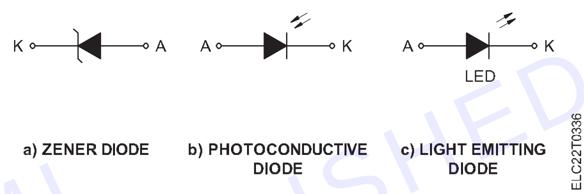
Fig 10



a) PHYSICAL APPEARANCE OF DIODES

b) SYMBOL OF DIODE

Fig 11



a) ZENER DIODE

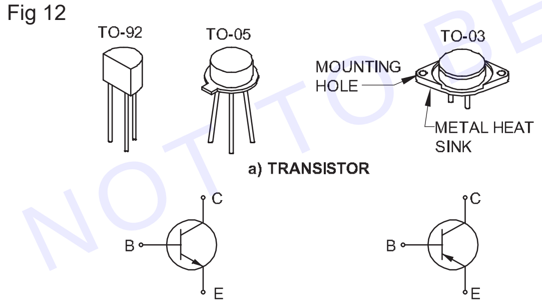
b) PHOTOCONDUCTIVE DIODE

c) LIGHT EMITTING DIODE

Transistor : Figure 12a shows the physical appearance of transistors. There are two symbols to represent a transistor. (Fig 12b). The selection of a symbol is based on either the NPN or the PNP type of transistor.

SCR (Silicon controlled rectifier) : Figure 14a shows the physical appearance of one type of SCR and the symbol is shown in Fig 13b. SCRs are also called thyristors and used as switching devices.

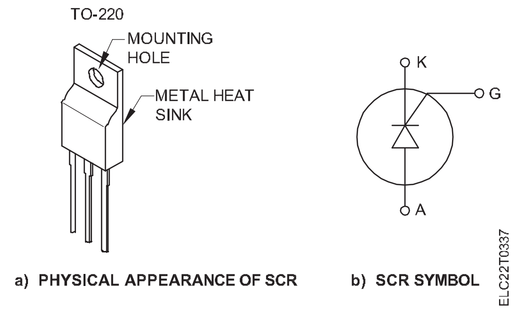
Fig 12



a) TRANSISTOR

b) SYMBOL

Fig 13



a) PHYSICAL APPEARANCE OF SCR

b) SCR SYMBOL

Diac : A diac (Fig 14a) is a two-lead device like a diode. It is a bidirectional switching device. Its symbol is shown in Fig 14b.

Triac : A triac is also a semiconductor device with three leads like two SCRs in parallel. The triac can control the circuit in either direction. (Fig 15)

Bridge rectifier or diode bridge : It is a single package of four semiconductor diodes connected in bridge circuit. The input AC and the output DC leads are marked and terminated as shown in the Figure 16.

Fig 14

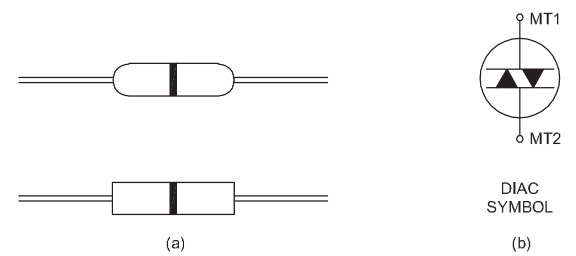


Fig 15

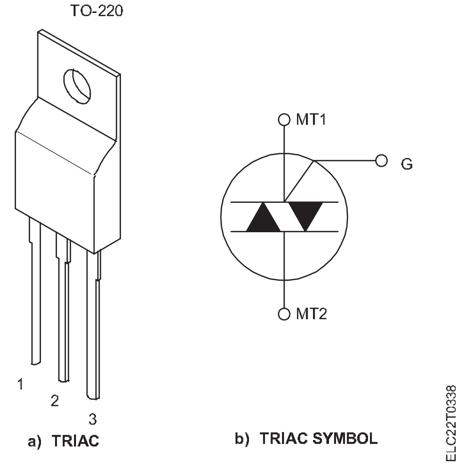
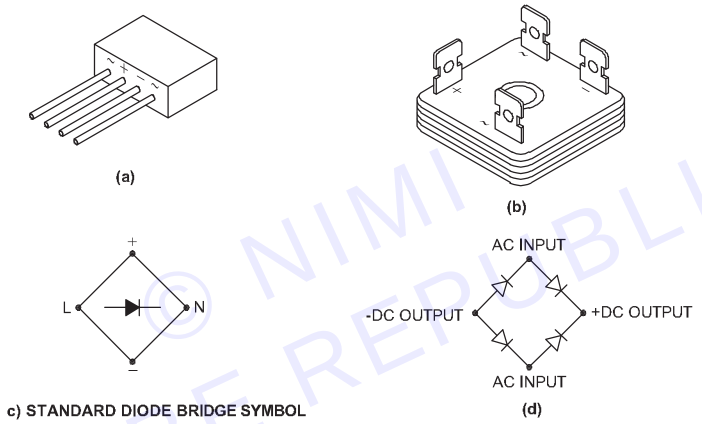


Fig 16



UJT (Uni-junction transistor) : It has two doped regions with three leads and has one emitter and two bases (Fig 17).

FET (Field effect transistor) : Fig 18a give a pictorial view of the component, and the related symbol to represent the field effect transistor is shown in Fig 18b. The selection of the symbol is based on whether the FET is a 'N' channel or a 'P' channel one.

In the active components few basic components discussed have and many more advanced components associated with modern circuits are in use.

Fig 17

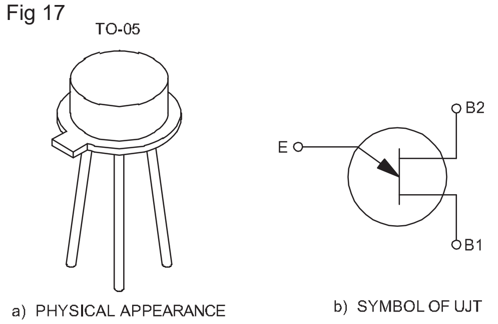
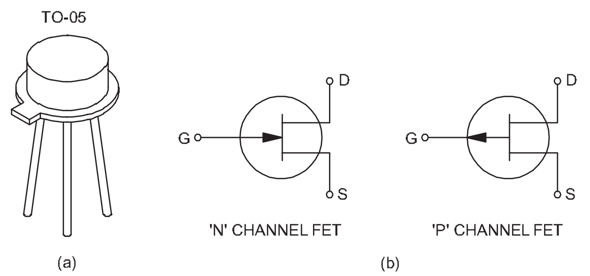


Fig 18



PN Junction - semi conductor diodes

Objectives: At the end of this lesson you shall be able to

- explain diffusion in pn junction and barrier potential
- explain forward and reverse biasing of pn junction and semi conductor diodes and its vi characteristics
- state the applications specifications and classification of diodes
- state the method of testing diode and identifying the polarity
- state special diodes and their functions and PIV.

PN junction: A diode is made by combining P and N materials. The surface at which these materials meet is the PN junction.

Diffusion occurs when P and N materials are joined together.(Fig 1) some electrons in the N material, near the junction, are attracted to the holes in the P material, thus leaving holes in the N material. The diffusion of electrical charges produces a potential difference in a small area near the junction (Fig 2).As a result, the material will conduct in one direction but not in the opposite direction. For this reason, the area in which this emf exists is called a barrier.

The internal barrier potential (Vb) : Although it is an internal contact potential that cannot be measured directly, the effect can be overcome by 0.3V for a Ge junction or 0.7 V for Si. The barrier voltage is more for Si because its lower atomic number allows more stability in the covalent bonds as already stated.

The PN junction, with the depletion zone magnified, shows the iron that has +ve and -ve charges produce the internal contact potential Vb at the barrier. (Fig 2)

Fig 1

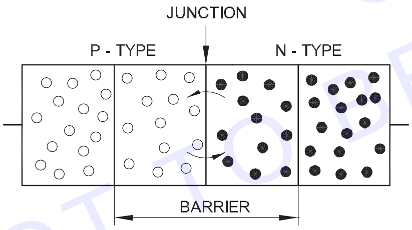
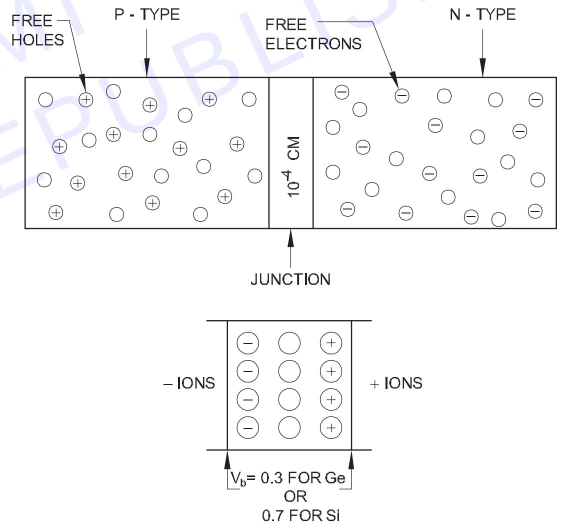


Fig 2



A PN device is knows as a diode. The diode and its symbol are in Fig 3. This type of construction permits the current to flow in one direction but not in the opposite direction.

Biasing the PN junction

Forward Bias : A forward-biased PN junction is in Fig 4 The positive terminal is connected to the P-side and the negative terminal of the DC supply is connected to the N-side of the junction.

A current will flow through the diode as in the Fig 4.

Reverse Bias: If the polarities of the DC supply are as shown in Fig 5, the PN junction is said to be reverse-biased. That is, the P side is connected to the negative and the N-side is connected to the positive terminals of the supply. Fig 5 shows the battery connection reversed (reverse bias). At the same instant, a shift in electrons in the P material causes the positive holes to appear further away from the junction near the end for the diode, which is connected to the negative terminal of the battery. This action produces a wider barrier at the PN junction through which the electrons cannot flow. (A very small current leakage may however occur).

V-I characteristic of PN junction : The static current voltage characteristic is in Fig 6.

Fig 3

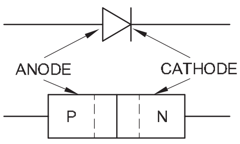


Fig 4

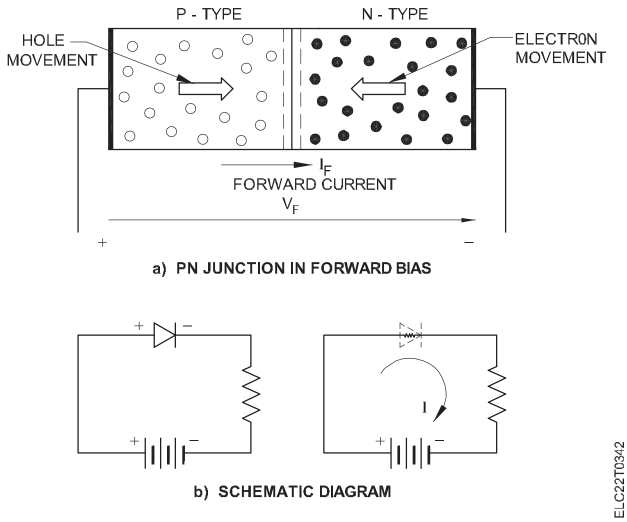


Fig 5

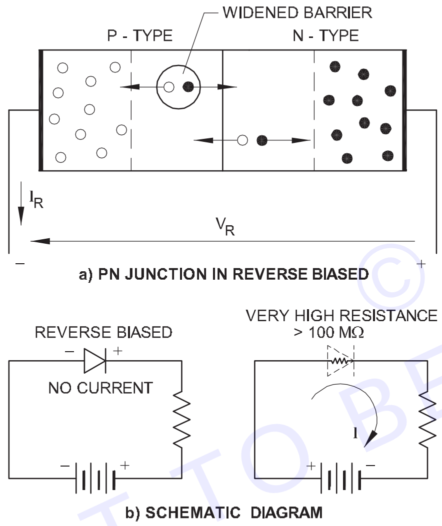
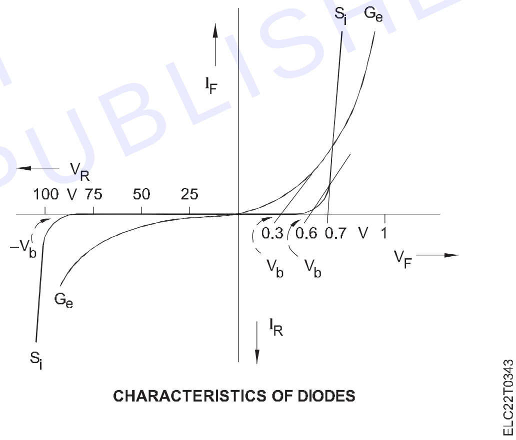


Fig 6



The current in the forward direction increases rapidly upon reaching the forward voltage Vb which is known as the barrier potential or the junction potential and the barrier potential for germanium is 0.3 V and for silicon it is 0.7 V.

The behaviour of the PN junction is limited by the maximum forward current, as too much of current may destroy a diode due to the excess heat generation.

The current in the reverse direction of the junction is very small. Upon reaching —Vb in the reverse direction, the reverse current suddenly increases. —Vb in the reverse direction where the current starts increasing is called the knee potential or breakdown voltage. Normally the diode should not be operated in this region. The knee voltage depends on the type of diode which varies from 3V to 20 kV or more.

Application of diodes : Semi conductor diodes are used for various applications. Some of the major areas of application are listed below.

- Modulation and demodulation in communication receivers.
- Switching high speed digital circuits

- Low power and high power rectification
- As surge protectors in EM relay and other circuits.
- For clipping, clamping wave-forms.

For different applications, diodes of different current carrying capacity, different PIV capacity and so on are required. Therefore, manufacturers make diodes to cater to varied applications with different specifications. Before using a diode for a particular application, it is a must to find out whether the voltage, current, and temperature characteristics of the given diode match the requirement or not.

Important specifications of a diodes

The material : The diode is made-of doped semi-conductor material. This could be Silicon or Germanium or Selenium.This is important because the cut-in voltage depends upon the material the diode is made-of. For example, in Ge diodes the cut-in voltage is around 0.3V, whereas in Si diodes the cut-in voltage is around 0.7V.

Maximum safe reverse voltage : Denoted as VR or Vr that can be applied across the diode. This is known as peak-inverse-voltage or PIV. If a higher reverse voltage than the rated PIV is applied across the diode, it will become defective permanently.

Maximum average forward current : If or IF that a diode can allow to flow through it without getting damaged.

Forward voltage drop : VF or Vf that appears across the diode when the maximum average current, If flows through it continuously

Maximum reverse current : Ivr that flows through the diode when the maximum reverse voltage, PIV is applied.

Maximum forward surge current : Is that can flow through the diode for a defined short period of time.

The maximum junction temperature: The temperature upto which the diode junction can withstand without mal functioning or getting damaged.

Testing diodes using ohmmeter: A simple ohmmeter can be used to quickly test the condition of diodes. In this testing method, the resistance of the diode in forward and reverse bias condition is checked to confirm its condition.

Recall that there will be a battery inside an ohmmeter or a multimeter in the resistance range. This battery voltage comes in series with the leads of the meter terminals as in Fig 7.In Fig 7 the lead A is positive, lead b negative.

If the polarity of the meter leads are not known at first, the polarity of the meter leads can be determined by using a voltmeter across the ohm meter terminals.

If the positive lead of the ohmmeter, lead A in the Fig 7 is connected to the anode of a diode, and the negative (lead B) to the cathode, the diode will be forward-biased. Current will flow, and the meter will indicate low resistance.

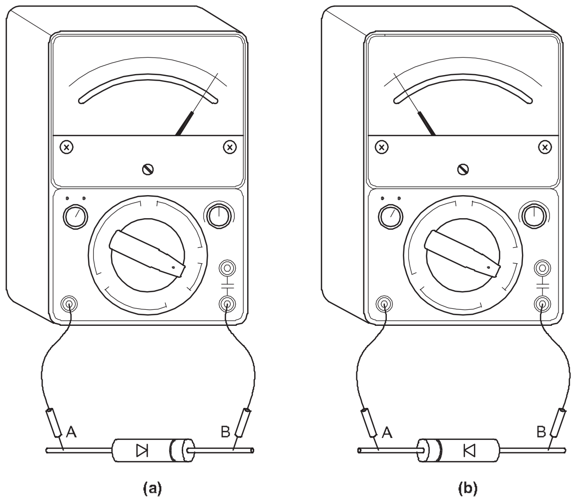
On the other hand, if the meter leads are reversed, the diode will be reverse-biased. Very little current will flow because a good diode will have very high resistance when reverse biased, and the meter will indicate a very high resistance.

While doing the above test, if a diode shows a very low resistance in both the forward and reverse biased conditions, then, the diode under test must have got damaged or more specifically shorted. On the other hand, a diode is said to be open if the meter shows very high resistance both in the forward and reverse biased conditions.

Polarity marking on the diodes: The cathode end of a diode is usually marked by a circular band or by a dot or by plus (+) sign. In some diodes the symbol of the diode, which itself indicates the polarities, is printed on the body of the diode.

Special diodes: All diodes are basically PN junction diodes and are made according to the application. There are many special purpose diodes are in use in which zener diodes widely used for voltage regulation.

Fig 7



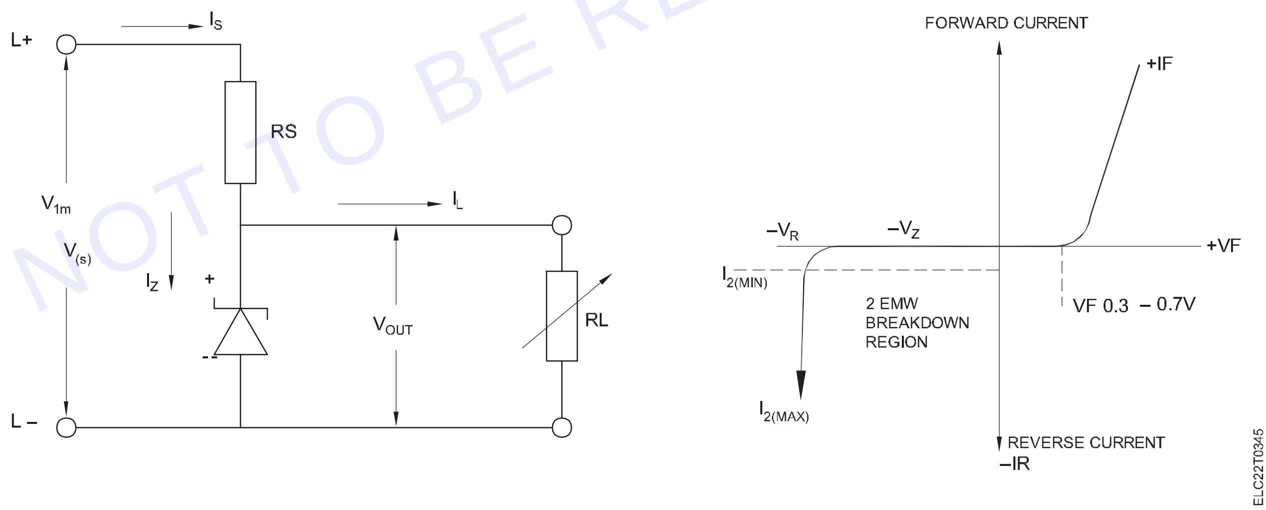
Zener diode: This diode specially designed for voltage regulation. A wide range of voltage regulated zener diodes are available.

It is a PN junction diode doped heavily for regulation purpose. It has a normal VI characteristic when it is forward biased. But the characteristic are changed abruptly when it is connected in reverse bias.

In the reverse bias condition a leakage current in the order of Microamps will flow. When the reverse voltage reaches to a particular designed voltage a sudden breakdown known as avalanche breakdown happens.

When a heavy current flows at constant voltage, the voltage continue to remain constant. Further increase in voltage, the current suddenly increases. Fig 8 shows the reverse characterises of zener diode.

Fig 8



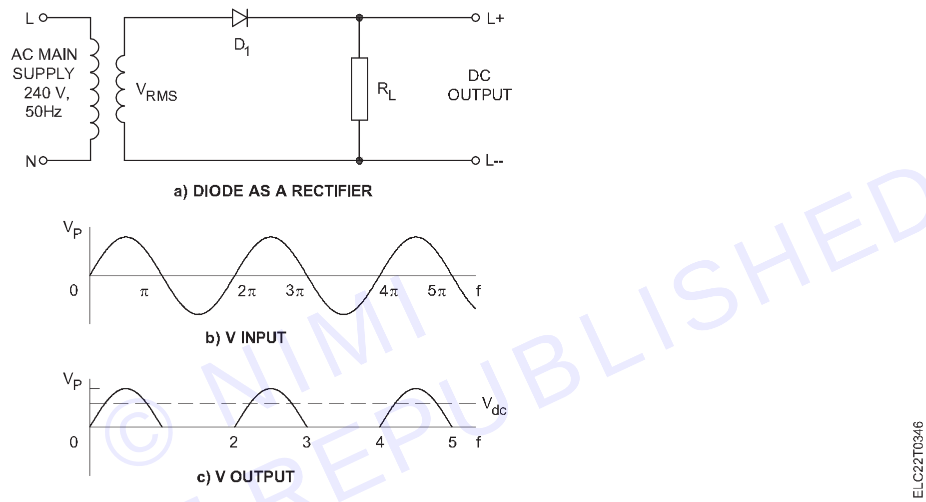
Rectifiers

Objectives: At the end of this lesson you shall be able to
- state the purpose of rectifier in power supply circuit
- explain the working of half-wave, full-wave and bridge rectifier circuit
- state the need of filter circuit to rectifier circuits
- state the different types filter circuit for rectifiers.

Most of the electronic equipment, both entertainment and professional, need DC voltage for operation. The power supply converts AC supply voltage into DC. Diodes are used as rectifier in a power supply circuit.

Half wave rectifier: This simplest form of AC to Dc converter is by using one diode such an Ac to Dc converter is known as half-wave rectifier as in Fig 1.

Fig 1



A diode D1 and a load resistance RL in series are connected across the secondary of a step down transformer (Fig 1(a). The transformer steps up or steps down the supply voltage as needed. Further the transformer isolates the power line and reduces the risk of electrical shock. During the positive half-cycle of the input line frequency, (Fig 1b) the diode anode is made positive with respect to the cathode. The diode D1 conducts because it is forward-biased. Current flows from the positive end of the supply through diode D1 and RL to the negative terminal of the input. During this period of time, a voltage is developed across RL. The polarity of the voltage is as indicated in Fig 1C.

During the negative half cycle of AC input line frequency, the diode is reverse-biased. Practically no current flows through the diode and the load RL and there is no voltage output.

DC output: The voltage drop across the forward biased diode is low, because the resistance of the forward-biased diode is very low. Ge diode drops 0.3V and Si diode drops 0.7V. Ignoring the small voltage drop across the diode. We can find the relationship between AC input and DC output voltage.

The AC input wave-form is shown in Fig 1b.

$V_{rms} = 0.707\ V_p$

$$V_p = \frac{V_{rms}}{0.707}$$

In Fig 1C, the DC output is shown. The diode produces only half cycle of the Ac input. The average value of this half wave is the DC output voltage.

$V_{dc} = 0.318\ V_p$

$$= 0.318 \times \frac{V_{rms}}{0.707}$$

$$= 0.45\ V_{rms}$$

For example if the input AC voltage is 24 volts the output DC of the half wave rectifier will be Vdc = 0.45 x 24= 10.8 V

The DC load current is $I_{dc} = \frac{V_{dc}}{R_L}$

Ripple frequency: From Fig 1 it is evident that the frequency of the rectified pulsating DC is same as the frequency of the input AC signal. This is true for all half-wave rectifiers.

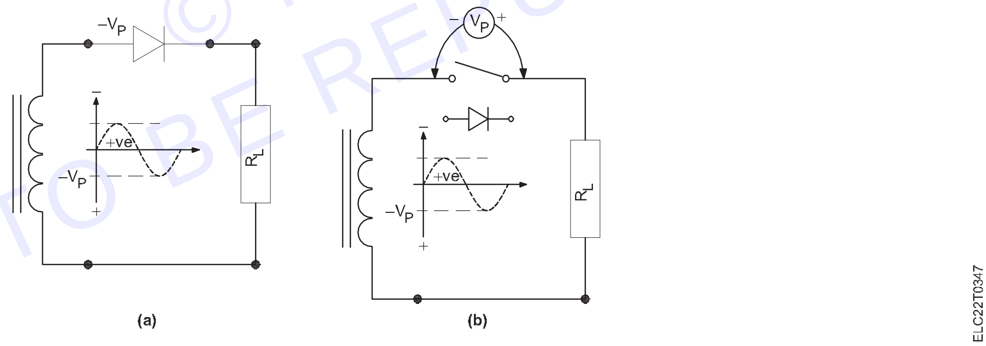
Peak inverse voltage: Fig 1(a) shows the half-wave rectifier at the instant the secondary voltage is at its maximum negative peak.

In this condition, since the diode is reverse biased, it behaves as an open switch as in Fig 2b. Since the diode is reverse biased, there is no voltage across the load RL. Therefore, from Kirchhoff's Voltage law, all the secondary voltage appears across the diode as shown in Fig 2a. This is the maximum reverse voltage that appears across the diode in the reverse biased condition. This voltage is called the peak reverse voltage or more commonly as the peak inverse voltage (PIV). Therefore, in a half-wave rectifier the peak inverse voltage across the diode is equal to the -ve peak value of the secondary voltage $V_{s(peak)}$. Since the -ve peak voltage and +ve peak voltage in a sinusoidal wave is same in magnitude, the peak inverse voltage (PIV) across the diode in a halfwave rectifier can be taken as a $V_{s(peak)}$.

In the example considered earlier, the PIV across the diode will be,

$$V_{s(peak)} = \frac{V_{s(rms)}}{0.707} = \frac{24}{0.707} = 33.9 = 34 \text{ volts}$$

Fig 2



To avoid break down of the diode used, the PIV appearing across the diode of the designed HW rectifier must be less than the PIV rating of the diode. For instance, in the above example to avoid break down of the diode, the PIV rating of the diode should be greater than 34 volts.

However this condition changes when a filter capacitor is used in the output DC circuit.

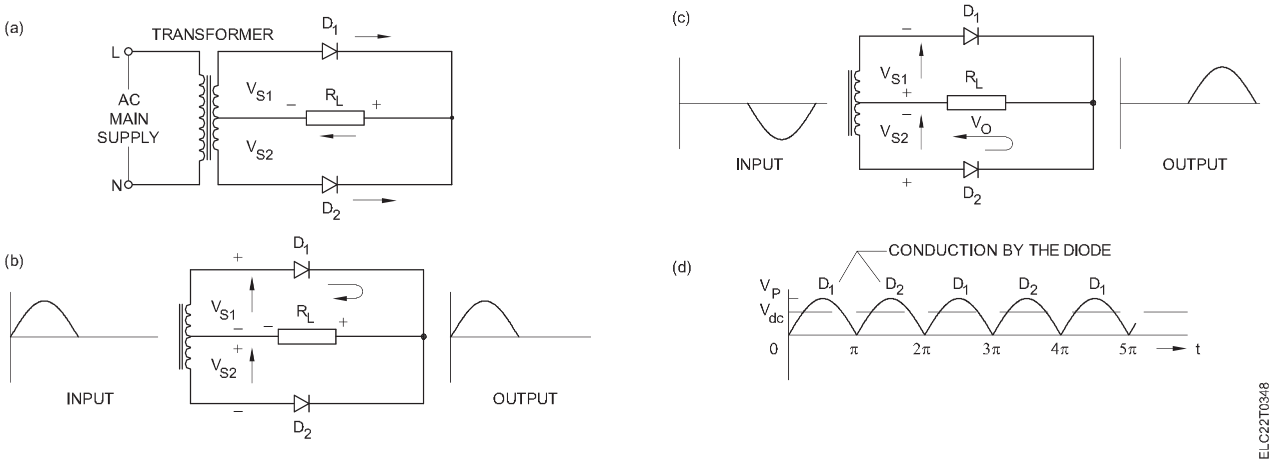
Full wave rectifier (FW): A full wave rectifier circuit is in Fig 3. The secondary winding of the transformer is centre-tapped. The secondary voltage is divided equally into two halves, one end of the load RL is connected to the centre tap and the other end of RL to the diodes.

It is seen that two half-wave rectifiers are conducting on alternate half cycles of the input Ac.

During the positive half cycle of the secondary voltage, diode D1 is forward-biased and diode D2 is reverse-biased. (Fig 3b) The current flows through the load resistor RL, diode D1 and the upper half of the secondary winding.

During the negative half cycle of secondary voltage, diode D2 is forward-biased and diode D1 is reverse-biased. Therefore, current flows through the load resistor RL diode D2 and the lower half of the secondary winding. (Fig 3c)

Fig 3



The load current is in the same direction during both the half-cycles of the AC input. The output of the full-wave rectifier is shown in Fig 3d.

DC output : Since a full wave rectifier is nothing but a combination of two half-wave rectifiers, the average or DC value of a full wave rectifier is naturally twice the output of a half wave rectifier driven by the same secondary voltage.

From Fig 3 it i s evident that the average of DC value of a full wave rectified output is

V_{dc} = 0.318 $V_{s(peak)}$ + 0.318 $V_{s(peak)}$

V_{dc} = 0.636 $V_{s(peak)}$

where, $V_{s(peak)}$ is the equal peak voltage between the centre-tap and any one end A or B of the transformer secondary.

In terms of $V_{s(rms)}$ V_{dc} of full wave rectifier is given by,

$V_{s(rms)}$ = 0.707 $V_{s(peak)}$

$$\text{Therefore, } V_{dc} = 0.636 = \frac{V_{s(rms)}}{0.707} = 0.9\ V_{s(rms)}$$

Example

Suppose the secondary voltage of the transformer is 24-0-24V(rms), the Dc output voltage of a full wave rectifier using this transformer will be,

For a two diode full wave rectifier

Vdc = 0.9 Vs(rms)

Therefore, in the given example

V_{dc} = 0.9 x $V_{s(rms)}$ = 0.9 x 24 = 21.6 volts

Ripple frequency in a full wave rectifier: From

Fig 3c it can be seen that two cycles of output occur for each input cycle of AC voltage. This is because, the full wave rectifier has inverted the negative half cycle of the input voltage. As a result, the output of a full wave rectifier has frequency double the input AC frequency. If mains AC supply is used as input to a full wave rectifier, the mains frequency is 50 Hz, the output frequency of the pulsating DC will be 100 Hz.

Note: This increased ripple frequency has certain advantages when the pulsating DC is smoothed. This will be dealt with in further lesson.

Peak inverse voltage: Fig 4 shows the full wave rectifier at the instant the secondary voltage reaches its maximum positive value.

Applying Kirchhoff's law around the outside loop, we get, $2V_{s(peak)}$ - Reverse voltage(PIV)

across D_2 + Forward voltage across D_1 = 0

Neglecting the small forward voltage across D1 we have, 2Vs(peak) = PIV across D2 + 0 = 0

or PIV across D_2 = $2V_{s(peak)}$

From the above it can be seen that each diode in a fullwave rectifier must have PIV rating greater than the peak value of the full secondary voltage. $2V_{s(peak)}$

In the example considered earlier, the PIV of diodes should be 2 $V_{s(peak)}$.

$$V_{s(peak)} = \frac{V_{s(rms)}}{0.707} \quad = \quad 2\,V_{s(peak)} = \frac{2 \times V_{s(rms)}}{0.707}$$

$$= \frac{2 \times 24}{0.707} = 68 \text{ volts (approx.)}$$

Current rating of diodes in a full wave rectifier : If the load, RL connected in the fullwave rectifier is, say 10W the DC current through it will be,

$$dc = \frac{V_{dc}}{10\,\Omega}$$

In the example considered above, Vdc = 21.6 volts

Therefore, $I_{dc} = \frac{21.6}{10} = 2.16$ amps.

It is interesting to note this current Idc is shared by the two diodes D1 and D2. This is because each diode conducts only for one half cycle. Therefore, the DC current through each diode is half the total DC load current Idc. Hence, the maximum current through each diode with 10W load will be 2.16/2 = 1.08 amps. From this it follows that the current rating (If(max)) of each diode need only be half the maximum/rated load current.

NOTE: In a halfwave rectifier, since there is only one diode, the current rating of the diode used should be the maximum current through the load unlike in the case of a full wave rectifier in which the current rating of the diodes used is only half the maximum current through the load.

Example: In a two diode full wave rectifier, with a load current requirement of 1.8 amps, what should be the current ratings of the diodes used?

Since it is a two diode full wave rectifier, the current rating of each diode should be = 1/2 the total load current.

Therefore If(max) of diodes should be = 1.8 amps/2 = 0.9 amps.

It is fine if a diode of 1 amp current rating is used for this rectifier circuit.

Disadvantages of TWO DIODE full wave rectifier : The full wave rectifier using two diodes and centre tap transformer has the following disadvantages

- A centre-tapped transformer that produces equal voltages on each half of the secondary winding is difficult to manufacturer and, hence, expensive.
- Centre-tapped transformers are generally bulkier than ordinary transformers, and, hence, occupy larger space.
- In a two diode full wave rectifier, only half of the secondary voltage is made use at a time although it works in both +ve and -ve half cycles.

Bridge rectifier : It is a full-wave rectifier. The circuit is in Fig 5a. In the bridge rectifier four diodes are used. There is no centre tap on the secondary of the transformer.

During the positive half of the secondary voltage, diodes D2 and D3 are forward-biased. Hence current flows through diode D2 load resistance RL and D3 to the other end of the secondary. This is illustrated in Fig 5b. During the negative half of the secondary voltage, diodes D1 and D4 are conducting . The current flows through diode D4, resistor RL and diode D1 to the other end of the secondary. This is illustrated in Fig 5c.

In both cases the current flows through the load resistor in the same direction. Hence, a fluctuating DC is developed across the load resistor RL. This is shown in Fig 5d.

Fig 4

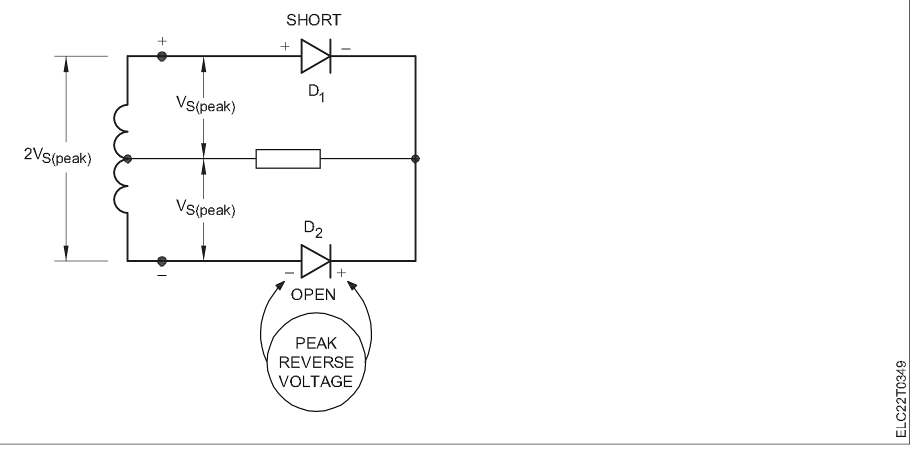
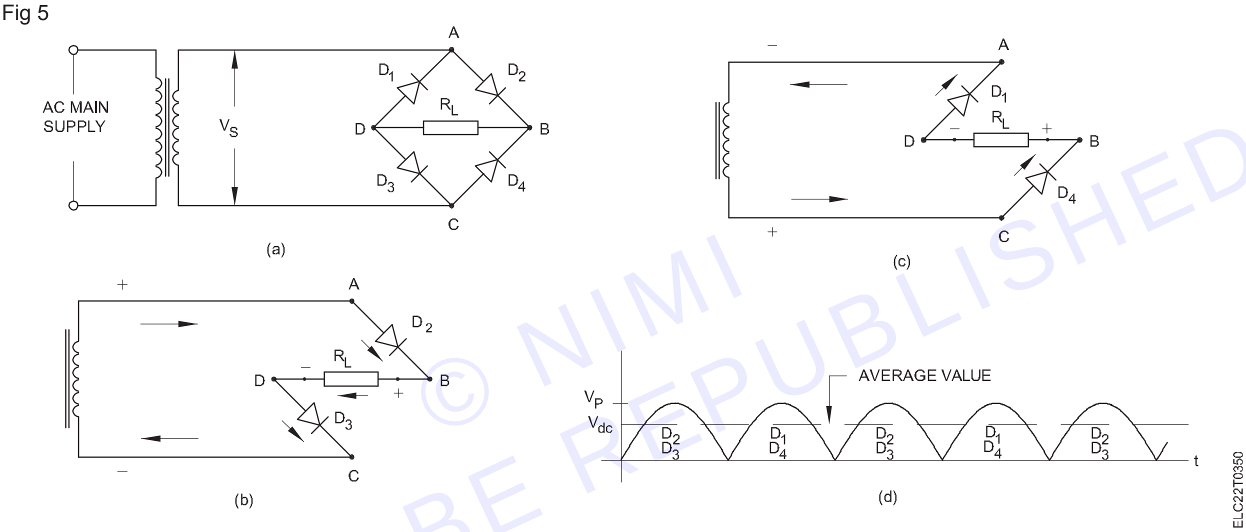


Fig 5



DC output: Fig 6 shows the input AC and the output pulsating DC wave-form of a bridge rectifier.

This wave-form is similar to that of the full wave rectifier using a centre-tap transformer. Hence, the average DC value of the output is,

V_{dc} = 0,636 $V_{s(peak)}$

or V_{dc} = 0.9 $V_{s(rms)}$

where, Vs(rms) is the full secondary AC rms voltage.

NOTE: In a two -diode full wave rectifier $V_{s(rms)}$ refers to only half for the total secondary voltage whereas in a bridge rectifier $V_{s(rms)}$ refers to full secondary voltage.

Example: In Fig 5, if the transformer secondary voltage $V_{s(rms)}$ is 24 volts, the rectified DC voltage V_{dc} across the load RL will be,

From equation ....2, V_{dc} for a bridge rectifier is given by, Vdc = 0.9 $V_{s(rms)}$

In the given example, $V_{s(rms)}$ = 24 volts

Therefore, V_{dc} = 0.9 x 24 = 21.6 volts

NOTE: Using the same transformer, a two-diode full wave rectifier would have given only 10.8 volts which is half of that of bridge rectifier output.

Ripple frequency - Bridge rectifier: The pulsating DC output of a bridge is similar to the two diode full wave. Hence as in a two diode fullwave rectifier, the output ripple frequency of the bridge rectifier is also twice the input AC frequency.

Peak inverse voltage - Bridge rectifier: Fig 7 shows a bridge rectifier at the instant the secondary voltage has reached its maximum value.

Diode D4 is ideally short (as it is conducting) and D1 is ideally open. summing the voltages around the outside loop and applying Kirchhoff's law,

$V_{s(peak)}$ - PIV across D_1 + 0 = 0

or PIV across D_1 = $V_{s(peak)}$

Therefore, the peak inverse voltage across D_1 is equal to the peak secondary voltage $V_{s(peak)}$

In a similar way, the peak inverse voltage across each diode will be equal to the peak secondary voltage $V_{s(peak)}$ of the transformer secondary. Hence the PIV ratings of the diodes used should be greater than $V_{s(peak)}$

Example

In Fig 7 if the transformer secondary voltage $V_{s(rms)}$ is 24 volts, find the minimum PIV of diodes used. In a bridge rectifier PIV across the diodes is same and is equal to $V_{s(peak)}$

Therefore, in the given example,

$$PIV = V_{sd(peak)} = \frac{V_{s(rms)}}{0.707} = \frac{24}{0.707} = 34 \text{ volts}$$

Fig 6

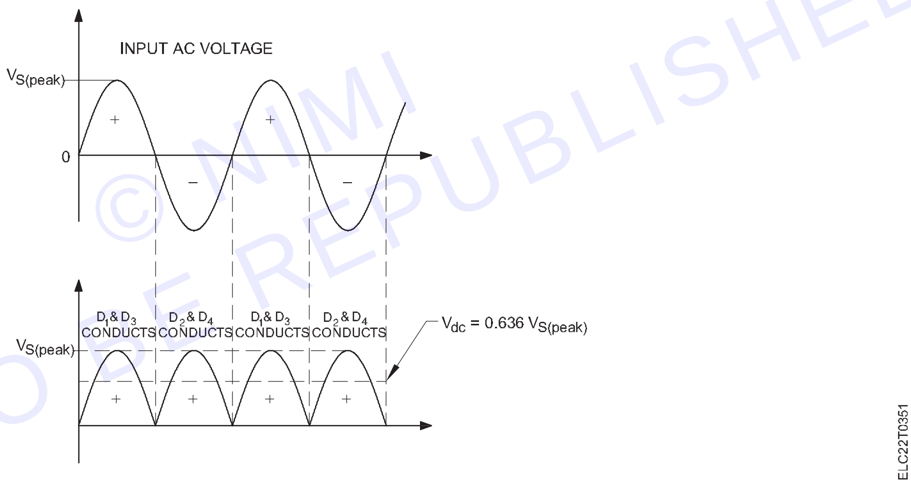
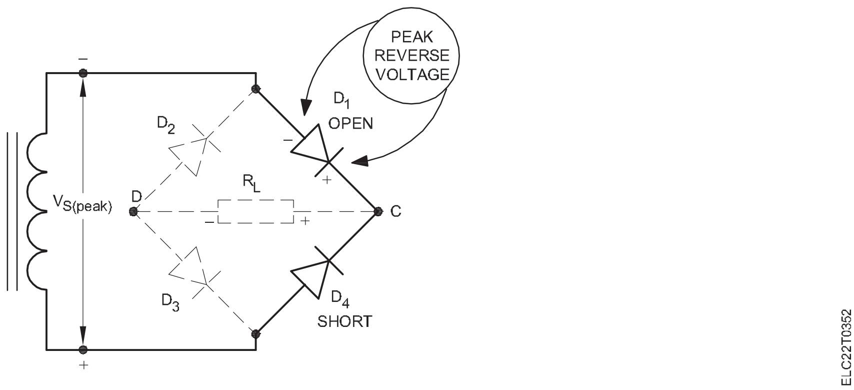


Fig 7



Current rating of diodes in bridge rectifiers : As in the case of a two diode fullwave rectifier even in a bridge rectifier is in Fig 5, diode pairs D_1, D_3 and D_2 D_4 carry half the total load current1. This is because each diode pair is conducting only during one half of the AC input cycle.

The only disadvantage of bridge rectifiers, D_1, D_3 and D_2, D_4 is that, this circuit uses four diodes for full wave rectification instead of two as in two-diode fullwave rectifier. But this disadvantage is compensated by the simple transformer requirement of the bridge rectifier and higher DC output level. Hence, bridge rectifiers are the most popular AC to DC rectifiers for most applications.

Encapsulated bridge rectifiers are available as a single pack with two terminals for AC input and two terminals for DC output.

The following table provides data for a normally used diode having the current rating of one ampere.

Maximum ratings

Rating	Symbol	Type Number							Unit
		IN 4001	IN 4002	IN 4003	IN 4004	IN 4005	IN 4006	IN 4007	
Peak repetitive reverse voltage Working peak reverse voltage DC blocking voltage	$V_{RM(rep)}$ $V_{RM(wkg)}$ V_R	50	100	200	400	600	800	1000	Volts
Non-repetitive peak reverse voltage (half wave, single phase, 50 Hz peak)	$V_{RM\ (nonrep)}$	75	150	300	600	900	1200	1500	Volts
RMS reverse voltage	Vr	35	70	140	280	420	560	700	Volts
Average rectified forward current (Single phase, resistive load, 50Hz, T_A = 75°C)	Io			1.0					Amp
Non-repetitive (Half sine wave t=10m sec)	IFM			30					
Maximum thermal resistance junction temperature to ambient (lead length = 25 mm)	TJA			85					
Maximum Operating and storage junction temperature range	$T_j T_{stg}$			-65 to 175					

Other diode specifications can be obtained from the data book).

A comparison of half-wave, fullwave and bridge rectifier is given below in a tabular form

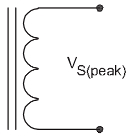
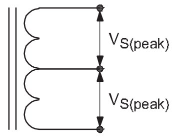
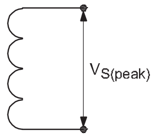
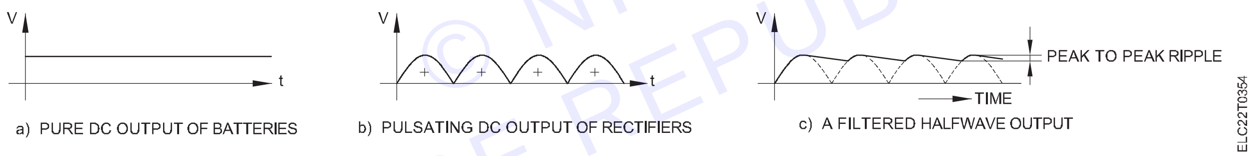
	Half wave	Full wave	Bridge
Number of diodes required	1	2	4
Transformers peak output voltage			
DC output voltage in terms of $V_{s(peak)}$	$0.318\ Y_{s(peak)}$	$0.636V\ V_{s(peak)}$	$0.636V\ V_{s(peak)}$
DC output voltage in terms of $V_{s(rms)}$	$0.45\ V_{s(rms)}$	$0.9\ V_{s(rms)}$	$0.9V_{s(rms)}$
Diode current rating	$I_{L(max)}$	$0.5\ I_{L(max)}$	$0.5I_{L(max)}$
Peak inverse voltage	$V_{s(peak)}$	$2V_{s(peak)}$	$V_{s(peak)}$
Ripple frequency	f_{input}	$2f_{input}$	2_{finput}

Fig 8



Filter circuits : Alternating current is rectified to provide a steady DC voltage similar to the output of a battery as shown in Fig 9a. But the output of rectifiers in a pulsating DC as in Fig 9b.

Pulsating DC voltages cannot be used in most of the electronic circuits. For example a buzzing sound will be obtained from a radio if these pulsations are not removed in the output of the rectifiers. The circuits used to filter off or reduce the pulsation in the DC output of rectifiers are known as smoothing circuits or popularly as Ripple filters.

Ripple : The small voltage fluctuations in the output of a filter like those shown in figure 9c are called Ripple.

Filter circuit components : Filter circuits are normally combinations of capacitors, inductors and resistors.

Types of filter circuits : The different filter circuits in use are

1 Capacitor input filter.

2 RC filter

3 Series inductor filter

4 Choke input LC filter

5 π filter.

The rate at which the capacitor discharges between points B and C in Fig 10b depends upon the time constant RLC. longer this time constant is, the steadier is the output voltage.

Calculation of Ripple : While designing a filter circuit the following methods can be used to calculate theoretically the ripple voltage in the output of the filter circuit.

Method 1

Knowing the required load current, IL, for a given value of frequency f and capacitance C, the peak-to-peak ripple voltage can be found using the formula,

$$V_{rip(p-p)} = \frac{I_L}{F_r C} \text{..........} (2)$$

Where

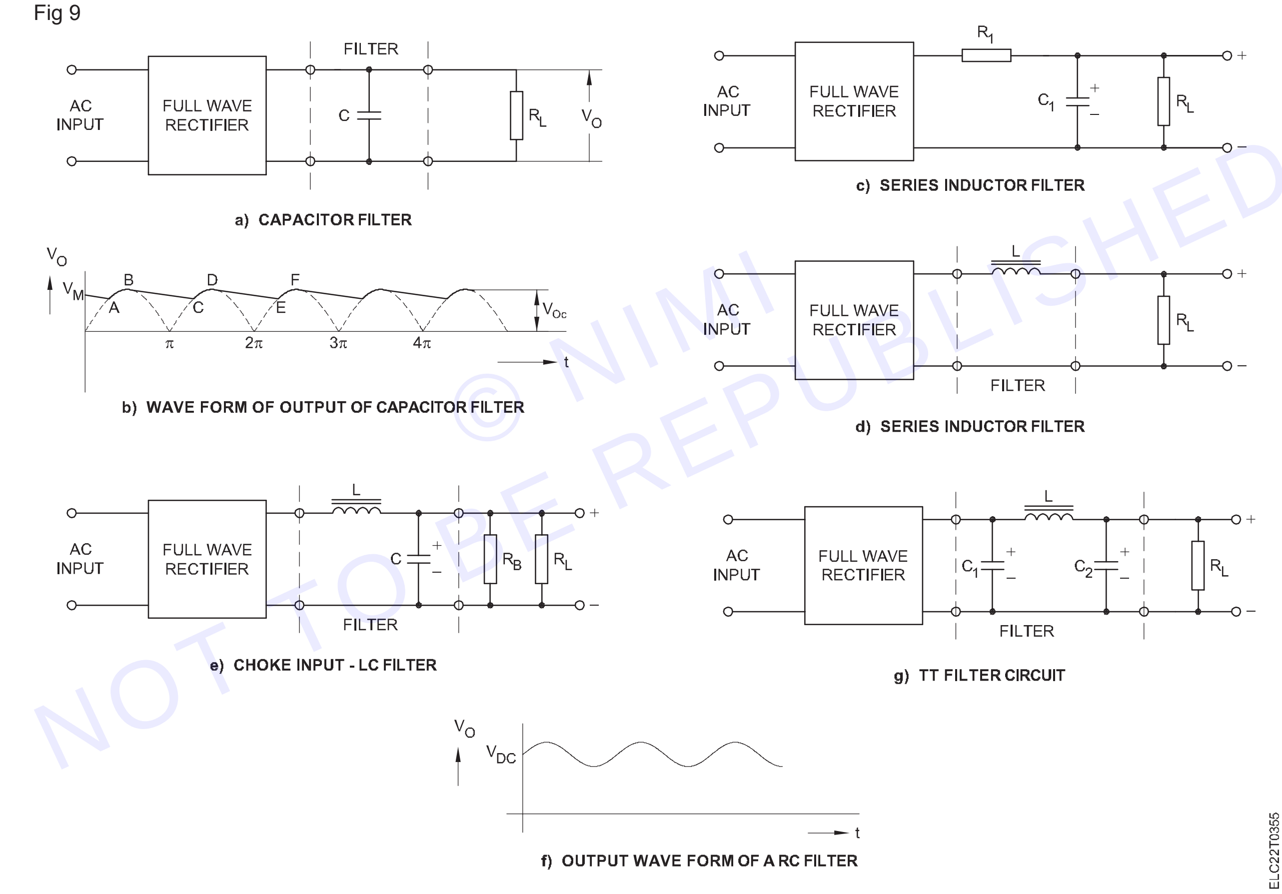
$V_{r(p-p)}$ = peak-to-peak ripple voltage in volts

i_L = required Dc load current, in Amps

F_r = ripple frequency, in Hz

C = capacitance in Farads

Fig 9



Fixing the permissible Vr(p-p) and knowing f and IL the required value for C can also be found using this formula

Method 2

Another method of expressing the ripple in the output DC is by ripple factor r defined as,

$$\text{Ripple factor, } r = \frac{V_{r(rms)}}{V_{dc}}$$

where,

r = ripple factor (dimension less)

$V_{r\ (rms)}$ = rms value for ripple voltages.

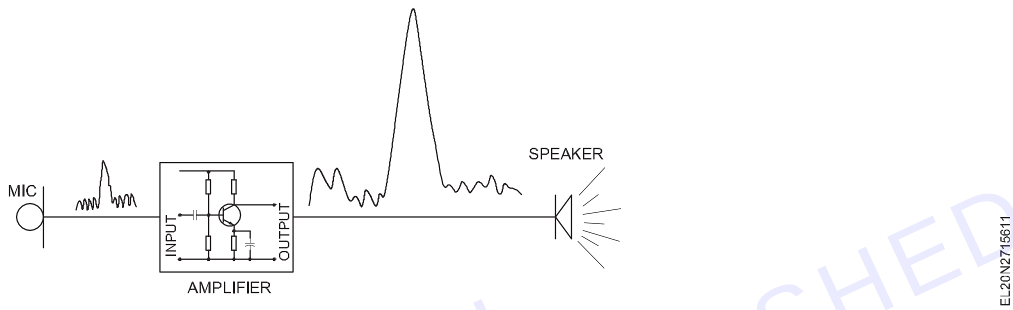
V_{dc} is the measured dc voltage at the output.

Transistors

Objectives: At the end of this lesson you shall be able to
- explain the construction of bipolar transistors
- explain the classification and working of PNP and NPN transistors
- state the important packages and type number systems of transistor
- explain the methods of testing transistor.

Introduction: Transistor is an active device which can be compared to the heart of modern electronics. It accepts small electrical signal either in the form of current or voltage at the input and then amplifies (increase the amplitude) and provides a large signal at the output as in Fig 1. Transistors are used in almost all electronic gadgets such as radio, TV, tape recorder, computer etc.,

Fig 1



Before the transistors were invented (1947), certain devices are used known as vaccum tubes or valves which were used in amplifiers.

Compared with the present day transistors the vacuum tubes were big in size, consumed more power, generated lot of unwanted heat and were fragile. Hence vaccum tubes became obsolete as soon as transistors came to market.

Transistors were invented by walter H. Brazil and John Barlow of Bell Telephone Laboratories on 23rd Dec. 1947. Compared to vaccum tubes transistors have several advantages. Some important advantages are listed below.

- Very small in size
- Light in weight
- Minimum power loss in the form of heat
- Low operating voltage
- Rugged in construction
- Long life and cheap.

To satisfy the requirements of different applications, several types of transistors in different types of packaging are available. As in diodes, depending upon the characteristics, transistors are given a type number such as BC 107, 2N 6004 etc., The characteristics data corresponding to these type numbers are given in Transistor data books.

Transistor are available as bi polar, field effect and unijunction etc.,

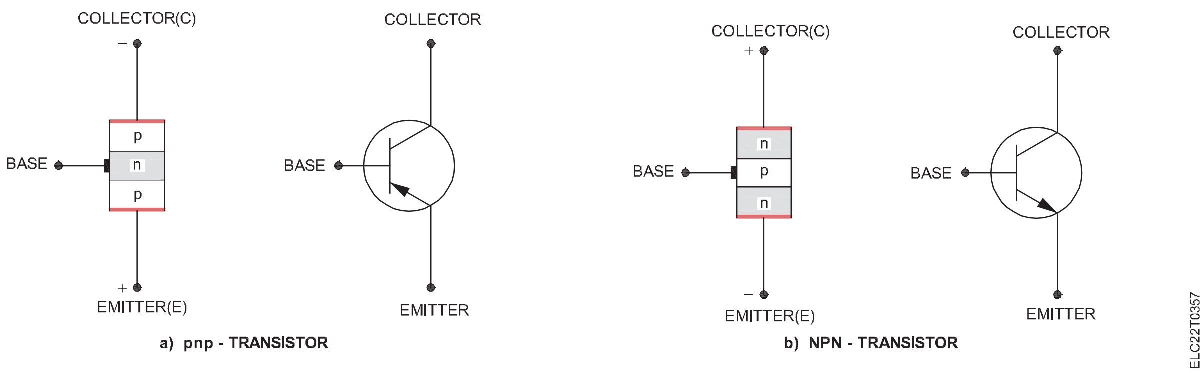
A bipolar junction transistor uses two opposite polarity of doped semiconductor i.e. ‘N’ type and ‘P’ type.

A field-effect transistor uses electrostatic field of charged carriers for its working.

An unijunction transistor uses a single junction of ‘P’ and ‘N’ type semiconductor.

Construction of bipolar junction transistors : The bipolar junction transistor is a three-element device (emitter, base, collector) made up of silicon or germanium materials by various methods like point contact, grown junction, alloy junction, diffusion junction and epitaxial. The construction of the transistor and the symbols, NPN and PNP, are shown in Fig 2.

Fig 2



A transistor is represented with the symbol shown. The arrow at the emitter shows the current flow through the transistor.

In most of the transistors, the collector region is made physically larger than the emitter region since it is required to dissipate more heat. The base is very lightly doped and is very thin. The emitter is heavily doped. The doping of the collector is more than that of the base but less than of the emitter.

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Classification of transistors

1 Based on the semiconductor used

- Germanium transistors
- Silicon transistors

Like in diodes, transistors can be made, using any one of the above two important semiconductors. However, most of the transistors are made using silicon. this is because, silicon transistors work better over a wide temperature range (higher thermal stability) compared to germanium transistor.

Method of finding the semi conductor used in Transistor

Transistor data books give information about the semi conductor used in any particular transistor.

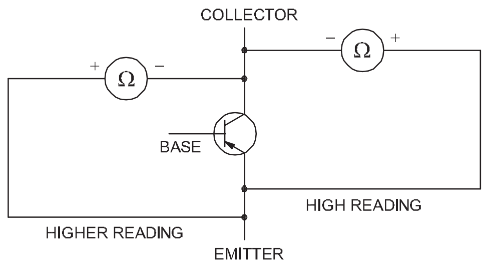
In the absence of data, still a quick check can be made with an ohmmeter to determine whether a transistor is made from silicon or germanium. In the test of a PNP transistor in Fig 3 first connect the ohmmeter negative lead to the collector and the positive lead to the emitter. With this hook-up a high resistance reading from the emitter to the collector will be shown.

Then reverse the ohmmeter lead connections, and the resistance reading will go even higher. If it is possible to read the ohms on the meter scale, it is germanium transistor. If the reading is in the megohms-to-infinity range, it is a silicon transistor.

2 Based on the way the P and N junctions are organised as in Fig 4

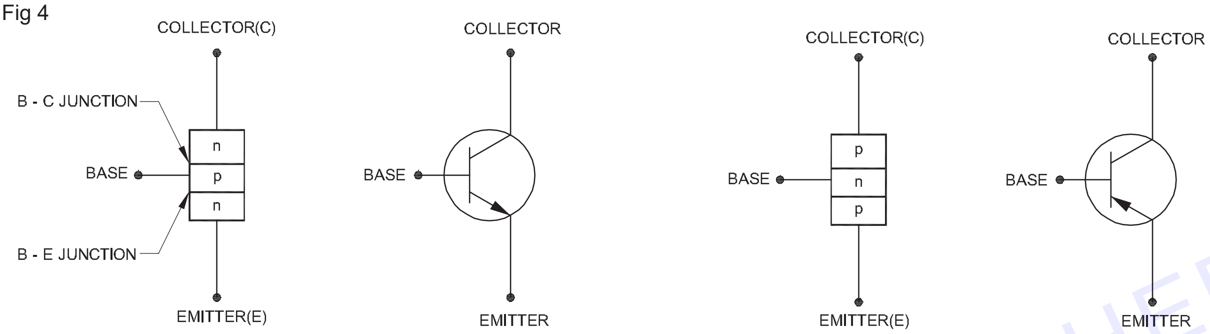
- NPN transistor
- PNP transistor

Fig 3



OHMMETER TEST RESULTS PROVE WHETHER THE PNP TRANSISTOR UNDER TEST IS MADE FROM GERMANIUM OR SILICON

Fig 4



a) pnp - TRANSISTOR b) NPN - TRANSISTOR

Both NPN and PNP transistors are equally useful in electronic circuits. However, NPN transistors are preferred for the reason that NPN has higher switching speed compared to PNP.

Operation of NPN transistor : During the normal operation of the transistor for amplifications the emitter base junction must be forward-biased, and the base collector junction must be reverse-biased, as in Fig 5.

If VEB is greater than the barrier potential (0.3 V for germanium and 0.7 V for silicon), the electrons in the emitter are repelled by the negative polarity of VEB and sent to the base. After filling a few holes in the base, these electrons can flow in either of the two directions. A few of the electrons are attracted to the positive terminal of VEB, producing base current IB. Many electrons in the base and collector are attracted by the high potential of VCB, producing collector current Ic. Emitter current IE is equal to base and collector currents.

IE = IB + Ic

Working of PNP transistor: For proper operation of a PNP transistors as amplifier the base emitter junction must be forward-biased and the collector-base junction must be reverse-biased as in Fig 6.

Holes which are the majority carries are injected from the emitter into the base region. By the reverse biasing of the base-collection junction, the collector region is made negative with respect to the base, and hence holes, which carry a positive charge, penetrate into to base and flow across the collector junction and flow into the external applied voltage.

Method of identifying PNP and NPN transistors : Whether a transistor is PNP or NPN can be found with the help of transistor data book.

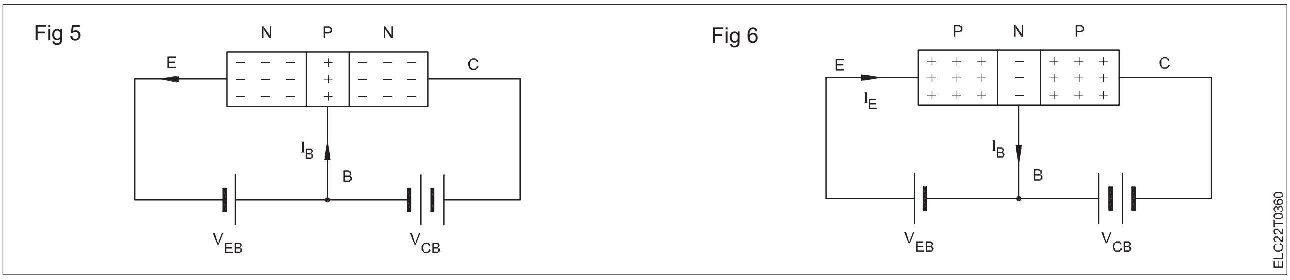
In the absence of data the following procedure may be adopted to identify the type of transistor whether it is PNP or NPN.

PNP identification : To identify the type of transistor first, make sure which is the positive lead and which is the negative lead from the ohmmeter. If necessary, take of the back for the instrument and check the polarity of the battery against the lead connections (positive to positive, negative to negative).

To test the transistor for its type:

1 Hook the positive lead from the ohmmeter to the base of the transistor. Fig 7

2 Connect the negative lead from the ohmmeter first to one transistor lead, then to the other.

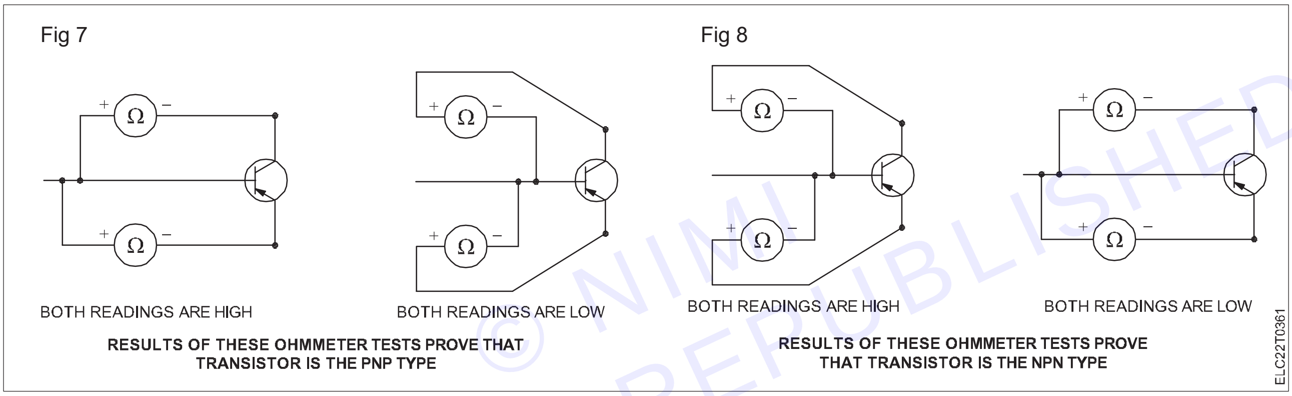


3 If both readings shows high resistance, hook the negative ohmmeter lead to the base of the transistor. (Fig 7)

4 Connect the positive lead from the ohmmeter first to one transistor lead, then to he other.

5 If both readings show low resistance, then it is a PNP transistor.

NPN identification : Suppose the ohmmeter tests show high resistance with the negative ohmmeter lead connected to the base of the transistor and the other lead is switched from transistor lead to transistor lead. See Fig 8 for reference.



Continue testing as follows:

1 Reverse the ohmmeter leads, connecting the positive lead to the base of the transistor.

2 Connect the negative lead from the ohmmeter first to one transistor lead, then to the other.

3 If the readings show low resistance, then it is a NPN transistor.

3 Based on the power handling capacity of transistors, they are classified as

1 Low power transistors less than 2 watts

2 Medium power transistors is 2 to 10 watts

3 High power transistors more than 10 watts

Low power transistors, also known as small signal amplifiers, are generally used at the first stage of amplification in which the strength of the signal to be amplified is low. For example to amplify signals from a microphone, tape head, transducers etc.,

Medium power and high power transistors, also known as large signal amplifiers are used for achieving medium to high power amplification. For example, signals to be given to loudspeakers etc. High power transistors are usually mounted on metal chassis or on a physically large piece of metal known as heat sink. The function of heat sink is to, take away the heat from the transistor and pass it to the surrounding air.

Transistor data books give information about the power handling capacity of different transistor.

4 Based on the frequency of application

- Low frequency transistor (Audio Frequency of A/F transistors)
- High frequency transistor (Radio frequency of R/F transistors)

Amplification required for signals of low or audio range of frequencies in Tape recorders, PA systems etc., make use of A/F transistors. Amplifications required for signals of high and very high frequencies as, in radio receivers, television receivers etc., use R/F transistors.

Transistors data books give information for any particular transistor as to whether it is a AF of RF transistor.

Testing of transistor : A transistor can be tested for all specifications shown in the data book. But verification of almost all specifications, except a few requires an elaborate step up and can damage the transistor permanently.

The condition of a transistor with two diodes connected back to back will be as shown in Fig 9(a) & (b)

An ohmmeter can be used to check the junction either for an open circuit or a short circuit. The short is indicated by R practically zero ohms. A very high R of many megohms, in the direction of infinite ohms, means an open circuit. Power must be off in the circuit for ohmmeter readings. Preferably, the device is out of the circuit to eliminate any parallel paths that can affect the resistance readings for a transistor, low resistance from base to emitter or base to collector indicate forward bias and when the ohm-meter/multimeter leads are transferred the resistance should be very high indicate reverse bias.

Probable possibilities are

1 When the ratio of reverse to forward R is very high, the junction is good.
2 When both the forward and reverse R are very low, close to zero, the junction is short-circuited.
3 When both the forward and reverse R are very high, close to infinity, the junction is open.
4 When both junctions are good transistor is good.
5 For a transistor without terminal details, base can be identified easily by identifying between collector and emitter terminal.

Normally for any power transistor, collector is connected to the metallic part/case to dissipate excess heat generated.

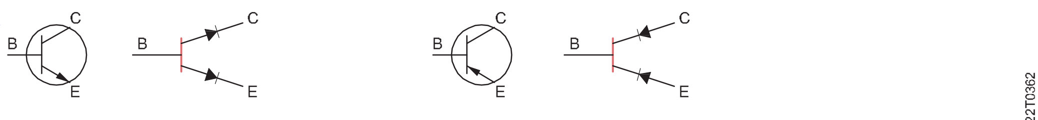
6 With a high voltage multimeter (motwane multimeter with 9 V cell in W x 100 range), emitter base junction shows some reverse resistance due to zener action which should be treated as high resistance for all purpose.

A germanium transistor has very low forward resistance for each of junction and a high resistance in the reverse direction, while a silicon transistor has moderate forward resistance and infinity reverse resistance.

Fig 10a shows a NPN transistor and Fig 10b shows a PNP transistor. The imaginary diodes1 and 2 can be tested as similar to testing any diode. When a diode is tested, if the ohmmeter shows high resistance in one direction and low resistance in another direction, then the diode corresponding to that diode junction can be regarded as GOOD. One important point to note in a transistor is that, both the diodes of the transistor should be GOOD to declare the transistor as GOOD.

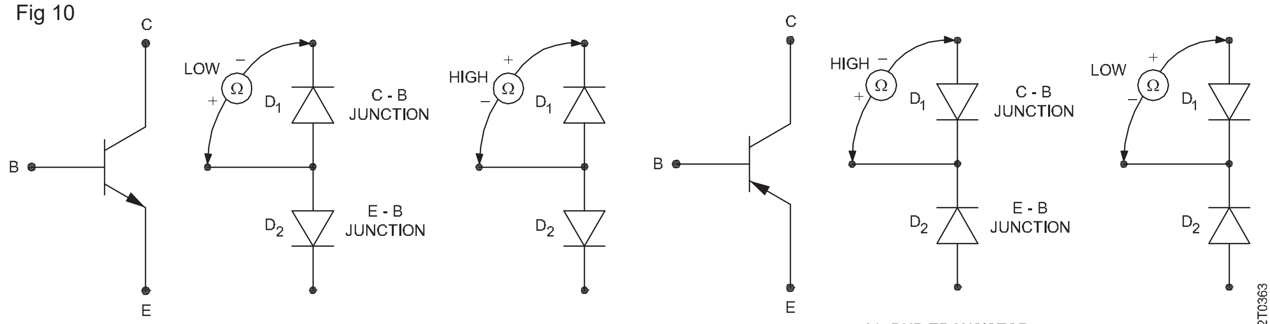
When testing, a transistor using ohmmeter, it is suggested to use the middle ohmmeter range (Rx 100) because, ohmmeters in low range can produce excessive current and ohmmeters in high range can produce excessive voltage which may be sufficient to damage small signal transistors.

Fig 9



a) NPN b) PNP

Fig 10



a) NPN TRANSISTOR b) PNP TRANSISTOR

Transistor biasing and characteristics

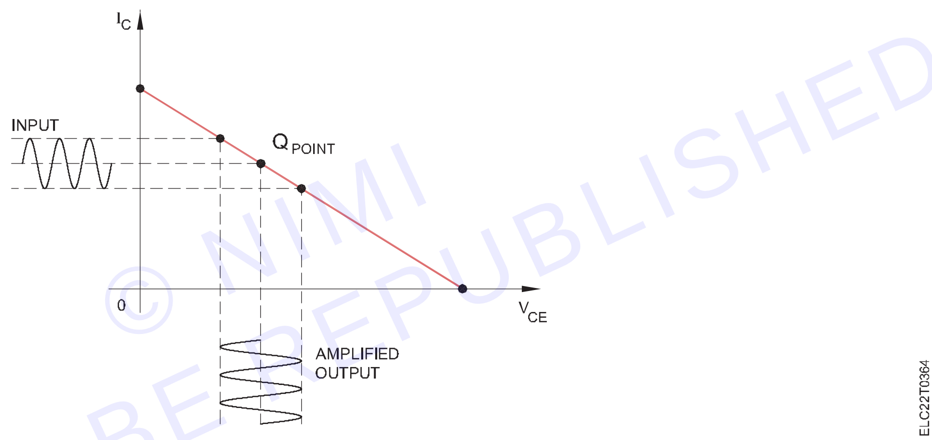
Objectives: At the end of this lesson you shall be able to
- state the need and type of transistors biasing
- state the reason for shifting Q point due to temperature and β_{dc} changes
- state the necessity and importance of transistor characteristics
- state the importance of DC load line and meaning of Q point in transistors characteristics.

Need of biasing of transistor

Before any one rides a motor cycle or drives a car, he has to start the engine and keep the engine running. In simple terms biasing transistors is similar to keeping the transistor started before making the real use of it. Once the transistor is started, like the engine of a car, it can be made to amplify, like covering the distance by driving the car.

Before an ac signal is fed to a transistor, it is necessary to set up an operating point or the quiescent(Q) point of operation. Generally this Q point is set at the middle of the DC load line. Once the Q point is set, then the incoming ac signals can produce fluctuations above and below this Q point as in Fig 1.

Fig 1



For the normal operation of a transistor amplifier circuit, it is essential that there should be

a a forward bias on the emitter-base junction and

b Reverse-bias on the collector-base junction

In addition, the amount of bias required is important for establishing the Q point which is dictated by the mode of operation desired.

If the transistor is not biased correctly, it would

1 Work inefficiently and

2 Produce distortion in the output signal.

It is desirable, that once selected, the Q point should remain stable i.e. should not shift its position due to temperature rise which cause variation in b (VBE) or leakage currents.

Further the amplitude variations in current and voltage of the input signal must not drive the transistor either into saturation of cut off.

Stable Q point: A set Q point of a transistor amplifier may shift due to increased temperature and transistor b value changes. Therefore, the objective of good biasing is to limit this shifting of the Q point or to achieve a stable Q point.

The Q point is nothing but a point in the output characteristic of the transistor. This point corresponds to a particular value of IB, IC and VCE. Further , the collector current IC depends both on IB and b of the transistor. If IB changes, Ic also changes, and hence, the Q point changes. If b changes, again IC changes, and hence, the Q point gets shifted.

Shifting of Q point due to temperature: Remember that a transistor is a temperature sensitive device. Any increase in the junction temperature results in leakage current. this increased leakage current in turn increases the temperature and the effect is cumulative. This chain reaction is called thermal run away. If this thermal run away is not stopped, it may result in the complete destruction of the transistor due to excessive heat. In transistors, due to this increased leakage current, the base current increases, and hence, the Q point gets shifted. This change in the set Q point affects the performance of the amplifier resulting in distortion.

Shifting of Q point due to bdc changes: Practically two transistors of the same type number may have different value of b. this is due to the manufacturing process of transistors. Hence, when a transistor is replaced or changed, due to different b of the replaced transistor, the Q point again gets shifted.

Therefore, a stable biasing is one which does not shift the Q-point even if temperature varies and/or the b of the transistor changes.

Different methods for transistor biasing: There are several ways to bias a transistor for linear operation. This means, there are several ways of setting up a Q point near the middle of the dc load line.

The methods used for providing a bias for transistors are

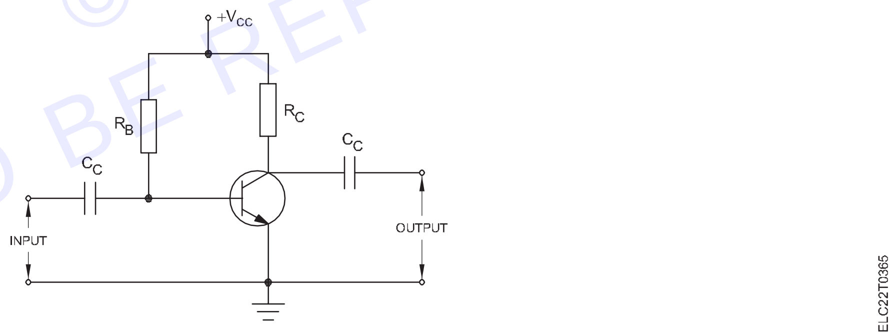
1 fixed bias or base bias

2 self-bias or emitter bias or emitter feed back bias

3 voltage divider bias

Fixed bias or base bias: The circuit in Fig 2 provides a fixed bias by means of the power source Vcc and the base resistor RB

Fig 2



Self-bias arrangements are not practicable for small values of current because the dc Q point changes due to

– poor Beta sensitivity

– bias voltages and current do not remain constant during transistor operation due to temperature variation.

Hence, in a base-biased transistor, it is impossible to set up a stable Q point. Therefore, base biasing of transistors is not generally done in linear amplifier circuits. However, base biasing is commonly used in digital circuits (discussed in further lessons) where transistor are used as a switch and not as a linear amplifier.

2 **SELF BIAS or EMITTER BIAS or emitter feedback bias:** Fig 3 shows a emitter-biased transistor. This type of biasing compensates for the variations in temperature and keeps the Q point fairly stable.

Let the temperature rise-causing rise in Ic and consequently rise in Ic. Then the current in RE increases. The increased current in RE increases the dc voltage drop across RE, reduces the net emitter to the base bias, and the base current, and hence reduces the collector current. Thus the presence of the self-biasing resistor RE reduces the increase in Ic and improves the operating point stability.

However if bdc increases, the collector current increase. This inturn increases the voltage at the emitter. This increased emitter voltage decreases the voltage across the base-emitter junction and therefore, the base current reduces. This reduced base current results in less collector current, which partially offsets the increase in Ic due to increase bdc.

Emitter bias is also referred to as emitter feedback bias. This is because an output quantity, i.e., the collector current, produces a change in an input quantity i.e., the base current. The term feedback means a portion of the output is given back to the input. In emitter bias, the emitter resistor is the feedback element because it is common to both the output and input circuits.

3 VOLTAGE-DIVIDER bias: Collector to base bias: Fig 4 shows a typical voltage-divider bias. This type of biasing is also called the universal bias because, this is the most widely used type of biasing in linear circuits.

Fig 3

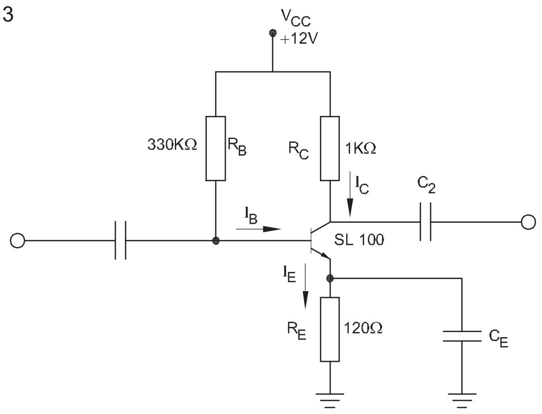
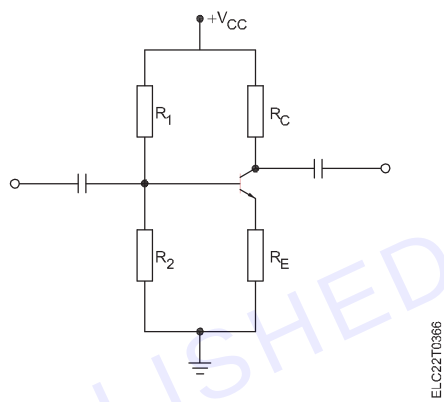


Fig 4



This type of biasing is known as voltage divider bias because of the voltage divider formed by resistors R1 and R2. The voltage drop across R2 should be such that it forward biases the emitter diode.

Emitter current in voltage divider bias : Assume that the base lead is open as shown in Fig 5b. Looking back at the unloaded voltage divider,

$$V_{TH} = \frac{R_2}{R_1 + R_2} = V_{CC}.$$

NOTE: VTH is known as the Thevenin's voltage. Refer reference books for Thevinin's theorem.

Now assume that, the base lead is connected back to the voltage divider as in Fig 5a. then, voltage VTH drives the base of the transistor. In other words, the circuit simplifies to Fig 5a and the transistor acts like the controlled current source.

Because the emitter is boot-strapped to the base,

$$I_E = \frac{V_{TH} - V_{BE}}{R_E}$$

Fig 5

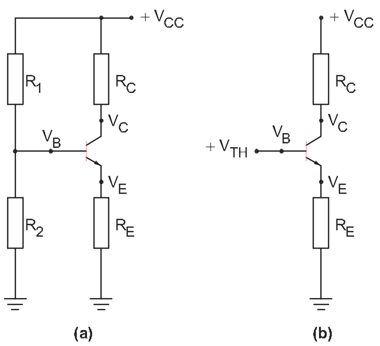
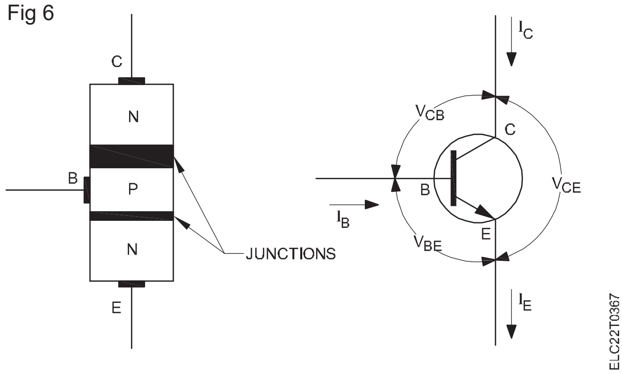


Fig 6



The collector current Ic will be approximately equal to IE.

Notice that bdc does not appear in the formula for emitter current. This means that the circuit is not dependent on variations in bdc. This means that the divider-biased transistor has a stable Q point.

Because of the stable Q point, voltage-divider bias is the most preferred form of bias in linear transistor circuits. Hence, divider bias is used almost universally.

Transistor characteristics

In a transistor there are two PN junctions followed by three voltage parameters V_{BE}, V_{BC}, V_{CE} and three current parameters I_B, I_C, I_E is in Fig 6.

Any change in any one parameter causes changes in all the other parameters. Hence it is not very easy to correlate the effect of one parameter with the others. To have a clear understanding of their relationship a minimum of two characteristics graphs should be plotted for any transistor. They are,

– Input characteristics

– Output characteristics

For simplicity in understanding, consider a common-emitter amplifiers circuit (Fig 7). The two characteristics graphs are in Fig 8.

The graph at Fig 8 shows the relationship between the input voltage V_{BE} and input current IB for different values of V_{CE}

To find the input characteristics from the circuit as in

Fig 7 keep V_{CE} = 0 constant; increase V_{BE} at regular steps of 0.1V and note the value of IB at each step. Repeat the above procedure for different value of V_{CE} say V_{CE} = 5V and 10V.

Input characteristic curves can be obtained by plotting IB on the Y axis against V_{BE} on the X axis. A typical input characteristic is in Fig 9.

Fig 7

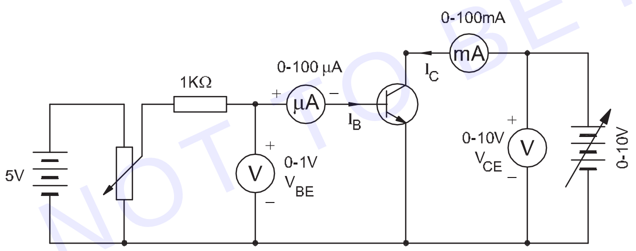
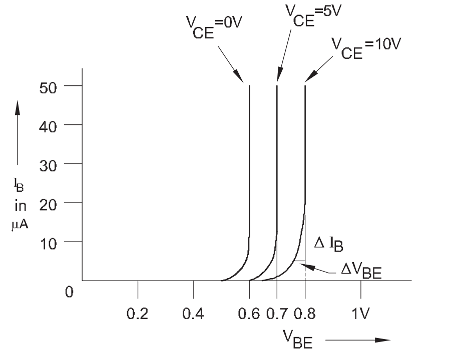


Fig 8



INPUT CHARACTERISTICS OF A COMMON EMITTER AMPLIFIER

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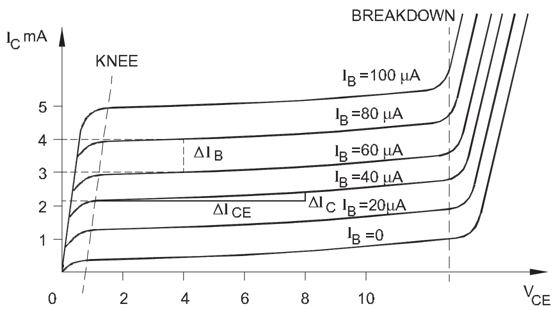
Fig 9



OUTPUT CHARACTERISTICS

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The reason for deviation of the characteristic curve for V_{CE}, 5V and 10V from V_{CE} 0 volt is, at higher values of VCE the collector gathers a few more electrons flowing through the emitter. This reduces the base current. Hence the curve with higher V_{CE} has slightly less base current for a given V_{BE}. This phenomenon is known as early effect.

However for the practical purposes the difference in gap is so small it can be regarded as negligible.

The CE input characteristic curves resemble the forward characteristic of a PN diode. The input resistance can be calculated by using the formula.

$$R_{in} = \frac{V_{BE}}{I_B} = \frac{0.72 - 0.7}{20\,\mu A - 10\,\mu A} = \frac{0.02}{10\,\mu A} = 2k\Omega$$

$(\mu = \text{micro})$

The voltage gain can be calculated by using the formula:

$$V_{gain} = \frac{V_{CE}}{I_{BE}} = \frac{10\,V - 5\,V}{0.15\,\mu A - 0.65\,\mu A} = \frac{5\,V}{0.1\,\mu A} = 50$$

Output CE characteristics: To find the output characteristics, keep I_B=0 micro-amp constant, increase V_{CE} in regular steps of 1_V and note the value of I_B at each step. Repeat the above procedure for IB = 20 micro-amp, 40 micro-amp and 60 micro–amp.

Output characteristics curves can be obtained by plotting Ic on the Y axis against V_{CE} on the X axis. A typical output characteristics curve is shown in Fig 9.

It is seen that as V_{CE} increases from zero, Ic rapidly increases to a near saturation level for a fixed value of I_B. As shown, a small amount of collector current flows even when I_B= 0. It is called leakage current I_{CEO}. Since the main collector current is zero, the transistor is said to be cut-off.

For simplicity in understanding consider on the output characteristic curve where I_B = 40 μA.

The output resistance can be calculated by the formula

$$R_0 = \frac{V_{CE}}{I_C} = \frac{8 - 2}{2.15\,mA - 2\,mA} = \frac{6}{0.15\,mA} = 40\,k\,\text{ohms}.$$

Current gain can be calculated by the formula

$$\text{Beta}\ \beta = \frac{I_C}{I_B} = \frac{4mA - 3\,mA}{80\,\mu A - 60\,\mu A} = \frac{1\,mA}{20\,\mu A} = 50$$

In the common base configuration, the current gain can be calculated by the formula:

$$\text{Alpha}\ \alpha = \frac{I_C}{I_E} = \frac{\beta}{1+\beta} = \frac{50}{1+50} = 0.98$$

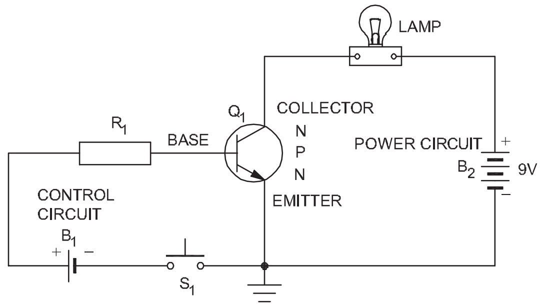
Transistor as a switch, series voltage regulator and amplifiers

Objectives: At the end of this lesson you shall be able to

- explain the function of the transistor at cut-off and saturation condition
- explain the operation of a transistor as a switch and its application
- state the working of series voltage regulator using transistor
- state the classification of amplifiers.

The operation of transistor as switch: The switching action for Q1 in Fig 1 illustrates how the output current can be controlled at the input. Note the following important operating characteristics.

Fig 1

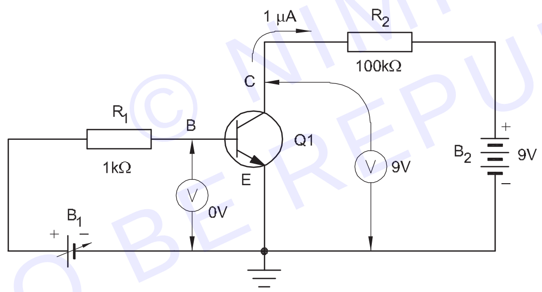


- The transistor is normally off, without any output current unless forward voltage is applied in the base-emitter circuit.
- The forward voltage controlling the base current determines the amount of output current.

In Fig 2 the control circuit of the input determines the base current. For the power circuit, the output is the collector current. An NPN transistor is used for Q1. This type requires positive VBE forward voltage. The emitter is common to both (a) the control circuit at the input and (b) the power output circuit.

The base emitter junction of Q1, in Fig 1 can be forward biased by the battery B1. Switch S1 must be closed to apply the forward voltage. Reverse voltage for the collector of Q1 is supplied by B2.The reverse polarity means that the N collector is more positive than the base. With switch S1 open, no current flows in the base-emitter (or control) circuit.

Fig 2



The reason is that the forward voltage is not applied. Therefore, the resistance from the emitter to the collector of the transistor is very high. No current flows in the power circuit, and the lamp does not light.

Next, assume that switch S1 is closed. This causes a small current to flow in the control circuit. R1 is a current limiting resistor for the base circuit. Therefore, the resistance from the emitter to the collector of the transistor drops. Consequently, a large current flows in the power circuit, causing the lamp to light.

Finally, the opening of the switch S1 in the control circuit cause the lamp in the power circuit to go out. This is because the resistance from the emitter(E) to the collector (C) of Q1 has again increased to near infinity.

In summary, a small current in the control circuit causes a large current to flow in the power circuit. With no current in the control circuit, the transistor acts like an open switch. With some current in the control circuit, the transistor acts like a closed switch.

Operation of transistor switching circuit : The schematic circuit in Fig 2 shows the measured voltages and collector current Ic in the 'transistor off' circuit. Note that only a tiny leakage current of 1micro amp flows from the emitter to the collector. The resistance from E to C is calculated as

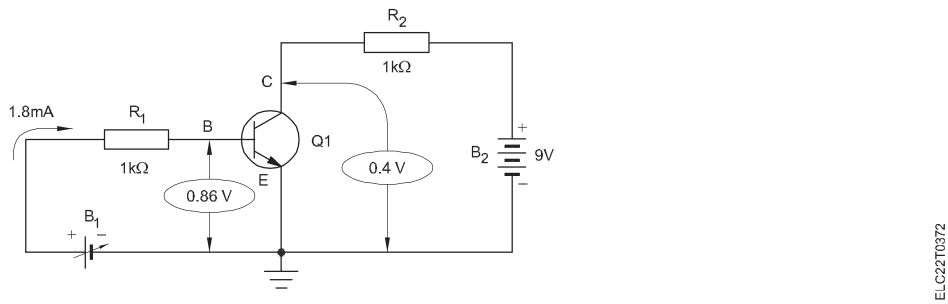
$$R = \frac{V}{I} = \frac{9\ V}{0.000001\ A} = 9\ \text{megohm}$$

The transistor has a resistance of 9 Megohm, which is like the open or off condition of a switch.

The schematic in Fig 3, shows the measured voltages and currents in the 'transistor on' circuit. First, the voltage from the emitter to the base has been increased by adjusting B1. The forward-biased voltage of 0,86V at the emitter-base junction of the transistor causes 1.8 mA to flow in the control circuit. This current in turn causes the resistance of the transistor from E to C to drop. The effect is that a large current of 85mA flows from the collector of the transistor. The resistance from E to C in Fig 4 is calculated as

$$R = \frac{V}{I} = \frac{0.4\ V}{0.085A} = 4.7\ ohm$$

Fig 3



The resistance of the transistor from E to C has dropped from its previous high value of 9 megohm to a low value of 4.7 ohm. As a result, the transistor is acting like a closed switch.

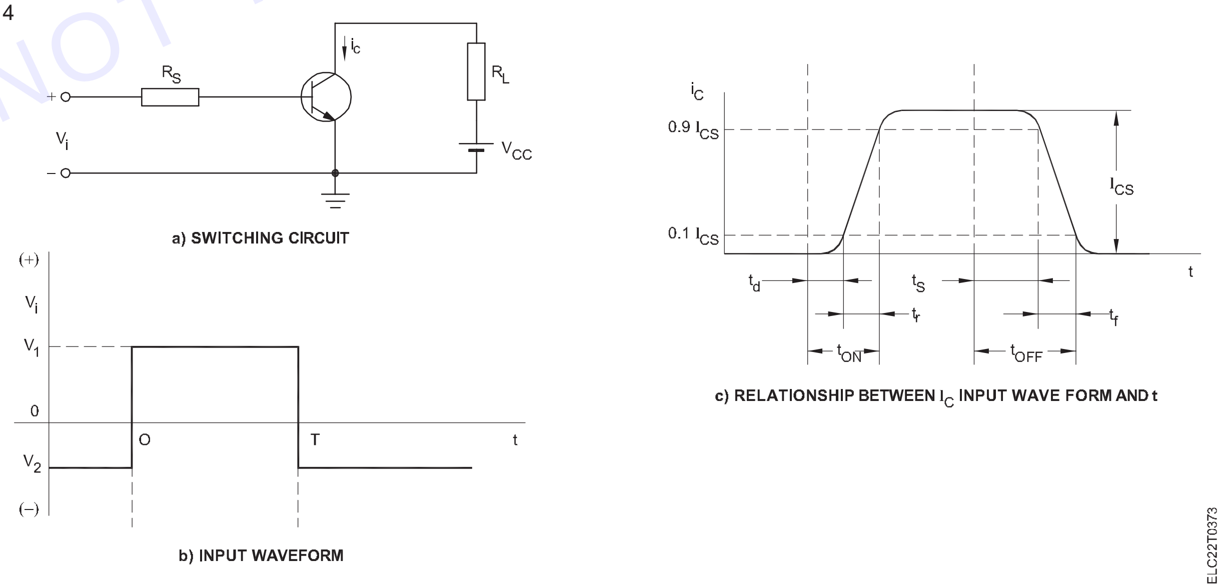
The transistor in Fig 2 is said to be at cut off position. It has reached its maximum resistance from E to C and has cut off the current. The very tiny current still flowing is due to minority current carriers in the transistor, which is the leakage current.

The transistor in Fig 3 is said to be at saturation. It has reached its minimum resistance from E to C, which produces the maximum collector current. When used as a switch, the transistor is driven to cut off or to saturation by the base current caused by the emitter-base voltage.

Transistor switching times : Now let us pay attention to the behaviour of the transistor as it makes a transition from one state to the other. Consider the transistor circuit in

Fig 4a, driven by the pulse wave-form in Fig 4b. This wave-form makes transitions between the voltage levels V2 and V1. At V2 the transistor is at cut off, and at V1 is applied between the base and the emitter through a resistor R1 which may be included explicitly in the circuit or may represent the output impedance of the source in the wave-form Fig 4b.

Fig 4



The response of the collector current Ic to the input wave-form, together with its time relationship to that waveform, is in Fig 4c. The current does not immediately respond to the input signal. Instead, there is a delay, and the time that elapses during this delay, together with the time required for the current to rise to 10 percent of its maximum (saturation) value ICS = Vcc/RL, is called the delay time td. The current waveform has a nonzero rise time tr which is the time required for the current to rise from 10 to 90 percent of ICS. The total turn-on time tON is the sum of the delay and rise time,

$t_{ON} = t_d + t_r$

When the input signal returns to its initial state at t = T

(Fig 4b), the current again fails to respond immediately. The interval which elapses between the transition of the input waveform and the time when ic has dropped to 90 percent of ICS is called the storage time ts. The storage interval is followed by the fall time tt, which is the time required for ic to fall from 90 to 10 percent of ICS. The turn off time to tOFF is defined as the sum of the storage and fall times,

$t_{OFF} = t_s + t_F$

The application of transistor switch: The transistor switch is used

- as an electronic on and off switch
- in the stable, mono-stable and bi-stable or filp-flop multi-vibrator circuits
- in the counter and pulse generator circuit
- in the clipping circuits
- as a sweep starting switch in the cathode ray oscilloscope equipment
- as a relay, but unlike the mechanical relay, the transistor has no moving mechanical parts.

Series voltage regulator

Voltage regulated power supply using zener diode is the simplest form of voltage regulator. But, zener voltage regulators have two main disadvantages:

1 When the load current requirement is higher, say of the order of a few amperes, the zener regulator requires a very high wattage zener diode capable of handling high current.

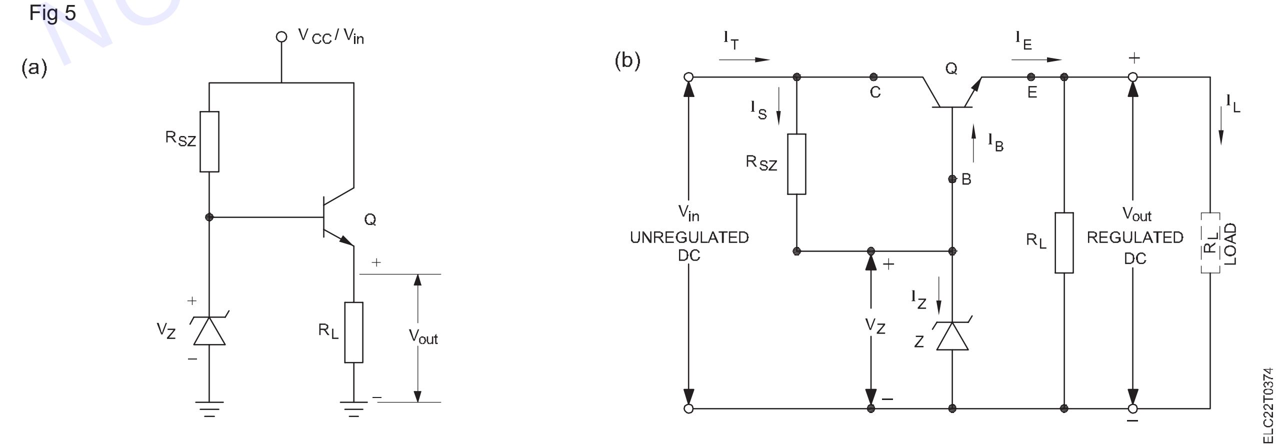
2 In a zener regulator, the load resistor sees an output impedance of approximately the zener impedance, RZ which ranges from a few ohms to a few tens of ohms (typically 5W to 25W). This is a considerably high output impedance because the output impedance of a ideal power supply should be zero ohms.

These two disadvantages of zener regulators are overcome in a simple series regulator shown in Fig 5.

The simple series regulator is in Fig 5a, redrawn in

Fig 5b is nothing but a zener regulator followed by an emitter follower. A circuit like this can hold the load voltage almost constant, thus working as a voltage regulator.

Fig 5



Classifications of amplifiers : An amplifier is an electronic circuit which is used to amplify or increase the level of weak input signals into very high output signals. Transistors are used as amplifiers in most circuits. In addition, resistors, capacitors and a biasing battery are required to form complete amplifier circuits.

Almost all electronic systems work with amplifiers. We are able to hear the news or other programmes on our radio, simply because the amplifier in the radio amplifiers the weak signals received by its antenna.

Classification of amplifiers: Linear amplifiers are classified according to their mode of operation, i.e. the way they operate according to a predetermined set of values. Various amplifier descriptions are based on the following factors.

1 Based on the transistor configuration

- a common emitter (CE) amplifier
- b common collector (CC) amplifier
- c common Base (CB) amplifier

2 Based on the output

- a voltage amplifier
- b current amplifier
- c power amplifier

3 Based on the input

- a small signal amplifier
- b large signal amplifier

4 Based on the coupling

- a RC coupled amplifier
- b transformer coupled amplifier
- c impedance coupled amplifier
- d direct coupled amplifier

5 Based on the frequency response

- a audio frequency (AF) amplifier
- b intermediate frequency (IF) amplifier
- c radio frequency (RF) amplifier
- d VHF and UHF amplifiers

6 Based on the feedback

- a current series feedback amplifier
- b current parallel feedback amplifier
- c voltage series feedback amplifier
- d voltage parallel feedback amplifier

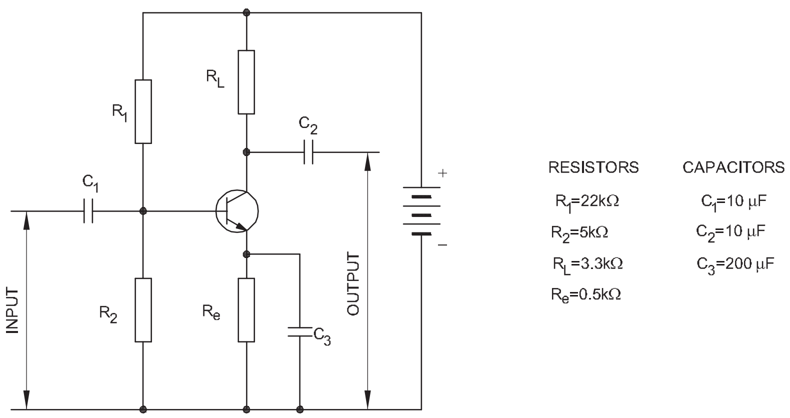
7 Based on the biasing conditions

- a Class A power amplifier
- b Class B power amplifier
- c Class AB power amplifier
- d Class C power amplifier

Of the above mentioned, serial numbers one and two are explained at this state. Some of the amplifiers dealt in this book for detailed study the students can refer to any standard books for the remaining portions depending on their special interest.

Common-emitter amplifier: This type of circuit is by far the most frequently used. It has the greatest power gain, substantial current and voltage gains, and is specially advantageous in multistage application when a high gain is a primary requirement. A common-emitter amplifier stage with biasing from a single D.C supply battery is in Fig 6.

Fig 6



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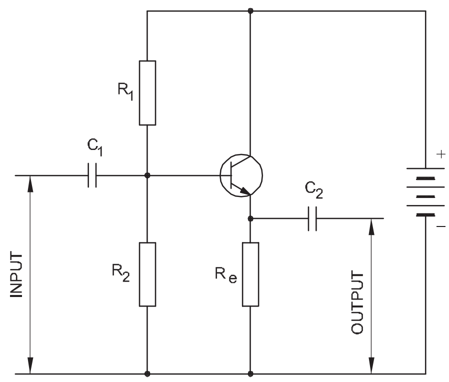
The a.c. signal is applied between the base and the emitter and the output is taken from the collector. For the transistor to operate, the emitter base junction must be forward-biased, the resistors R_1 and R_2 setting the base voltage so that the emitter is forward-biased. The collector current flows through the load resistors R_L and R_e and the voltage developed by R_L at the collector is the output.

The voltage gain of a transistor is largely determined by the value of this particular resistor since the voltage developed across it due to change in the collector current is far greater than that developed across the base resistor from the input signal.

Resistor Re is included to minimise the effect of temperature changes in the collector current. To prevent Re from reducing the signal gain by current feedback, a capacitor C_3 may be included in parallel with R_e.

Common-collector amplifier: In this configuration, the collector is the common point for the input and output circuits, the input signal being applied between the base and collector and taken off between the emitter and collector, Fig 7. The notable feature is the large input impedance virtually equal to that of the parallel circuit of R_1 and R_2. The output resistance is, however, low and, hence it follows that the voltage gain is low, but a high current amplification can be obtained.

Fig 7



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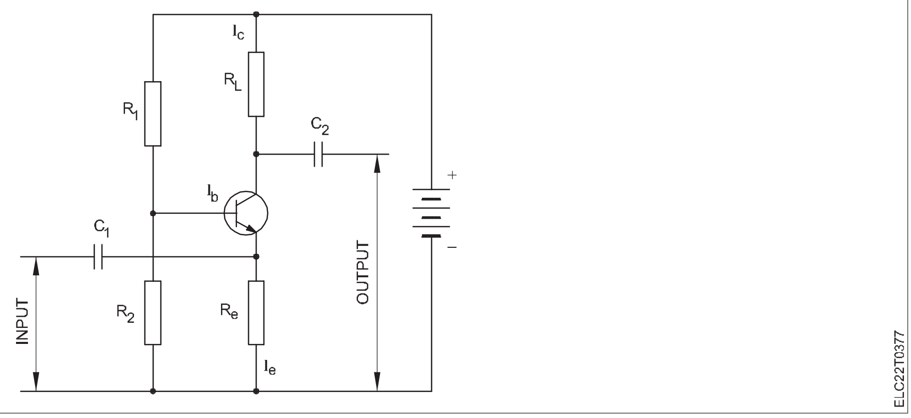
The functions of the capacitors C_1 and C_2 are the same as for the common-emitter stage, as the potential networks R_1 and R_2 which provide forward bias for the emitter-base junction. The main advantage of the common-collector circuit is the readiness with which it may be directly coupled to any point in a circuit regardless of voltage.

Common-base amplifier: In this circuit the base is the common terminal between the emitter terminal and the collector terminal. The emitter current I_c is the input current and the collector current I_c is the output current. (Fig 8) Since $Ie = I_b + I_c$ and since in this circuit Ie is greater than I_c, by the value of Ib, the current gain I_c/I_e will always be slightly less than one. Therefore, there can be no current gain in a common-base circuit. However, because of the low impedance of the forward-biased emitter-base junction and the high impedance of the reverse-biased collector-base junction a sizable voltage gain is obtained.

For instance, if we assume that input resistance of 200Ω, a load resistance of 50K and a current gain of 0.98, the voltage gain is 0.98 x 50k/200 = 245

Voltage amplifier: An amplifier is a circuit that incorporates one or more transistors and is designed to increase an alternating signal applied to the input terminals. It is called a voltage amplifier. If the size or magnitude of the output voltage is considerably greater than the input voltage, it is called the voltage gain of the amplifier.

Fig 8



The main function of a voltage amplifier is to produce a given gain with the minimum of distortion, i.e. the output voltages should have the same wave-form as the input wave-form, but should of course be much higher in magnitude. Examples for the voltage amplifier are the common base and the common emitter amplifiers.

Current amplifier: The function of the current amplifier is when the current injected in the base, load can influence to much greater current to flow in the emitter-collector circuit.

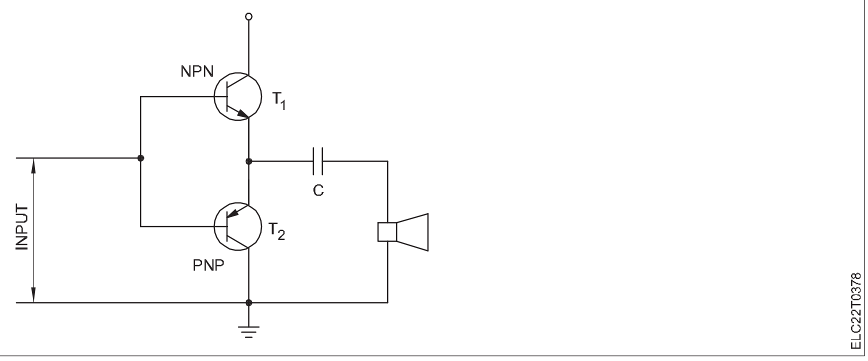
The remarkable result is that, if the base current is increased by a certain proportion, the base current in the collector current gives rise to a corresponding, but much larger changes in the collector current. We have achieved current amplification. The ratio of the output current to the input current is called the current gain of the amplifier.

An example for the current amplifier is the common-emitter, common-collector amplifier. The current gain of common-emitter amplifier is 50 to 300 and that of the common-collector amplifier is 50 to 500.

Power amplifier : Power amplifiers are used to drive the output mechanism, e.g. a loudspeaker, a pair of earphones, a moving coil meter or some other type of indicating device. The main function of a power amplifier is to deliver a good deal of undistorted power into the output device or load circuit. Examples for the power amplifiers are class A, class B, class AB and class C.

Fig 9 shows the complementary symmetry Class B push-pull power amplifier circuit. In a complementary pair of power amplifiers, one of them is an NPN type and the other a PNP type. With no input signal, neither transistor conducts and the output is zero. When the input signal is positive going, the NPN transistor T1 conducts and the PNP transistor T2 is cut off. When the signal is negative going, T1 is tuned of while T2 conductors. The maximum efficiency of this circuit is about 78%.

Fig 9



Function generator and cathode ray oscilloscope (CRO)

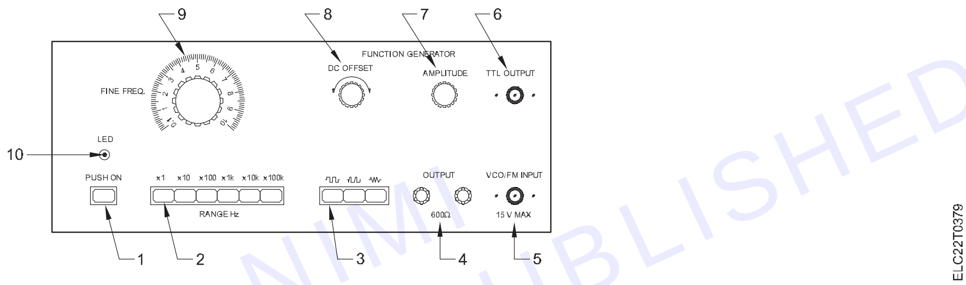
Objectives: At the end of this lesson you shall be able to
- explain the use and control of function and AF (audio frequency) generator
- explain the function of CRO with block diagram
- state the functions of various controls in CRO
- state the use of CRO in electronic circuits.

Introduction: A function generator is an equipment capable of providing sine, square and triangular wave outputs at different frequencies and amplitude. It has a maximum of 20 volts peak to peak single amplitude. A function generator finds applications in frequency modulations, tone control, Audio electronic, other laboratory and research work.

Panel controls and features of function generator

The front panel controls of function generator. (Fig 1)

Fig 1



1 **Power ON-OFF switch:** To turn on the function generator this button should be depressed. To turn off the same button should be pressed to release.

2 **Range selectors:** The range selection is of decade frequency type. The output frequency is given by the product of range selected and frequency dial indication. For example if the 10 K range button in depressed and frequency dial is at 2, then the output frequency is 20 KHz.

3 **Function selectors:** These selectors select the desired output waveform. (square, sine or Triangle)

4 **Output jack:** The wave forms selected by the function switches are available at this jack.

5 **VCO input jack:** An external voltage (not exceeding ± 20V peak) input will vary the output frequency. The change in frequency is directly proportional to the input voltages.

6 **TTL JACK:** A TTL (Transistor, Transistor logic) square wave is available at this jack. This output is independent of the Amplitude.

7 **Amplitude control:** This controls the amplitudes of the output signal.

8 **Offset control:** This controls the DC offset of the output.

9 **Fine frequency dial:** The output frequency of the wave forms is given by the product of the setting of this dial and the range selected.

Operating information: The function generator is powered by 240V. AC mains. When the power ON switch is depressed the LED will glow.

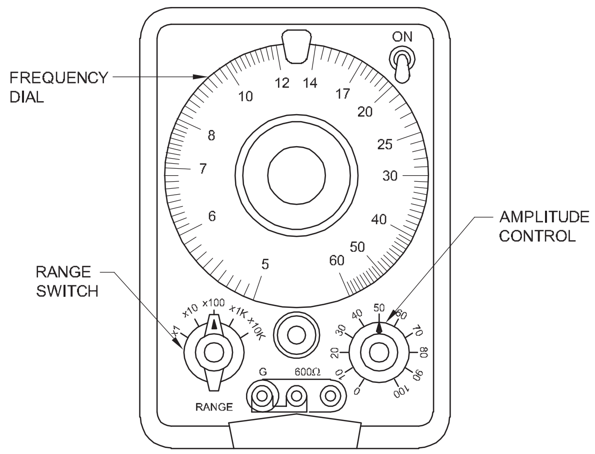
The desired frequency is set by depressing the frequency range switch an positioning the fine frequency dial.

The desired wave from is selected by depressing the appropriate function button from sine, square or triangle.

The amplitude of the selected output signal is adjusted by Amplitude control knob. A variation of the display amplitude from 0-20 V peak is possible. The TTL output is not affected by the amplitude control.

Audio Frequency (AF) Generator (Fig 2): Audio frequency generators produce sine wave signals from 20 Hz to 20 kHZ. Certain type of AF generators produce sine wave upto 100 kHZ. In addition to sine wave there may be provision to produce square waves too.

Fig 2



AUDIO FREQUENCY GENERATOR

These generators contain a variable amplitude control which changes the signal amplitude from 10 mv to 20V. With the help of this generator the audio amplifier stages in radio, TV recorders and audio amplifier could be tested.

While the frequency range switch selects the desired frequency range switch selects the desired frequency range, the frequency dial is used to select the frequency within the desired range.

Cathode ray oscilloscope (CRO)

Introduction: The oscilloscope is an electronic measuring device which provides a visual presentation of any wave form applied to the input terminals. Cathode ray tube (CRT) like a television tube provides the visual display of the signal applied as a wave form on the front screen. An electron beam is deflected as it sweeps across the tube face, leaving a display of the input signal.

An oscilloscope usually consists of:

– Attenuator
– amplifiers
– saw-tooth generator
– gate amplifiers or Z-amplifier
– Trigger
– CRT (cathode ray tube)
– power supply

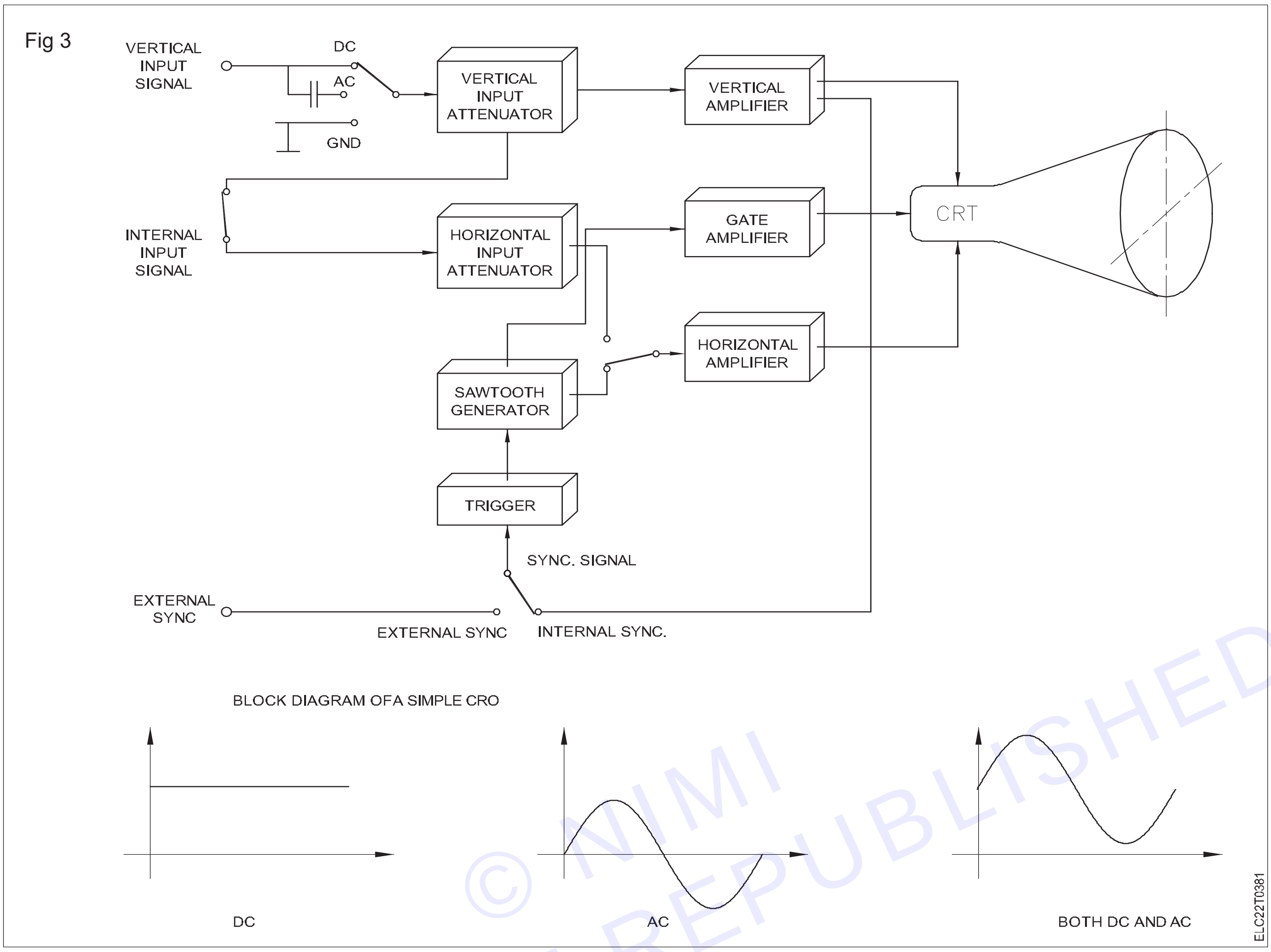
The block diagram of a simple cathode ray oscilloscope is shown in Fig 3.

Attenuator : The input signal should be attenuated to a suitable magnitude before it is applied to the amplifier. The attenuators are employed at the input of both vertical and horizontal amplifiers.

Amplifier : The amplifiers of an oscilloscope consist of a vertical amplifier and a horizontal amplifier. The vertical amplifiers amplify the vertical input signal before it is applied to the Y-plates. The horizontal amplifier amplifies the signal, before it is connected to the X-plates.

Saw-tooth generator: The measuring signal of any shape is connected to the Y-input(plates) and then it appears on the screen. The signal on X-plates should be such that the image on the screen is similar to that on the Y-plates. Hence a saw-tooth signal is required to be connected to the X-plates which makes the image on the screen like the signal connected at the vertical plate. The saw-tooth signal is called the time base signal, and is produced by the saw-tooth generator. The shape of the saw-tooth signal is shown in Fig 4. The time-base signal consists of trace, retrace and hold off period.

Fig 3



Gate amplifier or Z-amplifier: It is desirable that the image seen on the screen of the CRT must be continuous, that is, the electron beam is desired to appear only in the trace period of the time-base signal. The retrace period of the electron beam must not be visible on the screen. Therefore, the gate amplifier is required to control the electron beam in order that it appears only in the trace period.

The signal from the gate amplifier is a square wave and is related to the time-base signal. This is illustrated in Fig 5.

Trigger (Gate amplifier output) : As mentioned earlier, the measuring signal-wave form is connected to Y-input, which appears on the screen. In order to make the wave-form stationary on the screen, it is required that the starting point of the time base signal has to be fixed related to the signal connected to the Y-input. This is known s 'synchronization'. The functional stage which performs synchronization is the trigger.

Fig 4

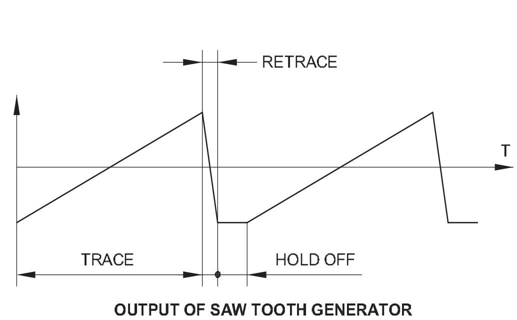
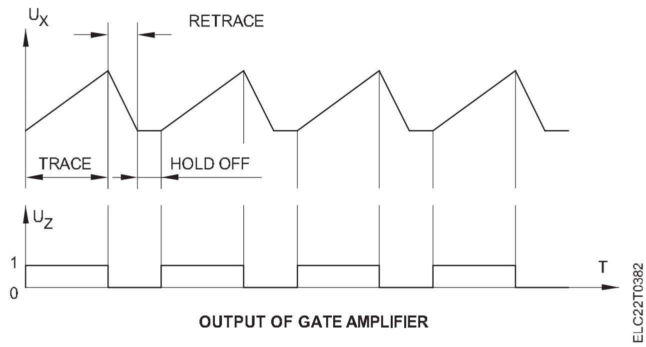


Fig 5



The trigger will produce a pulse or impulse for triggering the time-base. Every time the time-base is triggered, one saw-tooth wave-form is produced.

There are three forms of triggering in an oscilloscope.

Internal triggering : The signal which is supplied to the trigger is the internal signal of the CRO produced by using the signal from the vertical input signal. The sequence of signal processing is shown in Fig 6.

External triggering : The signal which is supplied to the trigger is the external signal, produced by using the signal from the external, sync.

Line triggering : The signal which is supplied to the trigger is the signal from the power supply of CRO. (Not shown in the block diagram)

Switches are provided to select the form of triggers as required. In a CRO, suitable timing can be selected that causes the image on the screen to be stationary.

CRO (The Cathode ray tube): The constructional features are explained later in this text.

Power supply: Low voltage and high voltage DC supplies which are required for the oscilloscope function are produced by rectifier filters and switch mode power supply circuits.

Controls and their functions in a cro: The operating controls on the front panel of a general purpose oscilloscope is shown in Fig 7. The names of the controls and their functions are listed below.

Fig 6

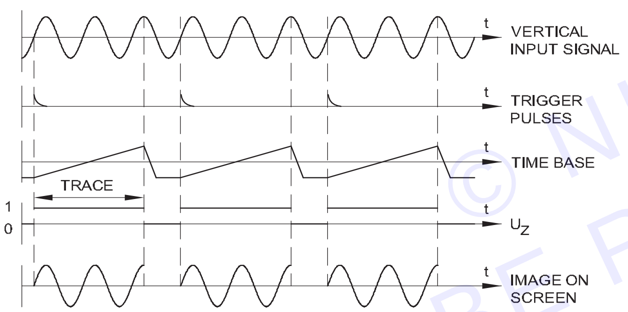
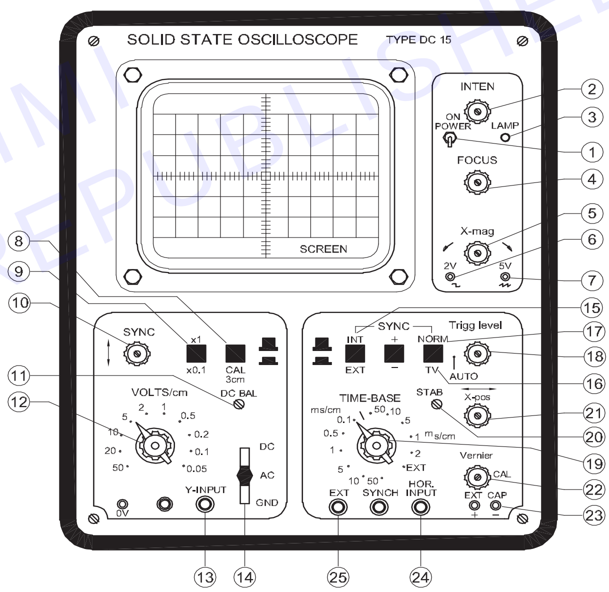


Fig 7



CATHODE RAY OSCILLOSCOPE

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General

Power-on (1): It is toggle switch meant for switching on power. In the ON position, power is supplied to the instrument and the neon lamp (3) glows.

Intensity (2): It controls the trace intensity from zero to maximum.

It controls the sharpness of the trace. A slight readjustment of this control may be necessary after changing the intensity of the trace.

X-Magnification (5): It expands length of the time-based from 1 to 5 times continuously, and makes the maximum time-base to 40ns/cm.

Square wave (6): This provides a square wave of 2 V (p-p) amplitude to enable the user of the scope to check the Y-calibration of the scope.

Saw-tooth wave (7): This provides a saw-tooth, wave-form output coincident to the sweep-speed switch with an output of 5V (p-p). The load resistance should not be less than 10 k ohms.

Vertical section

Y (10) : This control enables the movement of the display along the y-axis.

Y (13) : It connects the input signal to the vertical amplifier through the AC-DC-GND coupling switch (14)

AC-DC-GND coupling switch (14): It selects coupling to the vertical amplifier, in DC mode, it directly couples the signal to the input; in AC mode, it couples the signal to the input through a 0.1 MF, 400-V capacitor. In GND position, the input to the attenuator (12) is grounded, whereas the Y-input is isolated.

Volts/cm (Attenuator) (12): It is a 10-position attenuator switch. It adjusts the sensitivity of the vertical amplifier from 50 m V/cm to 50 V/cm in 1,2,5,10 sequence. The attenuator accuracy is ±3%.

x1 or x 0.1 switch (9)

When switched in x 0.1 or position, it magnifies the basic sensitivity to 5 m V/cm from 50 m V/ cm

CAL switch (8): When pressed, a DC signal of 15 m V or 150 m V is applied to a vertical amplifier depending upon the position of x1-x0.1 switch (9) position.

DC bal (11): It is a preset control on the panel. It is adjusted for no movement of the trace when either x1 - x0.1 switch (9) is pressed, or the position of AC-DC-GND coupling switch (14) is changed.

X-Position (21): This control enables the movement of display along the X-axis.

Trigger level (18): It selects the mode of triggering. In AUTO position, the time-base line is displayed in the absence of the input signal. When the input signal is present, the display is automatically triggered. The span of the control enables the trigger point to be manually selected.

Time-base (19): This sector switch selects sweep speeds from 50 ms/cm to 0.2Ms/cm in 11 steps. The position marked EXT is used when an external signal to be applied to the horizontal input (24)

Vernier (22): This control is a fine adjustment associated with the time-based sweep-selector switch (19). It extends the range of sweep by a factor of 5. It should be turned fully clockwise to the CAL position for calibrated sweep speeds.

Sync. selector (15, 16, 17): The INT/EXT switch (15) selects internal or external trigger signal. The +ve or -ve switch (16) selects whether the wave-form is to be triggered on +ve or -ve step. NORM/TV switch (17) permits normal or TV (line frequency) frame.

Stab (20): It is a preset control on the panel. It should be adjusted so that you just get the base line in the AUTO position of the trigger level control (18). In any other position of the trigger level control, you should not get the base line.

Ext. Cap (23): This pair of connectors enables the time-base range to be extended beyond 50 ms/cm by connecting a capacitor at these connectors.

Hor. input (24): In connects the external signal to the horizontal amplifier.

Ext. sync. (25): It connects the external signal to the trigger circuit for synchronization.

Application of CRO

AC voltage measurement: The screen of the cathode ray oscilloscope usually has a plastic gratitude overlay, marked in centimeter divisions. The vertical amplitude of any wave form indicates peak-to-peak voltage.

To measure unknown AC voltages the main supply AC should be isolated through a isolation transformer and the attenuator is set to 50 V/ div. The AC-DC switch is set to AC position (out). Voltage to be measured is connected to the input and common terminal. Set the time base switch to display several cycles of the wave form. Adjust the V/div switch to get a wave form at a convenient height such that the positive and negative peaks appears with-in the screen.

Measure the vertical amplitude (no. of divisions peak-to-peak) of the voltage on the screen. Now multiply the amplitude by the volts/div setting to find the peak-to-peak voltage value.

Example : Assume a vertical deflection of 6.4 divisions as in Fig 8 and a volt/div setting of 5 volts.

Peak-to-peak voltage = 6.4 x 5 = 32 V

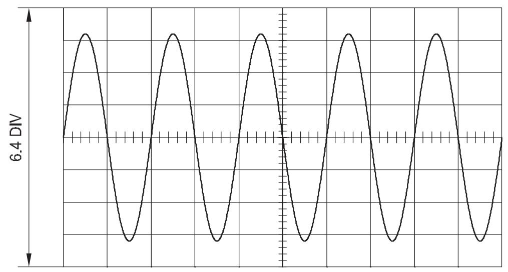
therefore peak voltage = 16 V

therefore RMs voltage = 16 x 0.707 = 11.31 V

$$\text{or RMS voltage} = \frac{\text{Peak to peak voltage}}{2.83} = \frac{V_{PP}}{2 \times \sqrt{2}}$$

$$= \frac{32}{2 \times \sqrt{2}} = 11.31\text{v}$$

Fig 8



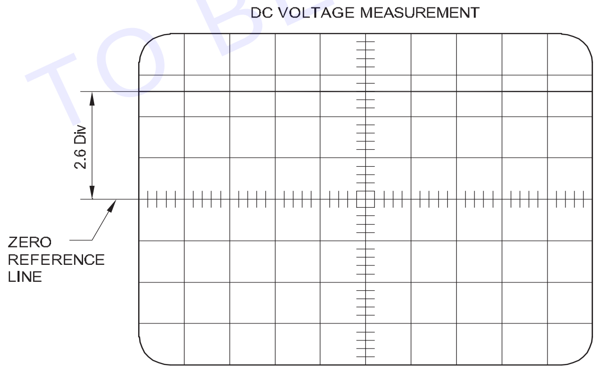
DC voltage measurement : The input selector switch is set to DC position. Adjust the Y shift position to get the trace at the centre of the screen. This line represents zero DC volts. Connect the +ve of the DC voltage to be measured to input terminal and the -ve to the common terminal. Now the horizontal line will move up. (Down for reverse polarity) the volts/div switch is set as required.

Now measure the vertical distance in divisions form the zero reference line.

The DC voltage can be found by multiplying the vertical distance (division) with VOLT/DIV setting.

An example is worked out with reference to Fig 9

Fig 9



Assume a vertical deflection of 2.6 division and a Volts/Div setting of 20 V.

DC voltage = 2.6 x 20 = 52V.

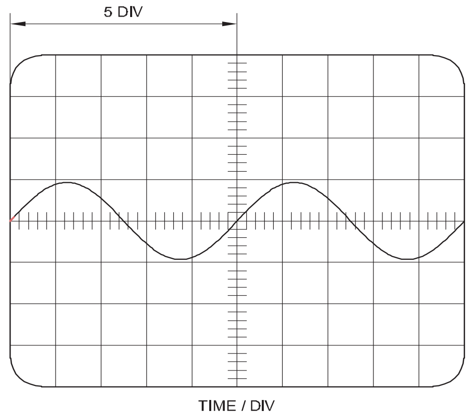
Measurement of time and frequency: The wave-form to be measured is connected to the V input. The volts/ Div switch is set to display a suitable vertical amplitude of the wave-form. The Time/Div switch is set to display approximately two cycles of the wave-form to be measured. Adjust the Y-SHIFT control to move the trace so that the measurement points are on the horizontal centre line. The X-SHIFT control is adjusted to move the start of the measurement points to a convenient reference line.

The distance (divisions) between the points of one cycle is measured as in Fig 10.

The product of the divisions of one cycle and the setting of time/div switch gives the period of one cycle.

Fig 10

PERIOD AND FREQENCY MEASUREMENT



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The frequency can be determined by the formula

$$\text{Frequency} = \frac{1}{\text{Time period}}$$

where frequency is in hertz and time in seconds.

Example

Time = Div x time base setting

= 5 x 0.2 ms

= 1 ms

$$\text{therefore frequency} = \frac{1}{T} = \frac{1}{1 \times 10^{-3}} = 1000\,\text{Hz}$$

Frequency = 1 kHz.

Printed circuit boards (PCB)

Objectives: At the end of this lesson you shall be able to

- state the types of etchants used for etching and preparation of etchant solution
- state the reasons for agitating the etchant solution while etching
- list the important points while drilling holes on PCBs
- list the advantages of marking component positions on PCBs.

Introduction

Printed circuit board in which the connecting wires are replaced by a thin conducting path called copper or silver foil which is moulded in one side of the insulated board. The insulating board is generally made up of phonetic, paper or fibre glass or epoxy.

The moulded conducting path generally known as tracks size depend on the power of the circuit. The width of tracks are varied few millimeters to less than one millimeter depend on the circuit.

The thin tracks less than one millimeter made up with silver tracks where IC circuits and micro controller circuits are to be made. Several process moulded to make PCB and it is explained below.

Etching

Once the required portions on the copper foil side of the laminate is painted/masked and dried, the next step is to remove the copper present in the unmasked portions of the laminate. This process is known as etching.

Only after etching the unwanted areas of the copper foil, the metal side of the laminate gets the actual shape of the circuit connection required.

Etching is done using any one of the following chemicals;

– Alkaline ammonia

– Sulpuric-hydrogen peroxide

– Ferric chloride

– Cupric chloride

The ratio of ferric chloride and water decides the rate of etching. The typical ratio is, 100mg of concentrated ferric chloride powder/liquid for one litre of water. This Fecl3 is prepared in a plastic tray of suitable size such that the painted laminate to be etched can be fully immersed as shown in Fig 1.

Since ferric chloride is an acid solution, although diluted, it is harmful to the skin. Hence, rubber gloves are to be used while working with this solution.

The painted laminate to be etched is slid into the Fecl3 solution of required quantity, with the painted surface of the laminate facing the top as in Fig 1, such that, as the process of etching progresses, the extent of etching is visible.

To ensure speedy and uniform etching, the etchant solution is agitated lightly by shaking and tilting the tray as shown in Fig 2. Too much of agitation of the solution should be avoided, as this may peel off the ends of the painted tracks and remove those portions which were not intended to be etched.

Fig 1

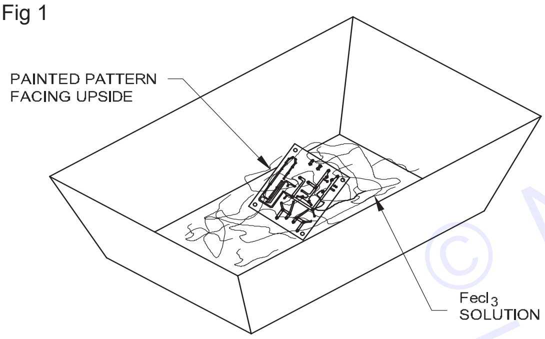
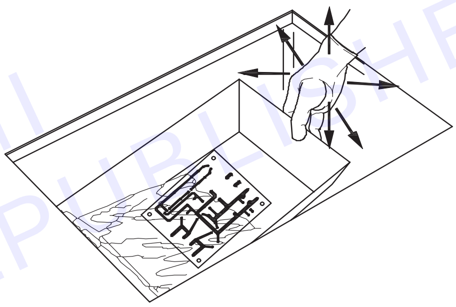


Fig 2



As the etching progresses, the copper in the unwanted portion is gradually removed. When the etching is complete, all the copper in the unwanted portion disappears and the etched portion will have the colour of the insulator of the laminate board.

Once the unwanted portions of copper are completely etched, the board is taken out of the solution and is cleaned using fresh water to remove the remaining Fecl3 solution. This stops any further etching process.

After cleaning the board using water and drying, the etch-resistant ink/paint on the lay out pattern is removed using solvents, such as, thinner or petrol. The cleaned board will then have bright copper stripes and pads, only in the required portions representing the circuit as in Fig 3.

Drilling holes on PCBs

The next step after etching and removing the mask/paint is to drill holes of required diameter at the pad centers for inserting the components, input/output and Vcc &

ground(Gnd) connections. Extra care is to be taken while drilling holes because carelessness while drilling may peel off the pad area of the copper. Some hints for drilling on PCB's are given below;

– If the point where drilling is to be made is not clear, punch the point again such that the drill bit sits at the punched point before starting the drilling.

– Use a high speed drill gun/machine.

– Use drill bits of the required size. If an exact size drill bit is not available, use a drill bit one size smaller but never one size larger.

– Fix the PCB firmly on a vice using a wooden block so that the PCB does not become loose while drilling and peel of the pad area copper.

– Ensure that all the points required are drilled because, once the components are mounted, drilling holes on the PCB may damage the mounted components due to vibration.

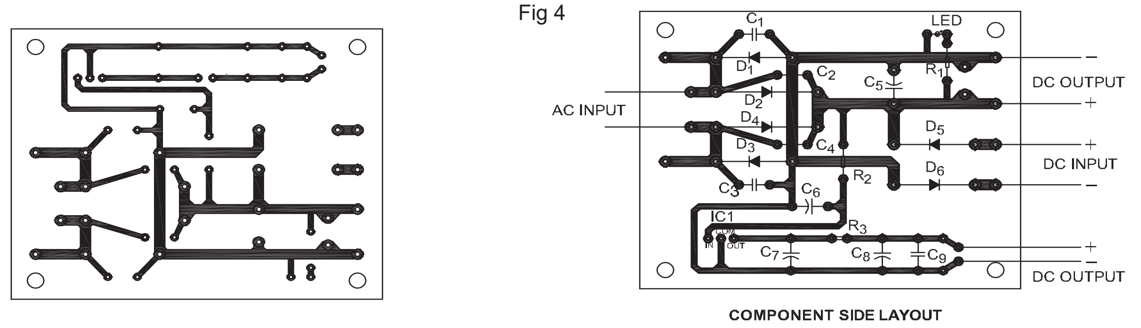
After drilling holes, clean the PCB such that it is free from burr and dust. Apply varnish on the layout pattern, to protect the copper pattern from corrosion.

Preparing and marking component lay out

A typical component side of a PCB with the components marked on it is in Fig 4.

Fig 3

Fig 4



Unijunction transistor (UJT) and FET and its application

Objectives: At the end of this lesson you shall be able to
- explain the construction and working principle of UJT
- make a quick test of UJT
- state the FET, JEFT principle, working biasing application as an amplifier
- list and explain the application of UJTs

Unijunction transistor(UJT) is a three terminal semiconductor device as shown in fig 1a. In its appearance it looks like a transistor as shown in Fig 1b. As shown in Fig 1a, it consists of two layers(a P-layer and a N-layer) and therefore it has only one junction(hence its name, uni-junction).

The symbol of UJT and its electrical equivalent circuit is shown in Fig 1c and 1d.

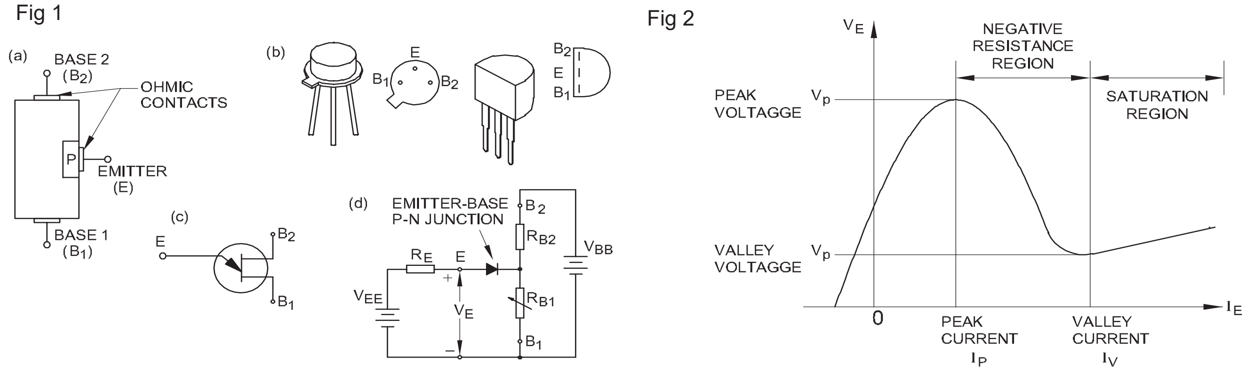
UJT is a special semiconductor device because it exhibits negative resistance characteristics as shown in Fig 2. The details of the characteristics are discussed in subsequent paragraphs.

Construction of UJT

2646 and 2N 2647 UJT's are available in the modified TO-18 case style as shown in Fig 1b.

Fig 1

Fig 2



Equivalent circuit of UJT

The electrical equivalent circuit of UJT is shown in fig 1d. The resistance between the B1 and B2 terminals is called the inter-base resistance RBB. The N-type silicon bar serves as a resistance divided into two parts RB1 and RB2 by the PN junction. The total of the internal RB1 and RB2 is the interbase resistance RBB. Value of RBB is typically in the range of 4 to 10 K ohms. Also rB1 usually a little greater than rB2 because the emitter is a little closer to B2.

The interbase resistance RBB is measured with the emitter open.

$R_{BB} = R_{B1} + R_{B2}$ at I_E=0.

Operation of UJT

The DC supply polarities for a UJT to function is shown in Fig 3. As can be seen from fig 3, B_2 is connected to +ve and B1 to ground. As a result current(conventional) flows from B_2 to B_1. This conduction results in a voltage gradient along the N-type silicon bar. Therefore there is a voltage in the region of the emitter junction(V_E) which is positive with respect to ground. The magnitude of this voltage is given by the simple voltage divider action between R_{B1} and R_{B2}.

$$V_E \text{ or } (V_{RB!}) = \frac{R_{B1}}{R_{B1}+R_{B2}} V_{BB} = \eta V_{BB} \qquad ....[1]$$

The Greek letter η (eta) is called the intrinsic stand-off ratio. This is an important data of any UJT and is invariably mentioned in all UJT data sheets. From the above equation, intrinsic stand-off ration η (eta) is given by,

$$\eta = \frac{R_{B1}}{R_{B1}+R_{B2}} \qquad ....[2]$$

UJT and its applications of triggering circuits

UJTs are employed in a wide variety of circuits involving electronic switching and voltage or current sensing applications. These include

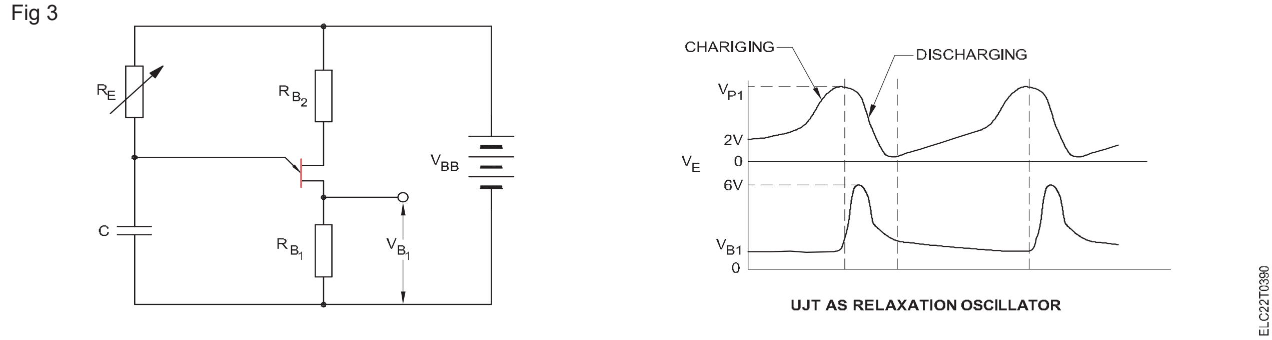
- triggers for thyristors
- as oscillators
- as pulse and saw tooth generators
- timing circuits
- regulated power supplies
- bistable circuits and so on.

Let us analyse the waveform generated across the capacitor and R1 with respect to the relaxation oscillator or free running oscillator as in Fig 3.

The negative - resistance portion of the UJT characteristic is used in the circuit shown in Fig 3 to develop a relaxation oscillator.

The wave form developed across the capacitor is shown in Fig 3 as VE, whereas the waveform produced across the resistor RB1 is shown as a pulse VB1.

Fig 3



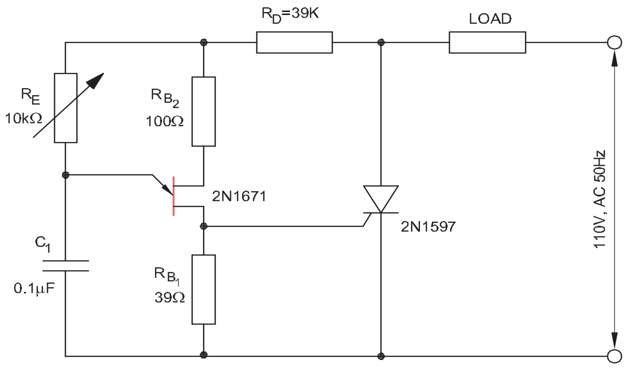
The frequency of oscillation

$$f = \frac{1}{R_E C}$$

Where RE is the value of variable resistor in ohms and C is the value of the capacitor in farad.

By varying the value of RE, the frequency of the oscillator can be varied. Although such an oscillator using a dc supply voltage could be used to trigger a SCR, there would be trouble in synchronizing the pulses with the cycles of alternating current. Fig 4 shows a stable triggering circuit for an SCR in which the firing angle can be varied from 0° to 180°.

Fig 4



UJT RELAXATION OSCILLATOR USED FOR TRIGGERING THE SCR

Field-effect transistor (FET)

The main difference between a Bi-polar transistor and a field effect transistor is that,

Bi-polar transistor is a current controlled device

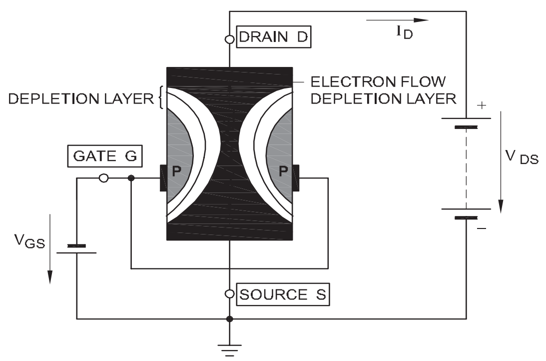
In simple terms, this means that the main current in a bi-polar transistor (collector current) is controlled by the base current.

Filed effect transistor is a voltage controlled device

This means that the voltage at the gate(similar to base of a bi-polar transistor) controls the main current.

In addition to the above, in a bi-polar trasistor (NPN or PNP), the main current always flows through N-doped and P-doped semiconductor materials. Whereas, in a Field effect transistor the main current flows either only through the N-doped semiconductor or only through the P-doped semiconductor as in Fig 5.

Fig 5



If the main current flow is only through the N-doped material, then such a FET is referred as a N-channel or N-type FET. The current through the N-doped material in the N-type FET is only by electrons.

If the main current flow is only through the P-doped material, then such a FET is referred as a P-channel or P-type FET. The current through the P-doped material in the P-type FET is only by Holes.

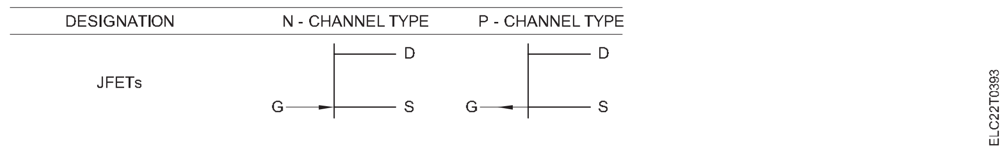
Unlike in bipolar transistors in which the main current is both by electrons and holes, in contrast in FETs depending on the type(P or N type) the main current is either by electrons or by holes and never both. For this reason FETs are also known as Unipolar transistors or Unipolar device.

There are a wide variety of FETs. In this lesson one of the fundamental types called as Junction Field Effect Trasistor (JFET) is discussed.

Junction Field effect Transistor (JFET)

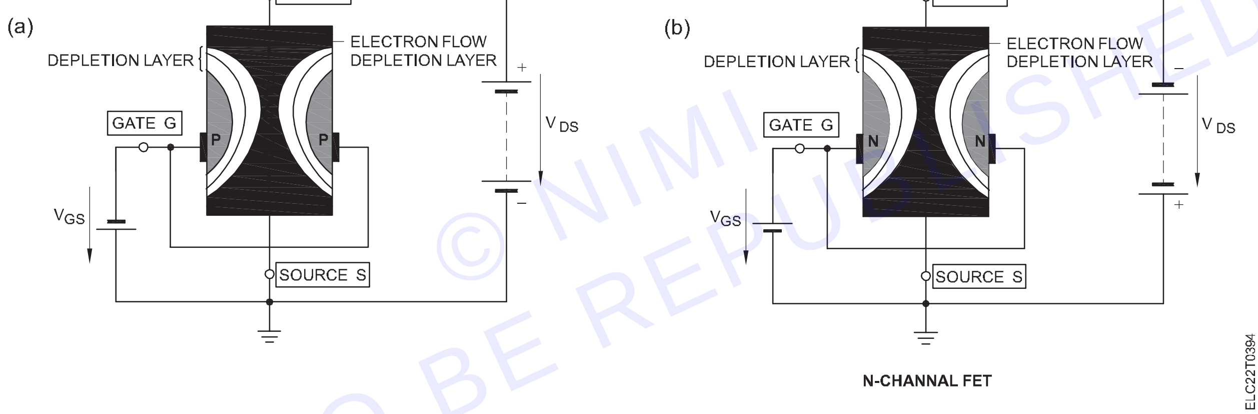
It is a three terminal device and looks similar to a bi-polar transistor. The standard circuit symbols of N-channel and P-channel type FETs are shown in Fig 6.

Fig 6



The internal diagram of a N-channel FET is shown in Fig 7.

Fig 7



FET notation listed below are essential and worth memorizing,

1 **Source terminal:** It is the terminal through which majority carriers enter the bar(N or P bar depending upon the type of FET).

2 **Drain terminal:** It is the terminal through which majority carriers come out of the bar.

3 **Gate terminal:** These are two internally connected heavily doped regions which form two P-N junctions.

4 **Channel:** It is the space between the two gates through which majority carriers pass from source to drain when FET is working(on).

Working of FET

Similar to Biploar transistors, the working point of adjustment and stabilization are also required for FETs.

Biasing a JFET

– Gates are always reverse biased. Therefore the gate current I_G is practically zero.

– The source terminal is always connected to that end of the supply which provides the necessary charge carriers. For instance, in an N-channel JFET source terminal S is connected to the negative of the DC power supply. And, the posive of the DC power supply is connected to the drain terminal of the JFET.

Whereas in a P channel JFET, Source is connected to the positive end of the power supply and the drain is connected to the negative end of the power supply for the drain to get the holes from the P-channel where the holes are the charge carriers.

Let us now consider an N channel JFET, the drain is made positive with respect to source by voltage V_{DS} as shown in Fig 8a. When gate to source voltage V_{GS} is zero, there is no control voltage and maximum electron current flows from source(S) - through the channel - to the drain(D). This electron current from source to drain is referred to as Drain current, ID.

When gate is reverse biased with a negative voltage(VGS negative) as shown in Fig 8b, the static field established at the gate causes depletion region to occur in the channel as shown in Fig 8b.

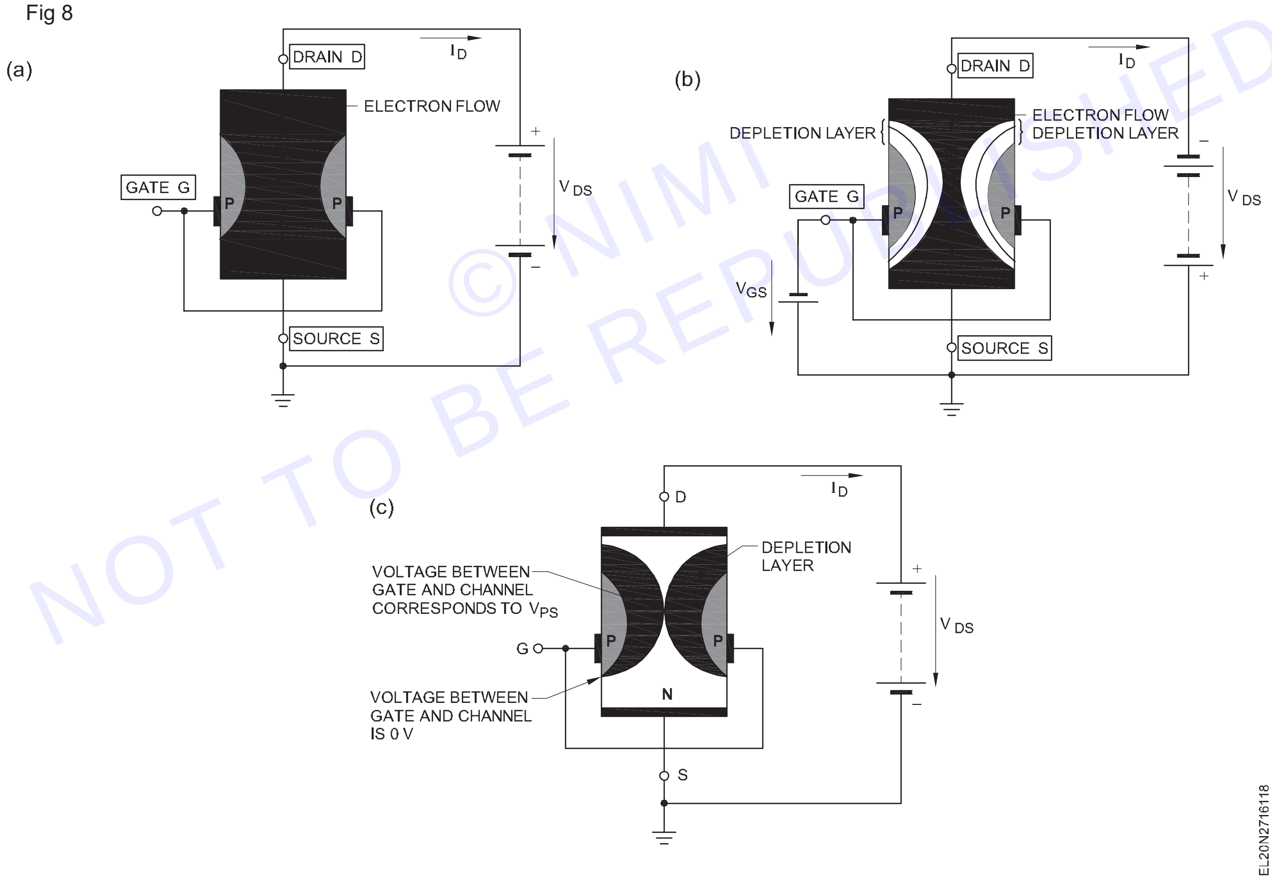
This depletion region decreases the width of the channel causing the drain current to decrease.

If VGS is made more and more negative, the channel width decreases further resulting in further decrease in drain current. When the negative gate voltage is sufficiently high, the two depletion layers meet and block the channel cutting off the flow of drain current as in Fig 8c. This voltage at which this effect occurs is referred to as the Pinch off voltage, V_P.

Thus, by varying the reverse bias voltage between gate and source($-V_{GS}$), the drain current can be varied between maximum current (with $-V_{GS}$=0) and zero current(with $-V_{GS}$=pinch off voltage). So, JFET can be referred as a voltage controlled devices.

P channel JFET operates in the same way as explained above except that bias voltages are reversed and the majority carrier of channel are holes.

Fig 8



Advantages of FET

1 Since they are voltage controlled amplifier this makes their input impedence very high

2 They have a low noise output. This makes them useful as preamplifiers where the noise must be very low because of high gain in the following stages.

3 They have better linearity

4 they have low inter electrode capacity.

Typical applications of JFET

One very important characteristic of JFET is its very high input impedence of the order of 109 ohms. This characteristic of FET, has made it very popular at the input stage of a majority of electronic circuits.

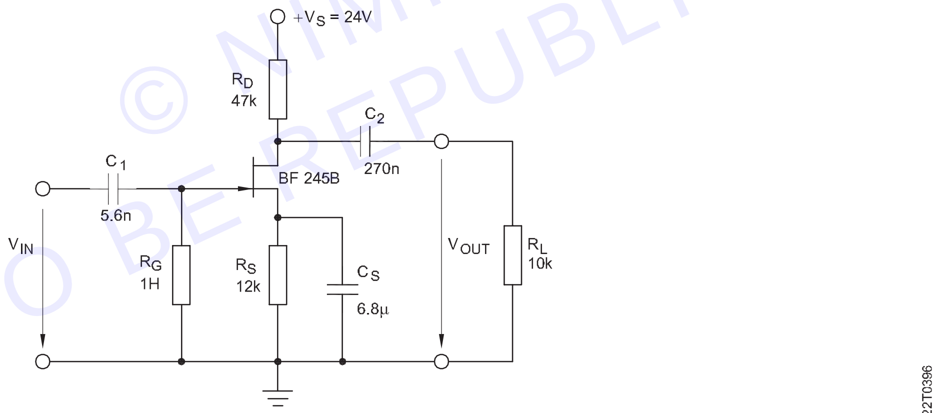
As discrete components FETS are mainly used in,

- DC voltage amplifiers
- AC voltage amplifiers(input stage amplifiers in HF and LF ranges)
- Constant current sources
- Integrated circuits of both analog and especially in Digital technology.

1 FET AC voltage amplifier

In the circuit at Fig 9, the amplification is determined by the design. it can be varied within certain limits of the drain resistance and the source resistance are made variable. Potentiometer can be connected in series for this purpose.

Fig 9



CIRCUIT DIAGRAM OF THE CALCULATED A.C VOLTAGE AMPLIFIER

Power supplies-troubleshooting

Objectives: At the end of this lesson you shall be able to
- list the initial activities involved in troubleshooting
- list the three general steps involved in troubleshooting
- list and explain the two popular methods of troubleshooting
- list the possible defects in a power supply.

Introduction

Troubleshooting in any equipment or in a circuit involves the following activities:

- To identify the exact nature of the problem.
- To identify the section causing the problem.
- To isolate and arrive at the exact cause(s).
- To confirm the causes by necessary tests.
- To replace the problem-causing parts.
- To re-test and confirm the satisfactory working.

The following are the general steps involved in troubleshooting.

i Physical and sensory tests

- Look for the most common physical faults, such as broken wires, cracked circuit boards, dry solders and burnt out components.
- Smell for hot or burning components.
- Feel with the fingers for unduly hot components.

ii Symptom diagnosis

Learn the operation of the system to be repaired with the help of its block diagram and its input and output specifications.

Observe the symptoms produced by the defective system, and determine which section or function would produce the symptoms.

iii Testing and replacing defective components

When the probable defective section has been diagnosed, check the probable components in that section of the circuit that are most likely to go defective in the order given below:

Components should be checked in the order given below because that is the order in which they fall in most cases.

- **Active high power components:** For example, components such as transistors, ICs, and diodes. High power devices are physically large in size and are used for handling the high power, generally in output circuits.
- **Active low power components:** These are the same as in (a) but are physically small and can handle smaller amounts of power.
- **High voltage/power passive components:** Such components are resistors, capacitors, transformers, coils, etc. which handle large amounts of voltage/power. They are found in power supplies and output circuits.
- **Low power passive components:** These are the same as in (c) but are physically smaller and handle comparatively less power and are low in value (ohm, microfarad, microhenry, etc.)

Note: This procedure may not turn out to be true always. Hence, do not attempt to replace common sense and meter measurements with the procedure.

While troubleshooting any electronic system, two main methods are generally adopted. They are:

Step-by-step method of troubleshooting: This approach is preferred by the beginners. In this approach, the problem causing part or section is identified by testing the parts or sections from the beginning to the end as shown in Fig 1.

Although this approach may take more time, this is the most suited approach for the beginners.

Shortcut or logical approach method of troubleshooting: This method is used by the experienced servicing people. In this method, the problem causing part or section is identified from the nature of the problem symptom. Divide and conquer procedure is adopted to arrive at the exact cause. This method takes less time comparatively.

Troubleshooting power supplies: All electronic systems can be broken down into blocks, generally based on their function. Fig 1 shows the various blocks of a simple power supply. Each block has a particular function to perform.

Before carrying out the troubleshooting of power supplies, the first thing to be done is to isolate the load connected to the power supply. This is because the connected load itself may be the cause of the problem as shown in the Fig 2.

Once it is confirmed that the power supply has the same defect even with the load disconnected, you can follow either the step-by-step approach or the logical approach to troubleshoot the power supply.

Step-by-step approach to troubleshoot power supply: In the step-by-step approach of troubleshooting, the various blocks of the power supply is in Fig 1 and the components of the blocks are checked one by one, starting with block 1 and in steps as given below.

Step 1: Confirm the presence and satisfactory level of the mains supply from which the power supply is powered.

Step 2: Switch the power ON and test and note down the exact nature of the problem. Although the nature of the problem has been already told, it is essential to confirm the exact nature of the problem. This is because, in a real life situation, the customer may not be a technical person to inform the exact nature of the problem.

Step 3: Carry out physical and sensory tests.

Step 4: Trace the circuit to identify any wrong polarity connections.

Step 5: Remove the power cord of the power supply from the mains and test the power cord.

Step 6: Test the transformer.

Step 7: Test the diode(s) of the rectifier section.

Step 8: Test the capacitor(s) of the filter section.

Step 9: Test the bleeder resistor, surge resistor and other resistors, if any.

Step 10: Test the output indicator lamps/LEDs.

After completing all the above steps, from the defective components identified, analyze the root cause for the problem and confirm that the cause will not reoccur if the identified components are replaced.

Step 11: Replace the identified defective component(s).

Step 12: Switch the power ON and test the power supply, first without load, and then connecting it to the load.

Fig 1

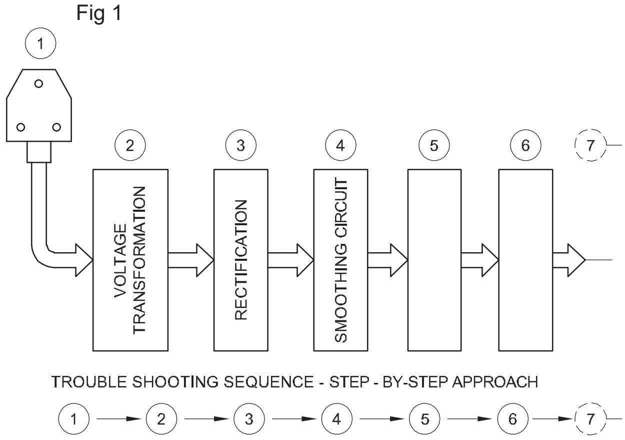
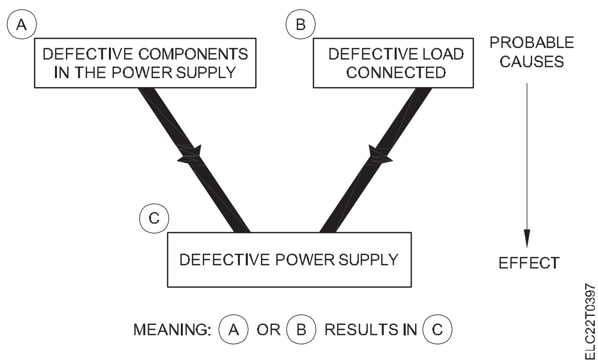


Fig 2



Power control circuit using SCR,DIAC,TRIAC & IGBT

Objectives: At the end of this lesson you shall be able to
- explain the construction and working of SCR,DIAC,TRIAC & IGBT
- explain power control circuits using SCR
- explain power control circuit using DIAC & TRIAC
- explain the construction and using of IGBT.

Introduction to power electronics devices

Industrial electronics is concerned primarily with electronics applied to industries such as industrial equipments, controls and processes. An important application of electronics in industries is in controlling of machinery.

In communication electronics, domestic & entertainment electronics, generally, the electronic devices operate with currents in the order of Microampere to Milliampere. For industrial applications, most frequently, devices are required to handle currents in the range of ampere to several thousands of ampere. This, therefore calls for high power electronic devices. One such high power electronic device frequently used in industrial electronic application is the SCR,TRIAC,IGBT and DIAC for associate triggering circuits.

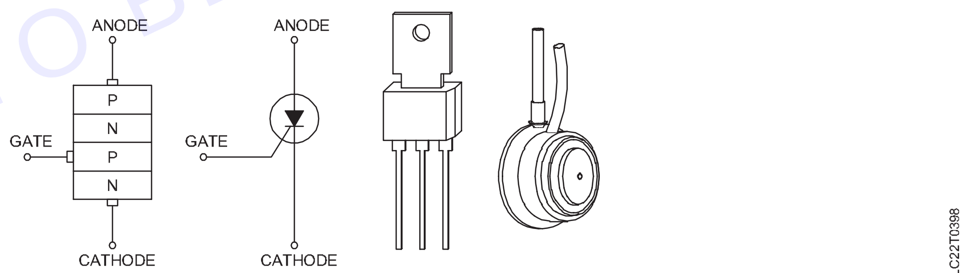
This devices can be used to run, dc motors from an ac power source, control power tool speed,also to control motor speeds of small appliances like, mixers and food blenders, illumination control, temperature control and so on.

Silicon Controlled Rectifier (SCR)

Before Silicon controlled rectifiers were invented(1956), a glass tube device called Thyratron was used for high power applications. Silicon Controlled Rectifier (SCR) is the first device of the thyristor family. The term thyristor is coined from the expression Thyratron-transistor. SCR is a semiconductor device. SCR does the function of controlled rectification. Unlike a rectifier diode, SCR has an additional terminal called the gate which controls the rectification(gated silicon rectifier).

The basic principle application of SCRs is to control the amount of power delivered to a load(motor, lamp, etc.,).A rectifier diode will have one PN junction. SCRs on the other hand will have two PN junctions (P-N-P-N layers). Fig 1 shows the electrical symbol, basic construction and a typical SCR packages.

Fig 1



Basic operation of SCR

When a gate direct current is applied to the gate terminal, forward current conduction commences in the SCR(latched into conduction). When the gate current is removed, the forward current through the SCR does not cut-off. This means, once the SCR is latched into conduction, the gate loses control over the conduction. The current through the SCR can be turned off only by reducing the current through it(load current) below a critical value called the **Holding current**.

Fig 2 shows how an SCR can be gated into conduction or turned off.

In Fig 2a, with switched S1 open the SCR is in OFF state and no current is flowing through the load.

In Fig 2b, when S1 is closed, a small gate current(around 1/1000 or less compared to load current) turns-ON (fires) the SCR. A heavy load current starts flowing through the SCR and load RL.

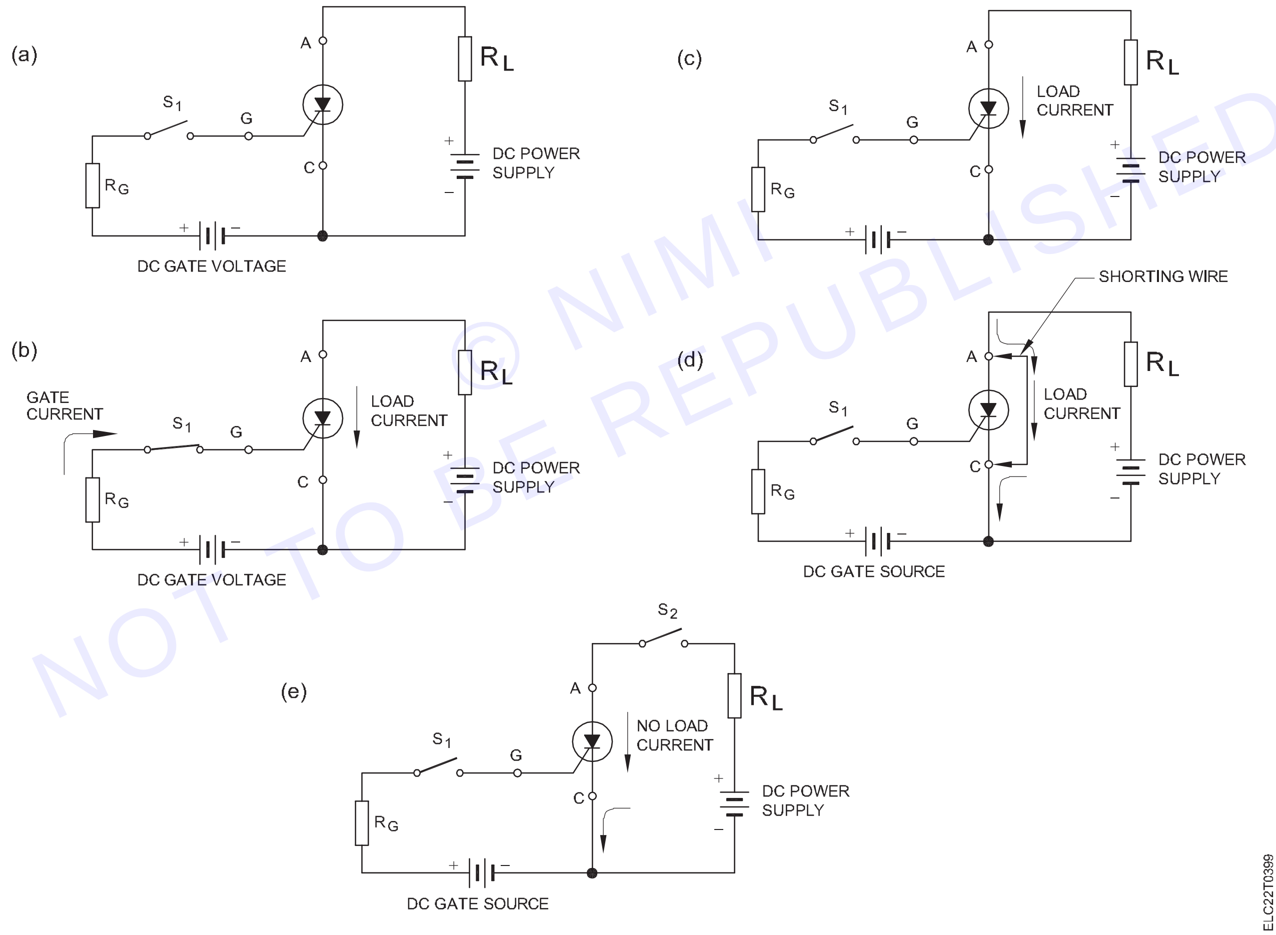
In Fig 2c, when S1 is opened, gate current becomes zero. This will have no effect on the current through the SCR and the heavy load current continues to flow through the SCR in the DC gate supply.

In Fig 2d, if a shorting wire is placed across the anode and the cathode terminals, the current though the SCR gets by-passed and all the current starts flowing through the shorted wire instead through the SCR. This means the current through the SCR is reduced below the rated holding current(minimum current required through SCR to keep it latched). This turns-OFF the SCR. Even when the shorting wire is removed the SCR remains to be in OFF state.

Fig 2e shows an alternative method of turning-OFF the SCR. In this instead of shorting the anode and cathode terminals of the SCR, the load current is cut-off by opening the Switch S2. This reduced current through the SCR below the holding current and thus turns- OFF the SCR. Once the SCR is turned_OFF, the SCR does not turn-ON even if the switch S2 is closed. To make the SCR fire again, with the switch S2 closed, the gate current should be made to flow by closing the switch S1.

Since the SCR does not conduct in the reverse direction, the anode of the SCR should always be positive with respect to cathode for conduction.

Fig 2



Important features of SCR,

- A very small gate current will control the switching OFF a large load current.

SCR operation with AC supply

Operation of SCR with AC circuit is similar to SCR operation . Fig 3 illustrates working of SCR in AC control circuits.

The SCR gate circuit consists of resistor R1, potentiometer R2 and silicon diode D1. Resistors R1 and R2 act as a variable voltage divider. By adjusting the value of R2 the gate current IG can be suitably modified. Diode D1 prevents negative voltage being applied to the gate when the ac supply is in the negative half cycle.

[X] During the +ve half cycle of the AC power source, as the positive half cycle voltage increases, the gate current IG increases. When IG reaches the trigger level, SCR fires and allows current IL to flow through the load.

From this point onwards the SCR impedance is low and current IL continues to flow throughout the +ve half cycle even though the gate current reduces below the trigger value(recall: once SCR is fired it continues to conduct even if the gate trigger is decreased or removed).

[Y] At the end of the +ve half cycle of AC power source, the +ve voltage drops to zero and SCR ceases to conduct(recall: one method of turning off SCR is to reduce the current through the SCR to below the holding current. This can be done by either opening the load circuit or reducing the supply to zero). Thus the SCR remains in off state throughout the negative half cycle.

Cycle [X] and [Y] repeats and current through the load flows in pulses as in Fig 3d.

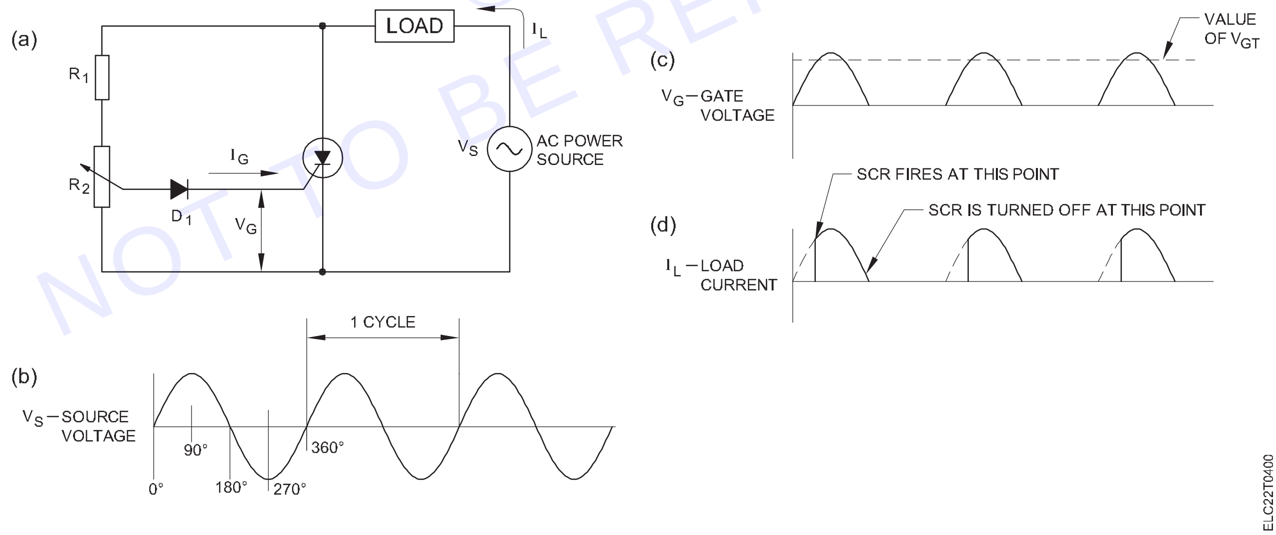
Fig 3b,3c shows the voltage wave forms of source and gate voltage.

If the value of R2 is varied, the point at which SCR triggers also varies changing the firing point shown in fig 3d. In the circuit shown in Fig 3a, the firing of SCR can be adjusted any where between almost 180 degrees(maximum) to 90 degrees(minimum).

This simple AC control circuit shown in Fig 3a using SCR can be used to control the current through the load during the +ve half cycle of AC. During the -ve half cycle the SCR remains turned off. Thus, SCR can be used as an excellent switching device in AC control circuits.

The circuit in Fig 3 is useful only in limited applications such as temperature control of soldering iron etc.,

Fig 3



Power control using SCR

- DC Motor speed control
- AC Motor speed control
- Regulated DC power supplies
- Power control
- Circuit breakers
- Time delay circuits

- Soft start circuits
- Pulse, logic and digital circuits and so on.

Speed control of DC motors: In this Related Theory information only brief outline of power circuits is discussed. Due variation of motor load currents, inductance effect in winding, the practical circuit should be modified to suit the requirement. DC motors consists of field winding and armature winding. The speed of DC motors can be varied by two methods,

1 controlling the field current

2 controlling the armature voltage

The first method is used for controlling the motor speed above the rated speed of the motor. The second method is used for controlling the motor speed below the rated speed of the motor.

Power circuit using triac and diac

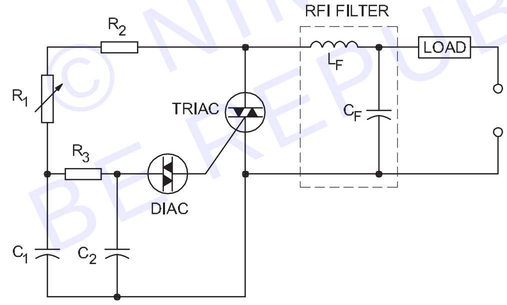
TRIAC or SCR for speed control of ac motors: Compared to SCR, Triac is most popular and works satisfactorily for lamp dimmer circuits and speed control of universal motors. Although both SCR and TRIAC can be used to phase control and vary the current through the lamp or motor, triac being a full wave device, symmetrically controls the phase of both half cycles of the applied ac.

The resultant full wave current format then produces smooth lamp or motor operation that can be attained from the half wave rectification using SCRs. This is particularly noticeable during low/dim light requirement or low speed for motors.

The circuit at Fig 4 shows a Triac phase control circuit for controlling the brightness of the lamp or speed of universal motors.

The load shown in circuit at Fig 4 is a general load rather than a motor symbol because, this circuit can also be used for light dimmers and for the control of heaters.

Fig 4



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This circuit features a double time constant phase-shift network. This reduces hysteresis in firing of the triac, thereby making the manual adjustment of dimmer operation or control off speed more repeatable.

The diac used as trigger device, adds to the reliability of the circuit. The elemental low-pass filter comprising LF and CF attenuates much of the radio-frequency interference (RFI) that gets generated and tries to get into the power line. This high frequency RF1 energy is generated by the extremely rapid turn-on time of the Triac. Which should be eliminated to avoid radio interference due to higher frequency content of the rectified wave form Otherwise, the frequency may interfere with reception at nearby places or in the main line circuit elsewhere.

Lamp dimmers: Lamp dimmer is a circuit which controls as ac power supplied to an incandescent lamp thereby controlling the intensity of light emitted by the lamp from almost zero to full brilliance.

Conventional and soft-start dimming of incandescent lights: Advantage of semi-conductor based light dimmers over the auto transformer connected light dimmers

Old technology light dimmers used high wattage rheostats adjustable auto-transformers or saturable reactors, which were large, expensive generated considerable heat and power loss. Present day semi-conductor light dimmers have overcome these difficiencies and have therefore become very popular for many applications.

Modern semi-conductor dimmers are inexpensive, reliable, small generate little heat, and are easy to control remotely. These properties have not only permitted semi-conductor dimmers to supersede older types in theatres and auditoriums with excellent results, but have made dimmers practical for built-in home lighting, table and floor lamps, projection equipment and other uses.

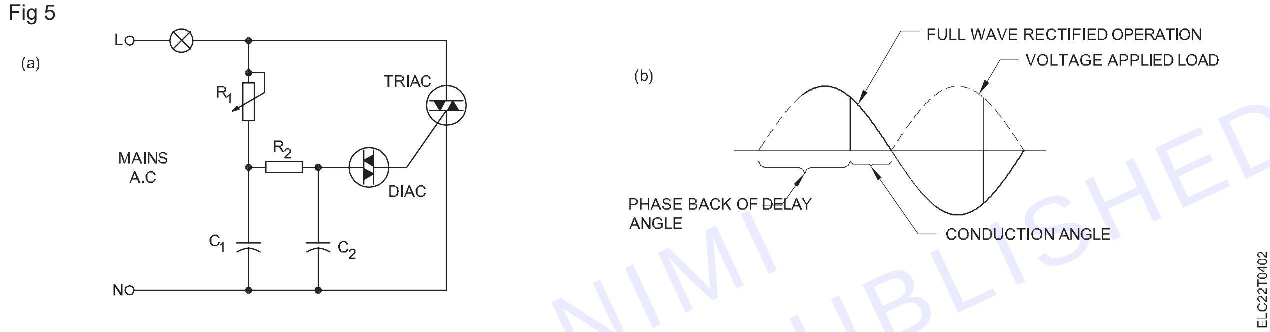
Semi-conductor based light dimmers: Two light dimmers for incandescent light bulbs are discussed below. Both these dimmer circuits control light intensity by adjusting the angle of conduction of a triac connected in series with the bulb. The first dimmer uses a very simple circuit that is ideal for highly compact applications requiring minimum cost. The second dimmer features soft starting for low in rush current and consequent long lamp life. Soft start lamp dimmers are especially useful with expensive lights with short lives, such as projection lamps and photo-graphic bulbs.

Simple light dimmer: The circuit shown in Fig 5 is a wide range light dimmer using very few parts. The circuit can be operated using any mains supply source (240V, 50Hz) by choosing appropriate value of circuit components. The circuit can control upto 1000watts of power to incandescent bulbs.

The power to the bulbs is varied by controlling the conduction angle of Triac. Many circuits can be used for phase control, but the single Triac circuit used is the simplest and is therefore chosen for this particular application.

The control circuit for this Triac must function as shown in Fig 5b. The control circuit must create a delay between the time voltage is applied to the circuit and the time it is applied to the load. The Triac is triggered after this delay and conducts current through the load for the remaining part of each alteration. This circuit can control the conduction angle from 0° to about 170° and provides better than 97% of full power control.

Fig 5



Light dimmer with soft-start option: The circuit at Fig 6 is a light dimmer with soft start option. Soft starting is desirable because of the very low resistance of a cold lamp filament compared to its hot resistance. At the time of initial switching on, the low resistance of the lamp causes very high inrush currents which leads to short filament/ lamp life. Lamp failures caused by high inrush currents is eliminated by the soft start feature, which applies current to the bulb slowly enough to eliminate high surges.

Operation of the circuit at Fig 6 begins when voltage is applied to the diode bridge consisting of D_1 through D_4. The bridge rectifies the input and applies a dc voltage to resistor R_1 and zener diode D_5. The zener provides a constant voltage of 20volts to unijunction transistor Q_1, except at the end of each alternation when the line voltage drops to zero. Initially the voltage across capacitor C_1 is zero and capacitor C_2 cannot charge to trigger Q_1. C_1 will begin to charge, but because the voltage is low, C_2 will have adequate voltage to trigger Q_1 only near the end of the half cycle. Although the lamp resistance is low at this time, the voltage applied to the lamp is low and the inrush current is small. Then the voltage on C_1 rises, allowing C_2 to trigger Q_1 earlier in the cycle.

At the same time the lamp is being heated by slowly increasing applied voltage and by the time the peak voltage applied to the lamp has its maximum value, the bulb has been heated sufficiently so that the peak inrush current is kept to a reasonable value.

Resistor R4 controls the charging rate of C2 and provides the means to dim the lamp. Power to the load can be adjusted manually by varying the resistance of R4. T1 is a pulse transformer. In addition to supplying the trigger to Triac, this transformer isolates the high current load circuit from the low power triggering circuit (gate isolation methods for Triac is discussed in further paragraphs).

A simple lamp dimmer cum Universal motor speed controller: In the lamp dimmer cum universal speed controller circuit is in Fig 7, a Triac is used as control device. Phase control technique is used to control conduction angle of the triac which inturn control the power fed to the lamp.

A lamp L is connected in series with ac mains supply to the Triac. The trigger pulses to Triac gate is given through Diac. The Diac is triggered at the same breakover voltage level (30V) during both positive and negative half cycles.

Potentiometer R_4 provides the facility for varying the intensity of light or speed of a universal motor.

Snubber circuit: One problem with the Triac control is the sudden application of reverse voltage across the triac immediately after it has stopped conduction. This is a serious problem when the load is a highly inductive as in motors. This reapplied voltage denoted by dv/dt can trigger-on (unwanted or false triggering) the device losing the phase control.

To avoid this false triggering, an R and C series network is placed across the circuit R_4 and C_4 as shown in Fig 7. This RC network slows down the rate of rise of voltage applied across the Triac. This RC circuit connected across the Triac circuit is called snubber circuit.

The inductance L and capacitor C1 forms a low pass filter to substantially reduce the radio frequency interference (RF) generated by the rapid turn-on and turn-off the triac.

Fan speed regulator: The lamp dimmer circuit at Fig 7 can be used equally well as a fan speed regulator. The only change to be made is to connect a fan in place of the lamp shown in the circuit at Fig 7. The speed can be varied from almost zero to full speed by just rotating POT R3.

Fig 6

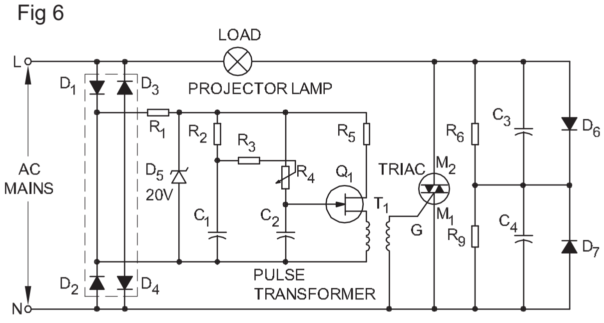
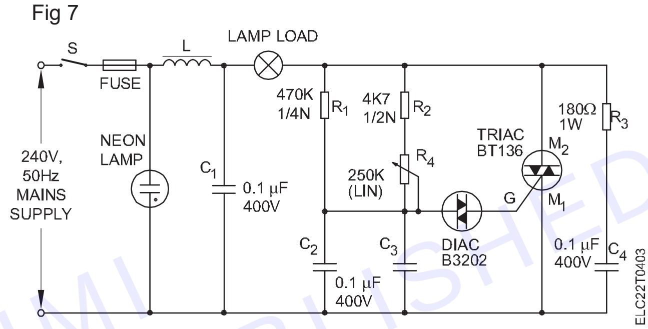


Fig 7



IGBT (Insulated Gate Bipolar Transistor)

The insulated Gate Bipolar Transistor (IGBT) is the latest device is power electronics. It is obtained by combining the properties of BJT and MOSFET. We know that BJT has lower on - state losses for high values of collector current. But the drive requirement of BJT is little complicated. The drive of MOSFET is very simple (i.e only voltage is to be applied between gate and source). But MOSFET has high on - state losses.

The gate circuit of MOSFET and collector emitter circuits of BJT are combined together to form a new device. This device is called IGBT. Thus IGBT has advantages of both the BJT and MOSFETs. Fig 8 shows the symbol of IGBT. Observer that the symbol clearly indicates combination of MOSFET and BJT.

The IGBT has three terminals : Gate (G), collector (C) and emitter (E), Current flows from collector to emitter whenever a voltage between gate and emitter is applied. The IGBT is said to have turned 'ON'. When gate emitter voltage is removed, IGBT turns - off. Thus gate has full control over the conduction of IGBT. When the gate to emitter voltage is applied, very small (negligible) current flows. This is similar to the gate circuit of MOSFET. The on - state collector to emitter drop is very small like BJT.

Structure of IGBT

The structure of IGBT is similar to that of MOSFET. Fig 9 show the vertical cross section of IGBT . In this structure observe that there is additional P+ layer. This layer is collector (Drain) of IGBT.

This P+ injection layer is heavily doped. It has the doping intensity of 10^{19} per cm^3. The doping of other layer is similar to that of MOSFET. n+ layers have 10^{19} per cm^3. P-type body region has doping level of 10^{16} per cm^3. The n- drift region is lightly doped (10^{14} per cm^3).

Punch through IGBT

The n+ buffer layer is not necessary for the operation of IGBT. The IGBTs which have n+ buffer layer are called punch through IGBTs. Such IGBTs have asymmetric voltage blocking capabilities. Punch through IGBTs have faster turn-off times. Hence they are used for inverter and chopper circuits.

Non - punch through IGBT

The IGBTs without n+ buffer layer are called non-punch through IGBTs. These IGBTs have symmetric voltage blocking capabilities. These IGBTs are used for rectifier type applications.

Fig 8

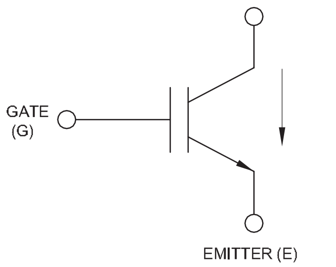
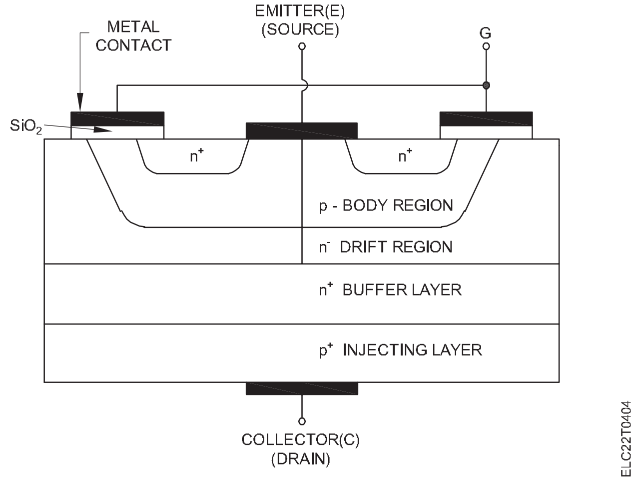


Fig 9



Operation of IGBT

When $V_{GS} > V_{GS}$(threshold), then the channel of electrons is formed beneath the gate as in Fig 10. These electrons attract holes from p+ layer. Hence, holes are injected from p+ layer into n- drift region. Thus hole / electron current starts flowing from collector to emitter. When holes enter p-type body region, they attract more electrons from n+ layer. This action is exactly similar to MOSFET.

Fig 11 shows the structure of IGBT showing how internal MOSFETs and transistors are formed. The MOSFET is formed with input gate, emitter as source and n- drift region as drain. The two transistors T_1 and T_2 are formed as in Fig 11. The holes injected by the P+ injecting layer go to the n- drift region. This n- drift region is base of T_1 and collector of T_2. The holes in the n- drift region further go to the p - type body region, which is connected to the emitter. The electrons from n+ region (which is emitter) pass through the transistor T2 and further in the n- drift region. Thus holes and electrons are injected in large amounts in n- drift region. This reduces the resistance of the n- drift region. This is called conductivity modulation of n- drift region. Note that such conductivity modulation does not exist in MOSFET. The connection of T_1 and T_2 is such that large amount of hole/electrons are injected in n- drift region.

Fig 10

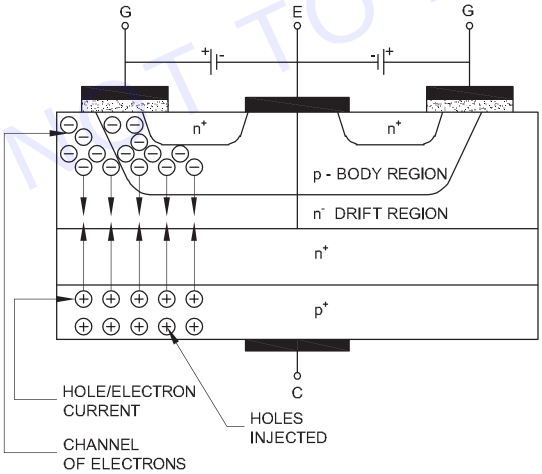
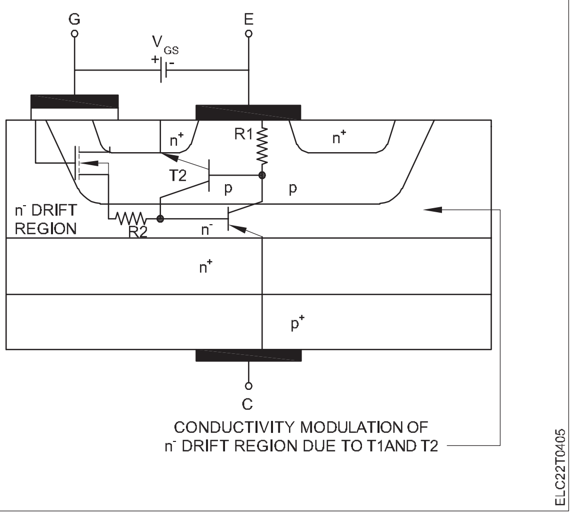


Fig 11



The action of T_1 and T_2 is like SCR which is regenerative. The gate serves as trigger for T_1 through internally formed MOSFET. Fig 12 shows the equivalent circuit. In this figure observe that when gate is applied ($V_{GS} > V_{GS}$(th)), the internal equivalent MOSFET turns on. This gives base drive to T_1. Hence T_1 starts conducting. The collector of T_1 is base of T_2. Therefore T_2 also turns on. The collector of T_2 is base of T_1. Thus the regenerative loop begins and large number of carriers are injected in n- drift region. This reduces the on- state loss of the IGBT just like BJT. This happens due to conductivity modulation of n- drift region.

When the gate drive is removed, the IGBT should turn- off. When gate is removed, the induced channel will be vanished and internal equivalent MOSFET will turn-off. Hence T_1 will turn -off if T_2 turns-off T_2 will turn - off if the p- type body region resistance R_1 is very very small. Under such situation, its base and emitter will be virtually shorted. Hence T_2 turns - off. Therefore T_1 will also turn - off. Hence structure of IGBT is organizes such that body region resistance (R_1) is very very small.

If R_1 is very very small, than T_2 will never conduct and the equivalent circuit of IGBT will be as in Fig 13. IGBTs are thus different than MOSFETs because of conduction of current from collector to emitter. For MOSFETs, on state losses are high since resistance of drift region remains same. But in IGBTs, resistance of drift region reduces when gate drive is applied. This resistance reduces because of P+ injecting region. Hence, on state loss of IGBT is very small.

Fig 12

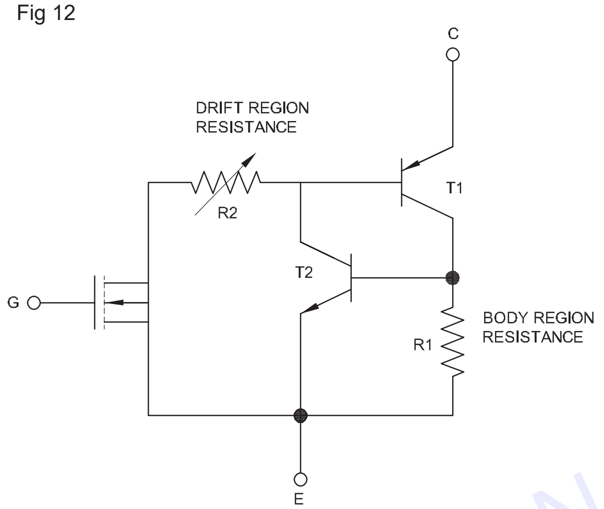
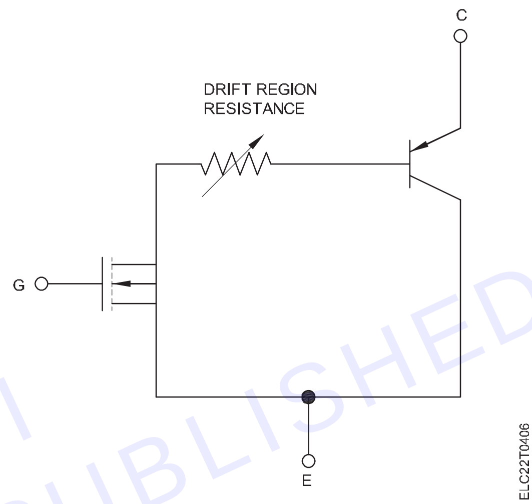


Fig 13



Merits, Demerits and Applications of IGBT

Merits of IGBT

1 Voltage controlled device. Hence drive circuit is very simple.

2 On - state losses are reduced.

3 Switching frequencies are higher than thyristors.

4 No commutation circuits are required.

5 Gate have full control over the operation of IGBT

6 IGBTs have approximately flat temperature coefficient.

Demerits of IGBT

1 IGBTs have static charge problems.

2 IGBTs are costlier than BJTs and MOSFETs.

Applications of IGBTs

1 AC motor drives, i.e. inverters.

2 DC to DC power supplies, i.e choppers

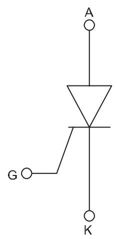
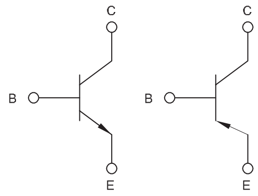
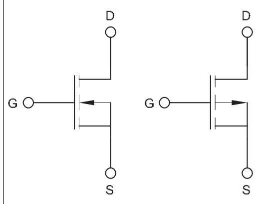
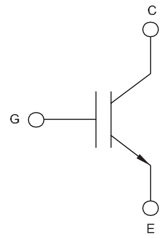
3 UPS systems.

4 Harmonic compensators.

Comparison of Power Devices

The power devices can be compared on the basis of switching frequency, gate drive circuit, power handling capacity etc. Table 1 shows the comparison of SCR, BJT, MOSFET and IGBT.

Table 1

S.No.	Parameter	SCR	BJT	MOSFET	IGBT
1	Symbol				
2	Triggered i.e latching or linear	Triggered or latching device	Linear trigger	Linear trigger	Linear trigger
3	Type of carriers in device	Majority carrier device	Bipolar device	Majority carrier device	Majority carrier device
4	Control of gate or base	Gate has no control once turned on control	Base has full control	Gate has full control	Gate has full control
5	On-state drop	< 2 Volts	< 2 Volts	< 4-6 Volts	< 3.3 Volts
6	Switching frequency	500 Hz	10 kHz	up to 100 kHz	20 kHz
7	Gate drive	Current	Current	Voltage	Voltage
8	Snubber	Unpolarized	Polarized	Not essential	Not essential
9	Temperature coefficient	Negative	Negative	Positive	Approximately flat, but positive at high current
10	Voltage and current ratings	10 kV/4kA	2 kV/4kA	1 kV/50 A	1.5 kV/400 A
11	Voltage blocking capability	Symmetric and	Asymmetric	Asymmetric	Asymmetric
12	Application	AC to DC converters, AC voltage controllers, electronic circuit breakers	DC to AC converters, induction motor drives, UPS, SMPS, Choppers	DC choppers, low powers, UPS, SMPS, brushless DC motor drives	DC to AC converters, AC motor drivers UPS choppers, SMPS etc,.

Integrated circuit voltage regulators

Objectives: At the end of this lesson you shall be able to
- explain integrated circuit
- state the classification of integrated circuit
- state the types of IC voltage regulators
- design voltage regulator for a required output voltage
- modify fixed voltage regulator to variable output regulator, circuit.

IC introduction

Integrated circuit

Electronic circuits invariably consist of a number of discrete components connected to each other in a specific way. For instance, the series regulator circuit discussed in earlier lessons, consists of transistors, zener diodes, resistors and so on, connected in a defined way for it to function as a regulator. If all these components instead of building on a board, if they are built on a single wafer of a semiconductor crystal, then, the physical size of the circuit becomes very small. although small, this will do the same job as that of the circuit wired using discrete components. Such miniaturised electronic circuits produced within and upon a single crystal, usually silicon, are known as Integrated circuits or ICs. Integrated circuits (ICs) can consists of thousands of active components like transistor, diodes and passive components like resistors and capacitors in some specific order such that they function in a defined way, say as voltage regulators or amplifiers or oscillators and so on.

Classification of Integrated circuits: Integrated circuits may be classified in several ways. However the most popular classifications is as follows:

1 Based on its type of circuitry

i Analog ICs - Example: amplifier ICs, voltage regulator ICs etc.

ii Digital ICs - Example: Digital gates, flip-flops, address etc.

2 Based on the number of transistors built into IC

i Small scale integration (SSI) - consists of 1 to 10 transistors.

ii Medium scale integration (MSI) - consists of 10 to 100 transistors.

iii Large scale integration (LSI) - 100 to 1000 transistors.

iv Very large scale integration (VLSI) - 1000 and above.

3 Based on the type of transistors used

i Bipolar - carries both electron and hole current.

ii Metal oxide semiconductor (MOS) - electron or hole current.

iii Complementary metal oxide semiconductor (CMOS) - electron or hole current.

Note: The terms MOS and CMOS are another type of transistor and the trainees are requested to refer any standard electronic book for further reference.

ICs are available in different packages and shapes. The usual packages are:

– dual in the packages DIP

– single in line package SIP and

– metal can packages.

ICs handling power more than IW are provided with heat sinks.

Advantages of integrated circuits over discrete circuit (Refer Table 1)

Table 1

Integrated circuits	Discrete circuits
1 All in a single chip	All are separate discrete components
2 Requires less space due to smaller size	Requires more space
3 Cheaper due to mass manufacture	Costlier due to individual components
4 More reliable due to specific construction	Less reliable
5 Easy for servicing and repairs	Difficult for servicing and repairs
1 ICs are manufactured for specific applications having specific circuits	Discrete devices can be used for any circuit
2 If any part of IC is defective, the entire IC is to be replaced	Only particular defective component requires replacement

When the advantages are considered, the disadvantages of IC are negligible. They are widely used for different applications such as voltage regulators, audio amplifiers, TV circuits, computers, industrial amplifiers etc. ICs are available in different pin configurations in different outlines suitable for different circuits.

Integrated circuit (IC) voltage regulators: The series voltage regulators discussed in earlier lessons are available in the form of integrated circuits (ICs). They are known as voltage regulator ICs.

There are two types of voltage regulator ICs. They are,

– Fixed output voltage regulator ICs

– Adjustable output voltage regulator ICs.

Fixed output voltage regulator ICs: The latest generation of fixed output voltage regulator ICs have only three pins as in Fig 1. They are designed to provide either positive or negative regulated DC output voltage.

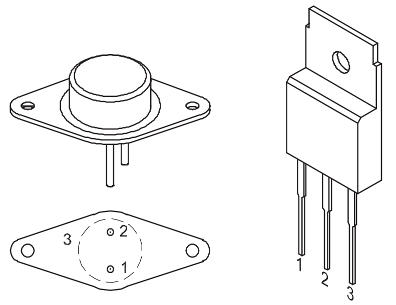
These ICs consist of all those components and even more in the small packages in Fig 1. These ICs, when used as voltage regulators, do not need extra components other than two small value capacitors as in Fig 2.

The reason behind using capacitor C1 is when the voltage regulator IC is more than a few inches from the filter capacitors of the unregulated power supply, the lead inductance may produce oscillations within the IC. Capacitor C1 prevents setting up of such oscillations. Typical value of bypass capacitor C1 range from 0.220µF to 1µF. It is important to note that C1 should be connected as close to the IC as possible.

The capacitor C2 is used to improve the transient response of the regulated output voltage. C2 bypasses these transients produced during the ON/OFF time. Typical values of C2 range from 0.1µF to 10µF.

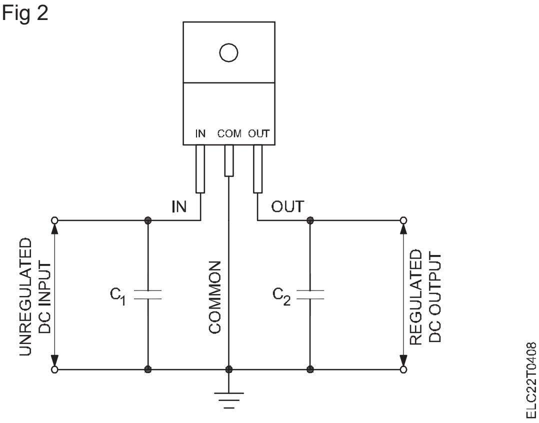
Fixed voltage three terminal regulators are available from different IC manufacturers for different output voltages (such as 5V, 9v, 12V, 24V) with maximum load current rating ranging from 100mA to more than three amps.

Fig 1



3 PIN IC REGULATOR

Fig 2



The most popular three terminal IC regulators are,

1 LMXXX-X series

Example: LM320-5, LM320-24 etc.

2 78XX and 79XX series

Example: 7805, 7812, 7912 etc.

A list of popular three terminal regulators is given in IC data book.

Specifications of three terminal IC regulators: For simplicity in understanding, let us consider the specification of a three terminal IC µA7812. The table 2 given below lists the specifications of µA7812.

Table 2

Parameter	Min.	Type.	Max.	Units
Output voltage	11.5	12	12.5	V
Output regulation		4	120	mV
Short-circuit output current			350	mA
Drop out voltage			2.0	V
Ripple rejection	55	71		dB
Peak output current		2.2		A

Identification of output voltage and rated maximum load current from IC type number

– 78XX and 79XX series are 3 Terminal voltage regulators.

– All 78XX series are positive output voltage regulators

– All 79XX series are negative output voltage regulators

The term XX indicates the rated output regulated voltage.

Example

7805

Indicates positive output regulator — Indicates output voltage is +5V

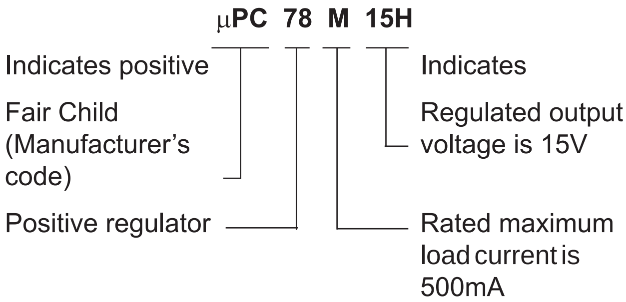
7912

Indicates negative output regulator — Indicates output voltage is –12V

It is important to note that, different manufacturers of 78 XX/ 79XX series such as Fair Child (MA/Mpc), Motorola, Signetics (SS) adopt slightly different coding schemes to indicate the rated maximum current of the three pin regulated. ICs. One such scheme is given below.

78LXX	-	L indicates rated maximum load current as 100mA.
78MXX	-	M indicates rated a maximum load current as 500mA
78XX	-	Absence of an alphabet between 78 and XX indicates that the rated maximum load current is 1A.
78SXX	-	S indicates rated maximum load current is 2amp.

Example

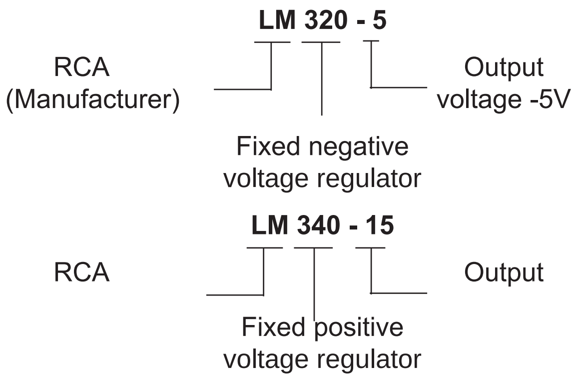


LM 3XX series of 3 terminal voltage regulators: In LM series of three terminal regulators, to find the specifications, it is suggested to refer to its data manual. However, the following tips will help in identifying whether the IC is a fixed positive or fixed negative regulator.

LM320-X and LM320-XX → Fixed –ve voltage regulators.

LM340-X or LM340-XX → Fixed +ve voltage regulators.

Examples



Binary numbers, logic gates and combinational circuits

Objectives: At the end of this lesson you shall be able to
- explain the digital electronics principle and positional notation and weightage
- explain decimal to binary conversion, binary odometer
- explain hexadecimal number system
- convert decimal to hexa, hexa to decimal and BCD system
- explain logic gates principle - NOT, OR and AND gates with truth table
- explain combinational gates - NAND, NOR with truth table and logic pulser.

Introduction

When we hear the word 'number' immediately we recall the decimal digits 0,1,2....9 and their combinations. Digital circuits do not process decimal numbers. Instead, they work with binary numbers which use the digits '0' and '1' only. The binary number system and digital codes are fundamental to digital electronics. But people do not like working with binary numbers because they are very long when representing larger decimal quantities. Therefore digital codes like octal, hexadecimal and binary coded decimal are widely used to compress long strings of binary numbers.

Binary number systems consists of 1s and 0s. Hence this number system is well suited for adopting it to the digital electronics.

The decimal number system is the most commonly used number system in the world. It uses 10 different characters to show the values of numbers. Because this number system uses 10 different characters it is called base-10 system. The base of a number system tells you how many different characters are used. The mathematical term for the base of a number system is radix.

The 10 characters used in the decimal number systems are 0,1,2,3,4,5,6,7,8,9.

Positional notation and weightage

A decimal integer value can be expressed in units, tens, hundreds, thousands and so on. For example decimal number 1967 can be written as 1967 = 1000 + 900 + 60 + 7. In powers of 10, this becomes.

10^3	10^2	10^1	10^0
1	9	6	7

$1 \times 10^3 = 1000$

$9 \times 10^2 = 900$

$6 \times 10^1 = 60$

$7 \times 10^0 = 7$

1967

i.e. [1967]10 = 1(103) + 9(102) + 6(101) + 7(100)

This decimal number system is an example of positional notation. Each digit position has a weightage. The positional weightage for each digit varies in the sequence 100, 101, 102, 103 etc starting from the least significant digit.

The sum of the digits multiplied by their weightage gives the total amount being represented as shown above.

In a similar way, binary number can be written in terms of weightage.

To get the decimal equivalent, then the positional weightage should be written as follows.

$[1010]_2 = 1(2^3) + 0(2^2) + 1(2^1) + 0(2^0)$

$= 8 + 0 + 2 + 0$

$[1010]_2 = [10]_{10}$

Any binary number can be converted into decimal number by the above said positional weightage method.

Decimal to Binary conversion

Divide the given decimal number by 2 as shown below and note down the remainder till you get the quotient - zero.

Example

Divisor	Number	Remainder	
	0		
2	1	1	→ MSB
2	2	0	
2	4	0	
2	8	0	
2	17	1	
2	34	0	→ LSB

The remainder generated by each division form the binary number. The first remainder becomes the LSB and the last remainder becomes the MSB of binary number.

Therefore, $[34]_{10} = [100010]_2$

Counting binary number

To understand how to count with binary numbers, let us see how an odometer (Km indicator of a car) counts with decimal numbers,

The odometer of a new car starts with the reading 0000.

After traveling 1Km , reading becomes 0001.

Successive Km produces 0002, 0003 and so on upto 0009

At the end of 10th Km , the units wheel turns back from 9 to 0, a tab on this wheel forces the tens wheel to advance by 1. That is why the number changed from 0009 to 0010. That is, the units wheel is reset to 0 and sent a carry to the tens wheel. Let us call this familiar action as reset and carry. The other wheels of odometer also reset and carry. For instance, after covering 999Km , the odometer shows 0999.

After the next Km , the unit wheel resets and carries, the tens wheel resets and carries, the hundreds wheel resets and carries and the thousands wheel advances by 1 to get the reading 01000.

Binary odometer

Visualize a binary odometer, a device whose wheels have only two digits 0 and 1. When each wheel turns, it displays 0 then 1 and then back to 0 and the cycle repeats. A four digit binary odometer starts with 0000.

After 1km, it indicates - 0001.

The next km forces the units wheel to reset and sends carry. So the number changes to 0010.

The third km results in 0011.

After 4km, the units wheel resets and sends carry, the second wheel resets and sends carry and the third wheel advances by 1. Hence it indicates 0100.

Table below shows all the binary numbers from 0000 to 1111 equivalent to decimal 0 to 15.

Decimal	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

Addition of binary numbers

Sum	Carry
0 + 0 = 0	0
1 + 0 = 1	0
0 + 1 = 1	0
1 + 1 = 0	1 (one plus one is equal to zero with carry one)

Ex: 1

```
  1 0
+ 1 1
-----
1 0 1
```

Ex: 2

```
1 + 1 + 1 = 1
        + 1     (One plus one plus one is equal to one with carry one)
         10
        + 1
         11
```

Hexadecimal number system: In hexadecimal system there are 16 characters. They are 0,1,2,3,4,5,6,7,8,9, A,B,C,D,E,F where A=10, B=11, C=12, D=13, E=14, F=15 in decimal. In this system, the base is 16. This system is mainly used to develop programmes for computers.

For Example

$[23]_{16} = [35]_{10}$; $16^1 \times 2 + 16^\circ \times 3 = 32 + 3 = 35$;

$[2C]_{16} = [44]_{10}$; $16^1 \times 2 + 16^\circ \times 12 = 32 + 12 = 44$;

Decimal to hexadecimal conversions

The conversion of decimal to hexadecimal is similar to binary conversion. Only difference is that divide the decimal number successively by 16, and note down the remainder.

	0		
16	1	1	⟶ MSB
16	27	11 or B	
16	432	0	⟶ LSB

$[432]_{10} = [1B0]_{16}$

Hexadecimal to Decimal

This conversion can be done by putting it into the positional notation.

Ex: $223A_{16} = 2 \times 16^3 + 2 \times 16^2 + 3 \times 16^1 + A \times 16^0$

$= 2 \times 4096 + 2 \times 256 + 3 \times 16 + 10 \times 1$

$= 8192 + 512 + 48 + 10$

$= 8762_{10}$

BCD (Binary Coded Decimal)

Binary Coded Decimal (BCD) is a way to express each of the decimal digits with a binary code, since there are only ten code groups in the BCD system, it is very easy to convert between decimal and BCD. Because decimal system is used for read and write, BCD code provides an excellent interface to binary systems. Examples of such interfaces are keypad inputs and digital readouts.

8421 code

The 8421 code is a type of binary coded decimal (BCD), binary coded decimal means that each decimal digit, 0 through 9 is represented by a binary code of four bits. The designation 8421 indicates the binary weights of the four bits (2^3, 2^2, 2^1, 2^0). The ease of conversion between 8421 code numbers and the familiar decimal numbers is the main advantage of this code. All you have to remember are the ten binary combinations that represents the ten decimal digits as shown in the Table.

Decimal digit	0	1	2	3	4
BCD	0000	0001	0010	0011	0100
Decimal digit	5	6	7	8	9
BCD	0101	0110	0111	1000	1001

The 8421 code is the pre-dominant BCD code, and when we refer to BCD, we always mean the 8421 code unless otherwise stated.

Inverters (NOT Gate)

An inverter is a gate with only one input signal and one output signal. The output state is always the opposite of the input state. Logic symbol is shown in Fig 1.

Transistor inverter

The Fig 2 shows the transistor inverter circuit. The circuit is a common emitter amplifier which works in saturation or in cut off region depending upon the input voltage. When Vin is in low level, say less than the transistor cut in voltage 0.6V in silicon type, the transistor goes to cut off condition and the collector current is zero. Therefore, Vout = +5V which is taken as high logic level. On the other hand, when Vin is in high level, the transistor saturates and Vout = Vsat = 0.3V i.e low level.

The table summarizes the operation

V_{in}	V_{out}
Low(0)	High(1)
High(1)	Low(0)

Fig 1

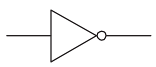
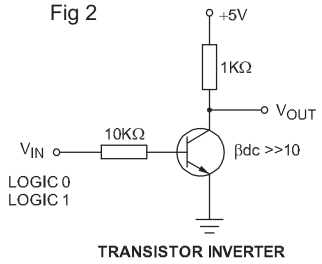


Fig 2



The logic expression for the inverter is as follows: Let the input variable be 'A' and the output variable be Y, then the output $Y = \overline{A}$.

OR and AND gate circuits

OR Gate : The output of an OR will be in 1 state if one or more of the inputs is in 1 state. Only when all the inputs are in 0-state, the output will go to 0-state. Fig 3 shows the schematic Symbol of an OR Gate :

The boolean expression for OR gate is Y=A+B.

The equation is to be read as Y equals A ORed B. Two-input truth table given below is equivalent to the definition of the OR operation.

Truth table for OR gate

A	B	Y=A + B
0	0	0
1	0	1
0	1	1
1	1	1

Electrical equivalent circuit

The Fig 4a shows the electrical equivalent circuit of an OR gate. It is evident that if any one of the switch is closed, there will be output.

Fig 3

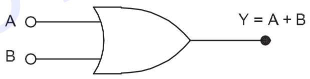
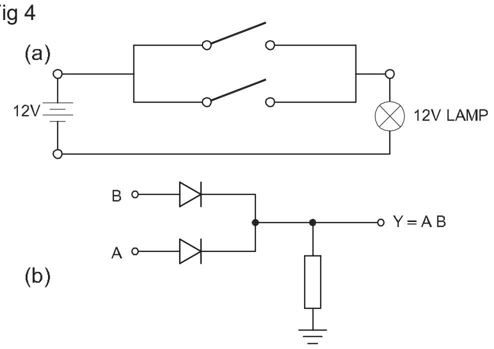


Fig 4



2 in-put OR gate using diode

The Fig 4b shows one way to build a 2-input OR gate, using diodes. The inputs are labeled as A and B, while the output is Y.

Assume logic 0 = 0V (low)

logic 1 = +5V (high)

Since this is a 2 input OR gate, there are only four possible cases,

Case 1: A is low and B is low. With both the input voltage low, both the diodes are not conducting. Therefore the output Y is in low level.

Case 2: A is low and B is high, The high B input voltage (+5V) forward biases the lower diode, producing an output voltage that is ideally +5V (actually +4.3V taking the diode voltage drop 0.7V into consideration). That is, the output is in high level. During this condition, the diode connected to input A is under reverse bias or OFF condition.

Case 3: A is high and B is low, the condition is similar to case 2. Input A diode is ON and Input B diode is OFF and Y is in high level.

Case 4: A is high, B is high. With both the inputs at +5V, both diodes are forward biased, since the input voltages are in parallel, the output voltage is +5V ideally [+4.3V to a second approximation]. That is, the output Y-is in high level.

OR gates are available in the IC form. IC7432 is a T.T.L OR gate IC having 4 OR gates inside it.

Simple application of OR gate

Intrusion detection

Simplified portion of an intrusion detection and alarm system is two windows and a door. The sensors are magnetic switches that produce a high(1) output when windows and doors are opened and a low(0) output when closed. As long as the windows and the door are secured, the switches are closed and all three of the OR gate inputs are in low(0). When one of the windows or the door is opened, a high(1) output is produced on that input of the OR gate and the gate output goes high. It then activities an alarm circuit to warn of the intrusion.

AND gates

The AND gate has two or more inputs but only one output. All input signals must be held high to get a high output. Even if one of the inputs is low, the output becomes low.

AND gate symbols for 2 input and 3 input gates are shown in Fig 5a and 5b.

Fig 5

Truth table

Two input AND gate

A	B	Y=AB
0	0	0
0	1	0
1	0	0
1	1	1

Three input AND GATE

A	B	C	Y=ABC
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Electrical equivalent circuit of an AND gate

The output is available only when both the switches are closed. IC7408 is a T.T.L quad AND gate IC. (Refer data book for pin diagram). The electrical equivalent of AND gate and AND gate using diodes are shown in Fig 6a and 6b.

Two input AND gate using diode

I condition

A=0, B=0, Y=0 as in Fig 7.

Fig 6

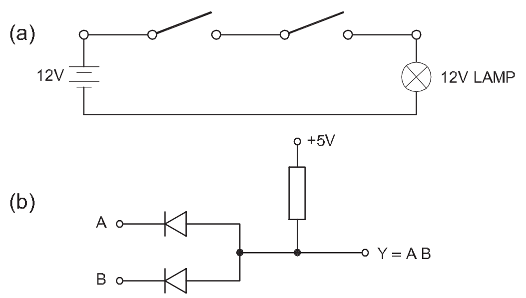
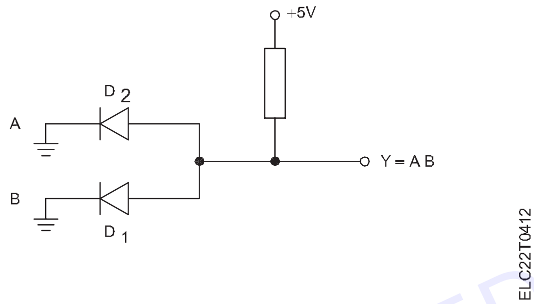


Fig 7

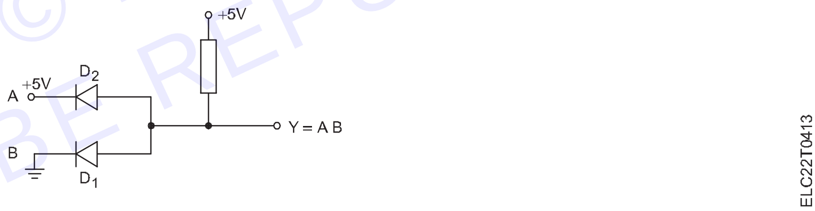


During the above condition I/P A and B are connected to ground to make logic low inputs. During this condition, both the diodes conduct, and pulls the O/P Y to logic-0.

II condition

A=0, B=1, Y=0 as in Fig 8.

Fig 8



In the II condition shown in the figure above, diode D1 is connected logic-0 input and diode D2 is connected to +5V [Logic high]. Diode D1 is in forward bias and conducts. Diode D2 is having equal potential (+5V) at anode and cathode. So potential difference between anode and cathode is 0. Hence diode D2 does not conduct. The output Y is pulled down to logic zero, since D1 is conducting.

III condition

A=1, B=0, Y=0 as in Fig 9.

The III condition is similar to the II condition. D2 is forward biased. D1 is reverse biased. Hence output Y is pulled to logic-0.

IV condition

A=1, B=1, Y=1 as in Fig 10.

In this condition both the diodes are reverse biased. So both the diodes act as open circuit. Therefore output y is +5V i.e y is in logic-1 condition.

AND gate as an Enable/Inhibit device

A common application of the AND gate is to enable (i.e to allow) the passage of a signal (pulse waveform) from one point to another at certain times and to inhibit (prevent) the passage at other times.

Fig 9

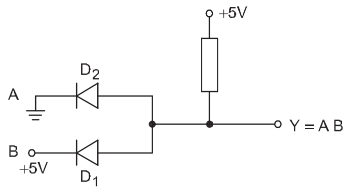
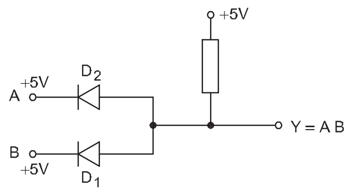


Fig 10



ELC22T0414

In Fig 11a AND gate controls the passage of a signal (waveform A) to a digital counter. The purpose of this circuit is to measure the frequency of waveform 'A'. The enable pulse has a width of precisely 1 second. When the enable pulse applied at B is high, waveform A passes through the gate to the counter, and when the enabled pulse is low, the signal is prevented (inhibited) from passing through. Refer Fig 11b for the waveforms of the above process.

Fig 11

ELC22T0415

During the 1 second interval of the enabled pulse, a certain number of pulses in waveform A pass through the AND gate to the counter. The number of pulses counted by the counter is equal to the frequency of the waveform A. For example, if 1000 pulses pass through the gate in the 1 second interval of the enabled pulse, there are 1000 pulses/sec. That is, frequency is 1000Hz.

Combinational gate circuits - NOR and NAND

NOR Gate

In Fig 12a the output y of the circuit equals to the complement of A OR B, because the circuit is an OR gate followed by a NOT gate. To obtain high output [Logic-1], both the inputs should be tied to low input [Logic-0]. For the rest of the other three possibilities, output will be zero, the combination of this OR and NOT gate is called as NOR gate.

Symbol (Fig 12b) :

Fig 12

ELC22T0416

We can define a NOR gate as follows:

The output of a NOR gate is 0, even if one of the inputs is in logic-1. Only when both the inputs are in logic-0, the output is in logic-1.

Truth table

A	B	A + B
0	0	1
0	1	0
1	0	0
1	1	0

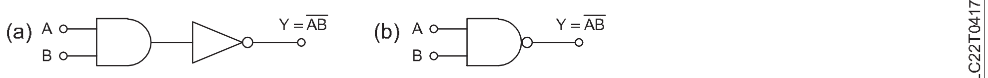
IC7402 is a T.T.L NOR gate IC. It contains 4 NOR gates. For pin details, refer data book.

NAND gate

An AND gate followed by a NOT gate forms the NAND gate as in Fig 13a. In this gate to get a low output (logic=0), all the inputs must be in high state and to get high output state, any one of the inputs or both inputs must be in low state.

Fig 13b is the standard symbol for a NAND gate. The inverter triangle has been deleted and the bubble is moved to the AND-gate output.

Fig 13



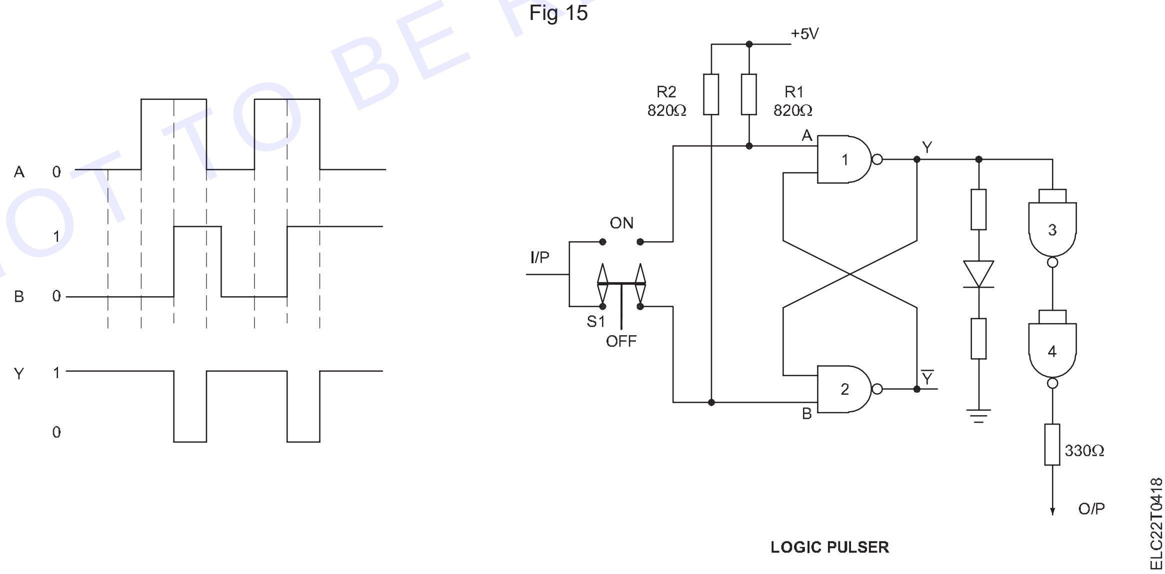
Truth table for NAND gate

A	B	$Y = \overline{AB}$
0	0	1
0	1	1
1	0	1
1	1	0

Pulsed operation: Output waveform Y is low only for the time intervals when both inputs A and B are high as shown in the timing diagram Fig 14.

Logic pulser: Fig 15 shows the circuit diagram of logic pulser, the circuit essentially consists of NAND gates connected debouncer circuit and its output is Double inverted. The LED indicates, pulses ON or OFF status.

Fig 14 Fig 15



When switch S1 is not pressed, (OFF position) B input of NAND gate No.2 is grounded, hence its output is forced to go logic HIGH. This HIGH output is feedback to NAND gate 1, A input of NAND gate 1 is also held HIGH through R1 resistor (820W) and thus the output of NAND gate-1 'Y' is at low. This logic low output keeps LED in OFF condition and this logic low is again double inverted at the logic pulser tip through NAND gate 3 and 4 to get logic low level at pulser tip.

When S1 is pressed to ON, A input of NAND gate is forced to go logic-low. Hence the output of this NAND gate is forced to go logic-HIGH. Therefore the 'Y' output is at logic-1, so LED glows and a logic-HIGH appears at probe tip. Also note that with HIGH at Y output, the inputs of NAND gate 2 are also at logic-HIGH and the output of NAND gate-2 is forced to go low. As long as switch S1 is at ON position the probe tip is HIGH. When it is released it springs back to OFF position, and the output returns to a logic-LOW condition.

Wave shapes - Oscillators

Objectives: At the end of this lesson you shall be able to

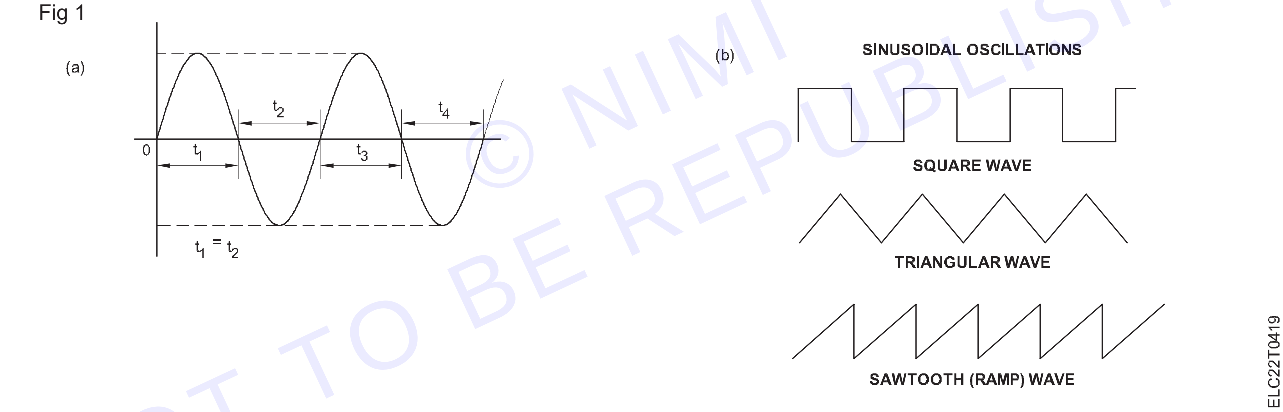
- state the working principle and gain of oscillator
- explain the RC phase-shift oscillator and frequency calculation
- state the features, gain and frequency of Hartley, colpitts and crystal oscillators
- state the working principle and frequency calculation of bistable and monostable multivibrator using CRO.

Oscillator: An oscillator is a circuit for producing voltages that vary in a regular fashion with respect to time. The output wave forms of oscillators are repeated exactly in equal successive intervals of time as in Fig 1a and Fig 1b.

The output wave-form of an oscillator may be sinusoidal as in Fig 1a. Such oscillators are known as sine wave oscillators or harmonic oscillators.

The output of oscillators may be square, triangular or saw-tooth wave forms as in Fig 1b. Such oscillators are known as non-sinusoidal oscillators or relaxation oscillators.

Fig 1



It was discussed earlier that positive feedback results in converting an amplifier into an oscillator. To provide positive feedback the feedback signal should be inphase with the input signal such that it adds up with the input signal.

In practice, an oscillator will have no input ac signal at all, but it still generates ac signal. An oscillator will have only a dc supply. The oscillator circuit, makes use of the noise generated in resistors at the switching on time of dc supply and sustains the oscillations.

To build an oscillator, the following are essential;

– An amplifier

– A circuit which provides positive feedback from output to input.

The gain of an amplifier with feedback is given by,

$$A_{vf} = \frac{A_V}{1 - kA_V}$$

kA_v is known as the loop gain of the amplifier. In the case of the amplifiers when the sign associated with kA_v is negative, the denominator has value more than 1. And, hence the value of Avt will always be less than Av (negative feedback). But, if the value of kA_v is made larger, such that, it approaches unity, and, if the sign associated with kA_v is negative then the value of the denominator decreases to less than 1, and hence, A_{vf} will be larger than A_v.

In case of oscillators, if the loop gain kAv is made positive, i.e. by feeding back signal which is in-phase with the input signal, then there will be an output signal even though there is no external input signal. In other words, an amplifier is modified to be an oscillator by positive feedback such that it supplies its own input signal.

Example

An amplifier has a voltage gain of 40 without feedback. Determine the voltage gains when positive feedback of the following amounts is applied.

i k = 0.01

ii k = 0.02

iii k = 0.025

Solution

i $Avf = \frac{A_V}{1-kA_V} = \frac{40}{1-0.01 \times 40} = \frac{40}{0.6} = 66.7$

ii $Avf = \frac{A_V}{1-kA_V} = \frac{40}{1-0.02 \times 40} = \frac{40}{0.2} = 200$

iii $Avf = \frac{A_V}{1-kA_V} = \frac{40}{1-0.025 \times 40} = \frac{40}{0} = \infty$ (Infinity)

In (iii) the gain of the amplifier become infinite when the loop gain kAv = +1. This is known as the critical value of the loop gain kAv. It is important to note that the output voltage cannot be infinite. Instead the amplifier will start working as an oscillator without the need of any separate input. If the feedback path contains a frequency selective network, the requirement of kAv = 1 can be met at only one particular frequency, such that, the output of the oscillator will be a sinusoidal signal of a particular frequency. Such oscillators are known as sine wave oscillators.

There are 3 types of oscillators.

1 Hartley oscillator

2 Colpitts oscillator

3 Crystal oscillator

Out of three Hartley oscillator only discussed.

Hartley oscillator: One of the simplest of sinusoidal oscillators is the Hartley oscillator shown in Figs 2a and 2b.

As in Fig 2a is a series fed Hartley oscillator. This circuit is similar to the tickler coil oscillator, but the tickler circuit coil L1 is physically connected to L, and is hence a part of L (like an auto-transformer). This oscillator is called series-fed because, the high frequency oscillations generated and the dc paths are the same, just as they would be in a series circuit. Series fed Hartley oscillators are not preferred due to their poor stability of oscillations.

Fig 2b is parallel fed Hartley oscillator commonly used in radio receivers. Parallel fed Hartley oscillators are known for their high stability of oscillations.

The circuit at Fig 2b is actually an amplifier with positive (regenerative) feedback to have sustained oscillations. The capacitor C2 and inductor L2 form the path for RF current in the collector to ground circuit.

RF current through L2 induces a voltage in L1 in proper phase and amplitude to sustain oscillations.

The position of the tap at the junction of L1 and L2 determines how much signal is fed back to the base circuit.

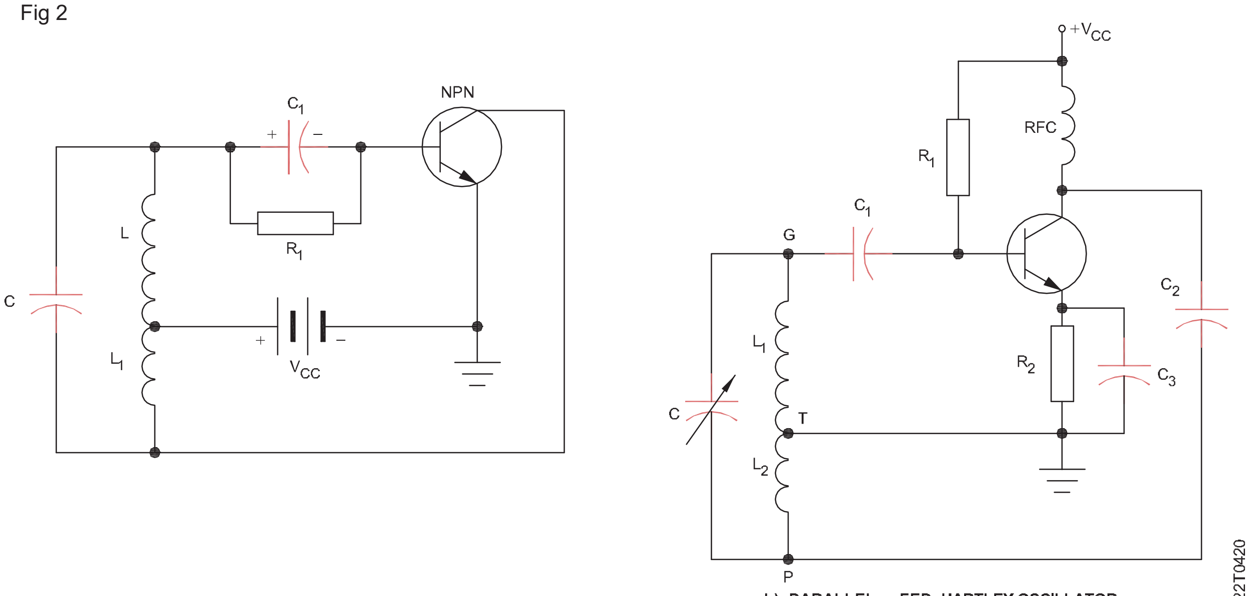
The capacitor C and the inductors L1 + L2 forms the resonant tank circuit of the oscillator which determines the frequency of oscillations. Capacitor C can be made variable capacitor for tuning the oscillator to different frequencies. C1 and R1 form the RC circuit which develops the bias voltage at the base.

The RF choke at the collector keeps the high frequency ac signal out of the Vcc supply. In cheaper oscillator circuits the RF choke is omitted and is replaced by a resistor.

Resistor R2 connected in the emitter provides dc stabilization. R2 is by-passed by C3 to prevent ac degeneration.

The Hartley oscillator coil has three connections. These are usually coded on the coil. If they are not, it is generally possible to identify them by a resistance check. The resistance between the taps T and P as in Fig 3, is small compared with the resistance between T and G., If the coil connections are not made properly, the oscillator will not work.

Fig 2



a) SERIES - FED HARTLEY OSCILLATOR

b) PARALLEL - FED HARTLEY OSCILLATOR

Checking oscillator frequency: The frequency of an oscillator can be computed if the values of L (L = L1 + L2) and C are known using the formula,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where, f is in hertz, L in henry, and C in farad.

The frequency of an oscillator may be measured in two ways,

- Using a direct read-out frequency meter also known as frequency counter which is most accurate, popular and easy to use.
- Using an oscilloscope with a calibrated time base to measure the period of the wave-form. From the measured period, 'T' frequency is calculated using the formula

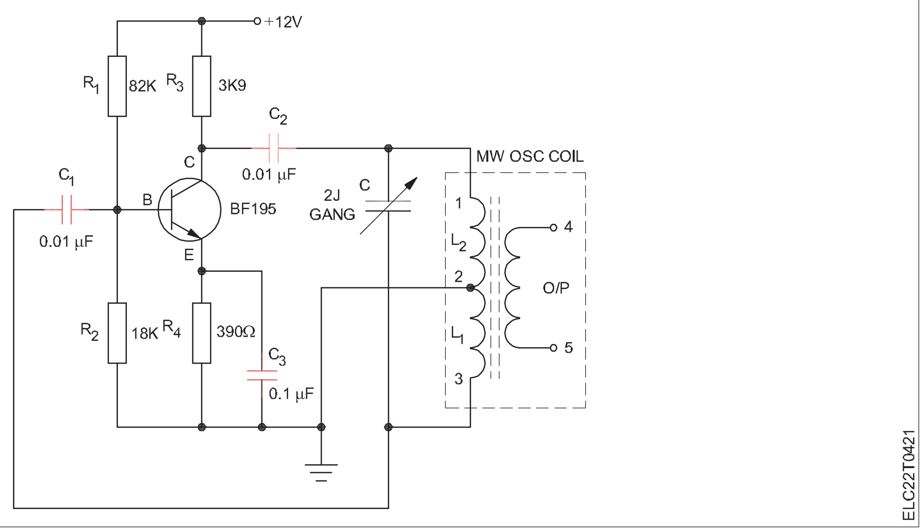
$$f = \frac{1}{T}$$

where, f is the frequency in Hz and 'T' the time period in seconds.

A practical hartley oscillator circuit using medium-wave oscillator coil as L is shown in Fig 3.

The advantage of using a medium wave oscillator coil for L is that the output can be taken out of the secondary winding (4 and 5) of the coil.

Fig 3



MODULE 12 : Induction Motors and Special Motors

LESSON 70-75 : Principle of induction motors

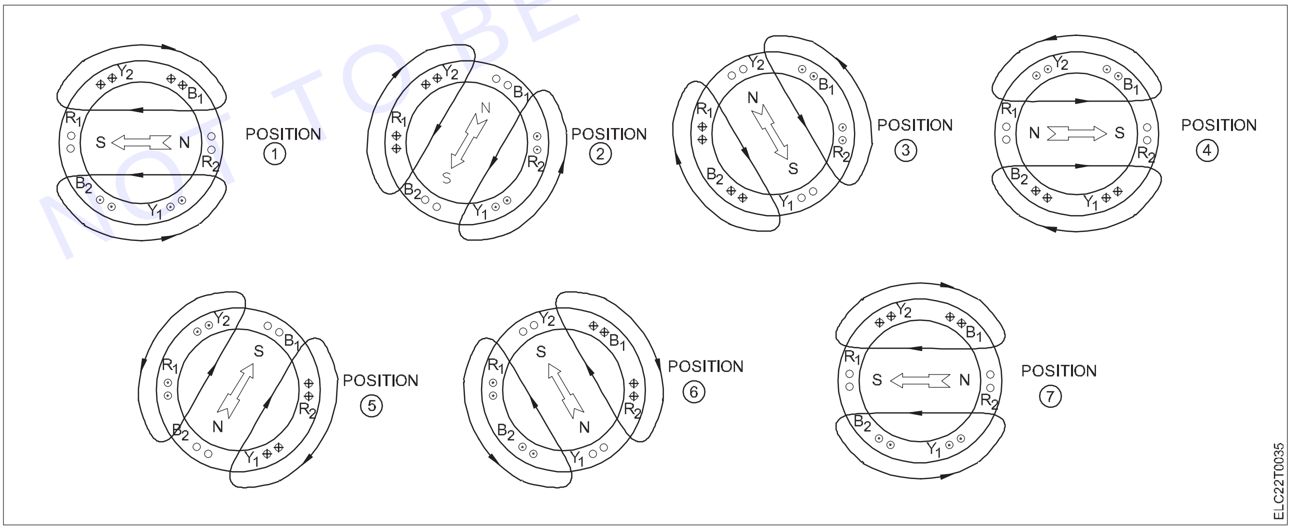
Objectives

At the end of this lesson you shall be able to:

- state the principle of 3 phase induction motor & wound rotar
- explain briefly the method of producing a rotating magnetic field
- explain necessary of starters, types of starters
- explain DOL, manual star Delta, Semi automatic, automatic star Delta, rotor wound & auto transform starters
- explain losses & speed controls of motors.

Working principle of three phase induction motor: An electrical motor is which converts electrical energy into a mechanical energy. In case of three phase AC operation, most widely used motor is Three phase induction motor. This type of motor is self-starting induction motor. It works on the same principle of dc motor, that is the current carrying conductor is placed in magnetic field will tend to create force. The induction motor differs from dc motor, the rotor of the IM is not electrically connected to the stator, but induces a voltage or current in the rotor by the transformer action. According to Faraday's laws an emf induced in rotor circuit due to the rate of change of magnetic flux linkage As the rotor winding in an induction motor are either closed through an external resistance or directly shorted by end ring, and cut the stator rotating magnetic field, an emf is induced in the rotor copper bar and due to this emf a current flows through the rotor conductor. Here the relative velocity between the rotating flux and static rotor conductor is the cause of current generation; hence as per Lenz's law the rotor will rotate in the same direction to reduce the cause i.e. the relative velocity.

To reverse the direction of rotation of a rotor: The direction of rotation of the stator magnetic field depends upon the phase sequence of the supply. To reverse the direction of rotation of the stator as well as the rotor, the phase sequence of the supply is the changed by changing any two leads connected to the stator.



Production of revolving field

The resultant magnetic field produced by the combined effect of the three currents is shown at increments is shown at in increments of 60degree for one cycle of the current.

At position 1 the phase currentIr is zero and coil R producing zero flux. the phase current Ib is positive and Iy is negative. The phase Ib is positive and Iy is negative. Considering the instantaneous current direction of these three phase windings at position 1 we indicate the current direction. Using Maxwell 's cork screw, the resulting flux by these currents will produce a flux. the arrows show direction of the magnetic field and the magnetic poles in the stator core. It will continue in position 2,3, etc. It will be seen that for successive increment of 60'0 electrical.

The resultant stator field will rotate further 60’0. So that from the resultant flux, position 1-7 it is obvious that for each cycle of applied voltage the field of the two pole stator will also rotate one revolution around its core. It will clear that the rotating magnetic field could be produced by a set of 3 phase stationary windings, placed at a 120’electrical apart and supplied with a 3 phase voltage.

Classification

Three phase induction motors are classified according to their rotor construction

Squirrel cage induction motor

Slip ring induction motor

Squirrel cage motors have a rotor with short circuited bars whereas slip ring motors have wound rotors having three windings either connected in star or delta,

Parts

Stator of an induction motor

There is no difference between squirrel cage and slip ring motor stators. The induction motor stator resembles the stator of revolving field three phase alternator. The stator part consists of three phase winding held in place in the slots of a laminated steel core which is enclosed and supported by a cast iron or a steel frame. The three phase windings are placed 120 degree electrical degrees apart and may be connected in either star or delta externally for which six leads are brought out to a terminal box mounted on the frame of the motor. When the stator is energised from a three phase voltage it will produce a rotating magnetic field in the stator core.

Rotor of a squirrel cage induction motor

The rotor of the squirrel cage induction motor contains no windings. Instead it is a cylindrical core constructed of steel laminations with conductor bars mounted parallel the shaft and embedded near the surface of the rotor core. These conductor bars are short circuited by an end ring. At either end of the rotor core. On large machines these conductor bars and the end rings are made up of copper with the bars brazed or welded to the end rings. In small machines the conductor bars and end rings are made of aluminium with the bars and rings cast in as part of the rotor core. The rotor bars are not insulated from the rotor core because they are made of metals having less resistance then the core. The induced current will flow mainly in them. Also the bars are usually not quite parallel to the rotor shaft but are mounted in slightly slewed position. This feature tends to produce a more uniform rotor field and torque also it helps to reduce some of the internal magnetic noise when the motor is running.

End shields

The function of the two end shields which are to support the rotor Shaft. They are fitted with bearings and attached to the stator frame with the help of studs or bolts.

Double squirrel cage induction motor.

Rotor construction and its working

The outer cage consists of bars of high resistance metals like brass and is short circuited by the end rings. The inner cage consists of low resistance metal like copper and is short circuited by the end rings. The outer cage has high resistance and low reactance whereas the inner cage has low resistance but being situated deep in the rotor core has a large ratio of reactance to resistance.at the time of starting the rotor frequency is the same as the stator frequency. Hence the inner cage which has higher inductive reactance offers more resistance to the current flow. A very little current flows through the inner cage at the time of starting.

The major part of the rotor current at the time of starting could flow through the outer ring which has high resistance. This high resistance enables to produce a high starting torque. As the speed increases the rotor frequency is reduced. At low frequency the total resistance offered for the current flow in the inner cage reduces due to reduction of reactance and the major pare of part of the rotor current will be in the inner cage rather than in the highly resistant outer cage.

Construction of a 3-phase squirrel cage induction motor - relation between slip, speed, rotor frequency, copper loss and torque

Objectives: At the end of this lesson you shall be able to:
- describe the construction of a 3-phase, squirrel cage induction motor
- describe the construction of double squirrel cage motor and its advantage
- explain slip, speed, rotor frequency, rotor copper loss, torque and their relationship.

Three-phase induction motors are classified according to their rotor construction. Accordingly, we have two major types.

– Squirrel cage induction motors

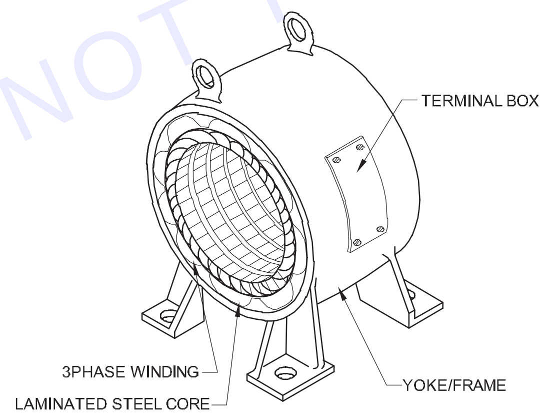
– Slip ring induction motors.

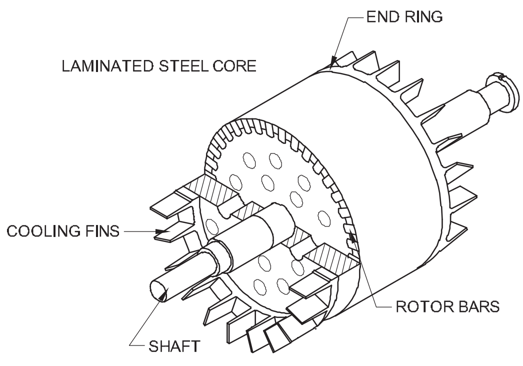
Squirrel cage motors have a rotor with short-circuited bars whereas slip ring motors have wound rotors having three windings, either connected in star or delta. The terminals of the rotor windings of the slip ring motors are brought out through slip-rings which are in contact with stationary brushes.

Stator of an induction motor: There is no difference between squirrel cage and slip-ring motor stators.

The induction motor stator resembles the stator of a revolving field, three-phase alternator. The stator or the stationary part consists of three-phase winding held in place in the slots of a laminated steel core which is enclosed and supported by a cast iron or a steel frame as shown in Fig 1. The phase windings are placed 120 electrical degrees apart, and may be connected in either star or delta externally, for which six leads are brought out to a terminal box mounted on the frame of the motor. When the stator is energised from a three-phase voltage it will produce a rotating magnetic field in the stator core.

Rotor of a squirrel cage induction motor: The rotor of the squirrel cage induction motor shown in Fig 2 contains no windings. Instead it is a cylindrical core constructed of steel laminations with conductor bars mounted parallel to the shaft and embedded near the surface of the rotor core. These conductor bars are short circuited by an end-ring at either end of the rotor core. On large machines, these conductor bars and the end-rings are made up of copper with the bars brazed or welded to the end rings as shown in Fig 3. On small machines the conductor bars and end-rings are sometimes made of aluminium with the bars and rings cast in as part of the rotor core.





CAGE-TYPE ROTOR IN PART SECTION SHOWING CAST ALUMINIUM BARS AND END RINGS

ELC22T0036

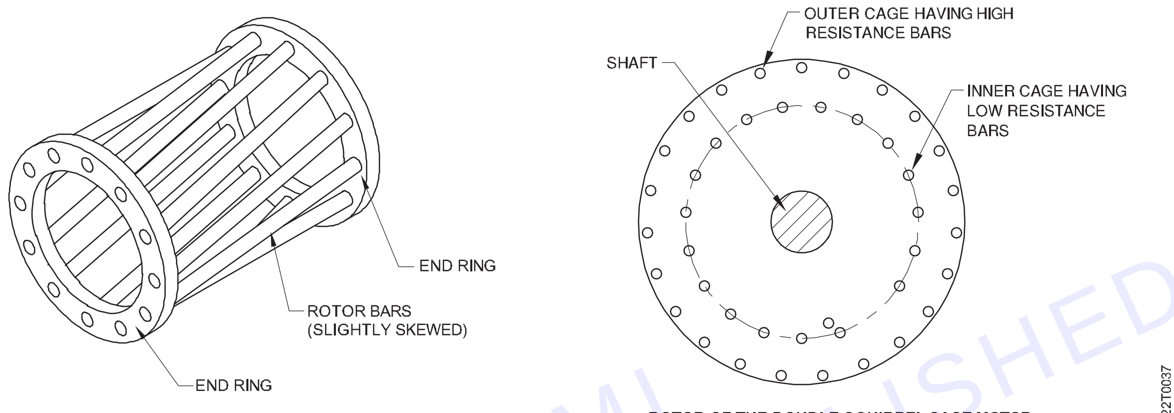
The rotor or rotating part is not connected electrically to the power supply but has voltage induced in it by transformer action from the stator. For this reason, the stator is sometimes called the primary, and the rotor is referred to as the secondary of the motor. Since the motor operates on the principle of induction; and as the construction of the rotor, with the bars and end-rings resembles a squirrel cage, the name squirrel cage induction motor is used. (Fig 3)

The rotor bars are not insulated from the rotor core because they are made of metals having less resistance than the core. The induced current will flow mainly in them. Also, the bars are usually not quite parallel to the rotor shaft but are mounted in a slightly skewed position. This feature tends to produce a more uniform rotor field and torque; also it helps to reduce some of the internal magnetic noise when the motor is running.

End shields: The function of the two end shields which are to support the rotor shaft. They are fitted with bearings and attached to the stator frame with the help of studs or bolts.

Double squirrel cage induction motor

Rotor construction and its working: This consists of two sets of conductor bars called outer and inner cages as shown in Fig 4. The outer cage consists of bars of high resistance metals like brass, and is short-circuited by the end-rings. The inner cage consists of low resistance metal bars like copper, and is short-circuited by the end-rings. The outer cage has high resistance and low reactance, whereas the inner cage has low resistance but being situated deep in the rotor core, has a large ratio of reactance to resistance.



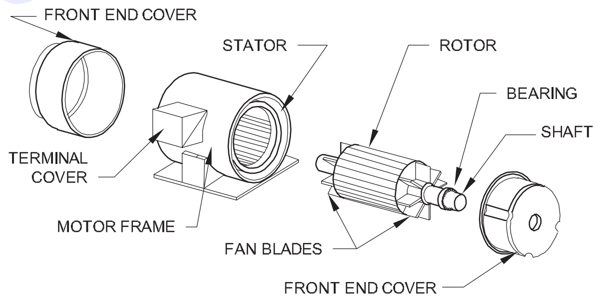
VIEW OF THE SQUIRREL CAGE MOTOR ROTOR BARS

ROTOR OF THE DOUBLE SQUIRREL CAGE MOTOR

At the time of starting, the rotor frequency is the same as the stator frequency. Hence the inner cage which has higher inductive reactance offers more resistance to the current flow. As such very little current flows through the inner cage at the time of starting.

The major part of the rotor current at the time of starting could flow through the outer ring which has high resistance. This high resistance enables to produce a high starting torque.

Fig 5 shows the exploded view of 3 phase squirrel cage induction motor.



PARTS OF 3 PHASE SQUIRREL CAGE INDUCTION MOTOR

Slip and rotor speed: The speed at which the rotor rotates is called the rotor speed or speed of the motor. The difference between the synchronous speed and the actual rotor speed is called the `slip speed'. Slip speed is the number of revolutions per minute by which the rotor continues to fall behind the revolving magnetic field.

When the slip speed is expressed as a fraction of the synchronous speed, it is called a fractional slip.

$$\therefore \text{ fractional slip } S = \frac{N_s - N_r}{N_s}$$

$$\text{Then percentage slip (\% slip)} = \frac{N_s - N_r}{N_s} \times 100$$

where N_s = synchronous speed of the stator magnetic field

N_r = Actual rotating speed of the rotor in r.p.m.

Most squirrel cage induction motors will have a percentage slip of 2 to 5 percent of the rated load.

Example

Calculate the percentage slip of an induction motor having 6 poles fed with 50 cycles supply rotating with an actual speed of 960 r.p.m.

Given:

Poles (P) = 6

N_r = Rotor speed = 960 r.p.m.

F = frequency of supply = 50 Hz

N_s = Synchronous speed

$$= 120\frac{f}{P}$$

$$= \frac{120 \times 50}{6} = 1000 \text{r.p.m.}$$

$$\% \text{ slip} = \frac{N_s - N_r}{N_s} \times 100$$

$$= \frac{1000 - 960}{1000} \times 100 = 4\%$$

Torque : The torque production in an induction motor is more or less the same as in the DC motor. In the DC motor the torque is proportional to the product of the flux per pole and the armature current. Similarly in the induction motor the torque is proportional to the flux per stator pole, the rotor current and also the rotor power factor.

Thus we have,

Torque is proportionally = Stator flux x rotor current x rotor power factor.

Let	E_1	be the applied voltage
	Ø	be the stator flux which is proportional to E1
	S	be the fractional slip
	R_2	be the rotor resistance
	X_2	be the rotor inductive reactance at standstill
	SX_2	be the rotor inductive reactance at fractional slip S
	K	be the transformation ratio between stator and rotor voltages
	E_2	be the rotor induced emf and equal to SKE1
	I_2	be the rotor current,
	Cosq	be the rotor power factor.
	Z_2	be the rotor impendence.

We can conclude mathematically the following final results.

T a Ø I_2 Cosq

This can be deduced in to a formula

$$T \propto \frac{SKE_1^2 R_2}{R_2^2 + S^2 X_2^2}$$

$$T \propto \frac{\text{Rotor copper loss}}{\text{Fractional slip}}$$

$$\text{Starting torque} \propto \frac{R_2}{R_2^{\,2} + X_2^{\,2}} \quad \text{as fractional slip S = 1}$$

$$\text{Maximum torque} \propto \frac{1}{X_2}$$

where X2 in inductive reactance of the rotor at standstill and is constant.

Rotor copper loss: Rotor copper loss is the loss of power taking place in the rotor due to its resistance and the rotor current. Though the resistance of the rotor for a squirrel cage motor remains constant, the current in the rotor depends upon the slip, transformation ratio between the stator and rotor voltages and the inductive reactance of the rotor circuit.

Insulation test on 3 phase induction motors

Objectives: At the end of this lesson you shall be able to:

- state the necessity for and the method of testing continuity and insulation resistance in a 3-phase induction motor
- state the necessity of continuity test before insulation test.

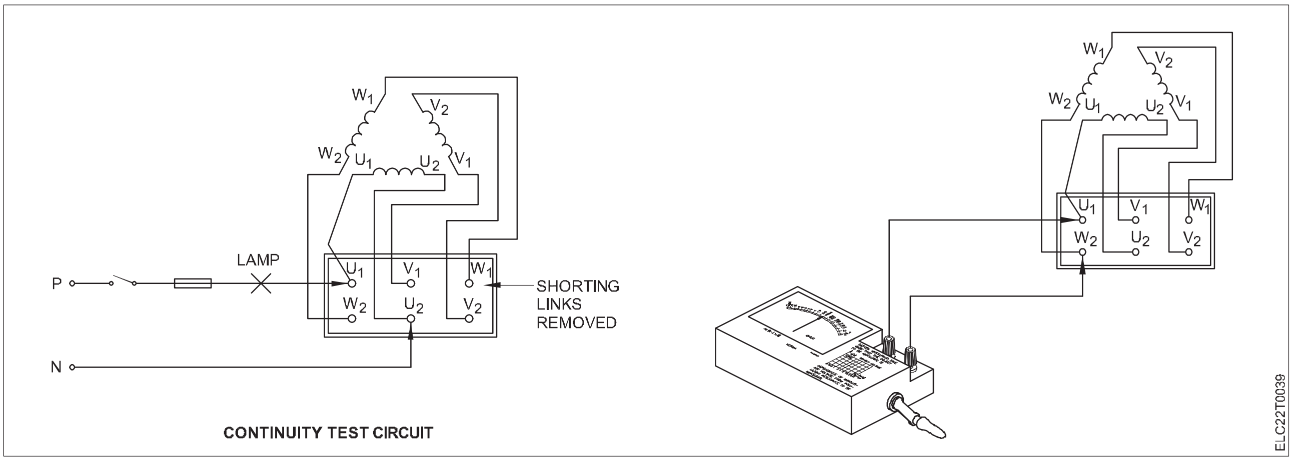
Necessity of continuity test before insulation test: While testing the insulation resistance between the winding and the frame, it is the usual practice to connect one prod of the Megger to the frame and the other prod to any one of the terminals of the winding. Likewise, when testing insulation resistance between windings, it is the usual practice to connect the two prods of the Megger to any two ends of a different winding. In all the cases it is assumed that the windings are in sound condition and the two ends of the same winding will be having continuity. However, it is possible the winding may have a break, and part of the winding may have a higher insulation resistance and the other part might have been grounded. Hence, to increase the reliability of the insulation resistance test, it is recommended that continuity test may be conducted in the motor before the insulation test, to be sure, that the winding is sound and the insulation resistance includes the entire winding.

Continuity test: The continuity of the winding is checked by using a test lamp in the following method as shown in Fig 1. First the links between the terminals should be removed.

The test lamp is connected in series with a fuse and a switch to the phase wire and the other end is connected to one of the terminals (say U1 in Fig 1). The neutral of the supply wire is touched to the other terminals one by one. The terminal in which the lamp lights is the other end of the winding connected to the phase wire (say U2 in Fig 1). The pairs are to be found in a similar manner. Lighting of the lamp between two terminals shows continuity of the winding. Lighting of the lamp between more than two terminals shows short between the windings.

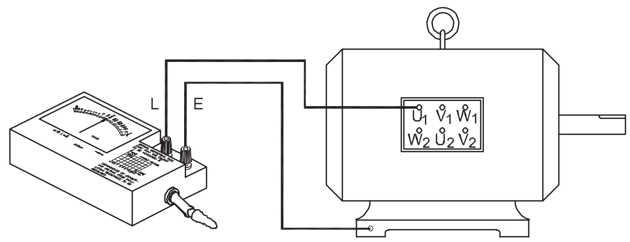
Limitations of lamp continuity test: However, this test only shows the continuity but will not indicate any short between the turns of the same winding.

Insulation test between windings: As shown in Fig 2, one of the Megger terminals is connected to one terminal of any one winding (say U1 in Fig 2) and the other terminal of the Megger is connected to one terminal of the other windings (say W2 in Fig 2).



When the Megger handle is rotated at its rated speed, the reading should be more than one megohm. A lower reading than one megohm shows weak insulation between the windings, and needs to be improved. Likewise the insulation resistance between the other windings is tested.

Insulation resistance between windings and frame: As shown in Fig 3, one terminal of the Megger is connected to one of the phase windings, and the other terminal of the Megger is connected to the earthing terminal of the frame. When the Megger handle is rotated at the rated speed, the reading obtained should be more than one megohm. A lower reading than one megohm indicates poor insulation between the winding and the frame and needs to be improved by drying and varnishing the windings.



Starter for 3-phase induction motor - power control circuits - D.O.L starter

Objectives: At the end of this lesson you shall be able to:

- state the necessity of starters for a 3-phase induction motor and name the types of starters
- explain the basic contactor circuit with a single push-button station for start and stop.

Necessity of starter: normal voltage is applied to the stationary motor, then, a very large initial current, to the tune of 5 to 6 times the normal current, will be drawn by the motor from the mains. This initial excessive current is objectionable, because it will produce large line voltage drop, which in turn will affect the operation of other electrical equipment and lights connected to the same line.

The initial rush of current is controlled by applying a reduced voltage to the stator winding during the starting period, and then the full normal voltage is applied when the motor has run up to speed. For small capacity motors, say up to 3 Hp, full normal voltage can be applied at the start. However, to start and stop the motor, and to protect the motor from overload currents and low voltages, a starter is required in the motor circuit. In addition to this, the starter may also reduce the applied voltage to the motor at the time of starting.

Types of starters: Following are the different types of starters used for starting squirrel cage induction motors.

- Direct on-line starter
- Star-delta starter
- Auto-transformer starter

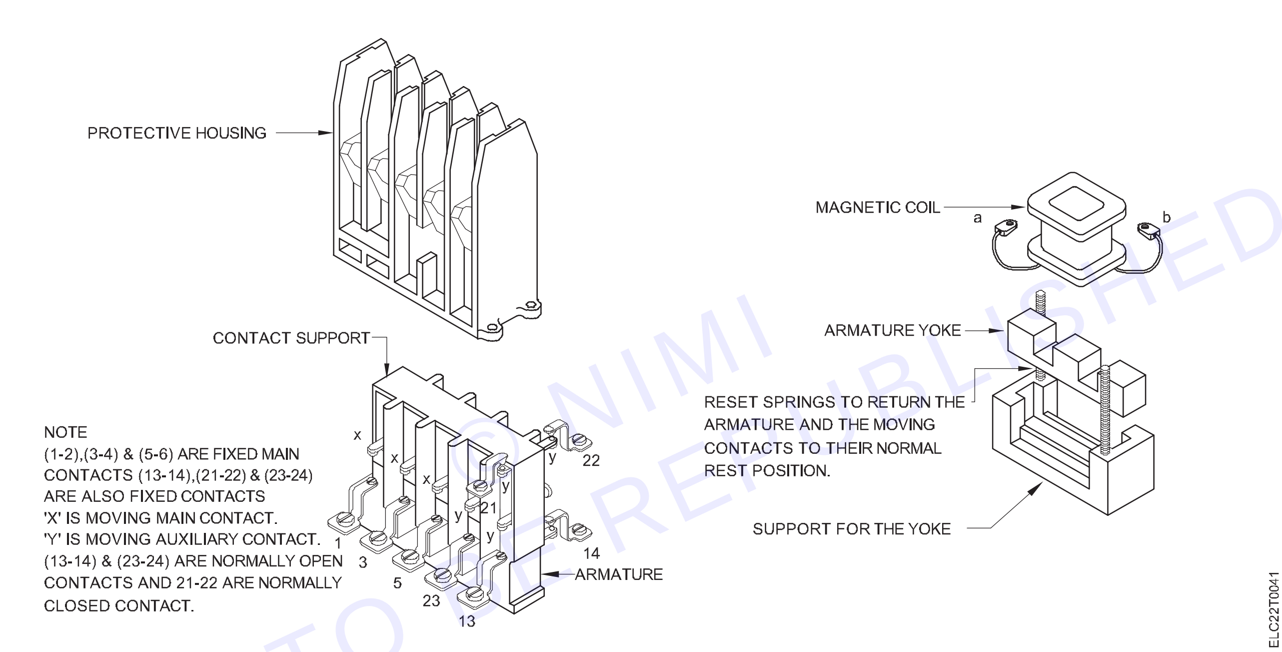
In the above starters, except for the direct on-line starter, reduced voltage is applied to the stator winding of the squirrel cage induction motor at the time of starting, and regular voltage is applied once the motor picks up the speed.

Selection of starter: Many factors must be considered when selecting starting equipment. These factors include starting current, the full load current, voltage rating of motor, voltage (line) drop, cycle of operation, type of load, motor protection and safety of the operator.

Contactors: The contactor forms the main part in all the starters. A contactor is defined as a switching device capable of making, carrying and breaking a load circuit at a frequency of 60 cycles per hour or more. It may be operated by hand (mechanical), electromagnetic, pneumatic or electro-pneumatic relays.

The contactors shown in Fig 1 consist of main contacts, auxiliary contacts and no-volt coil. As per Fig 1, there are three sets of normally open, main contacts between terminals 1 and 2, 3 and 4, 5 and 6, two sets of normally open auxiliary contacts between terminals 23 and 24, 13 and 14, and one set of normally closed auxiliary contact between terminals 21 and 22. Auxiliary contacts carry less current than main contacts. Normally contactors will not have the push-button stations and O.L. relay as an integrated part, but will have to be used as separate accessories along with the contactor to form the starter function.

The main parts of a magnetic contactor are shown in Fig 1 shows the schematic diagram of the contactor when used along with fused switches (ICTP), push-button stations and OL relay for connecting a squirrel cage motor for starting directly from the main supply. In the same way the direct on-line starter consists of a contactor, OL relay and push-button station in an enclosure.



Slip and rotor speed: The speed at which the field rotate is called synchronous speed. It depends upon the frequency of the supply and the number of poles for which the stator is wound

Hence

$$NS = \frac{120F}{P}$$

Ns = synchronous speed in rpm

P = no of poles

F = frequency of the supply

Actual speed: The speed at which the rotor rotate is called rotor speed or speed of the motor.

SLIP

Absolute slip (slip speed): - The difference between the synchronous speed and actual rotor speed is called the slip speed

S = Ns - Nr

Fractional slip – when the slip speed is expressed as a fraction of the synchronous speed it is called fractional slip

Fractional slip $S = \frac{(Ns-Nr)}{Ns}$

Percentage slip (%) -the slip is expressed in percentage then it is called percentage slip

$$S = \frac{(Ns-Nr)x100}{Ns}$$

Rotor frequency

The frequency of the rotor voltage is called rotor frequency. It is equal the product of the slip and the stator (supply) frequency

Rotor frequency Fr = fractional slip x stator frequency

$$Fr = \frac{(Ns-Nr) \times S}{Ns}$$

Fr = S x F

At the time of starting rotor is at rest and slip will be equal to one. The rotor frequency will be the same as the stator frequency. When the motor is running at high speed slip will be low and the frequency of the rotor will also be low.

Torque

The twisting moment developed in the rotor shaft by the interaction of the magnetic field of stator by rotor is called torque. In the dc motor the torque is proportional to the flux per pole and the armature current. Similarly, in the induction motor the torque is proportional to the pole, rotor current, and also the rotor power factor.

Stating torque - the torque available in the rotor during starting is called starting torque.

Torque = K x stator flux x rotor flux x rotor power factor.

$T\alpha$ Ir $\Phi\cos\Phi 2$

At starting rotor is stationary so S= 1

Rotor reactance Xr =2πsfL

A large starting torque rotor resistance should large

Voltage of the machine is reduced at starting the torque will be considerably reduced

Starting torque is directly proportional to applied square of the voltage

A maximum torque for a given machine for given speed rotor resistance must be small

Starters

Necessity of starter: If normal voltage is applied to the stationary motor, then as in the case of a transformer very large initial excessive current will be drawn by the motor from the mains. This initial excessive current is will produce large line voltage drop which in turn will affect the operation of other electrical equipment and lights connected to the same line. The initial current is controlled by applying a reduced voltage to the stator winding during the starting winding during starting period and then the full normal voltage is applied when the motor has run up to speed. For small capacity motors up to 3 hp full normal voltage can be applied at the start.

Compare the characteristics of a squirrel cage induction motor

S.No	Characteristics	Squirrel cage induction motor	Slip ring induction motor
1	Speed	Nearly constant but slightly falls with load	More speed falls with load than Squirrel cage induction motor
2	Torque	Starting torque is not so good Running torque is good	Starting torque higher than Squirrel cage induction motor and is three times full load torque. Running torque is good
3	Current	Starting current is high, about five times that full load current	Starting current is low, about two times of full load current
4	Speed control	Speed can be varied by pole changing method	It can be slightly changing the rotor resistance
5	Power factor	Low power factor 0.7-.08	High power factor 0.8-.09
6	Cost	Low	High
7	Uses	Factories for lathe , drill, blower,etc.	Used for high starting torque is wanted e.g. : lift, crane,etc.
8	Rotor construction	Bars are used in rotor. Squirrel cage rotor is very simple, rugged and long lasting. No slipring.	Winding wire is used. Wound rotor requires attention. Slip ring and brush fear need frequent maintenance.
9	Starting	Cam ne started by DOL ,star delta, auto transformer starters.	Rotor resistance starter is required.
10	Starting torque	Low	Very high
11	Starting current	High	Low
12	Speed variation	Not easy but could be varied in larger steps by pole changing or smaller incremental steps through thyristors or by frequency variation.	Easy to vary speed but speed change through pole changing is not possible. Speed change possible by insertion of rotor resistance –using thyristors –using frequency variation –injecting emf in the rotor circuit -cascading
13	Acceleration on load	Just satisfactory	Very good
14	Maintenance	Almost nil	Requires frequent maintenance

Types of starters

a Direct on line starter

b Star delta starter

c Step down transformer starter

d Auto transformer

Selection of starter

Many factors must be considered when selecting starting equipment. These factors include starting current the full load current voltage rating of motor, voltage drop, cycle of operation, type of load, motor protection and safety of operation

Types of over load relay

a Magnetic overload relay

b Thermal (bimetallic) overload relay

D.O.L. starter

Objectives: At the end of this lesson you shall be able to:

- state the specification of a D.O.L. starter, explain its construction, operation and application
- explain the necessity of a back-up fuse and its rating according to the motor rating.

A D.O.L. starter is one in which a contactor with no-volt relay, ON and OFF buttons, and overload relay are incorporated in an enclosure.

Construction and operation: A push-button type, direct on-line starter, which is in common use, is shown in

Fig 1. It is a simple starter which is inexpensive and easy to install and maintain.

There is no difference between the complete contactor circuit explained in Exercise 2.3.125 and the D.O.L. starter, except that the D.O.L. starter is enclosed in a metal or PVC case, and in most cases, the no-volt coil is rated for 415V and is to be connected across two phases as shown in Fig 1. Further the overload relay can be situated between ICTP switch and contactor or between the contactor and motor as shown in Fig 1, depending upon the starter design. Trainees are advised to write the working of the D.O.L. starter on their own

Specification of D.O.L. starters: While giving specification, the following data are to be given.

D.O.L. starter

Phases - single or three.

Voltage 240 or 415V.

Current rating 10, 16, 32, 40, 63, 125 or 300 amps.

No-volt coil voltage rating AC or DC 12, 24, 36, 48, 110, 230/250, 360, 380 or 400/440 volts.

Number of main contacts 2, 3 or 4 which are normally open.

Number of auxiliary contacts 2 or 3. 1 NC + 1 NO or 2 NC + 1 NO respectively.

Push-button - one `ON' and one `OFF' buttons.

Overload from setting – amp-to-amp. Enclosure - metal sheet or PVC.

Applications: In an induction motor with a D.O.L. starter, the starting current will be about 6 to 7 times the full load current. As such, D.O.L. starters are recommended to be used only up to 3 HP squirrel cage induction motors, and up to 1.5 kW double cage rotor motors.

Example

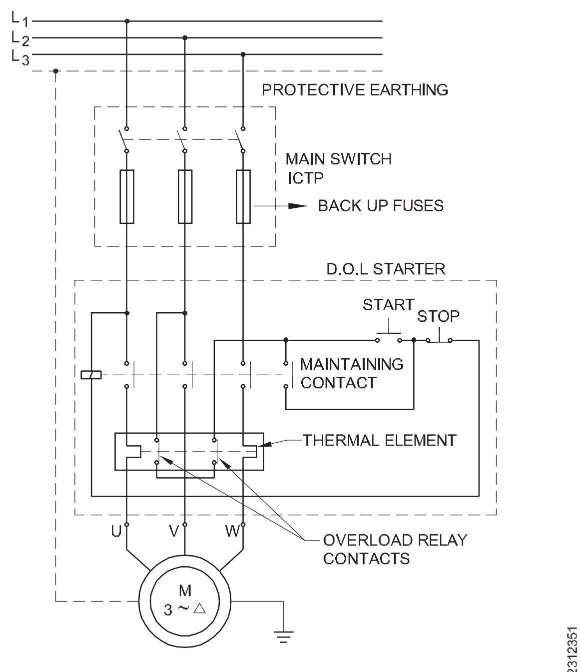
A 3-phase, 400V, 50 HZ, delta-connected induction motor draws a line current of 150 amps with a P.F. of 0.85 and is delivering an output of 100 (Metric) HP. Calculate the efficiency.

$$\% \text{ of efficiency} = \frac{\text{Output} \times 100}{\text{Input}}$$

$$= \frac{100 \times 735.5 \times 100}{\sqrt{3} \times 400 \times 150 \times 0.85}$$

$$= 83.3\ \%$$

Fig 1



WIRING DIAGRAM OF A DIRECT ON-LINE STARTER WITH PROTECTIVE DEVICES

Manual star-delta starter

Objectives: At the end of this lesson you shall be able to:

- state the necessity of a star-delta starter for a 3-phase squirrel cage induction motor
- explain the construction, connection and working of a star-delta switch and starter
- specify the back-up rating of the fuse in the motor circuit.

Necessity of star-delta starter for 3-phase squirrel cage motor: If a 3-phase squirrel cage motor is started directly, it takes about 5-6 times the full load current for a few seconds, and then the current reduces to normal value once the speed accelerates to its rated value. As the motor is of rugged construction and the starting current remains for a few seconds, the squirrel cage induction motor will not get damaged by this high starting current.

However with large capacity motors, the starting current will cause too much voltage fluctuations in the power lines and disturb the other loads. On the other hand, if all the squirrel cage motors connected to the power lines are started at the same time, they may momentarily overload the power lines, transformers and even the alternators.

Because of these reasons, the applied voltage to the squirrel cage motor needs to be reduced during the starting periods, and regular supply could be given when the motor picks up its speed.

Following are the methods of reducing the applied voltage to the squirrel cage motor at the start.

- Star-delta switch or starter
- Auto-transformer starter
- Step-down transformer starter

Star-delta starter: A star-delta switch is a simple arrangement of a cam switch which does not have any additional protective devices like overload or under-voltage relay except fuse protection through circuit fuses, whereas the star-delta starter may have overload relay and under voltage protection in addition to fuse protection. In a star-delta switch/starter, at the time of starting, the squirrel cage motor is connected in star so that the phase voltage is reduced to $1/\sqrt{3}$ times the line voltage, and then when the motor picks up its speed, the windings are connected in delta so that the phase voltage is the same as the line voltage. To connect a star-delta switch/starter to a 3-phase squirrel cage motor, all the six terminals of the three-phase winding must be available.

As shown in Fig 1a, the star-delta switch connection enables the 3 windings of the squirrel cage motor to be connected in star, and then in delta. In star position, the line supply L1, L2 and L3 are connected to the beginning of windings U1, W1 and V1 respectively by the larger links, whereas the short links, which connect V2 U2 and W2, are shorted by the shorting cable to form the star point. This connection is shown as a schematic diagram. (Fig 1b)

When the switch handle is changed over to delta position, the line supply L1, L2 and L3 are connected to terminals U1 V2, W1 U2 and V1 W2 respectively by the extra large links to form a delta connection. (Fig 1c)

Manual star-delta starter: Fig 2a shows the conventional manual star-delta starter. As the insulated handle is spring-loaded, it will come back to OFF position from any position unless and until the no-volt (hold-on) coil is energised. When the hold-on coil circuit is closed through the supply taken from U2 and W2, the coil is energised and it holds the plunger, and thereby the handle is held in delta position against the spring tension by the lever plate mechanism. When the hold-on coil is de-energised the plunger falls and operates the lever plate mechanism so as to make the handle to be thrown to the off position due to spring tension. The handle also has a mechanism (not shown in Fig) which makes it impossible for the operator to put the handle in delta position in the first moment. It is only when the handle is brought to star position first, and then when the motor picks up speed, the handle is pushed to delta position.

The handle has a set of baffles insulated from each other and also from the handle. When the handle is thrown to star position, the baffles connect the supply lines L1, L2 and L3 to beginning of the 3-phase winding W1, V1 and U1 respectively. At the same time the small baffles connect V2, W2 and U2 through the shorting cable to form the star point. (Fig 1b)

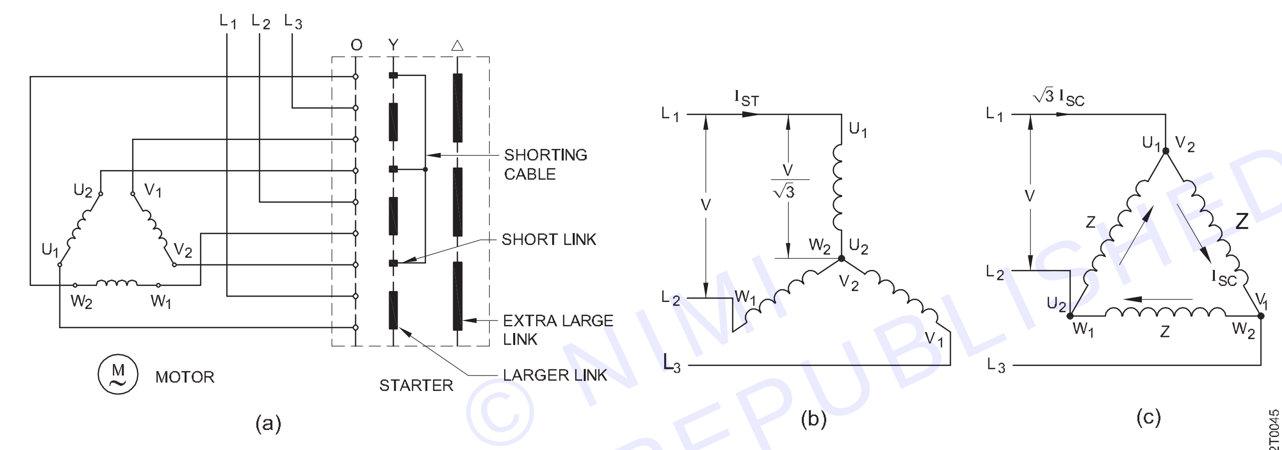
When the handle is thrown to delta position, the larger end of the baffles connect the main supply line L1, L2 and L3 to the winding terminals W1U2, V1W2 and U1V2 respectively to form the delta connection. (Fig 1c)

The overload relay current setting could be adjusted by the worm gear mechanism of the insulated rod. When the load current exceeds a stipulated value, the heat developed in the relay heater element pushes the rod to open the hold-on coil circuit, and thereby the coil is de-energised, and the handle returns to the off position due to the spring tension.

The motor also could be stopped by operating the stop button which in turn de-energises the hold-on coil.

Back-up fuse protection: Fuse protection is necessary in the star-delta started motor circuit against short circuits. In general, as a thumb rule for 415V, 3-phase squirrel cage motors, the full load current can be taken as 1.5 times the H.P. rating. For example, a 10 HP 3-phase 415V motor will have approximately 15 amps as its full load current.

To avoid frequent blowing of the fuse and at the same time for proper protection, the fuse wire rating should be 1.5 times the full load current rating of the motor. Hence for 10 HP, 15 amps motor, the fuse rating will be 23 amps, or say 25 amps.



CONNECTIONS OF MANUALLY OPERATED ROTARY TYPE STAR-DELTA SWITCH WITH INDUCTION MOTOR

Construction and operation

A push button type direct on line starter which is in common use. It is a simple starter which is expensive and easy to install and maintain.

It consists of a contractor, in most cases the no volt coil is rated for 415v and is to be connected across two phases. Further overloads relay can be situated between ICTP switch and contactor or between the contactor and motor, depending upon the starter design

Specification of D.O.L. starters

Phases –single or three

Voltage- 230or415

Current rating 10,16,32,40,63,125, or 300amps.

No of main contacts 2, 3, 1NC+1NO or 2NO+2NC

Over load from setting –amp-to-amp. Enclosure –metal sheet or PVC

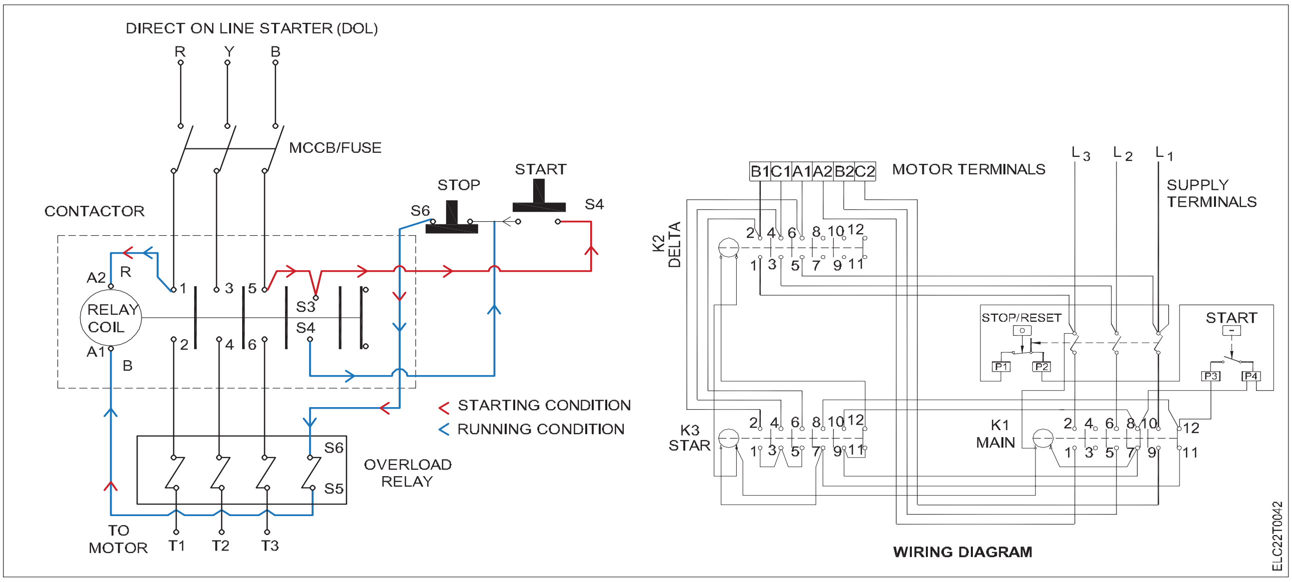
Applications

In an induction motor with a DOL starter the starting current will be about 6 to 7 times the full load current. These are recommended to be used only up to 3 HP squirrel cage induction motors and up to 1.5 kw double cage rotor motors.

Semi-automatic star delta starter

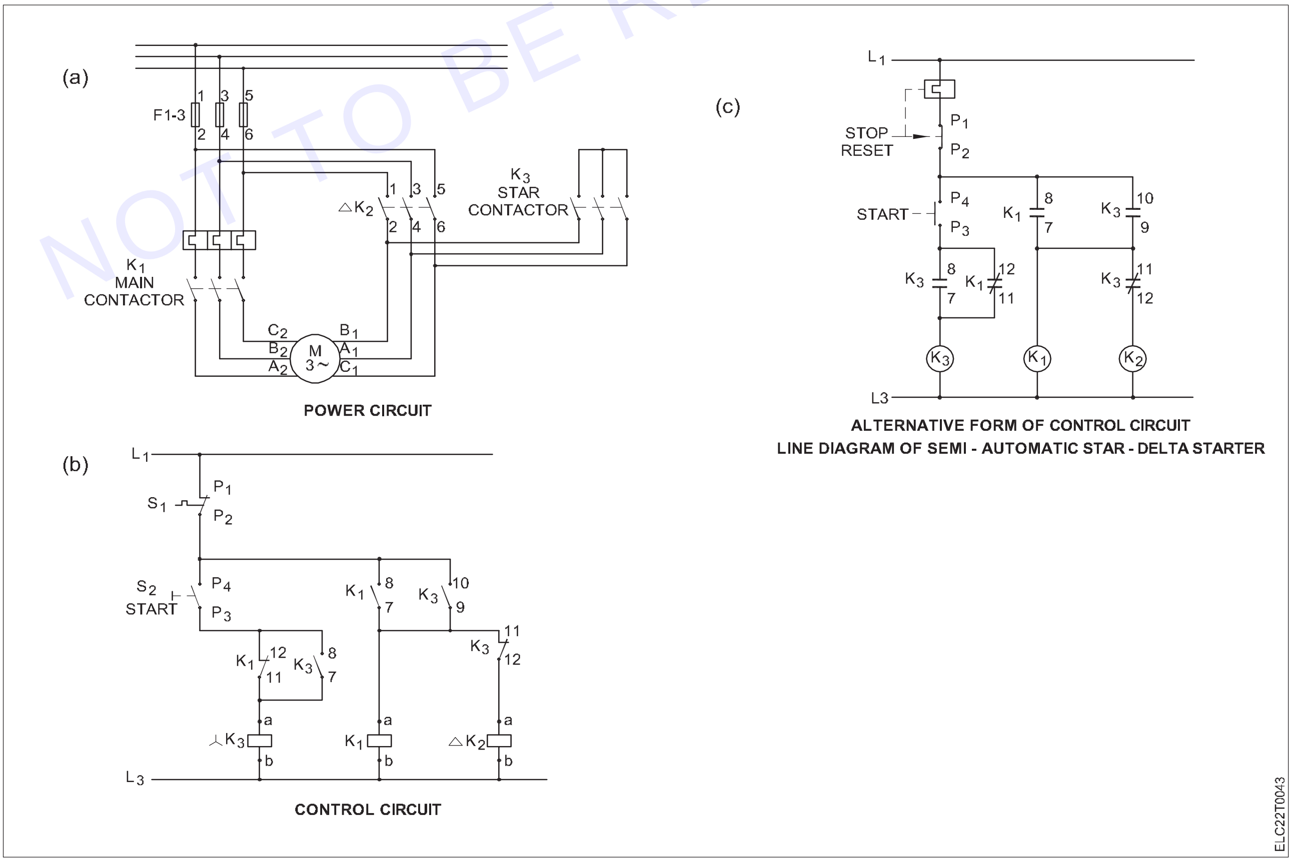
The squirrel cage induction motors with both ends of each of the three windings brought out are known as star delta motors. The use of manual star delta starter demands a special skill in handling the starter.

Figure shows the wiring diagram of Semi-automatic star delta starter



Operation

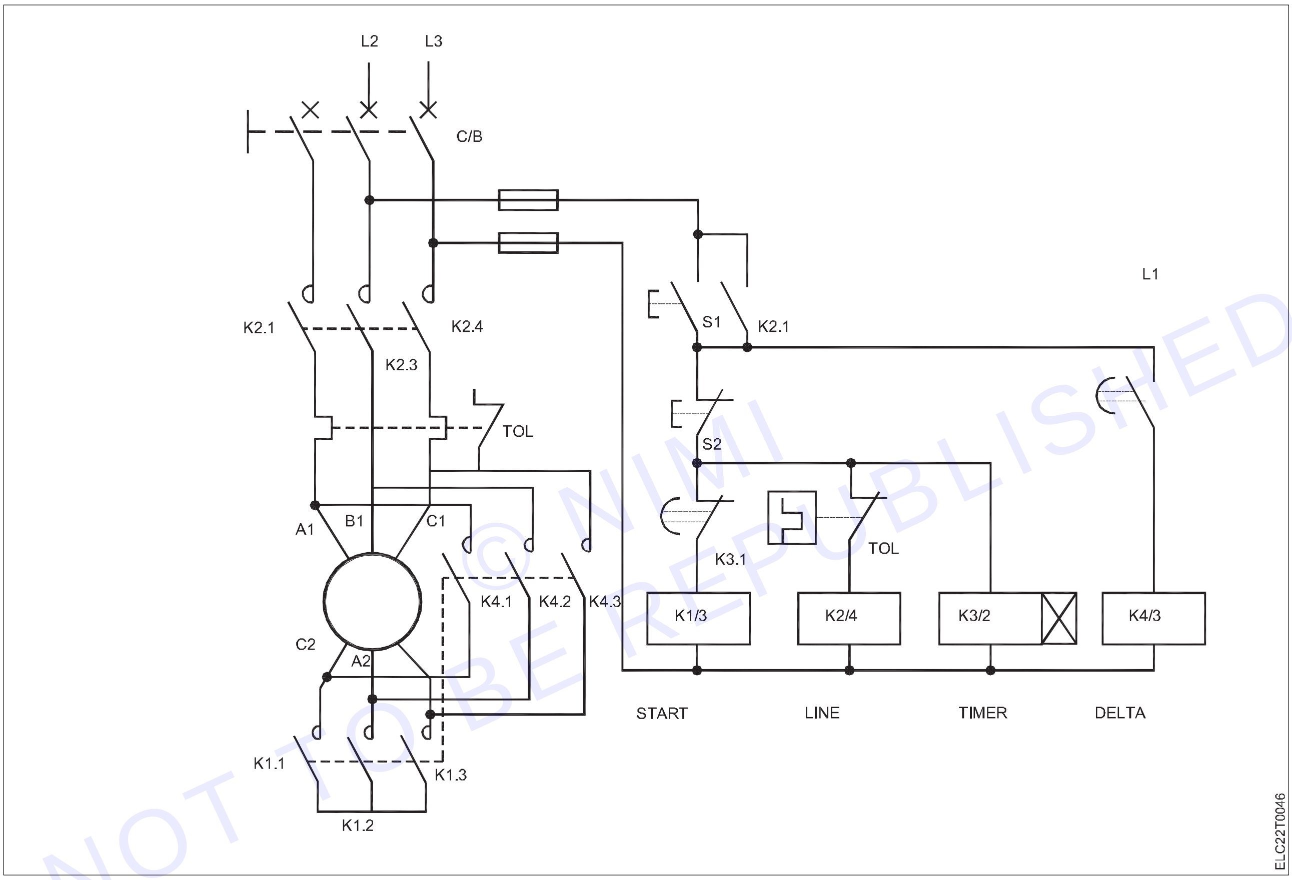
- When the start button S2 is pressed the contactor coil K3 energised through P4, P3 and K1 normally closed contact 12 and 11. When K3 closes, it opens the normally closed contact K3 closes it opens the normally close contact K3 between 11 and 12 and makes contact between 10 and 9 of K3. Once K1 energises the NO contact K1 point 8 and 7 establishes a parallel path to K3 terminal 10 and 9.
- The star contactor K3 remains energised so long as the start button is kept pressed. Once the start button is released, the K3 coil gets de-energised. The K3 contact cannot be operated because of the electrical interlock of K1 and normally closed contacts between terminals 12 and 11.
- When K3 contactor get de-energised the normally closed contact of K3 between terminals 11 and 12 established contact in the contactor K2 coil circuit. The delta contactor K2 closes.



Automatic star-delta star delta starter

Applications: The primary applications of star-delta motors are for driving centrifugal chillers of large central air conditioning units for loads such as fans, blower, pumps, and for situations where a reduced starting toque is necessary. A star delta motor is also used where a reduced starting torque is necessary. These are widely used on loads having high inertia and a long acceleration period. Three overload relays are provided on star delta starters. These relays are use so that they carry the motor winding current. This means that the relay units must be selected on the basis of the winding current, and not the delta connected full load current.

Operation: Pressing the start button S-energises the star contactor K3.once K3 energises the K3 NO contact closes and provide path for the current to close the contactor K1. The closing of contactor K1 establish parallel path to start button via K1 NO terminals 23 & 24. The time delay contact changes opening star contact. Co



Three phase slip induction motor - wound rotor

The slip ring induction motor could be used for industrial drives where variable speed and high starting torque are prime requirements. The construction of rotor is very much different.

Working: When the stator winding of the slip ring motor is connected to the 3-phase supply it produces a rotating magnetic field in the same way as squirrel cage motor. This rotating magnetic field induces voltages in the rotor windings and a rotor current will flow through the closed circuit. The rotor current will flow through the closed circuit formed by the rotor winding, the slip-rings, the brushes and the star connected external resistors. At the time of starting the external resistors are set for their maximum value. As such the rotor resistance is high enabling the starting current to be low. At the same time, the high resistance rotor circuit increases the rotor power factor and thereby the toque developed at the start becomes much higher than the toque developed in squirrel cage motors. As the speed up the external resistance is slowly reduced, rotor resistance the motor operates with low slip and high operating efficiency. The motor could be started for heavy loads with higher resistance or vice versa. The resistance in the external circuit could be designed and varied to change speed of the slip ring motor between 50to 100 percentage of the rated speed.

Starting torque

The torque developed by the motor at the instant if starting is called the starting torque.

Let E2 be the rotor emf per phase at standstill

X2 be the rotor reactance per phase at standstill

R2 be the rotor resistance per phase.

Therefore, Z2 = √(R2) ^2+(X2) ^2 rotor impedance per phase at standstill.

Then $I2 = \frac{E2}{Z2}$ $\cos \Phi 2 = \frac{R2}{Z2}$

Stand still or starting torque Tst = $K1\ E_2\ I_2 \cos \Phi 2$

If the supply cottage is constant, then the flux Φ and hence E2 is constant.

Therefore, starting torque = $K_2 R_2\ Z_2$ where K_2 is another constant

The starting torque of such a motor is increased by adding external resistance in the rotor circuit. The resistance is progressively cut out as the motor gain speed. The resistance is progressively cut as the motor gain speed. Rotor emf and reactance under running condition when the stator is stationary i.e. S =1 the frequency of the rotor emf is the same as that of the stator supply frequency. The value of emf induced in the rotor at standstill is maximum because the relative speed between the rotor and the rotating stator flux is maximum.

When the rotor starts running the relative speed between the rotor and the rotating stator flux is decrease. Hence the rotor induced emf is also decreased. The rotor emf become zero if the rotor speed become zero if the rotor speed become equal to the speed of stator rotating flux. Hence for a slip the rotor induced emf will be s times the induced emf at standstill.

Under running condition Er = s E2.

The frequency of induced emf will likewise become Fr = s F2 where F2 is the rotor current frequency at stand still.

Resistance starter for 3-phase, slip-ring induction motor

Objectives: At the end of this lesson you shall be able to:

- explain the rotor resistance starters used for a 3-phase, slip-ring induction motor.

Slip ring induction motor are started with full line voltage across the stator winding. To reduce the heavy starting current a star connected external resistance is added in the rotor circuit. The external resistances are cut out and the rotor winding ends are shorted once the motor picks up speed. Now days semi-automatic starter is used. By pressing the on button the contactor will close only when the shorting point A at the rotor resistance is in closed position. This is possible only when the handle is in the start position once the motor starts running the handle of the rotor resistance should be brought to run position to cut-out the rotor resistance.

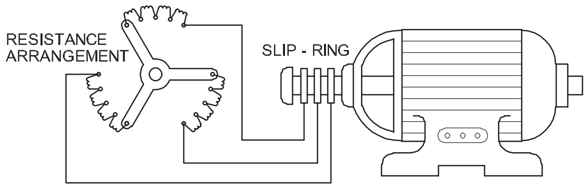
The position of the handle clearly indicates that at the start position the contact s is in the closed position and at the run position contact b is in the closed position but both cannot close at the same time. The on push button needs to be held in the pushed position till the handle is brought to the run position. during the run position the handle contact b closed the no-volt coil circuit and the pressure on the on button can be released.

If such a manual starter is used, there is a possibility that someone may apply full voltage to the stator when the rotor resistance is in a completely cut-out position, resulting in heavy rush of the starting current and poor starting torque. This could be eliminated by the use of a protective circuit in the resistance starter; thereby motor cannot be started until and unless all the rotor resistances are included in the rotor winding. Such a semi-automatic starter is shown in Fig 2.

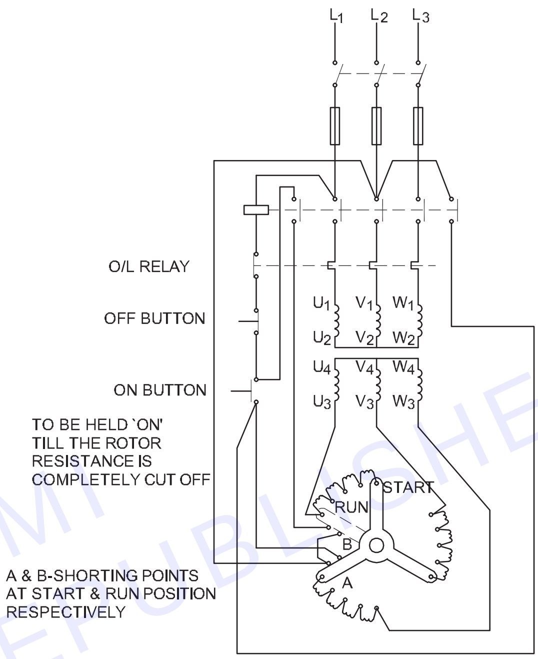
By pressing the 'ON' button, the contactor will close, only when the shorting point 'A' at the rotor resistance is in a closed position. This is possible only when the handle is in the start position. Once the motor starts running, the handle of the rotor resistance should be brought to 'run' position to cutout the rotor resistance.

The position of the handle clearly indicates that at the start position, the contact 'A' is in the closed position, and at the run position, contact 'B' is in the closed position, but both cannot close at the same time. The 'ON' push-button needs to be held in the pushed-position till the handle is brought to the run-position. During the run-position, the handle contact 'B' closes the no-volt coil circuit, and the pressure on the 'ON' button can be released.

In general, for small machines, the rotor resistance is air-cooled to dissipate the heat developed during starting. For larger machines, the rotor resistance is kept in an insulating oil tank for cooling. The starter shown is intended to start the motor only. As speed regulation through the rotor resistance needs intermediate positions, they are specially designed and always oil-cooled.



SLIP RING INDUCTION MOTOR WITH RESISTANCE STARTER



ROTOR RESISTANCE STARTER FOR
SLIP RING INDUCTION MOTOR

ELC22T0047

Auto-transformer starter

Objectives: At the end of this lesson you shall be able to:

- explain the construction and operation of auto-transformer starter
- explain power circuit and control circuit of auto-transformer starter

Auto-transformer starter

By connecting series resistances reduced voltage is obtained at the motor leads. It is simple and cheap, but more power is wasted in the external series resistances.

In auto transformer starting method the reduced voltage is obtained by taking tappings at suitable points from a three phase auto -transformer as shown in Fig 1. The auto transformers are generally tapped at 55, 65, 75 percent points. So that the adjustment at these voltages may be made for proper starting torque requirements. Since the contacts frequently break, large value of current acting some time quenched effectively by having the auto-transformer coils immersed in the oil bath.

The power circuit of the auto-transformer is shown in

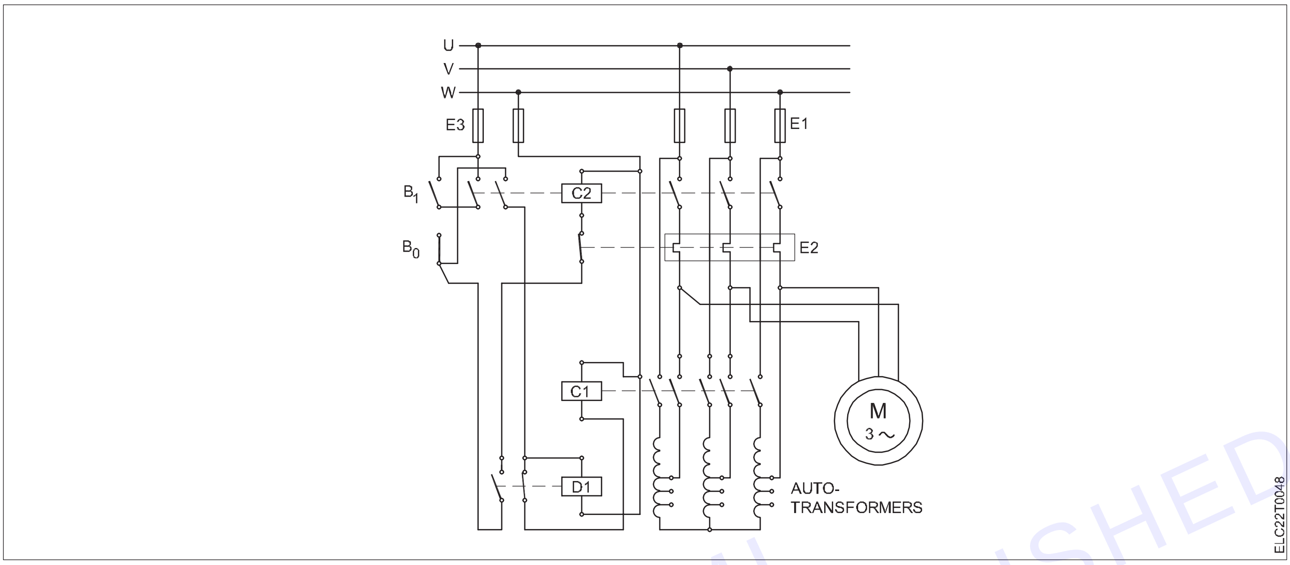
Fig 2a and control circuit of auto-transformer is shown in Fig 2b.

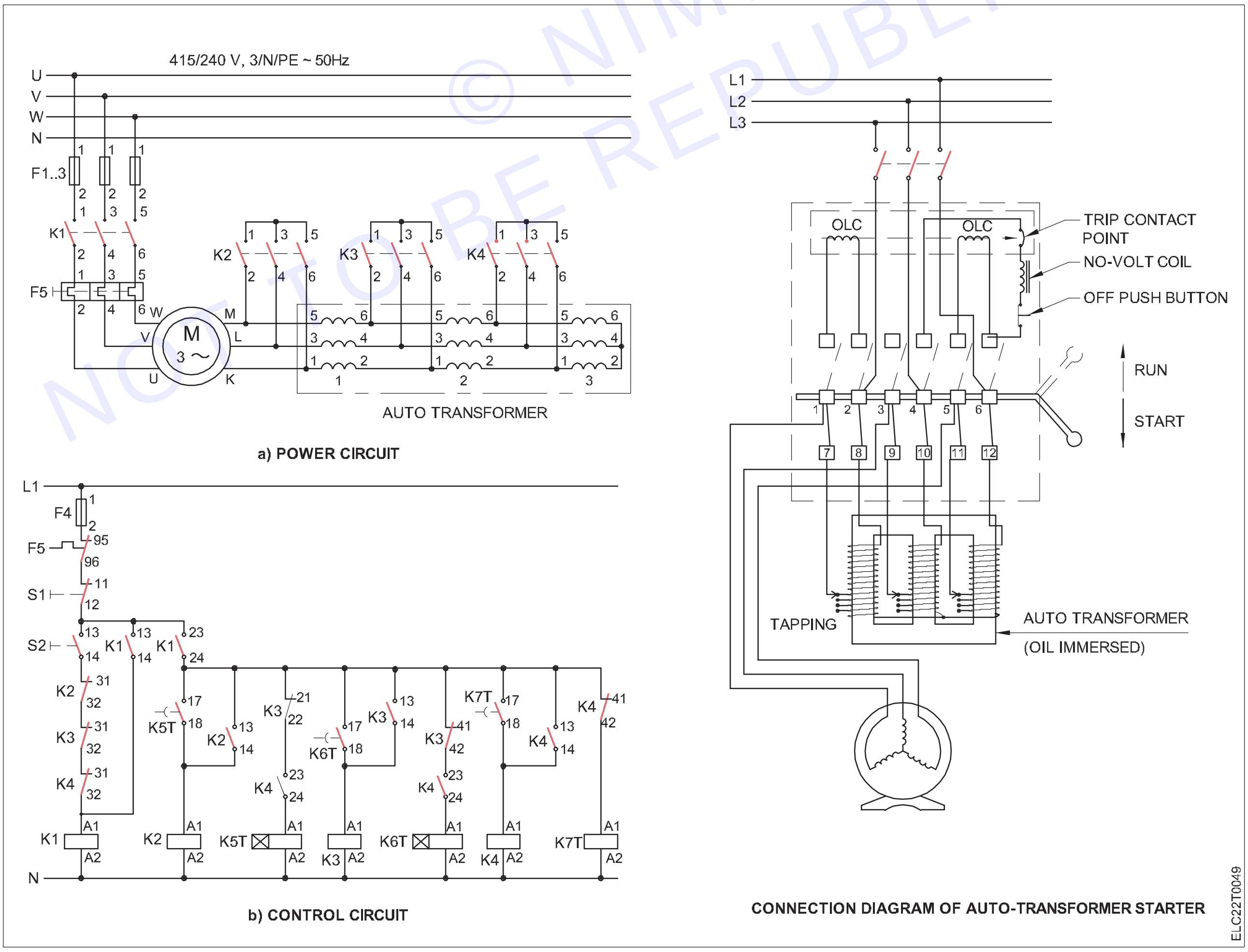
Auto-transformer starter - operation

In this type of starter reduced voltage for starting the motor is obtained from a three-phase star connected auto-transformer. While starting, the voltage is reduced by selecting suitable tappings from the auto-transformer. Once the motor starts rotating 75% of its synchronous speed, full line voltage is applied across the motor and the auto-transformer is cut off from the motor circuit.

Fig 3 shows the connection of an auto-transformer starter. To start the motor the handle of the starter is turned downward and the motor gets a reduced voltage from the auto-transformer tappings. When the motor attains about 75% of its rated speed the starter handle is moved upward and the motor gets full voltage. The auto-transformer gets disconnected from the motor circuit.

Hand operated auto-transformer starters are suitable for motors from 20 to 150 hp whereas automatic auto-transformer starters are used with large horse-power motors upto 425 hp.





Losses and efficiency of induction motor

There are two types of losses occur in three phase induction motor. These losses are,

1 Constant or fixed losses,

2 Variable losses.

Constant or fixed losses

Constant losses are those losses which are considered to remain constant over normal working range of induction motor. The fixed losses can be easily obtained by performing no-load test on the three phase induction motor. These losses are further classified as-

1 Iron or core losses,

2 Mechanical losses,

3 Brush friction losses

Iron or core losses

Iron or core losses are further divided into hysteresis and eddy current losses. Eddy current losses are minimized by using lamination. Since by laminating the core, area decreases and hence resistance increases, which results in decrease in eddy currents. Hysteresis losses are minimized by using high grade silicon steel. The core losses depend upon frequency. The frequency of stator is always supply frequency, f and the frequency of rotor is slip times the supply frequency, (sf) which is always less than the stator frequency. Hence the rotor core loss is very small as compared to stator core loss and is usually neglected in running conditions.

Mechanical and brush friction losses

Mechanical losses occur at the bearing and brush friction loss occurs in wound rotor induction motor. These losses occur with the change in speed. In three phase induction motor the speed usually remains constant. hence these losses almost remain constant.

Variable losses

These losses are also called copper losses. These losses occur due to current flowing in stator and rotor winding. As the load changes, the current flowing in rotor and stator winding also changes and hence these losses also changes. Therefore, these losses are called variable losses. The copper losses are obtained by performing blocked rotor test on three phase induction motor.

The induction motor electrical power the input to the three phase induction motor is three phase supply. So, the three phase supply is given to the stator of three phase induction motor. Let, P_{in} = electrical power supplied to the stator of three phase induction motor, V_L = line voltage supplied to the stator of three phase induction motor, I_L = line current, Cosφ = power factor of the three phase induction motor. Electrical power input to the stator, $P_{in} = \sqrt{3}V_L I_L \cos\varphi$ A part of this power input is used to supply stator losses which are stator iron loss and stator copper loss. The remaining power i.e(inputelectrical power – stator losses) are supplied to rotor as rotor input. So, rotor input $P_2 = P_{in}$ – stator losses (stator copper loss and stator iron loss).

Now, the rotor has to convert this rotor input into mechanical energy but this complete input cannot be converted into mechanical output as it has to supply rotor losses. As explained earlier the rotor losses are of two types rotor iron loss and rotor copper loss. Since the iron loss depends upon the rotor frequency, which is very small when the rotor rotates, so it is usually neglected. So, the rotor has only rotor copper loss. Therefore, the rotor input has to supply these rotor copper losses. After supplying the rotor copper losses, the remaining part of Rotor input, P_2 is converted into mechanical power, P_m.

Let P_c be the rotor copper loss,

I_2 be the rotor current under running condition,

R_2 is the rotor resistance,

P_m is the gross mechanical power developed.

$P_c = 3I_2^2R_2$

No-load test of induction motors

The induction motor is connected to the supply through a three phase auto transformer, the three phase auto transformer is use to regulate the starting current by applying low voltage at the start and the gradually increased to rated voltage. The ammeter and volt meters are selected based upon the motor specification. The no-load current of the motor will be very low up to 30% of full load.

The power factor of the motor on no load is very low in the range of 0.1 to 0.2 the watt meters selected are such as to give a current reading at low power factor. The wattmeter full scale reading will approximate equal to the product of the ammeter and voltmeter full scale deflection values

At no load the outfit delivered by the motor is zero. All the mechanical power developed in the rotor is used to maintain the rotor running at its rated speed. Hence the input power is equal to the no-load copper loss plus iron losses and mechanical losses.

Slip ring induction motor are started with full line voltage across the stator winding. To reduce the heavy starting current a star connected external resistance is added in the rotor circuit. The external resistances are cut out and the rotor winding ends are shorted once the motor picks up speed. Now days semi-automatic starter is used. By pressing the on button the contactor will close only when the shorting point A at the rotor resistance is in closed position. This is possible only when the handle is in the start position once the motor starts running the handle of the rotor resistance should be brought to run position to cut-out the rotor resistance.

V_{NL}= line stator voltage

I_{NL} = line current

P_{NI} = power input

The input power consists of the core loss Pc, friction and windage loss P(rot) and stator copper loss

$Pnl = Pc+Prot+3I^2Rs$

Where stator resistance Rs per phase obtained from a resistance measurement at the stator terminal

In star connection Rs =R/2

Delta connection Rs =2/3R

Blocked rotor rest

The connections are made similar to that of the no-load test. In this case the ammeter is selected to carry the full load current of the motor. Wattmeterswill be of a suitable range and its power factor is 0.5 to unity.

An auto transformer is used to giber a much lower percentage of the rated voltage. The rotor is locked by a suitable arrangement such that it cannot rotate even if the supply is given to the motor. The belt is over tightened on the pulley to prevent rotation.

As the rotor is in a locked condition it is equivalent to the short circuit secondary of a transformer. The frequency of the starter supply voltage is maintained at normal rated supply frequency.

The method of calculating the copper losses from the result is illustrated through the example given below.

Example

A 5 hp 400 V, 50 HZ four pole three phase induction motor was tested and the following data were obtained.

Blocked rotor test V_S =54, PS=430, I_S=7.5A.The resistance of the stator winding gives a 4V drop between the terminals rated DC current flowing.

$W_S = \sqrt{3}\ Vs\ Is\ COS\ \Phi s$

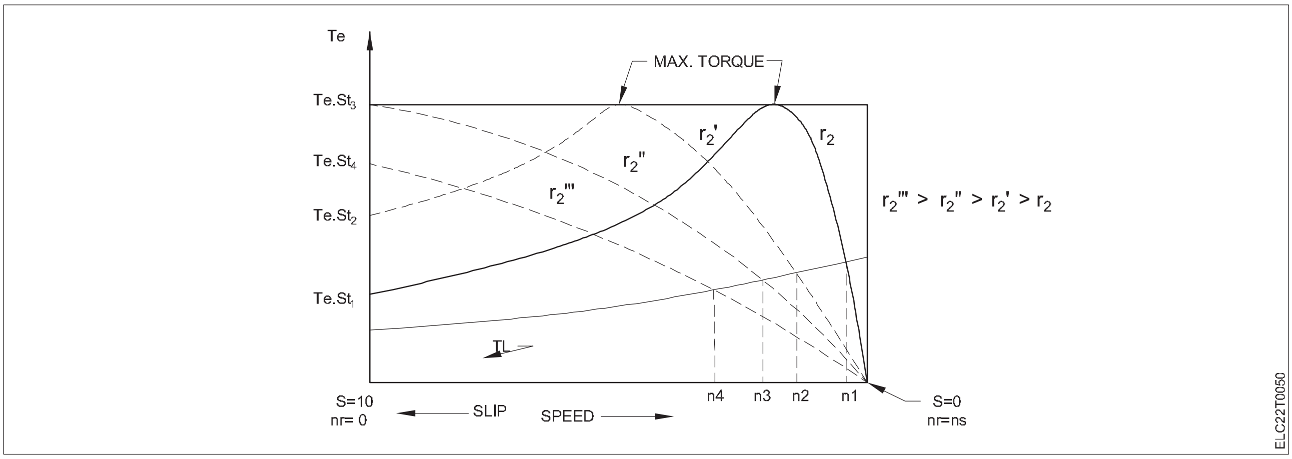
$$\text{Impedance } Ze = \frac{Vs}{\sqrt{3}Is} = \sqrt{Re^2 + Xe^2}$$

$$\text{Cos } \Phi = \frac{Ws}{\sqrt{3}\ Vs\ Is}$$

$= 430/\ (1.72*54*7.5) = 0.61$

Equivalent resistance Re /phase = $Ps/(3xIs^2)$ = 430/(3*7.52) = 2.5Ω

Equivalent reactance /phase =$\sqrt{Ze^2 - Re^2}$



$$Ze = \frac{54}{\sqrt{3x7.5}} = 4.1\Omega$$

$Xc = \sqrt{Ze^2 - Re^2} = \sqrt{4.1^2 - 2.5^2} = 3.4\Omega$

Full load copper loss = $3xI^2$ x Re =3*7.52*2.5^2 = 421.875 watts

Speed torque characteristics of induction motor

For a constant torque, the slip is directly proportional to the rotor resistance. If the resistance in the rotor circuit is increased, the slip is increased and the speed of the rotor is decreased. This method is applicable only to wound rotor induction motor.

From the figure 1 it is clear how does the speed vary with the change of rotor resistance.

At the normal operating condition, the slip increases with increasing torque hence they are obeying a linear characteristic. For a fixed load curve, the speed is downward from n_1 to n_4. From this figure we can also obtain the maximum torque at the starting at the resistance r_2''. So, this method has an advantage of achieving maximum torque at the starting period.

This type of speed control is used when the intermittent speed control is required. It has some drawbacks

1 The rheostat which is used to vary the resistance per phase causes unbalancing in rotor.

2 The resistances generate huge losses and generate heat in the system.

3 In case of a large machine the size of the rheostat will be large and in such case it is not easily portable.

4 It requires more maintenance, hence the cost associated with it is more.

5 This method cannot be used for industrial automation purpose since we have to change manually the value of the resistance.

Crawling of induction motor

Squirrel-cage motors sometimes exhibit a tendency to run stably at speeds as low as one-seventh of their synchronous speed Ns. This phenomenon is known as crawling of an induction motor. It is produced by the 7th harmonics in the windings.By proper design to reduce harmonics, the crawling can be reduced. When a sinusoidal voltage is applied to a certain type of load, the current drawn by the load is proportional to the voltage and impedance and follows the envelope of the voltage waveform. These loads are referred to as linear loads Examples of linear loads are resistive heaters, incandescent lamps, and constant speed induction and synchronous motors. Some loads cause the current to vary disproportionately with the voltage during each half cycle. These loads are classified as nonlinear loads, and the current and voltage have waveforms that are no sinusoidal, containing distortions, whereby the 50-Hz waveform has numerous additional waveforms superimposed upon it, creating multiple frequencies within the normal 50-Hz sine wave. The multiple frequencies are harmonics of the fundamental frequency. Application of non-sinusoidal voltages to motors results in harmonic current circulation in the windings of motors. Irms = $\sqrt{[(I_1)^2 + (I_2)^2 + (I_3)^2 + \ldots]}$, where the subscripts 1, 2, 3, etc. represent the different harmonic currents. The harmonics are grouped into positive (+), negative (-) and zero (0) sequence components. Positive sequence harmonics (harmonic numbers 1, 4, 7, 10, 13, etc.) produce magnetic fields and currents rotating in the same direction as the fundamental frequency harmonic. Negative sequence harmonics (harmonic numbers 2, 5, 8, 11, 14, etc.) develop magnetic fields and currents that rotate in a direction opposite to the positive frequency set. Zero sequence harmonics (harmonic numbers 3, 9, 15, 21, etc.) do not develop usable torque, but produce additional losses in the machine.

Cogging or magnetic locking

The rotor of a squirrel-cage motor sometimes refuses to start at all, particularly when the voltage is low. This happens when the number of stator teeth S1 is equal to the number of rotor teeth S2 and is due to the magnetic locking between the stator and rotor teeth. That is why this phenomenon is sometimes referred to as teeth-locking.It is found that the reluctance of the magnetic path is minimum when the stator and rotor teeth face each other rather than when the teeth of one element are opposite to the slots on the other. It is in such positions of minimum reluctance, that the rotor tends to remain fixed and thus cause serious trouble during starting. Cogging of squirrel cage motors can be easily overcome by making the number of rotor slots prime to the number of stator slots and skewing of the rotor conductors.

Method of speed control of 3 phase induction motor

Objectives: At the end of this lesson you shall be able to:

- list the speed control methods from stator and rotor side
- explain the speed control methods of 3 phase induction motor.

In 3 phase induction motor, speed can be controlled from both stator and rotor side

1 Speed control methods from stator side
   - By changing the applied voltage
   - By changing the applied frequency
   - By changing the number of stator poles

2 Speed control from rotor side
   - Rotor rheostat control
   - Cascade operation
   - By injecting EMF in rotor circuit

1 Speed control from stator side

a By changing the applied voltage: Torque equation of induction motor is

$$T = \frac{k_1 sE_2^2 R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$= \frac{3}{2\pi N_s} \frac{sE_2^2 R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

Rotor resistance R2 is constant and if slip s is small then sX2 is so small that it can be neglected. Therefore, T α sE_2^2 where E_2 is rotor induced emf and E_2 α V

And hence T α V^2, thus if supplied voltage is decreased, torque decreases and hence the speed decreases.

This method is the easiest and cheapest, still rarely used because-

1 A large change in supply voltage is required for relatively small change in speed.

2 Large change in supply voltage will result in large change in flux density, hence disturbing the magnetic conditions of the motor.

b By changing the applied frequency: Synchronous speed (Ns)of the rotating magnetic field of induction motor is given by,

$$N_s = \frac{120f}{P} \text{rpm}$$

where, f = frequency of the supply and P = number of stator poles.

Thus, synchronous speed changes with change in supply frequency, and thus running speed also changes. However, this method is not widely used. This method is used where, only the induction motor is supplied by a generator (so that frequency can be easily changed by changing the speed of prime mover).

c **Changing the number of stator poles:** From the above equation, it can be also seen that synchronous speed (and hence, running speed) can be changed by changing the number of stator poles. This method is generally used for squirrel cage induction motors, as squirrel cage rotor adapts itself for any number of stator poles. Change in stator poles is achieved by two or more independent stator windings wound for different number of poles in same slots.

For example, a stator is wound with two 3phase windings, one for 4 poles and other for 6 poles.

For supply frequency of 50 Hz

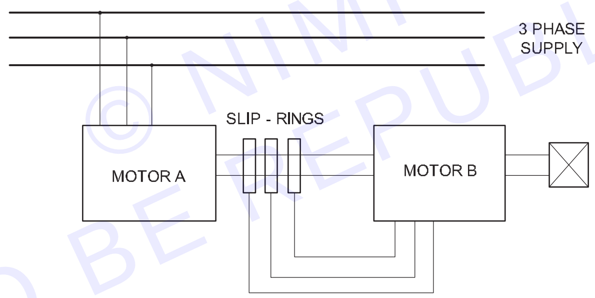
i Synchronous speed when 4 pole winding is connected, Ns = 120 x (50/4) = 1500 RPM

ii Synchronous speed when 6 pole winding is connected, Ns = 120 x (50/6) = 1000 RPM

2 Speed control from rotor side

a **Rotor rheostat control:** This method is similar to that of armature rheostat control of DC shunt motor. But this method is only applicable to slip ring motors, as addition of external resistance in the rotor of squirrel cage motors is not possible.

b **Cascade operation:** In this method of speed control, two motors are used. Both are mounted on a same shaft so that both run at same speed. One motor is fed from a 3phase supply and other motor is fed from the induced emf in first motor via slip-rings. The arrangement is as shown in Fig 1.



CASCADE OPERATION

Motor A is called main motor and motor B is called auxiliary motor.

Let, N_{s1} = frequency of motor A

N_{s2} = frequency of motor B

P_1 = number of poles stator of motor A

P_2 = number of stator poles of motor B

N = speed of the set and same for both motors

f = frequency of the supply

Now, slip of motor A, $S_1 = (N_{s1} - N) / N_{s1}$.

Frequency of the rotor induced emf in motor A, f1 = S1f. Now, auxiliary motor B is supplied with the rotor induce emf therefore, $N_{s2} = (120f_1) / P_2 = (120S_1f) / P_2$. Now putting the value of $S_1 = (N_{s1} - N) / N_{s1}$

$$N_{s2} = \frac{120f\,(N_{s1} - N)}{P_2 N_{s1}}$$

At no load, speed of the auxiliary rotor is almost same as its synchronous speed. i.e. N = Ns2. From the above equations, it can be obtained that

$$N = \frac{120f}{P_1 P_2}$$

With this method, four different speeds can be obtained

1 When only motor A works, corresponding speed = N_{s1} = 120f / P_1

2 When only motor B works, corresponding speed = N_{s2} = 120f / P_2

3 If cumulative cascading is done, speed of the set = N = 120f / (P_1 + P_2)

4 If differential cascading is done, speed of the set = N = 120f (P_1 - P_2)

c **By injecting EMF** in rotor circuit: In this method, speed of induction motor is controlled by injecting a voltage in rotor circuit. It is necessary that voltage (emf) being injected must have same frequency as of slip frequency. However, there is no restriction to the phase of injected emf. If we inject emf which is in opposite phase with the rotor induced emf, rotor resistance will be increased. If we inject emf which is in phase with rotor induced emf, rotor resistance will decrease. Thus, by changing the phase of injected emf, speed can be controlled. The main advantage of this method is a wide range of speed control (above normal as well as below normal) can be achieved. The emf can be injected by various methods such as Kramer system, Scherbius system etc.

Single phase motors & special type of motors

Objectives: At the end of this lesson you shall be able to:

- explain briefly the types of AC single phase motors
- explain the necessity and methods of split phasing the single phase to obtain a rotating
- explain the principle & construction, operation characterists & application of split phase motor, capacitor start - permanent capacitor motors
- shaded phase motor, capacitor start - permanent capacitor motor.

Single phase motors

Introduction: Single phase motors are working in single phase only. When stator is supplied by single phase AC supply, the field produced by it changes in magnitude and direction sinusoidally. Such an alternating field is equivalent to two fields of equal magnitude rotating in opposite direction at equal speed. These are in the fractional horse power sizes widely used in air crafts, power tools etc.

When fed from a single phase supply its stator winding produces a flux which is only alternating. This alternating flux acting on a stationary squirrel cage rotor cannot produce rotation. That is why a single phase motor is not self-starting.

Classification

1 Split phase motor.

   a Capacitor start induction run

   b Capacitor start capacitor run.

   c Resistor start induction run.

   d Induction start induction run.

   e Permanent capacitor motor.

   f Shaded pole motor.

2 Commutator motor

   a Series motor

   b Repulsion motor

3 Unexcited synchronous motor.

   a Reluctance motor

      1 Plain repulsion

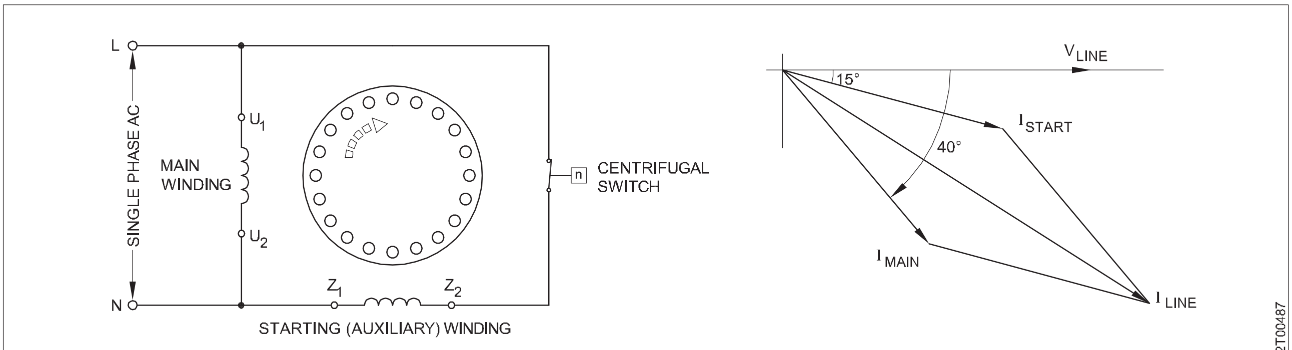
      2 Reluctance start induction run

      3 Reluctance induction motor

   b Hysteresis motor

Resistance start induction run motor

To make itself starting it is temporary converted in to a two phase motor during starting period. For this the stator of a single phase motor is provided with an extra winding known as auxiliary winding in addition to the main winding. The two windings are spaced 90 degrees electrically apart and connected in parallel across the single phase supply. (Fig 1)



(a) RESISTANCE START INDUCTION RUN MOTOR

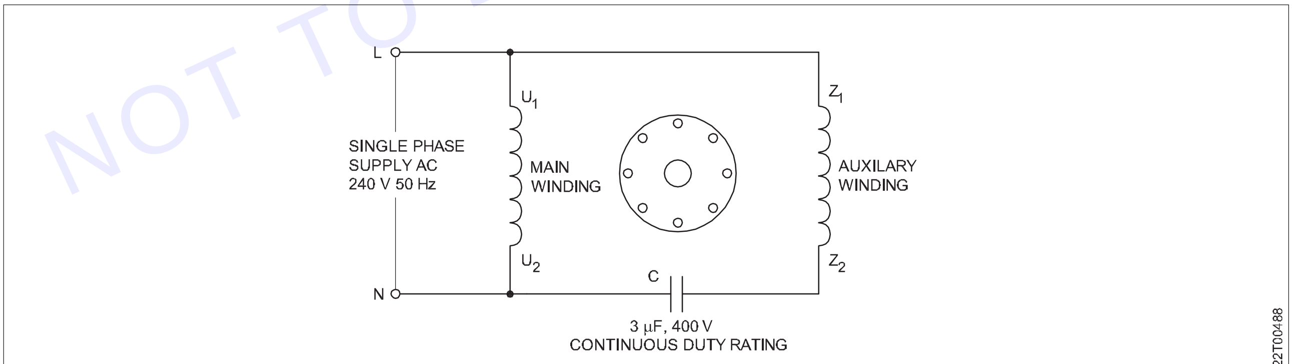
(b) PHASOR DIAGRAM AT THE INSTANT OF STARTING

The main winding has low resistance but high reactance whereas the auxiliary winding has high resistance low reactance. The current Is lags behind the applied voltage by 15 degrees whereas the current Im lags behind voltage by 40 degrees. A centrifugal switch S is connected in series with the auxiliary winding. Its function is to disconnect the auxiliary winding automatically from the supply when the motor has reached 70-80 % of its full load speed. If auxiliary winding is isolated more loss due to copper loss(I2R) and heat is produced. Its direction of rotation can be changed by changing either main winding or auxiliary winding.

Applications- Used in grinder, washing machine, wood working tool, driving fans etc.

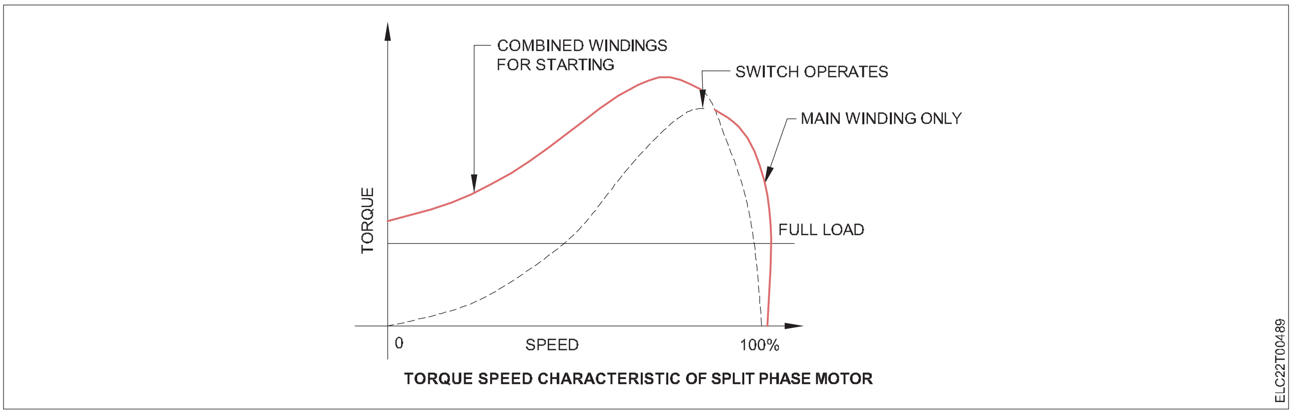
Induction start induction run motor

Instead of resistance start, inductance can be used to start the motor through a highly inductive starting winding. In such case the starting winding will have more number of turns embedded in the inner areas of stator slots so as to have high inductance. As the starting and main windings in most of the cases are made from the same gauge winding wire, resistance measurements have to be done to identify the windings. This motor will have a low starting torque, higher starting current and lower power factor. (Fig 2)



CIRCUIT DIAGRAM OF PERMANENT CAPACITOR MOTOR

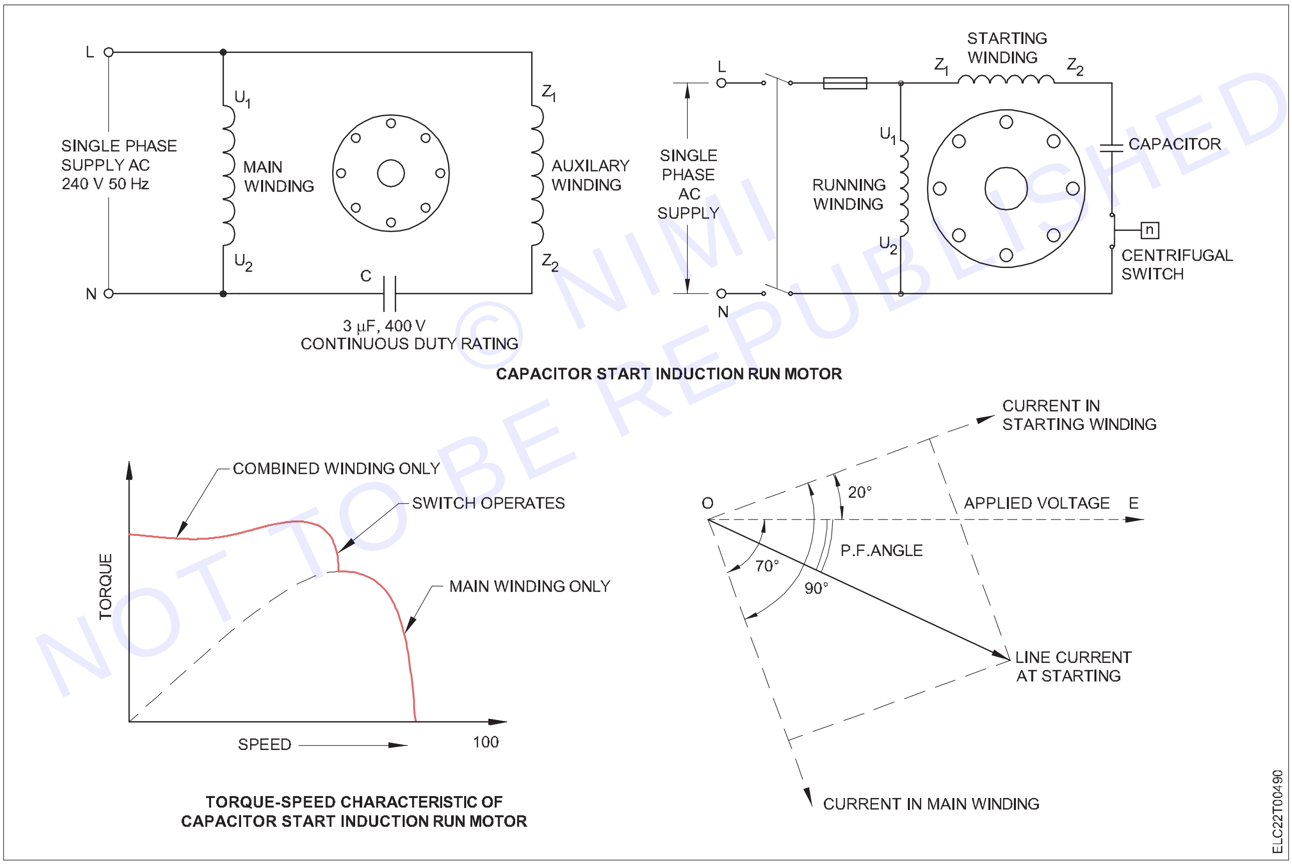
Torque speed characteristics of split phase motor (Fig 3)



TORQUE SPEED CHARACTERISTIC OF SPLIT PHASE MOTOR

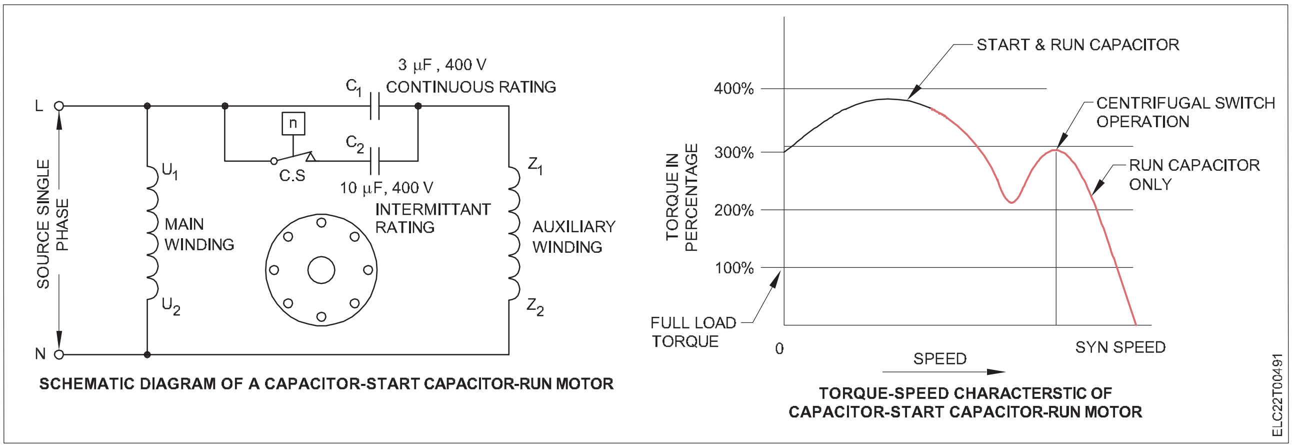
Capacitor start induction run motor. (Fig 4)

Torque speed characteristics (Fig 5)



In this motor a centrifugal switch is provided in series with the capacitor of capacitance of (60-120 micro farad). The centrifugal automatically disconnect the starting winding when the motor attains 75% of its normal speed. The starting winding of capacitor start induction motor is designed for short time ratings. It has good starting torque even from low starting current and therefore suitable for driving compressors, pumps etc. Methods of change of direction of rotation is similar to that of split phase induction motor.

Capacitor start capacitor run motor (Fig 6)



It is the only single phase motor which has high starting torque and high power factor from no load to full load. In this motor there are two condensers connected in parallel to each other but series with starting winding.

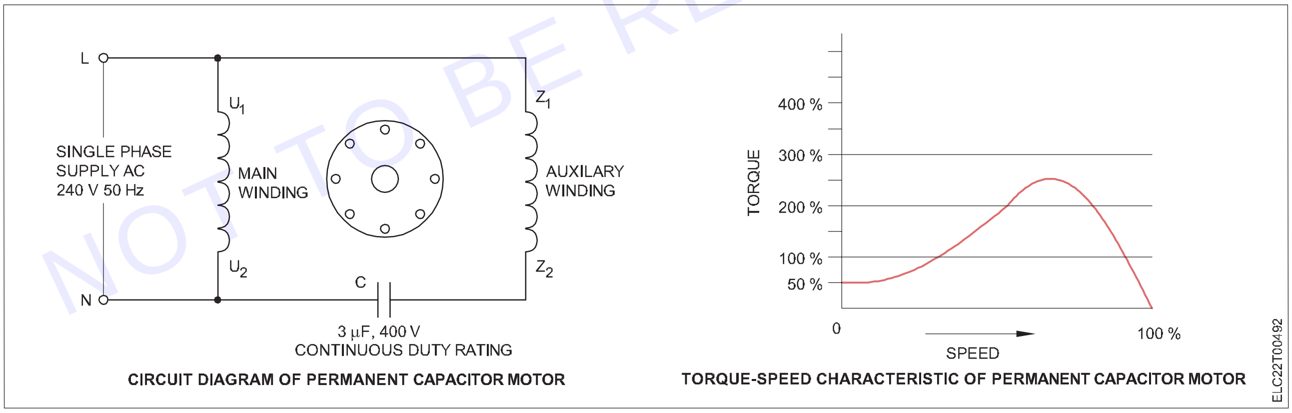
At the time of starting the starting condenser remains in the circuit which is three times higher in value than running condenser. After the motor has achieved its normal speed thwarting condenser is cut off from the circuit by centrifugal switch and thus only running condenser is left in the circuit which is comparatively of low value.

Application

It is used for operating compressors of air conditioner and big water coolers etc.

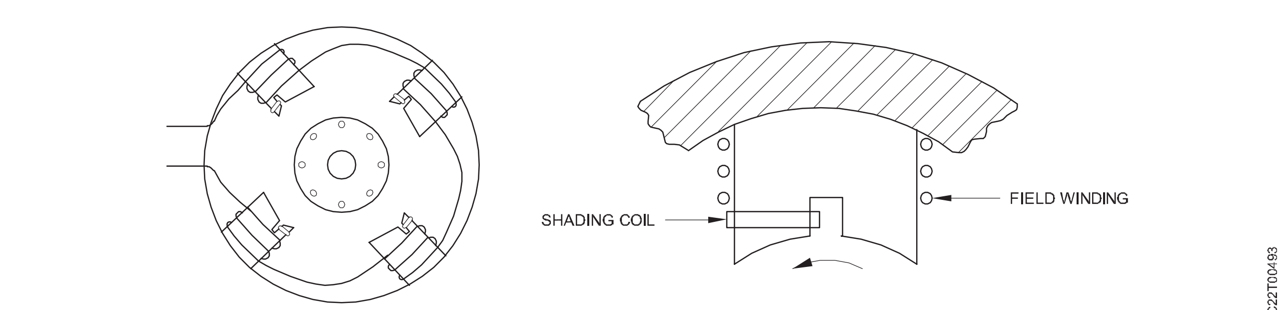
Permanent capacitor motor

In this case there is no centrifugal switch the starting winding is connected in series with the capacitor. This capacitor remains permanently in series even in running condition `this motor has very low starting torque which is only 50 % of the full load torque. This type motor is only used in ceiling fans, and where low torque is needed.



Shaded pole motor

It is a single phase induction motor provided with the auxiliary short circuited winding. This short circuited winding termed as shading coil consists of a low resistance ring embedded on one side of each stator pole and is used to provide the necessary torque. A shaded pole motor has a squirrel cage rotor and salient poles on which main pole winding is done. In addition to the main pole winding on the salient poles, a short circuited low resistance copper ring is also put to enclose about 1/3rd of pole shoe. This short circuited copper ring is known as shading ring and acts as another winding.



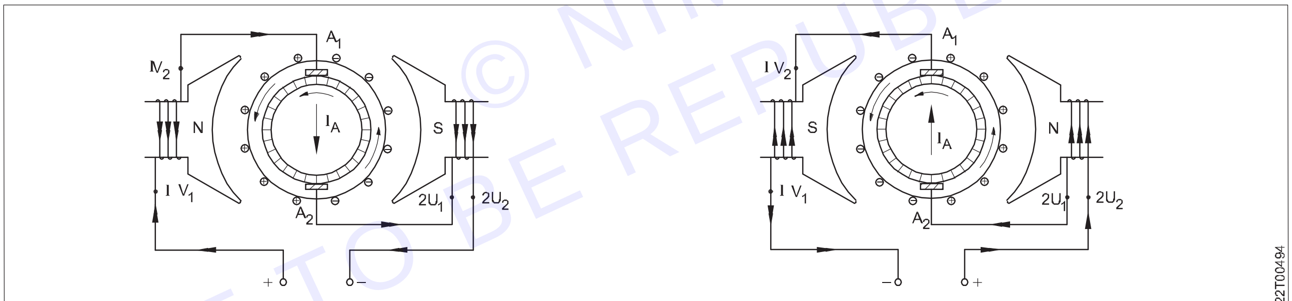
SHADED POLE MOTOR

When the main winding is supplied from single phase AC supply it produces a field flux which induces EMF in the shading ring. This EMF causes current to flow in the short circuited ring which produces flux. According Lenz's law this flux opposes the main produced by the main winding. Due to the opposition of flux maximum value of the flux in the shading part of the pole lags behind the flux in the unshaded part of the pole. This shifting of flux produces the same effect as the rotating magnetic field in a three phase motor. The direction of rotation of this motor cannot be changed. Shaded pole have low starting torque and hence are used in small table fan, ceiling fan etc.

Commutator moto

Universal motor

The motor which operates on both AC and DC supply is called universal motor. If through a DC series motor alternating current is passed it will develop a torque which is always unidirectional because the current in both armature and field winding changes simultaneously. The field winding is connected in series with armature winding. It has high torque and high speed. The speed is above the synchronous speed.



a) INSTANTANEOUS AC POLARITY IN +VE HALF OF THE CYCLE
b) INSTANTANEOUS AC POLARITY IN -VE HALF OF THE CYCLE

Repulsion motor

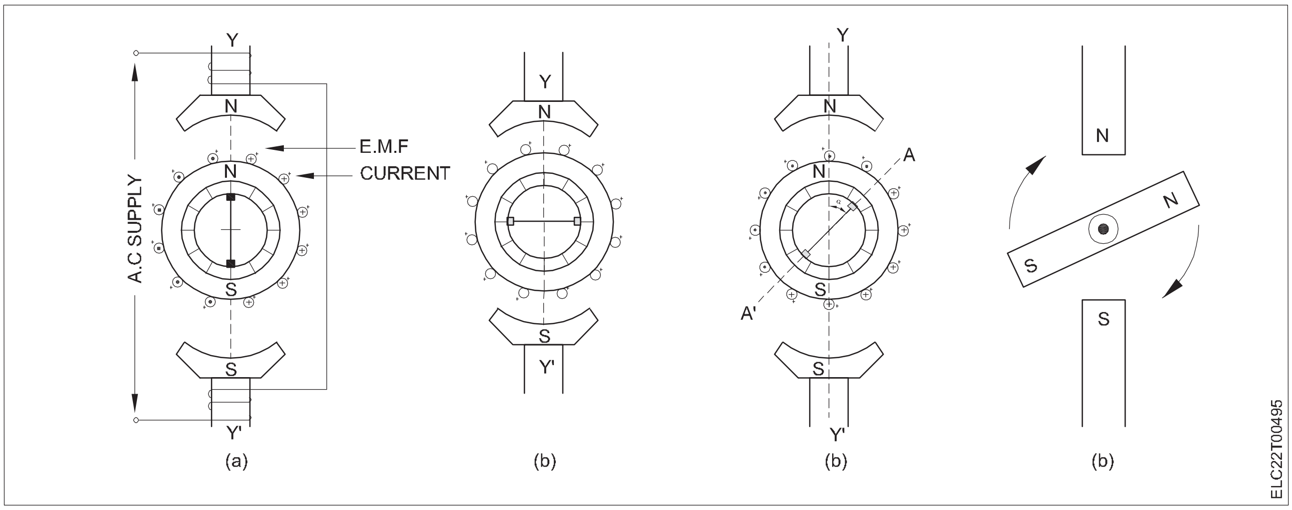
The principle of operation of repulsion motor is that like poles of two magnets repel and unlike poles attract each other. It has two or four stator poles having stator windings would in the stator slots. A commutator is mounted on the rotor shaft. Two brushes are placed in such a way that they make sliding contacts with the commutator. The brushes are advanced by 20 degrees in the rotational direction, so as to meet the requirements of ac supply. The rotor has no connection with the stator and it works as the secondary winding of a transformer while the stator works as primary. When ac is applied to the stator then an emf is induced in the rotor winding due to mutual induction. The brushes are short circuited to start the flow of induced current in the rotor. The induced current will energise the rotor poles. The polarities of the rotor and stator poles will be the same and thus they will repel each other and will set the rotor under rotation.

Types of repulsion motor

Repulsion start motor

1 Repulsion start –run motor

2 Repulsion induction motor



Repulsion start motor

In this motor the brushes are advanced by 20 degrees from the direction of the main field. When 230V AC is applied to the stator then 25-30V are reduced in the rotor windings. The brushes are short circuited so that a current may flow in the rotor windings which may energise the rotor poles since the stator and rotor poles have the same polarities, therefore the rotor will start to rotate. The wire used for short circuiting brushes should have a low resistance. As the motor speed up the torque will increase. Initially the motor has a low torque and draws small current in the start. Different speeds can be obtained by advancing or retarding the brushes. If the brushes are advanced further, then the motor speed will increase and vice versa. The speed will be zero if the brushes are adjusted in the neutral axis. For an advance angle of 20 degrees the motor speed will be maximum but in opposite direction.The motor is suitable for lifting heavy loads crane, host etc

Repulsion start-run motor

The motor start in the same manner as a repulsion start motor starts. But as the rotor attains nearly 70% speed of its full speed value a copper ring short circuits all the segments of the commutator. The copper ring is thrown over the commutator by the centrifugal mechanism. Also the brushes are lifted above the commutator due to same mechanism, otherwise the brushes will continue to cause sparking. After short circuiting the commutator segment the will start to work as an induction motor. In start the motor having high torque with low speed but now it has low torque and high speed.

Repulsion induction motor

In this motor the stator winding is similar to that of an induction motor of a repulsion start motor, but the rotor has two separate windings. The inner winding of squirrel cage type motor winding while the outer winding is of repulsion start rotor type, which is connected to the commutator. In start the motor works as an ordinary repulsion motor and cage winding has no effect owing its high inductance.

The motor a high efficiency high starting torque and power factor up to 0.9. As a disadvantage there is more sparking at the commutator and the motor will require more maintenance. It is suitable for driving workshop machinery.

Stepper Motors

Industrial motors convert electric energy into mechanical energy. They cannot be used for precision positioning of an object or precision control of speed without using closed-loop feedback. Stepping motors are ideally suited for situations where either precise positioning or precise speed control or both are required in automation systems. This motor rotates through a fixed angular step in response to each input currentpulse received by its controller. They can be controlled directly by computers, microprocessors and programmable controllers.

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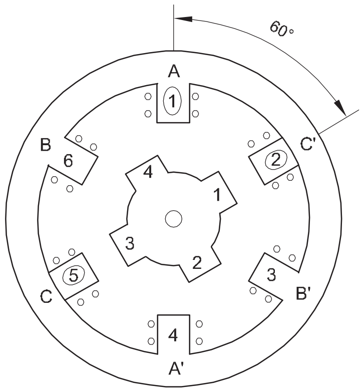


Step angle

The angle through which the motor shaft rotates for each command pulse is called the step angle β.

The step angles can be as small as 0.72º or as large as 90º. But the most common step sizes are 1.8º, 2.5º, 7.5º and 15º.

$$\beta = \frac{(N_s - N_r)}{N_s . N_r} \times 360^\circ$$

$$\beta = \frac{360^\circ}{mN_r} = \frac{360^\circ}{\text{No.of stator phases} \times \text{No.of rotor teeth}}$$

Rotor and stator poles (teeth) Nrand Ns and number of stator phases (m).

Types of stepper motors

i Variable Reluctance Stepper Motor

ii Permanent Magnet Stepper Motor

iii Hybrid Stepper Motor

1 A stepper motor is a digital electromagnetic device where each pulseinput results in a discrete output i.e. a definite angle of shaft rotation. It is ideally-suited for open-loop operation because by keeping a count of the number of input pulses, it is possible to know the exact position of the rotor shaft.

2 In a VR motor, excitation of the stator phases gives rise to a torque in a direction which minimizes the magnetic circuit reluctance. The reluctance torque depends on the square of the phase current and its direction is independent of the polarity of the phase current. A VR motor can be asingle-stack or multi-stack motor.

3 A permanent-magnet stepper motor has a permanently-magnetized cylindrical rotor. The direction of the torque produced depends on the polarity of the stator current.

4 A hybrid motor combines the features of VR and PM stepper motors. The direction of its torque also depends on the polarity of the stator current. Its step angle b = 360º / mNr.

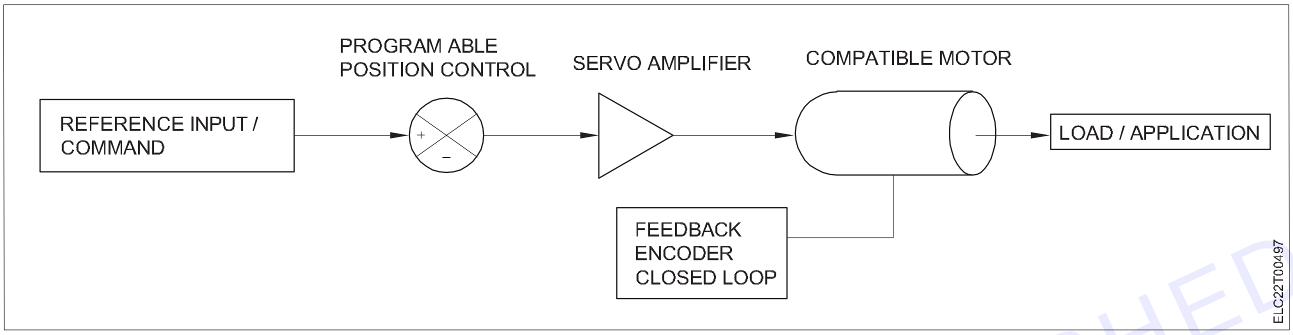
5 In the 1-phase ON mode of excitation, the rotor moves by one full-step for each change of excitation. In the 2-phase-ON mode, the rotor moves in full steps although it comes to rest at a point midway between the two adjacent full-step positions.

Servo motor

A servo motor is a rotory actuator that allows for precise control of angular position. It consists of a motor coupled to a sensor for position feedback. It also requires a servo drive to complete the system. The drive uses the feedback sensor to precisely control the rotory position of the motor. Servo motors are mainly used on angular or linear position and for specific velocity and acceleration.

Working of servo motor

A servo motor has a system called closed loop control. This system includes a comparator and a feedback path its like a setup that constantly check and adjusts the motor to keep it in the right place. The comparator is an important part of the servo motor. It carefully checks where the motor is right now and compares it to where its supposed to be. If there is difference, it signals that there's an error, signal the motor to make the necessay adjustment to get to the correct position.



Servo motors are commonly controlled using a method called Pulse Width Modulation (PWM). This technique requires the transmission of an electrical signal containing pulses of different lengths to the motor. This pulses have a width that varies 1 to 2 mill seconds, and they are send repeately at a rate of 50 times per seconds to the servo motor. The adjustment of the pulse with serves as a means to effectively control the position of the rotating shaft in the servo motor.

Types of servo motors

i D.C. servo motor

ii A.C. servo motor

Application of servo motors

1 **CNC machines:** Sevo motors are used in CNC machine. They control the movement of cutting tools

2 **Industrial Automation:** They are used in conveyors, packing machines printing presses.

3 **Robotics:** Servo motor are used in robot arms, grippers and joints to achive accurate positionly and smooth position. This enables robots to perform tasks with pricision such as assembly, welding & material handling.

4 **Aerospace and defence:** Servo motors are used in aircraft control surfaces, missile guidance sytsem and unmanned aerial vehicle.

5 **Electronics :** Servo motor are commonly used in electronic devices as cameras, DVD playes & home automation systems.

6 **Renewable energy:** Servo motors are used in solar tracking system to adjust the position of solar panels. Optimising their orientation to sub for increased energy capture.

MODULE 13 : Synchronous Machines

LESSON 76-85 : Alternator principle, EMF equation, charateristics and voltage regulation parallel operation

Objectives

At the end of this lesson you shall be able to:

- explain the working principle of an alternator, construction and types of alternator
- state e.m.f. equavation of the alternator
- explain the load characteristics of an alternator and voltage regulation
- state the necessity and conditions of paralling of alternators
- explain the methods of paralling two 3 phase alternator.

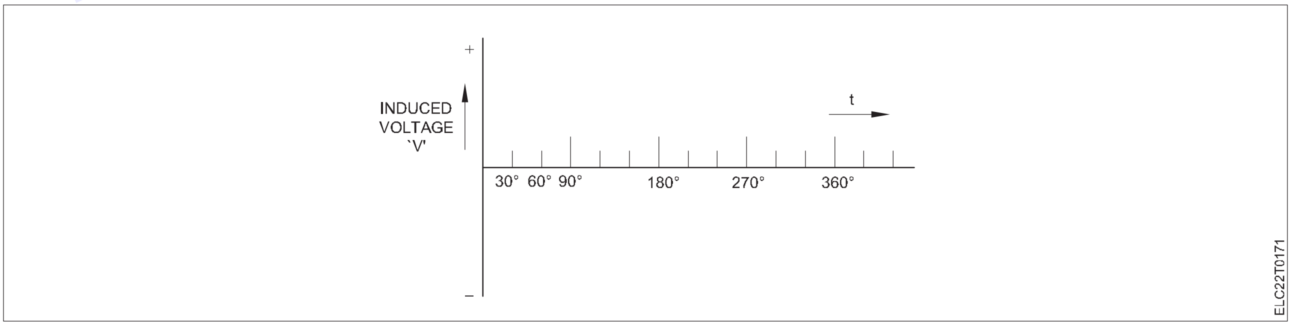
Principle of an alternator: An alternator works on the same principle of electromagnetic induction as a DC generator. That is, whenever a conductor moves in a magnetic field so as to cut the lines of force, an emf will be induced in that conductor. Alternatively whenever there is relative motion between the field and the conductor, then, the emf will be induced in the conductor. The amount of induced emf depends upon the rate of change of cutting or linkage of flux.

In the case of DC generators, we have seen that the alternating current produced inside the rotating armature coils has to be rectified to DC for the external circuit through the help of a commutator. But in the case of alternators, the alternating current produced in the armature coils can be brought out to the external circuit with the help of slip-rings. Alternatively the stationary conductors in the stator can produce alternating current when subjected to the rotating magnetic field in an alternator.

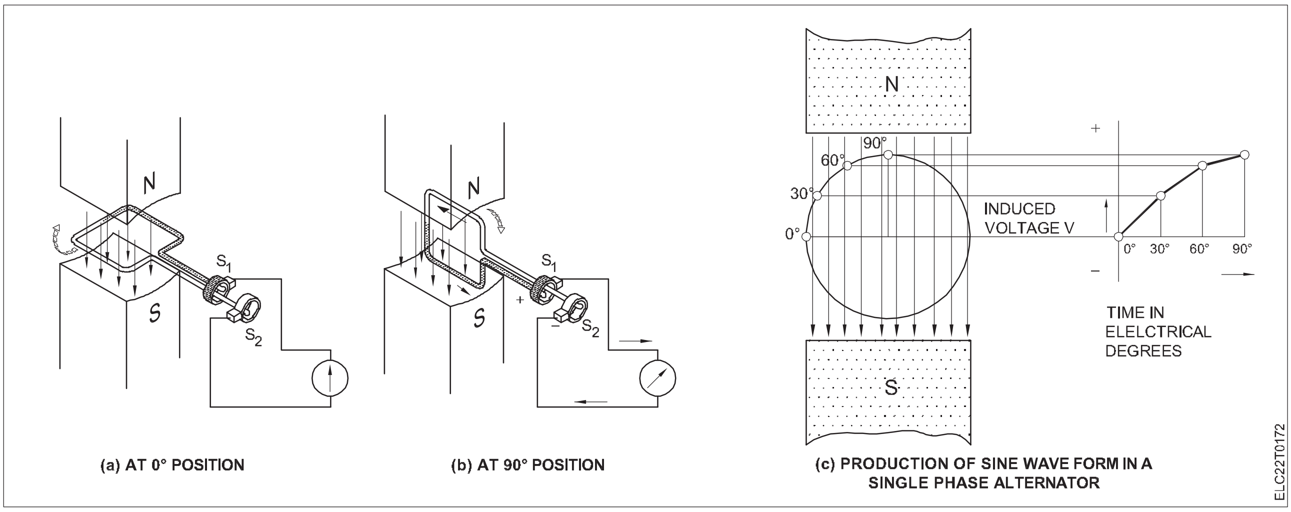
Production of sine wave voltage by single loop alternator: Fig 2a shows a single loop alternator. As it rotates in the magnetic field, the induced voltage in it varies in its direction and magnitude as follows.

To plot the magnitude and direction of the voltage induced in the wire loop of the AC generator in a graph, the electrical degrees of displacement of the loop are kept in the `X' axis as shown in Fig 1 through 30 electrical degrees. As shown in Fig 2c, three divisions on the `X' axis represent a quarter turn of the loop, and six divisions a half turn. The magnitude of the induced voltage is kept in the `Y' axis to a suitable scale.

The part above the X-axis represents the positive voltage, and the part below it the negative voltage as shown in Fig 1.



The position of the loop at the time of starting is shown in Fig 2a and indicated in Fig 2c as `O' position. At this position, as the loop moves parallel to the main flux, the loop does not cut any lines of force, and hence, there will be no voltage induced. This zero voltage is represented in the graph as the starting point of the curve as shown in Fig 2c. The magnitude of the induced emf is given by the formula Eo = BLV Sin θ



(a) AT 0° POSITION (b) AT 90° POSITION (c) PRODUCTION OF SINE WAVE FORM IN A SINGLE PHASE ALTERNATOR

where

B is the flux density in weber per square metre,

L is the length of the conductors in metres,

V is the velocity of the loop rotation in metres per second and

q is the angle at which the conductor cuts the line of force.

As sin $\theta = 0$

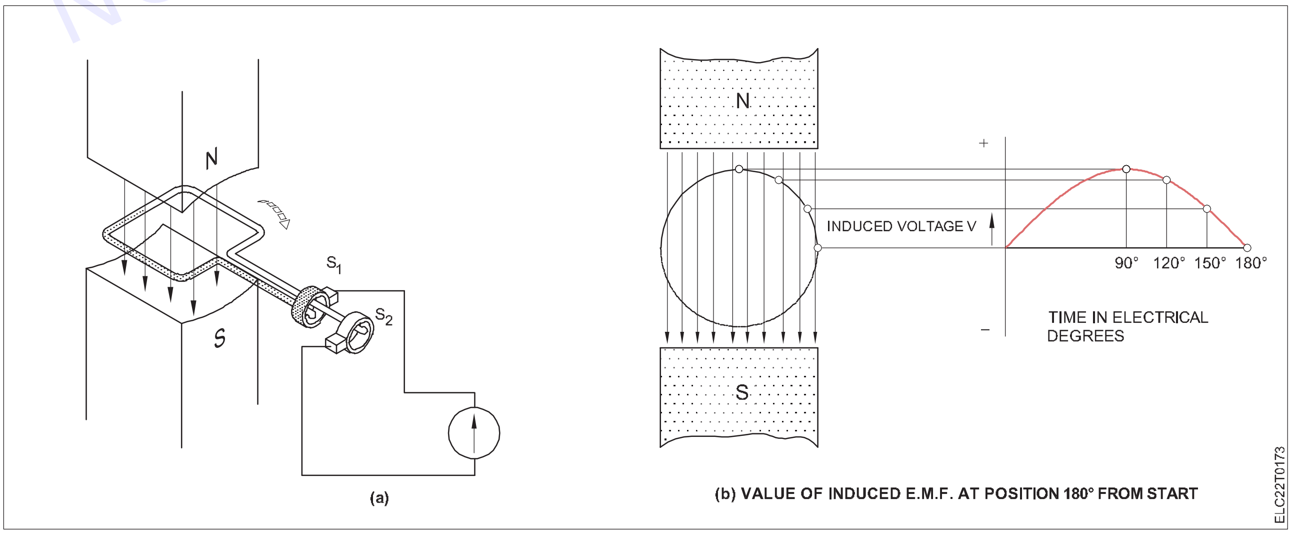
E at 0 position is equal to zero. As the loop turns in a clockwise direction at position 30° as shown in Fig 2c, the loop cuts the lines of force and an emf is induced (E_{30}) in the loop whose magnitude will be equal to BLV Sinq where q is equal to 30°.

Applying the above formula, we find the emf induced in the loop at 90° position will be maximum as shown in Fig 2c.

As the loop turns further towards 180° it is found the number of lines of force which are cut will be reduced to zero value. If the quantity of emf induced at each position is marked by a point and a curve is drawn along the points, the curve will be having a shape as shown in Fig 3b.

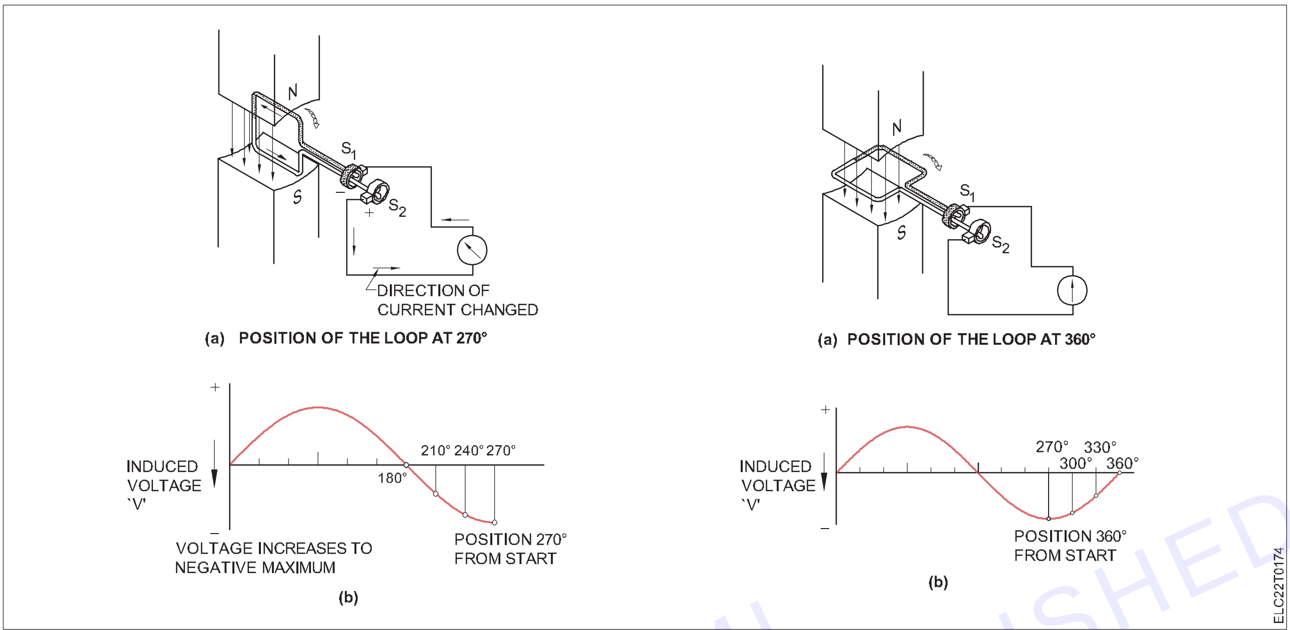
During the turn of the loop, from 0 to 180°, the slip ring S1 will be positive and S2 will be negative.

However, at 180° position, the loop moves parallel to the lines of force, and hence there is no cutting of flux by the loop and there is no emf induced in the loop as shown in Fig 3b.



(a) (b) VALUE OF INDUCED E.M.F. AT POSITION 180° FROM START

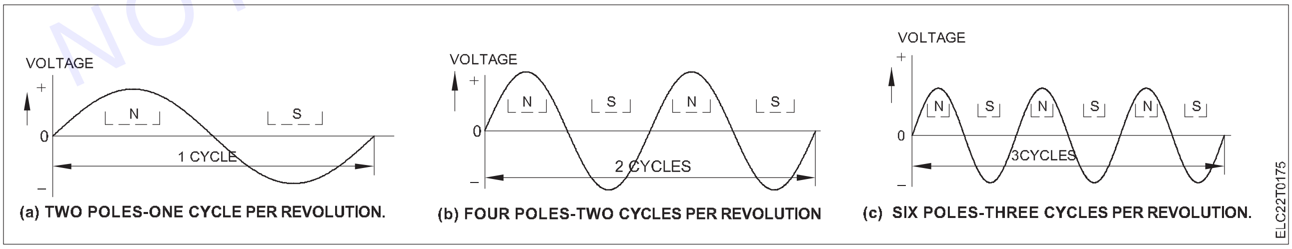
Further during the turn of the loop from the position 180° to 270°, the voltage increases again but the polarity is reversed as shown in Fig 4b. During the movement of the loop from 180 to 360°, the slip ring S_2 will be positive and S_1 will be negative as shown in Fig 4a. However, at 270° the voltage induced will be the maximum and will decrease to zero at 360°. Fig 5b shows the variation of the induced voltage in both magnitude and direction during one complete revolution of the loop. This is called a cycle.



This type of wave-form is called a sine wave as the magnitude and direction of the induced emf, strictly follows the sine law. The number of cycles completed in one second is called a frequency. In our country, we use an AC supply having 50 cycles frequency which is denoted as 50 Hz.

Relation between frequency, speed and number of poles of alternator: If the alternator has got only two poles, the voltage induced in one revolution of the loop undergoes one cycle. If it has four poles, then one complete rotation of the coil produces two cycles because, whenever it crosses a set of north and south poles, it makes one cycle.

Fig 6 shows the number of cycles which are produced in each revolution of the coil, with 2 poles, 4 poles and 6 poles. It is clear from this that the number of cycles per revolution is directly proportional to the number of poles, `P' divided by two. Therefore the number of cycles produced per second depends on P/2, and the speed in revolutions per second.



Therefore frequency $F = \frac{P}{2} \times 'n'$

where `n' is in r.p.s.

`P' is the number of poles.

Generally speed is represented in r.p.m.

Then we have frequency $F = \frac{PN}{2 \times 60} = \frac{PN}{120}$

where P is number of poles and N is speed in r.p.m.

Accordingly we can state that the frequency of an alternator is directly proportional to the number of poles and speed.

Types and construction of alternators

Objectives: At the end of this lesson you shall be able to:

- explain the construction, and the various types of alternators

Classification according to the number of phases: Another way of classifying the alternators is based on production of single or 3-phase by the alternator. Accordingly the types are 1) single-phase alternators 2) three-phase alternators.

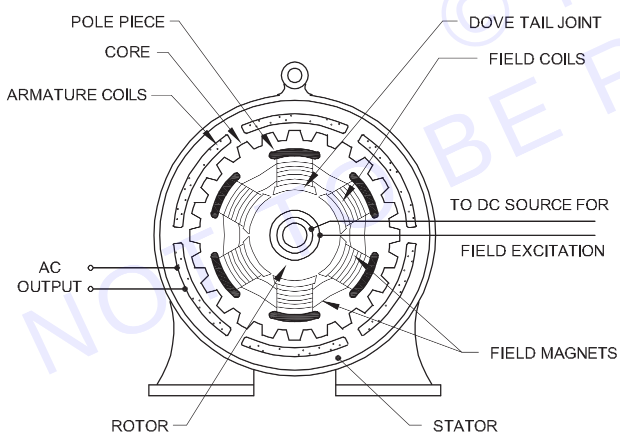
Single-phase alternators: A single-phase alternator is one that provides only one voltage. The armature coils are connected in `series additive'. In other words, the sum of the emf induced in each coil produces the total output voltage. Single phase alternators are usually constructed in small sizes only. They are used as a temporary standby power for construction sites and for permanent installation in remote locations.

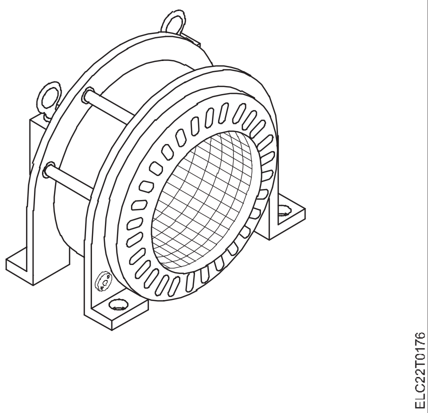
Three-phase alternators: This alternator provides two different voltages, namely, phase and line voltages. It has 3 windings placed at 120° to each other, mostly connected in a star having three main terminals U,V,W and neutral `N'.

These alternators are driven by prime movers such as diesel engines, steam turbines, water wheels etc. depending upon the source available.

Construction of alternators: The main parts of a revolving field type alternator are shown in Fig 1.

Stator: It consists of mainly the armature core formed of laminations of steel alloy (silicon steel) having slots on its inner periphery to house the armature conductors. The armature core in the form of a ring is fitted to a frame which may be of cast iron or welded steel plate. The armature core is laminated to reduce the eddy current losses which occur in the stator core when subjected to the cutting of the flux produced by the rotating field poles. The laminations are stamped out in complete rings (for smaller machines) or in segments (for larger machines), and insulated from each other with paper or varnish. The stampings also have holes which make axial and radial ventilating ducts to provide efficient cooling. A general view of the stator with the frame is shown in Fig 2.

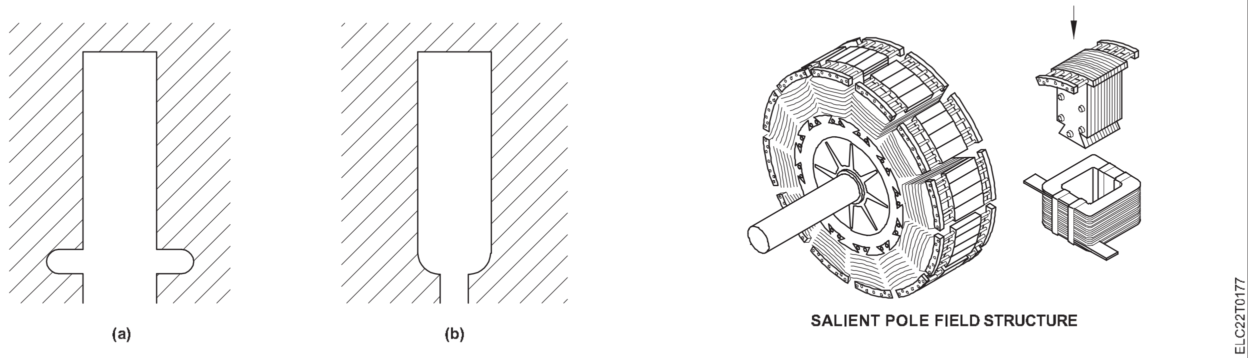




Slots provided on the stator core to house the armature coils are mainly of two types, (i) open and (ii) semi-closed slots, as shown in Fig 3a and b respectively.

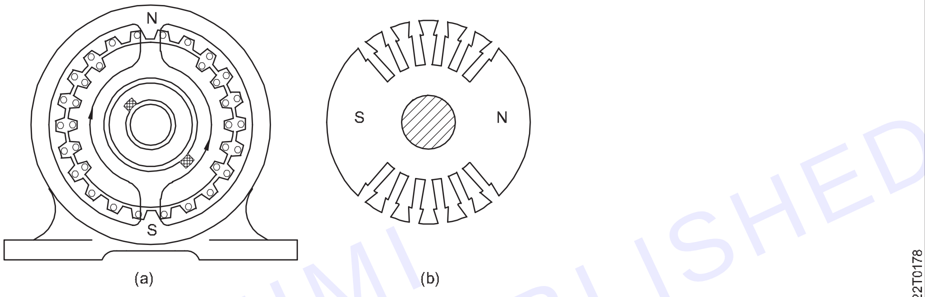
The open slots are more commonly used because the coils can be form-wound and pre-insulated before placing in the slots resulting in fast work, less expenditure and good insulation. This type of slots also facilitates easy removal and replacement of defective coils. But this type of slots creates uneven distribution of the flux, thereby producing ripples in the emf wave. The semi-closed type slots are better in this respect but do not permit the use of form-wound coils, thereby complicating the process of winding. Totally closed slots are rarely used, but when used, they need bracing of the winding turns.

Rotor: This forms the field system, and is similar to DC generators. Normally the field system is excited from a separate source of low voltage DC supply. The excitation source is usually a DC shunt or compound generator, known as an exciter, mounted to the same alternator shaft. The exiting current is supplied to the rotor with the help of two slip- rings and brushes. The field poles created by the excitation are alternately north and south.



SALIENT POLE FIELD STRUCTURE

Rotating field rotors are of two types, namely (i) salient pole type as shown in Fig 4 and (ii) smooth cylindrical type or non-salient pole type, as shown in Fig 5.



NON-SALIENT POLE TYPE FIELD STRUCTURE

Salient pole type: This type of rotor is used only for slow and medium speed alternators. This type is less expensive, having more space for the field coils and vast heat dissipating area. This type is not suitable for high speed alternators as the salient poles create a lot of noise while running in addition to the difficulty of obtaining sufficient mechanical strength.

Fig 4 shows the salient pole type rotor in which the riveted steel laminations are fitted to the shaft fitting with the help of a dovetailed joint. Pole faces are curved to have uniform distribution of the flux in the air gap leading to production of sinusoidal wave form of the generated emf. These pole faces are also provided with slots to carry the damper winding to prevent hunting.

Salient pole type alternators could be identified by their larger diameter, short axial length and low or medium speed of operation.

Smooth cylindrical or non-salient pole type rotor: This type is used in very high speed alternators, driven by steam turbines. To have good mechanical strength, the peripheral velocity is lowered by reducing the diameter of the rotor and alternatively with the increased axial length. Such rotors have either two or four poles but run at higher speeds.

To withstand such speeds, the rotor is made of solid steel forging with longitudinal slots cut as shown in Fig 5a which shows a two-pole rotor with six slots. The winding is in the form of insulated copper strips, held securely in the slots by proper wedges, and bound securely by steel bonds.

One part of the periphery of the rotor in which slots are not made is used as poles as shown in Fig 5b.

Smooth cylindrical pole type alternators could be identified by their shorter diameter, longer axial length and high speed of operation.

Rating of alternators

An electrical machines is usually rated at the load, which is can carry without over heating and damage to insulation. i.e the rating of electrical machine is governed by the temperature rise caused by internal losses of the machine. The copper loss in the armature (I2R) depends upon the strength of the armature current and is independent of power factor.

The output in kW is proportional to power factor for the alternator of a given kVA. For example output of 1000 kVA alternator on full load will be 200, 500, 800, 1000 kW at power factor 0.2, 0.5, 0.8 and unity respectively but copper losses in armature will remain the same regard less of power factor.

For the above reasons alternators are usually rated in kVA (kilo Volt Ampere).

Hunting

Hunting is a phenomenon in alternator which is caused by continuous fluctuation in load. When the load on the alternator is frequently changing, then the rotor of the alternator runs unsteadily making a noise of a whistle due to oscillations, or vibrations set up in the rotor. This phenomenon is called as hunting of alternators.

Hunting is prevented by the Damper Windings provided in the field pole core.

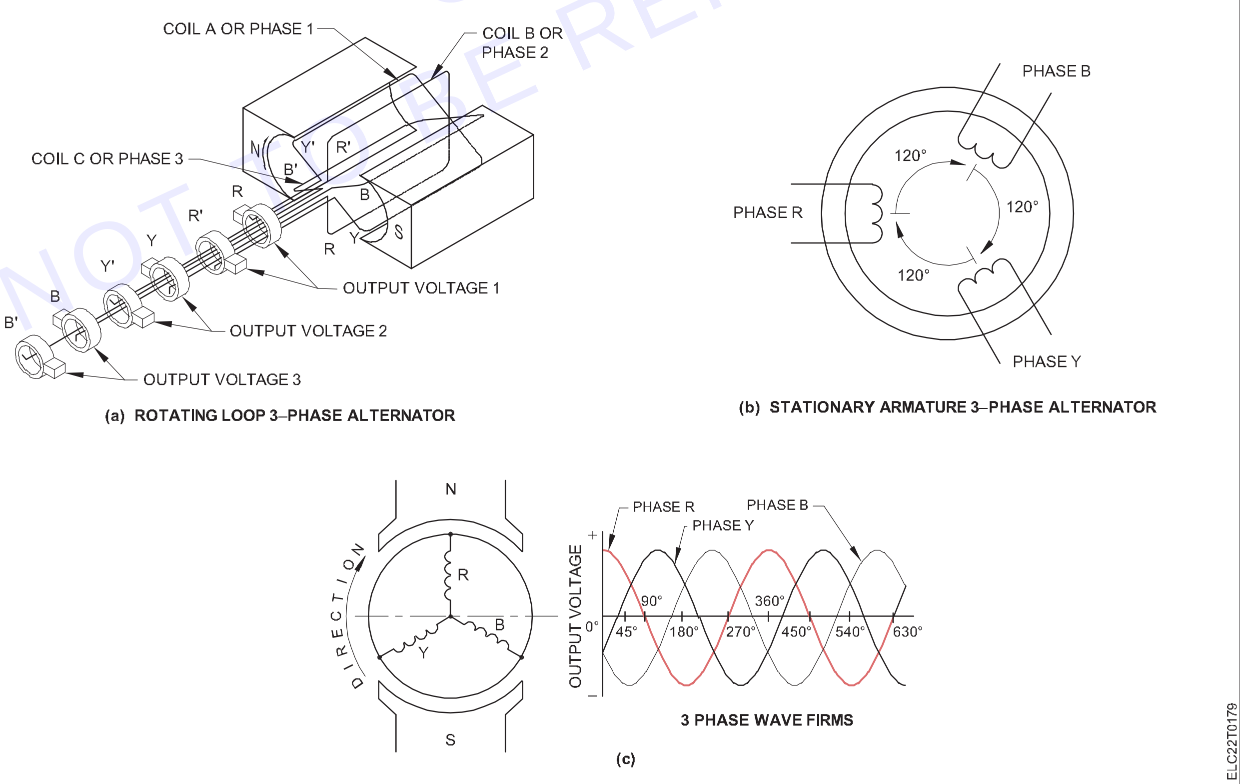
Generation of 3-phase voltage and general test on alternator

Objectives: At the end of this lesson you shall be able to:

- xplain the method of generating 3-phase voltage wave-forms by a 3-phase alternator
- state the phase sequence of 3f supply
- state the method of testing an alternator for continuity insulation and earth connection
- state e.m.f. equation of the alternator
- state the I.E.E. regulations and B.I.S. recommendations pertaining to earthing of the alternator

Generation of three-phase voltage: Basically, the principle of a three-phase alternator (generator) is the same as that of a single phase alternator (generator), except that there are three equally spaced coils or windings which produce three output voltages which are out of phase by 120° with each other.

A simple rotating-loop, three-phase generator with its output voltage wave-forms is shown in Fig 1c.



(a) ROTATING LOOP 3–PHASE ALTERNATOR

(b) STATIONARY ARMATURE 3–PHASE ALTERNATOR

3 PHASE WAVE FIRMS

(c)

As shown in Fig 1a, three independent loops spaced about 120° apart are made to rotate in a magnetic field with the assumption that the alternator shown is a rotating armature type. As shown in Fig 1a, the three loops are electrically isolated from each other and the ends of the loops are connected to individual slip rings. As the loops are rotating in a uniform magnetic field, they produce sine waves. In a practical alternator, these loops will be replaced by a multi-turn winding element and distributed throughout the rotor slots but spaced apart at 120° electrical degrees from each other. Further, in practice, there will not be six slip rings as shown in Fig 1a but will have either four or three slip rings depending upon whether the three windings are connected in a star or delta respectively.

We also know, as discussed earlier, that the rotating magnetic field type alternators are mostly used. In such cases only two slip rings are required for exciting the field poles with DC supply. Fig 1b shows a stationary, 3-phase armature in which individual loops of each winding are replaced by coils spaced at 120 electrical degrees apart. However, the rotating part having the magnetic poles is not shown.

Fig 1c shows the rotating armature type alternator in which the 3 coils of the three-phases are connected in star which rotates in a two-pole magnetic field. According to Fig 1c, the coil `R' moves under the influence of the `N' pole cutting the flux at right angles, and produces the maximum induced voltage at position `Oo' as shown in the graph as per Faraday's Laws of Electromagnetic induction. When the coil `R' moves in a clockwise direction, the emf induces falls to zero at 90 degrees, and then increases to -ve maximum under the influence of the south pole at 180 degrees. Likewise the emf induced in the `R' phase will become zero at 270 degrees and attain +ve maximum at 360 degrees. In the same manner the emf produced by coils `Y' and `B' could be plotted on the same graph. A study of the sine wave-forms produced by the three coils RYB shows that the voltage of coil `R' leads voltage of coil `Y' by 120°, and the voltage of coil `Y' leads voltage of coil `B' by 120°.

Phase sequence: The phase sequence is the order in which the voltages follow one another, i.e. reach their maximum value. The wave-form in Fig 1c shows that the voltage of coil R or phase R reaches its positive maximum value first, earlier than the voltage of coil Y or phase `Y', and after that the voltage of coil B or phase B reaches its positive maximum value. Hence the phase sequence is said to the RYB.

If the rotation of the alternator shown in Fig 1c is changed from clockwise to anticlockwise direction, the phase sequence will be changed as RBY. It is the most important factor for parallel connection of poly phase generators and in poly phase windings. Further the direction of rotation of a 3-phase induction motor depends upon the phase sequence of the 3-phase supply. If the phase sequence of the alternator is changed, all the 3-phase motors, connected to that alternator, will run in the reverse direction though it may not affect lighting and heating loads.

The only difference in the construction of a single phase alternator and that of a 3-phase alternator lies in the main winding. Otherwise both the types of alternators will have similar construction.

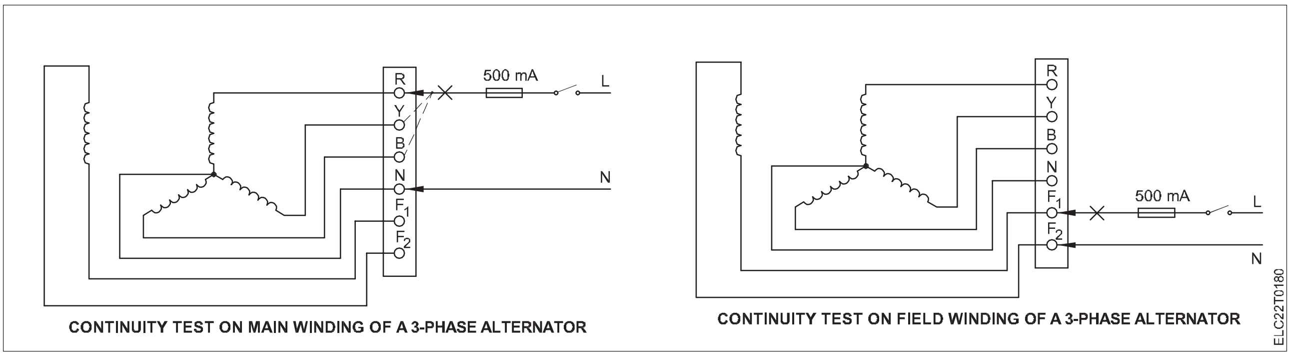
General testing of alternator: Alternaters are to be periodically checked for their general condition as they will be in service continuously. This comes under preventive maintenance, and avoids unnecessary breakdowns or damage to the machine. The usual checks that are to be carried out on an altenator are:

- continuity check of the windings
- insulation resistance value between windings
- insulation resistance value of the windings to the body
- checking the earth connection of the machine.

Continuity test: The continuity of the windings is checked by the following method as shown in Fig 2.

A test lamp is connected in series with one end to the neutral (star point) and the other end to one of the winding terminals (R Y B). If the test lamp glows equally bright on all the terminals RYB then the continuity of the winding is all right. In the same way, as shown in Fig 3, we can test the field leads F1 and F2 for field continuity.

Testing continuity with the test lamp only indicates the continuity in between two terminals but will not indicate any short between the same windings. A more reliable test will be to use an ohmmeter to check the individual resistances of the coils, and compare them to see that similar coils have the same resistance. The readings, when recorded, will be useful for future reference also.

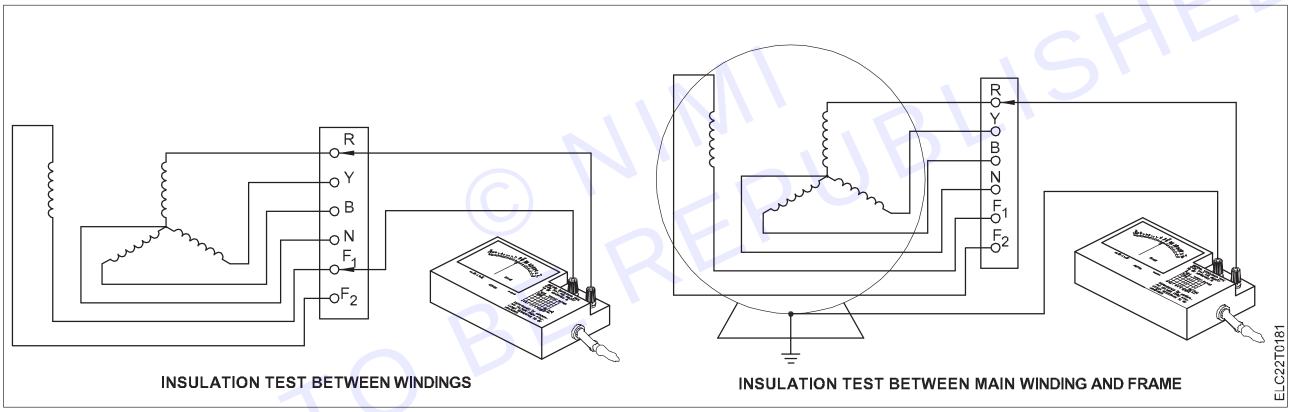


For insulation resistance test

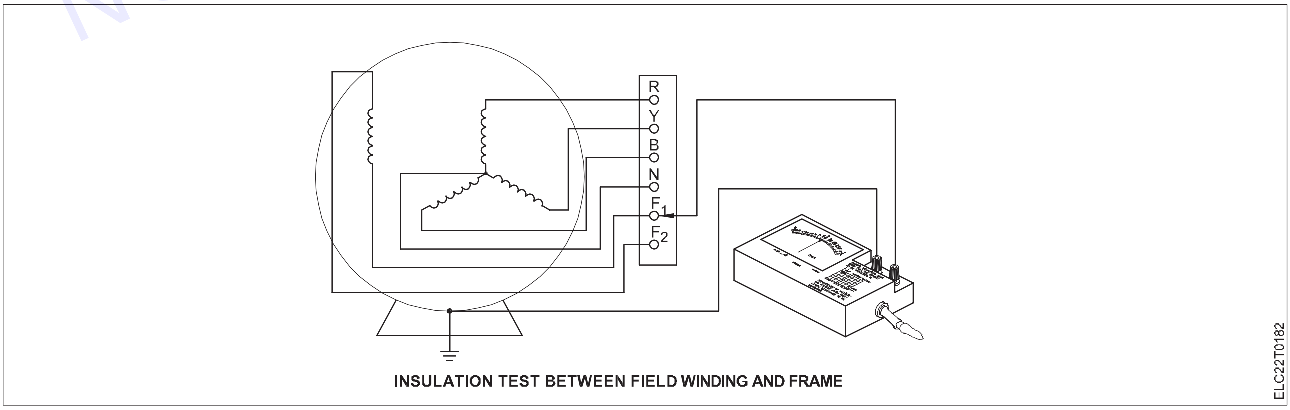
Between windings: As shown in Fig 4, one end of the Megger lead is connected to any one terminal of the RYB and the other is connected to F1 or F2 of the field winding. If the Megger reads one megohm or more, then the insulation resistance is accepted as okay.

If there is short, between the armature and field windings, the Megger reads zero ohms. If it is weak, it shows less than one megohm.

Testing insulation resistance between body and windings: As shown in Fig 5, one lead of the Megger is connected to one of the leads of the RYB, and the other lead of the Megger is connected to the body. If the insulation between the windings and the frame is all right, the Megger reads more than one megohm.



The field is tested by connecting one terminal of the Megger to F1 or F2 of the field and the other terminal to the body as shown in Fig 6. If the insulation between the field and the frame is all right, the Megger reads more than one megohm. A lower reading than one megohm shows weak insulation and leakage to the ground.



Caution

While conducting the insulation resistance test, if the Megger reads zero, then it should be concluded that the insulation of the winding has failed completely and needs thorough checking.

The permissible insulation resistance should not be less than 1 megohm.

Emf equation of the alternator

Objectives: At the end of this lesson you shall be able to:

- explain the emf equation to calculate the induced emf in an alternator

Equation of induced emf: The emf induced in an alternator depends upon the flux per pole, the number of conductors and speed. The magnitude of the induced emf could be derived as stated below

Let Z = No.of conductors or coil sides in series/phase in an alternator

P = No.of poles

¦ = frequency of induced emf in Hz

Ø = flux per pole in webers

kf = form factor = 1.11 - if emf is assumed to be sinusoidal

N = speed of the rotor in r.p.m.

According to Faraday's Law of Electromagnetic Induction we have the average emf induced in a conductor is equal to rate of change of flux linkage

$$= \frac{d\varnothing}{dt}$$

$$= \frac{\text{change of total flux}}{\text{time duration in which the flux change takes place}}$$

In one revolution of the rotor (ie in 60/N seconds), each stator conductor is cut by a flux equal to PØ webers.

Hence the change of total flux = dØ = PØ and the time duration in which the flux changes takes place

= dt = 60/N seconds.

Hence the average emf induced in a conductor

$$= \frac{d\varnothing}{dt} = \frac{P\varnothing}{\frac{60}{N}} \text{ volts} \qquad \text{-------- Eq 1}$$

Substituting the value for $\frac{120\int}{P}$ in eqn 1

we have the average emf induced in a conductor =

$$= \frac{P\varnothing 120\int}{P60} \text{ volts} = 2\varnothing\int \text{ volts} \qquad \text{------ Eq. 2}$$

If there are Z conductors in series per phase we have the average emf per phase = 2ØfZ volts.

Then r.m.s. value of emf per phase = average value x form factor

= V_{AV} x K_F

= V_{AV} x 1.11

= 2ØfZ x 1.11

= 2.22ØfZ volts.

Alternatively r.m.s. value of emf per phase = 2.22Ø¦2T volts

= 4.44ØfT volts

where T is the number of coils or turns per phase and Z = 2T.

This would have been the actual value of the induced voltage if all the coils in a phase were (i)full pitched and (ii) concentrated or bunched in one slot. (In actual practice, the coils of each phase are distributed in several slots under all the poles.) This not being so, the actually available voltage is reduced in the ratio of these two factors which are explained below.

Pitch factor (K_p or K_c): The voltage generated in a fractional pitch winding is less than the full pitch winding. The factor by which the full pitch voltage is multiplied to get voltage generated in fractional pitch is called pitch factor, and it is always less than one; and denoted as Kp or Kc. Normally this value is given in problems directly; occasionally this value needs to be calculated by a formula Kp = Kc = Cos a/2

where a is the electrical angle by which the coil span falls short of full pitch.

Distribution factor (K_d): It is imperative that the conductors of the same phase need to be distributed in the slots instead of being concentrated at one slot. Because of this, the emf generated in different conductors will not be in phase with each other, and hence, cannot be added together to get the total induced emf per phase but to be added vectorially. This has to be taken into account while determining the induced voltage per phase.

Therefore, the factor by which the generated voltage must be multiplied to obtain the correct value is called a distribution factor, denoted by Kd and the value is always less than one. The formula for finding the value of Kd is given below.

$$K_d = \frac{\text{Sin } m\beta/2}{m \text{ Sin } \beta/2}$$

where m is the number of slots per phase per pole

$$\beta = \frac{180^o}{\text{No. of slots per pole}}$$

Characteristic and voltage regulation of the alternator

Objectives: At the end of this lesson you shall be able to:

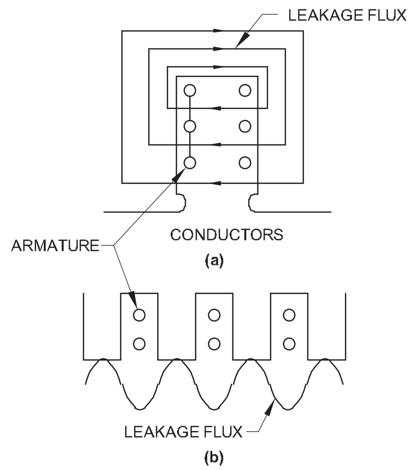
- explain the load characteristic of an alternator and the effect of the P.F. on terminal voltage
- explain the regulation of alternators and solve problems therein.

Load characteristic of an alternator: As the load on the alternator is changed, its terminal voltage is also found to change. The reason for this change is due to the voltage drop in the alternator because of

- armature resistance Ra
- armature leakage reactance XL
- armature reaction which, in turn, depends upon the power factor of the load.

Voltage drop in armature resistance: Resistance of each phase winding of the alternator causes a voltage drop in the alternator, and it is equal to IpRa where Ip is the phase current and Ra is the resistance per phase.

Voltage drop in armature leakage reactance: When the flux is set up in the alternator due to the current flow in the armature conductors, some amount of flux strays out rather than crossing the air gap. These fluxes are known as leakage fluxes. Two types of leakage fluxes are shown in Figs 1a and b.



Though the leakage fluxes are independent of saturation, they do depend upon the current and the phase angle between the current and the terminal voltage `V'. These leakage fluxes induce a reactance voltage which is ahead of the current by 90°. Normally the effect of leakage flux is termed as inductive reactance XL and as a variable quantity. Sometimes the value XL is named as synchronous reactance to indicate that it refers to working conditions.

Voltage drop due to armature reaction: The armature reaction in an alternator is similar to DC generators. But the load power factor has considerable effect on the armature reaction in the alternators.

The effects of armature reaction have to be considered in three cases, i.e. when load power factor is

- unity
- zero lagging
- zero leading.

At unity P.F. the effect of armature reaction is only cross- magnetising. Hence there will be some distortion of the magnetic field.

But in the case of zero lagging P.F. the effect of armature reaction will be de-magnetising. To compensate this de-magnetising effect, the field excitation current needs to be increased.

On the other hand, the effect of armature reaction due to zero leading P.F. will be magnetising. To compensate the increased induced emf, and to keep the constant value of the terminal voltage due to this additional magnetising effect, the field excitation current has to be decreased.

Rating of alternators: As the power factor for a given capacity load determines the load current, and the alternator's capacity is decided on load current, the rating of the alternator is given in kVA or MVA rather than kW or MW in which case the power factor also is to be indicated along with the wattage rating.

Example: A 3-phase, star-connected alternator supplies a load of 5 MW at P.F. 0.85 lagging and at a voltage of 11 kV. Its resistance is 0.2 ohm per phase and the synchronous reactance is 0.4 ohm per phase. Calculate the line value of the emf generated.

Full load current = $I_L = \dfrac{P}{\sqrt{3}E_L \cos\theta}$

$$\frac{5 \times 1000 \times 1000}{\sqrt{3} \times 11000 \times .85} = 309 \text{ Amps.}$$

In star $I_L = I_P$

IR_a drop = 309x0.2=61.8 V

Ix_L drop = 309 x 0.4 = 123.6 V

Terminal voltage (line)=11000 V

Terminal voltage(phase) $= \dfrac{11000}{\sqrt{3}} = 6350V$

Power factor = 0.85

Power factor angle = θ = Cos –1(.85)

= Cos 31.8°

Sin θ = 0.527.

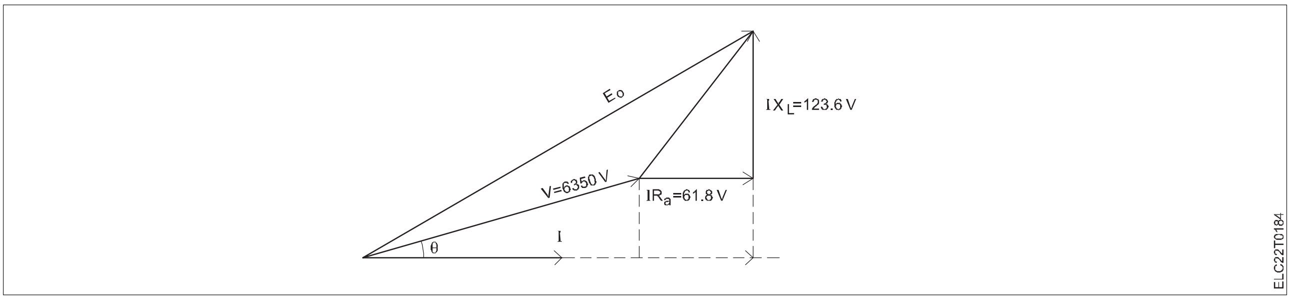
Drawing the vector, as shown in Fig 2, with the above data, we have

$$E_o = \sqrt{(V\cos\theta + IR_a)^2 + (V\sin\theta + IX_L)^2}$$

$$= \sqrt{(6350 \times 0.85 + 61.8)^2 + (6350 \times 0.527 + 123.6)^2}$$

= 6468.787 volts.

$$\text{Line voltage} = \sqrt{3}E_P = \sqrt{3} \times 6469 = 11204V$$



The voltage regulation of an alternator: The voltage regulation of an alternator is defined as the rise in voltage when the load is reduced from the full rated value to zero, with the speed and field current remaining constant. It is normally expressed as a percentage of the full load voltage.

$$\%\text{ of voltage regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

where V_{NL} - no load voltage of the alternator

V_{FL} - full load voltage of the alternator

The percentage regulation varies considerably, depending on the power factor of the load, and as we have seen for leading P.F. the terminal voltage increases with load, and for lagging P.F. the terminal voltage falls with the load.

Example: When the load is removed from an AC generator, its terminal voltage rises from 480V at full load to 660V at no load. Calculate the voltage regulation.

$$\%\text{ regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

$$\frac{660 - 480}{480} \times 100 = 37.5\%$$

Parallel operation and synchronisation of three phase alternators - brushless alternator

Objectives: At the end of this lesson you shall be able to:

- state the necessity and conditions for paralleling of alternators
- explain the methods of paralleling two 3 phase alternators
- state the effect of changes in field excitation and speed on the division of load between parallel operation.

Necessity for paralleling of two alternators : Whenever the power demand of the load circuit is greater than the power output of a single alternator, the two alternators to be connected in parallel

Conditions for paralleling (synchronising) of two 3 phase alternators

- The phase sequence of both 3 phase alternators must be same. It can be checked by using phase sequence meters
- The output voltages of the two 3 phase alternators must be same.
- The frequency of both the alternators must be same

Dark lamp method : The following describes the method of synchronizing two alternators using the dark lamp method.

Fig 1 illustrates a circuit used to parallel two three-phase alternators. Alternator 2 is connected to the load circuit. Alternator 1 is to be paralleled with alternator 2 Three lamps rated at double the output voltage to the load are connected between alternator 2 and the load circuit as shown. When both machines are operating, one of two effects will be observed:

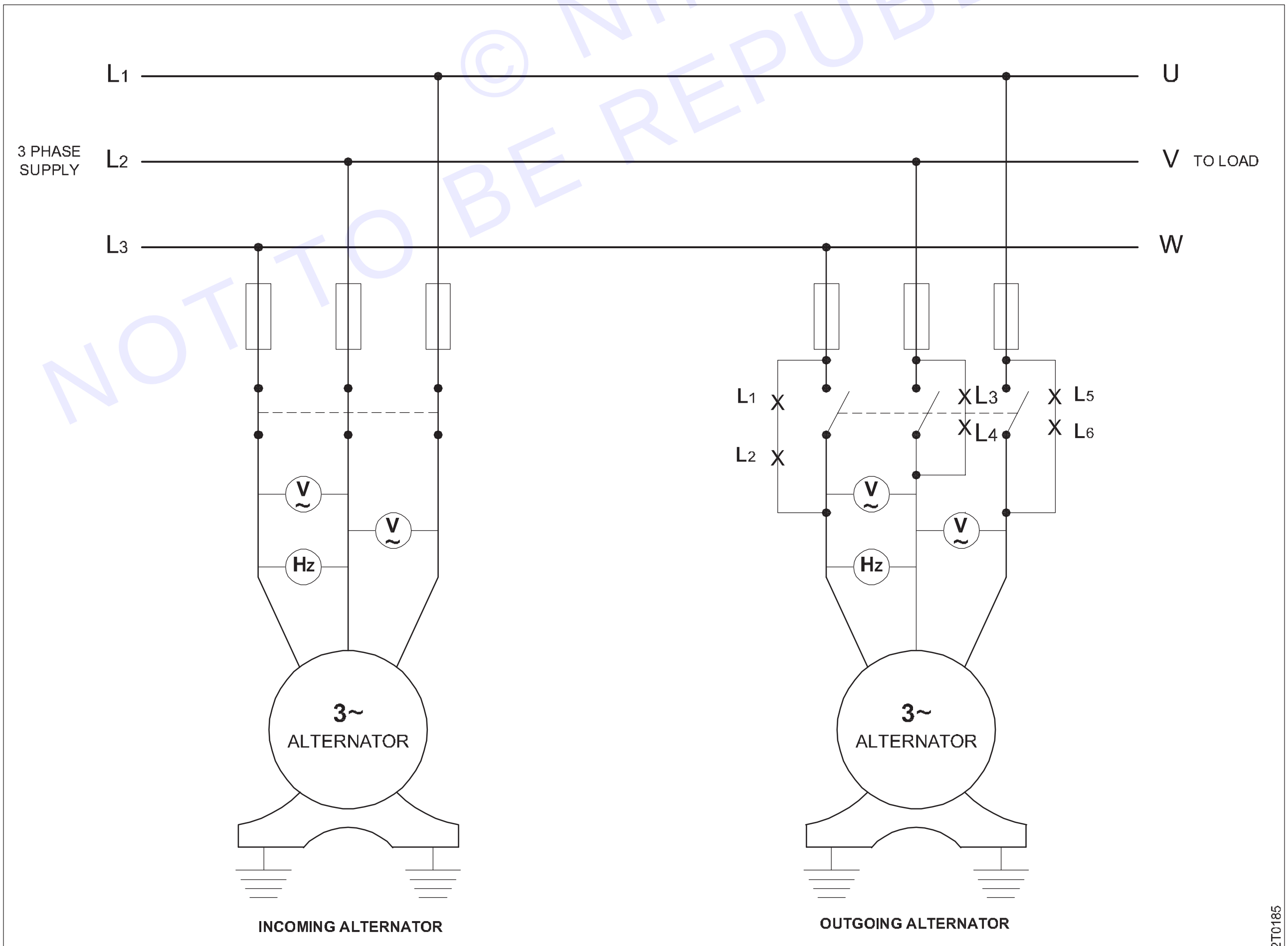
1 The three lamps will light and go out in unison at a rate which depends on the difference in frequency between the two alternators.

2 The three lamps will light and go out at a rate which depends on the difference in frequency between the two machines, but not in unison. In this case, the machines are not connected in the proper phase sequence and are said to be out of phase. To correct this, it's necessary to interchange any two leads to alternator 1. The machines are not paralleled until all lamps light and go out in unison. The lamp method is shown for greater simplicity of operation.

By making slight adjustments in the speed of alternator 1 the frequency of the machines can be equalized so that the synchronizing lamps will light and go out at the lowest possible rate. When the three lamps are out, the instantaneous electrical polarity of the three leads from 1 is the same as that of 2 At this instant, the voltage of 1 is equal to and in phase with that of 2 Now the paralleling switch can be closed at the middle period of the darkness of the lamps so that both alternators supply power to the load. The two alternators are in synchronism, according to the three dark method.

The three dark method has certain disadvantages and is seldom used. A large voltage may be present across an incandescent lamp even though it's dark (burned out). As a result, it's possible to close the paralleling connection while there is still a large voltage and phase difference between the machines. For small capacity machines operating at low speed, the phase difference may not affect the operation of the machines. However, when large capacity units having low armature reactance operate at high speed, a considerable amount of damage may result if there is a large phase difference and an attempt is made to parallel the units.

Two bright, one dark method (Dark and bright lamp method) : Another method of synchronizing alternators is the two bright, one dark method. In this method, any two connections from the synchronizing lamps are crossed after the alternators are connected and tested for the proper conditions for paralleling phase rotation. (The alternators are tested by the three dark method.) Fig 2 shows the connections for establishing the proper phase rotation by the three dark method. Fig 2 shows the lamp connections required to synchronize the alternator by the two bright, one dark method.



PARALLEL OPERATION OF 3 PHASE ALTERNATOR BY DARK LAMP METHOD

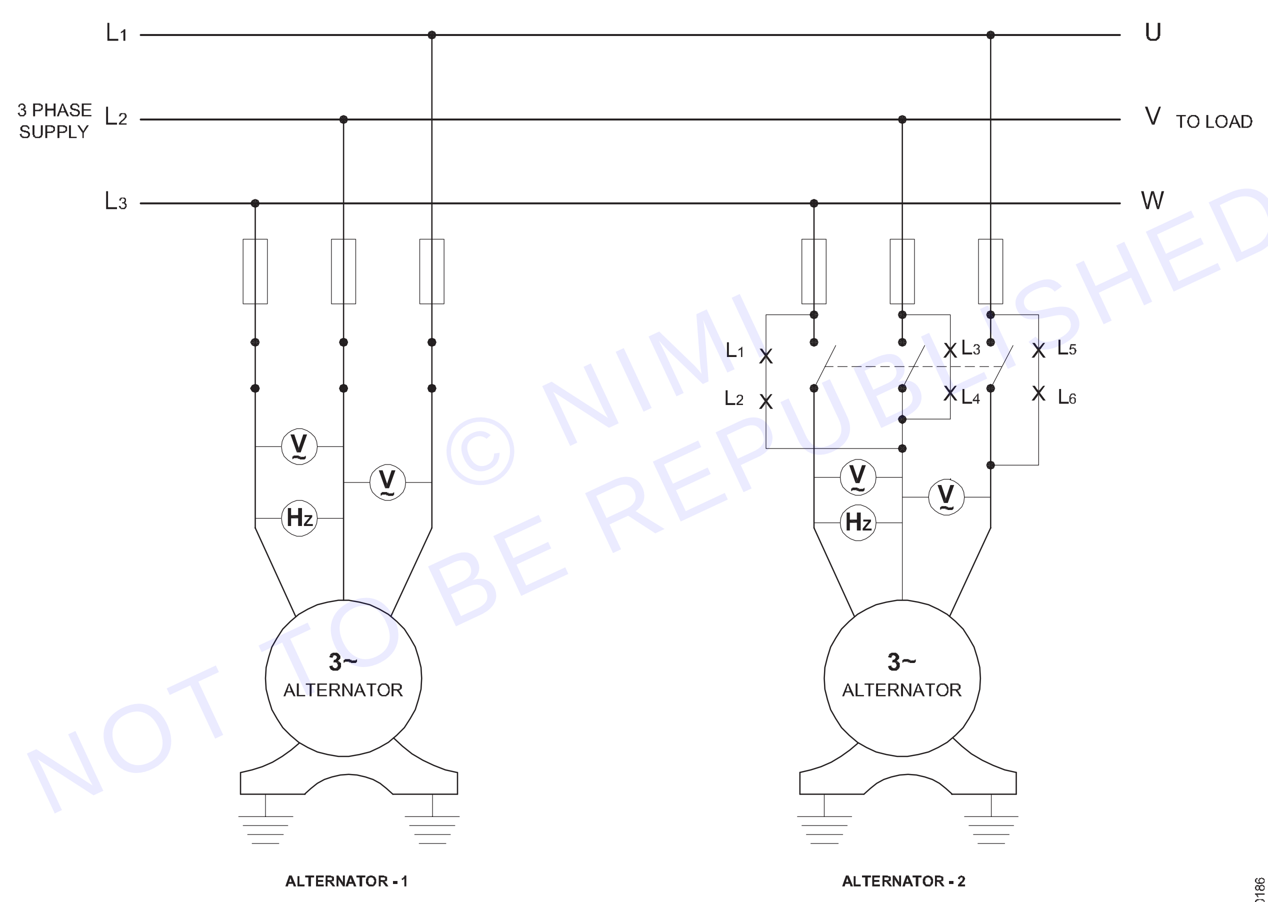
When the alternators are synchronized, lamps 1 and 2 are bright and lamp 3 is dark. Since two of the lamps are becoming brighter as one is dimming, it's easier to determine the moment when the paralleling switch can be closed. Furthermore, by observing the sequence of lamp brightness, it's possible to tell whether the speed of the alternator being synchronized is too slow or too fast and can be connected it.

At the moment when the two lamps are full bright and one lamp is full dark, the synchronizing switch can be closed.

Now the both alternator are synchronized and share the load according to their ratings.

Effect of changing the field excitation and power factor

A change in the excitation of an alternator running in parallel with others effects only its KVA output it does not effect the KW output. A change in the excitation thus effects only the power factor of its output.



DARK & BRIGHT LAMP METHOD

MG set and rotary converter

Objectives: At the end of this lesson you shall be able to:

- list the advantages of direct current over alternating current
- list the methods of converting AC to DC
- state the advantages and disadvantages of MG-set
- describe the rotary converter construction and its working.

The AC system has been adopted universally for the generation, transmission and distribution of electric power. It is more economical than a DC system of generation, transmission and distribution. There are applications where DC is either essential or more advantageous over AC.

DC is essential in the following applications.

- Electrochemical process such as electroplating, electro-refining etc.
- Storage battery charging.
- Arc lamp for search light and cinema projectors.

Direct current is more advantageous in the following applications.

- Traction purposes - DC series motor.
- Operating telephones, relays, time switches.
- Rolling mills, paper mills, elevators where fine speed control, frequent starting against heavy torque and rotation in both directions are required, DC motors are more suitable.

The conversion of AC to DC has become a necessity due to the above reasons.

Methods : The methods of conversion of AC to DC

- Motor-generator set
- Rotary converter
- Mercury arc rectifier
- Metal rectifiers
- Semi-conductor diodes and SCR

Out of the above five the motor generator sets and semi-conductor rectifiers are now mostly in use. The other types have become obsolete for obvious reasons.

Motor generator set : It consists of a 3-phase AC motor directly coupled to a DC generator. In the case of larger units, the AC motor is invariably a synchronous motor and the DC generator is usually compound.

Advantages

1 The DC output voltage is practically constant. The output (DC) voltage is not affected by changes in AC supply voltage.

2 DC output voltage can be easily controlled by the shunt field regulator.

3 The M.G set can also be used for power factor correction, where synchronous motor is used for driving the generator.

Disadvantages

1 It has a comparatively low efficiency.

2 It requires more floor space.

Rotary or synchronous converter

A rotary converter is used when a large DC power is required. It is a single machine with one armature and one field. It combines the function of a synchronous motor and a DC generator. It receives alternating current through a set of slip rings mounted on one side of the armature rotating synchronously (Ns = 120 f/P) and delivers direct current from the opposite end through the commutator and brushes.

Construction : In general construction and design, a rotary converter is more or less like a DC machine. It has interpoles for better commutation. Its commutator is larger than that of a DC generator of the same size because it has to handle a larger amount of power.

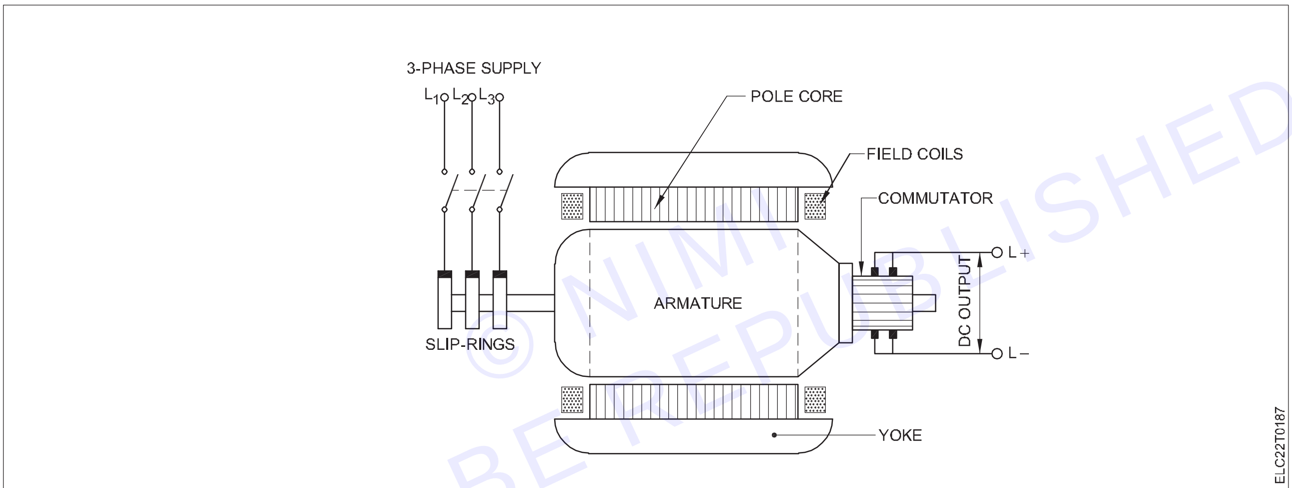
The only added feature are -

- a set of slip-rings mounted at the end opposite to the commutator end
- dampers in the pole faces as in a synchronous motor.

A simple sketch illustrating the main parts of a rotary (synchronous) converter is shown in Fig 1.

The fact that the emf induced in the armature conductors of a DC generator is alternating and that it becomes direct (unidirectional) only due to the rectifying action of the commutator, the slip-rings are to be connected to some suitable points on the armature winding to use this machine as an alternator.

The rotary converter armature is mostly lap wound. The number of parallel paths in the armature is equal to the number of poles. Therefore the number of equi-potential points on the armature is equal to the number of pairs of poles. The number of tappings taken to each slip-ring is, therefore, equal to the number of pairs of poles. For a 3-phase lap wound rotary converter, it is essential that the number of armature conductors per pole should be divisible by 3.



Operation : In its normal role, the machine is connected to a suitable AC supply through the slip-rings and it delivers direct current at the commutator. In this application the machine runs as a synchronous motor receiving AC power from the slip-ring side and as viewed from the commutator end, it runs as a DC generator delivering DC power.

Converter aspects for comparison	M.G.Set	Rotary converter
Machinery	Two machines i.e. one AC another one DC generator	Single machine
Cost	Very costly	Costly
Noise	Noisy	Noisy
Efficiency	Very low because of two rotating machines	Low
Maintenance cost	High	High
Overloading capacity	Cannot be over loaded	Cannot be overloaded
Power factor of AC factor	Low power factor	Good power
Attention during its operation	Less attention required	No attention required
Space required	Very high	Low

Maintenance of MG set

Objectives: At the end of this lesson you shall be able to:

- list out the points to be considered for maintenance of MG set.

The MG set must be maintained by inspecting electrically and mechanically. The following points to be considered while carrying out maintenance.

Electrical inspection list

- General cleaning of all electrical components and control panels
- Check/rectify motor insulation resistance by megger
- Check/rectify earth wiring
- Check/rectify main switch fuses
- Check/rectify stator, brushes etc.
- Check/rectify bearings of motor, rotating parts and use oil grease for proper lubrication
- Check/rectify/check starting panel
- Check/rectify over load relays
- Check/rectify loose connections and tighten them
- Replace damaged flexible conductors and cables
- Check/rectify the control system
- Replace the carburized non operative contactor if necessary.

Carry out the maintenance work in MG set by referring the mechanical inspection list and lubrication instruction given below

Mechanical inspection list

- Clean thoroughly and do visual inspection
- Check/rectify motor couplings and bearings
- Check for tightness of coupling, checking formulation both,
- Checking of pipeline flanger
- Check/rectify machine for functional operation and verify with the operator
- Lubrication, Maintenance prints
- Check/rectify the bearings for the lubrication
- Use oil gun/grease to lubricate the same.

A separate register is to be maintained by the maintenance authority to keep the records for each maintenance on all working days.

Attend the breakdown maintenance of mechanical and electrical nature, during the operation of the MG set.

Synchronous motor

Objectives: At the end of this lesson you shall be able to:

- explain the working principle of synchronous motor
- explain the constructional details of synchronous motor
- state the different methods of starting a synchronous motor
- state the application of synchronous motor.

Introduction

A synchronous motor is a machine which converts electrical energy into mechanical energy while rotating at a constant speed equal to synchronous speed. The synchronous generators can operate either as generators or as motors. When operating as motors – by connecting them to three phase source – they are called synchronous motors. As the name implies, synchronous motors run in synchronism with the revolving magnetic field. The speed of rotor is therefore tied to the frequency of source. As the frequency is fixed, the motor speed stays constant, irrespective of load or voltage of the three phase line. However, synchronous motors are not used so much because they run at constant speed.

Construction

Synchronous motors are identical in construction to salient pole AC generators. The stator is composed of a slotted magnetic core, which carries three phase winding. Consequently, the winding is also identical to that of three phase induction motors.

The rotor has a set of salient poles that are excited by a DC current. The exciting coils are connected in series to two slip rings and the DC current is fed into the winding from an external exciter.

In some synchronous motors slots are also punched along the circumference of salient poles. They carry a squirrel cage winding similar to that in three phase induction motors. This damping winding serves to start the motor.

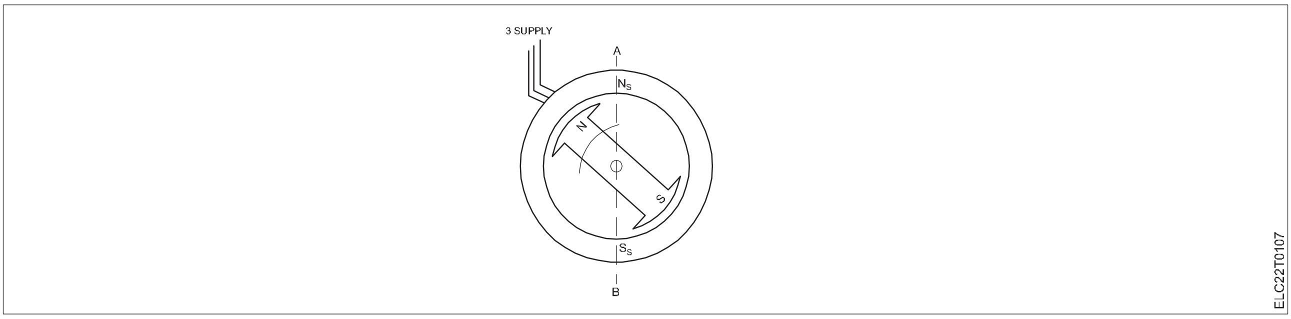
Modern synchronous motors often employ brushless excitation similar to that used in synchronous generators. A relatively small three phase generator called exciter, and a three phase rectifier are mounted at one end of the motor shaft. The DC current from rectifier is fed directly into salient pole windings without going through brushes and slip rings. The current can be varied by controlling the small exciting current, that flows in stationary field winding of the exciter.

The rotor and stator always have the same number of poles. As in case of induction motor, the number of poles determines the synchronous speed of the motor.

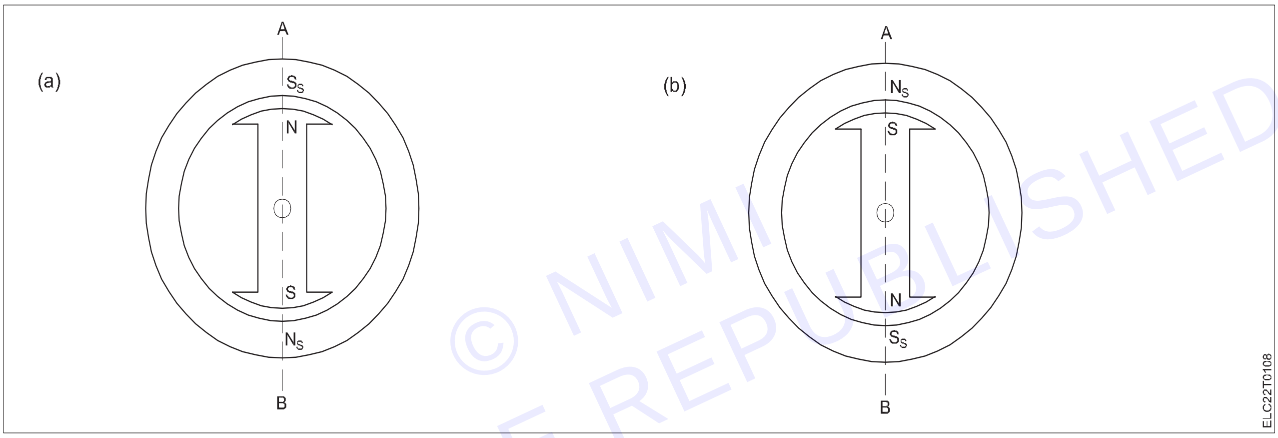
Working principle

When a three phase winding is fed by a 3 phase supply, then a magnetic flux of constant magnitude but rotating at synchronous speed, is produced. Consider a two-pole stator of Fig 1, in which are shown two stator poles (marked N_S and S_S) rotating at synchronous speed, say, in clockwise direction. With the rotor position as shown, suppose the stator poles are at that instant situated at points A and B. The two similar poles, N (of rotor) and N_S (of stator) as well as S and S_S will repel each other, with the result that the rotor tends to rotate in the anticlockwise direction.

But half a period later, stator poles, having rotated around, interchange their positions i.e. N_S is at point B and S_S at point A. Under these conditions, N_S attracts S and S_S attracts N. Hence, rotor tends to rotate clockwise (which is just the reverse of the first direction). Hence, we find that due to continuous and rapid rotation of stator poles, the rotor is subjected to a torque which is rapidly reversing i.e., in quick succession, the rotor is subjected to torque which tends to move it first in one direction and then in the opposite direction. Owing to its large inertia, the rotor cannot instantaneously respond to such quickly-reversing torque, with the result that it remains stationary.



Now, consider the condition shown in Fig 2 (a). The stator and rotor poles are attracting each other. Suppose that the rotor is not stationary, but is rotating clockwise, with such a speed that it turns through one pole-pitch by the time the stator poles interchange their positions, as shown in Fig 2 (b). Here, again the stator and rotor poles attract each other. It means that if the rotor poles also shift their positions along with the stator poles, then they will continuously experience a unidirectional torque i.e., clockwise torque, as shown in Fig 2. The rotor (which is as yet unexcited) is speeded up to synchronous / near synchronous speed by some arrangement and then excited by the DC supply.



Advantages and disadvantages

Advantages

1 It is a constant speed motor and its speed remains constant from no load to full load.

2 By varying the field excitation, the power factor can be adjusted as desired.

Disadvantages

1 These motors cannot be used for variable mechanical load.

2 As this motor is not self-starting type, it cannot be started on load.

3 To operate this motor its field system requires DC supply.

4 This motor cannot be used for variable speed applications.

5 Hunting is produced in this motor.

Method of starting: As the synchronous motors are not self-starting, they have to be rotated at the time of starting to their synchronous speed / near synchronous speed. A synchronous motor can be started by following methods:

1 By Pony motor method.

2 As an induction motor.

Starting by pony motor method: In this method, another small induction motor (known as pony motor) having a pair of poles less than that of the synchronous motor to be started (or an oil engine) is mechanically coupled with the shaft of the synchronous motor. This small pony induction motor is first started from AC supply mains and then DC supply from the exciter of the motor is applied to the field of the synchronous motor. AC supply is not provided to the armature (AC stator) of the synchronous motor at this time.

The synchronous motor now operates as a synchronous generator and an alternating emf is generated in its armature. Now this synchronous motor, operating as alternator is to be synchronised with the mains supply. After synchronising, the supply to the pony motor is cut off and then the motor continuous to work as a synchronous motor.

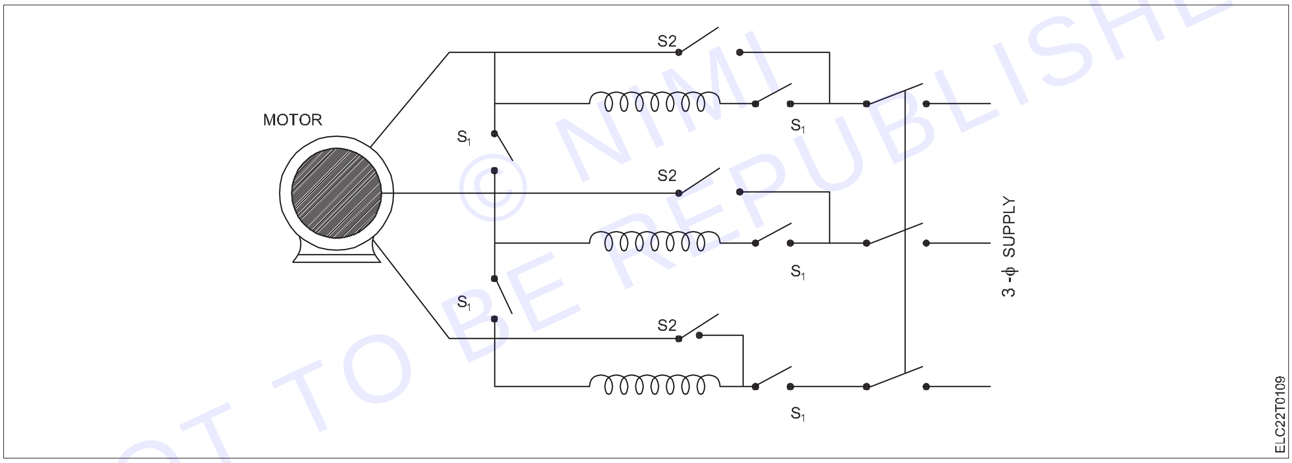
Starting as an induction motor

In this method the synchronous motors, which are provided with damping winding on the face of salient poles of the rotor, is started as an ordinary squirrel cage induction motor. The damping winding acts as squirrel cage winding which consists of thick copper bars placed in the slots made on the faces of the rotor poles and short circuited by heavy copper rings at both the sides of the rotor.

To start the synchronous motor, the DC supply to the field winding is kept disconnected and the AC supply is applied to the armature winding. The motor starts as a squirrel cage induction motor. When the motor rotates at its maximum speed, the DC supply to the field is switched on. Then the rotor and stator poles get interlocked with each other, because of the flux of rotating magnetic field is seeking the minimum reluctance path through the core of the salient poles and the motor now acts as a synchronous motor.

However, two points should be noted:

1 At the beginning, when voltage is applied, the rotor is stationary. The rotating field of the stator winding induces a very large e.m.f. in the rotor during the starting period, though the value of this e.m.f. goes on decreasing as the rotor gathers speed. Normally, the field windings are meant for 110-V (or 250 V for large machines) but during starting period there are many thousands of volts induced in them. Hence, the rotor windings have to be highly insulated for withstanding such voltages.



2 When full line voltage is switched on to the armature at rest, a very large current, usually 5 to 7 times the full-load armature current is drawn by the motor. In some cases, this may not be objectionable but where it is, the applied voltage at starting, is reduced by using autotransformers. However, the voltage should not be reduced to a very low value because the starting torque of an induction motor varies approximately as the square of the applied voltage. Usually, a value of 50% to 80% of the full-line voltage is satisfactory. For reducing the supply voltage, the switches S_1 are closed and S_2 are kept open. When the motor has been speeded-up, S_2 are closed and S_1 opened to cut out the transformers.

Procedure for starting

While starting a modern synchronous motor provided with damper windings, following procedure is adopted.

1 First, main field winding is short-circuited.

2 Reduced voltage with the help of auto-transformers is applied across stator terminals. The motor starts up.

3 When it reaches a steady speed (as judged by its sound), a weak D.C. excitation is applied by removing the short-circuit on the main field winding. If excitation is sufficient, then the machine will be pulled into synchronism.

4 Full supply voltage is applied across stator terminals by cutting out the auto-transformers.

5 The motor may be operated at any desired power factor by changing the D.C. excitation.

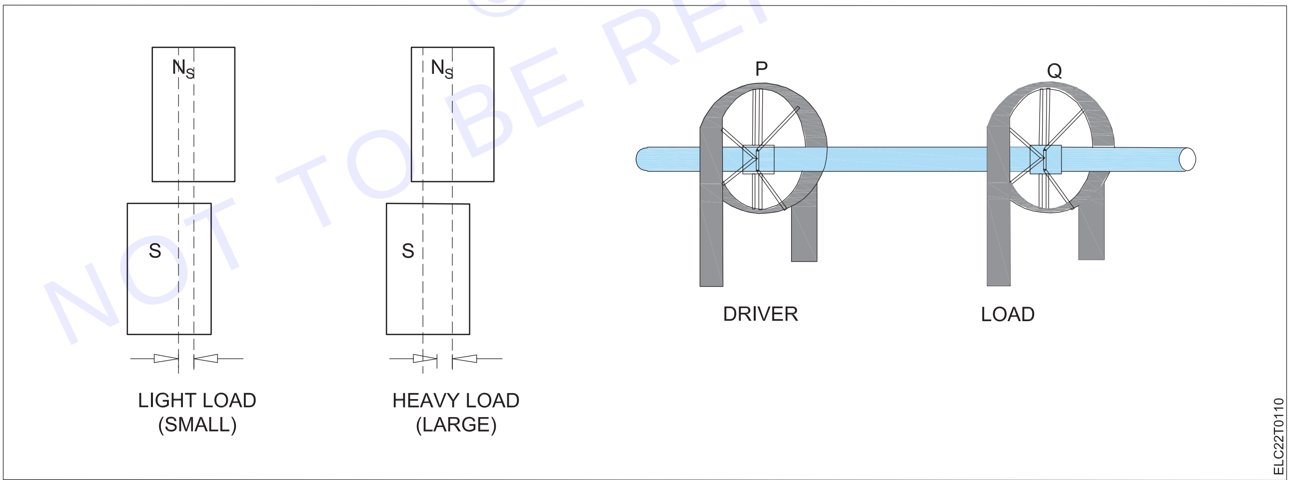
The rotor, which is as yet unexcited is speeded up to synchronous / near synchronous speed by some arrangement and then excited by the D.C. source. This produces alternate N and S poles around the circumference of the rotor. If the poles at this moment happens to be facing poles of opposite polarity on the stator, a strong magnetic attraction is set up between them. The mutual attraction locks the rotor and stator poles together and the rotor is literally yanked into step with the revolving field. The torque developed at this moment is called pull in torque.

The pull in torque of a synchronous motor is powerful, but the DC current must be applied at the right moment. If it should happen that the emerging N, S poles of the rotor are opposite to the N, S poles of the stator, the resulting magnetic repulsion produces a violent mechanical shock. The motor will immediately slow down and the circuit breakers will trip. In practice, starters for synchronous motors are designed to detect the precise moment when excitation should be applied. The motor then pulls automatically and smoothly into step with the revolving field.

Once the motor turns at synchronous speed, no voltage is induced in squirrel cage windings and so it carries no current. Consequently, the behaviour of a synchronous motor is entirely different from that of an induction motor. Basically a synchronous motor rotates because of the magnetic attraction between the poles of rotor and the opposite poles of the stator.

However, it is important to understand that the arrangement between the stator and rotor poles is not an absolutely rigid one. As the load on the motor is increased, the rotor progressively tends to fall back in phase (but not in speed as in D.C. motors) by some angle (Fig 4) but it still continues to an absolutely rigid one. As the load on the motor is increased, the rotor progressively tends to fall back in phase (but not in speed as in D.C. motors) by some angle (Fig 4) but it still continues to run synchronously. The value of this load angle or coupling angle (as it is called) depends on the amount of load to be met by the motor. In other words, the torque developed by the motor depends on this angle, say between N_S & S.

The working of a synchronous motor is, in many ways, similar to the transmission of mechanical power by a shaft. In Fig 5 are shown two pulleys P and Q transmitting power from the driver to the load. The two pulleys are assumed to be keyed together (just as stator and rotor poles are interlocked) hence they run at exactly the same (average) speed. When Q is loaded, it slightly falls behind owing to the twist in the shaft (twist angle corresponds to in motor), the angle of twist, in fact, being a measure of the torque transmitted. It is clear that unless Q is so heavily loaded as to break the coupling, both pulleys must run at exactly the same (average) speed.



Various torques associated with a synchronous motor

1 Starting torque

2 Running torque

3 Pull-in torque and

4 Pull-out torque

1 Starting torque

It is the torque (or turning effort) developed by the motor when full voltage is applied to its stator (armature) winding. It is also sometimes called breakaway torque. Its value may be as low as 10% as in the case of centrifugal pumps and as high as 200 to 250% of full-load torque as in the case of loaded reciprocating two-cylinder compressors.

2 Running torque

As its name indicates, it is the torque developed by the motor under running conditions. It is determined by the horse-power and speed of the driven machine. The peak horsepower determines the maximum torque that would be required by the driven machine. The motor must have a breakdown or a maximum running torque greater than this value in order to avoid stalling.

3 Pull-in torque

A synchronous motor is started as induction motor till it runs 2 to 5% below the synchronous speed. Afterwards, excitation is switched on and the rotor pulls into step with the synchronously rotating stator field. The amount of torque at which the motor will pull into step is called the pull-in torque. Torque motors are designed to provide maximum torque at locked rotor or near stalled conditions

4 Pull-out torque

The maximum torque which the motor can develop without pulling out of step or synchronism is called the pull-out torque. Normally, when load on the motor is increased, its rotor progressively tends to fall back in phase by some angle (called load angle) behind the synchronously-revolving stator magnetic field though it keeps running synchronously. Motor develops maximum torque when its rotor is retarded by an angle of 90º (or in other words, it has shifted backward by a distance equal to half the distance between adjacent poles). Any further increase in load will cause the motor to pull out of step (or synchronism) and stop.

Reluctance torque

If we gradually reduce the excitation of the synchronous motor when it is running at no-load, it can find that the motor continuous to run at synchronous speed even when the excitation current is zero. The reason is that the flux produced by the stator prefers to cross the short gap between the salient poles and the stator rather than the much longer air gap between the poles. In other words, because the reluctance of the magnetic circuit is less in the axis of the salient poles, the flux is concentrated in that area. On account of this phenomenon, the motor develops a reluctance torque.

If a mechanical load is applied to the shaft, the rotor poles will fall behind the stator poles and the stator flux change its shape accordingly. Thus a considerable reluctance torque can be developed without any DC excitation at all.

The reluctance torque becomes zero when the rotor poles are midway between the stator poles. The reason is that the N and S poles on the stator attract the salient poles in opposite direction. Consequently, the reluctance torque is zero precisely at that angle where the regular torque attains its maximum value, namely at 900. The reluctance torque reaches its maximum at 45°.

The main points regarding the above three cases can be summarized as under:

1 As load on the motor increases, Ia increases regardless of excitation.

2 For under-and over-excited motors, power factor tends to approach unity with increase in load.

3 Both with under-and over-excitation, change in power factor is greater than in Ia with increase in load.

4 With normal excitation, when load is increased change in Ia is greater tends to become increasingly lagging.

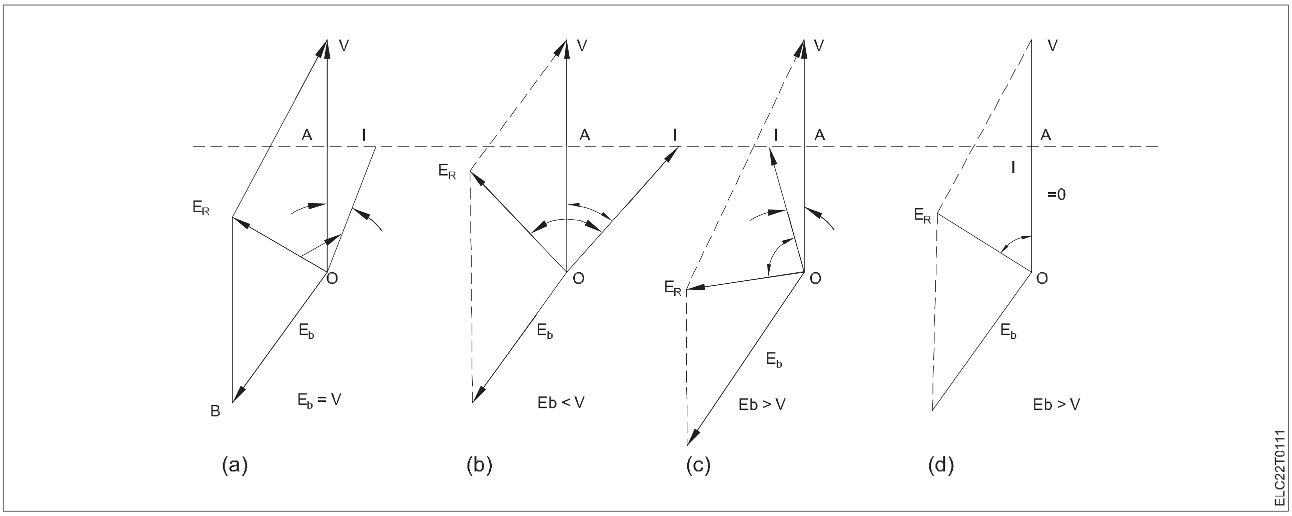
Effect of excitation on armature current and power factor

The value of excitation for which back e.m.f. (Eb) is equal (in magnitude) to applied voltage V is known as 100% excitation. We will now discuss what happens when motor is either over-excited or under-excited.

Consider a synchronous motor in which the mechanical load is constant (and hence output is also constant if losses are neglected).

Fig 6(a) shows the case for 100% excitation i.e., when Eb = V. The armature current I lags behind V by a small angle. Its angle with ER is fixed by stator constants i.e. tan = XS / Ra.

In Fig 6(b) excitation is less than 100% i.e., Eb< V. Here, ER is advanced is armature current (because it lags behind E clockwise and so increased but its power factor is decreased (ϕ has increased). Because input as well as V are constant, hence the power component of I i.e. I cos ϕ remains the same as before, but wattles component I sin ϕ is increased. Hence as excitation is decreased, I will increase but power factor will decrease so that power component of I will remain constant. Incidentally, it may be noted that when field current is reduced, the motor pull-out torque is also reduced in proportion.



Two important points to be noted are:

1 The magnitude of armature current varies with excitation. The current has large value both for low and high values of excitation. In between, it has minimum value corresponding to a certain excitation. The variations of current are known as 'V' curves because of their shape.

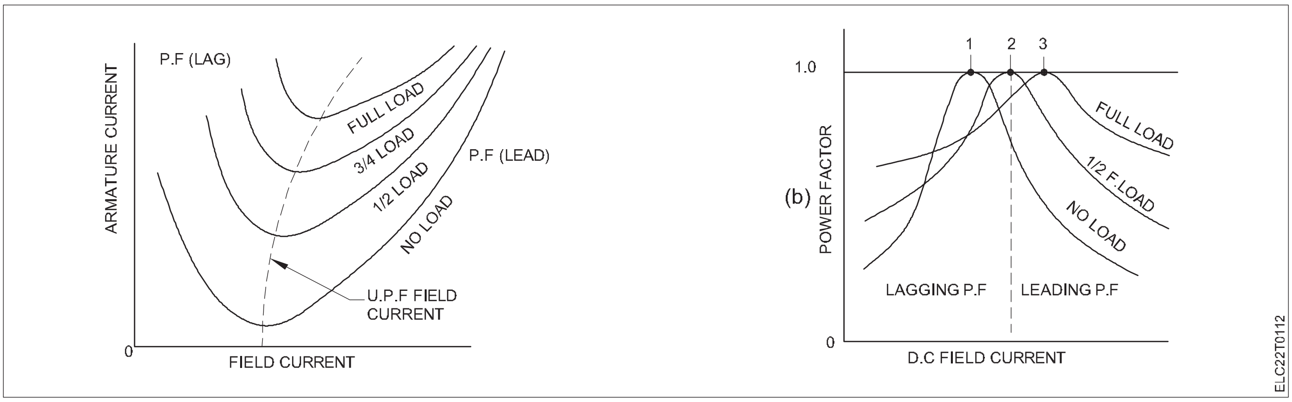
2 For the same input, armature current varies over a wide range and so causes the power factor also to vary accordingly. When over excited, motor runs with leading power factor and with lagging power factor, when under excited. In between the power factor is unity. The variation with power factor with excitation curve looks like inverted 'V' curve (Fig 8). It would be noted that minimum armature current corresponds to unity power factor.

Fig 6(c) represents the condition for over excited motor, i.e. when Eb>V. here the resultant voltage vector ER is pulled anticlockwise and so as I. it is seen that now motor is drawing a leading current. It may also happen for some value of excitation, that I may be in phase with V, i.e. power factor is unity. Fig 6(d). at that time the current drawn by the motor would be minimum.

It is seen that an over-excited motor can be run with leading power factor. This property of the motor renders it extremely useful for phase advancing (and so power factor correcting) purposes in the case of industrial loads driven by induction motors and lighting and heating loads supplied through transformers. Both transformers and induction motors draw lagging currents from the line. Especially on light loads, the power drawn by them has a large reactive component and the power factor has a very low value. This reactive component, though essential for operating the electric machinery, entails appreciable loss in many ways. By using synchronous motors in conjunction with induction motors and transformers, the lagging reactive power required by the latter is supplied locally by the leading reactive component taken by the former, thereby relieving the line and generators of much of the reactive component. Hence, they now supply only the active component of the load current. When used in this way, a synchronous motor is called a synchronous capacitor, because it draws, like a capacitor, leading current from the line. Most synchronous capacitors are rated between 20 MVAR and 200 MVAR and many are hydrogen-cooled.

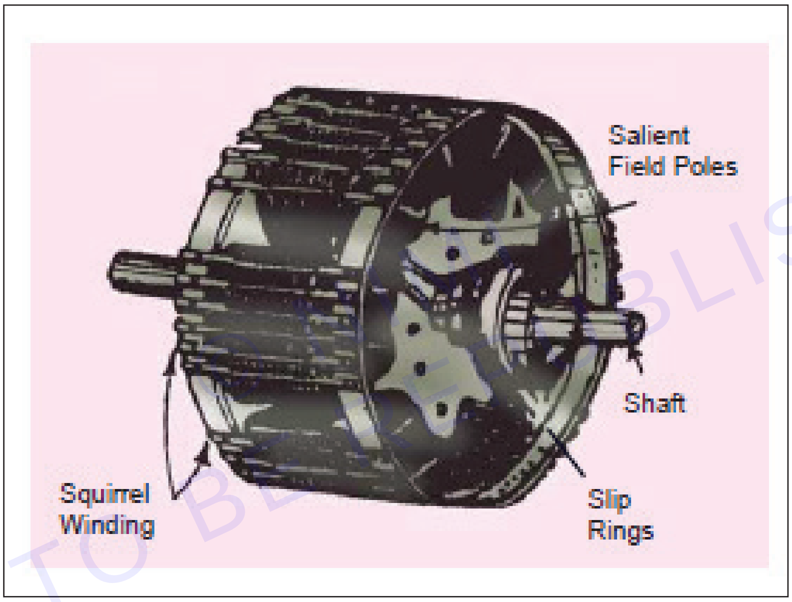
V Curves

The V-curves of a synchronous motor show how armature current varies with its field current when motor input is kept constant. These are obtained by plotting A.C. armature current against D.C. field current while motor input is kept constant and are so called because of their shape (Fig 7). There is a family of such curves, each corresponding to a definite power intake. In order to draw these curves experimentally, the motor is run from constant voltage and constant-frequency bus-bars. Power input to motor is kept constant at a definite value. Next, field current is increased in small steps and corresponding armature currents are noted. When plotted, we get a V-curve for a particular constant motor input. Similar curves can be drawn by keeping motor input constant at different values. A family of such curves is shown in Fig 7.



Hunting or surging or phase swinging

When a synchronous motor is used for driving a varying load, then a condition known as hunting is produced. Hunting may also be caused if supply frequency is pulsating (as in the case of generators driven by reciprocating internal combustion engines).



We know that when a synchronous motor is loaded (such as punch presses, shears, compressors and pumps etc.), its rotor falls back in phase by the coupling angle. As load is progressively increased, this angle also increases so as to produce more torque for coping with the increased load If now, there is sudden decrease in the motor load, the motor is immediately pulled up or advanced to a new value of corresponding to the new load But in this process, the rotor overshoots and hence is again pulled back in this way, the rotor starts oscillating (like a pendulum) about its new position of equilibrium corresponding to the new load If the time period of these oscillations happens to be equal to the natural time period of the machine then mechanical resonance is set up The amplitude of these oscillations is built up to a large value and may eventually become so great as to throw the machine out of synchronism To stop the build-up of these oscillations, dampers or damping grids (also known as squirrel-cage winding) are employed These dampers consist of short circuited Cu bars embedded in the faces of the field poles of the motor. The oscillatory motion of the rotor sets up eddy currents in the dampers which flow in such a way as to suppress these oscillations. But it should be clearly understood that dampers do not completely prevent hunting because their operation depends upon the presence of some oscillatory motion However, they serve the additional purpose of making the synchronous motor self-starting. As said above, almost all synchronous motors are equipped with dampers or squirrel cage.

Comparison between synchronous and induction motors

1 For a given frequency, the synchronous motor runs at a constant average speed whatever the load, while the speed of an induction motor falls somewhat with increase in load.

2 The synchronous motor can be operated over a wide range of power factors, both lagging and leading, but induction motor always runs with a lagging power factor which may become very low at light loads.

3 A synchronous motor is inherently not self-starting.

4 The changes in applied voltage do not affect synchronous motor torque as much as they affect the induction motor torque. The breakdown torque of a synchronous motor varies approximately as the first power of applied voltage whereas that of an induction motor depends on the square of this voltage.

5 A D.C. excitation is required by synchronous motor but not by induction motor.

6 Synchronous motors are usually costlier and complicated than induction motors, but they are particularly attractive for low-speed drives (below 300 rpm.) because their power factor can always be adjusted to 1.0 and their efficiency is high. However, induction motors are excellent for speeds above 600 rpm.

7 Synchronous motors can be run at ultra-low speeds by using high power electronic converters which generate very low frequencies. Such motors of 10 MW range are used for driving crushers, rotary kilns and variable-speed ball mills etc.

Application

Synchronous motors find extensive application for the following classes of service:

1 Power factor correction

2 Constant-speed, constant-load drives

3 Voltage regulation

a Power factor correction

Overexcited synchronous motors having leading power factor are widely used for improving power factor of those power systems which employ a large number of induction motors and other devices having lagging power factor such as welders and fluorescent lights etc.

b Constant-speed applications

Because of their high efficiency and high-speed, synchronous motors (above 600 rpm.) are well-suited for loads where constant speed is required such as centrifugal pumps, belt-driven reciprocating compressors, blowers, line shafts, rubber and paper mills etc. Low-speed synchronous motors (below 600 rpm.) are used for drives such as centrifugal and screw-type pumps, ball and tube mills, vacuum pumps, chippers and metal rolling mills etc.

c Voltage regulation

The voltage at the end of a long transmission line varies greatly especially when large inductive loads are present. When an inductive load is disconnected suddenly, voltage tends to rise considerably above its normal value because of the line capacitance. By installing a synchronous motor with a field regulator (for varying its excitation), this voltage rise can be controlled. When line voltage decreases due to inductive load, motor excitation is increased, thereby raising its power factor which compensates for the line drop. If, on the other hand, line voltage rises due to line capacitive effect, motor excitation is decreased, thereby making its power factor lagging which helps to maintain the line voltage at its normal value.

Stopping of synchronous motors

Owing to the inertia of the rotor and its load, a large synchronous motor may take several hours to stop after being disconnected from the line. To reduce the tome following braking methods are used:

1 Maintain full DC excitation with the armature in short circuit.

2 Maintain full DC excitation with the armature connected to three external resistors.

3 Apply mechanical braking.

In methods 1 & 2, the motor slows down because it functions as generator, dissipating its energy in the resistive elements of the circuit. Mechanical brake is usually applied only after the motor has reached half speed or less. A lower speed prevents undue wear of the brake shoes.

MODULE 14 : AC & DC Windings

LESSON 86-92 : Winding and insulating materials

Objectives

At the end of this lesson you shall be able to:

- list out the insulating materials used for winding and their applications.

Insulating materials : In winding work, proper selection of insulating materials is an important criterion. The ageing factor of the insulation of Power equipment and apparatus depends upon many factors, such as temperature, Power and mechanical stress, vibration, moisture, dirt and chemical reaction.

Materials: The following are the common insulating materials used for winding purposes.

- Leatheroid paper
- Pressphan paper
- Triplex paper
- Millinex paper
- Micanite paper (mica folium)
- Empire cloth
- Glass fibre cloth
- Cotton tape
- Empire tape
- Fibre glass tape
- Cotton sleeves
- Empire sleeves
- Fibre glass sleeves
- PVC sleeves
- Bamboo
- Hemp thread
- Terylene thread
- Varnish

Winding wires

Objectives: At the end of this lesson you shall be able to:

- list out the winding wires used for winding.

Winding wires : The annealed copper conductors, normally in round shape, are used for winding small and medium capacity Power machines and equipments. These copper wires are provided with a variety of insulation as stated below.

- Super-enamelled copper wire (S.E.)
- Single cotton-covered copper wire (S.C.C.)
- Double cotton-covered copper wire (D.C.C.)
- Single silk-covered copper wire (S.S.C.)
- Double silk-covered copper wire (D.S.C.)
- PVC-covered copper winding wire

Generally super-enamelled copper winding wire with medium covering is used for most of the winding applications, whereas for some special applications super-enamelled copper wire with thick covering may be used.

Field coils and armature of certain DC machines might be wound with super-enamelled, DCC or DSC copper winding wires.

PVC covered copper winding wire is mainly used for submersible pumps.

The winding wires are available in different sizes and grades of insulation.

Armature winding - terms - types - rewinding of mixer/ liquidizer

Objectives: At the end of this lesson you shall be able to:

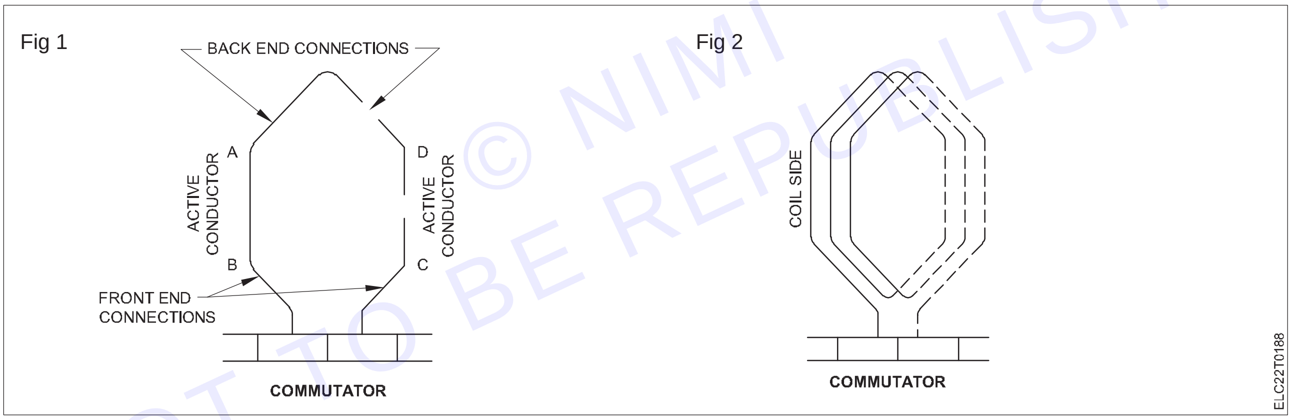
- define the general terms used in DC armature winding
- explain the different types of DC armature winding.

DC armature winding : It is a closed coil winding, wherein the coil ends are connected through the commutator segments to form the closed circuit.

Terms used in DC armature winding

Coil or winding element : Length of a wire lying in the magnetic field and in which an emf is induced is called an active conductor.

Referring to Fig 1, we find the two active conductors AB and CD along with their end connections constitute one coil or winding element of the armature winding. The coil may consist of a single turn only as shown in Fig 2 or multi-turns as shown in Fig 3. A single-turn coil or winding element will have two conductors only. But a multi-turn coil may have many conductors per coil side. In Fig 2 for example, each coil side has 3 conductors. The group of conductors constituting a coil side of a multi-turn coil is tied together with a tape as a unit (Fig 3) and is placed in the armature slot. It may be noted that each winding element has two connecting leads and each commutator bar has two connecting leads brought from the winding. As such there are as many commutator bars as the number of winding elements.



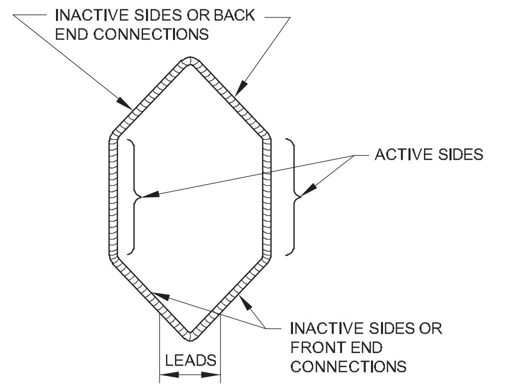
Active sides : These are the sides which lie within the slots. They are also known as coil sides. The induction takes place only in the active sides of the coil while they move in the magnetic field. (Fig 3)

In winding calculation these active sides are considered as conductors. The coil has got two conductors irrespective of the number of turns.

Inactive sides : That part of a coil which does not lie in the slot is known as the inactive side of a coil. No induction takes place in the inactive sides.

Example: Back and front end connections. (Fig 3)

Fig 3



Leads of coil : The ends coming out from a coil are known as leads of a coil. Every coil has got two leads.

Pole-pitch(Yp) : It may be variously defined as:

- the periphery of the armature divided by the number of poles of the machine i.e. the distance between two adjacent poles. It is denoted by Yp.
- it is equal to the number of armature conductors (or armature slots) per pole. For example, if there are 48 conductors, 24 coils, 24 slots and 4 poles, then the pole pitch is

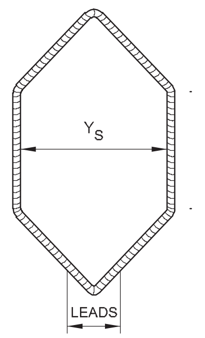
$$Y_P = \frac{\text{Number of slots}}{\text{Number of poles}} = \frac{24}{4} = 6 \text{ in terms of slots}$$

or

$$Y_P = \frac{\text{No. of conductors}}{\text{No. of poles}} = \frac{48}{4} = 12 \text{ in terms of conductors}$$

Coil-span or coil-pitch(YS) : The coil-span or coil-pitch is the distance, measured in terms of armature slots or armature conductors between two sides of a coil. It is in fact the periphery of the armature measured in terms of slots or conductors spanned by the two sides of the coil. It is denoted by YS as shown in Fig 4.

Fig 4



Coil-pitch YS is calculated in the same way as is done for Pole pitch.

Hence the modified calculation will be

$$Y_S = \frac{\text{No. of slots}}{\text{No. of poles}} - K = \frac{S}{P} - K \text{ (in terms of slots)}$$

$$= \frac{\text{No. of conductors}}{\text{No. of poles}} - K = \frac{C}{P} - K \text{ (in terms of conductors)}$$

where K = any part of S/P or C/P that is subtracted to make Ys an integer.

Back pitch (YB) : The distance measured in terms of the armature conductors which a coil advances on the back of the armature is called back pitch and is denoted by YB. This is illustrated in Figs 5 and 6. The back pitch is also equal to the coil-pitch.

Fig 5

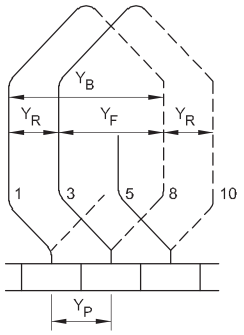
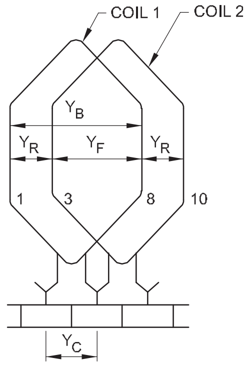


Fig 6



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As shown in Fig 7, coil side 1 is connected on the back of armature to coil side 8 (same coil). Hence YB = 8 – 1 = 7 conductors.

Front pitch(YF) : The number of armature conductors or elements spanned by a coil on the front (commutator end of an armature) is called the front pitch and is designated by YF. This is shown in Figs 5,6 and 7. Coil side 8 is connected to coil side 3 (second coil) through the commutator segment. Hence YF= 8 – 3 = 5 conductors.

Average pitch (YA) : The average of the front pitch YFand the back pitch YB is called average pitch.YA

$$\text{i.e., } Y_A = \frac{Y_B + Y_F}{2}$$

It is expressed in number of conductors.

Resultant pitch (YR) : In general, it may be defined as the distance between the beginning of one coil and the beginning of the next coil to which it is connected or it is the distance between the beginnings of two consecutive coil sides as shown in Figs 7 and 8 and denoted by letter YR. As in Fig 9, YR=YB–YF, i.e. YR =7–5 =2 conductors. The resultant pitch YR depends upon the type of winding like lap or wave, as well as simplex or multiplex.

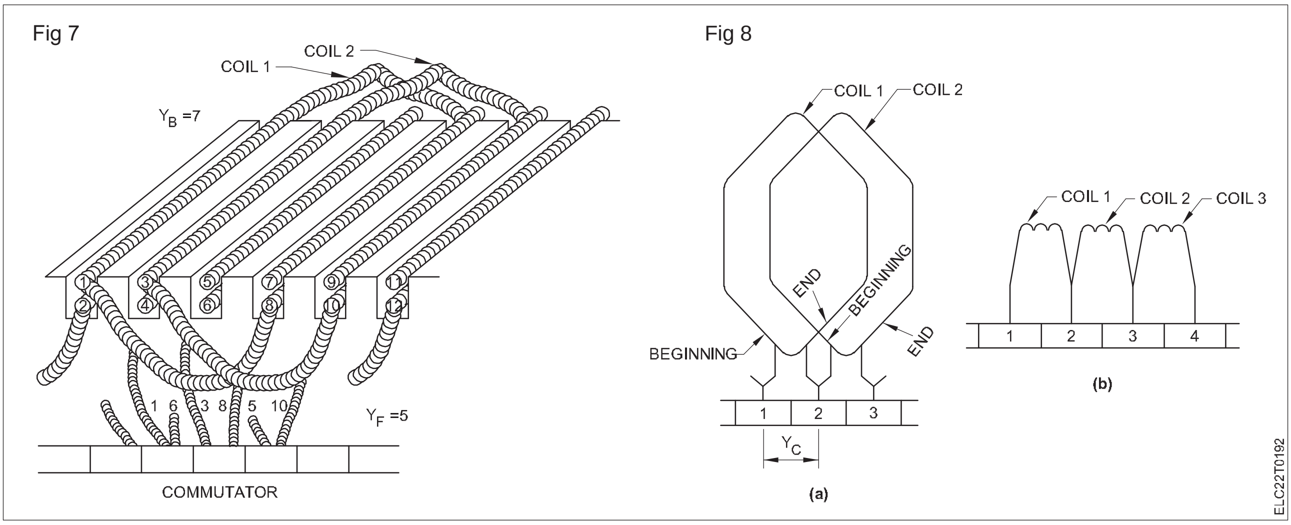
Commutator pitch(Yc) : It is the distance (measured in commutator bars or segments) between the segments to which the two ends of a coil are connected. It is denoted by Yc. From the Figs 5,6 and 7, it is clear the commutator pitch Yc = 1 segment.

The commutator pitch Yc varies with the type of winding, like lap or wave as well as simplex or multiplex.

Types of DC armature windings

Lap and wave winding : The DC armature windings are classified into two main groups, lap and wave windings. The difference between them is the manner in which, the leads are connected to the commutator segments.

Simplex lap winding : In a simplex lap winding, the end lead of coil 1 is connected to the beginning lead of the adjacent coil(coil 2) through the commutator segments. The commutator pitch of one segment is maintained. Fig 8 shows the lead connection of a simplex lap winding.



Duplex lap winding : In duplex lap winding, the end lead of coil 1 is connected to the beginning lead of coil 3, through commutator segments. The commutator pitch of two segments is maintained as shown in Figs 9a and b.

In triplex lap and quadruplex lap windings, the end leads of coil 1 are connected to the beginning leads of coil 4 and coil 5 respectively through commutator segments. In general commutator pitches

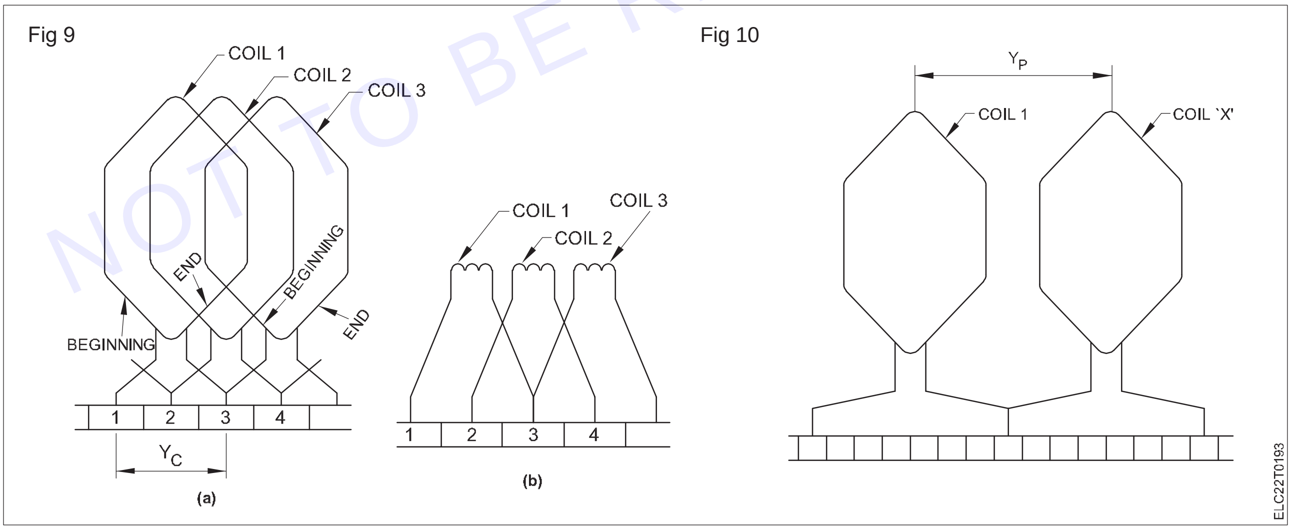
Yc = 1 segment for simplex lap winding

Yc = 2 segments for duplex lap winding

Yc = 3 segments for triplex lap winding

Yc = 4 segments for quadruplex lap winding.

Simplex wave winding : In simplex wave winding, the end lead of the coil 1 is connected to the beginning of a coil placed at a distance equal to one pole pitch. (Fig 10)



Duplex wave winding : In duplex wave winding there is parallel combination of two simplex wave windings as shown in Fig 11.

Triplex wave winding : Triplex wave winding will have a parallel combination of three simplex wave windings, and so on.

The width of the brush will be such that in simplex lap or wave winding, the brush will make contact with only one segment. The brush will contact two segments in duplex, three in triplex and four in quadruplex. (Refer to Fig 12)

Fig 11

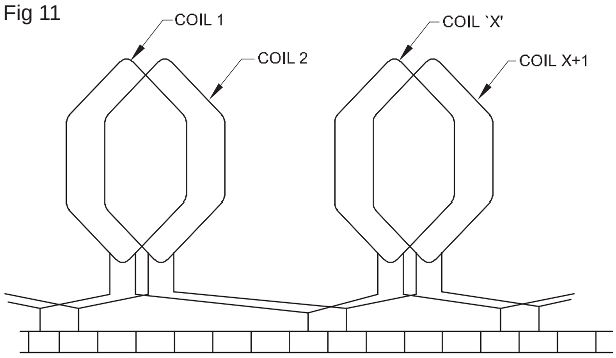
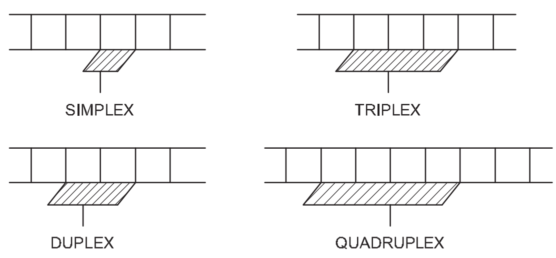


Fig 12



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Progressive lap or wave winding : In progressive lap or wave winding, the front pitch YFwill be less than the back pitch YB, i.e. as you lay the coils clock-wise, the connections to the commutator segments will also proceed clockwise as in Figs 13a and b. In progressive winding, Yc is referred to as +1.

Retrogressive lap or wave winding: In retrogressive lap or wave winding, the front pitch $Y_F$will be greater than the back pitch Y_B, i.e. as you lay the coils clockwise, the connection to the commutator segments will proceed anticlockwise as shown in Figs 14 a & b. In retrogressive winding Yc is represented as -1.

Fig 13

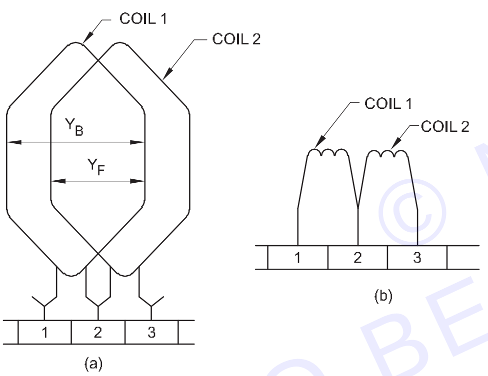
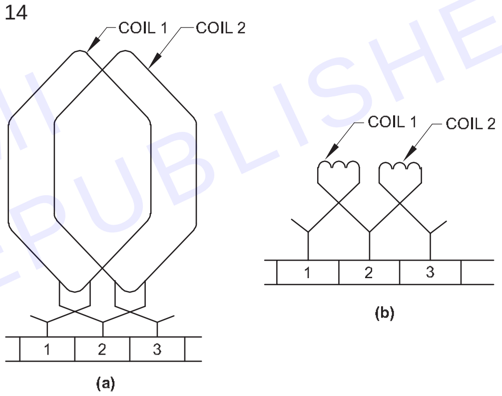


Fig 14



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Simplex lap and wave winding - developed diagram

Objectives: At the end of this lesson you shall be able to:

- state the conditions for Lap winding and wave winding
- calculate and draw the developed ring diagram for simplex lap and wave winding.

Development winding diagram : To draw the development winding diagram, the winding particulars like number of conductors, number of poles, pitches, types of windings etc. are required. For any DC armature winding, there shall be as many coils as the number of commutator segments. Further, the number of coils will be the multiple of the number of slots, i.e. for a single layer, there will be double the number of slots as that of the commutator segments and for a double layer there will as many slots as the commutator segments.

Lap winding

Conditions for lap winding : For lap winding the following terms and conditions are to be fulfilled.

- The front pitch YFand the back pitch YBshould be approximately equal to the pole-pitch YP.
- Both the front pitch YFand the back pitch YBshould be an odd number.
- The back pitch YBand the front pitch YFshould differ by 2 conductors, for simplex lap winding. In the case of multiplex winding, it is equal to 2 x No. of `plex'.

Ex. For duplex 2x2 = 4 conductors.

For triplex 2x3 = 6 conductors and so on.

The average pitch should be as given by the formula

Commutator pitch should be

Y_C = ± 1 for simplex

= ± 2 for duplex

= ± 3 for triplex and so on.

- The number of parallel paths `A' in the armature will be the multiple of the number of poles. A = P, in the case of simplex lap winding, i.e 2-pole armature winding will have 2 parallel paths, 4-pole armature winding will have 4 parallel paths and so on. However, the number of parallel paths for multiplex winding will be equal to A = P x No. of `plex'.
- There must be as many brushes as there are poles.
- The brushes must be wide enough to cover atleast m segments, where 'm ' is the 'plex' (multiplicity) of the winding.

Progressive winding

$$\text{Back pitch} Y_B = \frac{Z}{P} + 1$$

Front pitch $Y_F = Y_B$ 2 x plex

Reprogressive winding

$$\text{Front pitch} Y_F = \frac{Z}{P} + 1$$

Back pitch $Y_B = Y_F$ 2 x plex

To make the winding possible as lap-winding, Z/P must be an even number.

Considering the above points, only the armature having the designated slots can be wound for lap winding.

Calculations : The following calculations are made for finding out winding pitches and coil connections with commutator segments for simplex lap winding.

Example

No. of commutator segments	6
No. of slots	6
No. of poles	2

Type of winding simple lap.

As pointed out earlier the winding should be in double layer only.

Solution

No. of coils = No. of commutator segments = 6 coils

No. of conductors or coil sides = No. of coils x 2
= 6 x 2 = 12 conductors.

$$\text{Pole pitch} Y_P = \frac{\text{No. of slots}}{\text{No. of poles}} = 6/2 = 3 \text{ slots}$$

$$\text{Also } Y_P \text{ in terms of conductors } = \frac{\text{No. of conductors}}{\text{No. of poles}} = 12/2 = 6 \text{ conductors}$$

No. of conductors/slot = 12/6 = 2 conductors/slots.

Hence the winding is double layer winding.

$$\text{Back pitch } Y_B = \frac{Z}{P} + 1 = 12/2 + 1 = 6 + 1 = 7$$

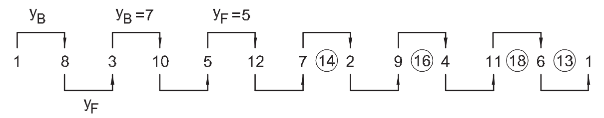
Front pitch Y_F = Y^B 2 x Plex = 7 2 = 5

Y_B = 7 and Y_F = 5 for progressive winding

Y_B = 5 and Y_F = 7 for retrogressive winding

The winding sequence of conductors for progressive lap winding is shown in Fig 1.

Fig 1



Winding Table

Coil	Conductor		Slot		Commutator segments	
	From	To	From	To	From	To
1	1	8	1	4	I	II
2	3	10	2	5	II	III
3	5	12	3	6	III	IV
4	7	2	4	1	IV	V
5	9	4	5	2	V	VI
6	11	6	6	3	VI	I

Development winding diagram for 12 conductors, 2 poles, 6 slots, 6 segments, simplex double layer lap winding

Fig 2 shows the arrangement of coils in the respective slots and the connection of the coils with the segments.

Development diagram with conductors : Fig 3 shows the arrangement of armature conductors in the slots and connections to commutator segments.

Fig 2

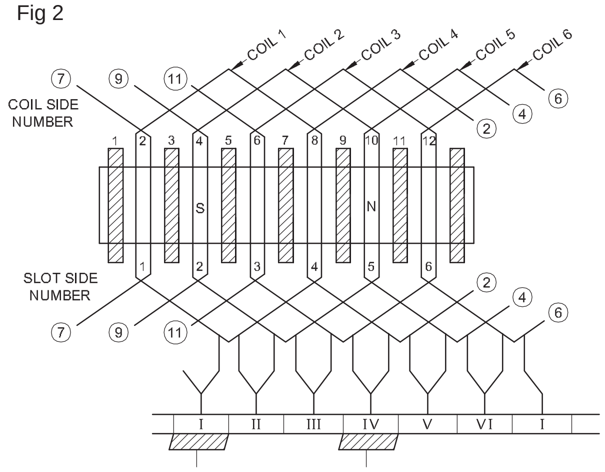
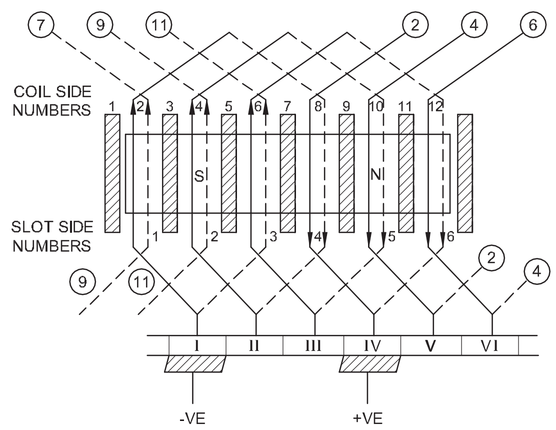


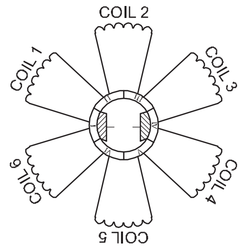
Fig 3



Ring diagram : Fig 4 shows the connection of 6 coils with the commutator segments in the form of a ring diagram.

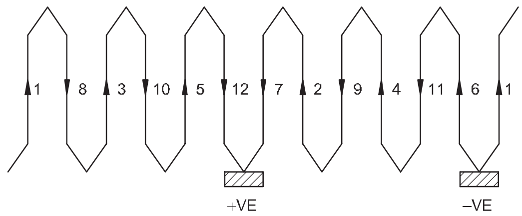
Sequence diagram : This diagram is mainly used to trace the direction of current in the coil sides (conductors). With the help of this diagram the brush position can be located. (Fig 5)

Fig 4



RING DIAGRAM

Fig 5



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Wave winding

Conditions for wave winding : For wave winding, the following terms and conditions should be fulfilled.

- The front pitch YF and back pitch YB should be approximately equal to the pole pitch YP.
- Both the front pitch YF and the back pitch YB should be an odd number.
- The back pitch YB and the front pitch YF may be of the same value or may differ by 2 conductors, in the case of simplex, and the same or 2 or 4 conductors for multiplex wave winding, depending upon the condition

$$Y_A = \frac{Y_B + Y_F}{2} \quad \text{approximately}$$

- The average pitch should be as given by the formula

$$Y_A = \frac{Y_B + Y_F}{2} \quad \text{(or)}$$

$$Y_A = \frac{\text{No.of conductors} \pm 2 \text{ x plex}}{\text{No. of poles}}$$

$$Y_A = \frac{Z \pm 2}{P} \text{ for simplex wave winding}$$

$$= \frac{Z + 2}{P} \text{ for progressive simplex wave winding}$$

$$= \frac{Z - 2}{P} \text{ for retrogressive simplex wave winding}$$

$$Y_A = \frac{Z \pm 4}{P} \text{ for duplex wave winding}$$

$$Y_A = \frac{Z \pm 6}{P} \text{ for triplex wave winding and so on}$$

$$Y_C = \frac{\text{No.of commutator segments} \pm m}{\text{Pairs of poles}} = \frac{C \pm m}{p/2}$$

where Y_c is the commutator pitch

C = total number of commutator segments

p = number of poles

m = the plex of the winding.

The commutator pitch Ycshall be equal to the average pitch Y_A. Y_c= YA

The resultant pitch is the sum of the front and back pitches. $Y_R = Y_B + YF$

- The number of coil sides must satisfy the following relations.

  $Z = P \times Y_A \pm 2$ where P is the number of poles.

- In the case of simplex wave winding the number of parallel paths `A' is equal to 2 only, irrespective of the number of poles. However the number of parallel paths increases in multiples of the plex of the windings.

  Eg. A = 2 x plex.

Considering the above points, only an armature having designated slots can be wound for wave winding.

- Two brushes are necessary, but as many brushes as there are poles may be used, and they must be set so that they short-circuit only the coils cutting no flux.
- The brushes must be wide enough to cover atleast `m' segments where 'm' is the 'plex' of the winding.

Calculations : The following calculations are made for finding out winding pitches and coil connections with commutator segments for simplex wave winding.

Example

Number of commutator segments	7 Nos.
Number of slots	7 Nos.
Number of poles	2 Nos.
Type of winding	Wave.

Winding table

1 The number of coils = Number of commutator segments = 7 coils.

2 The number of conductors or No. of coil sides = No. of coils x 2 = 7 x 2 = 14 conductors.

3 Pole pitch $Y_P = \frac{\text{No.of slots}}{\text{No. of poles}} = 7/2 = 3.5$ slots,

say 3 slots

Also, $Y_P = \frac{\text{No.of conductors}}{\text{No. of poles}} = 14/2 = 7$ conductors

4 No. of conductors/slot = 14/7 = 2 conductors/slot. Hence, the winding is double layer.

5 Average pitch $Y_A = \frac{Z \pm 2}{P}$

$= \frac{14+2}{2} = 16/2 = 8$ (for progressive winding).

$= \frac{14-2}{2} = 12/2 = 6$ (for retrogressive winding).

Hence $Y_A = Y_C = 8$ or 6.

6 Taking $Y_A = 8$ for progressive winding we have

$2Y_A = 2 \times 8 = 16 = Y_B + Y_F$

$Y_B \quad Y_F = 2$

$Y_B + Y_F = 16.$

Hence back pitch $Y_B = 9$ and front pitch $Y_F = 7$.

Taking YA= 6 for retrogressive winding we have

$2Y_A = 2 \times 6 = 12 = Y_B + Y_F$

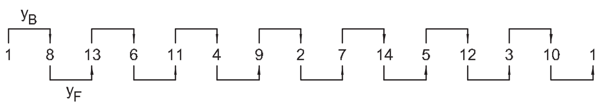
$Y_B - Y_F = 12$.

Hence, back pitch $Y_B = 7$ and front pitch $Y_F = 5$ for retrogressive wave winding.

The winding sequence of conductors for retrogressive wave winding is shown in Fig 6.

$Y_B = 7$, $Y_F = 5$.

Fig 6



Winding Table

Coil	Conductor		Slot		Commutator segments	
	From	To	From	To	From	To
1	1	8	1	4	I	VII
2	13	6	7	3	VII	VI
3	11	4	6	2	VI	V
4	9	2	5	1	V	IV
5	7	14	4	7	IV	III
6	5	12	3	6	III	II
7	3	10	2	5	II	I

Development winding diagram for 14 conductors, 2 poles, 7 slots, 7 segments, simplex, double layer wave winding

Development diagram with coil connection : Fig 7 shows the arrangement of coils in their respective slots and their connection to the segments.

Development diagram with conductors : Fig 8 shows the arrangement of armature conductors in the slots and the connection to commutator segments.

Fig 7

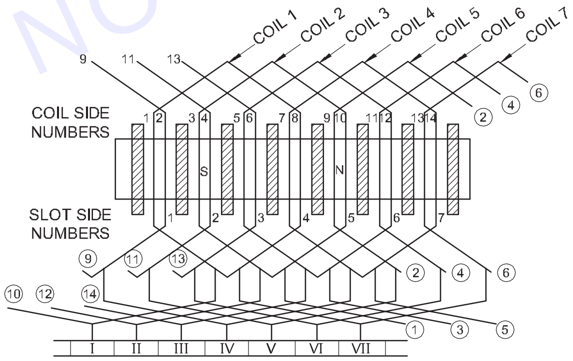
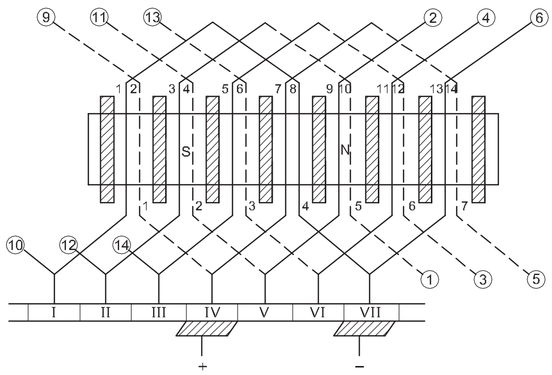


Fig 8



Ring diagram : The ring diagram of wave winding in the case of a 2-pole armature will appear similar to that of lap winding, but the coil ends will be connected as shown in Fig 9.

Sequence diagram : This diagram (Fig 10) is mainly used to trace the current direction of the coil sides (conductors) and, thereby, locate the brush position. Please note the brush is placed at a distance of 3 commutator segments i.e. less than 180° geometrical (app.155°).

Fig 9

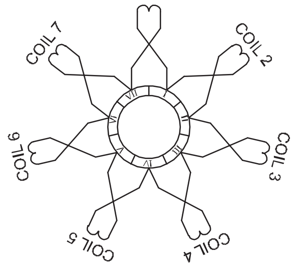
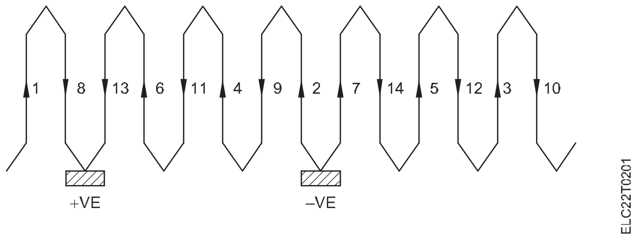


Fig 10



Testing of armature winding

Objectives: At the end of this lesson you shall be able to:

- describe the methods of testing armature, such as the
  – winding resistance test
  – insulation resistance test
  – growler test
  – voltage drop test..

Testing the winding : After an armature is wound and the leads are connected to the commutator, a test should be conducted. From this test, defects may be revealed, which might have occurred during winding. The common defects in armature windings are grounding, shorts in the coils, open in the coil and reversal in the coil connection. These defects can be located by different test procedures.

Armature winding resistance test : Resistance of the armature coil is measured by using a low range ohmmeter and preferably with the Kelvin bridge. Resistance between consecutive segments in the case of simplex lap winding (for wave and multiplex windings at a distance of commutator pitch Yc) is measured. Fig 1 shows a simple arrangement to measure the resistance between the successive commutator segments.

As shown in Fig 1, a cotton tape with a counterweight is passed around the commutator to hold the connecting leads to the segments. Measurement of resistance is done in all the coils by changing the position of the connecting leads to successive commutator segments. The resistance measured should be the same in all coils. Lower resistance shows short in turns, while a higher resistance shows higher numbers of turns or open in the coil.

Insulation resistance test : With a bare copper wire short all the commutator segments. (Fig 2) Test the insulation resistance between the body and the commutator segments by a 500V Megger, for armatures rated up to 250 volts. The IR so measured shall be greater than 1 megohm. If the value is less than 1 megohm, moisture in the winding or a weak insulation is to be suspected.

Fig 1

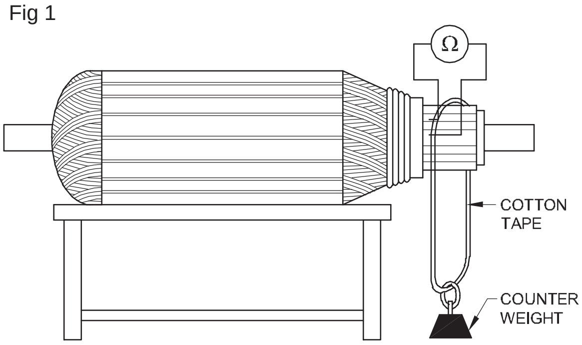
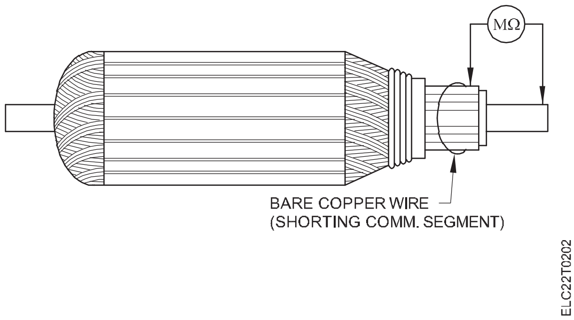


Fig 2



This test is sometimes conducted by a series test lamp and is called the 'ground test'. It will only indicate if any coil is grounded, and not the insulation resistance.

Growler test : A simple and most common method to test armature winding for short and open coils is by a growler.

Growler : There are two types of growlers - 1) internal and 2) external growlers. An external growler is used for testing small armatures and an internal growler for large DC armatures and AC motor stator windings.

External growler : An external growler, shown in Fig 3, is an electromagnetic device that is used to detect and locate grounded, shorted and open coils in an armature.

This growler consists of a coil wound around an iron core and is connected to a 240 volt AC line. The core is generally H shaped and cut out on top so that the armature will fit on it, as shown in Fig 4.

When an alternating current is applied to the growler coil, the voltage will be induced in the armature coils by transformer action.

Fig 3

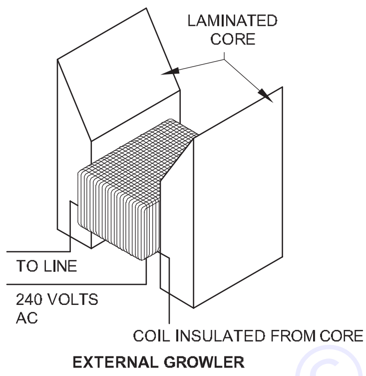
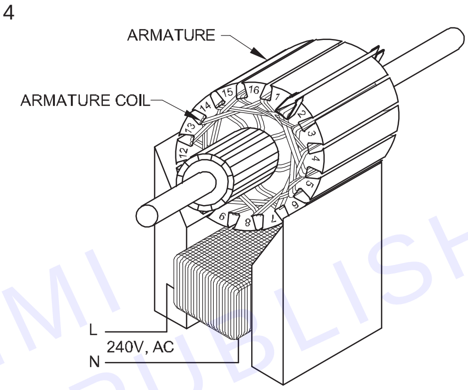


Fig 4



Internal growler : An internal growler, such as the one used for stators, may be used for armatures as well. These are made with or without built-in feelers. The growler with a built-in feeler has a flexible blade attached to the growler so that a hacksaw blade or similar instrument is not necessary. This type is especially desirable in smaller stators that have no room for a separate feeler. Fig 5 shows an internal growler with a separate feeler, used for large armatures.

Growler test for grounded coil : The armature to be tested is placed on the growler and then the growler is switched 'ON'. Place one lead of an AC milli-voltmeter on the top commutator bar and the other meter lead on the shaft, as shown in Fig 6.

Fig 5

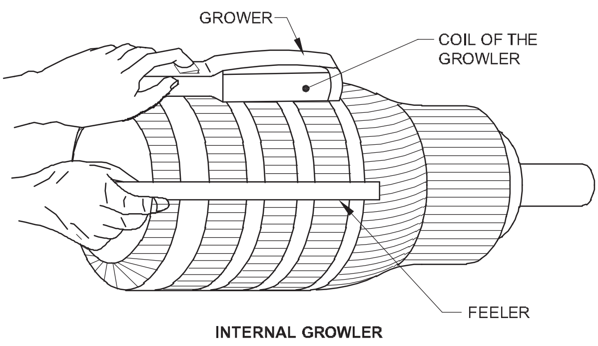
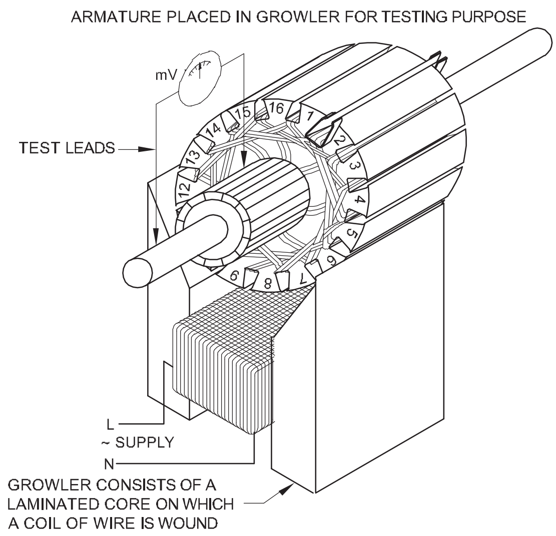


Fig 6



If a reading is noticed on the meter, turn the armature so that the next commutator bar is in the same position as the earlier one, and test as before. Continue in this manner until all the bars are tested. Where the meter gives no deflection, it is an indication that the grounded coil is connected to this particular bar.

Growler test for shorted coil : The procedure to test for short circuits in an armature is as follows.

The armature to be tested is placed on the growler and then the growler is switched on. A thin piece of metal, such as a hacksaw blade, is held over the top slot of the armature as shown in Fig 7. In case of short in the winding, the blade will vibrate rapidly and create a growling noise. If the blade remains stationary, it is an indication that no short exists in the coil under test. After several top slots have been given the hacksaw blade test, turn the armature so that the next few slots are on top. Test as before and continue this procedure for the entire armature.

An armature having cross connections or equalizers cannot be given the hacksaw blade test. This type of armature will cause the blade to vibrate at every slot, which would seem to indicate that possibly every coil is shorted.

Test for open coil : Growlers are also provided with meters (milli-volt or ammeter) on the panel with variable resistance. In this case an open in the armature coil can be found out as follows.

Growler test for an open coil : To locate an open coil with a growler, set up the armature on the growler in the usual manner. Test the top two adjacent bars with an AC milli-voltmeter as shown in Fig 8. Rotate the armature and continue testing the adjacent bars. When the milli-voltmeter bridges the two bars connected to the open coil, the meter pointer will not deflect. All the other bars will give a deflection. This test for an open coil can be made without the meter by shorting the two top bars with a piece of wire. Absence of a spark indicates that the coil is open. The open may be either at the commutator bar or in the coil itself. The procedure may be used to determine the location of the leads of a shorted coil. However, the hacksaw blade test is the most satisfactory method of determining a shorted coil.

Fig 7

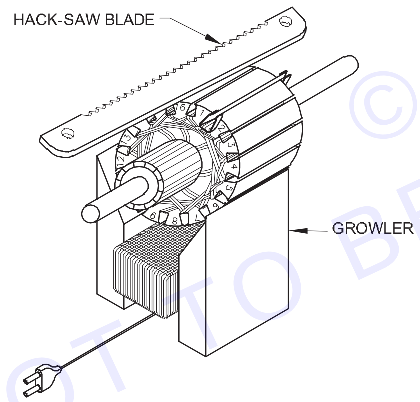
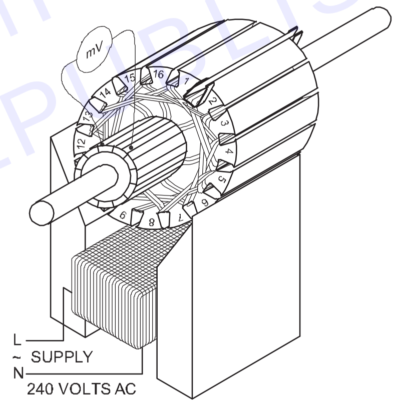


Fig 8



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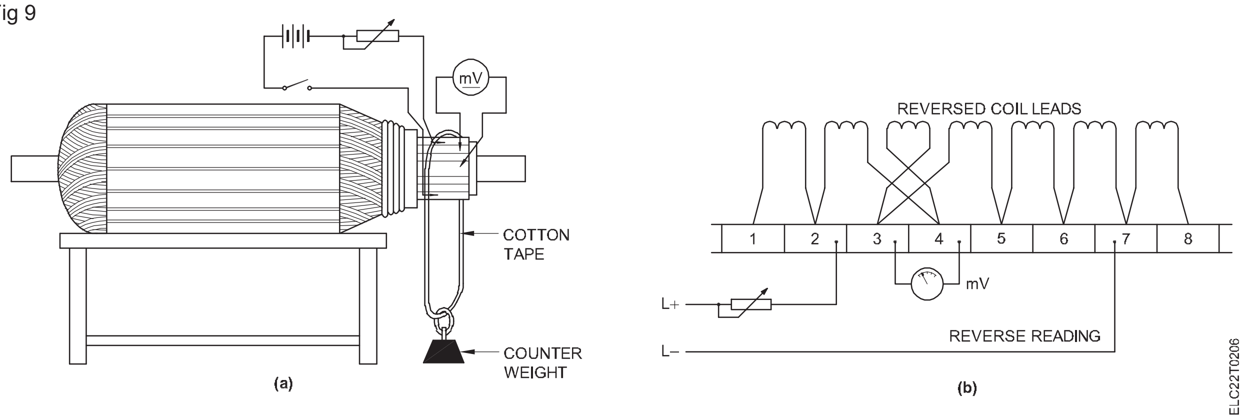
Drop test : The most accurate method of testing the armature for correct resistance, number of turns, short and open and reversed coil connection is by the drop test. Connect a low voltage DC supply across the commutator segments at a distance of pole pitch. Insert a variable resistance in series with the circuit. Switch 'ON' the DC supply and connect a milli-voltmeter to the adjacent segments as in Fig 9a and b.

Adjust the readings to a specified value, by using a variable rheostat. Record the milli-voltmeter readings on the consequent commutator segments by rotating the armature in one direction. The position of the segments and the connection should be the same as in the first set up. The result could be concluded as enumerated below.

- If all the readings are the same, the winding is correct.
- If the milli-voltmeter reads zero or low voltage, the coil connected to the segment is short.
- If the milli-voltmeter reads high voltage, the coil connected to the segment is open.
- If the milli-voltmeter deflects in the reverse direction as shown in Fig 9b, the coil connected with the segment is reversed.

Generally armatures are tested as a routine for insulation resistance and for shorted coils. Only when a fault in the armature winding is suspected, a drop test is conducted.

Fig 9



Winding a small transformer

Objectives: At the end of this lesson you shall be able to:

- state the important data to be taken for rewinding the transformer
- explain the rewinding procedure for small transformers
- calculate the number of turns per volt using the formula and determine primary and secondary turns
- determine the dimensions of the transformer, size of bobbin and size of winding wire
- explain the tests to be carried out after winding the transformer.

Rewinding of small transformer

It is necessary to rewind a transformer when the winding is burnt out or badly damaged.

While dismantling transformers, care should be taken to record the necessary particulars (data) by which the rewinding process becomes easy and the original performance of the transformer is assured.

Recording the data : The following data have to be taken from the transformer before and during disassembling.

1 Number of windings/turns/ layers.

2 Size of wires and insulation.

3 Input/output voltages & currents.

4 KVA ratings.

5 Conncetion diagrams.

6 Terminal marking / lead position

7 Types of cores / number of stampings

8 Physical condition of bobin / core.

9 Insulation schemes like size and specification of bindings, layer,interlayer,inter windings, bobin,lead wires, sleeves etc.

If the old bobbin is reused for winding, it shall be cleaned well and shall be free from any break or crack. If a new bobbin is used it shall be checked with the stamping (core) for proper assembly to avoid too much air gap or too tight a fitting.

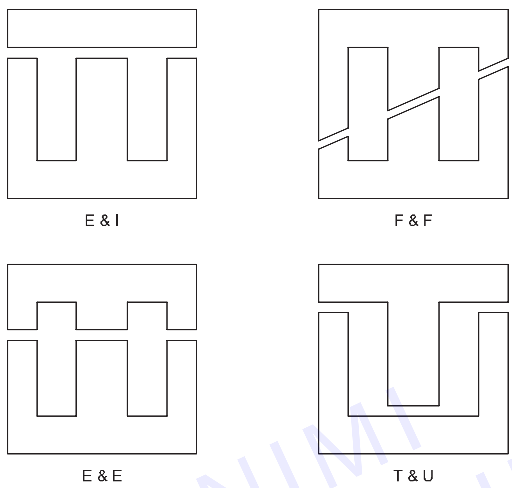
For winding, a suitable size of wire shall be selected from the data and the size of wire shall be measured as per I.S. 4800 (Part - I) 1968.

The size of the wire can be measured with insulation but it shall be within the limit of tolerance. The insulation scheme shall be followed as per the data taken. Where proper material is not available an equivalent type and size may be selected. Turns and tapping of the winding shall be made as in the original.

Method of stacking : Before stacking the core, stampings shall be checked for dents, bends and core insulation. Dents on the core shall be removed, and any mangled core shall be set right. Stacking shall be done as in the original sequence and pattern.

All the stampings available for the transformer shall be stacked without leaving out any. Fig 1 shows the different shapes of cores used for a shell type transformer. Leads shall be properly sleeved and terminated.

Fig 1



Procedure of rewinding a transformer: As stated above, if all the necessary winding details are obtained while disassembling the burnt out transformer, the rewinding procedure is more or less easy. However, if you have to prepare a new transformer the following information will be of great help.

Designing a transformer : Small transformers are generally of 'SHELL TYPE'. In shell type, both the primary and secondary windings are mounted on the centre limb of the core. For designing of a small power transformer proceed as stated below.

STEP NO.1

Find the total output power from the load voltage and current of the transformer.

$P_2 = E_2 \times I_2$ ....Formula 1.

The following example is given for your guidance.

Primary voltage - 240 V

Secondary voltage - 6V

Secondary total current - 2A

From the example the output power is calculated as 6 x 2 = 12VA.

STEP NO.2

Find the input watts.

$$P_1 = \frac{P_2}{\%\,\text{Efficiency}}$$ .... Formula 2

Normally the efficiency of a transformer will be 80 to 90. As in the example

$$P_1 = \frac{6 \times 2 \times 100}{80} = 15\ \text{VA.}$$

STEP NO.3

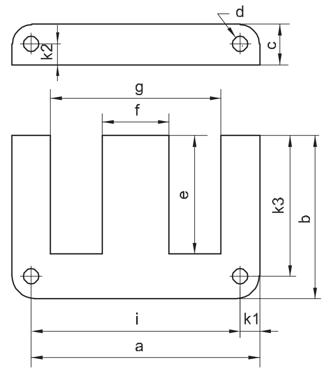
Determine the required cross-sectional area of the core of the transformer.

For finding the cross-sectional area, certain parameters like the flux density of the metal used for laminations, frequency of supply, allowable current density in the winding wire and power input to the transformer need to be known.

Cross section = 20 x 21=420 sq.mm or 4.2 sq. cm

Table 1 gives the standard size of stampings having E and I type laminations as available in the market which is given for your guidance. Fig 2 gives the dimensions of the stampings.

Fig 2



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For the core area 4.248 sq.cm we can use the core of dimension having 20 mm as width and core thickness of 21mm.

The nearest size sheet should be selected from the standard size of the stamping table. Here we assume the centre limb width to be 20 mm, and hence, the core E.I. 60 is selected. However, you may select any other type to suit the cross-section. But the other details like the number of stampings and the bobbin dimensions may change accordingly.

STEP NO.4

The next step is to calculate the voltage per turn using Formula 4.

$e = 4.44 \times B \times A \times f \times 10^{-4}$ ....Formula 4.

where e - voltage per turn

B - flux density in tesla

A - area of iron core in cm2

f - frequency in Hertz

Example

e = 4.44 x 0.8 x 4.24 x 50 x 10-4 = 0.0753 volts.

STEP NO.5

Calculate the primary coil turns.

$$N_1 = \frac{240}{0.0753} = 3187 \text{ turns (approx.)}$$

Calculate the secondary coil turns.

$$N_2 = \frac{6}{0.0753} = 80 \text{ turns (approx.)}$$

Add 10% to compensate the voltage drop (internal) in the secondary winding i.e. N2 = 88 turns.

STEP NO.6

Calculate the size of wire with respect to the input power.

P = E x I ; I = P/E and according to the example,

Primary current = I_1 = 15/240 = 0.0625A

Secondary current = I_2 = 15/6 = 2.5A.

Cross-section of primary conductor considering 3A/mm2 as current density will be

A = 0.0625/3 = 0.020833 mm2

Diameter = 0.1628 mm

Say i.e. = 0.160 mm dia. or 37 SWG approximately

Cross-section of secondary conductor considering 3A/mm2 as current density will be

A = 2.5/3A = 0.8333 mm2

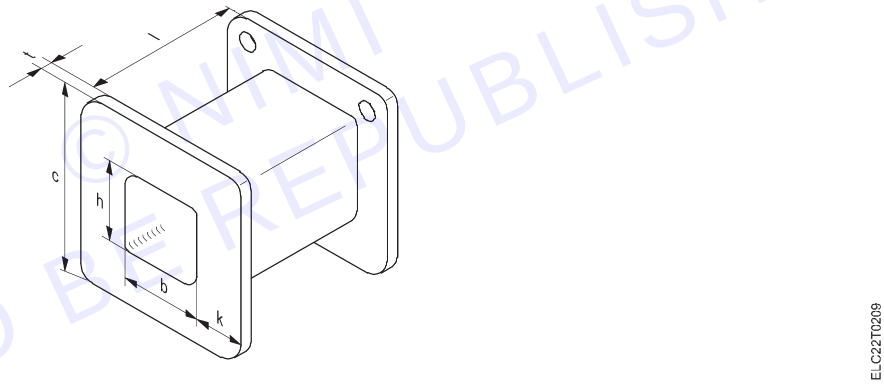
Diameter = 1.029 mm

Say = 1.00 mm dia. Hence 19 SWG.

STEP NO.7

Fig 3 gives the general dimensions of a bobbin. Here the bobbin selected is EI 60/21 which suits the core thickness of the centre limb taken earlier as 21 mm and core width as 20 mm.

Fig 3



STEP NO.8 : Check the feasibility of accommodating the number of turns of primary and secondary within the winding space.

Though the number of turns in the primary is to be 3187 of 37 SWG and the secondary to be 88 turns of 19 SWG super enamelled copper wire, it is atmost important to check whether these windings along with the respective insulation could be accommodated within the winding space of the core. This has to be determined before taking up the winding.

CONCLUSION : For the transformer as in the example, the derived winding data is as follows.

Transformer rating

Primary - 240V

Secondary - 6V

Frequency - 50 Hz

Volt ampere input - 15 VA

Core : Core area 20 x 21 mm as decided in Step 3.

Bobbin: Breadth 20.6 mm, height 21 mm, length 26.7 mm and the total height of the flange 42.7 mm as decided in step 7.

Wire sizes and turns

Primary - 3187 turns of size 0.16 mm or 37 SWG

Secondary - 88 turns of size 1.00 mm or 19 SWG

Stampings: Considering the thickness of each stamping as 0.35 mm, for the total thickness of 21 mm we may require 60 stampings. Considering the space between stampings and the stacking we may require 55 stampings only. Hence EI 60/21 type 55 numbers of stampings having 0.35 mm thickness are to be procured.

Testing of transformer after rewinding: After rewinding the core assembly, the transformer is to be inspected for proper tightness of the core and coil as well as proper termination of the end leads.

Insulation resistance test : Insulation resistance is measured between windings and core with a 500 volts Megger. The reading so obtained shall be infinity and in no case below one megohm.

Transformation ratio test: Keeping the transformer secondary open, the primary shall be connected to the rated AC voltage. With the help of suitable voltmeters both the primary and secondary voltage shall be measured.

Load test : The transformer shall be connected with a suitable load, so that the full load secondary current flows through the secondary of the transformer winding. The raise in the winding temperature shall be observed by a suitable industrial thermometer, on the load.

The transformer temperature will raise initially and after some time the temperature will come to a standstill. This raise in temperature shall be noted and it shall be within the limit of class of insulation of the transformer designed.

Short circuit test : Where it is not possible to load the transformer directly, the secondary winding of the transformer shall be short circuited and the low voltage on the primary shall be adjusted through a dimmerstat so that full load secondary current flows through the secondary winding of the transformer. The transformer so switched on shall be tested for raise in temperature to ascertain the class of insulation.

Generally oil-cooled transformers are of class-A where-as air-cooled transformers may be class

Table 1

Standard size of stampings

Specification of stampings	a	b	c	d	e	f	g	i	k1	k2	k3
EI42	42	28	7	3.5	21	14	28	35	3.5	—	24.5
EI48	48	52	8	3.5	24	16	32	40	4	—	28
EI54	54	36	9	3.5	27	18	36	45	4.5	—	31.5
EI60	60	40	10	3.5	30	20	40	50	5	—	35
EI66	66	44	11	4.5	33	22	44	55	5.5	—	38.5
EI78	78	52	13	4.5	39	26	52	65	6.5	—	45.5
EI84	84	56	14	4.5	42	28	56	70	7	—	49
EI92	92	62.3	11.3	4.5	51	23	69	82	5	6.5	57.5
EI106	106	70.5	14.5	5.5	56	29	77	94	6	8.5	64.5
EI130	130	87.5	17.5	6.8	70	35	95	115	7.5	10	80
EI150	150	100	20	7.8	80	40	110	135	7.5	12.5	92.5
EI170	170	117.5	22.5	8	95	45	125	150	10	12.5	107.5
EI195	195	134.5	25.5	9.5	109	51	144	171	12	13.5	122.5
EI231	231	166	29	10	137	58	173	204	13.5	15.5	152.5

Nominal thickness of stampings:0.35 mm and 0.5 mm. 'A' or 'E'.

AC motor startor re-winding

Objectives: At the end of this lesson you shall be able to:
- tate the terms used in AC winding
- explain the different types of AC winding.

Fundamental terms used in AC Winding: Before taking up AC winding, the trainee should be familiar with the terms used in AC winding as explained in the following paragraphs.

Coil : A number of turns connected in series is called a coil. A coil has two active sides and two inactive sides.

Turn: It is the closed path of the conductor which is formed by connecting the two inductors under two dissimilar poles N and S. (Fig 1)

Active side of a coil : It is that part of the coil which lies in the slots of the core. It is also known as an inductor. (Fig 1)

Inactive side of a coil : It is the portion of the coil which joins the two active sides of a coil. (Fig 1)

Leads of a coil : These are the two ends of a coil which are used for the connection. Leads are also known as jumpers which may be symmetrical or unsymmetrical as shown in Fig 2.

Fig 1

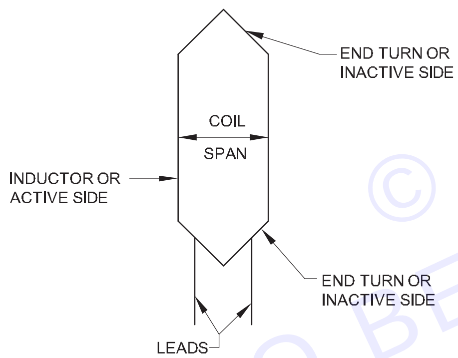
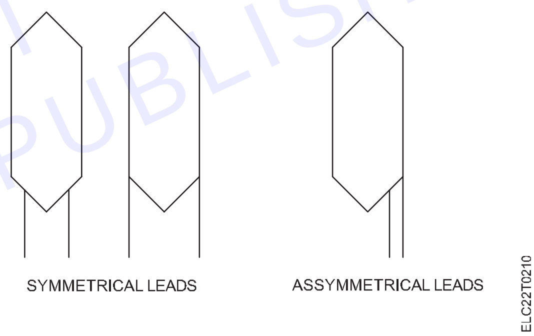


Fig 2



Pole pitch : The distance between the centre of two adjacent opposite poles is called the pole pitch. Pole pitch is measured in terms of slots or coil sides.

$$\text{Pole pitch} = \frac{\text{No. of slots in the stator}}{\text{No. of poles}}$$

Coil pitch/span and coil throw : The distance between the two active sides of a coil under adjacent dissimilar poles is called coil pitch/span. Fig 3 shows the coil pitch/span and coil throw (i.e. coil pitch/span = 4 and coil throw is 1-5).

Pitch factor : Winding pitch need not be equal to the pole pitch. If the pole pitch and winding pitch are equal, the winding is called full pitched winding. If the winding pitch is less than the pole pitch, the winding is called fractional pitch winding or short pitch winding. While rewinding, the original winding pitch should not be changed. The machine designer would have chosen the winding pitch after considering the different factors required for the better performance of the machine. Any change in the original winding pitch of a machine will affect the performance of that machine. If the winding pitch is 4, then the coil throw is 1 to 5, and one side of the coil is placed in slot No.1 and the other side of the coil is inserted in slot No.5 as shown in Fig 3. Then the winding pitch is 5-1 = 4. The ratio between the winding pitch and pole pitch is called the pitch factor.

$$\text{Pitch factor} = \frac{\text{Winding pitch}}{\text{Pole pitch}}$$

Short pitch winding is usually used in almost all machines except variable speed motors. The reasons for adopting short pitch winding are given below.

1 Winding requires less copper.

2 Copper loss is less.

3 Efficiency of the machine is increased.

4 Winding occupies less space.

5 In alternators, the winding produces uniform sine wave.

Coil group : When you observe the direction of the current flow in a coil, you will see current in the two coil sides have opposite directions as shown in Fig 4(a).

Fig 3

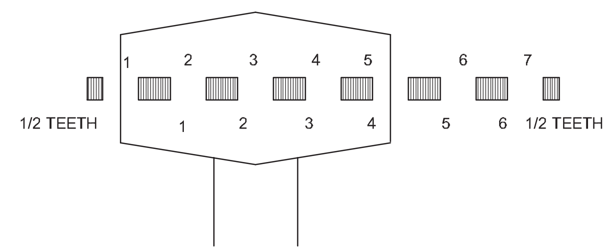
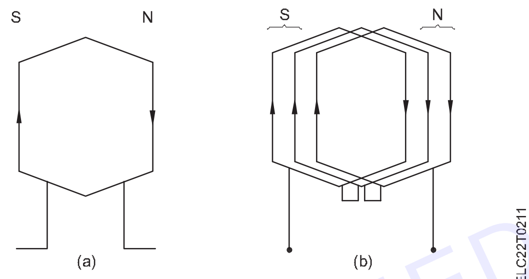


Fig 4



Accordingly the current in a single coil produces two dissimilar poles. In an ordinary winding, according to the design, one or more coils may be connected in series to form a group as shown in Fig 4(b).(Three coils form one group) The total number of coil groups in a winding is equal to the number of phases multiplied by the number of poles.

Total No.of coil groups = No. of phases x No. of poles

$$\text{Coil group per phase} = \frac{\text{Total No. of coil groups}}{\text{No. of phases}}$$

$$\text{Coil group per phase per pole} = \frac{\text{Total No. of coil groups}}{\text{No. of phases x No. of poles}}$$

Further the number of coils in a group per phase per pole

$$= \frac{\text{Total number of coils}}{\text{No. of phases x No. of poles}}$$

$$= \frac{\text{Total number of coils}}{\text{Total number of groups}}$$

Coil connections : The connection which joins a coil lead of one coil to the other coil lead of the same coil group is called 'coil connection' and is shown in Fig 5.

Pole connection : The connection which joins a coil group of one phase to another coil group of the same phase of the winding is called pole connection or group connection, and is shown in Fig 5.

Whole-coil winding: A whole coil winding is one in which the number of coils per phase is equal to the number of poles in the machine. Refer to Fig 6.

Fig 5

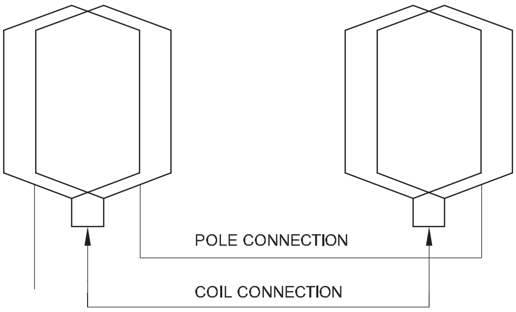
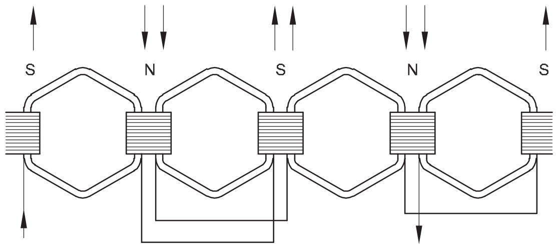


Fig 6



FULL COIL WINDING 4-COILS 4-POLES RIGHT TO RIGHT OR LEFT TO LEFT CONNECTION

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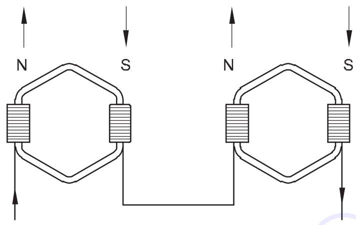
Half coil winding : A half coil winding is one in which the number of coils per phase is equal to half the number of poles in the machines. Half coil winding is generally done in the winding of ceiling fans, double speed motors etc. Refer to Fig 7.

Single layer winding : In single layer winding each slot contains only one coil side as shown in Fig 8 and the number of coils in the machine is equal to half the number of slots in the stator or armature. In single layer winding the coil pitch is usually taken in odd numbers.

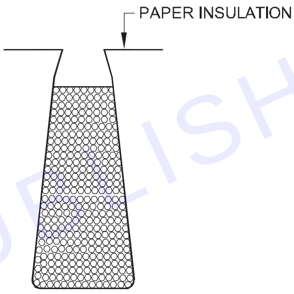
Fig 7



HALF COIL WINDING 2-COILS 4-POLES

RIGHT TO LEFT OR LEFT TO RIGHT CONNECTION

Fig 8



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Double layer winding : In double layer winding each slot contains two coil sides (i.e.one upper and one lower) as shown in Fig 9 and the number of coils is equal to the number of slots in the stator.

Balanced winding : When the coil groups contain the same number of coils per phase per pole the winding is termed as 'balanced winding'. It is also known as 'Even Group' winding and is shown in Fig 10.

Fig 9

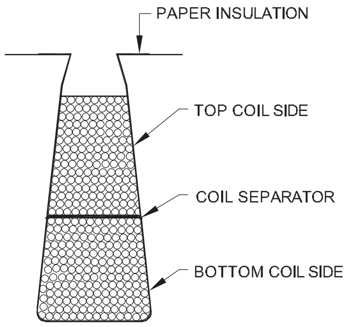
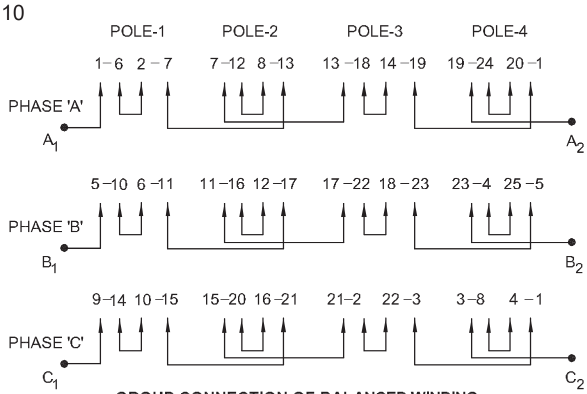


Fig 10



GROUP CONNECTION OF BALANCED WINDING

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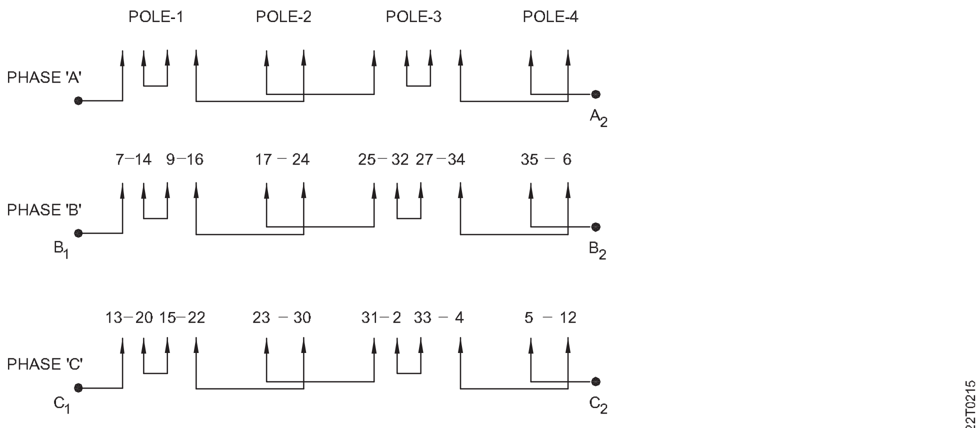
Unbalanced winding : If the coil group contains an unequal number of coils per phase per pole then the winding is called 'unbalanced winding'. It is also sometimes called 'odd group' winding and is shown in Fig 11.

It is important that there must be an equal number of coils in each phase whether the winding is balanced or unbalanced as shown in Figs 10 and 11.

Concentrated winding : If in any winding the number of coils/pole/phase is one, then the winding is known as 'concentrated winding'. In this winding each coil side occupies one slot.

Distributed winding : In this winding the number of coil/pole/phase is more than one - arranged in different slots. In this case each coil has the same pole pitch.

Fig 11



GROUP CONNECTION OF UNBALANCED WINDING

Partially distributed winding: In this winding the coil sides do not occupy all the slots, but some slots remain empty and they are called dummy slots.

Fully distributed winding : It is a winding in which not a single slot remain empty.

Different types of AC Windings

The types of AC windings according to shape are as follows.

a Basket winding

b Concentric winding

c Skein winding

d Flat loop Non-overlapped winding

e Flat loop overlapped or chain winding

f Skew winding

g Diamond coil winding

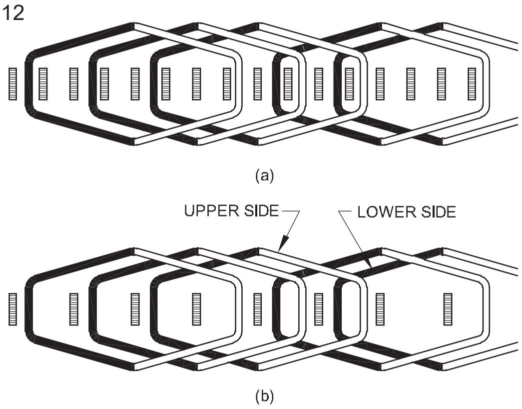
h Involute coil winding

Basket winding : After the completion of the winding, the ends of the winding resemble the weaving of a basket and hence it is known as basket winding. Basket winding is of two types. a) Single layer basket winding as shown in Fig 12a, double layer basket winding as shown in Fig 12b.

Concentric (or box type) winding : This winding has two or more than two coils in a group, and the coils in each group have the same centre. In each group, the coil pitch is not equal, and, therefore, do not overlap each other.

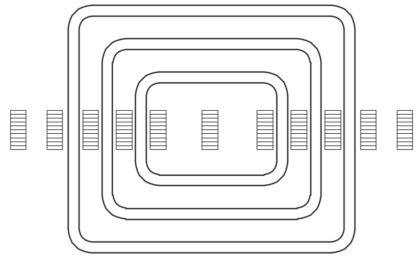
In this winding the coil pitches are not equal and each coil of the group has a difference of 2 slots in its pitch. Though it requires more labour to insert coils due to different coil spans, the design allows more cooling space. This winding is usually provided in single phase motor winding. This is shown in Fig 13.

Fig 12



BASKET WINDING

Fig 13



CONCENTRIC WINDING

ELC22T0216

3 phase squirrel cage induction motor winding (single layer distributed winding)

Objectives: At the end of this lesson you shall be able to:

- explain the winding terms and calculations pertaining to single layer distributed type winding
- explain how to draw the end and coil connection diagrams
- state how to draw the ring and developed diagrams.

Distributed type winding: The most common type of winding found in 3-phase motors is the distributed type winding. A distributed type winding is one in which the size of all the coils, coil pitch and shape will be the same as these coils are normally former wound. By virtue of the arrangement of these coils in slots, the coils overlap each other. Distributed winding may be of single or double layer type.

Single layer winding : Single layer winding is one in which there will be as many coils as half the number of slots. For example 6 coils in the case of 12 slots, 12 coils in case of 24 slots, 18 coils in the case of 36 slots and so on. In short, there will be only one coil side per slot.

Calculation for single layer distributed winding : The winding data of the distributed single layer winding will be within the following limitation. (As an example 3- phase, 24 slots, 12 coils, 4 poles is illustrated below).

I Grouping

i) $\text{No. of coils/phase} = \frac{\text{Total No. of coils}}{\text{No. of phases}}$

As in the example

No. of coils per phase = 12/3 = 4 coils/phase.

ii For whole coil connection

$$\text{No. of coils/phase/pole} = \frac{\text{Total No. of coils}}{\text{No. of phases} \times \text{No. of poles}}$$

As in the example

$$\text{No. of coils/phase/pole} = \frac{12}{3 \times 4} = 1\,\text{coil/phase/pole}$$

iii For half coil connection

$$\text{No. of coils/phase/pair of poles} = \frac{\text{Total No. of coils}}{\text{No. of phases} \times \text{pair of poles}}$$

As in the example

$$\text{For each phase and pair of poles} = \frac{12}{3 \times 2}$$
$$= 2 \text{ coils / phase / pair of poles}$$

For the example taken, half coil connection is possible for distributed winding by taking full pitch and placing coil in alternate two slots., but it is not in practice. Hence whole coil connection is taken as an example.

II Pitch

$$\text{Pole pitch} = \frac{\text{Total No. of slots}}{\text{No. of poles}}$$

As in the example, pole pitch = 24/4 = 6 slots.

ii Coil pitch

In AC winding the relation between the coil pitch and the pole pitch is given below.

a Coil pitch = Pole pitch Then the winding is called full pitch winding.

b Coil pitch < Pole pitch Then the winding is called fractional pitch - short chorded winding.

c Coil pitch > Pole pitch Then the winding is called as fractional pitch - long chorded winding.

Further, if the winding is double layer, all the above 'a', 'b' and 'c' are possible. But for single layer distributed winding as the coils should be placed in alternate slots only, the coil pitch ought to be in odd number.

As in the example, coil pitch = pole pitch = 24/4 = 6 slots.

Here 6 is an even number and winding cannot be of full pitch, so the next alternative is to select a fractional pitch. Therefore the coil pitch can be taken either as 5 or 7. Normally AC windings should either have full pitch or short chorded fractional pitch. Hence a suitable pitch is taken of 5 slots.

iii Coil throw

The coil throw for coil pitch '5' as in the example is 1 - 6.

III Electrical degrees

i Total electrical degrees = 180º x No. of poles

(180º is the distance between poles)

ii $$\text{Slot distance} = \frac{180^0 \times \text{No. of poles}}{\text{No. of slots}}$$

As in the example: Slot distance = (180x4)/24 = 30º

IV Phase displacement

i For three-phase winding, displacement between the phases should be 120º .

ii Phase displacement in terms of slots = 120o/slot distance

As in the example, 120º/30º = 4 slots

V Winding sequence

In three-phase winding the distance between the starting end of one phase to the starting end of another phase should have 120 electrical degrees. Hence we should arrange the winding such that

'A' phase starts from say 1st slot

'B' phase starts from 1st slot + 120o and

'C' phase starts from 1st slot + 120o + 120o.

As in the above example, 'A' phase starts from say 1st slot

'B' phase should start from 1+4 = 5th slot

'C' phase should start from 1+4+4 = 9th slot.

VI Arrangement of coils

As the winding is in a single layer, the coil shall be placed in alternate slots i.e. if one coil side of coil number one is placed in slot number one which is an odd number, the other coil side of the first coil should be laid in an even number slot. Hence placement of coils should start in slot numbers 1,3,5,7,9 and so on leaving the slot numbers 2,4,6,8 and so on to receive the other coil sides of the coils.

As in the example the 12 coils are to be laid in slots (pitch = 5 slots)

1-6, 3-8, 5-10, 7-12, 9-14, 11-16, 13-18, 15-20,

17-22, 19-24, 21-26(2), 23-28(4).

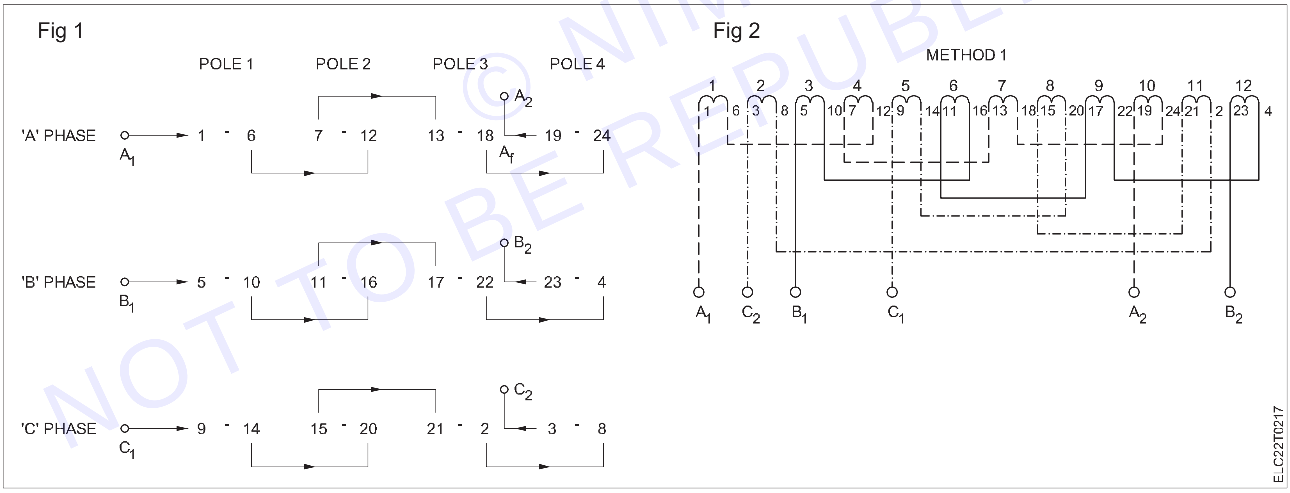
VII End connections

As discussed, for grouping of coils in normal practice, the end connections shall be whole coil connection. As in the example in Fig 1.

VIII Coil connections

In whole coil connection, the connection of the coil group shall be from finish to finish and start to start for the group of coils.

There are several ways of connecting the coils in groups. Fig 2 shows one method and Fig 3 shows another method. However, you are advised to check the formation of the poles with the help of a ring diagram and clock rule. The procedure is explained in the subsequent paras.



IX Ring diagram

Cross check the end connections as follows. Write the end connection table and mark the direction of current using the clock rule. Note that when three-phase supply is given to the windings, and if two phases carry current inward , the third phase will carry current outward.

Referring to method 1 shown in Fig 2, the current direction in the coil sides could be marked as shown in Fig 4.

Now arrange the slots in the sequential order and mark the direction of current in the slots accordingly by arrows which ultimately shall represent production of the required number of poles as shown in Fig 5.

Developed winding diagram: The development winding diagram will give a clear picture of the coil sides in relevant slots grouping, coil end connections and lead termination. A 24 slots, 12 coil, 4 pole, 3 phase single layer distributed winding development diagram is shown in Fig 6 for your guidance.

Fig 3

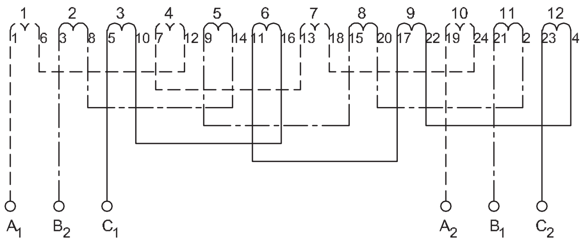


Fig 4

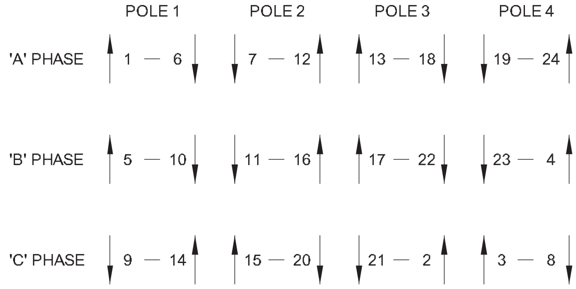


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Fig 5

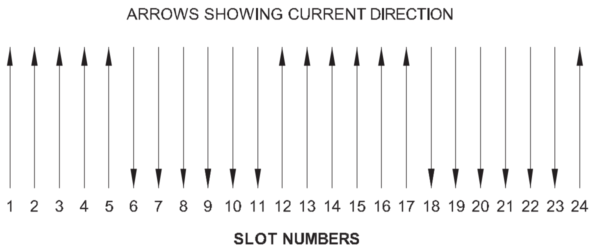
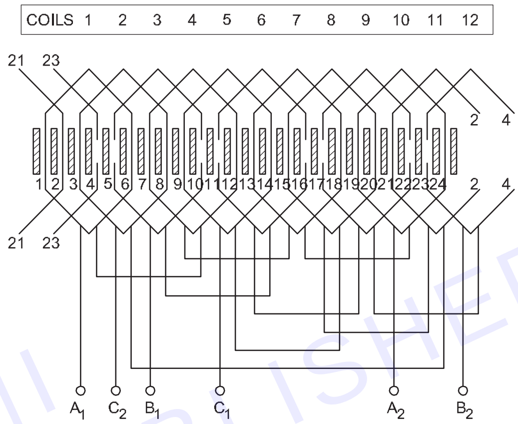


Fig 6



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Method of placing coils in a basket or distributed winding

Objectives: At the end of this lesson you shall be able to:

- state the various methods employed to prepare gang or group of coils
- explain the method of placing coils in the single layer basket winding
- explain the method of placing coils in a double layer basket winding.

The procedure outlined below is common for single or three-phase distributed winding. However this type of basket (distributed) winding is very popular in three phase motors.

The coils can be wound using a single former and then they can be interconnected by coil connections as shown in Fig 1. Most of the three-phase motors with the exception of very large ones with formed windings, use coils wound in groups as shown in Fig 2.

Fig 1

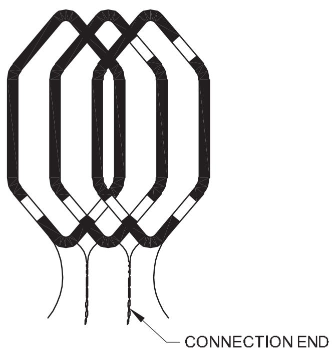
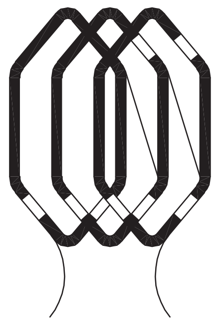


Fig 2



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The number of coils in each group will depend on the number of phases and number of poles. This practice of winding coils in groups is called group or gang winding.

In group winding several coils are wound before the wire is cut. This saves time and space by eliminating the necessity of connecting coils to one another then soldering them and then insulating them.

Fig 3 shows a winding head mounted on a bench type coil winding drive. The wire is wound around six wheels mounted on a shaft. Other types of forms are also used. Fig 4 shows a coil winder for producing oval or round coils.

Fig 3

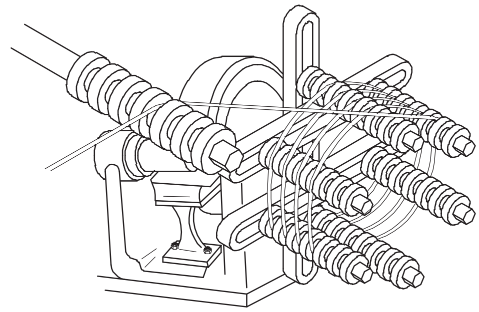
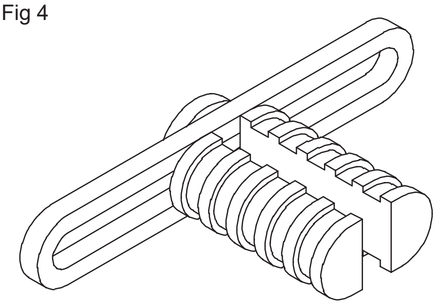


Fig 4



Coils for small motors may be wound in rectangular form and then two sides shaped into a diamond shape by pulling at the centre of the opposite ends as shown in Fig 5. Insertion of coils in single layer basket winding (formed individual coils).

In single layer winding there are half the number of coils as there are slots. For example a machine with 12 coils and 24 slots will have single layer winding. The appearance of a single layer winding is shown in Fig 6 in which the coil pitch is 1-6. While placing coils in a single layer we have to place the coil sides in alternate slots only.

Fig 5

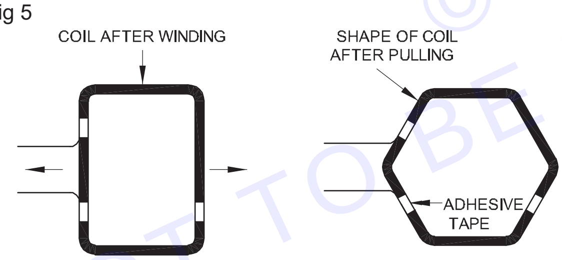
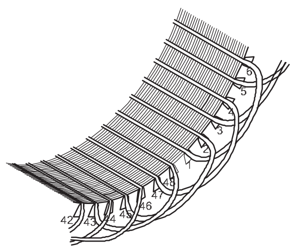
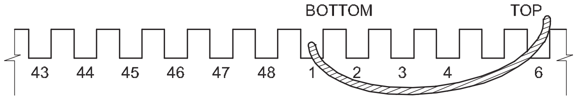


Fig 6



Let us take for example a 48 slot 24 coil 8 pole motor with the coil pitch of 1 to 6. Fig 7 illustrates the way in which the single layer winding is to be placed in the slot. This will be noticed from the diagrams there is only one coil side per slot. Fig 7 shows one coil side of the first coil placed in slot number 1.

Fig 7



Generally any slot can be identified as slot 1 with the help of chalk markings or a spot of paint. The other coil side of the same coil is left out on the core. This coil is called a throw coil. The left out coil side may lie in the right hand side as shown in Fig 7 or left hand side of the stator, when viewed from the connection end. However this depends upon the original winding pattern. The coil overhanging ends can be wrapped up to 2/3 of the length with a cotton tape of 0.175 mm thickness. To avoid the inserted coil turns from coming out of the slot while handling other coils, it is preferred to wedge temporarily the slot using a foot (Skill Information 1203) soon after the insertion of coil is over. In single layer winding the coil sides should be placed in alternate slots as shown in Fig 8.

In Fig 8 coil 1 is placed in slot No.1 and the other coil side of the same coil is left over the stampings. To avoid damage to the left out coil side, a leatheroid paper of width larger than the width of the core is placed between the core and the coil as shown in Fig 8. After placing the coil side in the slot use the awl to fold the insulation paper (slot liner) one side over the other, slip the separator paper over the folding and then slip the formed fibre or bamboo wedge over the top of the coil. The wedge should extend about 3 to 6 mm beyond the slot liner. The procedure is shown in Fig 9.

Fig 8

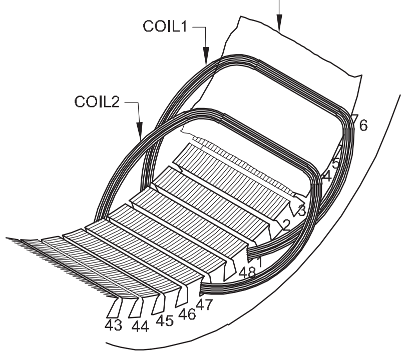
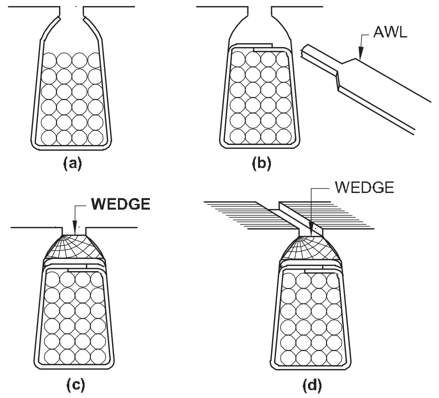


Fig 9



Some prefer to wedge the slots temporarily till all the coils are inserted and the winding is tested for grounding. Once the test results are o.k., then permanently wedge the slots.

In the next step left coil side of coil 2 is placed in slot number 47 (leaving slot No.48 which is adjacent to slot No.1) and the right coil side of coil 2 is left in the core. (Fig 8) Next place left side of the coil 3 in slot number 45 and leave the right side of the coil over the core. Remember to extend the leatheroid paper insulation between the core and the coil. By examination it will be found that the left out (right) coil side of coil No.3 which has left coil side inserted in slot No.45 should be inserted in slot 2 according to the assigned coil pitch. Now insert the left out right coil side of coil 3 in slot No.2 as shown in Fig 10.

In general, unless the left out coil side of any coil falls, according to the assigned pitch, next to the occupied slot, proceed further to insert one coil side only. Again proceed to insert the left coil side of coil 4 in slot No.43 and the right coil side of coil 4 in slot No.48 as shown in Fig 11.

Fig 10

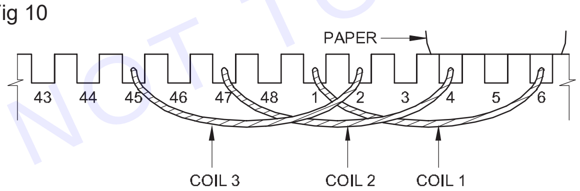
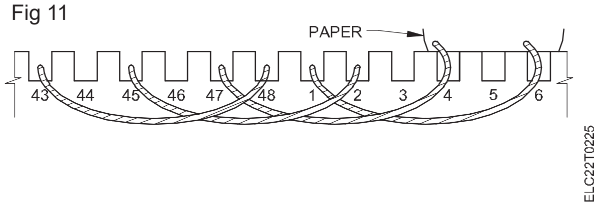


Fig 11



Proceed likewise to fill up the slots and complete the insertion of coils in the slots.

Insertion of coils in double layer (lap) winding

Let us consider a 3-phase machine with 24 slots, 24 coils, 4 poles and having a slot pitch of 1-6 and a coil pitch 1-12 in terms of coil sides.

ASSUMPTION: Individual coils numbering 24 are former wound and kept ready . Procedure given below is for the developed winding diagram shown in Fig 12.

Accordingly Fig 13 shows the numbered slots. Table 1 shows the position of the coil sides in the slots. The coil sides in the bottom are given odd numbers and the coil sides of top are given even numbers.

Fig 12

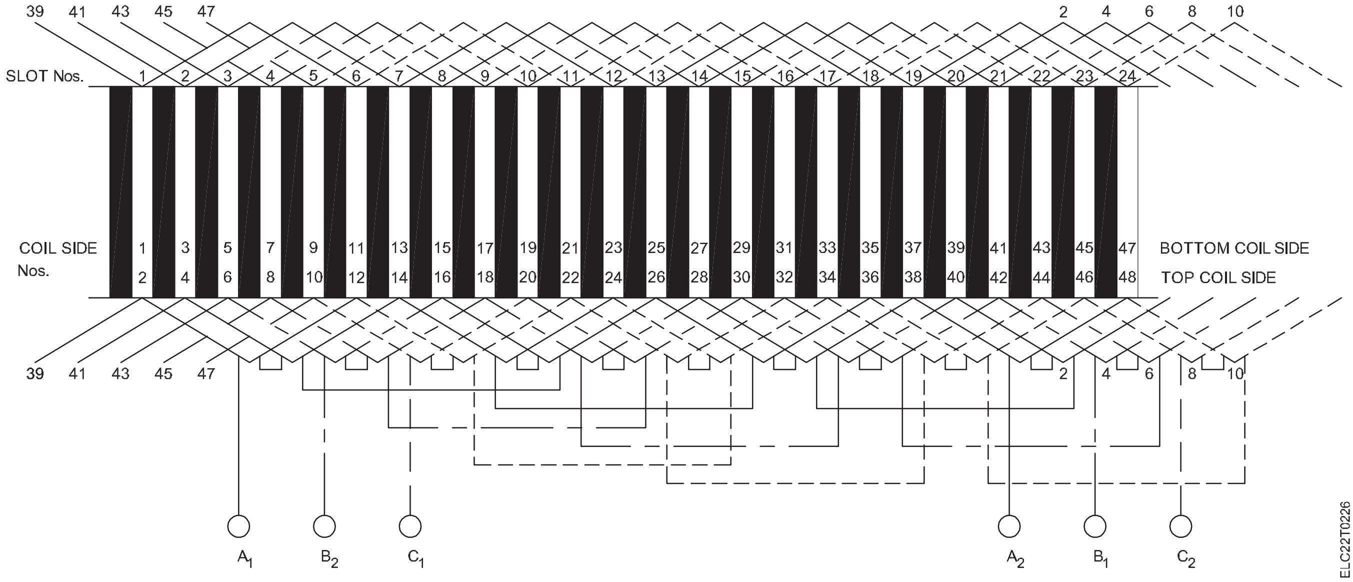


Table 1

Slot	Bottom	Top
1	1	2
2	3	4
3	5	6
4	7	8
5	9	10
6	11	12
7	13	14
8	15	16
9	17	18
10	19	20
11	21	22
12	23	24
13	25	26
14	27	28
15	29	30
16	31	32
17	33	34
18	35	36
19	37	38
20	39	40
21	41	42
22	43	44
23	45	46
24	47	48

Winding is arranged such that looking from the connection end, the bottom coil is on the left side and the top coil sides is in the right side as shown in Figs 13 and 14.

Fig 13

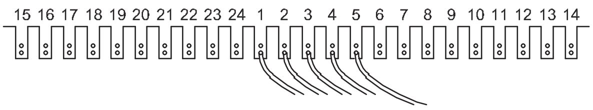
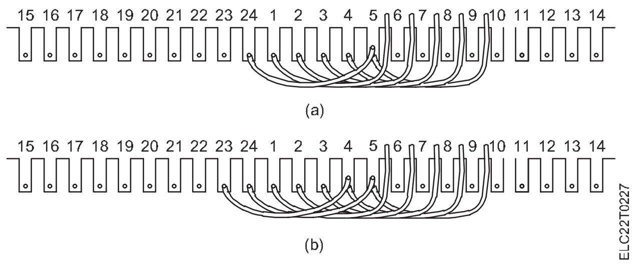


Fig 14



Further the connection end of the winding in the stator is to be identified from the data with respect to the terminal box.

Referring to the developed diagram (Fig 12) and Table 1, if the bottom coil side 1 is inserted in slot 1, then the other coil side of the same coil which is 12, should be inserted in the slot number 6 as a top coil side. As such there should be a certain approved procedure to start the winding.

Proceed as, first insert one coil in slot number 5 and leave the other coil side on the core. Use a suitable fibre foot or wedge for slot 5 to secure the winding. (Fig 15). To avoid damage to the insulation in the process of winding, insert a thick leatheroid paper of a width larger than the core between the left out coil side and the core, as shown in Fig 8. Let the length of the leatheroid paper be sufficient enough to cover 5 coil sides at a stretch.

Insert the coils in slot numbers 4,3,2 and 1 in sequence as shown in Fig 13 and wedge them temporarily as shown in Fig 15. Let the other coil side lie on the core with the protected leatheroid paper between the coils and the core. These coils are called throw coils. For the protection of insulation of the throw coil you can tie the bunch of coil sides together with a cotton tape and tie the whole lot to the stator as shown in Fig 16. Remember to ensure the leatheroid paper is well kept between the bunched coils and the core.

Fig 15

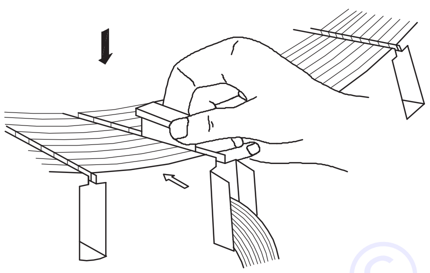
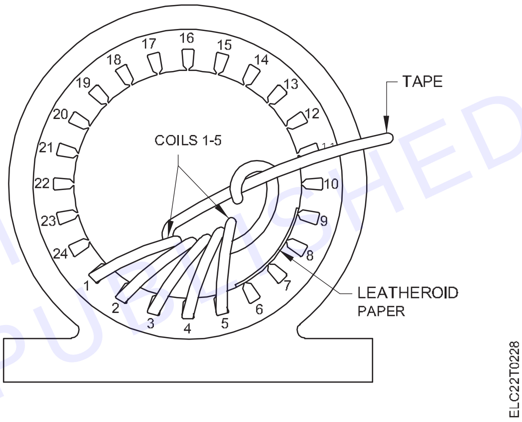


Fig 16



Use of coil separation : Before inserting the top coil side over the bottom coil side of the same slot it is necessary to insulate the coil sides inside the slot by the use of coil seperators. This is because each coil side within one slot may belong to different phases and the voltage between them may be high.

Fig 17

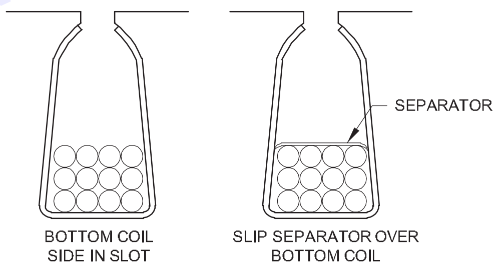
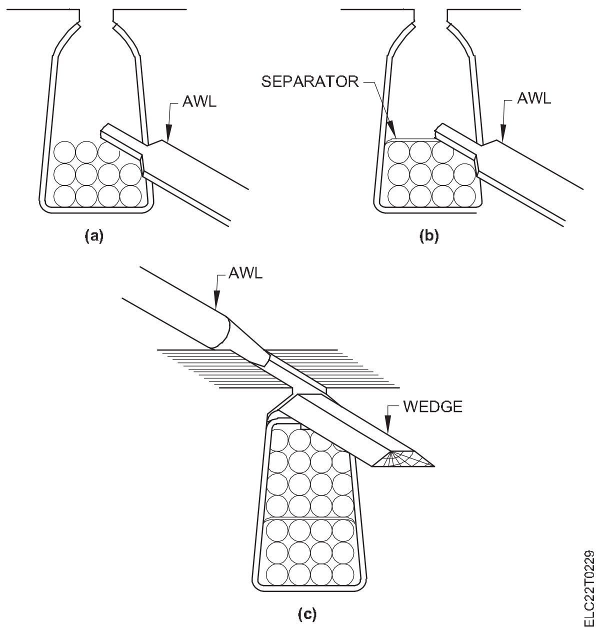


Fig 18



To insulate the coil sides from each other within the slot follow the procedure shown in Fig 17 for both open and semi-closed slots. A creased separator or insulation paper of proper width, length and thickness (usually 0.25 to 0.375 mm) is used as insulation between the top and bottom coil sides in the slot. Slide an awl over the bottom coil side as shown in Fig 18a and press it over the bottom coil and slide the separator underneath the awl as shown in Fig 18b. Let the separator project about 10mm beyond the core on either side.

Method of overlapping : Now insert one coil side in slot number 24 (coil side 47) and the other coil side of the same coil (coil side 10) in slot number 5 as the top coil over the bottom coil side 9. Likewise insert another coil side 45 of a next coil in slot number 23 and the other coil side 7 of the same coil in slot number 4. Proceed likewise till you reach slot number 6. During this process as you reach near about the 10th slot or much earlier you will feel the hindrance of the throw coils which are tied to the stator. At that time untie the cotton tape from the stator and tie the bunch in the opposite side of the stator as shown in Fig 19 with a leatheroid paper in between the coils and the core.

While tieing the cotton tape see that the slot number 6 is easily approachable without any difficulty. After inserting the bottom coil side 11 in slot 6 insert the corresponding other coil side 22 in slot 11 as the top coil side. After inserting the top coil side fold the slot liners one side over the other, insert the separator and the wedge.

Now untie the throw coil bunch and release the free end of the coil in slot 5 and insert the same as top coil side in slot 10. Proceed likewise to insert the coils from slots 4,3,2 and 1 in the corresponding slots.

Overhang Insulation : Now cut and prepare the leatheroid paper to the shape of half moon as in the original which is to be used as phase insulation between the overhanging coils. According to the developed diagram coil sides 1 and 3 form the first phase, 5 and 7 the second phase and 9 and 11 form the 3rd phase. Identify these coils and start inserting the leatheroid paper between 3 and 5 as well as between 7 and 9.

Thus proceed to insert this phase insulation for the entire winding as shown in Fig 20. If you find the space between these coils is less, you may use a fibre wedge to prime the coils to facilitate insertion of the leatheroid paper. Do not use too much force which may crack the slot liner insulation and result in grounding the coils with the stator core.

End connections : There are three types of connections to be made - first the coil connection for coil grouping, second for connecting the coil groups in one phase, and thirdly connecting the lead wires. Better to proceed one by one in the above sequence. Any connection to be made in winding the wires should start with proper identification of the coil ends. For a beginner, it may be necessary to refer to the developed diagram, connection diagram, as well as the actual winding often to eradicate the confusion.

Fig 19

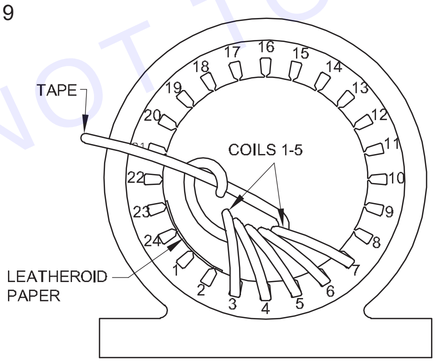
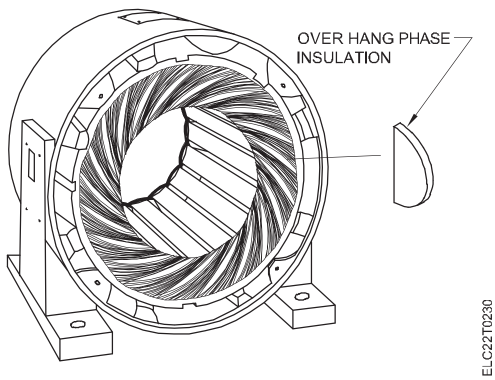


Fig 20



Three-phase induction motor winding (single layer - concentric type - half coil connection)

Objectives: At the end of this lesson you shall be able to:

- state the general requirements pertaining to the concentric type of winding in 3-phase motors
- state the merits and demerits of concentric type winding
- explain the preparation of a winding table for concentric type winding
- explain how to draw the end and coil connection diagrams
- explain how to draw the developed and ring diagrams.

3-phase concentric winding : In general, concentric winding is found in single phase motors, and occasionally, this type of winding is also used for 3-phase motors.

This concentric winding has to have two or more coils in a group consisting of different pitches. Further in 3- phase concentric winding, all the three phases consist of the same number of coils, and produce similar concentric poles. Stepped formers are used to prepare coils for concentric winding.

Merits and Demerits of concentric winding: This type of winding has some merits and demerits also.

Merits

1 This type of winding has more space for cooling.

2 No need of raising (lifting) the coil sides to interleave them during the winding.

3 It is easy to shape the coils uniformly.

4 Possible to save copper, because in distributed winding all the coils are of the same size; on the other hand in concentric winding, coil groups only will be uniform, but coils of different pitches in concentric form are used.

5 As there is no interleaving of the coil sides, the winding could be done by machine resulting in faster production.

6 It is easy to make the end connection.

7 Easy to wind, as there is no overlapping of coils.

Demerits

1 Skilled labour is required to insert the coils in the slots.

2 A stepped former is required.

3 Not as efficient as basket winding.

1 Grouping

The example given below will clarify the following:

a whether concentric type of winding is possible for a given stator

b If yes, whether it should be half coil or whole coil connected winding.

Example

3-phase induction motor having 36 slots 12 coils 4 pole stator

We have

$$\text{No. of coils per phase} = \frac{\text{Total No. of coils}}{\text{No. of phases}}$$

$$= \frac{12}{3} = 4 \text{ coils/phase}$$

For whole coil connection

$$\text{No. of coils/phase/pole} = \frac{\text{No. of coils/phase}}{\text{No. of poles}}$$

$$= \frac{4}{4} = 1 \text{coils/phase/pole}$$

As such there will be only one coil in a group. But concentric winding should have two or more coils in a group. In this case concentric winding is not possible. Alternatively grouping can be done for half-coil connection, i.e.

$$\text{No. of coils/phase/pair of poles} = \frac{\text{Total No. of coils}}{\text{No. of phase x No. of pair of poles}}$$

$$\text{As per the example } \frac{12}{3 \text{ x } 2} = 2 \text{ coils}$$

i.e. 2 coils/phase/pair of poles.

As per the above example, only half-coil connected concentric winding is possible whereas for the following example having data 48 slots, 24 coils, 4-pole, 3-phase stator winding both whole coil and half coil connections are possible. Hence it is necessary to trace the group connection very carefully before stripping the stator to determine whether the winding connection is whole coil or half coil.

2 Pitch

1

$$\text{Pole pitch} = \frac{\text{No. of slots}}{\text{No. of poles}}$$

$$\text{As per the example } \frac{24}{4} = 6 \text{ slots}$$

As the winding is concentric, there should be 2 or more pitches normally. According to the above example 2 pitches for half-coil connections are required.

Further it is necessary to have the average pitch equal i.e. to the pole pitch.

(i.e.) coil pitch = pole pitch +1

As per the example coil pitch is 6+1.

Therefore outer coil pitch = 6 + 1 = 7

and inner coil pitch will be = 6 - 1 = 5

(i.e.) Coil throw = 1 - 8 and 1 - 6 In practice it is written as 1 - 8 and 2 - 7.

3 Electrical degrees

i Total electrical degrees = 180º x No. of poles.

As per the example = 180º x 4 = 720º.

ii Slot distance in degrees $= \frac{180° \text{ x } 4}{\text{No.of slots}}$

$$= \frac{180° \text{ x } 4}{24} = 30°$$

4 Phase displacement

i For three-phase winding phase displacement should be equal to 120o

ii Phase displacement in terms of slots

$$= \frac{120°}{\text{slot distance in degrees}}$$

$$\text{As per the example} = \frac{120°}{30°} = 4 \text{ slots}$$

5 Winding sequence

As per the example

A phase starts from 1st slot.

B phase starts from 1+4 = 5th slot and

C phase starts from 1+4+4 = 9th slot.

6 Arrangement of coils

As in the example 12 coils with pitches as 7 & 5 slots.

1-8,2-7; 5-12, 6-11; 9-16, 10-15; 13-20, 14-19; 17-24, 18-23; 21-4, 22-3.

Grouping of coils

The coil should start from every alternate 2 slots (i.e.) 2 slots for top sides and two slots for bottom sides. As per the example, coils start from 1 & 2, 5 & 6, 9 & 10, 13 & 14, 17 & 18, 21 & 22.

As the connection is half-coil type, with the help of one group of coils, 2 poles need to be created. Hence grouping is as follows:

A	B	C
1-8, 2-7	5-12, 6-11	9-16, 10-15
13-20, 14-19	17-24, 18-23	21-4, 22-3

In whole coil connection, the starting end connection is from the alternative groups (i.e.) if 'A' starts from the first group, 'B' starts from third group and 'C' starts from fifth group. Whereas in half-coil connection, the starting ends will be from continous group, if 'A' starts from the first group, 'B' starts from second group and 'C' starts from the third group. Refer to the developed diagram.

7 End connections (Fig 1): Half coil connection.(End to start and start to end)

Coil connections : Half coil connection. (Fig 2)

In half coil connection, the connection of the coil group shall be from the finish end to the start end and then from the start end to the finish end of the group coils as shown in Fig 2.

Fig 1

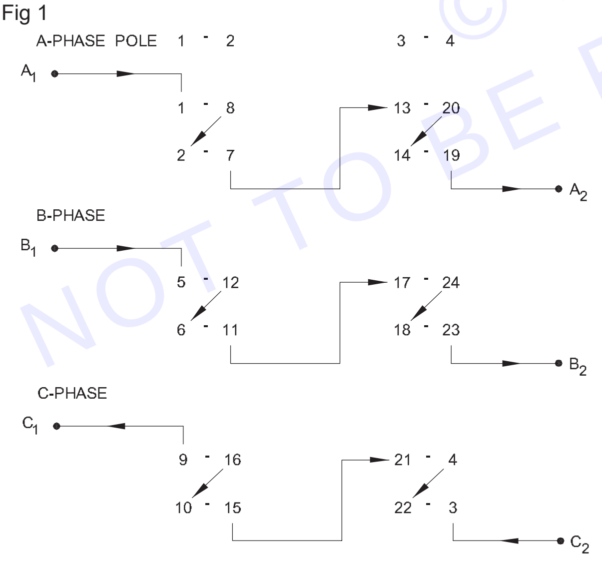
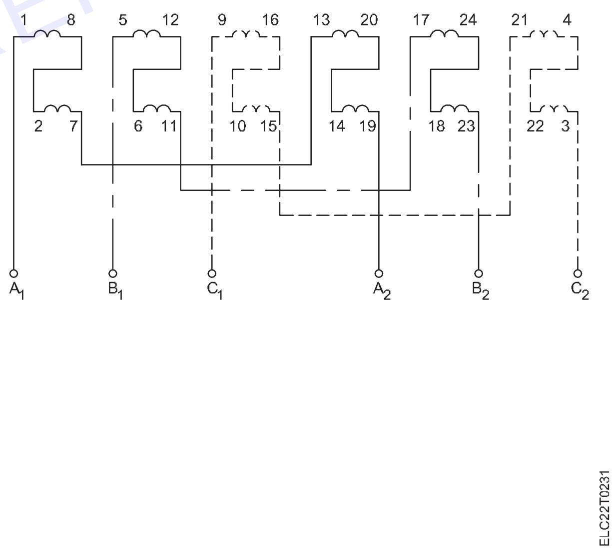


Fig 2



Development diagram : Draw the development diagram showing the coil group and end connection. As an example a development diagram is shown in Fig 3.

Ring diagram

Cross check the end connection with the help of the ring diagram as explained below. Write the end connection table and mark the direction of current using the clock rule. Note that when a three-phase supply is given to the windings at an instant, and if two phases carry current in one direction, the third phase carries current in the opposite direction as shown in Fig 4.

Fig 3

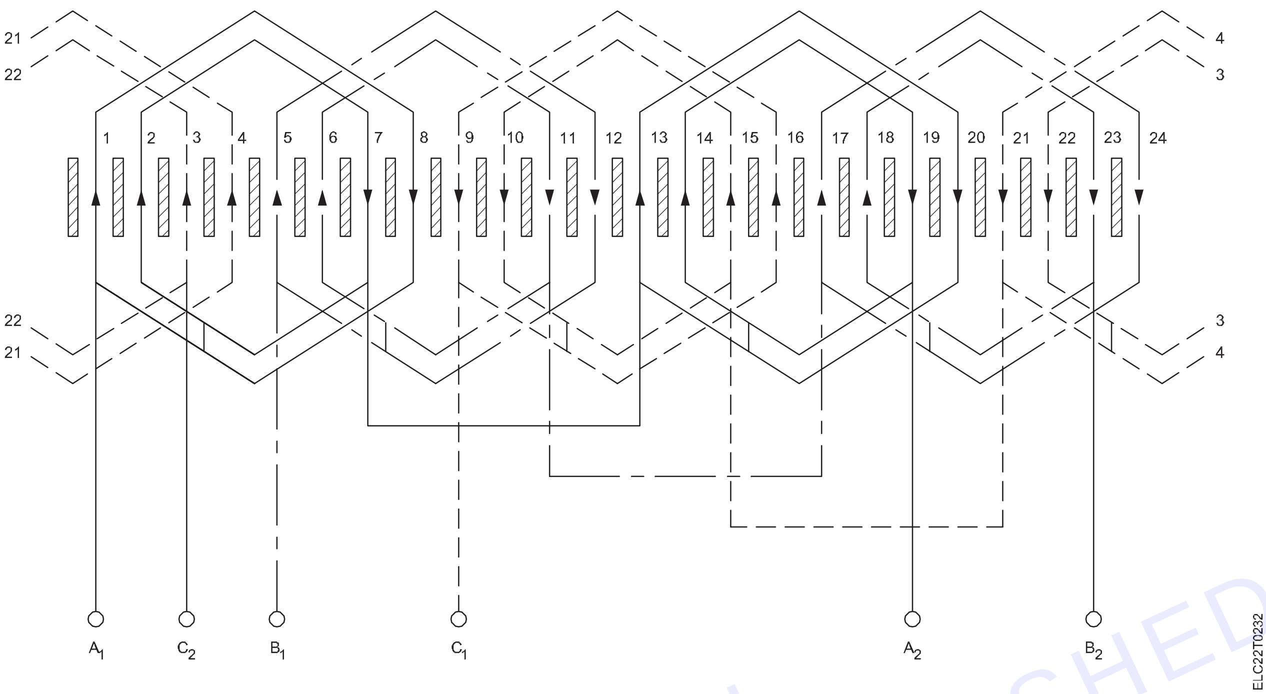
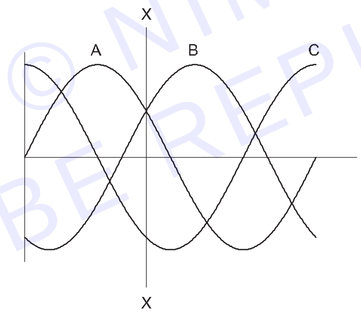


Fig 4



PHASE	P_1 & P_2	P_3 & P_4
A phase	↑ 1 - 8 ↓	↑ 13 - 20 ↓
	↑ 2 - 7 ↓	↑ 14 - 19 ↓
B phase	↑ 5 - 12 ↓	↑ 17 - 24 ↓
	↑ 6 - 11 ↓	↑ 18 - 23 ↓
C phase	↓ 9 - 16 ↑	↓ 21 - 4 ↑
	↓ 10 -15 ↑	↓ 22 - 3 ↑

Refer to Fig 4 in which at the instant shown in x-x we have phases A and B as positive polarity and C has negative polarity.

Mark the direction of current in the slot and it shall represent production of the required number of poles as per the example given below.

Whenever you come across a 3-phase induction motor having a single layer concentric type half coil winding follow the above mentioned procedure and prepare the winding table. Subsequently draw the end connection, development and ring diagrams.

↑ ↑ ↑ ↑ ↑ ↑	↓ ↓ ↓ ↓ ↓ ↓	↑ ↑ ↑ ↑ ↑ ↑	↓ ↓ ↓ ↓ ↓ ↓
1 2 3 4 5 6	7 8 9 10 11 12	13 14 15 16 17 18	19 20 21 22 23 24
N	S	N	S

3 phase squirrel cage induction motor - double layer distributed type winding

Objectives: At the end of this lesson you shall be able to:

- explain the meaning of double layer winding
- explain the winding terms and calculations pertaining to double layer distributed type winding
- draw the end and coil connection diagrams
- draw the ring and developed diagrams.

There are different types of winding used in 3-phase AC motors. Some of the 3-phase windings are double layer, that is, there will be as many coils as the number of slots. For example 12 coils in the case of 12 slots, 24 coils in the case of 24 slots. 36 coils in the case of 36 slots, 48 coils in the case 48 slots. Further in the case of distributed winding the size of all the coils, pitch and shape will be the same as these coils are normally former wound. By virtue of the arrangement of these coils in slots, they overlap each other just like in a woven basket. This is also a type of distributed winding.

In double layer winding each slot contains two coil sides i.e. the bottom half contains the left hand coil side while the top half contains the right coil side of some other coil.

Calculations for double layer distributed winding : The winding data of the distributed double layer winding will be within the following limitations. As an example 3-phase double layer distributed winding for an induction motor having 36 slots 36 coils 4 poles is discussed below.

I Grouping

1 $\text{No. of coils/phase} = \dfrac{\text{Total No. of coils}}{\text{No. of phase}}$

As per the example,

$\text{No. of coils/phase} = \dfrac{36}{3} = 12$ coils per phase.

2. $\text{No. of coils/phase/per pole} = \dfrac{\text{Total no. of coils}}{\text{No. of phase} \times \text{No. of poles}}$

$\text{No. of coils/phase/pole} = \dfrac{36}{3 \times 4} = 3 \text{ coils/phase/pole}$

II Pitch

$\text{Pole pitch} = \dfrac{\text{No. of slots}}{\text{No. of poles}}$

As per the example, pole pitch $= \dfrac{36}{4} = 9$ slots

2 **Coil pitch :** Similar to the single layer winding the coil pitch can be short-chorded, long-chorded or equal to the pole pitch. The pitch of the double layer distributed winding may be odd or even number. As per the example, the pole pitch is equal to 36/4 = 9 slots and the no. of coils per group is 3. Hence the coil pitch may vary from 9 + 3 that is 6,7 or 8 in the case of short corded winding, 9 in the case of full pitch winding and 10,11 or 12 in the case of long chorded winding. Hence the possible coil throws can be taken as

1 to 7 and 1 to 8 for short chorded winding

1 to 9 and 1 to 10 for full pitched winding

1 to 11, 1 to 12 and 1 to 13 for long chorded winding.

Normally the winding is designed for either short chorded or full pitch. Occasionally a long chord is used by the designer in double speed winding. The reason for not using long chorded winding is, it requires more chord length resulting in the requirement of more copper, and hence, increased heat losses.

3 **Coil throw :** According to the above example the coil throw for the coil pitch of 8 will be 1-9.

III Electrical degrees :

Total electrical degrees = 180º x No. of poles

[180o distance between poles]

Slot distance in degrees = $\frac{\text{Total electrical degrees}}{\text{No. of slots}}$

$$= \frac{180° \text{ x No. of poles}}{\text{No. of slots}}$$

$$\text{As per the example } \frac{180 \text{ x } 4}{36} = 20°$$

IV Phase displacement

i For three-phase winding each phase winding should be displaced by 120 electrical degrees.

ii Phase displacement in terms of slots =

$$\frac{120° \text{ (Electrical)}}{\text{Slot distance in degrees}}$$

$$\text{As per the example } \frac{120°}{20°} = 6 \text{ slots}$$

V Winding sequence : In three-phase winding, the starting end of one phase winding to the starting end of the second phase winding should have a distance of 120 electrical degrees.

Hence if the ‘A’ phase starts say in the Ist slot then the ‘B’ phase should start from the 1st slot+120o.

Further ‘C’ phase should start from the 1st slot+120o+120o.

As in the example ‘A’ phase starts from, say, 1st slot

‘B’ phase should start from 1+ 6 = 7th slot and

‘C’ phase should start from 1+ 6 + 6 = 13th slot.

VI Placing of the coils in double layer winding: As the winding is double layer, the laying of coils should start in adjacent slots.

That is the coils should be placed in slot 1, slot 2, slot 3 and so on.

As in the above example the arrangement of coils for the selected pitch 8 will be as given below:

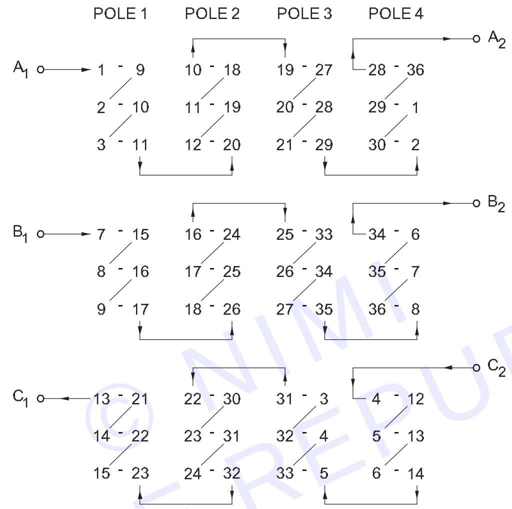
Fractional pitch Short chorded winding

	Pitch 8	Coil throw 1-9	
Pole	**A-Group**	**C-Group**	**B-Group**
P1	1-9, 2-10, 3-11	4-12, 5-13, 6-14	7-15, 8-16, 9-17
P2	10-18, 11-9, 12-20	13-21,14-22,15-23	16-24,17-25,18-26
P3	19-27, 20-28,21-29	22-30,23-31,24-32	25-33,26-34, 27-35
P4	28-36, 29-1, 30-2	31-3, 32-4, 33-5	34-6, 35-7, 36-8

Though the possible pitches are 6,7,8,9,10,11 and 12 the above example is given for the pitch equal to 8 only. Trainees are advised to write the table for other pitches to have a better understanding of the winding.

VII End connections : Draw the end connections as shown in Fig 1.

Fig 1

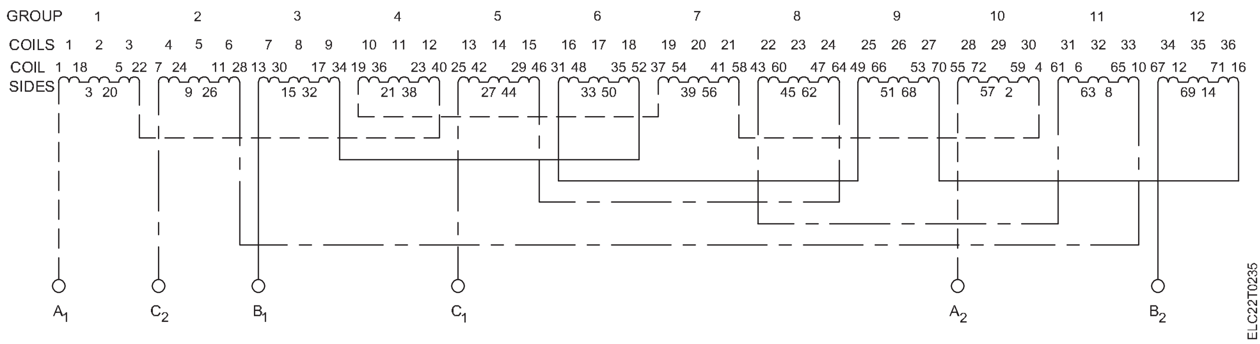


GROUP AND PHASE CONNECTION OF WINDING

VIII Coil connections : In whole coil connection, the connection of coil groups shall be from the finish end to the finish end and the start end to the start end of the group of coils of the same phase. Either of the following two methods shown in Figs 2 and 3 could be followed.

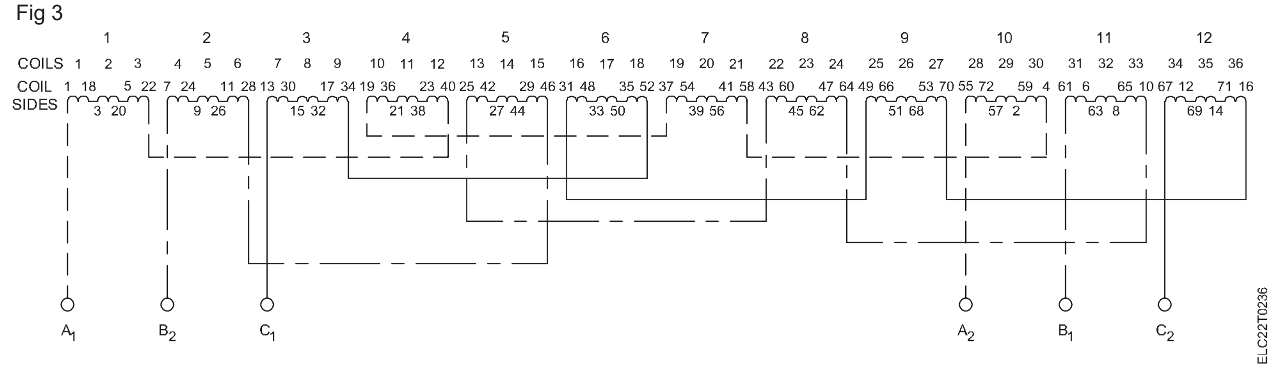
METHOD 1

Fig 2



METHOD 2

Fig 3



IX Cross check the end connections: Write the end connections table as illustrated below in Fig 4 and mark the direction of currents using the clock rule.

When three phase supply is given to the 3-phase winding, if two phases carry current inwards, the third phase will carry current outwards.

X Ring diagram

Mark the direction of current in the respective slots and then check the production of the required number of poles as shown with ring diagram. (Fig 5)

Fig 4

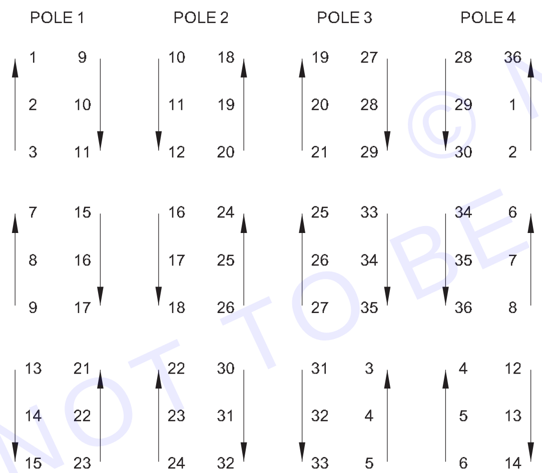
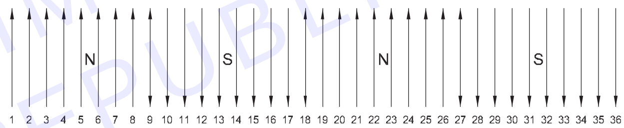


Fig 5



As per the above ring diagram, in all 4 poles are produced. One pole is produced at each of the area contained by the eight slots. In slots 9,18,27 and 36 coil sides carry current in the opposite directions and hence, the flux in those slots gets neutralized. This happens in the short chorded winding. Based on the above information draw the developed diagram.

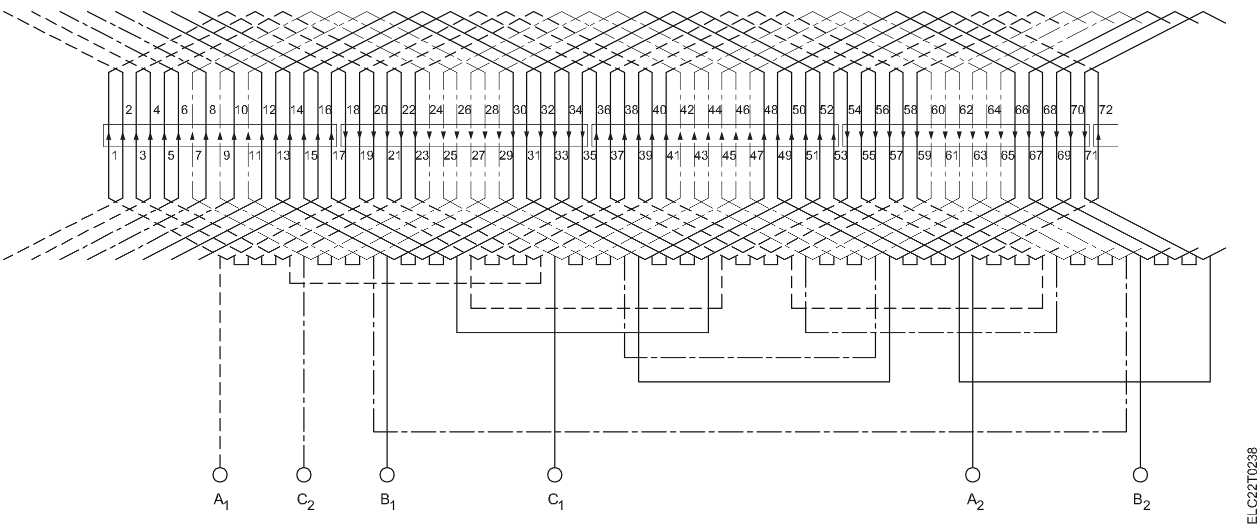
XI Developed diagram : A developed diagram is shown in Fig 6 in which the connections are shown for the method 1 referring to Fig 2.

XII Fractional pitches : After the group and lead connections are over, the sleeved joints are to be tied with the overhang with the help of hemp threads.

Winding is then to be tested and varnished.

The motor is then to be assembled and test run for at least eight hours to check its performance on no load. Wherever loading facilities are available the newly wound motor can be checked for its load performance.

Fig 6



Testing of windings

Objectives: At the end of this lesson you shall be able to:

- test the rewound motor for continuity and measure the coil resistance
- test the coils of the winding for short circuit using internal growler or voltmeter or ohmmeter
- test the winding for ground and insulation resistance
- test the winding for correct magnetic polarity using a magnetic compass or screwdriver or a search coil
- test the 3-phase winding for equal value of phase currents
- test the newly wound motor under no-load.

After the motor is rewound the following tests are carried out in the windings.

1 Continuity test/resistance test.

2 Short circuit test/growler test.

3 Insulation resistance test.

4 Polarity test.

5 Unbalanced current test - for 3-phase winding.

6 No-load test.

Continuity test/resistance test : This test is done to check up the continuity of each winding. If there is any open in the winding, it is to be rectified.

The usual cause of an open circuit in a winding is loose connection or break in the winding wire. The open circuit may be located by connecting one lead of the test lamp to one end of the winding and touching the other lead to the end of each coil end in sequence in the same phase.

Refering to Fig 1, if the lamp does not glow at point 3 but glows at point 2 then the third coil is faulty. If the lamp glows at 2 and 3 but not at 4 then the fourth coil is faulty. By repeating this process the coil which has the open circuit, can be identified.

Similarly, the other winding can also be tested for open circuit.

The resistance of each coil may be measured by a low range ohmmeter. The resistance of each coil must be the same. The high value of resistance or infinity value indicates open in the windings.

If there is any open in one coil, that coil can be bypassed and left out in the chain of windings. Then the motor can run, but if the open is in more than one coil, bypassing of the coil is not possible. This type of repairing is possible for small capacity motors where the winding has a large number of coils. Ex: Ceiling fans. But this procedure should be avoided as far as possible.

If the polarity of one or two coils in a multiple pole fan motor is changed the fan will run slowly and produces more heat.

Short circuit test/growler test : Two or more turns that contact each other electrically will cause a short circuit in the winding. This short circuit will cause excessive heat to be developed during the operation of the machine.

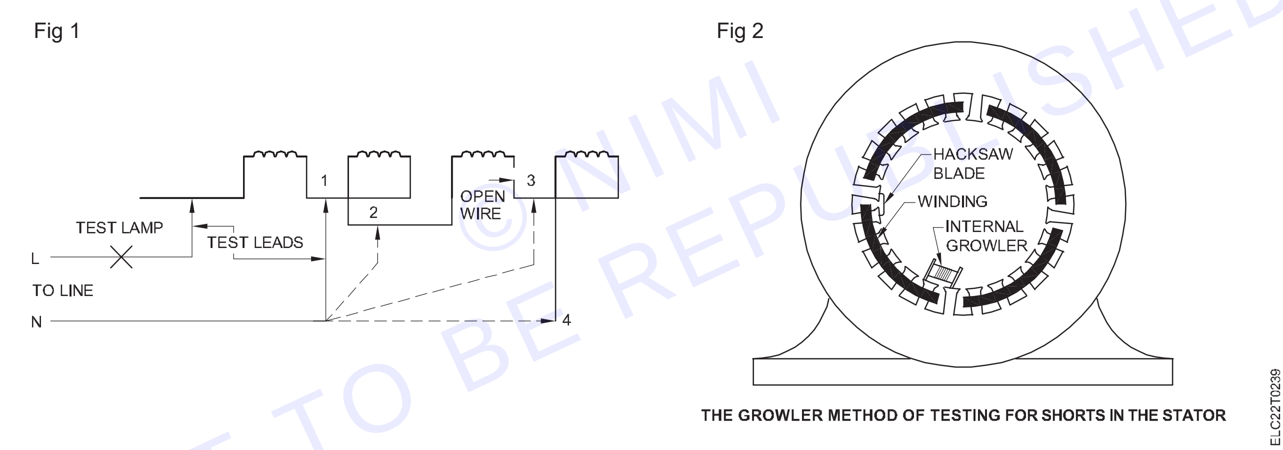
Short circuit can be detected by any one of the following methods.

a Internal growler method

b Voltage drop test

c Ohmmeter method.

Internal growler method : The internal growler consists of a coil of wire wound on a laminated iron core and connected to 240V AC supply. After the stator is removed the growler is placed on the core of the stator and moved from slot to slot as shown in Fig 2. A shorted coil will be indicated by rapid vibration of a metal blade provided with the growler and in some types of internal growlers, glow of the neon lamp provided with the growler indicates short in winding.



THE GROWLER METHOD OF TESTING FOR SHORTS IN THE STATOR

Voltage drop method : In this method the winding is connected to a low voltage DC supply as shown in Fig 3 and the voltage drop is measured across each coil by a milli voltmeter. The voltage drop across good coils will be the same whereas voltage drop across shorted coils will be low.

Ohmmeter method : For this method, measure the resistance of the each coil by a low range ohmmeter or Kelvin bridge or Post Office Box. All the coils should read the same value of resistance. The coil which reads lower resistance than the other coils or that which reads zero resistance is assumed to be shorted and needs replacement. On the other hand the coil which reads high resistance when compared to similar coils or which reads infinite value of resistance indicates open in that particular coil.

Ground test and insulation/resistance test : Grounded winding may cause a fuse to blow up or it may cause the winding to smoke, depending on the extent of the ground. It may give shock to persons when they come in contact with the frame which is not properly earthed.

The aim of this test is to check any direct connection between windings and earth(ground). For this, the neutral of the supply is connected to the body of the machine and the phase wire is connected through a series test lamp. The open end of the test lamp is touched to each end of the winding in sequence. If the lamp remains dark it means winding is not grounded and if it glows, the winding is earthed. This is a fast, rough practical method.

If a Megger is used for testing the grounded winding, one terminal of the Megger is connected to the body and other to the windings as shown in Fig 4. If the pointer of the Megger shows infinity, the winding is correct and there is no connection between the windings and the body. Insulation resistance between windings and the body of the machine is measured by a 500 volts Megger and the readings so obtained shall not be less than 1 Megohm in the case of 3-phase and single phase motors. For additional safety 2 megohms are necessary in the case of ceiling and table fans.

Fig 3

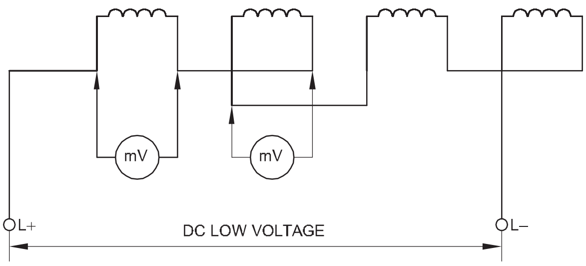
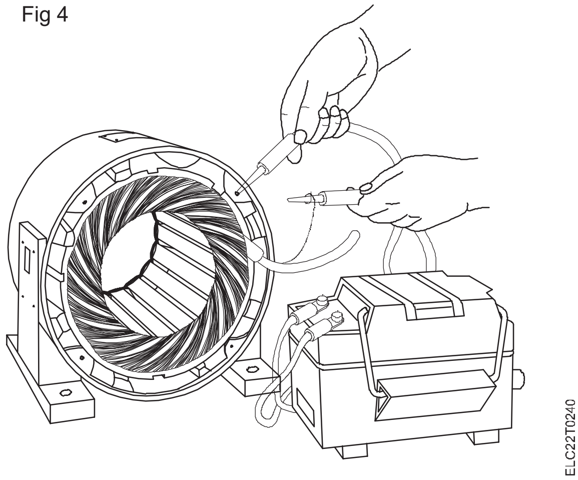


Fig 4



Polarity Test: Correct coil group connection in the winding ensures correct polarity. If there is any confusion in the coil group connections then the polarity test is necessary to be carried out to check proper polarity.

There are three methods recommended as explained below.

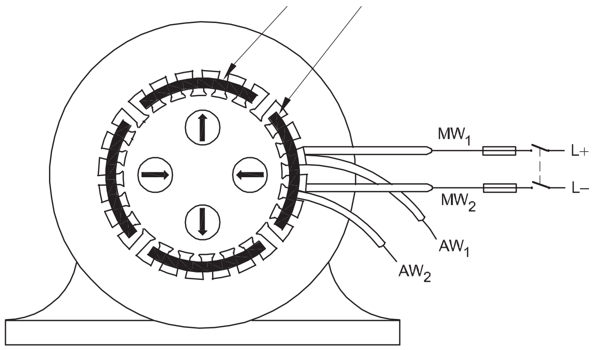
a Magnetic compass method

b Two screwdrivers method

c Search coil method

Magnetic compass method : In this method, the stator is placed in a horizontal position and a low DC voltage is applied to the winding. The compass needle is then held inside the stator and moved slowly from one pole area to another pole area as shown in Fig 5. The compass needle will reverse itself on each pole if the winding is correctly connected. If there is same direction of indication between two adjacent poles, a reverse pole is indicated.

Fig 5



THE COMPASS METHOD OF TESTING FOR REVERSED POLES

No-load test : After impregnation and assembly of motor, check the rotor for free rotation. Connect the motor to the rated supply voltage. Run the motor at no load and record the no-load voltage, current and speed of the motor. In no case these readings increase beyond name-plate values. Inspect the bearing sound and vibration. Normal sound without vibration is an indication of a good job. However, the perfection of the winding job could be ascertained only through a load test.

Single phase, split phase type motor winding (Concentric coil winding)

Objectives: At the end of this lesson you shall be able to:

- state the important points to be followed while winding split phase motors
- explain about coil distribution in concentric winding
- prepare the winding table, draw the connection and developed diagrams for concentric coil winding in single phase, split phase type motors.

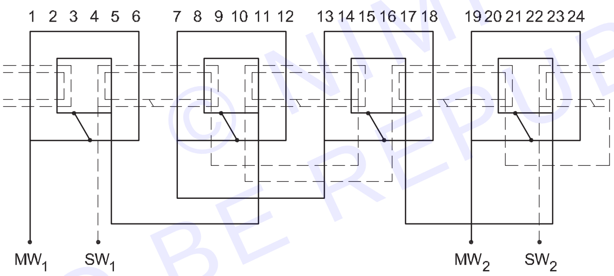
Split phase type: In general, single phase motors use a capacitor to split the phase. Some motors are, as found in fans, have the capacitor permanently connected to the supply. In some motors, the capacitor is used only for the starting period, then while running it is disconnected from the supply by the use of a centrifugal switch mechanism. In some other types of motors there are two capacitors, one for starting and the other for running. However, depending upon the power, function and the design of the motor, the capacitor value will be different in each case. Observe this point every time you come across the split phase motor.

There are certain points to be followed while winding a split phase motor.

1 The single phase winding may have different shapes of coils as explained below.

   a **Concentric coil winding (Fig 1):** This winding requires coils of different shapes in a phase/pole group, and different sizes between the phases in order to accommodate in the slots and for placing both main and starting windings. In addition to this, the coils in the same group may have different number of turns.

Fig 1



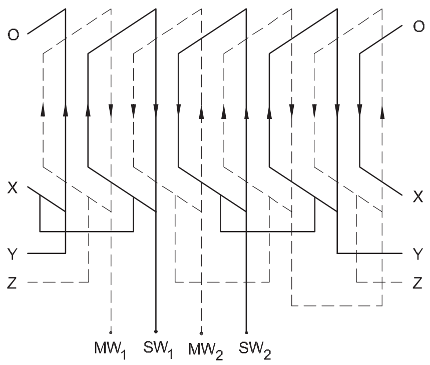
SINGLE PHASE CONCENTRIC WINDING 24SLOTS 4POLES

ELC22T0242

   b **True mesh shaped coils (Fig 2):** These coils are of the same size and shape and the end windings form a very tight roll.

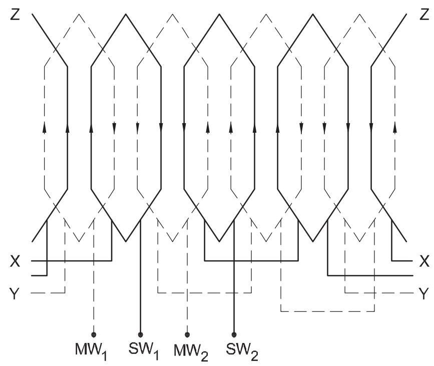
   c **Diamond mesh shaped coils (Fig 3):** These coils are of the same size and shape and the end winding is longer and flatter than the true mesh type coils. The end of the coils has a loop, knuckle or nose.

Fig 2



MESH SHAPED COILS

Fig 3



DIAMOND MESH SHAPED COILS

ELC22T0243

2 The main and starting winding should be placed 90 electrical degrees apart from each other.

3 All the coil groups may or may not have the same number of coils.

4 The main winding is kept first in the stator slots and the starting winding is kept over the main windings.

5 Normally, the main winding consists of thick winding wire, and the starting winding of thin winding wire. In certain motors both the windings may have same size of winding wire.

6 The number of turns in the main and starting windings may or may not have the same number of turns.

7 In concentric coil winding, the coils in the same group may or may not have the same number of turns.

8 Each slot may contain one or two coil sides.

9 The overhang of the coils should be of exact in size. If it is less, the insertion of the coils will be difficult and if the size is more, the coils may not allow the end covers to be fitted.

10 While inserting concentric coils, start with the smaller pitched coil set.

11 There may be empty slots in the stator. Note their position.

Concentric winding: Concentric type of winding is probably the most common type of winding used in fractional horsepower single phase motors. The winding may be hand wound or may be form wound.

As the starting winding is designed to split the phase and is used to start the motor, it may have less slots (coils) allotted when compared to the main winding. For example there may be 8 coils for main winding and 4 coils only for the starting winding.

Further it is a standard practice to wind only about 70% of the slots of a single phase motor, as owing to the effect of the distribution or spread factor, no advantage is gained by making a single phase winding any wider. Even if the whole of the slots were to be wound, the extra winding would be useless for producing the useful torque.

Similarly it has been found that in single phase motors, no extra loss takes place if all the slots of each pole face are not wound. Thus the running winding looses nothing in efficiency, because some of the slots of each pole are taken for the starting winding.

Winding calculation and diagrams for concentric type winding : Let us discuss the following examples.

Example 1

Prepare the winding table, draw the connection and developed diagrams for a single phase, 4 pole, whole coil connected capacitor motor having 24 slots, 12 coils (8 coils for main and 4 coils for starting winding) with pitches 5, 3 for the main and 5 for the starting winding.

$$\text{Number of coils per pole in main winding} =$$

$$\frac{\text{Total number of main winding coils}}{\text{Number of poles}} = \frac{8}{4} = 2 \text{ coils/pole}$$

In other words, there will be 8 coils in the main winding forming 4 pole groups. Each group will have two coils under each pole. Pitches assigned will be 5 and 3 for each coil group.

Number of coils per pole in starting winding = 4/4 =1 coil /pole.

There will be 4 groups in starting winding having one coil per group. Pitch assigned will be 5 for the coil.

Summarising the results we have the coil group as given below in Table 1.

Table 1

Winding	Groups	Coil per pole	Pitches	Coil throw	Connection
Main	4	2	5, 3	1-6, 2-5	Whole coil-end to end and start to start
Starting	4	1	5	1-6	Whole coil-end to end and start to start.

Calculation of electrical degrees required for phase splitting

Total electrical degrees = 180 x Total number of poles

= 180x4= 720 electrical degrees

Degrees/slot = 720/24 = 30 electrical degrees

No. of slots required for 90 electrical degrees dis-placement between main and starting winding = 90/30 = 3 slots.

Hence if the main winding starts in, say, slot number one, then the starting winding should be started in 1+3 = 4th slot.

Computing the above information in a winding table we have Table 2.

Table 2

Winding table

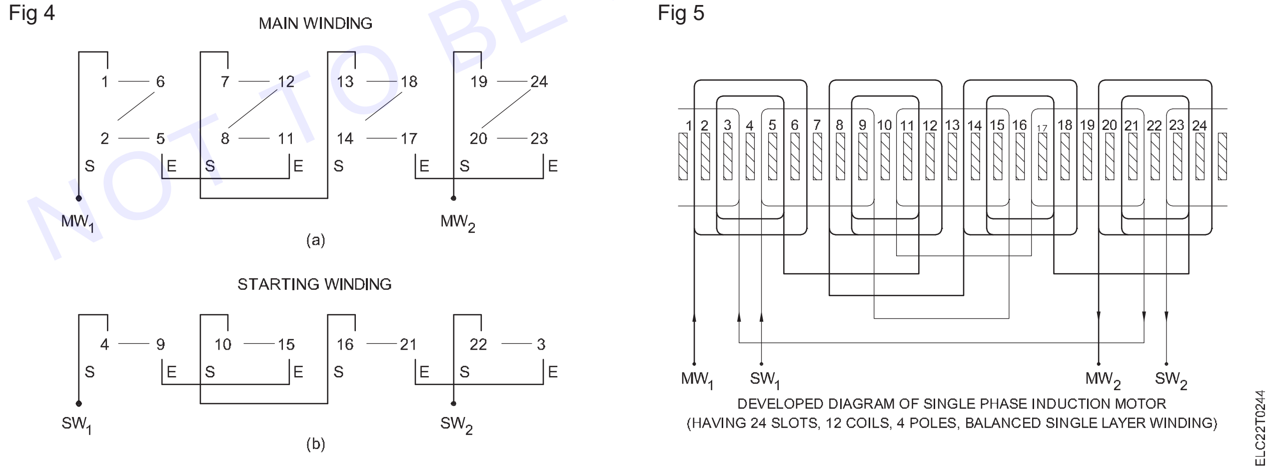
	Slot position for poles			
Winding	**I pole**	**II pole**	**III pole**	**IV pole**
Main	1 - 6	7 - 12	13 - 18	19 - 24
	2 - 5	8 - 11	14 - 17	20 - 23
Starting	4 - 9	10 - 15	16 - 21	22 - 3

Remembering whole coil connection the connection diagram is to be drawn as shown in Fig 4.

Remember 'S' is for starting and 'E' for end connection.

Based on the winding table the developed diagram is drawn as shown in Fig 5.

Fig 4 Fig 5



Example 2 : Prepare the winding table, draw the connection and developed diagrams for a single phase, 4-pole, whole coil connected capacitor motor having 36 slots 28 coils (16 coils for main and 12 coils for the starting winding).

Coil per group in main winding 16/4=4 coils/group/poles

Coil per group in starting winding 12/4 = 3 coils/group/poles

$$\text{Pole pitch} = \frac{\text{Number of slots}}{\text{Number of poles}} - 1 = \frac{36}{4} - 1 = 9 - 1 = 8$$

The coil throw for main winding will be 1-9 and the winding table will be as shown in Table 3.

Table 3

Main winding - winding table

For the same group	1st pole	2nd pole	3rd pole	4th pole
1st coil	1 - 9	10 - 18	19 - 27	28 - 36
2nd coil	2 - 8	11 - 17	20 - 26	29 - 35
3rd coil	3 - 7	12 - 16	21 - 25	30 - 34
4th coil	4 - 6	13 - 15	22 - 24	31 - 33

Calculate the degrees/slot.

Total electrical degrees = 180 x 4 = 720 electrical degrees.

Degrees/slot = 720/36 = 20 electrical degrees

For phase displacement of 90 electrical degrees we require 90/20 = 4.5 slots. As it is impossible to start at 4.5 slots, let us start the starting winding in slot No.5.

Hence the coil throw for starting winding will also be 1 - 9, but it starts in the 5th slot. As such the winding table will be as shown in Table 4

Table 4

Starting winding - winding table

For the same group	1st pole	2nd pole	3rd pole	4th pole
1st coil	5 - 13	14 - 22	23 - 31	32 - 4
2nd coil	6 - 12	15 - 21	24 - 30	33 - 3
3rd coil	7 - 11	16 - 20	25 - 29	34 - 2

There will be several slots having 2 coil sides and some slots may have single coil side only.

Remembering the whole coil connection, the connection diagram will be as shown in Fig 6.

Based on the above, the developed diagram is shown in Fig 7.

Fig 6

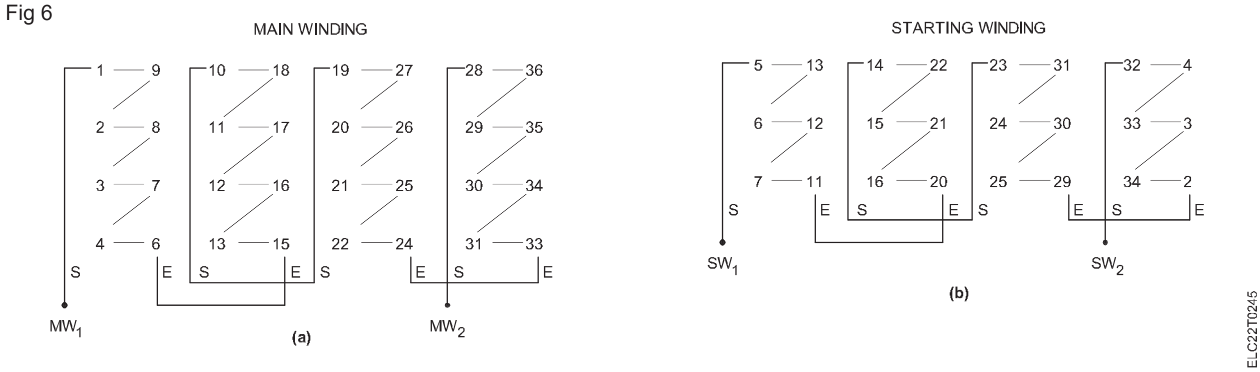
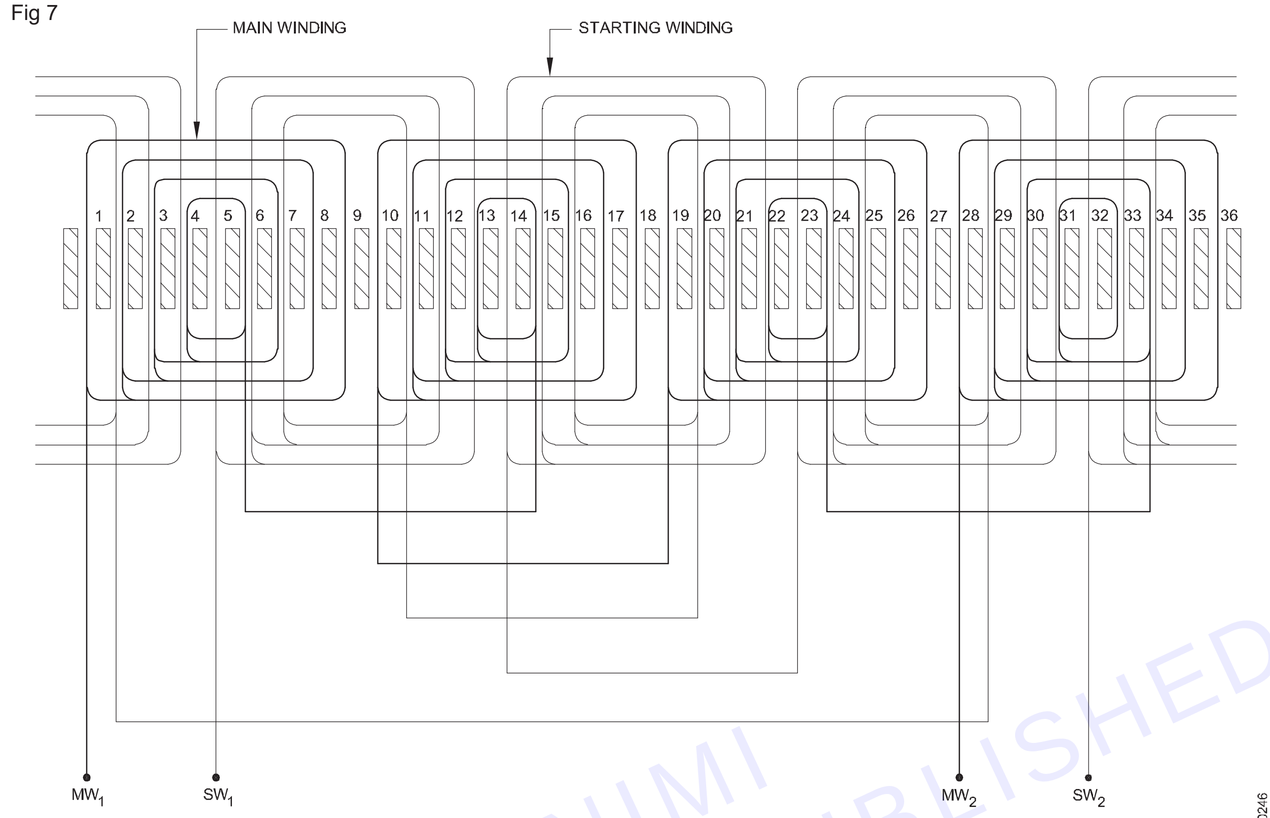


Fig 7



DEVELOPED DIAGRAM OF SINGLE PHASE 4POLE WHOLE COIL CONNECTED CAPACITOR MOTOR HAVING 36 SLOTS 16 COILS FOR MAIN WINDING 12 COILS FOR STARTING WINDING

MODULE 15 : Industrial Programmable Systems

LESSON 93-100 : AC/DC drives

Objectives

Objectives: At the end of this lesson you shall be able to:

- state the classification types and working of AC & DC drives
- state the applications of AC & DC drives
- describe the block diagram, parts of DC drive and advantages and disadvantages of DC drives.

Electrical drives

An electric drive can be defined as an electromechanical device for converting electrical energy into mechanical energy to feed motion to different machines and mechanisms for various kinds of process control. (Fig 1)

Motion control is required in large number of industrial and domestic applications like transportation, systems, rolling mills, paper machines, textile mills, machine tools, fans, pumps, robots, washing machines etc.

Systems employed for motion control are called Drives, and may employ any of prime movers such as diesel or petrol engines, gas or steam turbines, steam engines, hydraulic motors and electric motors; Supplying mechanical energy for motion control Drives employing electric motors are known as Electrical drives. The block diagram of an electric drive is shown in Fig 2.

Fig 1

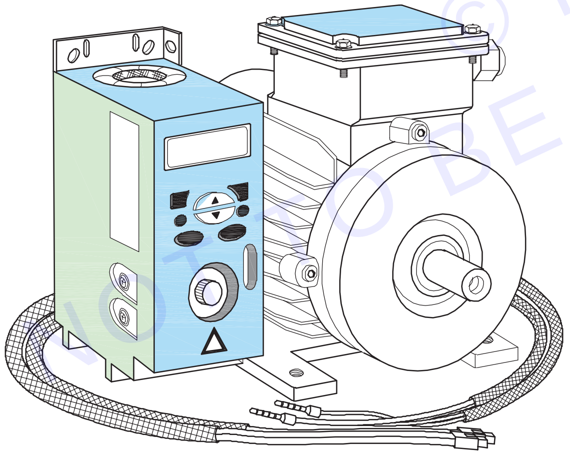
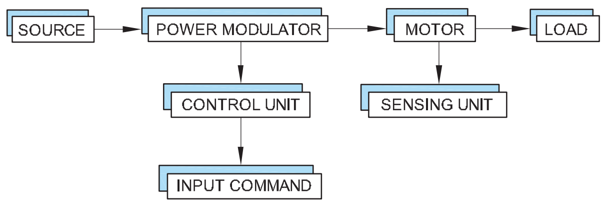


Fig 2



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Types of electric drives

i According to mode of operation

- Continuous duty drives
- Short time duty drives
- Intermittent duty drives

ii According to means of control

- Manual
- Semi automatic
- Automatic

iii According to number of machines

- Individual drive
- Group drive
- Multi - motor drive

iv According to dynamics and transients

- Uncontrolled transient period
- Controlled transient period

V According to methods of speed control

- Reversible and non - reversible uncontrolled constant speed
- Variable position control
- Reversible and non - reversible smooth speed control

Advantage of electrical drives

1 They have flexible control characteristics.

2 Drives can be provided with automatic fault detection systems. Programmable logic controller (PLC) and computers can be employed to automatically control the drive operation in a desired sequence.

3 They are available in wide range of torque, speed and power.

4 They are suitable to almost any operating conditions such as explosive and radioactive environments.

5 It can operate in all the four quadrants of speed - torque plane.

6 They can be started instantly and can immediately be fully loaded.

7 Control gear requirement for speed control, starting and braking is usually simple and easy to operate.

The requirement of refuel is not necessary.

Choice (or) selection of electrical drives: Choice of an electric drive depends on the important factors are.

1 Steady state operating conditions requirements. Nature of speed torque characteristics, speed regulation, speed range, efficiency, duty cycle, quadrants of operation, speed fluctuations if any, rating etc.

2 Transient operation requirements

3 Values of acceleration and deceleration, starting, braking and reversing performance.

4 Requirements related to the source. Types of source and its capacity, magnitude of voltage, voltage fluctuations, power factor, harmonics and their effect on other loads, ability to accept regenerative power.

5 Space and weight restriction if any.

6 Environment and location.

7 Reliability

Group electric drive

This drive consists of a single motor, which drives one or more line shafts supported on bearings. The line shaft may be fitted with either pulleys and belts or gears, by means of which a group of machines or mechanisms may be operated. It is also some times called as shaft drives.

Advantages: The advantages of electrical drives include the following:

- These drives are obtainable with an extensive range of speed, power & torque.
- Not like other main movers, the requirement of refuel otherwise heat up the motor is not necessary.
- They do not contaminate the atmosphere.
- Previously the motors like synchronous as well as induction were used within stable speed drives. Changeable speed drives utilize a DC motor.

- They have flexible manage characteristics due to the utilization of electric braking.
- At present, the AC motors motor is used within variable speed drives because of semiconductor converters development.

Disadvantages

The disadvantages of electrical drives include the following.

- This drive cannot be used where the power supply is not accessible.
- The power breakdown totally stops the entire system.
- The primary price of the system is expensive.
- The dynamic response of this drive is poor.
- The drive output power which is obtained is low.
- By using this drive noise pollution can occur.

Applications of Electrical Drives: The applications of electrical drives include the following.

- The main application of this drive is electric traction which means transportation of materials from one location to another location. The different types of electric tractions mainly include electric trains, buses, trolleys, trams, and solar-powered vehicles inbuilt with battery.
- Electrical drives are extensively used in the huge number of domestic as well as industrial applications which includes motors, transportation systems, factories, textile mills, pumps, fans, robots, etc.
- These are used as main movers for petrol or diesel engines, turbines like gas otherwise steam, motors like hydraulic & electric.

Thus, this is all about the fundamentals of electrical drives. From the above information, finally, we can conclude that a drive is one kind of electrical device used to control the energy which is sent to the electrical motor. The drive supplies energy to the motor in unstable amounts & at unstable frequencies, thus ultimately controls the speed and torque of the motor. Here is a question for you, what are the main parts of the electric drive.

Individual electric drive

In this drive each individual machine is driven by a separate motor. This motor also imparts motion to various parts of the machine.

Multi motor electric drive : In this drive system, there are several drives, each of which serves to actuate one of the working parts of the drive mechanisms.

e.g: Complicated metal cutting machine tools

Paper making industries.

Rolling machines etc.

A modern variable speed electrical drive system has the following components

- Electrical machines and loads
- Power modulator
- Sources
- Control unit
- Sensing unit

Electrical machine

Most commonly used electrical machines for speed control applications are the following.

DC machines

Shunt, series, compound, DC motors and switched reluctance machines.

AC machines

Induction, wound rotor, synchronous, permanent magnet synchronous and synchronous reluctance machines.

Special machines

Brush less DC motors, stepper motors, switched reluctance motors are used.

Power Modulators (Controller)

Functions

- It modulates flow or power from the source to the motor is imparted speed - torque characteristics required by the load.
- During transient operation, such as starting, braking and speed reversal, it reduces the motor current with in permissible limits.
- It converts electrical energy of the source in the from of suitable to the motor.
- It selects the mode of operation of the motor (i.e) motoring and braking.

Types of power modulators (Controllers)

- In the electric drive system, the power modulators can be any one of the following.
- Controlled rectifiers (AC to DC converter)
- Inverters (DC to AC converters)
- AC voltage controllers (AC to DC converters)
- DC choppers (DC to DC converters)
- Cyclo converters (Frequency conversion)

Electrical sources

Very low power drives are generally fed from single phase sources. Rest of the drives is powered from a 3-phase source. Low and medium power motors are fed from a 415V supply. For higher ratings, motors may be rated at 3.3KV, 6.6 KV and 11 KV. Some drives are powered from battery.

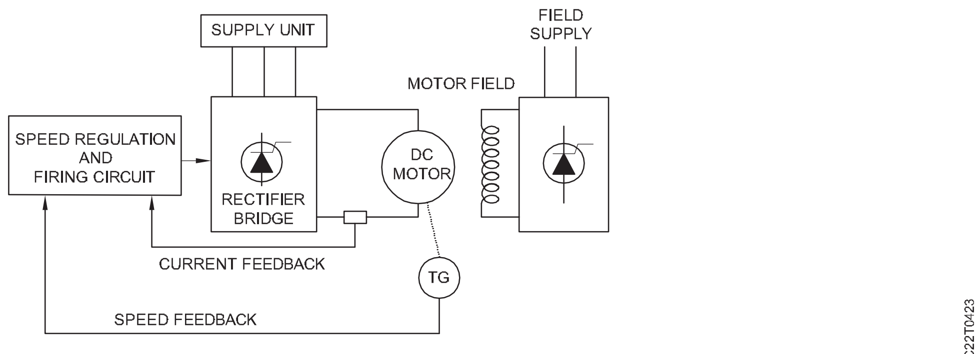
Sensing unit

- Speed sensing (from motor)
- Torque sensing
- Position sensing
- Current sensing and voltage sensing (from lines or from motor terminals from load)
- Temperature sensing

Control unit : Control unit for a power modulator are provided in the control unit. It matches the motor and power converter to meet the load requirements.

Block diagram of DC drive : The block diagram of a DC drive system is in Fig 3

Fig 3



COMPONENTS OF A DC DRIVE SYSTEM

DC drive input : Some thyristor based DC drives operate on a single phase supply and use four thyristors for full wave rectification. For larger motors 3 phase power supply is needed because the waveforms are much smoother. In such cases, six thyristors are needed for full wave rectification.

Rectifier Bridge : The power component of a controlled DC drive is a full wave bridge rectifier which can be driven by three phase or single phase supply. As mentioned above the number of thyristor may vary depends on the supply voltage.

A six - thyristor bridge (in case of three phase converter) rectifies the incoming AC supply to DC supply to the motor armature. The firing angle control of these thyristors varies the voltage to the motor.

Field Supply Unit (FSU) : The power is to be applied to the field winding is much lower than the armature power.

In many cases a two - phase supply is drawn from the three phase input (that supplies power to the armature) and hence the field exciter is included in the armature supply unit.

The function of the field supply unit is to provide a constant voltage to the field winding to create a constant field or flux in the motor. In some cases, this unit is supplied with thyristors to reduce the voltage applied to the field so as to control the speed of the motor above the base speed incase of permanent magnet DC motors, the field supply unit is not included in the drive.

Speed Regulation unit : It compares the operator instruction (desired speed) with feedback signals and sends appropriate signals to the firing circuit. In analog drives, this regulator unit consists of both voltage and current regulators. The voltage regulator accepts the speed error as input and produces the voltage output which is then applied to the current regulator.

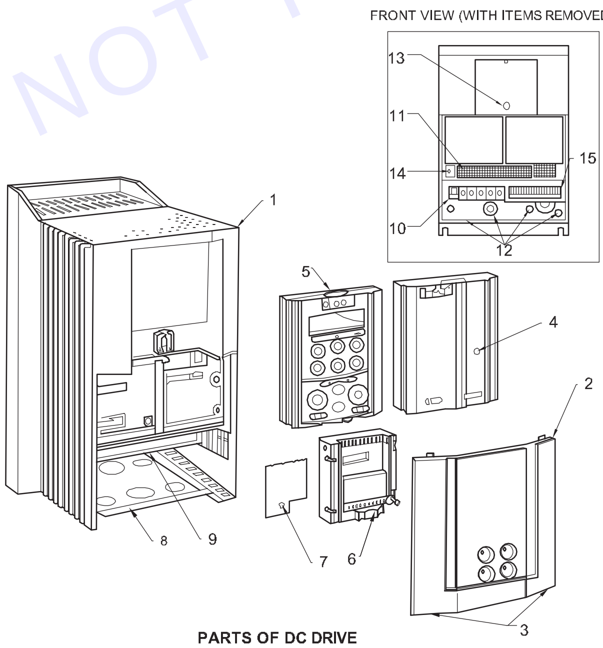
The current regulator then produces required firing current to the firing circuit. If more speed is required, additional current is drawn from the voltage regulator and hence thyristors conduct for more periods. Generally, this regulation (both voltage and current) is accomplished with proportional -integral- derivative controllers.

The field current regulator is also provided where speed greater than the base speed is required.

Parts of DC drive : DC drives of various brands with different ratings are available in the market. It is generally assembled in a metallic enclosure. The front panel has the power terminals, control terminals, keypad for controlling the drive etc. It has provision for connecting to PC for programming the drive.

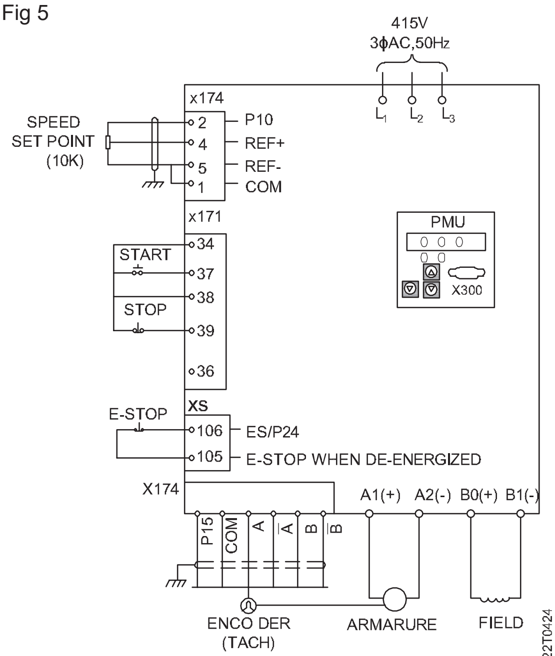
The main parts of DC drive are given below. (Fig 4&5)

Fig 4



PARTS OF DC DRIVE

Fig 5



CONTROL TERMINALS OF DC DRIVE

1 Main drive assembly
2 Terminal cover
3 Terminal cover retaining screw
4 Blank cover
5 Keypad
6 COMMS technology box (optional)
7 Speed feedback technology card (optional)
8 Gland plate
9 Power terminal shield
10 Power terminals
11 Control terminals
12 Earthing / grounding points
13 Keypad part
14 Programming part
15 Auxiliary power, external contactor, blower and isolated thermistor terminals

Power and control terminals

In DC drive, the front panel has the power terminals L1, L2 and L3 where 3 phase input supply of 415V can be connected.

There are control terminals given for speed adjust potentiometer, Torque adjust potentiometer, START/RUN/ STOP switch, JOG/RUN/ switch, AUTO/MAN switch, FORWARD/REVERSE switch etc. Terminal A1 & A2 and B0 & B1 are meant for armature and field connections respectively. Names and locations are illustrated in Fig 5.

Advantages of DC drive

- DC drives are less complex with a single power conversion from AC to DC.
- DC drives are normally less expensive for most horsepower ratings.
- DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose.
- Cooling blowers and inlet air flanges provide cooling air for a wide speed range at constant torque.
- Accessory mounting flanges and kits for mounting feedback tachometers and encoders.
- DC regenerative drives are available for applications requiring continuous regeneration for overhauling loads. AC drives with this capability would be more complex and expensive.
- Properly applied brush and commutator maintenance is minimum.
- DC motors are capable of providing starting and accelerating torques in excess of 400% of rated value.
- Some AC drives may produce audible motor noise which is undesirable in some applications.

Disadvantages of DC drive

- More complicated because of commutators and brushes.
- Heavier than AC motors.
- High maintenance is required.
- Large and more expensive than AC drive.
- Not suitable for high speed operation.

Speed control of 3 phase induction motor by VVVF/AC drive

Objectives: At the end of this lesson you shall be able to

- state about AC drives (VFD/VVFD) and changing of speed of AC motor by AC drive
- explain the operation of AC drive with block diagram
- list out the advantages and disadvantages of AC drive
- explain the components / parts and power and control terminals of AC drive
- state the parameter setting - speed control changes of direction of AC & DC drives / VFD/VVVFD (variable frequency drive/ variable voltage variable frequency drive)
- state the speed control of universal motor.

Variable Voltage Variable Frequency Drive (VVVFD)

The AC drive industry is growing rapidly and it is now more important than ever for technicians and maintenance personnel to keep AC drive installations running smoothly. AC drives change the speed of AC motor by changing voltage and frequency of the power supplied to the AC motor. In order to maintain proper power factor and reduce excessive heating of the motor, the name plate volts / hertz ratio must be maintained. This is the main task of VFD (Variable frequency drive).

Applications of AC drives

1 AC drives are used to stepless speed control of squirrel cage induction motors mostly used in process plants due to its ruggedness and maintenance free long life.

2 AC drives control the speed of AC motor by varying output voltage and frequency through sophisticated microprocessor controlled electronics device.

3 AC drive consists of rectifier and inverter units. Rectifier converts AC to DC voltage and inverter converts DC voltage back to AC voltage.

Changing of speed of AC motors by using AC drive

From the AC motor working principle, that the synchronous speed of motor Ns in rpm, is dependent upon frequency. Therefore by varying the frequency of the power supply through AC drive, it can control the synchronous speed.

Speed (rpm) = Frequency (Hertz) x 120 / No. of poles.

Where

Frequency = Electrical frequency of the power supply in Hz., No. of poles = Number of electrical poles in the motor stator. Thus the speed of AC motor can conveniently be adjusted by changing the frequency applied to the motor. There is also another way to make the AC motor work on different speed by changing the no. of poles, but this change would be a physical change of the motor. The VFD provides the controls over frequency and voltage of motor input to change the speed of a motor. Since the frequency is easily variable as compared with the poles variation of the motor. AC drives are frequently used.

Constant V/F ratio operation

If the same voltage is applied at the reduced frequency, the magnetic flux would increase and saturate the magnetic core, significantly distorting the motor performance. The magnetic saturation can be avoided by keeping the fm constant.

All AC drives maintain the voltage -to- frequency (V/f) ratio constant at all speeds for the reason that follows. The phase voltage V, frequency F and the magnetic flux f of motor are related by the equation.

$V=4.444\ f\ N\ \phi_m$

or

$V/f = 4.444 x\ N\ \phi_m$

Where N = number of turns per phase

ϕ_m = magnetic flux

Moreover, the AC motor torque is the product of stator flux and rotor current. For maintaining the rated torque at all speeds the constant flux must be maintained at its rated value, which is basically done by keeping the voltage - to - frequency (V/f) ratio constant.

Block diagram of AC drive

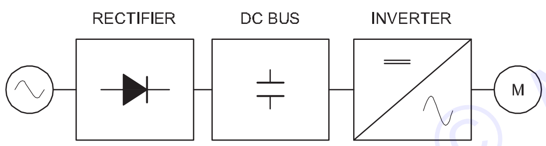
The Insulated - Gate - Bipolar- Transistor (IGBT) is in the past two decades come to dominate VFD as an inverter switching device.

IGBTs (insulated gate bipolar transistor) provide a high switching speed necessary for PWM (Pulse width Modulation) inverter operation. IGBTs are capable of switching on and off several thousand times a second. An IGBT can turn on in less than 400 nanoseconds and off in approximately 500 nanoseconds. An IGBT consists of a gate, collector and an emitter. When a positive voltage (typically +15 VDC) is applied to the gate the IGBT will turn on. This is similar to closing a switch. Current will flow between the collector and emitter.

An IGBT is turned off by removing the positive voltage from the gate. During the off state the IGBT gate voltage is normally held at a small negative voltage (-15 VDC) to prevent the device from turning on. So the gate can control the switching on/off operation of an IGBT.

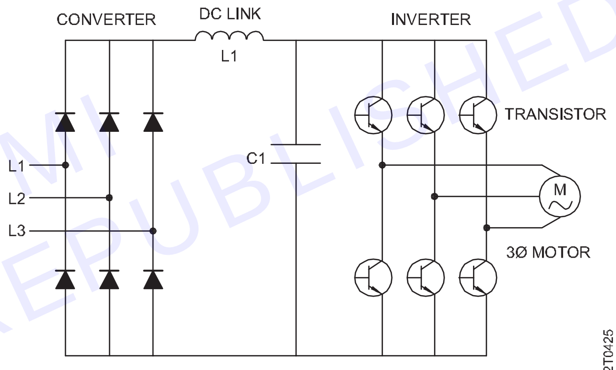
Fig 1 shows the block diagram of AC drive and Fig 2 shows the internal connection diagram. There are three basic sections of the AC drive; the rectifier, DC bus, and inverter.

Fig 1



BLOCK DIAGRAM OF AC DRIVE

Fig 2



INTERNAL CONNECTION OF AC DRIVE

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The rectifier in an AC drive is used to convert incoming AC power into direct current (DC) power. Rectifiers may utilize diodes, silicon controlled rectifiers (SCR), or transistors to rectify power . An AC drive using transistors in the rectifier section is said to have an "active front end.

After the power flows through the rectifiers it is stored on a DC bus. The DC bus contains capacitors to accept power from the rectifier, store it, and later deliver that power through the inverter section. The DC bus may also contain inductors, DC links, chokes, or similar items that add inductance, thereby smoothing the incoming power supply to the DC bus.

Inverter : An inverter is a device which converts DC into AC. The inverter contains transistors that deliver power to the motor. The "Insulated Gate Bipolar Transistor" (IGBT) is a common selection in modern AC drives. The IGBT can switch on and off several thousand times per second and precisely control the power delivered to the motor. The IGBT uses a method named "Pulse Width Modulation" (PWM) to simulate a current sine wave at the desired frequency to the motor.

Advantages and disadvantages of AC drive

Advantages

- They use conventional low cost 3 phase AC induction motors for most applications
- AC motors require virtually no maintenance and are preferred for application where the motor is mounted in an area not easily reached for servicing or replacement.
- AC motors are smaller, lighter, more commonly available and less expensive than DC motors.

- AC motors are better suited for high speed operation (over 2500 rpm) since there are no brushes, and commutation is not a problem.
- Whenever the operating environment is wet, corrosive or explosive, special motor enclosures are required. Special AC motor enclosure types are more readily available at lower prices.
- Multiple motors in a system must operate simultaneously at a common frequency/speed.

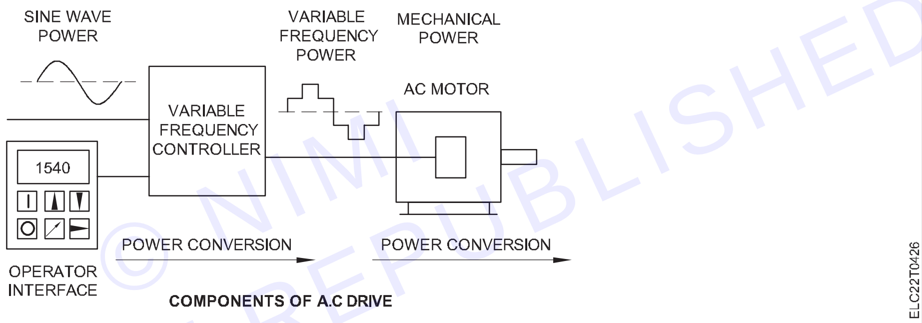
Disadvantages

- A standard motor can not adequately cool its winding at slow speed or handle the irregular electrical waveform from the AC drive.
- An AC drive requires installation of motor with heavier windings.
- AC drive has complicated electronics circuit, so fault rectification is costly.
- AC drives produce a simulated waveform, not a perfect sine wave. That degrade the power equality.

Components of AC drive

A variable frequency drive is a device used in a drive system consisting of the following three main sub-systems. AC motor, main drive controller assembly, and drive / operator interface as in Fig 3.

Fig 3



AC motor

The AC electric motor used in a VFD system is usually three - phase induction motor. Some types of single - phase motors can be used, but three - phase motors are usually preferred. Various types of synchronous motors offer advantages in some situations, but three - phase induction motors are suitable for most purposes and are generally the most economical motor choice. Motors that are designed for fixed - speed operation are often used. Elevated - voltage stresses imposed on induction motors that are supplied by VFDs require that such motors are designed for definite - purpose inverter-fed duty.

Controller : The VFD controller is a solid - state power electronics conversion, system consisting of three distinct sub-systems, a rectifier bridge converter, a direct current (DC) link, and an inverter. Voltage - source inverter (VSI) drives are the most common type of drives. Most drives are AC to AC drives in that they convert AC line input to AC inverter output. However, in some applications such as common DC bus or solar applications, drives are configured as DC-AC drives. The most basic rectifier converter for the VSI drive is configured as a three -phase, six -pulse, full-wave diode bridge.

In a VSI drive, the DC link consists of a capacitor which smooths out the converter's DC output ripple and provides a stiff input to the inverter. This filtered DC voltage is converted to quasi-sinusoidal AC voltage output using the inverter's active switching elements. VSI drives provide higher power factor and lower harmonic distortion than phase- controlled current - source inverter (CSI) and load - commutated inverter (LCI) drives.

In variable -torque applications suited for volts - per- Hertz (V/Hz) drive control. AC motor characteristics require that the voltage magnitude of the inverter's output to the motor be adjusted to match the required load torque in a linear V/Hz relationship. For example, 415V, 50Hz motors, this linear V/Hz relationship is 415/50=8.3V/Hz.

Although space vector pulse- width modulation (SVPWM) is becoming increasingly popular, sinusoidal PWM (SPWM) is the most straight forward method used to vary drives motor voltage (or current) and frequency. With SPWM control quasi- sinusoidal, variable - pulse-width output is constructed from intersections of a saw-toothed carrier signal with a modulating sinusoidal signal which is variable in operating frequency as well as in voltage (or current).

An embedded microprocessor governs the overall operation of the VFD controller. Basic programming of the microprocessor is provided as user - inaccessible firmware. User programming of display, variable, and function block parameters is provided to control, protect, and monitor the VFD, motor, and driven equipment.

Operator interface

The operator interface provides a means for an operator to start and stop the motor and adjust the operating speed. Additional operator control functions might include reversing, and switching between manual speed adjustment and automatic control from an external process control signal. The operator interface often includes an alphanumeric display and /or indication lights and meters to provide information about the operation of the drive.

An operator interface keypad and display unit is often provided on the front of the VFD controller shown in the Fig 3. The keypad display unit can often be cable - connected and mounted a short distance from the VFD controller. They are also provided with input and output (I/O) terminals for connecting push buttons, switches, and other operator interface devices or control signals. A serial communications port is also often available to allow the VFD to be configured, adjusted, monitored, and controlled using a computer.

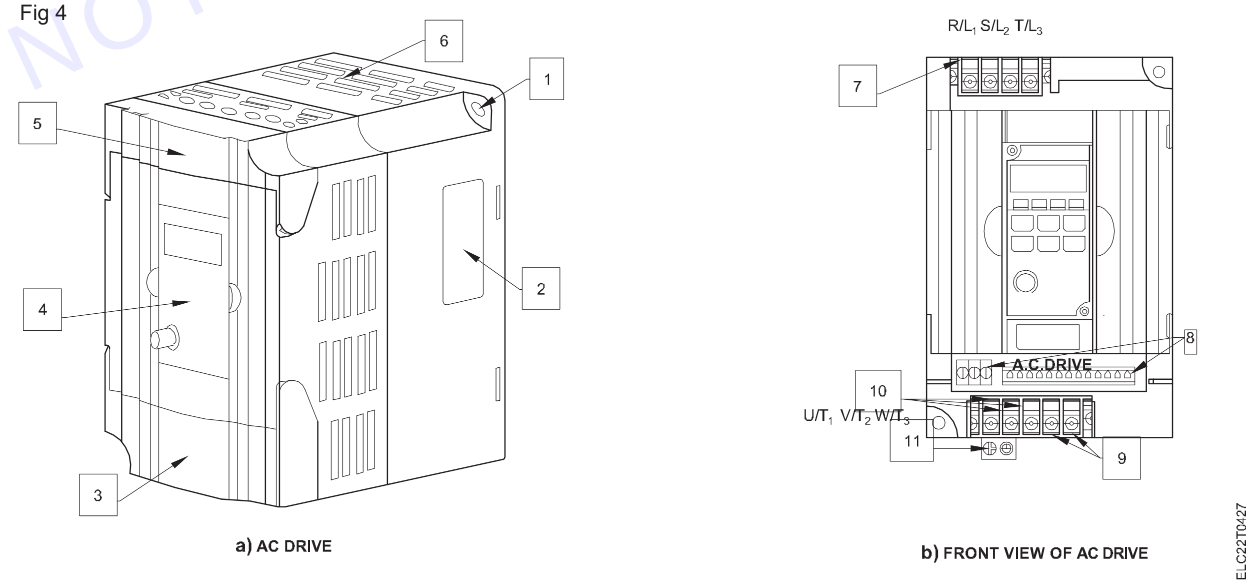
Operation of AC drive

When the VFD is started the applied frequency and voltage are increased at a controlled rate or ramped up to accelerate the load. This starting method typically allows a motor to develop 150% of its rated torque while the VFD is drawing less than 50% of its rated current from the mains in the low - speed range. A VFD can be adjusted to produce a steady 150% starting torque from standstill right up to full speed. However, motor cooling deteriorates and can result in overheating as speed decreases such that prolonged low -speed operation with significant torque is not usually possible without separately motorized fan ventilation.

With a VFD, the stopping sequence is just the opposite as the starting sequence. The frequency and voltage applied to the motor are ramped down at a controlled rate. When the frequency approaches zero, the motor is shut off. Additional braking torque can be obtained by adding a braking circuit (resistor controlled by a transistor) to dissipate the braking energy.

Part of AC drive (Fig 4a & 4b)

Fig 4



a) AC DRIVE

b) FRONT VIEW OF AC DRIVE

AC drives of various brand with different ratings are available in the market. It is generally assembled in a metallic enclosure. The front panel has the power input and output terminals, control terminals, keypad (operator interface) for controlling the drive etc. It has provision for connecting to PC for programming the drive.

The main parts are given below and shown in Fig 4a and 4b.

1 Mounting screw holes

2 Name plate label

3 Bottom cover

4 Digital keypad

5 Upper cover

6 Ventilation hole

7 Input terminals

8 Control Input/Output terminals

9 External brake resistor terminal

10 Output terminals

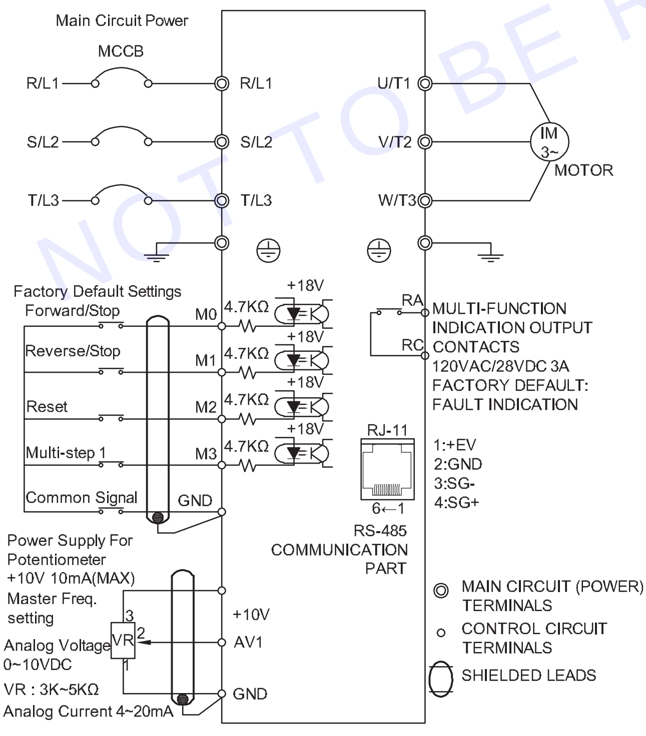
11 Grounding

Power and control terminals

In AC drive, the front panel has the input power terminals viz R/L1, S/L2 and T/L3 where 3 phase AC 415V, 50Hz supply is connected. The 3 phase induction motor is connected of output power terminals viz. U/T1, V/T2 and W/T3.

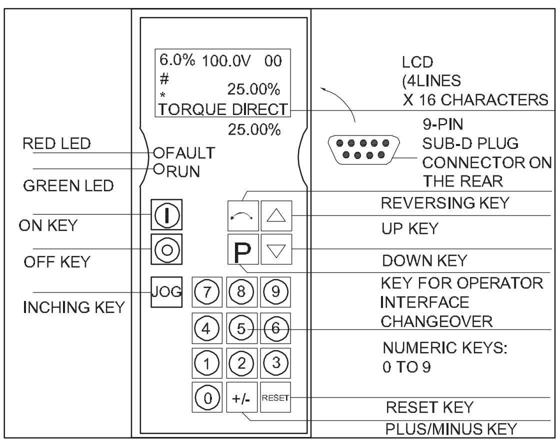
There are control terminals viz M0, M1, M2, M3, GND, +10V, AV1 etc. for starting/stopping/ reversing and speed control actions. Names and locations are given in Fig 5

Fig 5



CONNECTION DIAGRAM OF AC DRIVE & MOTOR

Fig 6



BASIC OPERATOR PANEL (BOP) KEY PAD

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Parameter settings of DC drive

As discussed in previous chapter, the speed of DC motor is directly proportional to the armature voltage (Eb) and inversely proportional to the field current(If) and also the armature current (Ia) is proportional motor torque.

In armature controlled DC drives, the drive unit provides a rated current and torque at any speed up to rated speed.

The Fig 6 shows Basic Operator Panel (BOP) keypad provided on the front panel meant for controlling the drive.

The LCD is used to monitor the parameter. To start the motor, 'ON' key is to be pressed, and to stop the motor 'OFF' key is to be pressed. There is 'JOG' key provided for inching operation.

There is a key 'P' given for operator interface, changing over the parameter setting can be done by using this key in association with (D) key and key (Ñ). Parameters like, voltage current, Torque etc will be displayed turn by turn on each pressing of 'P' key /button.

The (D) or (Ñ) keys are used to increase or decrease the values. Numeric keys are also can be used to enter the values directly.

LED indicators are provided to indicate the status of drive. Green LED indicates the system running where as Red LED indicates when fault is occurred.

Programming of DC drive is possible through, personal computer (PC) also. For this purpose a connector for connecting PC through interfacing cable is provided at the rear panel.

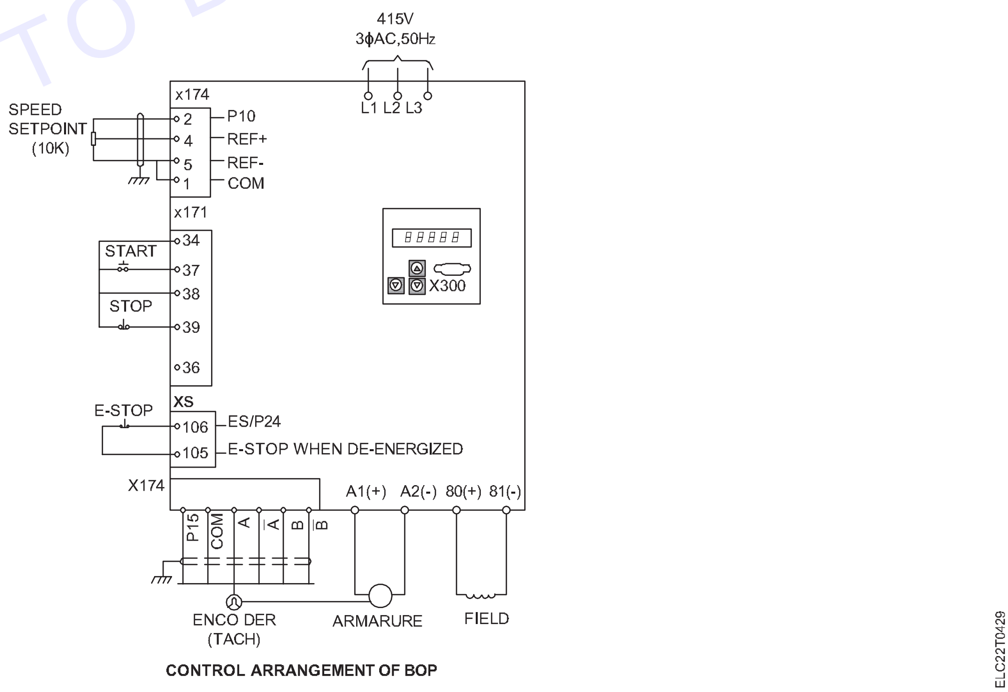
There may be variations in terms of names of key, display setting etc for different brands.

Operation of motor through DC drive

Fig 7 shows the operation of controls arrangement which is called as basic operator panel (BOP) .

The input supply connections and armature and field connections are well illustrated in fig 7. Input 3 phase AC, 415V, 50Hz supply can be connected L1, L2 and L3. The armature is connected across A1 and A2 where as the field is connected across B0 and B1 (The terminal names may vary depends on the type and make) an equipment ground conductor (Ground wire) must be connected to the controller mounting panel. Separate equipment grounding conductors from other major components Viz, motor, drive enclosure isolation transformer case (if used) in the system must also be connected continuously to a control connection point.

Fig 7



CONTROL ARRANGEMENT OF BOP

The AC input supply is provided should match the voltage and frequency given on the controller's name plate. Improper voltage may damage the equipment and insufficient current will cause erratic operation of the drive.

The shielded cable is recommended for the tachometer and all low level signal circuit to eliminate the possibility of electrical interference.

In some DC drives a speed adjusting potentiometer is provided to vary motor speed by controlling armature input voltage after the controller has been started. Some time a torque adjusting potential meter is used in place of speed adjusting potentiometer. It controls motor torque by controlling the DC current in the motor armature.

Starting and controlling the speed of DC motor

When the 'ON' button in BOP is pressed, the motor will start running. The desired speed can be attained by using 'P' button and D & Ñ buttons.

When the "OFF" button is pressed the motor will stop but AC line voltage remains connected to the controller and full field voltage is present. Armature voltage is reduced to zero. When pressing the "ON" button again the motor will accelerate to the preset speed.

Inching operation

For inching operation the 'JOG' position should be selected. Then the controller will operate only as long as the "ON" button is held pressed.

Changing the direction of rotation

In some model a 'reversing switch' is provided to change the direction of rotation of the motor. This switch is responsible for changing the polarity at the motor armature connection. First start the motor by pressing 'ON' button. The motor will run in forward direction. To change the direction of rotation, press "OFF" button and ensure that the motor is completely stopped. Now press the reversing button and then press the "ON" button. The motor will now run in the reverse direction. The reversing key has a provision which prevents direct transfer from one direction to the other.

Precautions during installation, connection and operation of DC drive

- Ensure all screws are tightened to the proper torque rating.
- During installation, follow all local electrical and safety codes.
- Ensure that appropriate protective devices (circuit breaker MCB or fuses) are connected between the power supply and DC drive.
- Make sure that the drive is properly earthed.
- Do not attach or remove wiring when power is applied to the DC drive.

Parameter setting of AC drive

As explained earlier the speed (N) of AC induction motor is directly proportional to the voltage (V) and frequency (f) of the applied power supply. Within the base speed limit, the torque (T) can be kept constant by maintaining a constant voltage / frequency (V/F) ratio. By increasing of speed to above base speed limit is also possible but at the cost of the torque.

(VFD /VVVFD (Variable Voltage Variable Frequency Drive) drives are used for efficient speed control of AC motors. The advantages of using drives to control the speed is already explained.

The AC drive has a front panel which includes two parts. Display panel and keypad. The display panel is provided with the parameter display and shows operation status of the AC drive. Keypad provides programming interface between users and AC drives. The Fig 8. shows the location of buttons and display unit on the front panel of AC drive.

Mode /Reset button

By pressing this button repeatedly the display will show status at the AC drive such as the reference frequency and output current. If the drive stops due to a fault, correct the fault first, then press this button to reset the drive.

Prog/Data button

By pressing this button will store the entered data or can show factory stored data.

Run/Stop button

To ‘start’ or ‘stop’ the AC drive operation this button is to be pressed.

This button can only be used to ‘stop’ the AC drive, when it is controlled by the external control terminals.

UP ∆ / down ∇ button

By pressing the ‘Up’ or ‘Down’ button momentarily parameter setting can be changed. These key may also be used to scroll through different operating values or parameters. Pressing the ‘Up’ or ‘Down’ button momentarily it will change the parameter setting in single unit increments. To quickly run through the range of settings, press ‘Down’ and hold the button.

Frequency setting knob

By using this knob, the frequency variation can be done.

‘RS 485’ communication port

Programming of AC drive can be done through personal computer (PC) also. For this, the drive should be interfaced with PC through ‘RS 485’ port.

LED displays are also given in the display unit to indicate the status of drive like ‘RUN’, ‘FWD’ and ‘REV’.

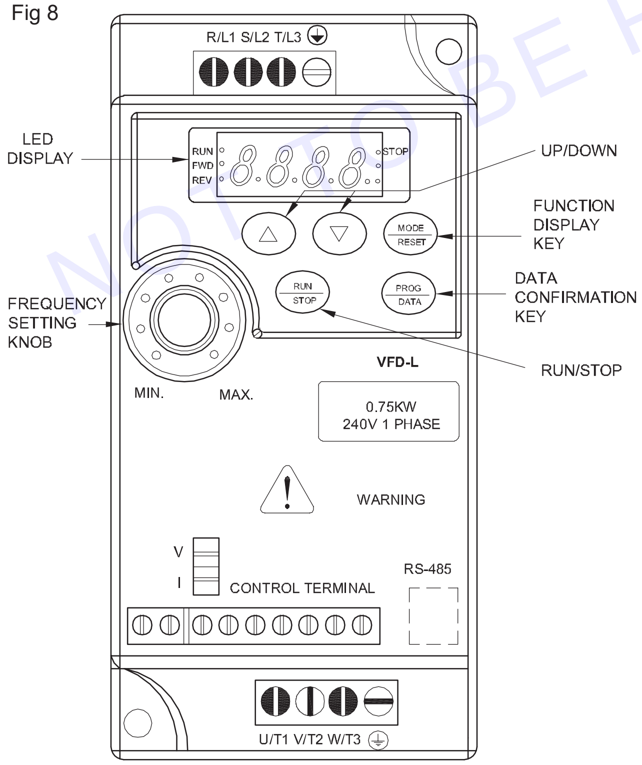
Operation of AC motor through drive

The motor and drive connections are well illustrated in

Fig 9. A 3Æ , 415V, 50Hz AC supply is connected to the drive input terminals R/L1, S/L2 & T/L3. Similarly output terminals of this drive is such as U/T1, V/T2 & W/T3 are connected to 3 phase induction motor. (The terminal names may vary depends on the type and make)

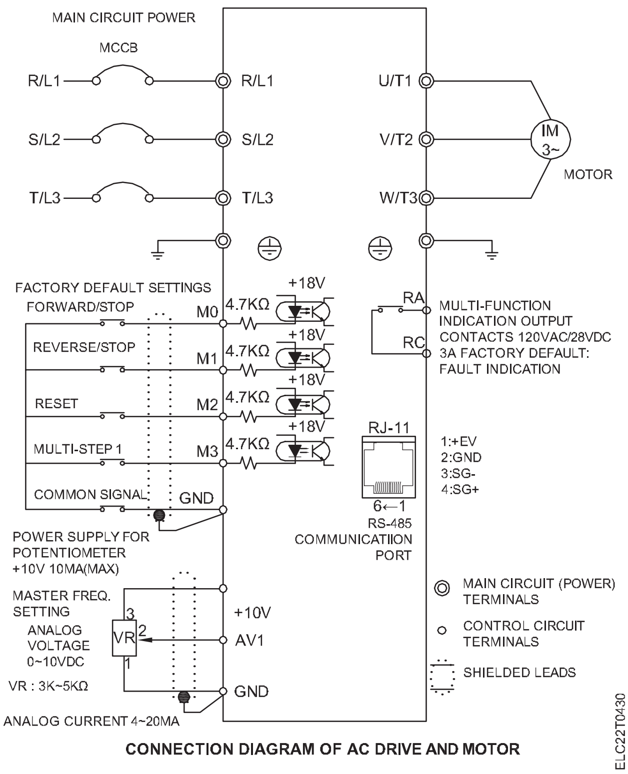
Both input end and output ends are earthed separately.

Fig 8



DISPLAY UNIT OF AC DRIVE

Fig 9



CONNECTION DIAGRAM OF AC DRIVE AND MOTOR

Changing of speed

The AC input supply provided, should match the voltage and frequency given on the nameplate. Improper voltage may damage the drive.

Programming can be done through 'MOD/RESET' button in association with D and Ñ button and the drives speed can be changed by using these buttons. The drive is started through 'RUN'/STOP' button.

The motor can be run at different speed by programming for the required speed.

Speed control of universal motors using SCR : Majority of domestic appliances like electric drilling machine, mixer etc., incorporate universal electric motors. Any of the half wave or full wave controls discussed earlier can be used to control speed of universal motors. Universal motors have some unique characteristics which allow their speed to be controlled very easily and efficiently with a feedback circuit is in Fig 10.

The circuit at Fig 10a provides phase controlled half wave power to the motor; that is, one the negative half cycle, the SCR blocks current flow in the negative half cycle, the SCR blocks current flow in the negative direction causing the motor to be driven by a pulsating direct current whose amplitude is dependent in the phase control of the SCR. The operation of the circuit shown in Fig 10 is as follows.

- Assuming that the motor is running, the voltage at point A in the circuit must be larger than the forward drop of diode D1, the gate to cathode drop of the SCR, and the emf generated by the residual mmf in the motor, to get sufficient forward flow to trigger the SCR.
- The wave form at point A (VA) for one positive half cycle is in Fig 10b and with VSCR, VD and motor generated emf VM. The phase angle at which the SCR would trigger is shown by the vertical dotted line.
- For any reason if the motor speed increases, then VM will increase, the trigger would move upwards and to the right along the curve so that the SCR would trigger later in the half - cycle thus providing less power to the motor, causing it to slow down. Similarly, if the motor speed decreases, the trigger point will move to the left and down the curve, causing the SCR to trigger earlier in the half cycle providing more power to the motor thereby speeding it up.
- Resistors R1, R2, R3 along with diode D1 and C1 forms a ramp generator. Capacitor C1 is charged by the voltage divider R1, R2 and R3 during the positive half cycle. Diode D2 prevents negative current flow during the negative half cycle, therefore C1 discharges through R2 and R3 during negative half cycle. Varying the value of R2 varies the trigger angle a.

A practical version of the circuit for controlling the speed of universal motors is in Fig 11.

As can be seen, the circuit at Fig 11 is quite similar to that at Fig 10 but for the addition of two transistors and a few resistors.

Fig 10

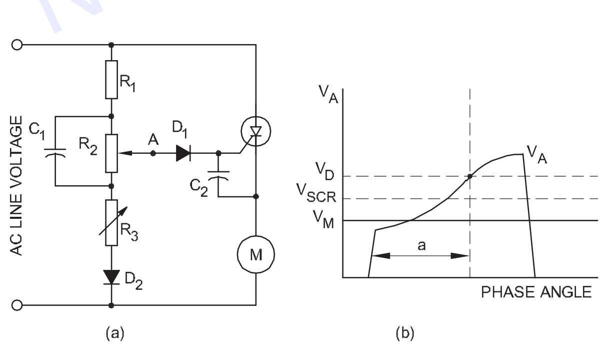
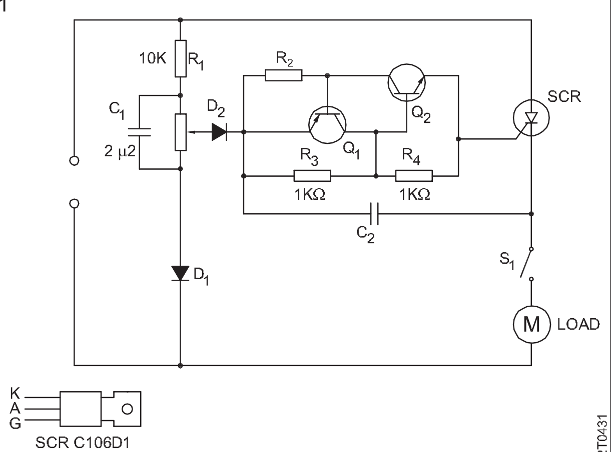


Fig 11



CIRCUIT DIAGRAM OF UNIVERSAL MOTOR SPEED CONTROLLER

In Fig 11, the action of Q1 - Q2 is to provide adequate gate current to trigger the SCR into conduction.

Q1 - Q2 and their associated resistors acts as a voltage sensitive switch. In each half cycle, C2 is able to charge via R1. As soon as voltage across C2 rises to suitable value. Q1 and Q2 both switch- on and partially discharge C2 into the gate of the SCR, thus delivering a pulse of high current to the SCR gate, independent of any current drive limitations of RV1. The Q1 - Q2 and C2 network thus enables virtually any SCR to be used in the circuit almost irrespective of its sensitivity characteristics.

The universal motor speed control circuit is in Fig 11 enables the motor speed to be smoothly varied from zero to 75% of maximum via a single control. It also incorporates built - in feedback compensation to maintain the motor speed virtually constant at any given speed setting, regard-less of load changes.

Voltage stabilizer and UPS

At the end of this exercise you shall be able to

- state the basic concept of stabilizer
- draw the block diagram and explain the function of each blocks
- state the working various types of voltage stabilizers
- state the basics of UPS system
- explain the block diagram of OFF line UPS and its various controls and functions
- explain the block diagram ON line UPS and advantages and disadvantages.

Voltage stabilizer

It is an electrical supply device controlled by electronic circuit which gives the constant output voltage irrespective of the variation in the high input supply voltage or disconnect the output circuit if the input voltage is very low or very high.

Every electrical device is designed to operate at a certain rated voltage for optimum efficiency and maximum length of service. Power supply voltages should not drop or rise by more than 5% of rated voltage as per IS.

The effect of voltage variations in commonly used electrical appliances are given below.

Sl.No.	Name of the equipment	Low voltage	High voltage
1	Incandescent lamp	Lamp efficiency decreases if the voltage is decreased.	Life of the lamp decreases or the lamp fuses in extreme cases.
2	Fluorescent lamp	If voltage is too low, lamp will not light up.	Life of the tube/choke decreases.
3	Electric stove, electric iron, water heaters, toasters etc.	Increases the heating time as heat produced is low.	Shortens the life of heating elements or heating elements burnt out.
4	Fans, vacuum cleaners	Efficiency decreases.	Life of the equipment is decreased
5	Washing machines, refrigerators and air-conditioners	Motor of the machine will draw more current from the line that results in overheating of the motor which may lead to burn out.	The motor insulation may fail and draw excess current which can lead to burn out.
6	Radios and television sets	Poor quality of reception, picture will not be clear in the television sets.	Life of the equipment is decreased
Some of the electronic equipment such as colour television sets are designed by the manufacturers with built in electronic stabilizers like Switch Mode Power Supplies (SMPS). Hence there is no need to provide an additional external stabilizers for these equipments.			

Types of AC voltage stabilizers

1 Stepped voltage stabilizer

   a) Manual

   b) Automatic relay type

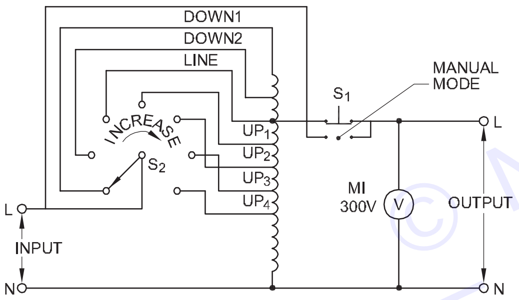
2 Servo voltage stabilizer

3 Constant voltage transformer

Stepped voltage stabilizer - manual type : Fig 1 shows an auto-transformer in which the output voltage increases as the tap changing switch S1 is turned clockwise. The output voltage can be seen by connecting a voltmeter in the output side as in Fig 1. Increasing or decreasing the output voltage near to the set value is possible by rotating the tap changing switch S2 in the appropriate direction within ±10% of the desired output voltage. A push-button switch S1 enables to measure the incoming voltage.

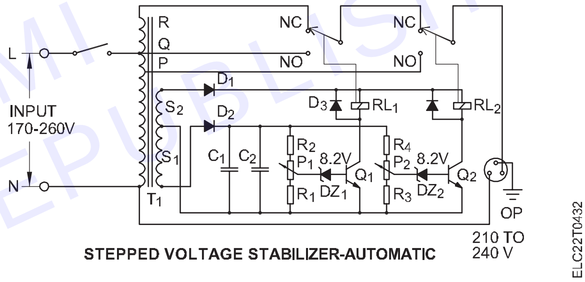
Stepped voltage stabilizer - automatic type : Fig 2 shows a stepped voltage stabilizer of the automatic type operated by relays. T1 is an auto-transformer with multiple tappings. S1 and S2 are two secondaries for relay operation. The secondary voltage of S1 is rectified and filtered for the use of the sensing circuit while voltage S2 is rectified and filtered for the use of the relay operation. P1 and P2 are pre-set resistors (variable resistors) used for adjustment. R1, P1 and R2 provide sensing voltage to the zener diode. DZ1 and R3P2 and R4 to the zener diode DZ2. Q1 and Q2 are two transistors used as switches. RL1 and RL2 are two relays.

Fig 1



STEPPED VOLTAGE STABILIZER-MANUAL

Fig 2



STEPPED VOLTAGE STABILIZER-AUTOMATIC

When the input voltage is low, say less than 200V, both DZ1 and DZ2 do not conduct as the voltages at the preset tappings are less than their zener diode voltages. This causes both transistors to cut off and the relays are in the off position. At the off position of the relays, NO contacts of both the relays connect terminal R of the auto-transformer to output which results in booster output voltage.

When the input voltage increases above 210V, but below 240V voltage across S1 increases proportionally. This increases the pre-set tap voltage, thereby the zener diode DZ1 conducts and hence make the transistor Q1 to ON. The relay RL1 operates and connects the supply voltage directly to the output through NO. contact of RL1 and NC contact of RL2. By this operation the output voltage will be the same as the input voltage.

When the input supply voltage increases above 240V the zener diode DZ2 gets voltage from P2 and hence conducts which makes Q2 to ON. This results relay RL2 energise and output is taken from NO. point of RL2. The output voltage reduces or bucks.

Usually 12V DC relays with the required current ratings of contacts are preferred for stabilizers. Diodes or capacitors are used across the relay coil to protect the transistors from reversed induced emf when the relays become OFF. LED indicators are sometimes used to indicate the mode of operation such as buck, normal, boost etc.

Stepped voltage stabilizers are available with different types of electronic circuits with one to three relays to provide an output voltage of 200-240V. They are specified for maximum input voltage variation and for their output, KVA ratings say 170 to 270 volts 1 KVA or 135 to 260 volts 0.5 KVA.

Some of the stabilizers are provided with over-voltage and under-voltage cut off to protect the connected equipment.

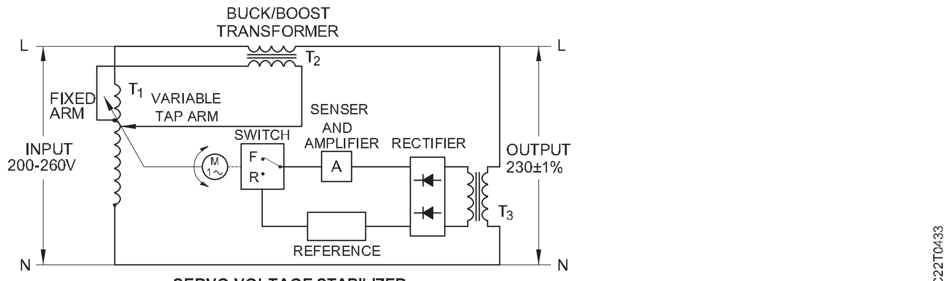
Applications : Stepped voltage stabilizers are used along with refrigerators, air conditioners, TVs, VCRs etc. Colour TVs with self-contained switch mode power supplies do not require voltage stabilizer as they are designed to operate from 130 to 260 volts.

Servo - voltage stabilizer

The servo voltage stabilizer employs a toroidal auto-transformer and a servo motor driven by a sensing circuit which senses the voltage. The difference between the output and nominal voltage is sensed by a sensing circuit which drives the servo motor. Any variations in mains cause the motor to move clockwise or anticlockwise thus correcting the voltage.

A servo voltage stabilizer is provided with three transformers function along with control circuits and a servo motor as in Fig 3. T1 is a continuously variable toroidal auto-transformer (variac) driven by a servo motor M.

Fig 3



SERVO VOLTAGE STABILIZER

The output from the variac, drives a series buck/boost transformer T2 so that boost takes place when the variable tap arm moves down and bucks the voltage when the arm moves up. The transformer T3 provides the required reference voltage and sensing voltage for the electronic circuit which drives the motor.

When the output voltage is less than the reference voltage, the electronic circuit senses the difference, drives the motor in one direction which results in increase in the output voltage.

When the output voltage increases above the ratings, the motor is driven in the opposite direction so that the output voltage increases. When the voltage difference in output and the reference are equal, the servo motor is switched off by the circuit.

A servo stabilizer provides constant voltage to an accuracy around ±1% or ±0.5% and a correction range 10 to 30 volt/sec.

A servo stabilizer is more accurate and also costlier, and, therefore, used with costlier equipments such as computers, xerox machines, medical electrical equipments etc.

Constant voltage transformer

A constant voltage transformer works on ferro-resonant principle. The variation in the primary flux with an unsaturated iron core does not affect the secondary flux with saturated iron core. Thus, the secondary induced voltage remains relatively independent of the voltage impressed upon the primary winding.

Basics of UPS systems : Most people take the mains AC supply for granted and use it almost casually without giving the slightest thought to its inherent defects and the danger posed to sophisticated and sensitive electronic instruments. For ordinary household appliances such as incandescent lamps, tubes, fans, TV and fridge, the mains AC supply does not make much of a difference, but when used for computers, medical equipments and telecommunication systems, a clean, stable, interruption-free power supply is of utmost importance.

UPS (Uninterrupted Power Supply) is the only solution available to an individual customer faced with the problem of ensuring high quality of power for critical loads. All UPS designs contain a battery charger to keep the battery fully charged by the power from mains. Small UPS normally comes with a sealed maintenance free (SMF) batteries which can provide 10 to 15 minutes of power backup, the backup time increases with the capacity of the battery. Tubular batteries or automotive batteries are used in medium and large capacity UPSs.

UPS classification : There are two broad categories of UPS topologies - OFF line, and ON line . These topologies differ in the way they serve the load when the mains is present and is healthy. They vary in features & pricing.

Off-line and on-Line : Off-line UPS filters the mains and feeds it directly to the load for most of the time. When the mains is unhealthy, perhaps due to a slight drop in voltage, the load is switched by a fast relay, in typically less than half a cycle, to an inverter deriving its power from a battery. The inverter generates a square or stepped waveform to emulate the mains-satisfactorily for most computers. This particular technique represents the lowest cost solution.

Online UPS converts AC mains into DC before inverting again to AC to power the load with a synthetic sine wave. A battery connected across the DC link acts as the backup power source.

This gives a supply for the computer that totally isolates the input mains from the load, removing all mains noise and with no break when the mains fails.

Standby/OFF Line block diagram (Fig 4) : In the off line UPS, the load is connected directly to the mains when the mains supply is available. When working over voltage/under voltage conditions are detected on the mains, the off line UPS transfers the load to the inverter. When the line is present, the battery charger charges the battery and the inverter may either be shut down or will be idling. Thus in an off line UPS, there is a load transfer involved every time, the mains is interrupted and restored. This transfer is effected by change- over relays or static transfer switches. In any case there will be a brief period during which the load is not provided with voltage. If the load is a computer and the transfer time is more than 5ms, then there is a chance that the computer will reboot.

Some modified designs incorporate a limited range of voltage regulation by transformer tapping and a certain degree of transient protection by using RF filters and MOV's (Metal Oxide Varistor). Off line UPS is an economical and simple design and hence it is preferred for small rating, low cost units aimed at individual PC user's market. When the load is really a critical one an off line UPS is not acceptable. Usually square wave output off line UPS are available in market with lower loading capacities.

Advantages of OFF line UPS: High efficiency, small size, low cost.

Disadvantages: There can be change over complaint in offline UPS. Off line very much depends on battery. If battery fails entire system fails. Sometimes during change- over computer re-boots which causes loss of files. Another disadvantage is that output voltage will be a varying one. Usually in the range of 200V-240V and hence not suitable to all electronic gadgets.

Front panel indications and rear panel sockets/switches used in UPS : All UPS systems have

- Fuse/Fuse holder
- Switches
- Sockets
- Panel indicator (LED and Neon lamp)
- Meters (Volt/Ampere)

Fig 5 and 6 shows the front and rear panel controls/sockets.

ON line UPS

In an ON line UPS, the inverter always supplies the load irrespective of whether mains power is available or not. The load is always left connected to inverter and hence there is no transfer process involved. When the mains power is present, it is rectified and applied in parallel with the battery. Hence all the supply system transients are isolated at the battery and the inverter always delivers pure sine wave of constant amplitude to the load.

Fig 7 represents a basic block diagram of an ON Line UPS.

In the block diagram (Fig 7), the mains input is stepped down to a lower level and applied to a thyristor based phase controlled AC to DC converter, employing firing angle(a) control. The PWM inverter which usually employs pulse width modulation using triangular/square wave carrier runs in battery mode. The output is filtered and given to the load. The PWM inverter is switched in the frequency range (50Hz) depending on the power rating and hence the DC side current drawn by the inverter will contain switching frequency components.

Along with the charging current the second harmonic component of DC side current of the inverter also flows into the battery. This second harmonic is quite large in value and this represents unnecessary strain on the battery. This is one of the major disadvantages of this design since it affects the battery life adversely.

When the mains is present the load power flows though the converter, reaches the battery node and from there flows into the inverter i.e there is double conversion of power. The converter, Inverter and the two level shifting transformers incur power losses in this process. Hence the efficiency of this design is lower than the Off line design.

In a properly designed control system the battery voltage is measured and compared with a set float voltage. The error is processed in a proportional controller and the processed error decides the charging current that should flow into the battery. Charging current will be a constant one for On line UPS.

Fig 4

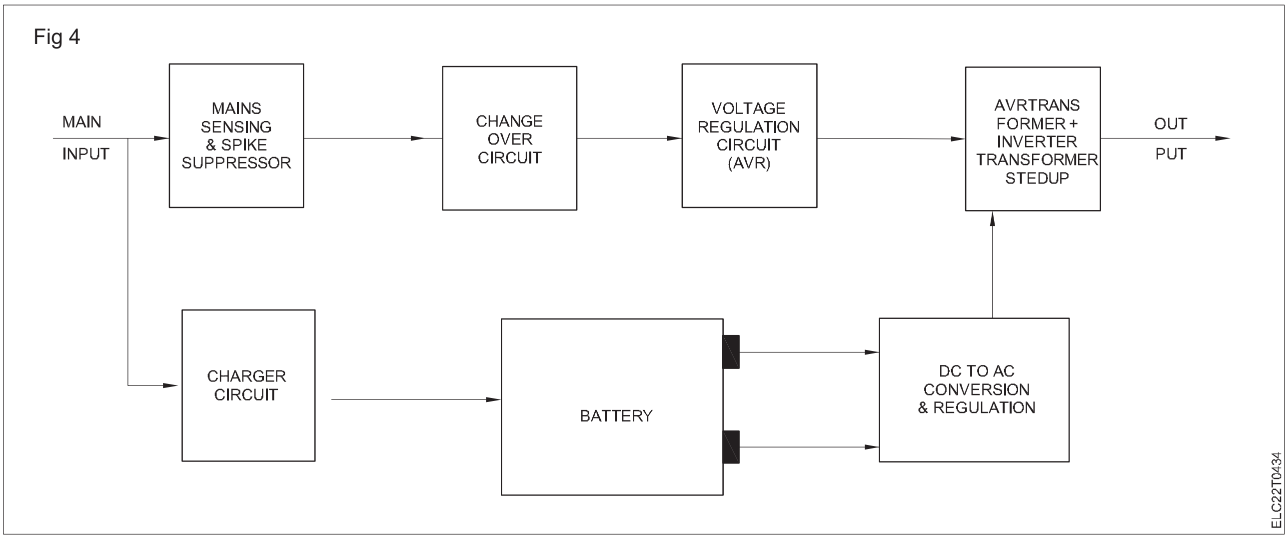


Fig 5 Fig 6

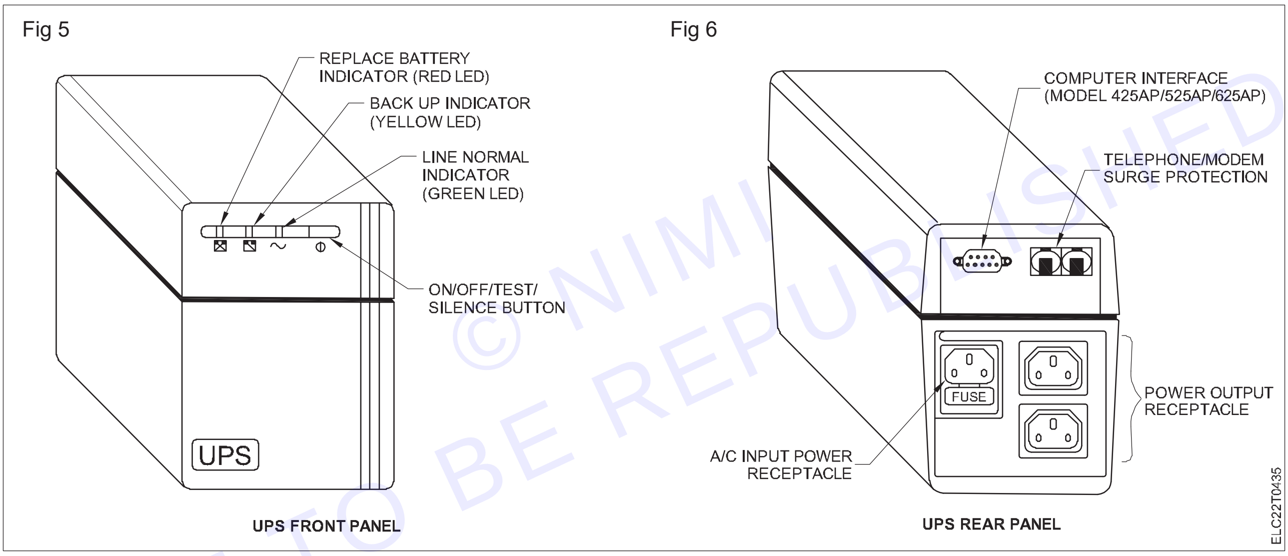
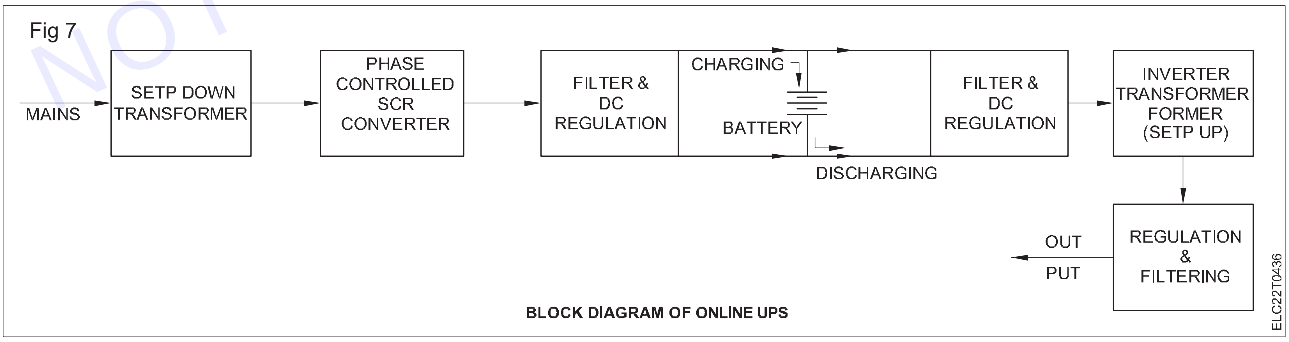


Fig 7



BLOCK DIAGRAM OF ONLINE UPS

Often it is found that the battery is in discharge mode even when mains is present i.e the battery shares the load current with the mains. This happens when the mains voltage is low and/or the output is loaded to above 75%. The efficiency of ON line UPS can be increased by using boost type power factor correction circuit.

Advantages

- Constant output voltage (No AVR card) free from changeover problem.
- Constant charging current.

Disadvantages

- complex in design, lower efficiency, higher cost, bigger in size and strain on the battery.

Battery charger and inverter

Objectives: At the end of this lesson you shall be able to

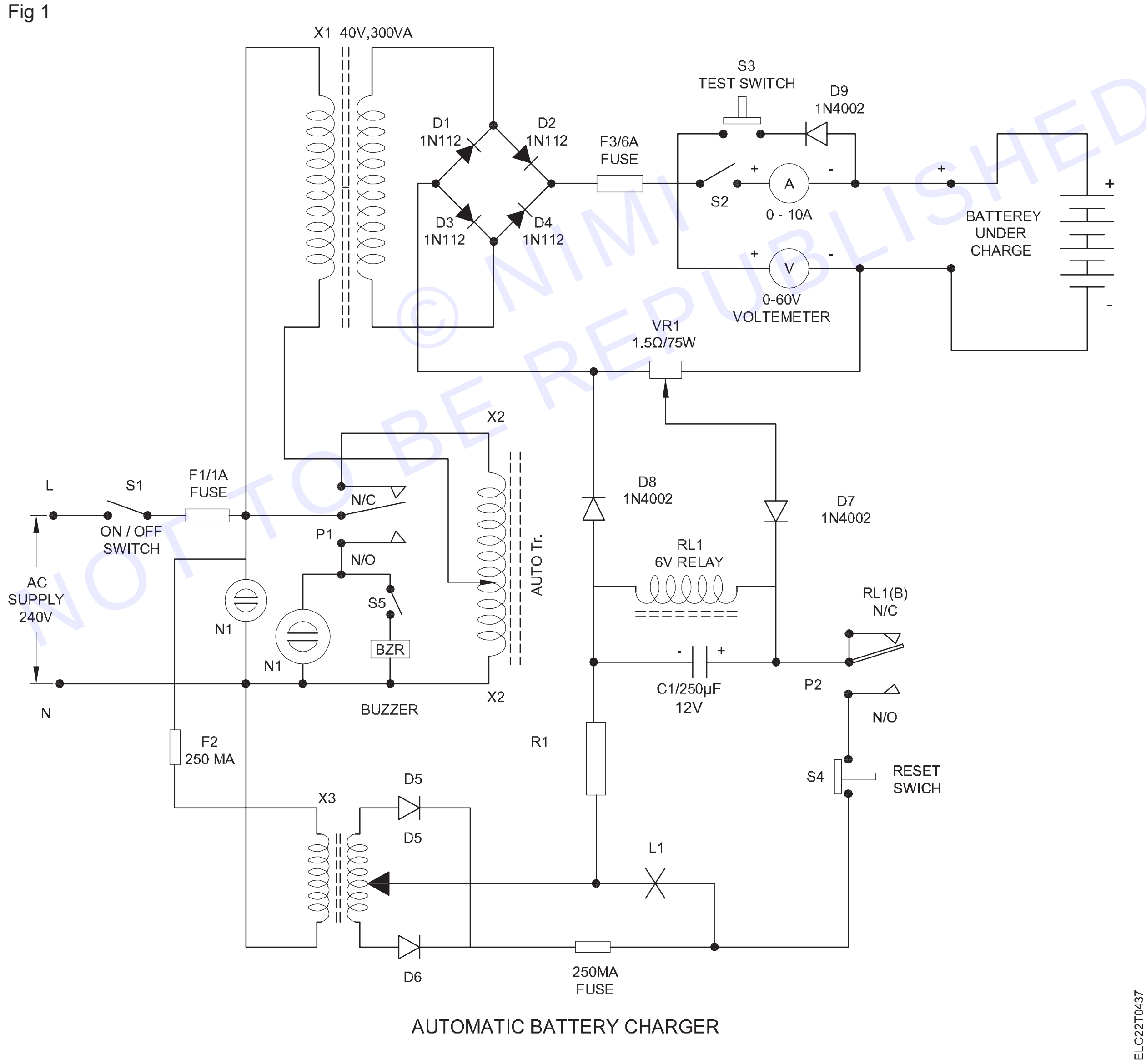
- explain the working of battery charger with the help of block diagram
- state the principle of inverter with the help of block diagram.

A Simple battery charger : The charger can charge 6V,12Vand 24V battery at Suitable current rate. This circuit has many protection built in it to protect the battery from overcharge and reverse polarity etc.

The charger consist of an auto transformer X2,(Fig 1) for supplying constant current and voltage.

A charger transformer 'X1' is connected to the auto transformer and the secondary of the X1 (fig 1) is rectified through full wave bridge rectifier and supplied to the battery under charger through. Ammeter voltmeter and a potentiometer (Fig 1)

Fig 1



AUTOMATIC BATTERY CHARGER

A step down transformer X3 is used to keep cut off relay is energised condition when the mains AC supply is cut off to the charger circuit. Relay RL1 used to cut off the AC mains supply to the charger circuit. Pole P1of relay RL1 is connected to AC mains supply and pole P2 is connected to cut off circuit.

Relay is energised by the centre tapping of potentiometer, which is set such that, the current in the charger circuit exceeds then it is energised and poles P1& P2 are connected to normally opened (NO)pin, switching ‘Off’ A/C mains supply to the circuit.

The test switch S3 is connected to check battery polarity, reset switch S4 is used to reset the charger, when any fault occurs. Then the charger is cut off and the Switch ‘S1’ is mains on/off switch.

A fully charged lead acid battery must be 2.1 volt/cell during on charge. It will increase upto 2.7V/cell. The voltage of a battery is multiple of the number of cells.

In discharged condition the voltage is 1.8V/cell, it should not be further discharged in this condition as it may permanently damage the cell.

E.g A 100AH (ampere hour)battery requires (100 AH/10Hr=10 Amp) 10 Amp. Charging current for 10 hours for fully charged. To get complete discharge at the rate of 5Amps will require 20 Hrs.

The fully discharged battery requires about 11/2 times more to get charged .If the battery is in dead (or)not in use for long time even in normal changing current is passed. These dead batteries require higher charge voltage to start the charging current.

Checking of battery : Acid level and specific gravity of electrolyte, will indicate the condition of battery whether it requires charging or not.

The hydro meter is used for checking the acid level in a battery .The scale in marked in the hydrometer from 1100 to 1300.when it is inserted in the battery, the reading

i 1100-1150 -indicates battery is down

ii 1200-1250- indicates battery is o.k.

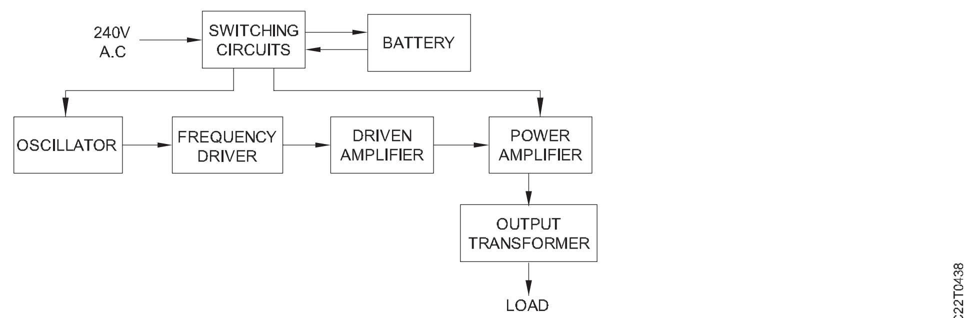
iii 1250-1300 indicates excess acid

Voltage testing : By using high rate discharge tester, the voltage the each cell must be 2.1V, If it indicates below than 1.8V, then it shows the battery is in fully discharged. It is still below 1.8V.Then the battery becomes dead condition.

Inverter : It is an electronic device, which converts a D.C potential (voltages) normally derived from a lead-acid battery into a stepped-up AC potential (voltage) which is similar to the domestic AC voltage.

Locating the fault and troubleshooting of an inverters which provide sine wave outputs or the use of PWM(Pulse Width Modulation) technology is very difficult. (Fig 2)

Fig 2



BLOCK DIAGRAM OF A DRIVEN INVERTER

Switching circuits : It is the input stage of a inverter. This circuits supplying the power to further stages and connected to battery. The DC supply of battery in this supplies to the switching circuits for various needs.

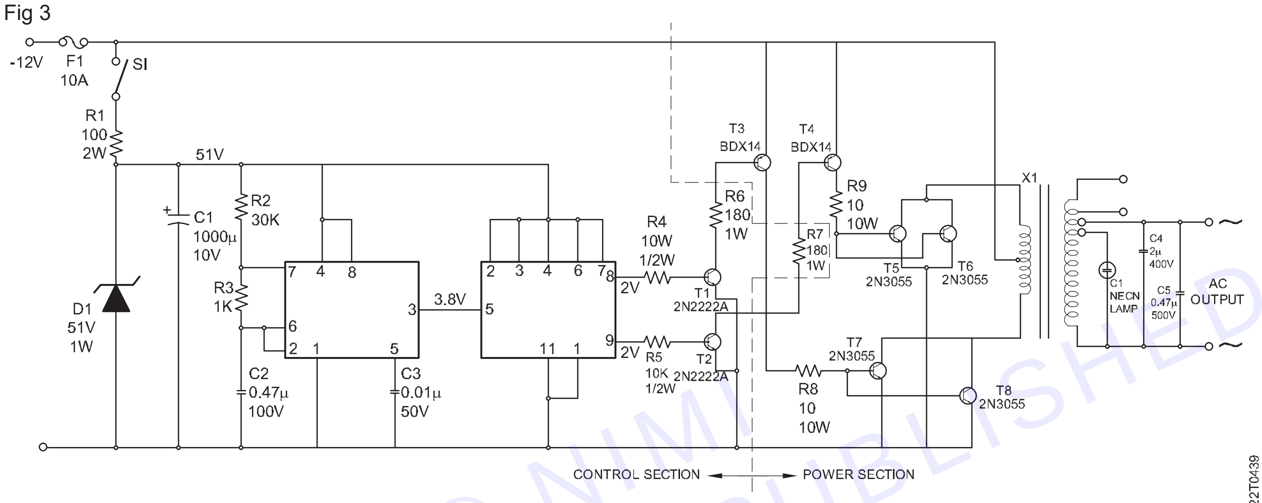
Oscillator

It is an electronic circuit which generates the oscillating pulses either through an IC circuit or a transistorized circuit. This oscillations are the production of alternate pulse of positive and negative (ground) voltage peaks of a battery and at a specified frequency (No.of positive peaks per second). These are generally in the form of square waves and the inverters are called square wave inverters.

The complete circuit diagram of a static 50Hz static inverter is in Fig 3.

The oscillator section of the inverter used a IC circuit to produce control signal frequency to the control and drianer section. The received oscillating frequency is amplified to a high current level using power transistor or MOSFET. IC 7473(JK Flip type) used to power amplification and control the frequency to the driver transistors T1 and T2 driving the power transistor to the required level as in the Fig 3.

Fig 3



COMPELETE CIRCUIT DIAGRAM OF 50Hz STATIC INVERTER

The two parallel connected power transistor T5, T6 and T7, T8 are connected to the output transformer which is used to step up the low level AC from the amplifies stage into the specified level.

The transformer secondary is supplied the required level of AC 240V. The generation of the oscillations due to which the process of voltage induction is able to take place across the windings of the transformer.

The inverter does not produce any power and the power produced by DC source. The inverter requires a relatively stable power source capable of supplying of enough current for the intended power demands of the system.

An inverter can produce square wave, modified sine wave, pulsed sine wave, pulse width modulated wave (PWM) or sine wave depending on circuit design.

The inverters more than three stages are more complex and expensive. Most of the electric devices are working with pure sine wave and AC motors directly operated on non-sinusoidal power may produce extra heat, and have different speed-torque characteristics.

Maintenance, service and troubleshooting in AC 3 phase squirrel cage induction motor and starters

Objectives: At the end of this lesson you shall be able to
- list and state about the maintenance schedule of AC 3 phase motor
- list out the possible faults, causes and remedies in 3 phase motors
- explain the mechanical problems in motor, bearings and their remedies
- state the lubrication techniques on learning
- explain the troubleshooting of AC motor starters and maintenance of starters.

Generally due to the rugged construction of the AC squirrel cage induction motor, it requires less maintenance. However to get trouble-free service and maximum efficiency, this motor needs a scheduled routine maintenance. As found in most of the industries the AC squirrel cage motor is subjected to full load for 24 hours a day and 365 days a year. Therefore the maintenance should be scheduled to have periodic maintenance for a selected area on daily, weekly, monthly, half yearly and yearly periods for increasing the working life of the motor and to reduce the break down time.

Maintenance schedule: Suggested maintenance schedule for the AC squirrel cage induction motor is given below as a guide.

Daily maintenance

- Examine earth connections and motor leads.
- Check motor windings for overheating. (Note that the permissible maximum temperature is above that which can be comfortably felt by hand.)
- Examine the control equipment.

In the case of oil ring lubricated machines

i examine bearings to see that oil rings are working

ii note the temperature of the bearings

iii add oil if necessary

iv check end play.

Weekly maintenance

- Check belt tension. In a case where this is excessive it should immediately be reduced and in the case of sleeve bearing machines, the air gap between the rotor and stator should be checked.
- Blow out the dust from the windings of protected type motors, situated in dusty locations.
- Examine the starting equipment for burnt contacts where motor is started and stopped frequently.
- Examine oil in the case of oil-ring lubricated bearings for contamination by dust, dirt etc. (This can be roughly ascertained on inspection by the colour of the oil).

Monthly maintenance

- Overhaul the controllers.
- Inspect and clean the oil circuit breakers.
- Renew oil in high speed bearings in damp and dusty locations.
- Wipe brush holders and check the bedding of brushes of slip-ring motors.
- Check the condition of the grease.

Half-yearly maintenance

- Clean the winding of the motors which are subjected to corrosive or other such elements. Also bake and varnish if necessary.
- In the case of slip ring motors check slip rings for grooving or unusual wear.
- Renew grease in ball and roller bearings.
- Drain all oil bearings, wash with kerosene, flush with lubricating oil and refill with clean oil.

Annual maintenance

- Check all high speed bearings and renew if necessary.
- Blow out clean dry air over the windings of the motor thoroughly. Make sure that the pressure is not so high as to damage the insulation.
- Clean and varnish dirty and oily windings.
- Overhaul motors that are subject to severe operating conditions.
- In the case of slip ring motors, check the slip ring for pittings and the brush for wear. Badly pitted slip rings and worn out brushes should be replaced.
- Renew switch and fuse contacts if badly pitted.
- Renew oil in starters that are subjected to damp or corrosive elements.
- Check insulation resistance to earth and between phases of motor windings, control gear and wiring.
- Check resistance of earth connections.
- Check air gaps.

Records : Maintain independent cards or a register (as per specimen shown in trade practical) giving a few pages for each machine and record therein all important inspections and maintenance works carried out from time to time. These records shall show past performance, normal insulation level, gap measurements, nature of repairs and time between previous repairs, and other important information which would be of help for good performance and maintenance.

Faults which occur in AC 3-phase squirrel cage motor can be broadly divided into two groups

They are

1 Electrical faults

2 Mechanical faults.

In most of the cases both the faults may be individually present or both may be present, as one type of fault creates the other fault. The following charts give the cause, the test to be carried out and possible remedy.

Chart 1

Motor fails to start

S.No	Cause	Test	Remedy
1	Overload relay tripped.	Wait for overload coils to cool. Push the reset button if separately provided. In some starters the stop button has to be pushed to reset the overload relay.	If motor could not be started check the motor circuit for other causes as outlined in this chart.
2	Failure of power supply.	Test the power supply at the starter incoming terminals.	If the supply is present in the incoming terminals of the starter, check the starter for fault. If not, check the main switch and fuses. Replace the fuses if necessary or restore power supply.
3	Low voltage.	Measure the voltage at the mains and compare with the name-plate rating.	Restore normal supply or check the cables for underrating.
4	Wrong connection.	Compare the connection with the original diagram of the motor.	Still if motor does not start, reconnect, after disconnecting the connection of the motor.
5	Overload.	Measure the starting torque required by load. higher output.	Reduce load, raise tapping on auto-transformer, install a motor of a
6	Damaged bearings.	Open the motor and check the play of bearings.	Replace if required.
7	Faulty stator winding.	Measure current per phase and they should be equal, if required measure resistance per phase; check insulation resistance between winding and earth.	Repair the fault if possible or rewind stator.
8	Wrong control connections.	Check the control circuit and compare it with the circuit diagram.	Reconnect the control circuit according to the manufacturer's circuit diagram.
9	Loose terminal connections at mains or at starter or at motor.	Check the terminal connection of the main switch, starter and motor for discolouring and loose nuts.	Tighten the terminals.
10	Driven machine is locked.	Disconnect the motor from the load.	If the motor starts satisfactorily check the driven machine and rectify the defect.
11	Open circuit in stator or rotor.	Check visually and then with multimeter/megger.	Rectify the defect or wind.
12	Short circuit in stator winding.	Check the phases and coil groups with the help of an ohmmeter or use internal growler.	Repair the winding or rewind.
13	Winding is grounded.	Test with a Megger or test lamp.	If the fault is found, repair or rewind.
14	Bearing stiff.	Rotate the rotor by hand.	If the rotor is stalled, dismantle the motor and rectify the defect.
15	Overload.	Check the load and belt tension.	Reduce the load or loosen the tight belts.

Chart 2

Motor starts but does not share load (Runs at low speed when loaded.)

S.No	Cause	Test	Remedy
1	Too low a voltage.	Measure voltage at the motor terminals and verify it with the name-plate.	Renew bad fuses; repair circuit and remove the cause of low voltage, like loose or bad contacts in starter, switches, distribution box,etc.
2	Bad connection.	Check the connection and contact of starter for loose contact.	Remove the fault as required.
3	Too low or high tension on driving belt.	Measure the tension and verify it with the instruction of the manufacturer.	Adjust the belt tension.
4	Open circuit in rotor winding.	Examine the rotor bars and joints.	Re-solder the rotor bars.
5	Faulty stator winding.	Check for continuity, short circuit and leakage.	Repair the circuit if possible or rewind the stator.
6	Defective bearings.	Examine bearings for play.	Replace the bearings.
7	Excessively loaded.	Measure the line current of the motor and compare it with its rated current.	Reduce the mechanical load on the motor.
8	Low frequency.	Measure the line frequency with a frequency meter.	If the line frequency is low inform the supply authorities and get it corrected.

Chart 3

Motor blows off fuses

S.No	Cause	Test	Remedy
1	Incorrect size of fuses	Check the size of the fuse wire (it should be rated for 1½ times its normal current); connect the ammeter in the circuit and test for excess load current.	Replace the fuse wire if necessary; repair the motor if it is due to electrical fault of stator or rotor.
2	Low voltage	Measure the line voltage.	Remove the cause of low voltage.
3	Excessively loaded	Measure the line current and compare it with its rated current.	Rectify the cause of overload or install a motor of higher output rating.
4	Faulty stator winding	Check for open circuit, short circuit or leakage of the stator as explained earlier.	Repair the fault; if not possible then rewind the stator.
5	Loose connection in starter	Check for loose or bad connection in the starter because it may cause unbalancing of current.	Rectify the loose connection; loose all the contact points of the starter with sandpaper and align the contacts.
6	Wrong connection	Check the connection with the original diagram.	Reconnect the motor if it still does not start.

Chart 4

Over Heating of the motor

S.No.	Cause	Test	Remedy
1	Too high or low voltage or frequency.	Check the voltage and frequency at the terminal of the motor.	Rectify the cause of low or high voltage or frequency as the case may be.
2	Wrong connection.	Compare the connection with the given circuit diagram.	Reconnect the connection if required.
3	Open circuit in rotor.	Loose joints of rotor bars cause heat.	Resolder the joints of rotor bars and end rings.
4	Faulty stator winding.	Check for continuity, short circuit and leakage as stated before.	Remove the fault if possible; otherwise rewind the stator winding. Remove dirt and dust from them if any.
5	Dirt in ventilation ducts.	Inspect ventilation ducts for any dust or dirt in them.	Reduce the load or loosen the belt. Rectify the single phasing defect.
6	Overload.	Check the load and the belt.	If the defect is with the driven machine repair it. If the problem is with the bearing, investigate and repair or replace with new one.
7	Unbalanced electrical supply.	Check the voltage for single phasing. Check the connections and fuses. Remove the load and check the rotor for free rotation.	If required replace the motor designed for this purpose.
8	Motor stalled by driven machine or tight bearing.	Check the motor - starter contactor	Loose the machine bearing or grease the bearing or replace the bearing.
9	Motor when used for reversing heats up.	Check the connection	Check the manufacturer's instructions.

Chart 5

Vibration and noise in motors

S.No.	Cause	Test	Remedy
1	Loose foundation bolts or nuts.	Inspect nuts and bolts of foundation for loose fittings.	Tighten the foundation nuts.
2	Wrong alignment of coupling.	Check alignment with a spirit level through dial test indicator.	Realign the coupling.
3	Faulty magnetic circuit of stator or rotor.	Measure the current in each phase and they should be equal. Check also per-phase resistance and they should be equal. Check the insulation resistance between the windings and the frame. In a newly wound motor there may be reversed coils in a pole-phase group which can be detected by the compass test.	Repair fault if possible or rewind the motor.
4	Motor running on single phase.	Stop the motor, then try to start. (It will not start on single phase). Check for open in one of the lines or circuits.	Rectify the supply.
5	Noisy ball bearing.	Check the lubrication for correct grade and low noise in the bearing.	If found, replace the lubricant or replace the bearing.
6	Loose punching or loose rotor on shaft.	Check the parts visually.	Tighten all the holding bolts.

7	Rotor rubbing on the stator.	Check for rubbing marks on the stator and rotor.	If found, realign the shaft to centre it or replace the bearings.
8	Improper fitting of end-covers.	Measure the air gap at four different points for uneven position of rotor	Open the screws of the side covers, and then tighten one by one. If trouble still covers. persists, remove the end cover, shift for next position and tighten the screws again.
9	Foreign material in air-gap.	Examine the air-gap.	File or clean out air-gap.
10	Loose fan or bearings.	Check looseness of the fan screw or bearings.	Tighten the fan screws or refit new bearings, if necessary.
11	Slackness in bearing on shaft or in housing.	Remove the bearings and inspect the inner looseness of the race on the shaft and outer race in the housing.	Send the motor to the repair shop for removing the looseness of the shaft and housing, if any.
12	Improper fitting of bearings.	Remove the end-covers and examine the assembly of bearings on the shaft or in the housing.	Refit the bearings on the shaft or in the housing.
13	Minor bend in shaft.	Check for alignment on the lathe.	Remove the bend or replace the shaft, if required.

Troubleshooting of motor starters

Objectives: At the end of this lesson you shall be able to

- state the troubles in the D.O.L. starter, their cause and their remedy
- check out the troubles in the mini manual starter, their cause and their remedy.

Introduction : The D.O.L. starter consists of the fixed contacts, movable contacts, no-volt coil, overload relay and start button which is in green colour and a stop button in red colour with a locking arrangement. The main purpose of the contactor is to make and break the motor circuit. These contacts in the contactor suffer maximum wear, due to frequent use and hence these contacts are made of silver alloy material.

A no-volt coil acts as under-voltage release mechanism disconnecting supply to the motor when the supply voltage fails or is lower than the stipulated value. Thus the motor will be disconnected from supply under these conditions.

A thermal overload relay unit is provided for the protection of the motor. This unit consists of a triple pole, bimetallic relay housed in a sealed bimetallic enclosure. This is provided with a current setting arrangement. After tripping on overload, the relay has to be reset by pressing the stop button. The relay can be reset only after bimetallic strips get cooled sufficiently.

In case the motor does not start even though the start button is pressed, observe whether the stop button is locked with a metallic locking piece provided near the stop button. Release it and press the start button, then observe the functioning of the motor.

Suppose the three phase supply is available and starter NVC is energising but the motor does not start, check for any foreign material in between the contact points. Remove it and test the starter again. Visually observe whether the contacts are closing properly.

If any contact is not closing properly or any burns and pittings are noticed on the contact surface, then remove the contact strips. Dress up properly with zero number sandpaper or with a smooth file or replace it if necessary.

When the no-volt coil is activated by the start button, the auxiliary contact of the starter should close to complete the NVC circuit and should remain in the closed position even after the start button is released.

If the overload relay is not functioning properly i.e. not tripping the motor as per setting of the current rating, then replace it with a new one as per with the original specification of the manufacturer.

If a humming and chattering noise is observed in the starter then check for the rated voltage. If the voltage is okay, then check for any gummy material adhered to the pole faces. If found, clean it properly. See whether the shading ring over the pole faces of the NVC is loose. Tighten it properly and also check the spring tension of NVC housing.

Suppose the starter trips often then, check up the load on the motor. (Might be due to overload or over tension of the belt) Reduce the load or tension of the belt. Further check up the motor current in each phase. If the motor takes higher current than specified even though the load is normal, then the fault is with the motor and not with the starter. After attending to the faults and rectifying them, reassemble the starter, connect it to the motor for proper functioning.

Starter check - chart given below could be used to locate trouble in a D.O.L. starter.

Maintenance of DOL starters

Trouble	Cause	Remedy
I Starter check chart		
1 Contacts chatter	Low voltage, coil is not picking up properly. Broken pole shading ring. Poor contact between the pole faces of the magnet. Poor contact between fixed and movable contacts.	Correct the voltage condition. In case there is persistent low voltage, check the supply of the transformer tapping. Replace. Clean the pole faces. Clean contacts and adjust, if necessary.
2 Welding or overheating.	Low voltage preventing magnet from sealing. Abnormal in rush current. Short circuit in the motor. Foreign matter preventing contacts from closing. Rapid inching.	Correct the voltage condition. In case of persistent low voltage, which is accepted normal change the NVC to lower voltage coil. Check excessive load current or use larger contactor. Remove the fault and check to ensure that the fuse rating is correct. Clean contacts with suitable solvent. Install larger device or caution the operator not to operate the inch button too quickly.
3 Short life of contact points	Weak contact pressure.	Adjust or replace contact springs.
4 Noisy magnets	Broken shading coil. Magnet faces not mating. Dirt or rust on magnet faces.	Replace magnet. Align or replace magnet assembly. Clean with suitable solvents.
5 Failure to pick up and seal the contacts.	Low voltage.	Check system voltage. In case persistent low voltage, change to a lower voltage coil.
	Coil open or short-circuited. Mechanical obstruction for the moving parts.	Replace the coil. Clean and check for free movement of contact assembly.
6 Failure of moving mechanism to drop out.	Voltage not removed. Worn or rusted parts causing binding. Residual magnetism due to lack of air gap in magnet path. Gummy substance on pole faces causing binding.	Check wiring in the NVC coil circuit. Replace parts. Replace worn out magnet parts or demagnetise the parts. Clean with suitable solvent.

7 Overheating of coil	Over-voltage. Short circuited turns in coils caused by mechanical damage or corrosion. High ambient temperature. Dirt or rust on pole faces increasing the air gap.	Check and correct terminal voltage. Replace coil. Relocate starter in a more suitable area or use a fan. Clean pole faces.
II Overload relays/ release		
1 Starter is tripping often. Sustained overload.	Incorrect setting of over load relay.	Reset properly. Check for faults/excessive motor currents.
2 Failure to trip (causing motor burn out).	Wrong setting of O.L relay. Mechanical binding due to dirt, corrosion etc.	Check O.L relay ratings and set a proper relay. Clean or replace. Incorrect control wiring. Check the circuit and correct it.
III Fuses		
1 Constant blowing of fuses	Short circuit or poor insulation in winding/wiring.	Check the motor and the circuit for insulation resistance.
2 Fuse not blowing under short circuit condition.	Fuse rating too high.	Replace with suitable fuse.
3 Fuse blowing off frequently.	Fuse rating too low. Overloading of feeder.	Replace with suitable fuse. Check for over-current, leakage and short circuit.

Troubleshooting in DC machines

Objectives: At the end of this lesson you shall be able to

- use the trouble shooting chart to rectify defects in i) DC machines in general ii) DC motors iii) DC generators.

DC machines have Power problems which are not normally found in AC machines. DC motors and generators have commutators and brushes, which cause special problems. If the commutator is properly maintained, it will give many years of useful service.

Chart 1 deals with DC motors and Chart 2 is for DC generator.

Chart 1

Troubleshooting chart for DC motors

Symptoms	Cause	Remedies
Motor will not start	a) Open circuit in starter. b) Low or no terminal voltage. c) Bearing frozen. d) Overload. e) Excessive friction.	a) Check for open starting resistor, b) Check the incoming voltage with name-plate rating and correct the supply voltage. c) Recondition the shaft and replace the bearing. d) Reduce the load. e) Check the bearing lubrication to makesurethattheoilissufficient quantity and of good quality. Disconnect motor from driven machine and turn motor by hand to see if trouble is in motor. Strip and reassemble motor; then check part by part for proper location and fit. Straighten or replace bent shaft.
Motor stops after running short time	a) Motor is not getting power. b) Motor is started with weak or no field. c) Motor torque insufficient to drive load.	a) Check voltage in the motor terminals: also fuses and overload relay. Rectify the defect. b) If adjustable-speed motor, check the rheostat for correct setting. If correct, check the condition of rheostat. Check the field coils for open winding. Check the wiring for loose or broken condition c) Check the line voltage with name plate rating. Use larger motor or one with suitable characteristic to match the load.
Motor runs too slow under load.	a) Line voltage too low. b) Brushes ahead of neutral plane. c) Overload.	a) Rectify the supply voltage or under load check and remove any excess resistance in supply line, connections or controller. b) Set brushes on neutral plane. c) Check to see that load does not exceed allowable load on motor.
Motor runs too fast under load.	a) Weak field. b) Line voltage too high. c) Brushes are out of neutral plane.	a) Check for resistance in shunt-under load field circuits. Check for grounds. b) Correct high voltage condition. c) Set brushes on neutral plane.

Chart 2

Troubleshooting chart for DC Generators

Symptoms	Cause	Remedies
Generator fails to build up voltage	a) The direction of rotation must have been reversed.	a) Change the direction of rotation
	b) Brushes not resting on the commutator.	b) Brushes to be set over the commutator in correct position.
	c) Residual magnetism is completely lost.	c) Run the generator as a DC motor or sometime (few seconds) or connect the field circuit to a battery or DC voltage to reestablish the residual magnetism.
	d) Generator speed is too low.	d) Generator speed should be restored to normal speed by increasing the prime mover speed.
	e) Short circuit in the armature.	e) Rectify the short circuit in the armature.
	f) Open circuit in the armature.	f) Test and rectify the open circuit.
	g) Short circuit in the field circuit.	g) Test and rectify the short circuit which may be in the coil. Faulty coil will show much less resistance than a good coil.
	h) Open circuit in field winding.	h) Check the continuity of the circuit and rectify the defect.

Maintenance procedure for DC machines

Objectives: At the end of this lesson you shall be able to
- state what is meant by preventive maintenance and its importance
- describe the recommended maintenance schedule for DC motors
- explain how to maintain the maintenance record.

Preventive maintenance: Preventive maintenance of Power machines consists of routinely scheduled periodical inspections, tests, planned minor maintenance repairs and a system of maintaining inspection records for future reference. Preventive maintenance is a combination of routine and planned operations.

Routine operations: Routine operations are those which follow fixed schedules to maintain Power motors at daily, weekly or at other fixed intervals.

Planned operation: By contrast, planned operation consists of additional work which is performed at irregular frequencies, and is determined by inspection and previous operating experience or the details of defects found in the maintenance records.

Necessity of preventive maintenance: By carrying out an effective preventive maintenance programme on Power machines, we can eliminate major failures of the machines, accidents, heavy repair costs and loss of production time. Proper preventive maintenance will lead to economy of operation, less down-time, dependable machine operation, longer machine life and lower overall cost of maintenance and repair.

Scheduling of preventive maintenance: Routine periodical inspection and tests may be scheduled to be carried out daily, weekly, monthly, half-yearly and annually depending upon the following factors.

- The importance of the motor/generator in the production
- The duty cycle of the machine
- The age of the machine
- The earlier history of the machine
- The environment in which the machine operates
- The recommendations of the manufacturer.

Recommended maintenance schedule for machines: While carrying out routine periodical maintenance, an electrician will make full use of his senses to diagnose and locate problems in Power machines. The sense of smell directs attention to burning insulation: the sense of feel detects excessive heating in winding or bearing; the sense of hearing detects excessive noise, speed or vibration and the sense of sight detects excessive sparking and many other mechanical faults.

Sensory impressions must also be supplemented by various testing procedures to localize the trouble. A thorough understanding of Power principles and the efficient use of test equipment are important to an electrician during this phase of operation.

The following maintenance schedule is recommended for DC machines.

1 Daily maintenance

- Examine visually earth connections and machine leads.
- Check the sparking at the commutator.
- Check the motor windings for overheating. (The permissible maximum temperature is near about that which can be comfortably felt by hand.)
- Examine the control equipment.
- In the case of oil-ring lubricated machines
  a) examine the bearings to see that the oil rings are working
  b) note the temperature of the bearings
  c) add oil, if necessary
  d) check end play.
- Check for unusual noise at the machine while running.

2 Weekly maintenance

- Examine the commutator and brushes.
- Check belt tension. In cases where this is excessive it should immediately be reduced. In the case of sleeve-bearing machines, the air gap between the rotor and stator should be checked.
- Blow out air through the windings of protected type machines situated in dusty locations.
- Examine the starting equipment for burnt contacts where machine is started and stopped frequently.
- Examine oil in the case of oil-ring lubricated bearings for contamination by dust, grit, etc.(This can be roughly judged from the colour of the oil.)
- Check foundation bolts and other fasteners.

3 Monthly maintenance

- Overhaul controllers.
- Inspect and clean the oil circuit breakers.
- Renew the oil in high- speed bearings which are in damp and dusty locations.
- Wipe the brush-holders and check the bedding of brushes of DC machines.
- Test the insulation of windings.

4 Half-yearly maintenance

- Check the brushes and replace, if necessary.
- Check the windings of machines subjected to corrosive and other elements. If necessary, bake the windings and varnish.
- Check the brush tension and adjust, if necessary.
- Check the grease in the ball and roller bearings, and make it up, where necessary, taking care to avoid overfilling.
- Check the current input to the motor or the output of the generator and compare it with normal values.
- Drain all the oil bearings, wash with petrol to which a few drops of oil have been added; flush with lubricating oil and refill with clean oil.

5 Annual maintenance

- Check all the high speed bearings, and renew, if necessary.
- Blow out all the machine winding thoroughly with clean dry air. Make sure that the pressure is not that high as to damage the insulation.
- Clean and varnish the oily windings.
- Overhaul the motors which have been subjected to severe operating conditions.
- Renew the switch and fuse contacts, if damaged.
- Check the oil in the starter and the grease/oil in the bearings.
- Renew the oil in the starters subjected to damp or corrosive elements.
- Check the switch conditions, resistance to earth between motor/generator windings, control gear and wiring.
- Check the resistance of earth connections.
- Check the air gaps in between the armature and field.
- Test the insulation of windings before and after overhauling the motors/generators.

6 Records

- Maintain a register giving one or more pages for each machine, and record therein all important inspections and maintenance works carried out from time to time. These records should show past performance, normal insulation level, air gap measurements, nature of repairs and interval between previous repairs and other important information which would be of help for good performance and maintenance.

While routine maintenance could be done either during the working of the machine or during short interval `down' periods, the planned maintenance requires to be done during holidays or by taking shut-downs of small duration.

Planned maintenance schedule needs to be decided, based on the routine maintenance reports entered in the maintenance card.

maintenance record

Maintaining a system of inspection records is a must in preventive maintenance schedule. This system uses a register as stated above or cards as shown below which are kept in the master file. By referring to these maintenance cards, the foreman can schedule the planned maintenance.

Maintenance card: The 1st page gives initial test results etc pertaining to the machine.

A careful study of the maintenance card helps the foreman to plan the shut-down date to facilitate early overhauling or planned maintenance schedule to prevent a major breakdown.

Method of maintenance: During the routine maintenance inspection, the investigations and adjustment to be carried out for the parts and accessories of the motors/generators are given below to improve the efficiency of preventive maintenance.

- Clean daily the motor/generator, switch gear and associated cables free from dirt, dust and grease. Use dry compressed air to drive away the dust from the machines.

Initial test results	Page 1
Resistance value of shunt winding ________	
Resistance value of series winding ________	
Resistance value of armature ________	
Insulation resistance value between	
armature and shunt field ________	
armature and series field ________	
series field and shunt field ________	
armature and frame ________	
shunt field and frame ________	
series field and frame ________	
The 2nd page gives the record of maintenance carried out, and, in particular the defects noted therein.	

- Check the bearing daily for excessive noise and temperature. If required, re-grease or re-oil the bearing with the same grade of grease/oil as in original. Do not mix different grades of grease together as it may result in forming sludge or acids, and spoil the bearings.
- Check the machine daily against strains of water or oil or grease which may leak from the surroundings. Take the necessary protective steps to prevent the leakage.
- Check daily the belts, gears and coupling for looseness, vibration and noise. Adjust/replace the parts, if found defective.
- Check weekly the brushes and the commutator for sparking and wear.
- Check weekly the bearing for proper lubrication.
- Check weekly the terminals and switch contacts.
- Inspect the brushes and the commutator once in a month for excessive wear, chatter and sparking. Worn-out brushes need to be replaced with the same grade brushes. Check spring tension on the brushes, and adjust, if necessary. Badly worn-out commutators need to be turned in a lathe or be replaced.
- Check monthly the brushes for proper seating. If necessary, reshape the brushes to proper curvature to suit the commutator surface.
- Check monthly the end plates and the shaft for excessive end play.
- Check monthly the main and auxiliary contact points of the switch gear for wear, pitting and burns. Badly worn out contact point needs replacement. Check the connection terminals for loose connection and scales or burning. Rectify the defects.
- Test monthly once the field windings and armature for insulation and ground faults. Low reading of insulation below 1 megohm indicates weak insulation. Dry out the winding, and re-varnish, if necessary.
- Check monthly once the foundation bolt and other fasteners for tightness.
- Once a year undercut the mica in between the commutator bars. Test the commutator and armature for shorts, open and ground faults.

Maintenance card

Report on routine maintenance **Page 2**

Date of maintenance	Scheduled maintenance carried out	Defects noted	Attended by (Signature)	Reported to (Signature)	Remarks

The 3rd page gives the details of the test carried out in the motor at intervals with corresponding readings

Maintenance card

Report on test details **Page 3**

Date of Test	Schedule	Test particulars	Test results	Tested by (Signature)	Reported to (Signature)	Remarks

From the above it is clear that atleast once in a year, the motor/generator needs a thorough overhauling in addition to frequent routine maintenance.

The 4th page gives the details of the defects, causes and repair carried out

Motor service card **Page 4**

Date of repair	Repair and parts replaced	Cause	Repaired by (Signature)	Supervised by (Signature)	Remarks

Control elements, accessories - layout of control cabinet

Objectives: At the end of this lesson you shall be able to:

- explain the layout marking methods and necessity
- state the methods of marking, cutting, drilling, fixing of accessories and components
- explain the methods of mounting and wiring the accessories
- state the various control elements used for control panel board
- list the different wiring accessories used in control panel wiring
- explain wiring of electrical 3 phase motor power and control circuit.

Introduction

Preparation of layout drawing and marking on control cabinet is very much essential, we must have a clear vision of mounting components and their location on panel board/ control cabinet.

There is no such important method inpratice to make the layout on control cabinet. However a neat layout on control cabinet is very much required.

The display and indicating instruments should be selected on the top position of the cabinet. Heavy and rare operated devices such as fuse breaker etc; are to be fixed on the bottom of the cabinet.

The components and fixtures should have sufficient space in between to carryout future repair (or) replace requirements. But too much space should not be provided, that will increase the size of the cabinet unnecessarily. While finalising the layout plan the relevant IE rulers to be followed for better result.

Layout marking

Wiring diagrams for power and control circuit should be developed for sequence of operation of automatic star - delta starter with forward and reverse. Types of protection, control, indication and measuring accessories needed should be finalized.

To wire up the above starter in a control panel the well designed and easily understandable layout should be finalized. Layout of the finalized wiring diagram should developed keeping important features of the control panel in mind. While designing the control panel the outside dimensions, the swing area of cabinet doors and area required for maintenance and tools kit have to be considered.

Control panel may be often used near the process area with high temperature, humidity and dust hence the arrangement for cooling fan and dehumidifier along with filters and intake and exhaust vents should be needed.

Suitable size of control panel which can accommodate all the controlling, protective, measuring, indicating and wiring accessories required for said wiring should be obtained or fabricated.

While selecting the control and protective accessories of the control panel the full load current of the individual load, total load and duty cycle, simultaneous operation of the load and 25% additional load capacity of the motors have to be considered.

The over load and short circuit protection may be given either ahead of the control panel by calculating the highest rating of the branch circuit or individual motors depends on space available, cost factor and sensitiveness of the operation.

The finalized layout may vary depends the individual design and mind application. However a sample layout marking for the above starter is given in the Fig 1.

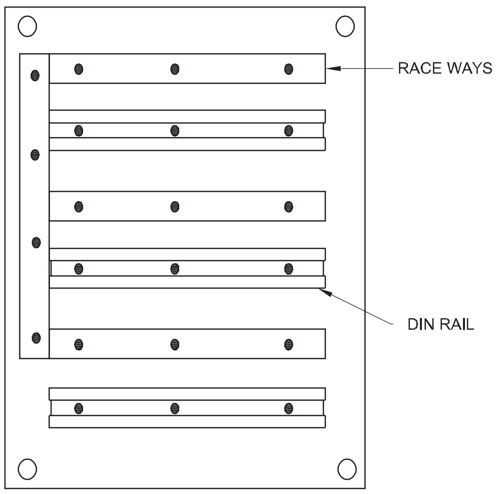
Once the panel layout is designed we must find out where and how to fit the accessories.

The finalized layout of accessories can be marked in the control panel using suitable marking device.

Cutting and drilling

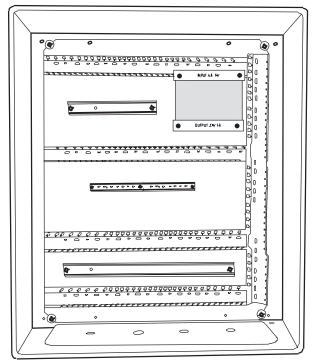
The mounting or fixing holes along with necessary tap or die in suitable size (if any) can be prepared in the front door and inside of the control panel as in Fig 2.

Fig 1



TYPICAL LAYOUT MARKINGS

Fig 2



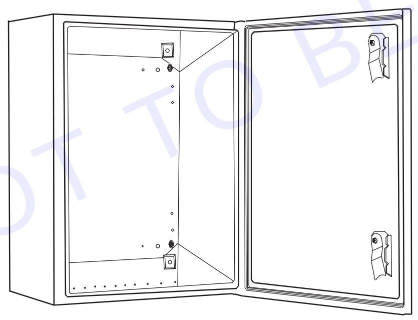
CONTROL PANEL WITH RACEWAYS / DIN RAILS

ELC22T0592

Din rail is a metal rail made from cold rolled carbon steel sheet with zinc plated or chromate bright surface finish used to mount the circuit breakers and control accessories without using screws as in Fig 2. DIN rail being fixed to the chassis before fitted the contactors and other accessories as in Fig 3.

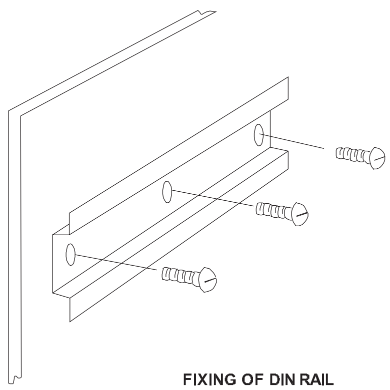
The standard specification of widely available DIN rail is top hat rail EN 50022 which dimension is 35 mm width and a 15 mm or 7.5 mm depth. They can be cut in to the required length and then screwed or bolted inside the panel before mounting any accessories and wiring begins as in Fig 4.

Fig 3



CONTROL PANEL WITH MOUNTING AND FIXING HOLES

Fig 4



FIXING OF DIN RAIL

ELC22T0593

Race way is one form of cable ducting used to carry the wiring between components and keeping the wires neat. The leads wires and cables are laid inside the raceways brought out through the holes / slots in the sides and can be inspected by removing the cover of the raceways.

The minimum spacing between components and raceways should be 100 mm for 415V systems and 50 to 75 mm for less than 415V system. The next stage is to clip the accessories to the rail and wire them.

Mounting and wiring the accessories in control panel

The accessories can be mounted on the DIN rails allowing sufficient space for easy maintenance, wiring and troubleshooting. The mounting should not move or lean in the DIN rail due to vibration or strain due to cables.

Contactor can be either flush mounted to the chassis or DIN rail - mounted . Contactor mounting type over load relay which have three pin connectors engage into the contactor terminals may be used to reduce the mounting and wiring time and labour.

To mount the contactor on rail first place the back top groove on the top of rail and turn it downwards against the lower rail which will cause the spring of the contactor to retract and snap into place behind the rail. There is a slot in the spring clip of the contactor so that the clip can be retracted using small screw driver or connector to remove the contactor if required. To avoid fouling the underneath of the accessories use screws with low profile heads.

The contactor arrangements and terminals are usually labeled which conforms to BS 5583. For example 1 and 2 for NC contacts, 3 and 4 for NO contacts, odd numbers like 1, 3 and 5 for incoming terminals and even numbers like 2, 4 and 6 for outgoing terminals of the main contacts of contactors and OLR.

The conductor should be trimmed off to that the conductor does not insert more than the half way through the connectors. Single strand wire should be folded back to give additional thickness. The over tightening of screw have to be avoided otherwise this can crush the strand and give a weak connection.

All the internal wiring should be terminated in the top and external wiring in the bottom of the connectors to avoid the crossover of both wirings. Flexible conduit and cables have to be installed in such a way that the liquid or water if any can drain away from the fitting and grommets.

An earth terminal usually green or green yellow to be clamped to the rail and ensure the cabinet and door are earthed properly.

An insulated separator can be used to isolate the high voltage connections from others. End stops are used to clamps the connectors together and close the open terminals on one end, sometimes the earth terminal will do the same job as in Fig 5.

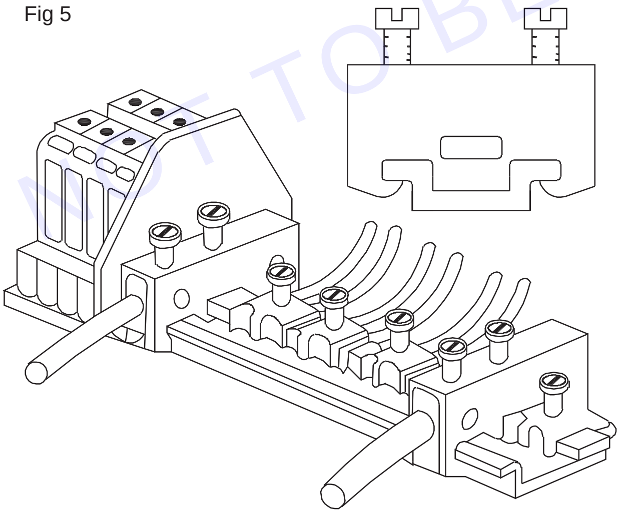
The control panel should be grounded properly so that control panel should have proper earthing bolts / nuts. If more ground points are used a common earth plate should be fixed inside the cabinet as in Fig 5.

U loops of the cables as long as possible facing down and anchored on each side of the hinged doors and panel with screws or bolts and do not use adhesive. Place the sleeve and spiral flexible conduits of suitable size over the cables running between the hinged doors and panel as in Fig 6.

The care to be given to the bundle of wires which is mounted on the hinged doors should not restrict the opening and closing of the door or the doors should not damage the wires.

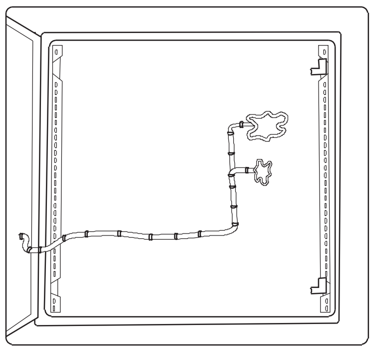
Minimize the use of cable ties if the raceways are used. They may be cut off during troubleshooting and rarely replaced.

Fig 5



TERMINAL CONNECTORS / EARTH TERMINAL WITH SEPERATOR

Fig 6



U LOOP OF CABLES

ELC22T0594

Routing and bunching

Routing : Conductors and cables should run from terminal to terminal without any intervening joins and cross over. Extra length should be left at connector / terminals where assembly needs to be disconnected for maintenance and servicing. Multi core cable terminations have to be adequately supported to avoid undue strain on the terminals.

Different colour may be used to aid identification of group of controls and functions.

The associated earth and neutral conductor should be routed close to the respective live conductors to avoid undue loop resistance.

Select the race ways to leave some slacks or looping of the cable inside it. The wires inside the race way should not more than the half fill.

Bunching and tying

Run the wires in horizontal and vertical lines avoid diagonal runs as possible. Do not run the wire over the other devices or race ways. Uses of spring cage terminals instead of standard screw terminals can reduce the termination error, the wiring and maintenance time which in turn reduce the cost and labour.

To connect the accessories, cut the individual control wires to the proper lengths, strips the insulation, mark wire identification, insert ferrules at the ends of wires, use suitable lugs or thimbles.

The wires should be neatly bundled, run in the race ways and routed with smooth radius bends.

All the terminals, wires and components should have identification marks and labels. A good labelling and identification will reduce the errors in termination, testing, maintenance and repairs. A legible and durable label in an efficient and cost effective manner may be chosen.

To the possible extent the power and control wiring should be run in separate race way or cable management which will reduce the radio interference, trouble shooting time and make the future alteration if any is easier.

By taking some extra cares like pest control, dust control, adequate terminal pressure, selection of proper wires and accessories, it can be ensured that the control panel has no failure time and with moderate maintenance it will be trouble free panel for entire life.

Where the multiple earths are used it is necessary to use a common earth terminal or connectors as in Fig 5.

Tests

Before energizing the control panel all necessary tests should be carried out like open, short, earth continuity and earth soundness etc. The supply voltage and frequency are also to be checked.

Control elements

Difference between control panel and switch board

A panel board contains a single panel or a group of panel units as single panel that includes bus-bars, protective devices and control switches, instruments and more starters etc.

For wiring of control panel board the following control elements / components and accessories are required.

They are

- Isolating switch
- Push button switch
- Indicating lamp
- MCB (Miniature Circuit Breaker)
- Contactors
- Electro mechanical relays
- Thermal over load relays
- Time delay relay (timers)
- Rectifiers
- Limit switches
- Control transformers etc.

Control elements for control panel

1 Isolating switch (Fig 7)

Isolating switch (Isolator) is a manually operated mechanical switch which isolates/disconnects the circuit which are connected with it from the supply system as and when required. It should be normally operated at "OFF" load condition.

It is available in different current, voltage rating and size.

2 Push button switch (Fig 8)

Push button is a simple push switch mechanism for making or breaking the circuit as and when required. It is made out of hard plastic or metal. An indicating lamp is incorporated with the push button switch to indicate start or stop is also available.

Fig 7

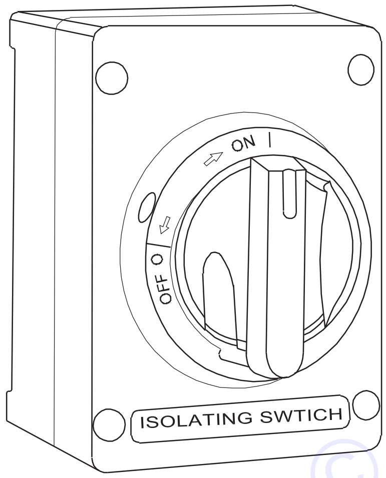
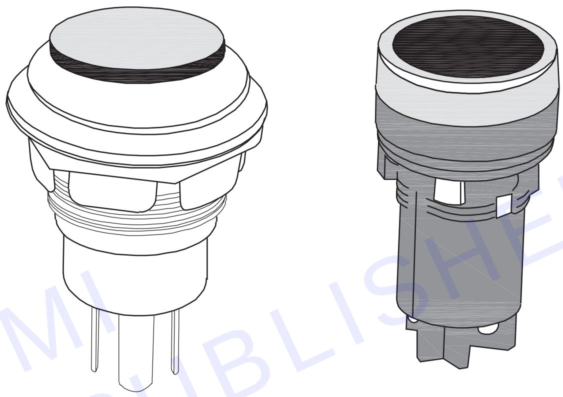


Fig 8



PUSH BUTTON SWTICHES

ELC22T0595

3 Indicating lamp (Fig 9)

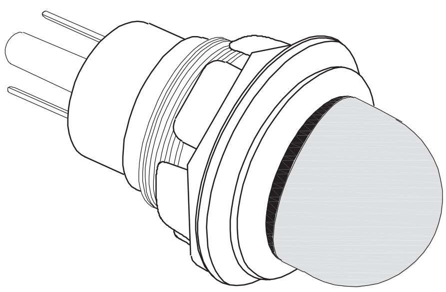
It is a low voltage, low wattage filament or neon or LED lamps used to indicate the various indication like availability of supply or motor ON/OFF, mains/motors fails or trip etc.

It is available in different size, colour and wattage. It should be generally fitted in the front side of the control panel with suitable holder.

4 MCB (Fig 10)

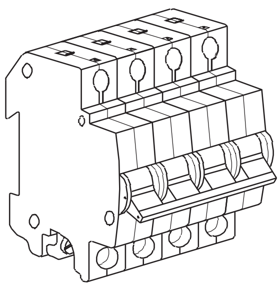
Miniature circuit breaker (MCB) is an electro mechanical protective device which protect an electrical circuit from short circuit and over load . It automatically turns off, when the current flowing through it exceeds the maximum allowable limit.

Fig 9



INDICATING LAMP WITH HOLDER

Fig 10



MINIATURE CIRCUIT BREAKER

ELC22T0596

5 Fuses

It is a protective device which is connected is series with the live wire to protect the circuit from short circuit and earth fault.

6 Contactors (Fig 11)

A contactor is an electrically controlled double break switch used for switching ON / switching OFF the electrical circuit, similar to a relay with higher current ratings. It is controlled by a circuit which has a much lower power level than the switched circuit.

7 Electro mechanical relays (Fig 12)

Electromechanical relays are electrically operated switches used to control a high powered circuit accessories using low power signal. When an electric current passes through its coil it produces a magnetic field that activates the armature to make or break a connection.

Current passes through its coil it produces a magnetic field that activates the armature to make or break a connection.

Fig 11

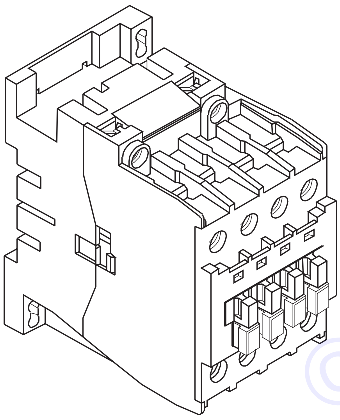
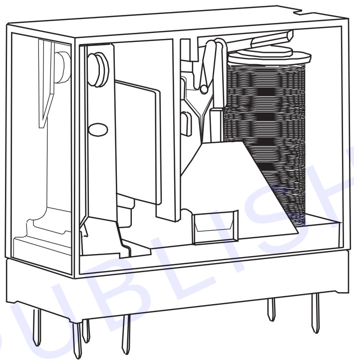


Fig 12



ELECTRO MECHANICAL RELAY

8 Thermal overload relays (Fig 13)

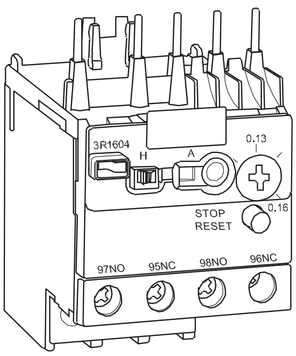
It is a thermally operated electromechanical device that protects motors from over heating and loading.

9 Time delay relay (timers) (Fig 14)

Time delay relays are simply the control relays in - built with a time delay mechanism to control the circuit based an time delay.

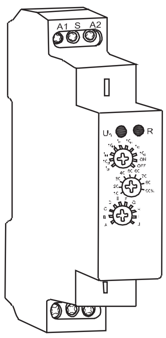
In time delay relays its contact will open or close after the pre-determined time delay either on energising or on de-energising its no volt coil. It can be classified into two types as ON delay timer and OFF delay timer.

Fig 13



THERMAL OVERLOADED RELAYS

Fig 14



TIMER

10 Rectifiers (Fig 15)

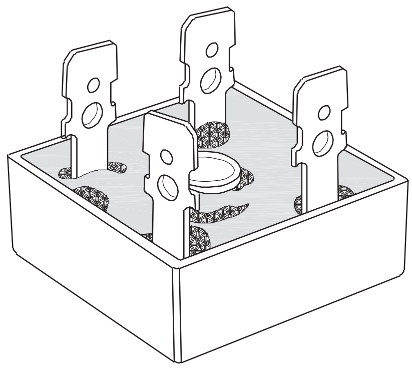
A rectifier is a static device consists of one or more diodes that converts alternating current (AC) to direct current (DC). A diode is like a one -way valve that allows an electrical current to flow in only one direction.

11 Limit switches (Fig 16)

Limit switch is a switch with an actuator which is operated by the motion of a machine part or an object.

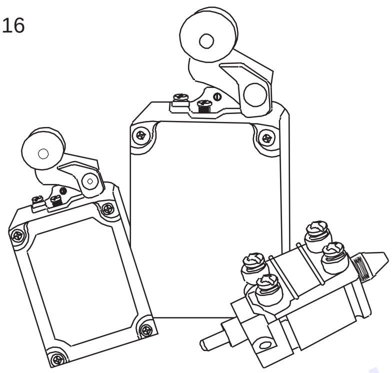
When an object or parts comes into contact with actuator, it operates the contacts of the switch to make or break an electrical connection. They are used to control the distance or angles of movement of any machine parts or axis or objects.

Fig 15



RECTIFIER

Fig 16



LIMIT SWITCHES

ELC22T0599

12 Control transformer

It is a transformer which is used to supply the power to the control or auxiliary circuit or equipment which does not intend for direct connection to the main supply.

13 Panel meter (voltmeter and ammeter)

They are the measuring instruments used to measure the various electrical parameter of the circuits such as voltage and current etc.

Wiring accessories for control panel wiring

1 PVC channel / Race ways (Fig 17)

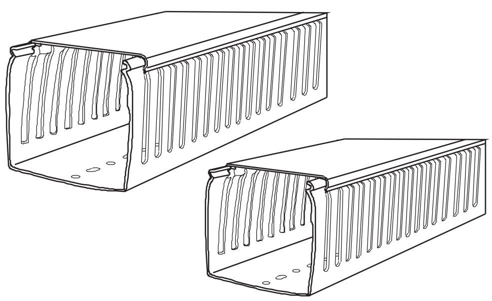
It is an inspection type PVC enclosed channel which provides a pathway for electrical wiring inside the control panel. It has the opening slots on both sides to facilitate the good ventilation and visual inspection.

It protects the wires from dust, humidity, corrosion, water intrusion, heat, mechanical damage and physical threats.

2 DIN rail (Fig 18)

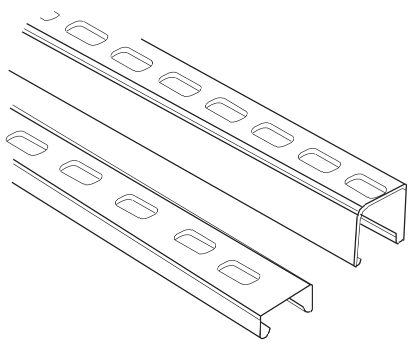
It is a zinc - plated or chromated metal rail which is used for mounting the control accessories like MCB, contactors and OLR etc, with out using screws inside the control panel.

Fig 17



PVC CHANNEL

Fig 18



ELC22T0600

3 G Channel (Fig 19)

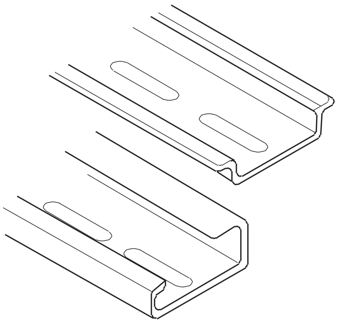
It is a zinc - coated metal channel which is especially used for mounting the feed through or spring load or double deck terminal connectors without using screw inside the control panel.

4 Terminal connectors (Fig 20)

It is the set of insulated screw terminals at both sides used to connect the accessories of the control panel with external control switches, limit switches, input supply and motor terminals etc.

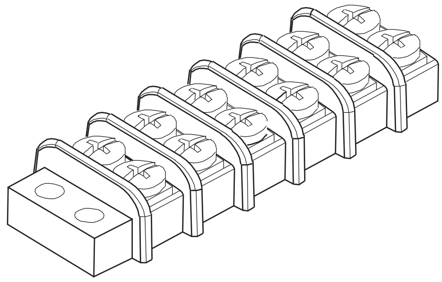
Terminal connectors with barrier strips and clamping plates provide a tight and electrically sound termination. It is available in various size, current and voltage ratings.

Fig 19



'C' CHANNEL

Fig 20



TERMINAL CONNECTORS

ELC22T0601

5 Wire ferrules (Fig 21)

It is a small circular ring made up of polymer plastics or rubber or fibre, used to easily identify the ends of wires which are to be connected into a particular terminals or accessories. It should be inserted on the both ends of a wire as collar or bracelet.

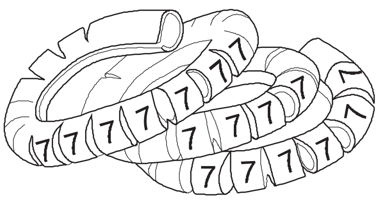
It is available is different size like 1 sq.mm, 1.5 sq.mm and 2.5 sq.mm etc generally in yellow colour printed with either numerical or alphabet letters on it.

6 Lugs and thimbles (Fig 22)

It is a cylindrical barrel along with circular rings or cylindrical rod or U shape or flat surface made up of aluminum or copper or brass, used to ensure the sound electric connection of the cable / wire on to the terminals. It prevent flare out of stripped and stranded cable, increase the conductivity of the connection, support the cable / wire and avoid the loose connection and sparking. Suitable crimping tool has to be used to connects them with cables / wires. It is available in different size like 1 sq.mm, 4 sq.mm, 25 sq.mm, 70 sq.mm, 125 sq.mm and so on.

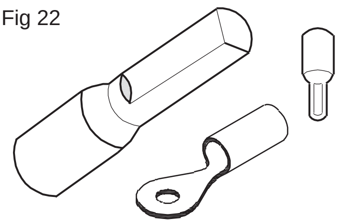
- Thimbles may also be referred as sockets.

Fig 21



WIRE FERRULES

Fig 22



LUGS AND THIMBLES

ELC22T0602

7 Cable binding straps and button (Fig 23)

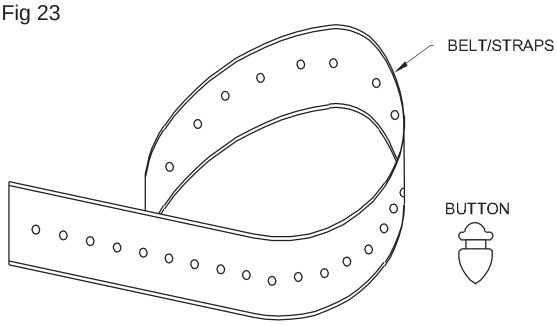
It is made up of PVC or polymer belt with a small holes at regular intervals, used to tie up, bunching, binding and dressing the cable / wires with help of buttons.

It is reusable and good insulator to the heat and electricity. It is generally available 8mm, 10 mm and 12 mm width.

8 Nylon cable ties (Fig 24)

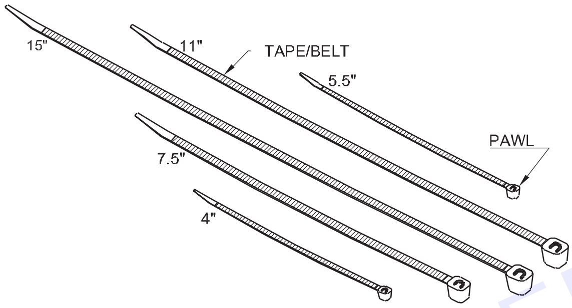
- It is a type of fastener used to hold or tie or bunch the wires / cable or group of cables.
- It is made of nylon tape or belt which has teeth that will engage with head of the pawl to form a ratchet and tightens the wires.
- In general the tie can not be loosened, or removed or reused. However some reusable ties are also available.
- it is available in different colour, length and width.
- Because of its low cost and easy to use, it is widely used in general purpose application also.

Fig 23



CABLE BINDING STRAPS AND BUTTON

Fig 24



NYLON CABLE TIES

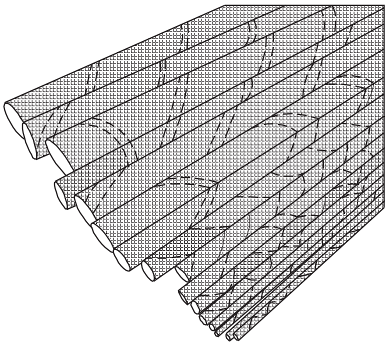
9 Sleeves (Fig 25)

- It is flexible tubular / cylindrical insulator into which the electric wire or cable or group of cables can be inserted.
- Apart from the electrical insulation and easy identification of wires, it also protect the wires from abrasion, heat, chemical, physical damage and radio interference.
- It is available is different colour, style, materials like carbon fibre, fabrics, Teflon, fibre glass, nylon, poly ethylene (PET) wrap, braided metal and heat shrink sleeves.

10 Grommets (Fig 26)

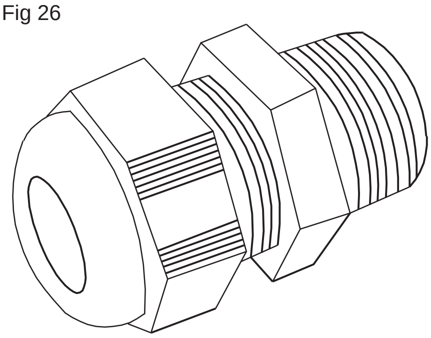
It is a type of bushing which is used to insulate and hold the cables when they pass through a punched / drilled holes of panels or enclosures. It is generally made of rubber, plastic, plastic coated metal and protect the cable from twist, tug, cut, break, strain, vibration etc and prevent the entry of dirt, dust, water, insects and rats into the panel. It may also called as glands.

Fig 25



WIRE SLEEVES

Fig 26



GROMMETS

11 Wire clips (Fig 27)

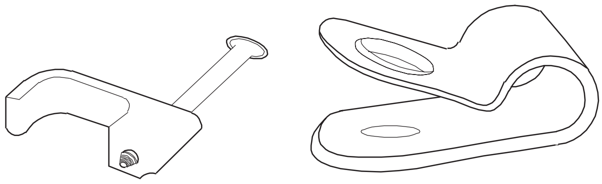
It is a type of fixing or fastening device which is used to fix and hold the cables or punch of cables in a secure manner.

Rotary type switches (Fig 28)

Rotary switches are most commonly used in lathes, milling and drilling machines due to their exact visual position and easiness in operation. These switches are operated by levers or knobs which in turn operate cams inside the switch to contact various terminals in sequence by the internal contact blocks. These cams and blocks are made of hard P.V.C. and are designed to withstand many operations. It is possible to get many circuit combinations by combining various cams and contact blocks. As the contact blocks, terminals and cams are spring-loaded, these switches should not be opened by inexperienced persons for repairs. Fig 28 shows 250V AC 15 Amps 2-pole three position flush mounting coin-slot operator.

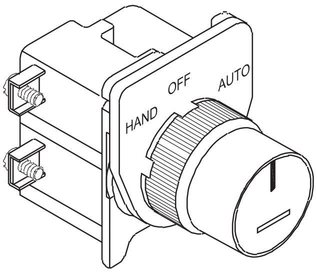
Function: This switches can do a number of functions, depending upon the cover and contact block combinations. According they can be used for ON/ OFF switch, manual Forward / Reverse operation, Manual star delta switches, Pole changing switches, Selection switch for meaning instrument etc..

Fig 27



WIRE CLIPS

Fig 28



ROTARY SWITCH

ELC22T0605

Motor control (Fig 29)

Introduction

Power distribution systems used in large commercial and industrial applications can be complex. Power may be distributed through switchgear, switchboards, transformers, and panel boards. Power distributed throughout a commercial or industrial application is used for a variety of applications such as heating, cooling, lighting, and motor-driven machinery. Unlike other types of power distribution equipment, which are used with a variety of load types, motor control centers primarily control the distribution of power to electric motors.

Basic motor control

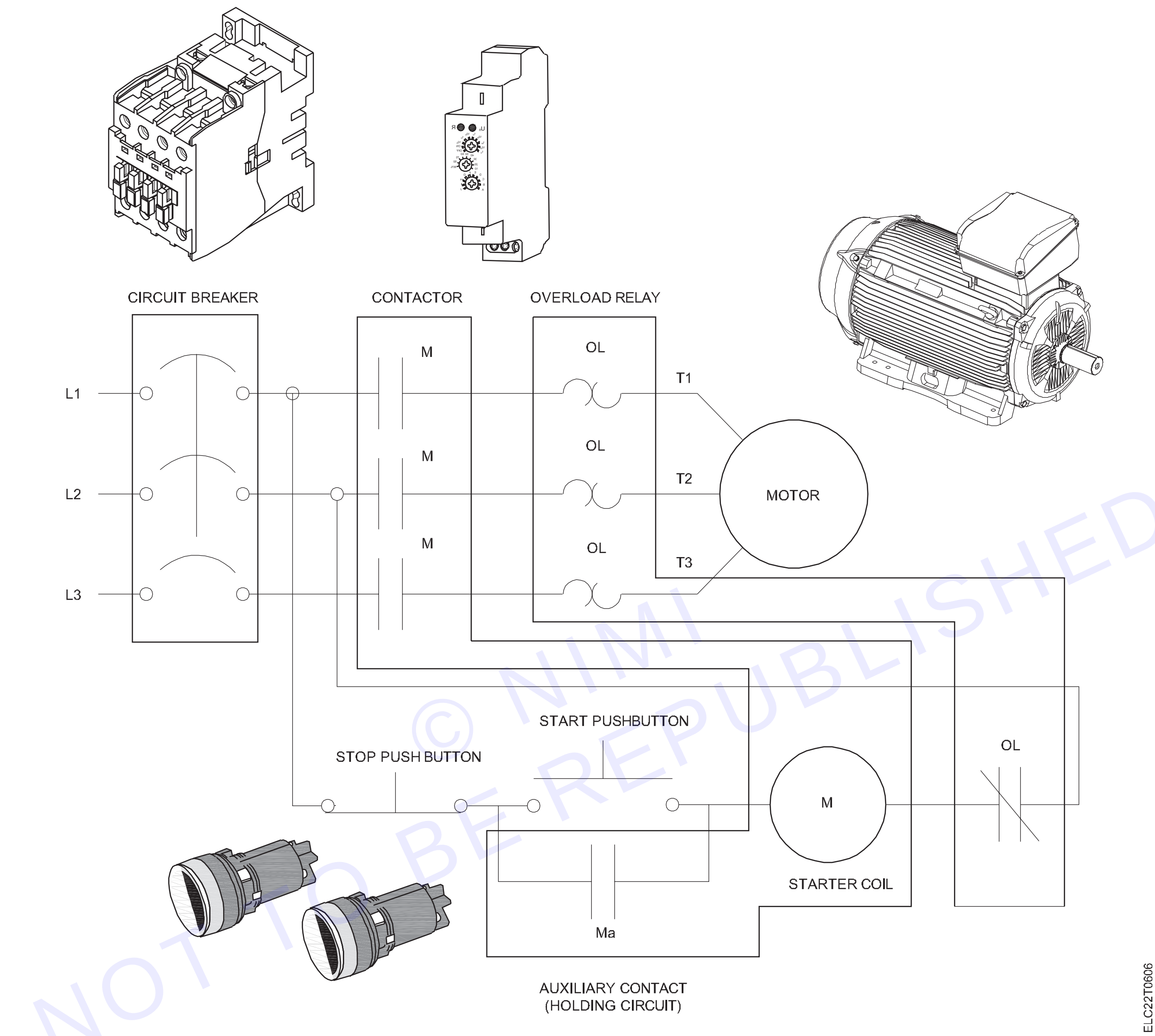
Wherever motors are used, they must be controlled. In Basics of Control Components, you learned how various control products are used to control the operation of motors. For example, the most basic type of AC motor control, involves turning the motor on and off. This is often accomplished using a motor starter made up of a contactor and an overload relay

The contactor's contacts are closed to start the motor and opened to stop the motor. This is done electromechanically and often requires using start and stop pushbuttons and other devices wired to control the contactor.

The overload relay protects the motor by disconnecting power to the motor when an overload condition exists. Although the overload relay provides protection from overloads, it does not provide short-circuit protection for the wiring supplying power to the motor. For this reason, a circuit breaker or fuses are also used.

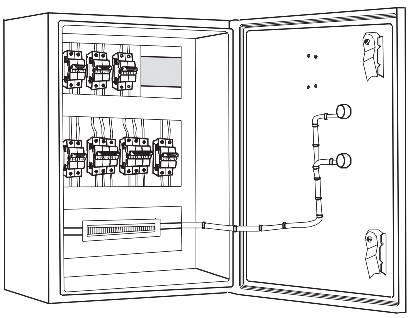
Motor starter

Fig 29



Typically, one motor starter controls one motor. When only a few geographically dispersed AC motors are used, the circuit protection and control components may be in an enclosure. (Fig 30)

Fig 30



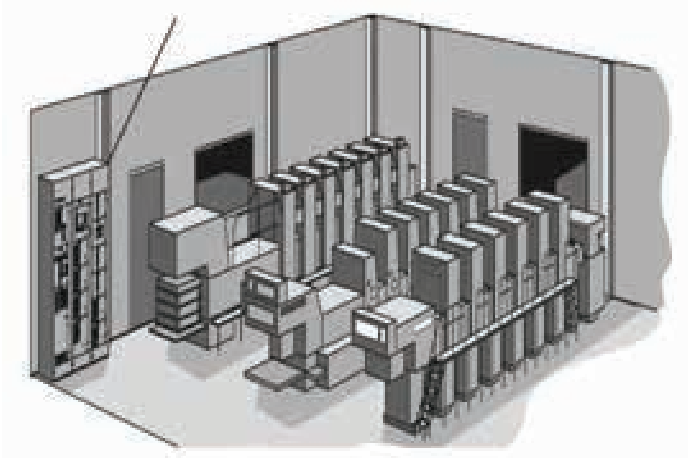
CONTROL PANEL WITH COMPLETE WIRING

Motor control centers (Fig 31)

In many commercial and industrial applications, quite a few electric motors are required, and it is often desirable to control some or all of the motors from a central location. The apparatus designed for this function is the motor control center (MCC).

Motor control centers are simply physical groupings of combination starters in one assembly. A combination starter is a single enclosure containing the motor starter, fuses or circuit breaker, and a device for disconnecting power. Other devices associated with the motor, such as pushbuttons and indicator lights, may also be included.

Fig 31



Advantages

Some of the advantages of using motor control centers are:

1 Ruggedness and reliability

2 Reduced time needed for installation and startup

3 Space saving design

4 Excellent component selection

5 Simplicity in adding special components

6 Ease of future modifications.

Drawing of control panel

Types of drawing

We use drawings to convey the information about a piece of equipment in a form which all those involved in its production, installation and service will under¬stand. To make this possible, standard drawing conventions have been adopted by most companies.

The information we need to be able to assemble the equipment will be only one item in the set of drawings and schedules which make up the complete design.

Circuit diagram (Fig 32)

This shows how the electrical components are con¬nected together and uses:

- Symbols to represent the components;
- Lines to represent the functional conductors or wires which connect them together.

A circuit drawing is derived from a block or functional diagram. It does not generally bear any relationship to the physical shape, size or layout of the parts and although you could wire up an assembly from the information given in it, they are usually intended to show the detail of how an electrical circuit works.

Wiring diagram (Fig 33)

This is the drawing which shows allthe wiring between the parts, such as:

- control or signal functions;
- power supplies and earth connections;
- termination of unused leads, contacts;
- interconnection via terminal posts, blocks, plugs, sockets, lead-through.

It will have details, such as the terminal identification numbers which enable us to wire the unit together. Parts of the wiring diagram may simply be shown as blocks with no indication as to the electrical compo¬nents inside. These are usually sub-assemblies made separately, i.e. pre-assembled circuits or modules.

Fig 32

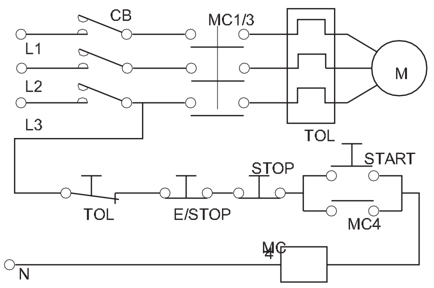
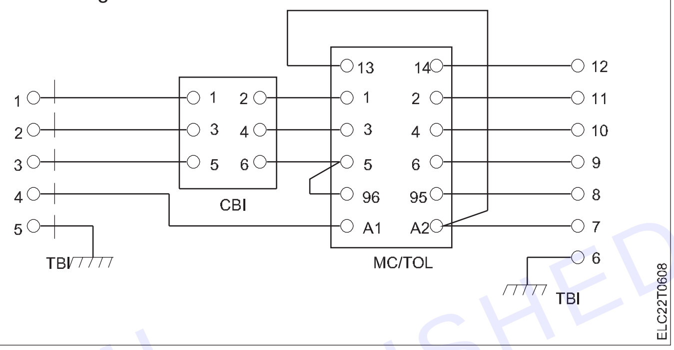


Fig 33



Wiring schedule

This defines the wire reference number, type (size and number of conductors), length and the amount of insulation stripping required for soldering.

In complex equipment you may also find a table of interconnections which will give the starting and finishing reference points of each connection as well as other important information such as wire colour, ident marking and so on.

Example:

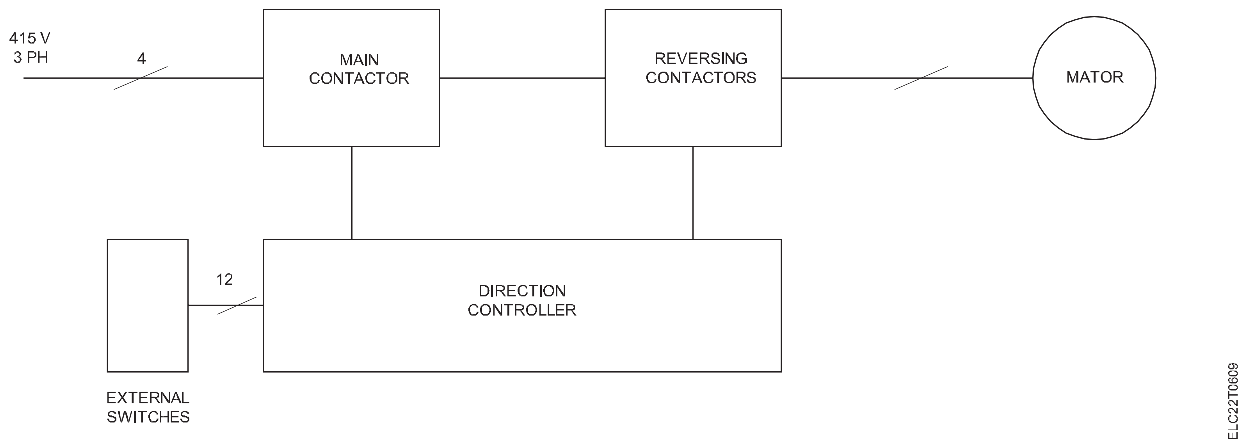
Motor ConSchedule: Motor control					
Wire No.	**From**	**To**	**Type**	**Length**	**Strip length**
1	TB1/1	CB1/1	1mm2	600mm	12mm
2	TB1/2	CB1/2	1mm2	650mm	12mm
3	TB1/3	CB1/3	1mm2	700mm	12mm
4	TB1/4	CB1/4	1mm2	750mm	12mm
5	TB1/5	CB1/5	1mm2	800mm	12mm

Block diagram (Fig 34)

The block diagram is a functional drawing which is used to show and describe the main operating principles of the equipment and is usually drawn before the circuit diagram is started.

It will not give any real detail of the actual wiring connections or even the smaller components and so is only of limited interest to us in the wiring of control panels and equipment.

Fig 34



Parts list

Although not a drawing in itself, in fact it may be part of a drawing. The parts list gives vital information:

- It relates component types to circuit drawing reference numbers.
- It is used to locate and cross refer actual component code numbers to ensure you have the correct parts to commence a wiring job.

Example:

Parts list			
Ref	Bin	Description	Code
C81	A3	KM Circuit Breaker	PKZ 2/ZM-40-8
MC	A4	KM Contactor	OIL 2AM 415/50
TOL	A4	KM Over load Relay	ZI-63

Componets used in control wiring (Fig 35)

Component mounting rails

- These rails - sometimes called 'DIN rails' - are metal strips with a special profile allowing components and sub-assemblies to be fixed onto a chassis plate without using screws.

There are two basic profiles available in two common sizes:

- Symmetrical or 'top hat'.
- Asymmetrical.

These are cut to the required length and then screwed or bolted to the chassis before any wiring begins.

Plastic trunking

- This is one form of cable ducting and used to carry the wiring between components. It pro¬vides protection while keeping the wires and cables neat.

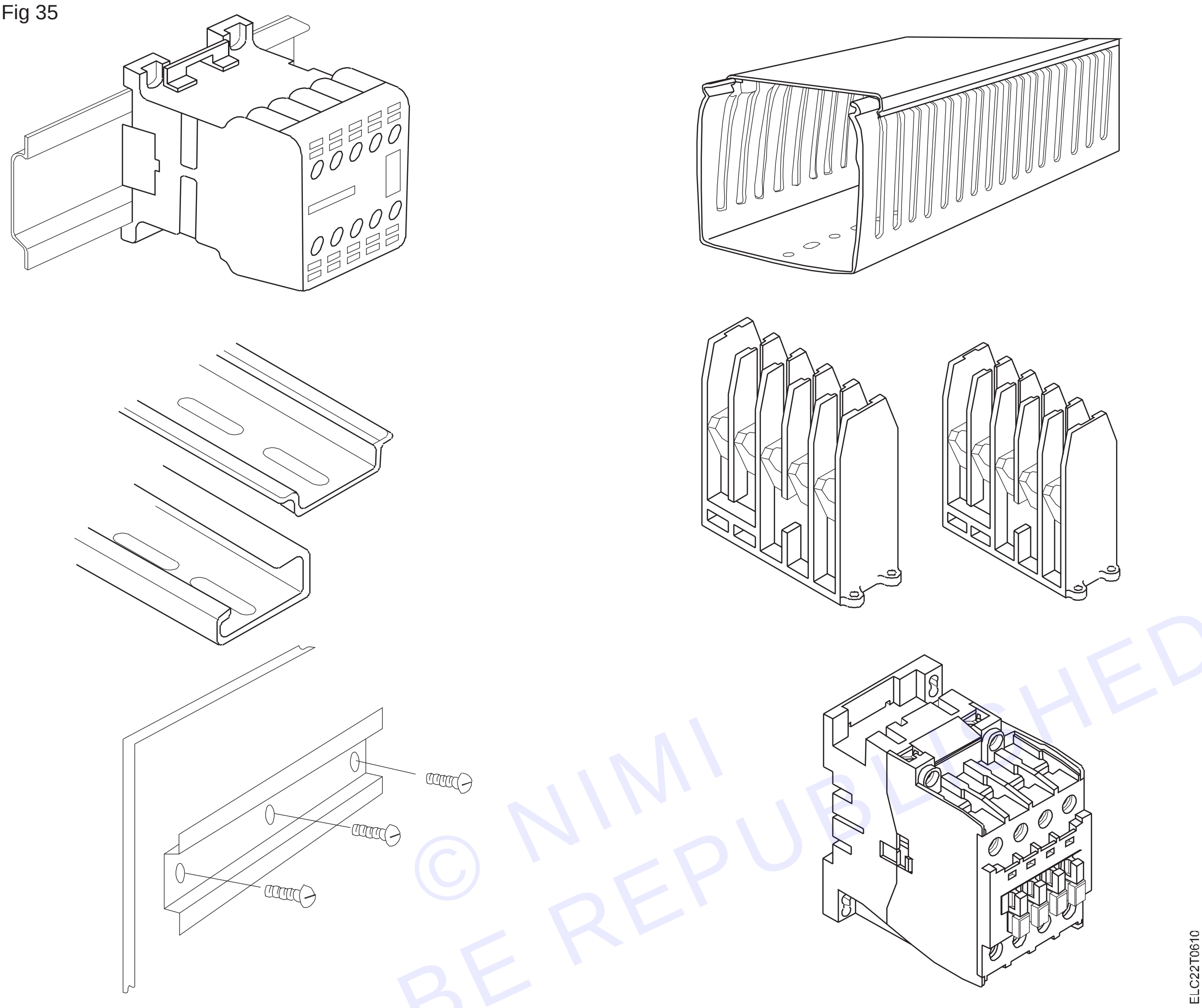
  Connector blocks

Clip-on terminals

Terminal blocks of various sizes and types provide a very common way of connecting the control assembly to the outside world.

- For most power controllers the main connections will be made via these screw clamp terminal units.

Fig 35



- These are made up using individual terminal assemblies which clip to DIN rails to make multiway strips.
- The terminal is specified in terms of the cross-sectional area of wire it will accept. This varies from 1.5 mm2 upwards.
- The most common way of terminating wires is the screw clamp with no more than two wires per terminal.
- The wire sizes are specified in data tables for plain wire ends and for those with ferrules on.
- Different colours may be used to aid identifica¬tion of groups of functions.

Contactors and relays

These are mechanical switching devices whose operation is controlled by an electromagnet. The electro-magnet consists of a coil of wire with many turns wound on to an iron core.

When the coil of the electromagnet is energised, the core becomes magnetised and attracts a moving armature. The armature is mechanically coupled to a set of electrical contacts. When the armature is attracted to the electromagnet, these contacts operate and complete the circuit.

As soon as the coil is de-energised, the contacts return to normal, usually under spring. Although relays and contactors use the same basic principle of operation, the way they achieve the end result is mechanically different. Relays usually have a hinged armature whereas contactors usually have a stronger solenoid action, which allows them to have larger contacts.Generally, a contactor is used to switch higher powers than a relay and needs more current to operate.

Control relays use the same principle as contactors and look similar but are usually smaller. They are intended for use in the control circuit and their contacts have a lower power rating than those of a contactor.

Electrical specification of contactor

Electrically, contactors consist of two main parts, the operating coil and the switching contacts. A contactor will have a number of contacts (or poles), usually three normally open contacts for power switching and a set of auxiliary contacts for use at lower current in the control circuit.

Their basic electrical specifications are mainly concerned with:

- the voltage required to operate the coil;
- whether the coil needs AC or DC;
- the current-carrying capacity of the contacts;
- the maximum voltage the contacts can switch.

The type of operation they will be used for further complicates the specification - for example, how often they will make and break in an hour and whether the load is inductive (an electric motor) or resistive (a heater element).

The choice of contactor depends upon:

- the type of voltage and mains supply;
- the load power;
- the load characteristics;
- the duty requirements.

These are combined into several categories. Briefly they are as follows:

For AC loads:

AC1 - resistive load switching. Least severe conditions.

AC2 - slip ring motor control switching.

AC3 - squirrel cage motor starting and breaking during normal running.

AC4 - as for AC3 but with higher operating frequency and also where the contactor may be required to break the motor starting current. Most severe conditions.

For DC loads:

DC1 - mainly resistive loads.Least severe conditions.

DC2 - starting and stopping shunt motors.

DC3 - as DC2 but allowing inching and plugging control.

DC4 - starting and stopping series motors.

DC5 - as DC4 but allowing inching and plugging control functions. Most severe conditions.

The use of a contactor - or relay - that is not up to the conditions in the circuit will rapidly fail in service.

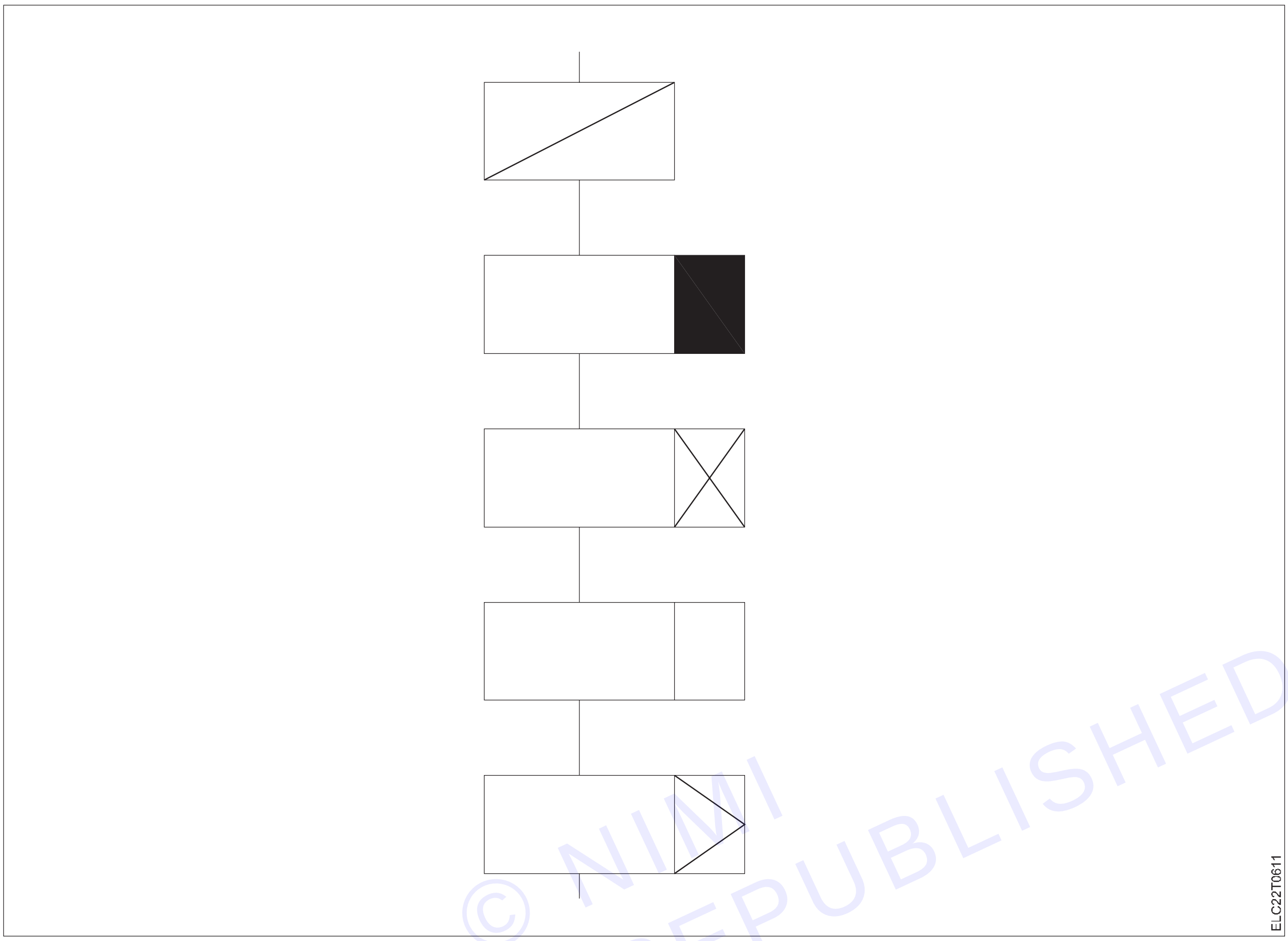
The contacts may weld or stick together causing power to be applied to a circuit after the contactor has been switched off.

Too much current can cause the contact to melt and disintegrate like a fuse.

Relay operating coil symbols

The symbol for a relay is in two parts: the operating coil and the contact set.

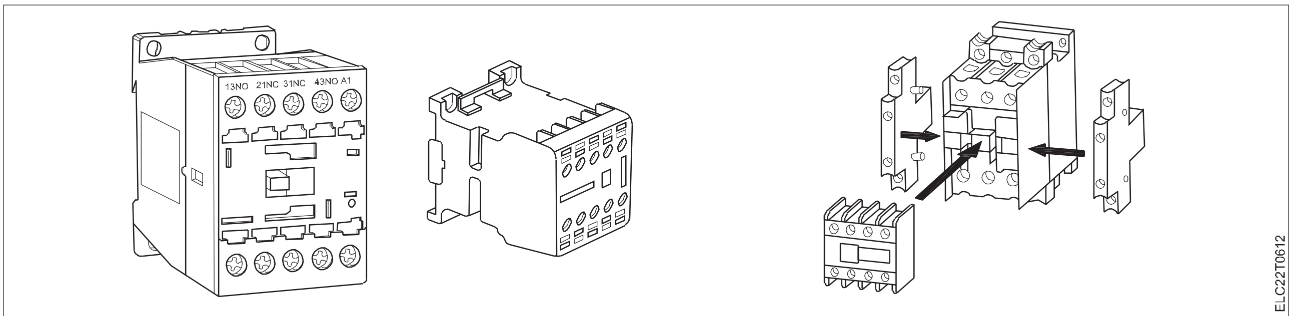
- General symbol
- Slow-to-release relay.
- Slow-to-operate relay.
- Polarised relay.
- Mechanically latched relay



Power control relays

Although the previous relays are also used in control panels, the so-called control relay uses a slightly different operating principle and is specifically designed to switch the higher powers found in control panels.

- There are a number of shapes and sizes but most are similar to those shown here.
- They can be either flush-mounted to the chassis or DIN rail-mounted.
- There are at least 3 sets of contacts in the main body with a wide range of contact combinations available.
- In addition there are auxiliary contact sets which are clipped to the sides and in some cases to the top of the main body.
- The connections are made with screw clamp terminals.
- The contact and coil terminals are at the front and are shrouded to stop fingers touching live connections.



Labelling

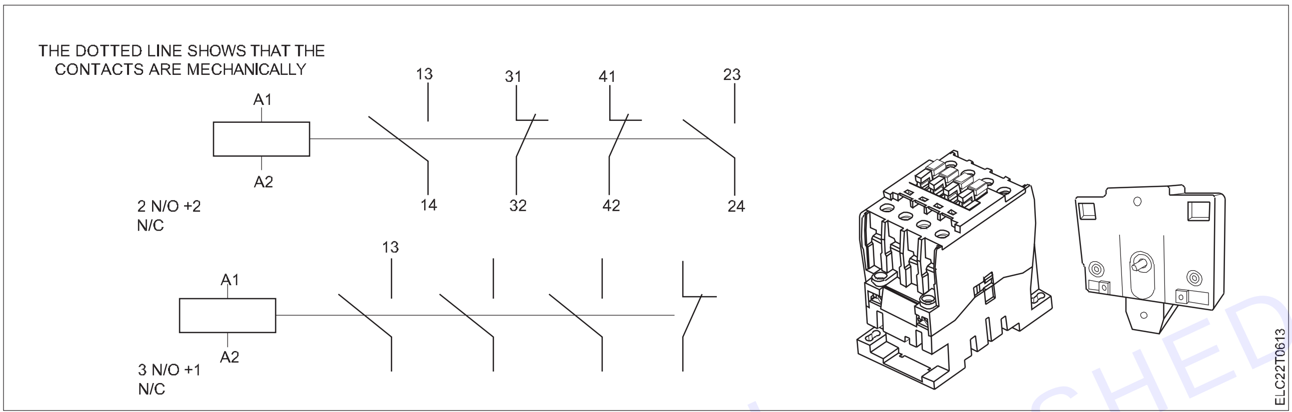
The contact arrangement and the terminal numbers are usually marked on the side of the relay, similar to that shown here.

Two numbers are used to mark relay contacts:

- First number identifies contact positions 1,2,3, etc.;
- Second number identifies contact type. For example: 1 and 2 for NC contacts; 3 and 4 for NO contacts.

Auxiliary contacts

- Auxiliary contacts can be fitted to the top or to the sides of most contactors.



Interlocks

- Two contactors may be interlocked so that only one will operate at any time. This may be used, for instance, when the two contactors switch a motor in different directions.
- The actual detail of fitting these interlocks differs but in general the interlock unit is fitted between the two contactors. For exact methods of fitting, read the instruction leaflet which will accompany the contactor.
- Moving spigots on either side engage in slots on each contactor.
- If the contactors are fitted to a DIN rail they must also be clipped together using the spring clips which will be supplied with the interlock kit.
- If they are fitted to the chassis then they are usually mounted to a plate before being fixed to the chassis.
- The contactors must not be able to move relative to each other on their mounting otherwise the interlock will fall out.
- Once fitted, check that they will only operate one at a time by pushing down the contactor armatures.
- Further add-on parts to a contactor-type control system includes overload prevention devices.
- A protection unit may have to be fitted, e.g. a thermal overload unit.
- These have three pin connectors which engage into the contactor's screw clamps.
- The overload unit has a changeover contact unit in addition to the three protected connections
- Most also have a clip to secure them to the base of the contactor.

Fuses

What we refer to as a fuse has several parts, the main body, the fuse holder or carrier and the fuse itself which is called the fuselink.

There are a wide variety of types, shapes and sizes available but there are only a couple which are in common use in control panel assembly.

- Fuses are an essential part of the safety element of the equipment.
- Because of this it is important mat the correct value and type is used as called for in the parts list.

Fuses are electrical safety devices that protect equipment and components from damage caused by overloaded circuits. When the current flowing in a circuit exceeds the rated value of the fuse, the current conductor in the fuse melts and opens the circuit. If the fuse is not present, or is too high a value, then it would be the circuit conductors or components that would melt and possibly burn.

The opening of a fuse indicates a fault somewhere in the circuit, switches off the faulty circuit from the power source and isolates it from other, unaffected circuits.

During over-current conditions the fuse interrupts the current source, limiting the energy allowed to pass. When a circuit carrying a current is interrupted in this way, an arc is created across the break. This arc only lasts a short time under normal circumstances but like the arc from an electric welding set, it can generate considerable heat. The fuse has to be capable of withstanding this arc. This characteristic is particularly important during short circuit conditions where the current can be very much higher than normal.

Fuse holders - or carriers - also have to be made so that they can carry the rated current as well as a high overload current for a short time. They also have to be made so mat they can withstand the highest voltage they will be subjected to. Standards also dictate the type of fuse that has to be used for different circuits.

Switches

A switch consists of a set of contacts manually operated by some form of actuator.

The actuator and contacts may be contained in a single moulded unit or more likely as a modular unit comprising a selection of actuators and contact sets.

Moulded one-piece

- These are generally for low current use and are more likely to be found in the low voltage control system.
- Panel-mounted one-piece units are fixed to the panel using:
- Either a central nut and lock washer - note the locating spigot, or
- Clipped into a square hole.

The wires are generally connected using crimped spades although they can be soldered

Modular

These are built up using a choice of parts fitted to a panel-mounted body. The most popular size fits a 20.5 mm panel hole. Other sizes are 16 mm and 30.5 mm. While the actual detail of assembly varies between manufacturers, they are all similar to the following representative units.

There are three main parts:

- The actuator.
- Mounting adaptor.
- Contact elements.

Switch actuators

This is the part which will operate the switch contacts. There are several variations including some with lamp indicators. The actuator is fixed to the panel through a hole with a large fixing nut behind the panel. A lettered facia can be fitted between the flange on the actuator body and the panel.

- Rotary switch.
- Push-button switch.
- Key-operated switch.
- Lever switch.

Switch actions

- **Momentary -** where the contacts are operated only while the actuator is operated. Sometimes referred to as spring return.

- **Latching -** sometimes called on-off or, with a button actuator, push on/push off where the contacts lock in one position when the button is pressed then released and only change back when the button is pressed a second time. Stay-put is yet another name.

  Rotary actuators can provide more than two positions and may be used to provide a selector-type switch.

Switch adaptors

These are used to hold the contact elements. Standard adaptors hold up to three contact elements alongside each other. Some adaptors are made complete with contacts (contact blocks).

- Front-mounting contact block. This clips to the actuator. The contact elements then clip into the rear of the adaptor.

Switch contacts

There are two basic types of contact:

- Normally open (NO).
- Normally closed (NC).
- A changeover set (CO), can be made from a combination of one NO and one NC by wiring them together as shown.

Rotary switch diagrams

The contact diagrams for rotary switches are often accompanied by an operational grid showing which contact operates in each position.

- Front panel view of a 4-position rotary switch with an ‘off position.
- This is sometimes referred to as a 0 position, 1 pole, 3 step switch.
- This is the circuit diagram showing the individual switch elements, in this case all NO.Lamps

Two symbols are shown recommended by BIS. • Indicator lamp.

- Signal lamp.

It is not important from an assembly point of view which is which.

The majority of indicators are panel-mounted. These consist of two main parts, the lamp holder and the bulb. The lampholder can take several forms:

- One-piece holder which fits through a hole in the panel.
- A nut holds it tight to the panel. Take care not to overtighten this otherwise the holder may be damaged.
- The bulb is fitted from the front.
- This type is very similar and fits in the same way but the bulb is fitted from the rear.

Earthing - the protective bonding circuit

The earthing of electrical equipment is a protective measure designed to protect us from electric shock by preventing the exposed conductive parts of the equipment from becoming live should a fault occur.

The exposed conductive parts are things like the metal cabinet housing the control circuits, the metal trunking carrying cables from the cabinet to the machine and the machine itself. Technically, they are all the conductive parts of the system that, under normal conditions, are not required to carry electric current

To see why this system works, we have to look at how the electricity supply is connected into a factory building.

The electricity is generated at the power station and then fed at very high voltages through the national grid. Eventually it will arrive at the local sub-station where it will be connected through a transformer to supply the factory.

Control panel layout and wiring practise

The quality of the wiring methods used in an industrial control panel can vary quite widely. This lesson summarizes some best practice when it comes to control panel layout and wiring.

The goal is to produce a panel that is logically arranged and easy to maintain for the life of control.

Basic wiring practices

1 **Wire:** Use all 600V 90 Deg. C rated wire. Use stranded wire. Note any exceptions so these can be added to the drawings or design notes.

2 **Wiring across a hinged door or panel:** U loop, as long as possible, facing down anchored on each side of the hinge with screws or bolts (no adhesive). Place sleeve or spiral wrap over the wires running over the hinge between the anchor points.

3 **Spacing between wired devices and wireway or other obstructions:** 2″ minimum; 2 1/2 – 3″ preferred for 120VAC and less. 4″ for 480 volts (enough to insert a closed fist between the device and the wire way or obstruction.

4 **Minimize the use of cable/wire ties if wire duct is used:** They get cut off when troubleshooting and are rarely replaced. A good wire management system should not require any wire ties. Make it a goal to use no wire ties except temporarily while wiring.

5 **Leaving Slack:** Generally, leave only “hidden” slack. Leave service loops as the wires leave or enter the device or terminal. Run wires in the wire way so they enter and run to the middle or far side of the wire way or duct. Take all corners in a wiring duct as wide as possible. Run wires in horizontal and vertical lines. This also adds further “slack” and improves the appearance. Avoid looping wires in the wire way unless the wire way is designed for this.

6 **General Wire Routing:** Run wires in horizontal and vertical lines, no diagonal runs. “Train” the wire by bending it to make neat vertical and horizontal lines. Delicate wire will require “training” by bending and forming the bend gradually. Wire in wire duct should be run so they do not cross each other excessively. Wire entering or leaving a wire duct should be brought to the front of the duct before entering/exiting where possible. Leave service loops and run wires in the wire way so they enter and run to the middle or far side of the wire way or duct and take all corners as wide as possible. Do not run wire over other devices, including the wire way. Elevate the duct and go under the duct with wires if needed. Review needed exceptions.

7 **Wiring Power and Motor Wiring:** Place Pig tail loops between devices that are spaced such that it makes it easier to remove wiring if the pig tail is added. Consider using High Flex power wires such as “Railroad Wire” or high strand count wire. Train the wire by bending it in the direction you want it to go or lay in the duct, rather than just trying to lay it in a wire duct and hope it “stays down” in the duct. See also “General Wire Routing”.

8 **Wiring Signal and Shielded Cables:** Use 18 AWG shielded, twisted pair (or Triad) type cables rated at 600V as the default signal wire type. Unless specifically required strip off a generous amount of the jacket so that each conductor can be easily accessed for removal, testing, and replacement. Also remove the jacket as it exits a wire duct, keeping the twists where the cable otherwise creates unwanted wire congestion. Examples: going to Analog I/O modules, or routing to elevated side terminals. Terminate all shields. Terminate all shields close to the signal wires. Consider using 2, 3, or even 4 high terminal blocks with jumper slots for signal wiring depending on the wiring needed. This allows busing the power supply voltages for a cleaner installation. Option: Place heat shrink tubing 1/2 over the cut end of the cable jacket and 1/2 over the exposed wires.

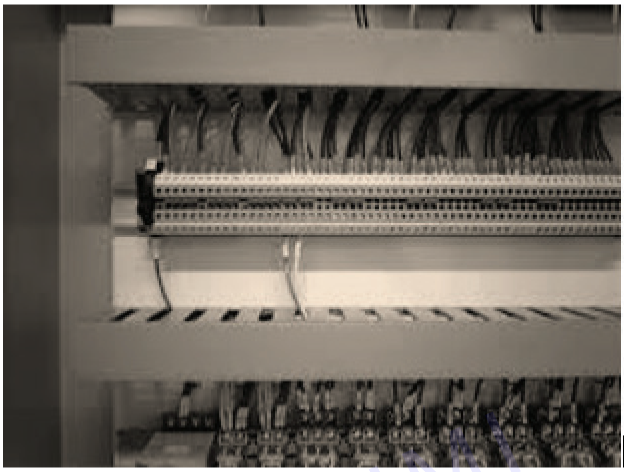
9 **Wiring Control Wires:** Use 14 SWG 600V (stranded) wire for 120VAC wire. Use 16 or 18 SWG 600V(stranded) wire for 24VDC wire for up to 10 and 5 amps respectively. Use “General Wire Routing” recommendations found elsewhere in this document.

10 **Terminations:** leave some bare wire showing to allow visual inspection and to avoid screwing down on the insulation. Wires should exit the terminal straight. Do not bend the wire at the point of termination. Instead loop or bend wires on the insulation that do not go straight to the wire way.

11 **Terminals:** Screw terminals:Use tubular, pressure plate type screw terminals that minimize wire distortions or damage when terminating. Position Terminals to allow visual inspection of the recessed connections. Elevate Control Terminals to allow wiring under the terminals if needed. Keep it stiff using a heavy-duty DIN rail or Hoffman Terminal Straps or equivalent. Angle and elevate terminals mounted on the side panel for wiring ease and to allow visual inspection of wiring in the terminals.

12 **Grounding Principle:** Wire all grounds to the incoming ground lug either directly or with a wire to the other ground bus bars. Add a main ground lug and/or a ground bus bar for each grounded power supply. A number of busbars can be utilized but should all be wired together and then to the incoming ground lug to at least 1 point if not two (2). This is in addition to the ground established through the panel. Use 2 ground wires from opposite ends of the bus or chain of ground bars if the ground is isolated. Wire the ground on all doors and subpanels and the cabinet itself to a ground bar terminated at the main ground lug. Wire all equipment and chassis grounds to the ground bar(s) which is terminated at the main ground lug. For additional details on grounding and bonding see the Grounding and Bonding post dedicated to just this subject.

Panel layout considerations



Example of good spacing between the terminals and the wire way.

1 **Optimize the Space:** Place I/O racks in the "bay" created by the wiring duct to allow room for the high density of wires going to them from the duct. Don't leave space where there is no wiring, typically the top of the I/O rack. Place similar sized devices in their own "bay" where possible. Consider the routing of all of the wires and how the various voltages will be kept separated.

2 **Spacing between wired devices and wire way or other obstructions:** 2″ minimum; 2 1/2 – 3″ preferred for 120VAC and less. 4″ for 480 volts (enough to insert a closed fist between the device and the wire way, another device, or obstruction.

MODULE 16 : Domestic Appliances

LESSON 101-103 : Domestic appliances - electric heaters electric cettle, geyser, washing machine

Objectives

At the end of this lesson you shall be able to:

- explain the domestic appliances
- explain the working principle and circuits electric heaters electric cettle
- explain working of electric iron, geysers, mixer, their dries
- state the concepts of netrual & earth.

Domestic appliences,based on heating effect

Effects of electric current

When an electric current flows through a circuit, its presence is judged by its effects, which are given below.

1 Chemical Effect

When an electric current is passed through a conducting liquid (i.e. acidulated water) called an electrolyte, it is decomposed into its constituents due to chemical action. The practical application of this effect is utilized in electroplating, block-making, battery charging, metal refinery, etc.

2 Heating Effect

When an electric potential is applied to a conductor, the flow of electrons is opposed by the resistance of the conductor and thus some heat is produced. The heat produced may be greater or lesser according to the circumstances, but some heat is always produced. The application of this effect is in the use of electric presses, heaters, electric lamps, etc.

3 Magnetic Effect

When a magnetic compass is placed under a current carrying wire, it is deflected. It shows that there is some relation between the current and magnetism. The wire carrying current does not become magnet but produces a magnetic field in the space. If this wire is wound on an iron core (i.e. bar), it becomes an electro-magnet. This effect of electric current is applied in electric bells, motors, fans, electric instruments, etc.

4 Gas Ionization Effect

When electrons pass through a certain gases sealed in a glass tube, it becomes ionised and starts emitting light rays, such as in fluorescent tubes, mercury vapour lamps, sodium vapour lamps, neon lamps, etc.

5 Shock Effect

The flow of current through the human body may cause a severe shock or even death in many cases. If this current is controlled to a specific value, this effect of current can be used to give light shocks to the brain for the treatment of mental patients

Definitions

1 Electro motive force (emf)

The force which causes current to flow in the circuit is called emf. Its symbol is E and ismeasured in volts (V). It can be calculated as:

emf = voltage at the terminal of source of supply + voltage drop in the source of supply

oremf = VT + 1R

2 Voltage

Voltage It is the electrical potential (i.e. pressure) between any two live wires or between one live wire and earth. Its symbol is V and the unit of measurement is volts. It is also measured by a voltmeter.

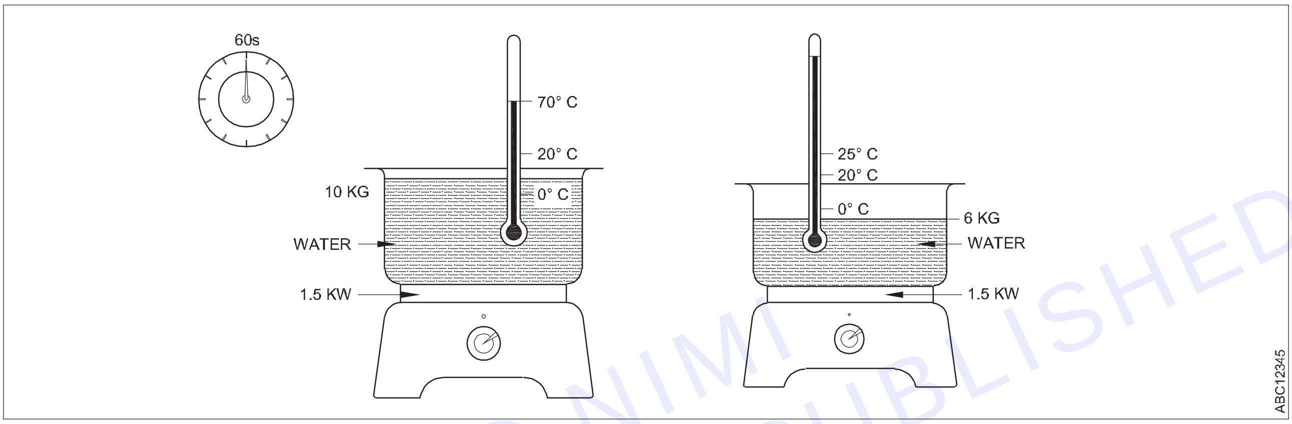
3 Electric current

Electric Current The flow of (electricity) electrons in one direction along any path or around any circuit is called electric current-Its symbol is / and its unit is ampere (A). The instrument by which the current is measured is called an ampere meter which is always connected in series with the circuit-

4 Heating effect of electric current

Temperature and heat: In daily life, the terms heat and temperature are often used to mean the same thing. But the terms are different in a technical sense. The difference between the two can, however, be easily clarified by means of an example.

If 6 litres of water and 10 litres of water are heated separately on a hotplate for the same length of time, beginning from the same initial temperature, then the same amount of energy has been supplied in each case. The end temperature reached, however, will be different in the two cases. The smaller quantity of water will have a higher end temperature, than the larger quantity of water.

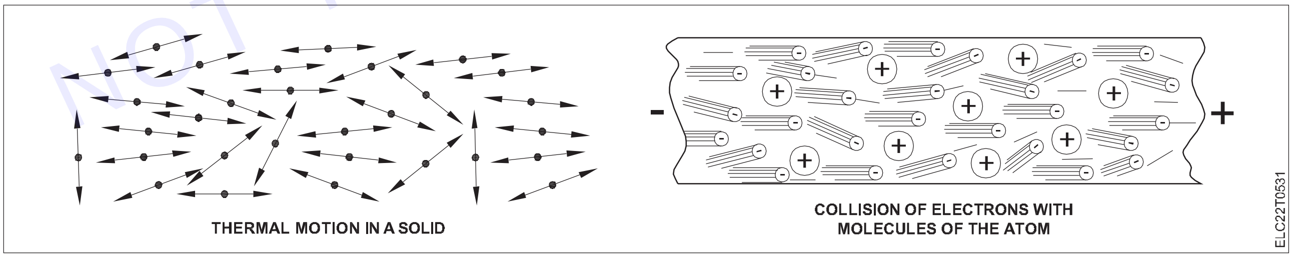


Temperature is a measure of the quantity of heat contained in unit substance (say molecule).

Development of heat in the electric circuit

Whenever electric current flows through a conductor, it produces some heat. The reason for this is that some energy is used up in causing the current to flow. This energy is given off in the form of heat.

This conversion of electrical energy into heat energy is due to the electrons colliding with the molecule of the conductor during their flow, i.e. inter-electronic and ionic collision during flow.



Some methods of producing heat

1 Resistance heating

Resistance heating utilizes the fact that a current flowing through a material produces heat. Some of the most common heat-resisting materials are aluminium, nickel, chromium, copper, iron, and cobalt in various proportions. Heat-resisting elements are commonly used in cooking appliances, electric space heating, and cloth-dryers and irons

2 Arc heating

An electric arc is produced by ionizing the air between two electrodes. The heat from the arc is us Arc heating: An electric arc is produced by ionizing the air between two electrodes. The heat from the arc is used for welding and melting metal

With welding, the material to be welded forms one electrode and the welding rod the other. To form the arc, the welding rod is touched to the material to be welded. The heat produced by the current flowing through the point of contact causes the metal to vaporize, thus causing the surrounding air to ionize. When the rod is pulled away from the material, the ionized air conducts the current forming an arc. Once the arc is produced, the heat generated causes the material and the rod to melt. The metal from the rod flows with that from the material to form a continuous seam

Measurement of heat energy

Unit: Heat

1 Kilocalorie

The kilocalorie (kcal) is the unit of heat in the mks system. It is defined as the amount of heat required to increase the temperature of one kg of water through 1°C. It has been experimentally proved that, if 4187J of electrical energy is completely converted to heat, it produces one kilocalorie of heat energy, i.e. 1 kilocalorie = 4187

2 Joule's law of heating

This law states that the heat generated in a conductor by the flow of an electric current is proportional to the square of the current value, the resistance of the conductor and the time for which the current flows

The above law can be expressed in the form of an equation as follows

$H = I^2Rt$ watt-seconds or joules

Where

I = current in the conductor in amperes

R = resistance of the conductor in Ohms

t = time for which the current flows in seconds

H = quantity of heat developed in joules

If current "I" ampere flows for 't' seconds through a resistance of R ohms, then the electrical energy consumed (I^2Rtjoules) is converted into heat so that we have

$H = I^2Rt$ Joules OR watt-seconds

3 Method used for heat transfer

Heat energy is generally transferred from one place or object to another by one of the three methods: conduction, convection or radiation. In most instances all the three methods are used in varying degrees. The system is named according to the primary method used.

The conduction method transfers heat from one object to another. One might say the object conducts Keats. An example of this method is cooking. A pan is placed on the cooking range in contact with the heating element. Heat is transferred from the element to the pan and from the pan to the ingredients in the panThe convection method transfers heat through a fluid or air. Hot water, steam, and warm air heating systems use the convection method.

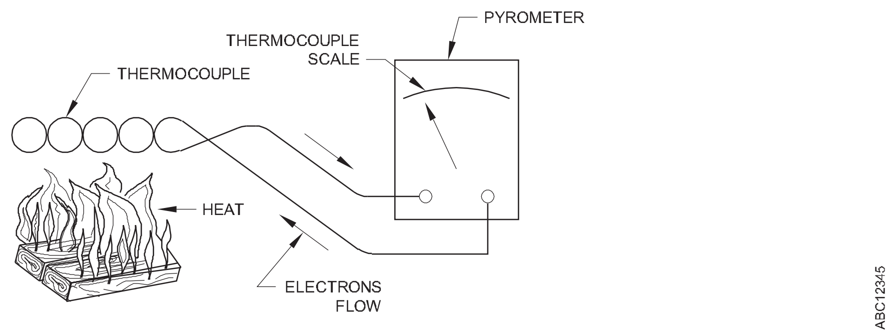
Heat radiation is accomplished when the heat rays are transmitted through space. The rays are absorbed by the objects they contact, thereby warming the objects. They do not warm the air but Heat radiation is accomplished when the heat rays are transmitted through space. The rays are absorbed by the objects they contact, thereby warming the objects. They do not warm the air but warm the objects into which they are absorbed. warm the objects into which they are absorbed.

4 Applications of heating effect

This principle of electricity is widely used in the operation of many electrical devices, such as electric lamps, fuses, arc welding, spot welding, domestic heating appliances.

5 Voltage by heat

If two dissimilar pieces of metal, such as iron and copper wires, are twisted together and heated in a flame, a potential difference or voltage will be developed across the ends of the wires. (Fig 3) Such a device is known as a THERMOCOUPLE. The thermocouple is used in PYROMETERS, to measure very high temperatures of furnaces.



6 Heating unit

A resistor when employed for producing heat is called a heating unit or heating element. It is generally made in three forms:

- Round wires
- ribbon wires
- strips

Round and ribbon wires are used in small heating units, such as electric stoves, room heaters, soldering irons, heat convectors, electric kettles, electric irons, hot plates, water heaters and other electric heating appliances. The round or ribbon wire is first wound over some insulating material such as mica or asbestos and then pressed between the surfaces to be heated.

Strips are generally employed in big furnaces where the quantity of heat required is very high.

Materials for heating elements

The material required for making heating element is either Kanthal or nichrome wire.

1 Kanthal

It is an alloy of chromium,Nickle, Iron, etc., prepared in different percentages of combination for different purposes. Its maximum working temperature is 1280°C (2336°F). Its specific resistance is 135 μΩ -cm at 20°C. Its melting point is approximately 1510°C (2750°F). It is specially used in big furnaces for annealing stainless steel and various types of pottery works.

2 Nichrome wire

It is an alloy of 80% Nickle and 20% chromium. The maximum temperature at which it can work safely, is 1150°C (2102°F). Its specific resistance is 110 μΩ -cm at 20°C. It is generally used for making elements of heating appliances for domestic purposes.

Temperature controll and types of heaters

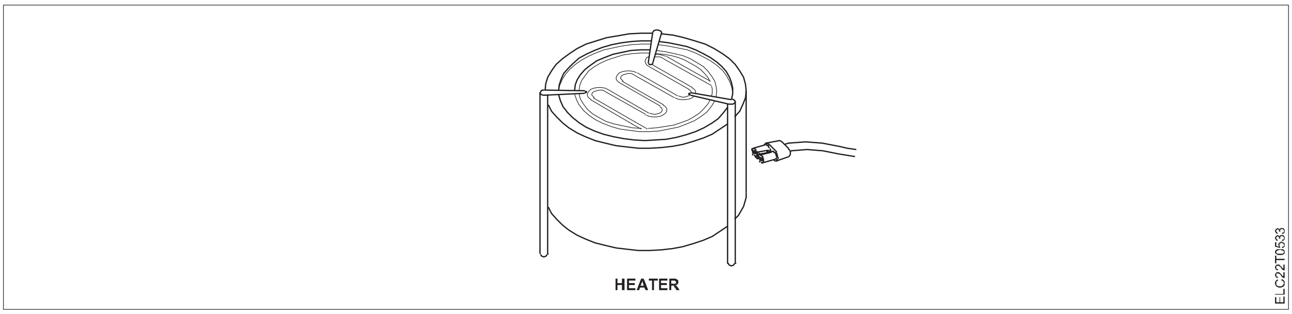
1 Electric heaters

A large variety of domestic appliances, such as the electric stove, room heater, soldering iron, electric irons, hot air circular, hair drier, electric kettle, toaster, hot plate and water heater are examples of electric heaters.All these appliances have heating elements made of Nichrome wire which has high specific resistance. This wire can be heated to high temperature in air without oxidizing. The elements are wound on mica or fire clay which is electrically insulated and can stand prolonged heating. Each device is designed for different power ratings and voltages. So before using them it is necessary to see the rating of the appliances for their satisfactory operation.

For purposes of safety a three-core flexible cable should always be used with all the appliances. Two wires are used as the main lead and the third one is the earth continuity conductor One end of it is connected to the metal body of the appliance and the other end to the earth pin of a three-pin plug top. The maximum operating voltage of all domestic appliances is 230 or 250 V and the power ratings are 750, 1000 and 1500 W.

2 Room heater

In these heaters, the heat produced is radiated by means of a Well-polished reflector.



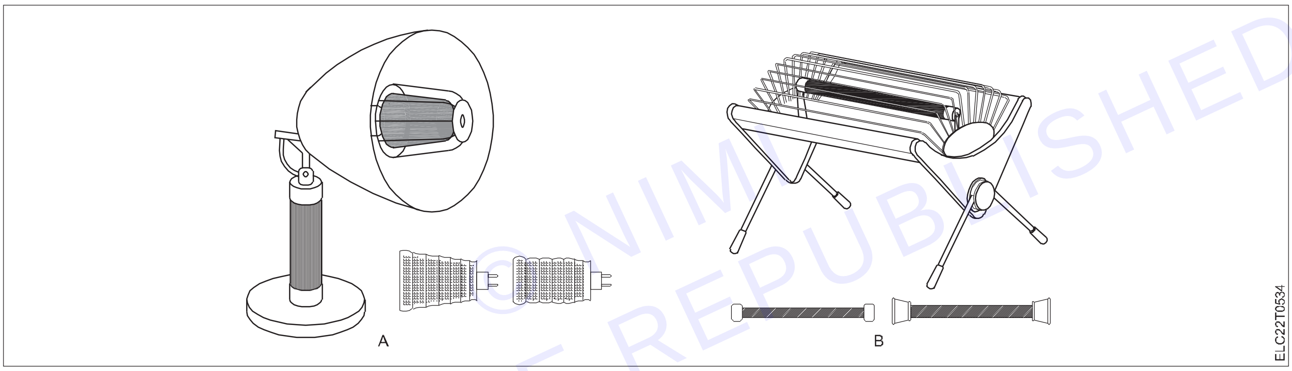
These heaters are of two types:

A Bowl-type room heater, and

B Rod-type room heater.

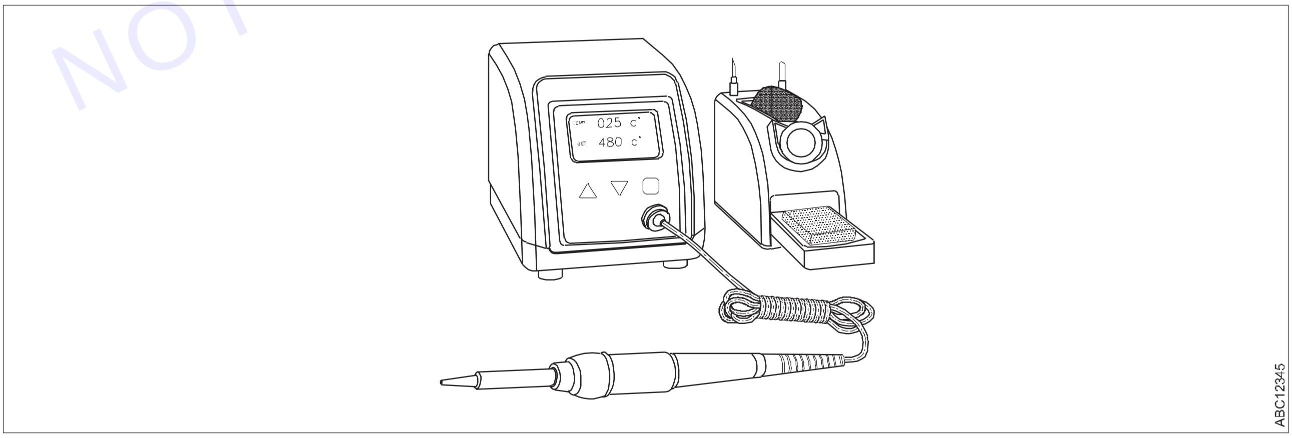
A room heater consists of an element, a reflector and a base plate. The element of the bowl-type room heater is wound over a cone-shaped or tubular-shaped porcelain insulator with two-pin bases as shown in figure A

The element of the rod-type room heater is wound over the china clay insulating rod. These heating rods may be either plug-in type or screw-in type as shown in figure B



Soldering iron

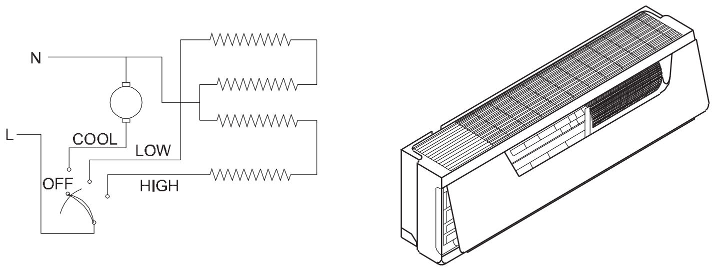
It consists of a copper bit, wooden handle and an element embedded in the copper bit This element heats up the copper bit of the soldering iron and for its easy handling a wooden handle is provided. The soldering irons are generally of 65, 125 and 250 VV, 230 volts and are used for soldering wire joints, commutator segments, etc



4 Air circulator

It consists of a fan motor of 1/60 hp, 2400 rpm, two elements of 1000 W each and a special rotary switch which can make contact with all the terminals of the switch at a time when required.

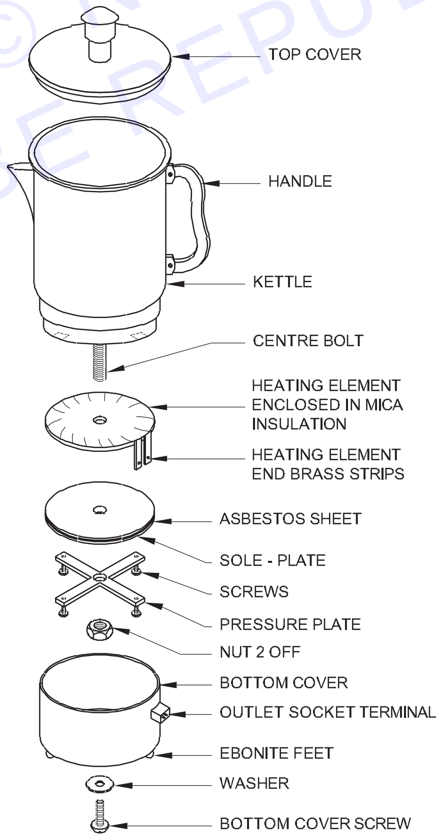
The fan circulates the cool air into the room when the switch makes contact at first posi-tion. At second position the fan delivers low heat and similarly at the third position maximum heat. The essential parts and connection are shown in Fig. It is only suitable for operating on 230 V ac and takes either 1000 or 2000 W.



5 Electric kettle

The electric kettle consists of a container, handle and an element. The element is made of a long, flat nichrome wire arranged in a zig-zag manner and fitted between the two sheets of mica. The element is properly fitted under the base of the kettle and is covered with a metal plate (which acts as a pressure plate) fitted with nuts. In some cases, the heating element is embedded in a brass chromium plated tube and insulated from it with some insulating material. Such a type of element is known as an immersion element and the kettle in which it is used is known as, an immersion-type electric kettle, as shown in Fig. This type of kettle is more efficient because the whole length of the immersion heater is dipped in the water and thus the heat loss is minimum. In this kettle a thermal plunger is also provided in the socket. When the kettle boils dry, the plunger is released by the trip lever. Due to excessive heat on this the plunger in the socket of the kettle pushes back the female connector socket and thus disengages the connector socket from the element. This lever does not permit the making of contact again. The contact of the female connector socket can only be made again by pushing the plunger inward to its original position when the element of the kettle has cooled down again.

The power taken by the electric kettle (heater type) is 450 W at 230 V and for the immersion-type electric kettle, it is 600 to 1500 W



ELECTRIC KETTLE

6 Electric Iron

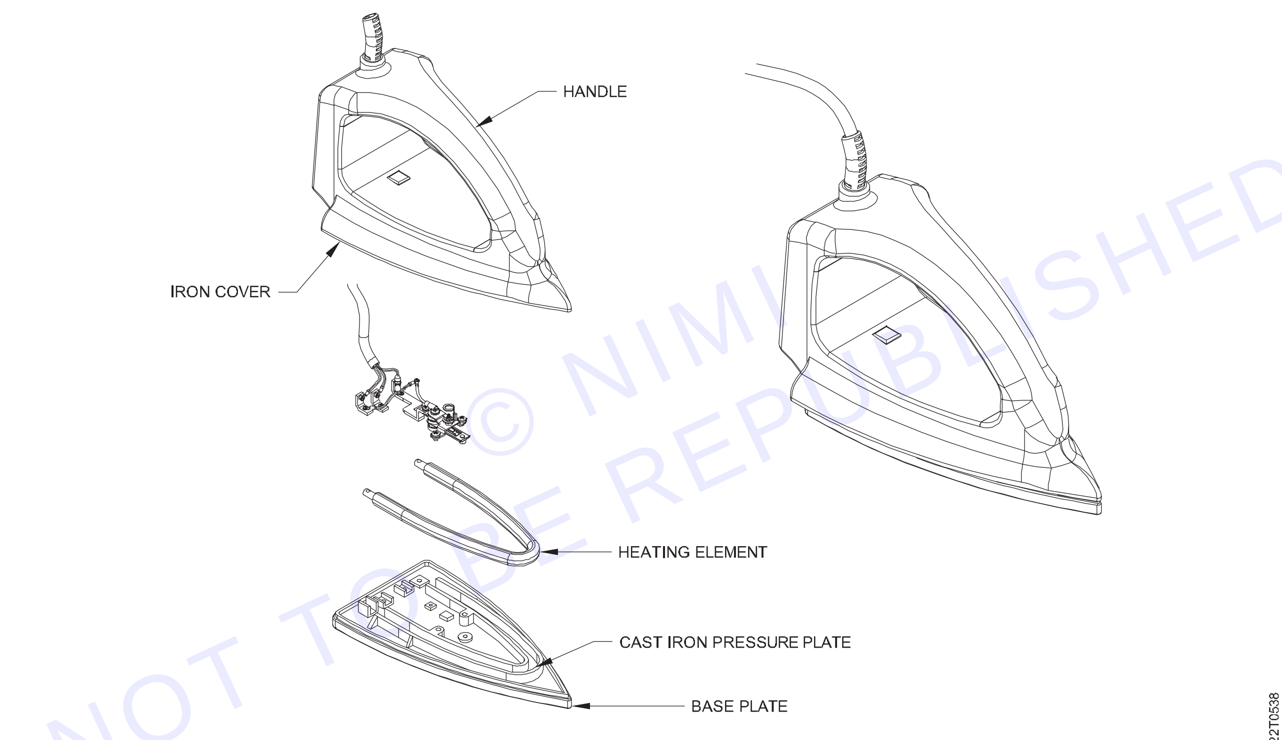
The main purpose of the electric iron is to press the clothes. Electric irons can be classified into two types as given below:

- Ordinary electric iron
- Automatic electric iron

Ordinary Electric Iron

It consists of chromium-plated base plate, an electric heating element of nichrome wire fitted between the two sheets of mica, a cast iron pressure plate, a chromium plated cover with insulated terminals and a handle. For heating it is connected with the supply by means of a female connector having flexible cord and a three-pin plug top. Figure shows the parts of an electric iron.

Electric iron



ELECTRIC IRON

Laundry iron

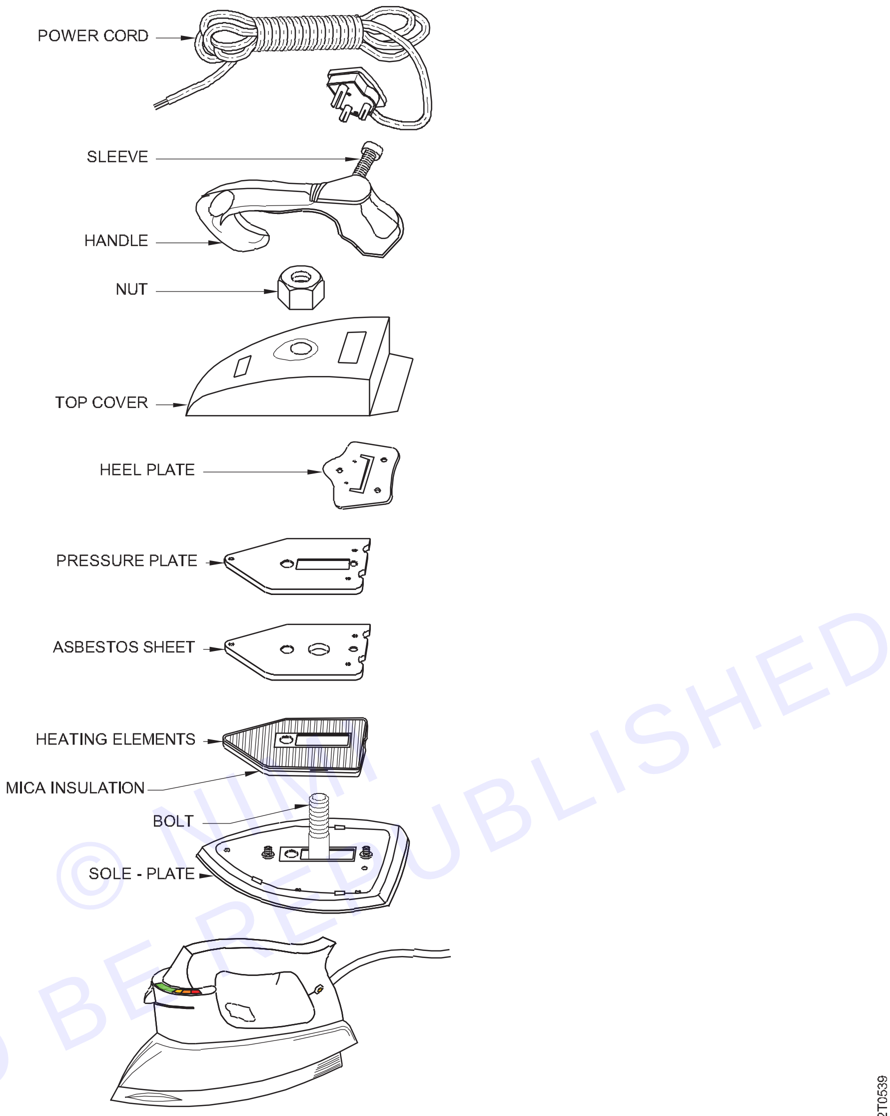
The power consumption of domestic electric iron is 450 W while laundry irons (bigger in size, shown in Fig. 5.11) are of 750, 1000 and 1500 W.

Automatic Electric Iron

In addition to the above mentioned parts, the automatic electric iron has a thermostat which is connected in series with the element. This thermostat controls the temperature, prevents overheating of the iron and thus avoids damage to the heating element. The necessity of the thermostat is due to the fact that some clothes like cotton and linen require high temperature for pressing while terylene and silk require low temperature. The required temperature can be obtained with the help of thermostat. The essential parts of an automatic iron shown below

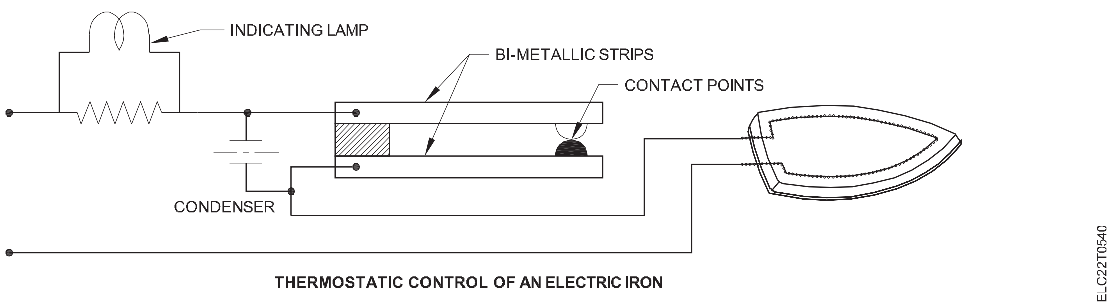
Thermostat

The thermostat is a switch which-operates automatically due to the variation of heat produced around it. It functions on the principle that different metals have different rates of expansion when heated. For example, brass has a greater coefficient of expansion than iron. If a strip is made of bimetal (i.e., say brass and iron) and heated beyond a certain temperature, it will bend downwards.



AUTOMATIC ELECTRIC IRON

The above principle is used in operating the thermostat (thermal switch). The thermostat has two contact points, namely, the fixed contact point and moveable contact point. The moveable contact of thermostat consists of a bimetal strip which is normally in contact with another strip of metal having fixed contact. The thermostat is connected in series with the heating element as shown in the Fig. and is fitted inside the cover of the iron above the pressure plate.



THERMOSTATIC CONTROL OF AN ELECTRIC IRON

After switching on the iron, the current starts to flow through this contact point and thus the temperature rises. When the temperature reaches beyond a certain adjusted temperature, the contact point of the bimetal strip opens which now stops the flow of current through the heating element. Thus the circuit of the heating element is opened. The circuit cannot be closed again till the base plate of the iron cools down again. After cooling the iron, the bimetal strip regains its original normal position and thus the circuit is again completed. By means of an insulated knob on the contact point, the distance between the contact points is adjusted. This regulates the temperature of iron for different types of clothes. It should always be kept in mind that the setting of the bimetal strip should not Tie disturbed because the rate of linear expansion is known to the manufacturer only. If once its setting is disturbed, it will stop functioning properly.

A condenser is connected across the contact point of the bimetal strip. Its function is to minimize the sparking at the contact point and thus increase the life of the contact point. A short-circuited condenser decreases the life of the element because it will always give path to the current, and the iron even afterithas become hot cannot then be operated through the contact point.

An indicator lamp of 2.8 V is also fitted in the handle of the iron and is connected across a small resistance which is connected in series with the element. When the lamp lights up, it indicates that current is passing through the heating element and when it goes off, it shows that iron has attained the required temperature and the current has stopped flowing. Automatic irons are of 750 W only.

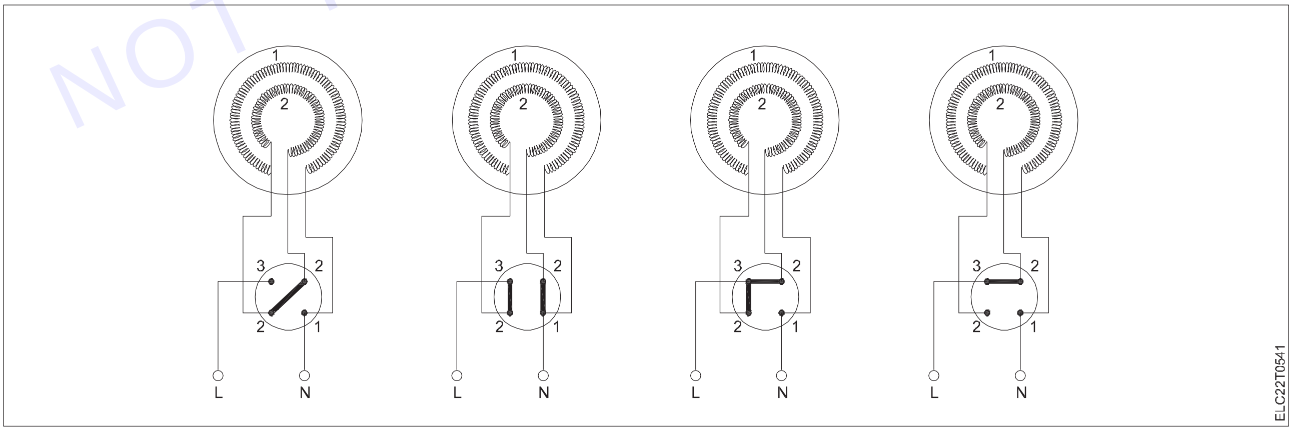
7 Hot Plate

Hot plates are used for cooking food stuffs. These are of two types, namely, the single hot plate and double hot plate

Double hot plate

Single hot plate

The heating element of the hot plate consists of a single or double spirally wound heating element which is embedded in between an insulating cemented material like plaster of paris or fire clay and then baked hard. The fire clay is then covered with a steel plate and the foodstuff boils over this plate. In simple design, the heating element is divided into two parts of equal heating capacity, as shown in Fig. Each element is independently controlled by a separate switch. When either switch is in the ON position it gives half of the full heat and when both switches are ON the full heat is available.



In other cases, heat is controlled by a separate special rotary switch which has four positions, giving full heat, medium heat, low heat and OFF. The heating element is divided into two parts. When the switch is in the full position, the two elements are connected in parallel and the element takes its full rated current.

8 Water heater

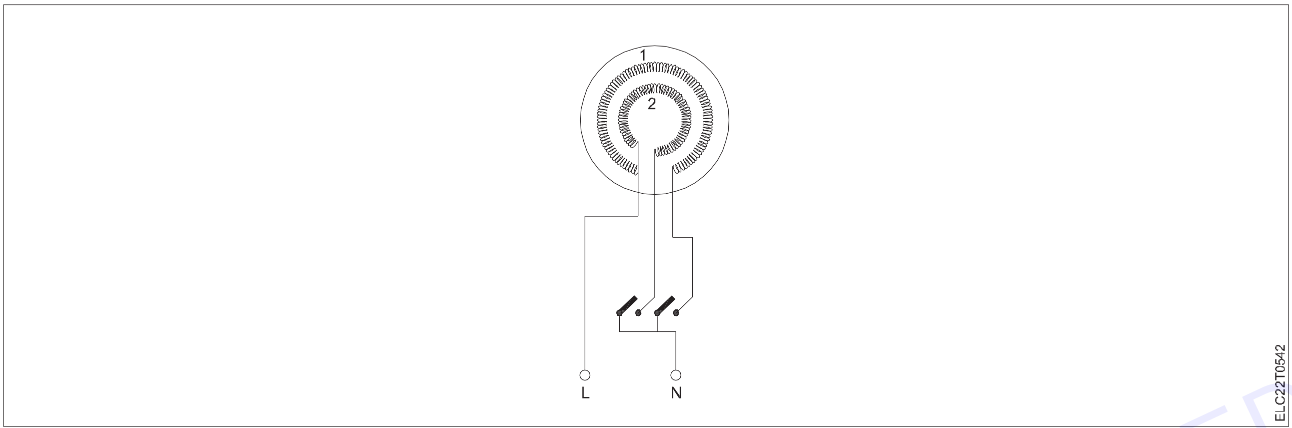
Water heaters are of two types:

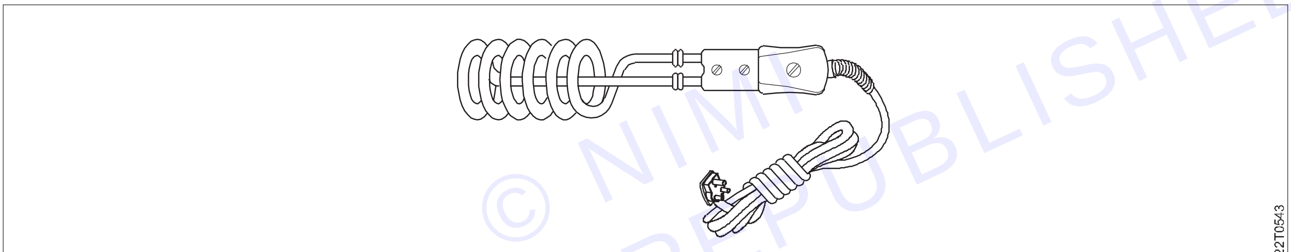
1 Immersion water heater

2 Storage water heater

1 Immersion water heater

As is apparent from the name, it is dipped in the vessel containing water for heating. There is a heating element in the brass chromium plated water-tight tube and insulated from it with an insulating mate¬rial like plaster of paris. There is no wastage of heat in it, so its efficiency is greater than other type of heaters. It is a portable water heater, as shown in Fig. The immersion heaters are manufactured in 250, 1000 and 1500 W ranges. The 250 W immersion heater is used for heating water for shaving purposes only.





IMMERSION WATER HEATER

2 Storage water heater

It consists of a double-walled reservoir known as the cistern, a heating element and a thermostat. It is not a portable water heater and is fixed on the wall where it is to be used It can be further divided into two classes:

i Non-pressure type water heater

ii Pressure type water heater

i Non-pressure type water heater

Figure shows a non-pressure type water heater. It is used at places where hot water is required at one service point only.

It has only one outlet for water without a stop cock. The water is controlled only from inlet side by a valve as shown in Fig. It consists of a double-walled chamber. The space between the two chambers is filled with a heat insulating material like glass wool or cork. The heating chamber generally consists of tinned copper and the outer covering of lead coated steel. This outer coating is given a final coat of white enamel paint. The inner chamber has a drip device, a thermostat for controlling the temperature of the water and a heating element erected vertically. The anti-drip device is connected to the outlet pipe which helps in having a quick cut-off of hot water.

When the inlet valve is opened, it allows an equal quantity of hot water into the outlet pipe. The pressure inside the chamber does not develop because the outlet valve is always opened.

It should be always remembered to earth all the metal coverings of the water heater.

ii Pressure type water heater

When the hot water is needed at more than one servicepoint and only one heater is to be used, then this type of water heater is used only. This kind of water heater gets water supply through the cistern (i.e., reservoir) which is connected to the water mains through a controlling float valve.The power consumption of a 25-litre bathroom geyser is either 1000 or 1500 W.

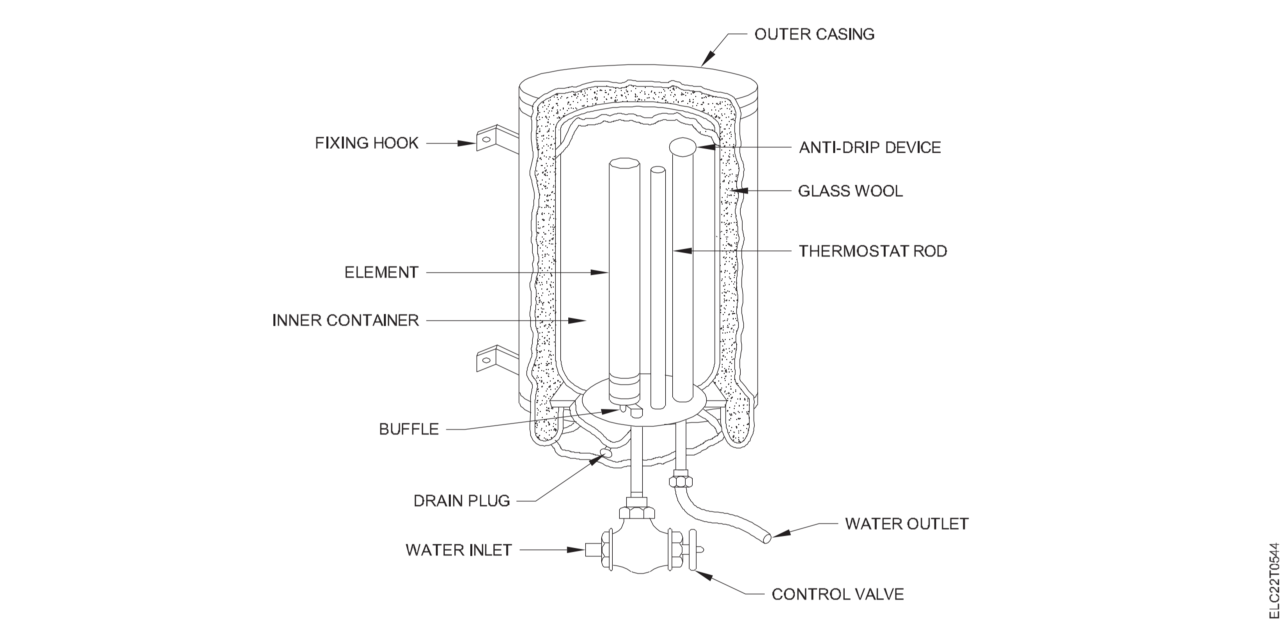


Figure shows the essential parts of this type of water heater. The heater cistern is always full of water. The cold water comes through the cistern and replaces the drained off hot water in the tank in equal volumes. The level of the water in the cistern always remains constant as it is controlled by a floating-ball valve. During the heating process, the water expands and a vent pipe is also provided for its expansion.

The main disadvantage in this water heater is that cold water mixes with hot water and thus reduces the temperature of the water at the service point. This type of water heater is also known as a constant volume pressure type water heater.

Point and only one heater is to be used, then this type of water heater is used only. This kind of water heater gets water supply through the cistern (i.e., reservoir) which is connected to the water mains through a controlling float valve.

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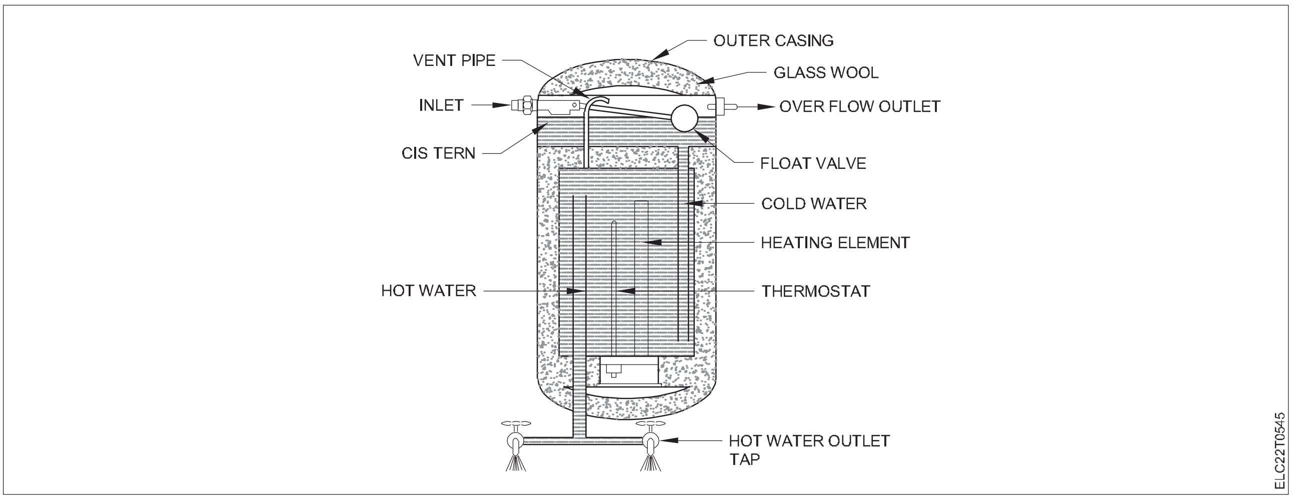
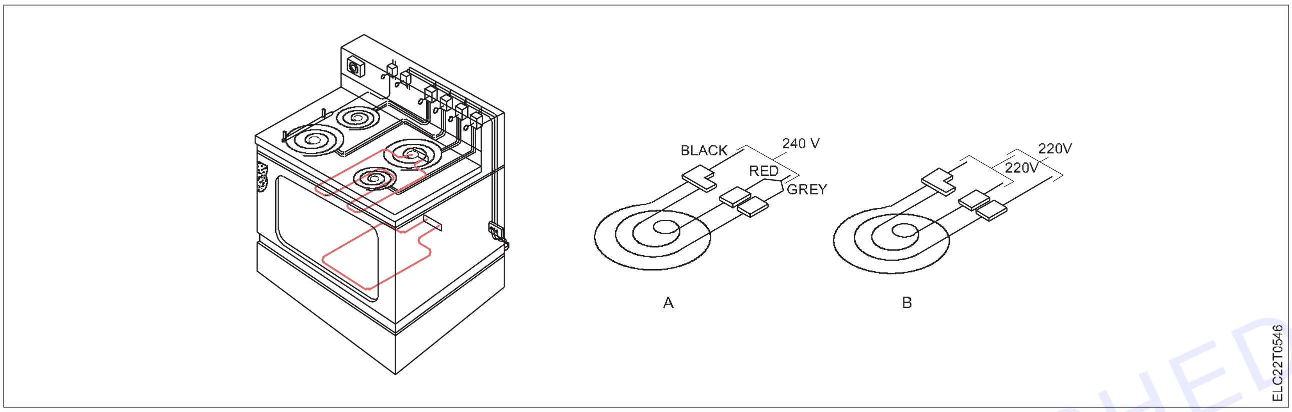
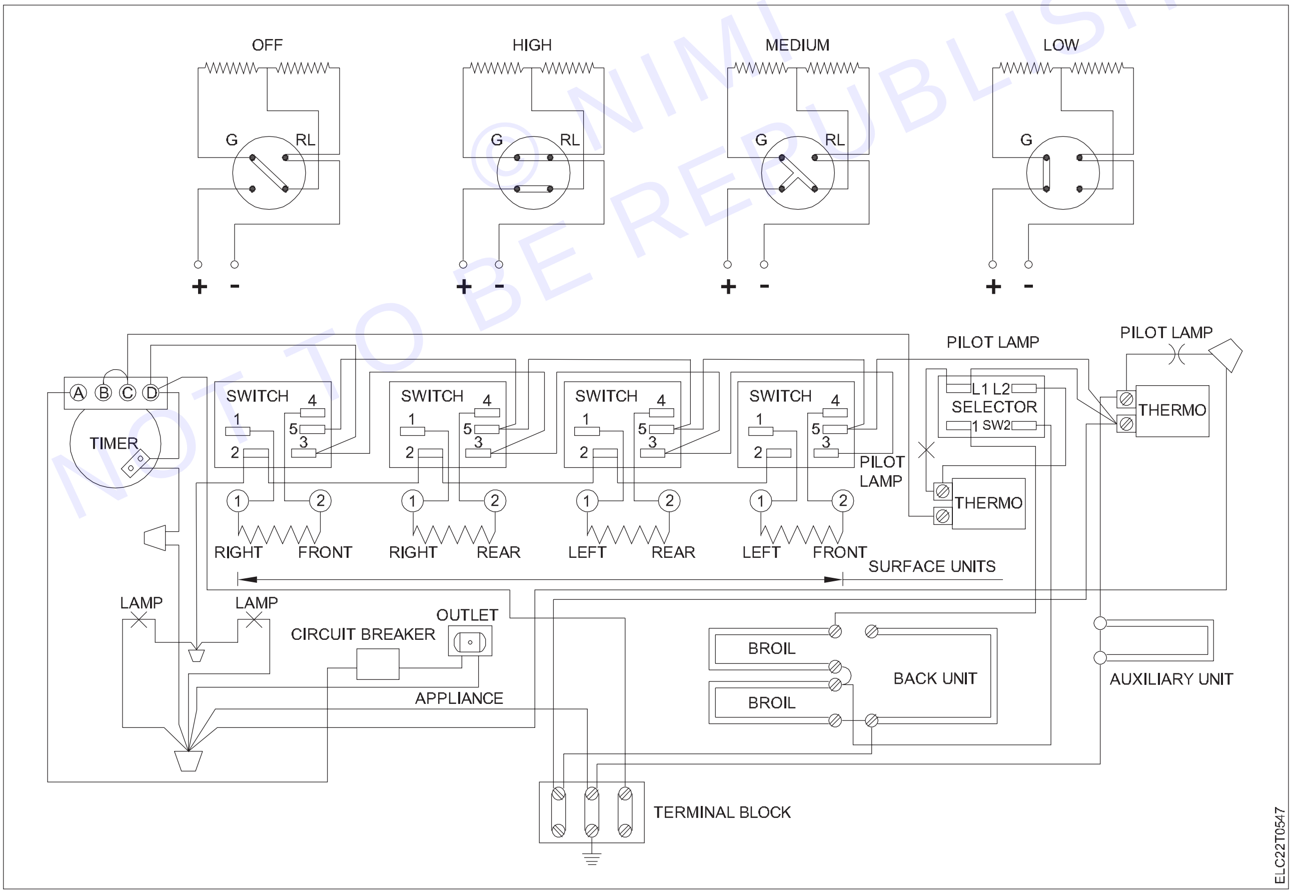


9 Electric cooking range

An electric cooking range is normally a combination of four- an oven and a hot plate. An electric range with a surface heating element is shown. The arrangement and method of the connection of the two elements in a surface heating element is shown.

In this type of heater, the element is not opened. The Nichrome wire heating element is kept inside a mineral insulated hollow tube. The method in which two elements are connected to obtain different temperature is shown in Fig 3. In the 'high' position both the elements are con¬nected across the supply. In the medium position the high wattage element is connected to the supply. In the medium position the high wattage element is connected to the supply. In the low position both the elements are connected in series





Toasters

Basically, a toaster is made up of a rack to hold the breadslice, and the heating elements located at the sides of the of the bread. The object is to heat the bread until it istoasted to the desired colour. The longer the bread is tested, the darker it will become. Therefore, time plays an important role in getting the desired degree of toasting.

Normal operating temperature range of the appliance:

The normal working temperature of a toaster heating elementsvaries from 385°C to 900°C. The toasting zone temperatureis about 260°C.

Rating of toasters:

The toasters are rated for 600 W, 750 W. 1000 W and 1250 W to work from 230 volts to 250 volts, 50Hertz supply.

Types of toasters: Toasters are available in two types.

1 Non-automatic toasters

2 Automatic toasters

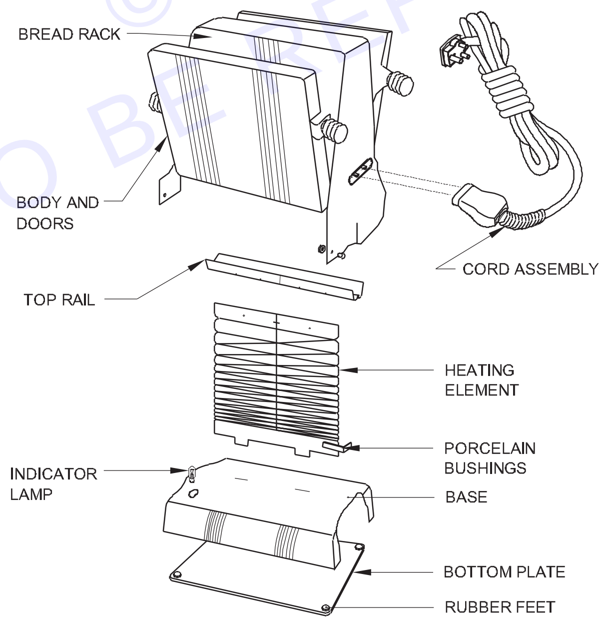
In some toasters, the user must keep watching the bread whileit is being toasted so that he can turn off the heat when thebread slice turns to the desired colour by trial and errormethod. This type of toaster is classified as a non-automatic toaster because the timing and switching off of theheat is left completely up to the user. An automatic toaster does all the necessary operations by itself.

1 Non-automatic toasters

Typically, the non-automatic toaster consists of a metal shell containing a bread rack and a series of heating elements. The doors on either side are hinged at the bottom, and swing out from the top and downward to a horizontal position

Fig shows the parts of a non-automatic toaster. Bread is placed on the doors, which are then closed, thus bringing one side of each slice of the bread close to the heating element mounted in the centre of the toaster shell. When one side is toasted, the door has to be opened manually.

The bread has to be turned manually for toasting the other side by following the same procedure. The non-automatic toaster has neither switches nor thermostats. Non-automatic toasters have been replaced almost universally by the automatic type



NON - AUTOMATIC TOASTER PARTS

2 Automatic toasters

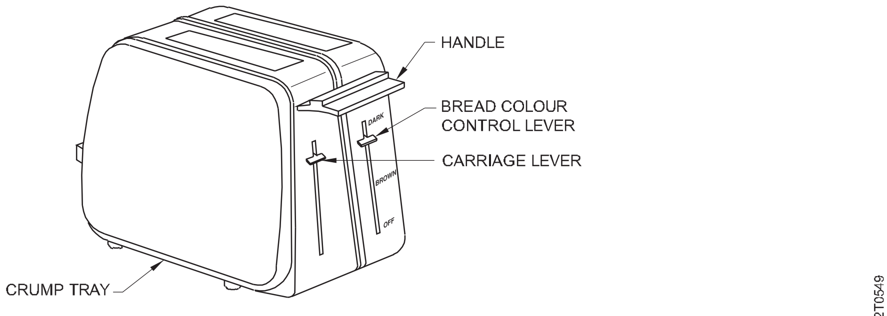
Automatic toasters are built in two and four bread slice sizes. They are often referred to as ‘automatic pop-up toasters’, and these toasters automatically perform the operation required fortoasting. Automatic toasters Automatic toasters are built in two and four bread slice sizes. They are often referred to as ‘automatic pop-up toasters’, and these toasters automatically perform the operation required fortoasting.

Basically automatic toasters are simple appliances with three working parts.

A bread carriage moves up and down inside the toaster walls and usually has an external control lever. The carriage when at down position operates a switch that turns the toaster 'on' and vice versa.

Heating elements, made of flat Nichrome wires, are positioned on both sides of the toaster wall. When current flows through them, they radiate heat fortoasting.

A mechanical timer inside the toaster is linked to a toast colour control outside. The control enables the user to adjust the toasting time for different types of breads or to suit the user's preference.



AUTOMATIC BREAD TOASTER

Washing machine

Objectives: At the end of this lesson you shall be able to:

- explain the washing machine
- state the types of washing machines and wash techniques
- state the function of mangle wringer for drying
- explain the function of drain pump and drive motor
- state the points to be noted while placing the washing machine at a suitable place.

Washing machine

It is a domestic electric appliance which is used to soak, rinse, wash, wringle /dry the cloth/fabrics etc.

Types of washing machines: The modern washing machines can be divided roughly into three main groups according to their function.

They are

– Ordinary

– Semi automatic

– Fully automatic.

i Ordinary type

Ordinary without timer: This machine uses the pulsator type technique in which a disc is fitted to the motor.

It has only one tub and one motor the dirty cloth is loaded in the tub, water is filled manually in the tub, detergent is added. The motor is switched on the pulsator disc moves the cloth around the tub and the time duration of washing is decided by the operator.

Ordinary with timer: Similar to the ordinary type, but added with a clock timer to select the time of wash from 1 to 15 minutes.

ii Semi-automatic type

This type has two tubs. One for washing and rinsing, the other for spin drying the cloths. The washing tub operates at lower speed whereas the spin drier tub operates at a higher speed. The machine may contain either one or two motors.

iii Fully automatic type

In this type, the micro processor enables to programme the wash cycle. There will be only one tub. The machine could be programmed for wash cycle, detergent intake and water input. The machine does washing, rinsing and also dry the cloth and stops.

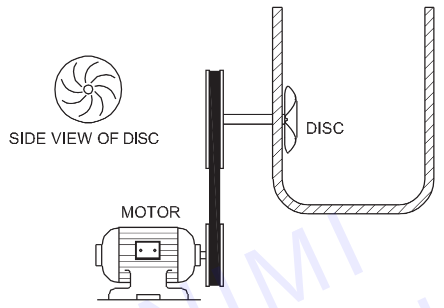
Further to the above types the washing machine could be further divided by the type of loading i.e. top loading and front loading. In some machines the water used for washing could be preheated with the help of an electric heater.

Types of wash techniques

In addition to the above classification, the washing machine could be catagorised according to the wash technique used as explained below.

The pulsator wash technique (Fig 1): This is the most common type pulsator wash technique, it has disc in concave shape used to rotate the clothes in water. Dirt is removed from the cloth by rubbing against tub wall surfaces and the disc. (Fig 1 & 2)

Fig 1



PULSATOR WASH TECHNIQUE

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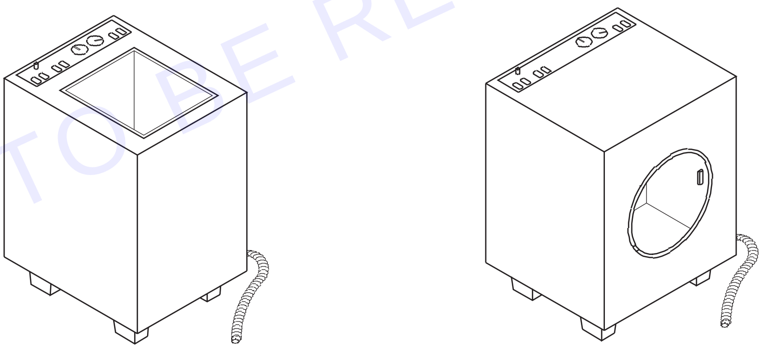
Fig 2



a) TOP LOADING

b) SIDE LOADING

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Tumbler type (Fig 3 a): In the tumbler type the washing is carried out by tumbling the cloths with the help of a simple drum. Here the construction is simple and cloths are tumbled around the drum by virtue of the drum itself being rotated by means of a pulley at the rear or the friction drive of the idlers.

The agitator wash technique (Fig 3b): An agitator which is long and cylindrical is installed at the centre of the washing tub. The water and cloths circulate around the agitator, thereby under going a thorough cleaning process. Not suitable for delicate fabric.

The air power wash technique: This machine uses air bubble technique to wash delicate fabrics smoothly.

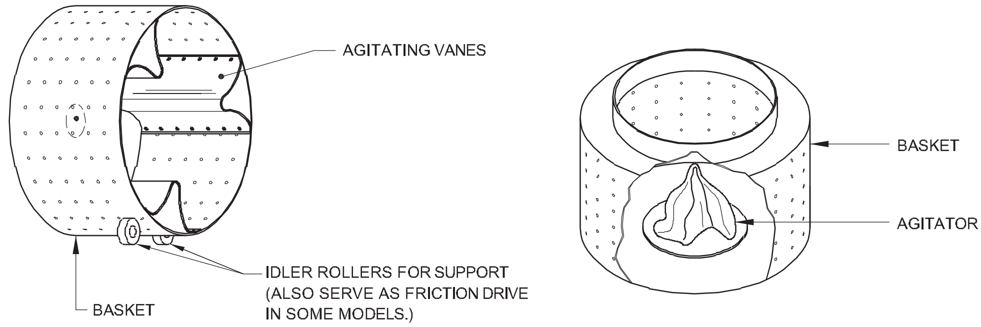
The chaos punch wash technique: A multifaceted method of washing, where in water is propelled upwards in the machine to prevent entanglement of garments punching, is done on clothes by forced water.

The water fall technique: This is more or less similar to chaos punch technique. This machine use jets of water which are pumped from below the pulsator in to the tub. The velocity and force of water removes the dirt. Most of the washing machines could be repaired by the electrician but micro processor controlled washing machine repair needs some more training and experience.

The conventional type with mangle wringer for drying: The conventional washing machines are relatively simple in operation and construction. The washing cycle in such a type of machine would consist of the user filling the central tub with water up to the water level mark. Soap and bleach are added.

Depending upon the types of the clothes to be washed the 'ON' time or the wash time of the machine is set and then 'the machine is switched 'ON'. Most machines have the agitator directly driven without any intermediate gears (Fig 4).

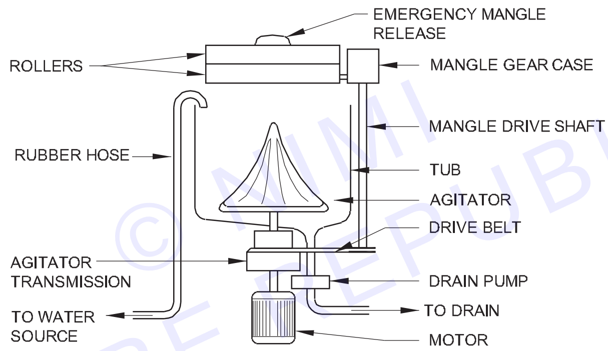
Fig 3



a) TUMBLER WASHING TUB

b) AGITATOR WASHING ARRANGEMENT

Fig 4

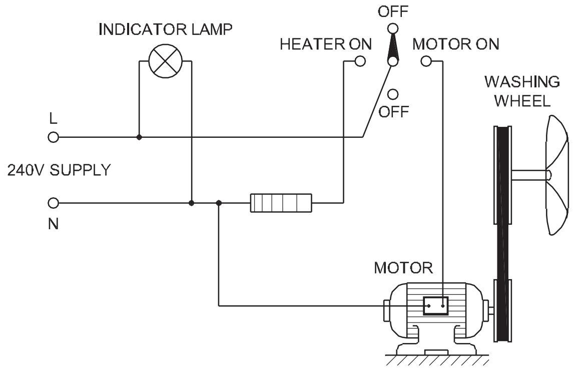


AGITATOR DIRECTLY DRIVEN BY MOTOR

The wash is stopped by the timer setting on the machine. The agitator is brought to a standstill and the drain pump is operated or the valve for gravity draining is activated. For rinsing the clothes the machine is switched 'ON' for a time duration such that all the detergent or soap is removed off the clothes. This cycle is called the rinse cycle. The clothes are then put through the mangle wringer to press and roll out all the water from the clothes.

Some type washing machines having heater, is generally immersion rod type which is permanently fixed in the bottom of the washing machine. The purpose is to produce warm water for loosening stubborn dirt particles of the clothes for quick cleaning. In these types generally heater is not repairable, once found defective it has to be replaced. Fig 5 shows the connection diagram of simple washing machine with heater .

Fig 5



SIMPLE WASHING MACHINE WITH HEATER

Precaution

i **The agitator should be stopped during the drain period, because if it were to continue operating without water in the tub, the required force on the agitator to rotate the clothes in the absence of water would be many times more causing motor to overload.**

ii **The bottom cable should be protected from the damage by the rats by using a rust proof welded mesh.**

The drive motor: The most popular type of motor used in a washing machine is a single phase 240 volts 50 Hz. capacitor start squirrel cage induction motor. These motors may range from 1/3 to 1/2 HP rating. These motors are normally protected from overload and overheating conditions by means of a bimetallic overload relay or a thermal switch. The motor is located in such a way that water leakages do not fall on to these motors.

Locating the machine: The machine should be so located that soft water is freely available, and outlet or water drain arrangement is also easily available. The supply board should have the rated 3 pin socket arrangement with proper earth brought to the 3 pin plug point. The flooring should be in level such that the machine rests properly to avoid unnecessary loading on the machine drum and vibrations.

Induction Heater

Objectives: At the end of this lesson you shall be able to:

- explain induction heater
- explain construction, advantages and disadvantages of induction heater.

An induction heater uses an electromagnetic field to heat food. When the heater is turned on, an electric current passes through a coil of metal, creating a magnetic field. This magnetic field then penetrates the metal of a cooking pan, inducing a current in the pan. The current then dissipates energy in the form of heat, cooking the food in the pan. (Fig 1)

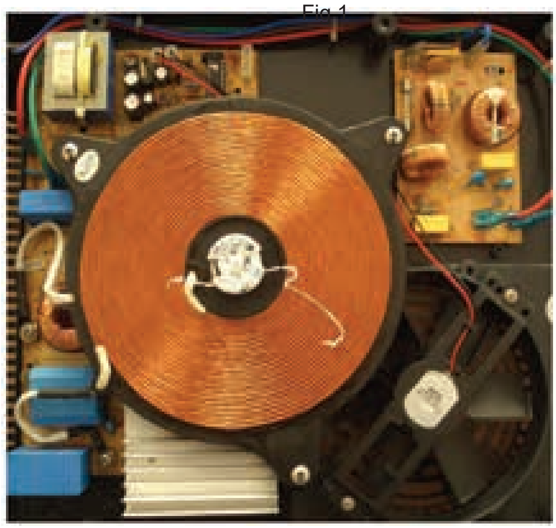
What is induction?

Electromagnetic induction, which is often referred to simply as induction, signifies the production of an electric current across an electric conductor, caused by a changing magnetic field. Electricity and magnetism are not two disjointed things; they are two entities originating from the same underlying phenomenon - electromagnetism.

Due to this, a change in a magnetic field leads to the generation of electric current. Similarly, a change in the electric field across a conductor produces a magnetic field. The latter is the working principle behind induction heater, which is pretty much all you need to know to understand the working of induction cooktops.

Fig 1

Fig 2



Induction heater

Inside view of an induction heater (Fig 2)

An induction heater looks like any other ceramic cooktop, with different zones for placing pans and pots of varying sizes. It consists of a tough, heat-resistant glass-ceramic plate on which the user places pots and pans that need to be heated. Directly underneath the plate there is an electromagnetic coil of metal that is electronically controlled. This is the main component responsible for heating the vessels kept above the heater.

When you switch on the power supply of the heater, an electric current passes through the coil. The electric current passing through the coil produces a magnetic field in all directions around the coil, including directly above it (where pots and pans are placed). (Fig 3) Note that until this point, no heat is generated, as the magnetic field being produced doesn't produce any heat unless a third object - the cooking pan - is introduced into the mix.

When a heater pan (made of a suitable material) is placed on the cooktop, the magnetic field produced by the coil penetrates the metal of the pan too. This fluctuating magnetic field now causes an electric current to flow through the material of the pan too. The current 'induced' on the surface of the pan in this way is called an eddy current, which is different from the electric current flowing through wires. Eddy currents are actually loops of electric current that are induced in a metallic field due to a changing magnetic field nearby.

This induced current travels around the metallic structure of the pan, dissipating some of its energy in the form of heat. This is the heat that raises the temperature of the pan placed on the cooktop and cooks the food inside the pan by heat transfer through conduction and convection.

Advantages and disadvantages of induction heater

1 Induction heaters are very energy-efficient, in that they transfer most of the energy to the cooking pan with minimal loss of energy. (Fig 4)

Fig 3

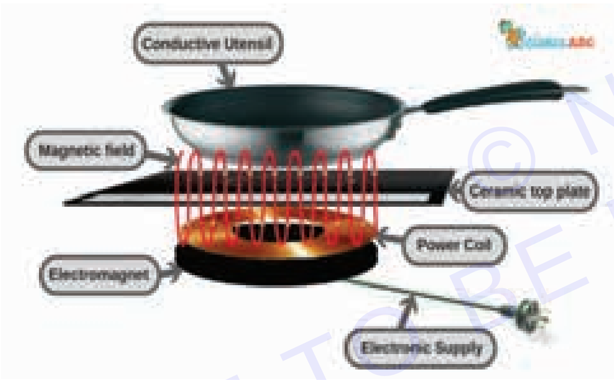


Fig 4

2 Also, induction cooktops heat stuff up very quickly, unlike regular stoves, which lose a great deal of energy to their surroundings.

3 They are also pretty easy to clean and operate and safe to use.

Disadvantages

A major drawback of induction heater is that they only work with pans and pots that are 'compatible' with them. The containers and vessels placed on the cooktop should contain iron in some form (e.g., stainless steel), as it's the only metal that efficiently produces eddy currents and generates heat through magnetic fields. Therefore, glass, aluminium and copper cookware cannot be used on induction heater.

In a nutshell, using an induction heater is a smart thing to do if you care about electrical efficiency, speedy heating, better cooking control and higher levels of safety. As for the suitability of your existing cookware for induction cooktops, just try sticking a magnet to them. If it sticks, then the pan/pot is fit to be used.

Food Mixer

Objectives: At the end of this lesson you shall be able to:

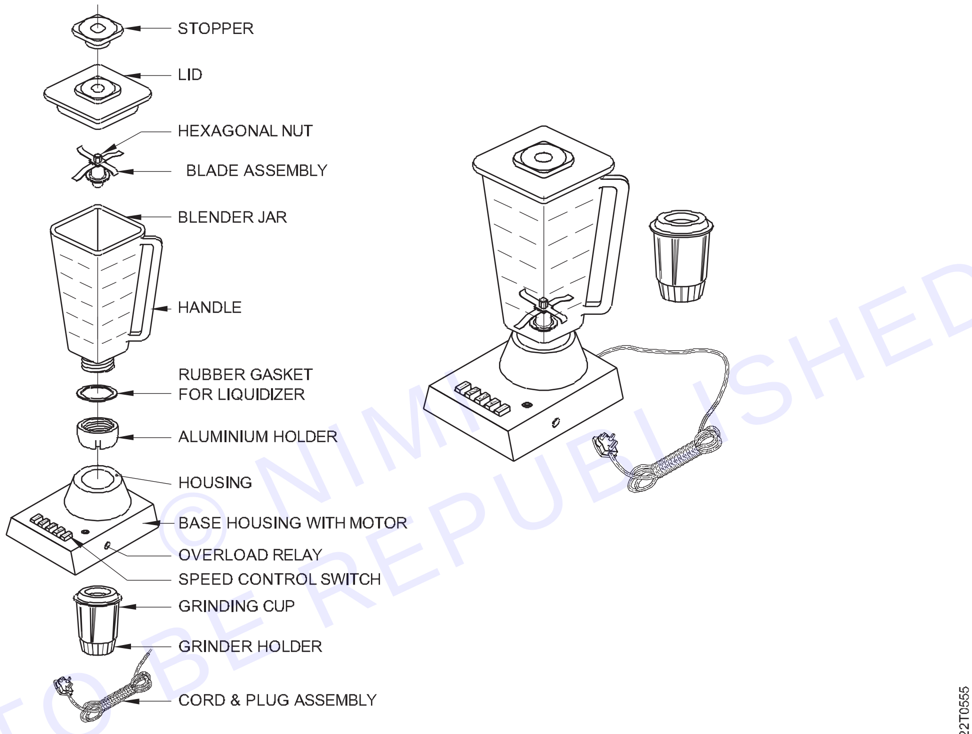
- explain the food mixer and its features
- state the maintenance and service procedures of mixer
- list their common problems, causes and suggest remedial measures.

Food mixer

It is an electric domestic appliance which is used to mix, juice, grind and blend the fruits and food grains.

A medium sized universal motor is used in it. Fig 1 shows an exploded view of a mixer.

Fig 1



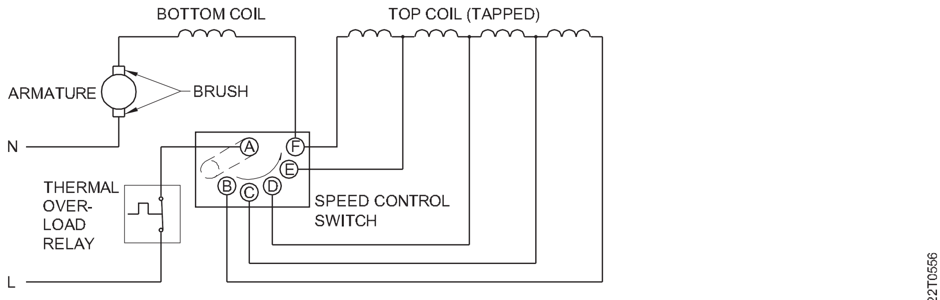
EXPLODED VIEW OF A FOOD MIXER

Features of the food mixer

The motor housing differs widely depending on the manufacturer. Special care to be taken for vibration-free running. Safety features such as overload trip, jar mounting lock (fixing) and proper lid closing are included in the appliances.

An AC universal motor is housed in the base. The jar contains the cutting knives which is the heart of the blending action. Fig 2 shows a schematic diagram of a typical mixer.

Fig 2



SCHEMATIC DIAGRAM OF A TYPICAL PORTABLE 5 SPEED FOOD MIXER

A food mixer power rating ranges from 100 to 750 watts. The revolution of the food mixer is 3000 to 14000 revolutions per min. The desired speed is selected on the control switch.

The time rating of running the mixer varies from 1 minute to 60 minutes depending upon the type. A tapped field coil enables speed selection through a rotary or push button switch.The food mixer normally runs at 3 speeds.

Maintenance and servicing of a food mixer: The manufacturer's service manual, if available, read it a number of times and follow the instruction. First listen to the complaint from the customer and make a note of it. Visually check the mixer right from the plug to the speed selector switch connections and enter the details in the maintenance card.

Test the mixer with and without the power cord for the continuity and insulation resistance. The insulation resistance value for the individual part should not be less than 1 Megohm. the power cord should be 3-core and the plug and socket should be of 3-pin/socket type with effective earth.

But double insulated (PVC body) mixers may have two core cable and 2-pin plug type. A damaged plug or power cord should be replaced. Check the brush tension and make it normal. Check the brush length; if found short by 2/3rd of its original length, replace it with the same specification brush or a brush obtained from the manufacturer of the mixer.

Check the switch for its proper function. Better to replace a faulty one with a new one having the same specification. Before opening the motor assembly, check the couplings for their proper form. Check the ply of the shaft and vertical movement to get an idea of the condition of the bearings.

Tight bearing may be due to misalignment, bend in the shaft, dried grease or lubricant, dirt, damaged commutator or due to damaged bearing.

Check the winding for burnt smell or discoloured look. Ascertain through the tests whether the winding is shorted, open or has lost its insulation resistance value. If required rewind or get the rewinding done from outside agencies.

While tightening the screws on the motor housing, spin the armature with your fingers at intervals during the assembling process to ensure that it is not getting bound.

Fix the jar/container on the drive coupling.

Connect the supply cord as per the circuit diagram.

Test the mixer for continuity and insulation resistance. Minimum acceptable insulation resistance value is 1 Megohm.

Connect the supply, and test for its working.

Repairs

Some of the common troubles encountered in the repair of mixers are given in the Table 1 which also gives the possible causes and their remedies.

Table 1

Trouble Shooting Chart

Problem	Possible cause	Corrective action
Mixer does not run.	a) Overload trip might have tripped.	a) Reset the overload relay and advice th customer not to overload the mixer in future.
	b) No power at the outlet.	b) If the mixer is running in your shop but not running at the customer's house ask the customer to get the socket repaired.
	c) Defective power cord or plug.	c) Test, repair or replace the power cord/plug.
	d) Locked shaft.	d) Unplug the supply and try to rotate the shaft by hand. Clean the bearings; lubricate the bearings as advised by the manufacturer. If the shaft is still tight, recondition or replace the bearings. The shaft might have got bent.
	e) Worn out brushes.	e) Replace the brushes and loose springs
	f) Open circuited.	f) Check the field and armature windings. If found defective get it rewound or replace

Blows fuse when switched on.	a) Shorted power cord. b) Locked shaft c) Defective armature or field coils. d) Poor insulation resistance. e) Low capacity fuse.	a) Replace the cord. b) As in 'd' above. c) Test the windings for short. If short is found, rewind or replace. d) Check, test and repair. e) Check the capacity of the fuse against the mixer rating. Replace if required.
Mixer runs but becomes hot.	a) Overloading of mixer. b) Time rating of mixer is exceeded. c) Bent shaft and rotor is rubbing the stator. d) Improper coupling. e) Shorted winding.	a) Bring down the load in the mixer or advise the customer to go for a higher capacity mixer. b) Check the duration the mixer is switched on by the customer and compare with the mixer c) Check, repair or replace if required. d) Check, repair or replace if required. e) Check, test and rewind if required.
Bad sparking at motor brushes.	a) Struck or worn out or loose brushes. b) Pittings or uneven commutator surface.	a) Check, reshape the brushes, replace the springs or reposition the brushes for proper tension. b) Use sand paper or turn the commutator on a lathe.
Mixer gives shock.	a) Water leaking and coming in contact with live terminals. (Double insulated mixers with plastic body and two pin plug. No earth connection). b) Vent hole in the mixer body c) Damaged power cord. d) Absence of earth connection. e) Live parts coming in contact with metal body.	a) Check the drain hole in the coupler head assembly for blockage. Check the jar examine for leakage due to loose shaft or worn out bearing, ebonite washer breakage. Repair or replace. b) Clean the vent hole. c) Check and replace if required. d) Check the earth connection in the mixer motor, power cord and at socket. Repair and re-do the earth connection if required. e) Check with a Megger and take corrective action if required.

Wet grinder

Objectives: At the end of this lesson you shall be able to:

- explain the wet grinder
- state the different types of wet grinders
- explain the parts of a wet grinder
- explain the possible faults in wet grinders and their remedies.

Wet grinder

It is a domestic electrical appliance, which is used to grind the wet grains.

Types: There are three types of wet grinders

– Conventional (regular) wet grinder.

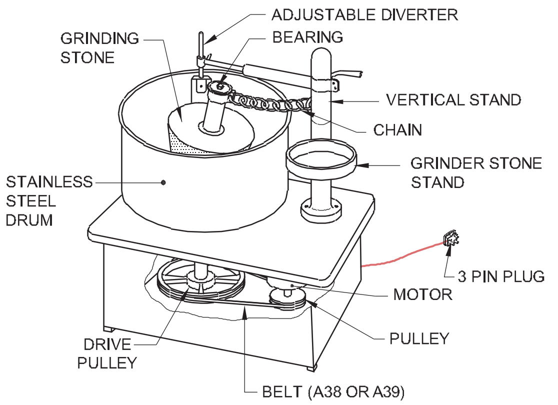
– Table top wet grinder.

– Tilting wet grinder.

Conventional (regular) wet grinder (Fig 1)

The most common wet grinder used in houses is the container rotating type wet grinder.

Fig 1



CONVENTIONAL WET GRINDER

Parts

The important parts of a wet grinder are :

– Motor

– grinding stone

– container

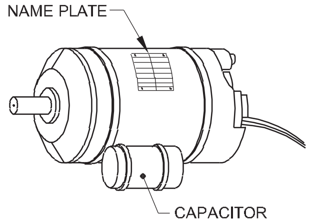
– pulley

– belt

– frame and stand

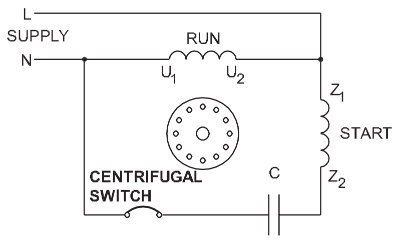
Motor: The motor used in the wet grinders is usually the capacitor start-induction motor (Fig 2 & 3). It has two windings. Both the starting and running windings are energised to start the motor, when the 70 to 80 % of the rated speed is reached, the starting winding is switched off by the centrifugal switching system. The motor then operates only on running winding.

Fig 2



GRINDER MOTOR

Fig 3

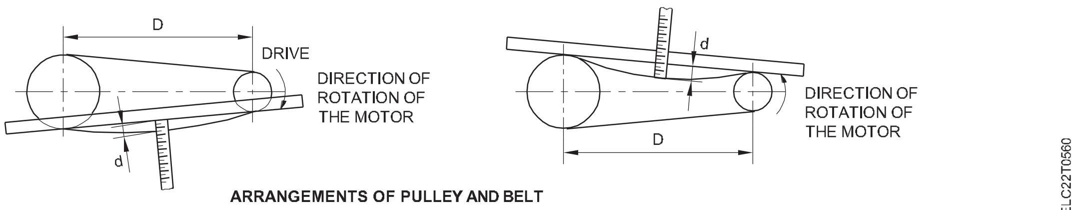


CIRCUIT DIAGRAM

Stone: The grinder stone consists of two parts of stones. One male and one female. The male part grinds the grains during rotation against conical cavity in the base (female stone). This female part is actually attached to the stainless steel container which rotates when the motor is energised. Both the stones are manufactured with hard granite which is usually whitish black in colour.

Pulley: The drum speed is lower than the motor speed, normally 500 to 600 r.p.m. The motor speed is normally 1450 r.p.m. and the speed of the drum is reduced by using a larger diameter pulley than the driven pulley, usually in the ratio of 1:3. The transmission of force between the driver pulley and the driven pulley is through a V belt of type No A 36 or A 39 (Fig 4).

Fig 4



ARRANGEMENTS OF PULLEY AND BELT

Frame and stand: The grinding stones, motor pulleys are all housed in a rectangular frame with sunmica or stainless steel covering or plastic moulding for decoration as well as safety. A separate vertical stand is provided on one side of the grinder for holding the male grinding stone. If the MS frame is used, it is usually to be chromium plated.

Wet grinder- maintenance and servicing: In wet grinders, the trouble may be classified into two types. Electrical faults and Mechanical faults. Some mechanical faults create electrical faults too.

Some common problems and their rectifications are given in the Table 1.

Safety measures

- Make sure power is turned off before working on electrical equipment.
- Plug to be removed from the socket.

Maintenance practices: An electrical machine or appliance to be maintained according to the programme already made. Certain maintenance practices to be observed are,

– Daily maintenance

– Monthly maintenance

– Yearly maintenance

Table 1

Sl.No.	Complaints	Causes	Test and remedy
1	Motor does not start	Short-circuited windings. Grounded winding. Grounded winding. Broken wire from line cord to windings. Defective capacitor. Blown fuse. Excessive load. Defective centrifugal switch.	Rewind the windings. Rectify or rewind the windings. Solder the joints; if not possible rewind the windings. Solder the broken wire in the line cord or change the line cord. Replace the correct capacitor. Find the cause and replace the fuse. Reduce the load. Rectify or replace the defective switch. Rectify or replace the centrifugal switch.
2	Motor starts but heats up rapidly	Centrifugal switch not opening. Short-circuited winding. Grounded winding.	Rectify or replace the centrifugal switch. Rewind the windings. Rectify or rewind the windings.

3	Motor runs too hot	Short circuited windings. Grounded winding. Bearing too tight. Short capacitor. Worn out bearings.	Rewind the windings. Rectify or rewind the windings. Clean and relubricate the bearing. Replace the capacitor. Replace the capacitor.
4	Motor runs slow	Insufficient lubrication or foul lubrication that tends to bind the motor shaft.	Clean and re-lubricate the bearing.
5	Motor runs intermittently	Intermittently open line cord.	Repair or replace the line cord.
6	Repair or replace the line cord.	Worn out bearings. Excessive end play. Bent shaft. Unbalanced rotor. Burrs on shaft. Loose parts. Worn out belts. Misalignment. Worn out centrifugal switch. Rotor rubs stator.	Clean and lubricate or replace the bearings. If necessary, add additional end play washers. Straighten or replace the shaft. Balance rotor. Remove burrs. Tighten the parts. Replace the belts . Align pulleys correctly. Replace centrifugal switch. Find the cause and rectify.
7	The user gets a shock	The user gets a shock and body of the motor. Broken ground strap. Broken ground strap.	Rectify isolation between body and the live parts of the motor. Replace ground strap. Inspect and repair ground connection.
8	Motor fuse blows	Grounded or short-circuited windings. Low capacity of fuses Grounded near the switch end of the winding	Rectify or rewind the windings. Replace with proper capacity of fuses. Repair or rewind the winding.
9	Smoke from motor (motor burnt out)	Overload. Shorter windings. Faulty centrifugal switch. Frozen bearing. Short capacitor	Reduce the load. Rewind the windings. Repair or replace the centrifugal switch. Clean and lubricate or replace the bearing. Replace the capacitor.
10	Rotor rubs stator	Dirt in motor. Burrs on rotor or stator. Worn out bearings. Worn out bearings.	Clean the motor. Remove burrs. Replace the bearing. Straighten or replace the shaft.
11	Excessive bearing wear	Belt too tight tension Dirty bearings Insufficient lubrication Thrust over load Bent shaft	Correct the mechanical condition. Clean and lubricate or replace the bearing Lubricate with appropriate lubricant. Reduce thrust load Straighten or replace the shaft.

12	Motor does not start but will run in either direction when started manually	Defective capacitor. Contacts of centrifugal switch not closed. Starting winding open.	Replace the capacitor. Clean the contacts of the centrifugal switch and check for operation. Replace, if found defective. check for operation. Replace, if found defective.
13	Motor slows down and Motor slows down and power under working condition.	Short circuited windings. Open circuited windings. Shaft bent.	Rewind the windings. Solder the joints; if not possible, rewind the windings. Straighten or replace the shaft.
14	Reduction in power of the motor. Gets too hot	Short-circuited or grounded windings. Sticky or tight bearings Interference between stator and rotor.	Rectify or rewind the windings. Clean and re-lubricate the bearings. Install new bearings.
15	Radio interference	Faulty ground Loose connections Defective suppression	Rectify poor ground connections. Tighten loose connections. Check filter, capacitors, chokes, if possible or replace the complete filter unit.

Daily maintenance: The parts are to be cleaned with cloth and the stone bearing is to be oiled. Inspect the belt tension and vibration.

Monthly maintenance: Oil and grease the main shaft of the grinder. Insulation test is to be carried out and recorded in the sheet provided.

Yearly maintenance: The electrical machine must be removed and overhauled. Insulate the winding by applying varnish. Check all the mechanical parts and rectify the defects, if any.

Pump set

Objectives: At the end of this lesson you shall be able to:

- explain pump set
- explain the method of selection of the type of pump and capacity of the motor taking various factor into consideration
- explain the types of pumps and use the table for selecting a proper type and capacity for requirement
- state how to select a proper location of pump installation and select proper control devices
- state troubleshoot in pumps.

Pump set

Pump set is a combination of an electric motor and a impeller/pump coupled together to pump the water from well (or) bore (or) sump etc.,

Selection of pump : The following points are to be considered before selecting a pump for lifting the water.

- The quantity of water to be lifted
- Height of water to be delivered
- The time for lifting.

Based on the above considerations the pump has to be selected along with the motor to lift the water from a well/ sump.

An illustration is given below to show how to calculate the required HP of the motor to a particular height and quantity of water to be lifted within a specified time.

Example: Calculation of HP for domestic pump set.

A pump driven by a single phase AC motor of 240V, 50 Hz has to deliver 1000 litre to a height of 30 metre within 15 minutes. Find the HP of the motor if the efficiency of the motor is 80%.

Given

Working voltage - 240V, 50 Hz

Quanity of water to be delivered - 1000 litre

Height of the water delivered - 30 m

Efficiency of motor - 80%

Time of delivery - 15 minute

Solution

Work done by the pump / minute =

$$\frac{\text{weight of the water x Height}}{\text{Time}} = \frac{1000 \times 30}{15} \text{ kgm/min.}$$

since 1 litre of water = 1 kg. of water

and 4500 kgm/minute = 1HP

$$\text{Pump output in HP} = \frac{1000 \times 30}{15 \times 4500} = 0.44 \text{ or } 0.5 \text{ HP}$$

$$\text{Input of the pump} = \frac{0.5 \times 100}{80} = 0.625 \text{ HP}$$

Next nearest HP of the motor recommended is 0.75 HP.

Pumps : Pumps can be classified mainly into two categories. They are

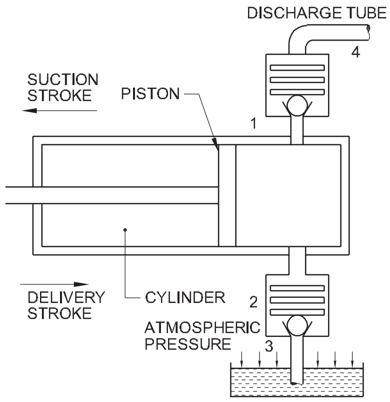
– Reciprocating pumps

– Rotary pumps.

Reciprocating pumps : In this type of pump, the main moving part has reciprocating motion only and hence the name. Fig 1 shows the main parts of a reciprocating pump.

When the piston moves towards left, a partial vacuum is created inside the cylinder. The check valve 1 in Fig 1 closes due to the suction effect of the vacuum, spring action and head of water in the discharge tube 4 but valve 2 Fig 1 opens and allows the water to fill the cylinder through the suction pipe 3 due to atmospheric pressure outside. This stroke of the piston is called suction stroke.

Fig 1



RECIPROCATING PUMP

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On the other hand when the piston moves towards right ie discharge or delivery stroke the liquid inside the cylinder is pushed out through check valve 1 and delivery pipe 4. During the delivery stroke valve 2 remains closed by the action of spring and the water pressure inside the cylinder.

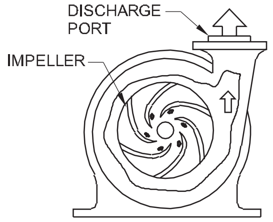
However, as the discharge of water takes place in this type of pump only during the discharge stroke, the pump creates a pulsating flow of water and not a continuous flow. This type of pump is called a piston pump.

Rotary pumps : There are very many varieties of this pump in the market. However centrifugal pumps, jet pumps and submersible pumps are the commonly used pumps for lifting water in houses.

Centrifugal pumps : Fig 2 shows the construction and operation of a centrifugal pump.

The operation of a centrifugal pump is based on centrifugal force. As the fluid being pumped enters the inlet or central section of the pump, the rotating action of the impeller vanes forces it to the outside of the pump casing (Fig 2).

Fig 2



FLUID FLOW IN A CENTRIFUGAL PUMP

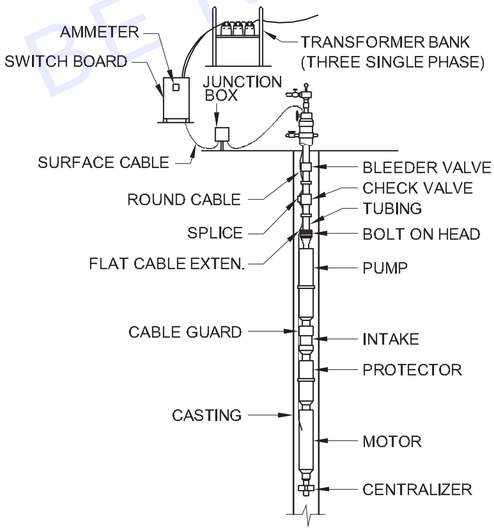
Because the fluid moves faster at the outer edge of the impeller the momentum increases. As more fluid enters the pump, more fluid momentum is built up in the casing that encloses the impeller. This momentum forces the fluid out of the pump discharge port.

The centrifugal pumps are used where large volumes of water are to be pumped at relatively low pressure.

Submersible pumps : This pump also comes under the category of centrifugal pumps and is found in use at places where water is found in great depth.

Submersible pumps have motor and pump in an axial length are submerged in water (Fig 3). Generally such pumps are used for borewells where the volume of water to be lifted exceeds the capacity of reciprocating pumps. The motor used in such types of pumps is of 3-phase.

Fig 3



ELECTRIC SUBMERSIBLE CENTRIFUGAL PUMP SYSTEM

The cables and motor windings have water proof sealing as they are immersed in water. Such pump sets will have following advantages.

– Diameter is smaller.

– Motor and pump are submerged in water. Hence needs no space on ground level.

– The motor and pump are entirely connected through metal pipes for delivering water.

– Efficiency is more as the motor with the pump will be to the level of water or inside the water.

– Cooling is effectively done by water only.

– Can be used for lifting water from any depth of sump or borewell as suction pipe is not used.

Disadvantages

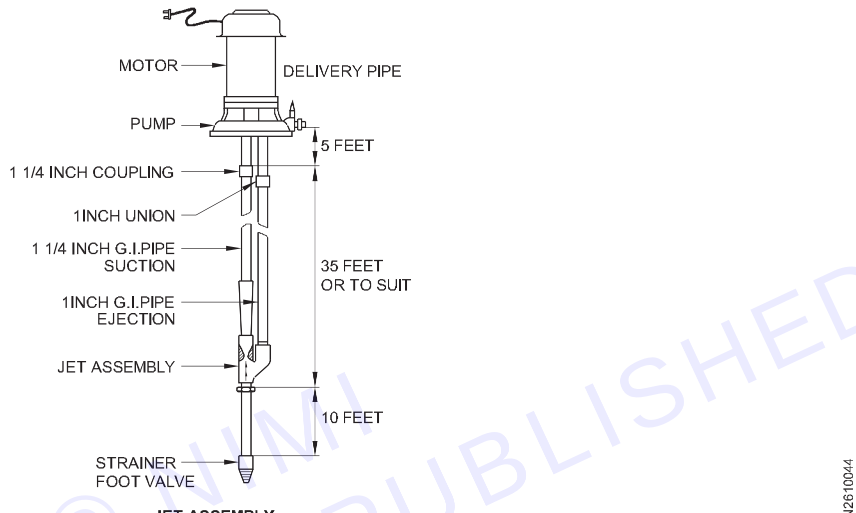
– Erection cost and initial cost of purchasing will be high.

– In case of any defects, it is necessary to remove entire unit along with the pipe line.

– Requires skilled worker for both erection and maintenance work.

Jet pumps : Another variety of centrifugal pump commonly used in the domestic wells an d borewells is the jet pump. In jet pumps, the motor and pump are assembled together in one block (Fig 4).

Fig 4



JET ASSEMBLY

The bottom portion of the pump has two connecting pipes. One is called suction pipe and the other is called ejection pipe. A portion of the water is sent through the ejection pipe to the jet assembly and it aids the water in the suction pipe to be lifted upwards by Venturi principle.

Suction, ejection and delivery pipes and motor capacity could be selected with the help of the performance

Table 1.

Almost all types of pumps may be independent units to be coupled with an electric motor through belts or couplings or may be single(mono) blocks comprising both motor and pumps.

Location of pump set : The pump should be installed as near as possible to the water source in order to reduce the suction lift and to achieve better performance.

Ample space should be provided around the pump for easy inspection and maintenance whenever required.

Before starting the pump ensure that.

– Shaft rotates freely by hand.

– The gland box is properly tightened.

– The valve, if there is any on the delivery branch, is opened.

Check the following during running condition.

– The direction of rotation is correct.

– Pump is running smoothly.

– Leakage of stuffing box is normal ie., 50 to 60 drops per minute in gland packed pump.

– The ball bearings do not get excessively hot.

Trouble shooting in pumps : In case of trouble in pumps, with the help of the trouble shooting chart (Table 2), locate the fault and rectify the defects.

Table 1

Troubleshooting chart

Sl.No.	Problems	Probable reason
1	Pump does not deliver water.	Pump casing and suction pipe is not primed.
2	Delivered water is not enough.	Delivery head is too high. Suction lift is too high.
3	Not enough pressure.	Impeller/suction pipe choked. Wrong direction of rotation. Leakage in suction pipe. Gland packings/mechanical seal worn out. Foot valve choked/not immersed in water. Impeller damaged. Wearing of shaft sleeve.
4	Pump takes too much power	Damaged ball bearing. Head is much lower. Mechanical friction is more in the rotating part. Shaft bent. Stuffing box is too tight (gland is too tight).
5	Pump leaks excessively.	Gland packings/mechanical seal worn out. Shaft sleeve worn out. Gland packings/mechanical seal are not in proper position.
6	Pump is noisy.	Hydraulic cavitation. Foundation is not rigid. Shaft bent. Rotating parts are loose or broken. Bearing worn out.

MODULE 17 : Estimation and Costing

LESSON 104&105 : Concept - Principle of plan estimation cost preparation

Objectives

At the end of this lesson you shall be able to:

- state the concept and principle of plan estimation
- calculate estimate and cost preparation of wiring layout
- describe safety regulation - 2010 multi storey building.

Principles of estimating and schedule of rates

Estimate: The method of calculating the cost of material and labour is called estimate.

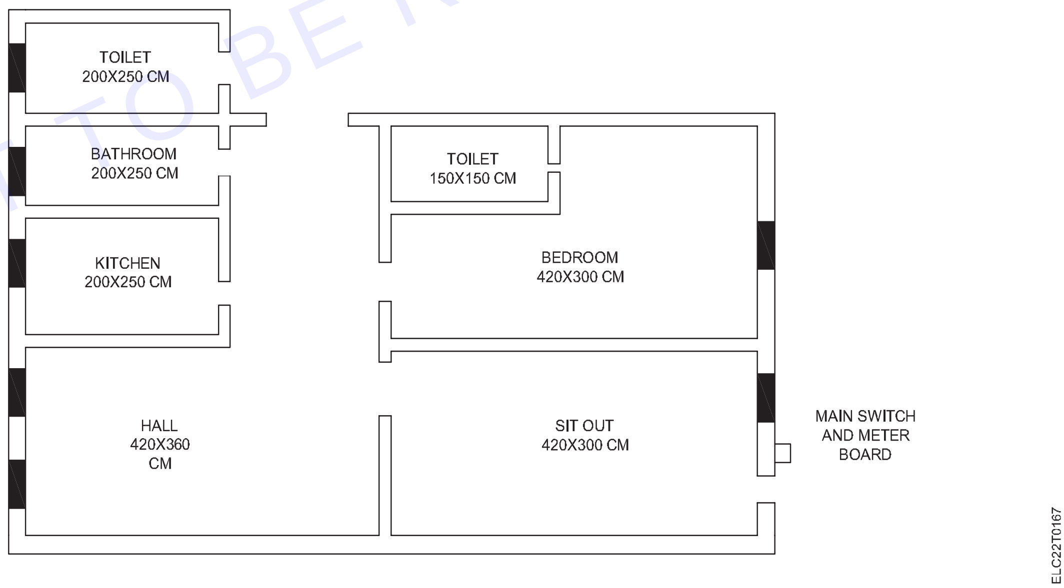
The idea of an estimate is to have the cost of work for arranging the funds and explore the market for the availability of materials.

The estimate should have additional funds or any contingencies required during the construction and generally an additional amount equivalent to 5% of the total cost is added to the estimate as contingencies.

For preparing an estimate, the following are necessary (Fig 1)

Drawing: The necessary drawings of the building with dimension are required for the execution of work and also for estimation. For electrical installation, the layout of the wiring should be shown on a separate drawing along with the positions of the points etc.

Fig 1



Specification of materials: Specification gives the details of materials, brand name, grade, quality, rating of voltage, current, quality of certification like ISO or BIS etc. It helps both the wireman and the consumer to select the material according to commercial practice, cost and requirements.

Schedule of rates and records

Specifications, rates and records are need for preparing and checking the estimates. They are also useful for materials procurement.

Schedule of rates (Electrical)

Sl No	Item specification	Unit	Rate
1	Ceiling rose- 2plate, 6A, 250V	Each	7.00
2	Ceiling rose- 3plate, 6A, 250V	Each	10.00
3	Tumbler switch- one way, surface type- 6A 250V	Each	8.00
4	Tumbler switch-two way, surface type- 6A 250V	Each	12.00

Select suitable wiring system

The next work in estimation is to select the suitable wiring system, from the list given below, depending upon the place of use, consumer's interest and local electricity board regulation.

1 Batten wiring

2 PVC casing and caping(Office and computer circuit)

3 PVC conduit wiring(surface or concealed)

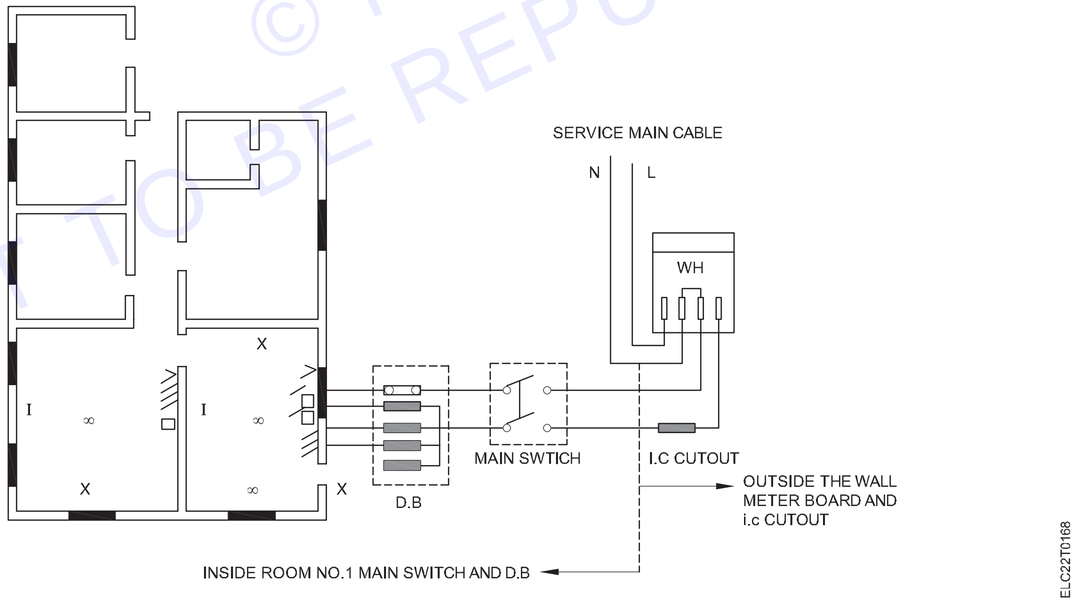
4 Metal conduit wiring(surface or concealed)

Concealed wiring has to be started well before the roof is caste. Hence, electrician should have discussion with civil engineer.

After deciding the type of wiring system, the electrician has to prepare the following depending upon the consumer's interest, durability of wiring accessories, cost, available work force.

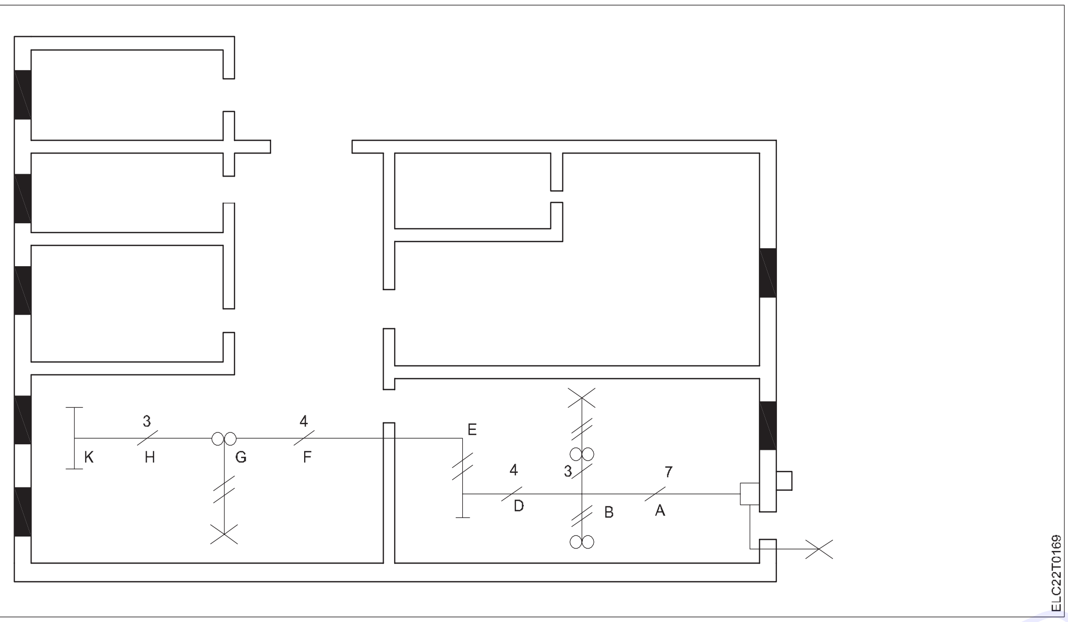
Step 1: Position of electrical points in each area of the house based on the consumer's requirement. (Fig 2)

Fig 2



Step 2: Prepare a layout of wiring on the building plan. (Fig 3)

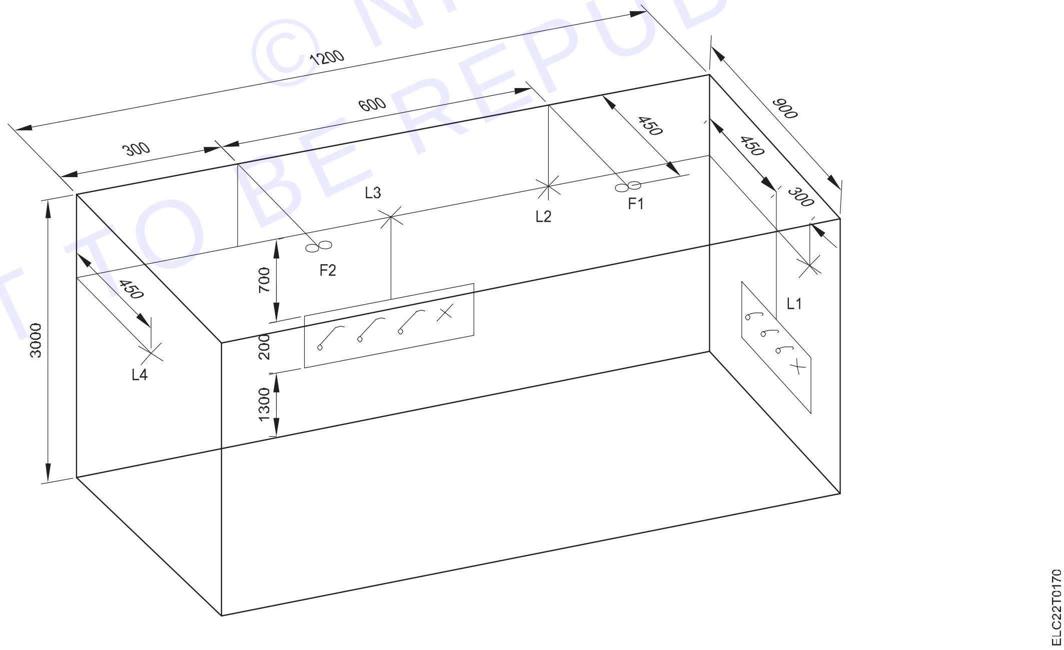
Fig 3



Step 3: Calculate the total connected load and to decide whether it is 3phase or single phase.

Step 4: Prepare a circuit diagram showing the connections and number of lighting and power circuit(cubical wiring model). (Fig 4)

Fig 4



Step 5: Prepare a list of electrical accessories to be procured.

Step 6: Calculate the length of different sizes of cable required, based on the load, voltage drop and number of cables in each circuit run.

Step 7: Calculate the length of different sizes of batten / PVC casing and capping / Metal conduit required based on the load, voltage drop and number of cables in each circuit run.

Step 8: Prepare a list of hardware like a screw, nails etc. required to execute the job.

Step 9: Calculate the labour charges for entire wiring.

Step 10: Calculate the cost of accessories, base materials(PVC, Batten, cables, hardware etc.) and labour charges

Step 11: Calculate the total cost of wiring, including 5% contingencies charge.

Before the selection of size of cable and their length, calculate the total load of the house and also to decide whether 3phase or 1phase.

Total connected load = whole of the load in a building.

Assuming total connected load is 2400W.

Current = 2400 / 240 = 10A.

Assumption of power factor is unity and single phase load.

Hence, copper cable 3/0.036 could be selected for main board.

Length of cable = main cable from meter board to the DB

= 2X 1.5 = 3m of size 3/ 0.36 copper cable

(1.5m is taken as rough value)

ROOM NO 1

A One tube light point

B One light point CIRCUIT 1

C Two fan points

D One 6A 3-pin socket

ROOM NO 2

A One tube light point

B One light point CIRCUIT 2

C One fan point

D Two 6A 3-pin socket

Circuit 1

Sl No	Description	Quantity	Wattage rating	Total wattage
1	Tube light(1200mm)	1	50	50
2	Light point	2	60	120
3	Fan points	2	60	120
4	6A, 3pin socket	1	100	100
				390W

Circuit 2

Sl No	Description	Quantity	Wattage rating	Total wattage
1	Tube light(1200mm)	1	50	50
2	Light point	1	60	60
3	Fan point	1	60	60
4	6A, 3pin socket	2	100	200
				370W

Total wattage = 390 + 370 =760W

As this is well within 800w rating of a branch circuit we can wire up the hall and sit out in one branch circuit. draw the position of the switches, sockets, lamps and fans in the house plan.

The total load is of lighting, fan and three pin sockets amounting to 760w which is less than 5A as such cables selected is 1mm2 copper cables, or aluminum cable of 1.5 mm2

Horizontal run j -150cm-1.5m

Total of two to five 25m

1 mm2cable required

Conduit run J= (2.5+0.9+0.8) x 2= 8.4m

Conduit run A = (1.5+0.9+0.8) X 7 =22.4m

---do-------- B= 1.1x 2 = 2.2m

---do-------- C= (1.05 x4+1.85X2) = 7.9m

---do-------- D=(1.5+0.8+0.9) X3 =9.6m

---do-------- F =(1.8+0.9+0.8) x 5=17.5m

---do-------- G =2.2---do-------- x2= 4.4m

---do-------- H= (2.2+0.8) x2 =6m

---do-------- K = (0.9+0.2) x 2=2.2m

Total = 80.6m, say 90m of cable required.

Copper wire 14swg for earthing router K, H, F, E, D and A =16.9m say 20m or 600g

Labour charge

Electrician =Rs150, two days = Rs 300/

Helper = Rs 90 two days = Rs180/

Three phase wiring installations

Separate and distinct circuit for lighting, fan, heating and power wiring

All the wiring conductors shall be run at a height of 2.5m along the wall or on ceiling.

Proper distribution of load should be done at the main db. and Brach db.

The load should have arranged as balanced on all the phases in case of three phase four wire system DB should be located at a convenient point (at the load center)The third pin of all the wall socket must be earthed with min size of earth conductor of GI ,14swg or 1.4 mm2aluminumAll the metal boards must be double earthed for medium and high voltage installation. The phase neutral and earth wire shall be distinctly marked.

General instruction about power installations:

1

2 For power circuit, 3000Watts and above.

3 Induction motors of 3HP and above should be of 3phase type.

4 Motors of up to 5HP can be controlled by DOL starters.

5 Induction motors above 5HP are to be started using starters in order to reduce starting current.

6 For internal wiring, VIR / PVC cables of suitable size is to be used in conduit pipes.

7 In factories, power distribution is effected from a suitable location, known as distribution centre, through a switch board.

8 All power equipments should have Iron clad switches and conduit pipes.

9 The length of flexible conduit should not exceed 1.25m.

10 The minimum cross sectional area of a conductor used in power wiring should not be less than 1.25mm2in the case of copper and 1.5mm2 in the case of Aluminium conductor.

11 Earth wire should be of copper or galvanized iron. The cross sectional area of copper earth wire should be greater than half of that of the largest rated current carrying conductor.

12 The fuse should be capable of carrying the starting current of the motor(normally two times).

13 Every main switch board should comply with the following provisions,

a A clear space of not less than 1mtr. In width should be provided in front of the switch board.

b If there are any attachments or bare connections at the back of a switch board, the space behind it should be either less than 22.5cm or more than 75cm in width, measured from the farthest protecting part of any attachment or conductor.

c If the space behind the switch board exceeds 75cm in width, there should be a passage way from either end of the switch board, clear to a height of 2mtr.

13 In the manufacturing industry, the maximum load connected to a 3phase, low tension supply of 415V to 100kVA.

14 If the load exceeds 100kVA and is below 1000kVA, a 11kV supply to be given to the consumer.

15 To get an EHT supply, the connected load should be more than 3000kVA.

16 Motors up to 150hp of low tension supply, 3ph.

17 Motor capacity above 150HV, HT supply 3.3kV, 6.6kV or 11kV rating.

MODULE 18 : Generation, Transmission and Distribution

LESSON 106-116 : Source of energy - thermal power generation, hydro and nuclear power station

Objectives

At the end of this lesson you shall be able to:

- explain conventional and energy source and state the various source of energy
- explain the working of hydroelectric power station
- explain the working of steam power station
- explain the working of nuclear power station
- explain the working of diesel power station.

Generation of electrical energy

Demand of an electrical system

The total power drawn by the customer of a large utility system fluctuates between wide limits depending on the seasons and time of the day. If we plot the duration of each demand on an annual base, we obtain the load duration curve. The demand of power give rise to three types of generating stations.

1 **Base power stations:** Base power stations deliver full power at all times: Nuclear stations and coal fired stations are particularly well adapted to furnish base demand.

2 **Intermediate power stations:** Intermediate power stations that can respond relatively quickly to changes in demand, usually adding or removing one or more generating units. Hydro power stations are well adapted for this purpose.

3 **Peak generating stations:** Peak generating stations that deliver power for brief intervals during the day. Such stations must be put into service very quickly.

Consequently, they are equipped with prime movers such as diesel engines, gas turbines, compressed air motors that can be started up in a few minutes. In this regard it is worth mentioning that thermal generating stations using gas or coal take from 4 to 8 hours to start up, while nuclear stations may take several days. Obviously such generating stations cannot be used to supply short term peak power.

Depending upon the form of energy converted into electrical energy, the generating stations are classified as under

1 Steam power stations

2 Hydroelectric power stations

3 Diesel power stations

4 Nuclear power station

Steam power station: A generating station which converts heat energy of coal combustion into electrical energy is known as a steam power station. A steam power station basically works on the Rankine cycle. Steam is produced in the boiler by utilizing the heat of coal combustion. The steam is then expanded in the prime mover (i.e., steam turbine) and is condensed in a condenser to be fed into the boiler again. The steam turbine drives the alternator which converts mechanical energy of the turbine into electrical energy. This type of power station is suitable where coal and water are available in abundance and a large amount of electric power is to be generated. (Fig 1)

Advantages

1 The fuel used is quite cheap.

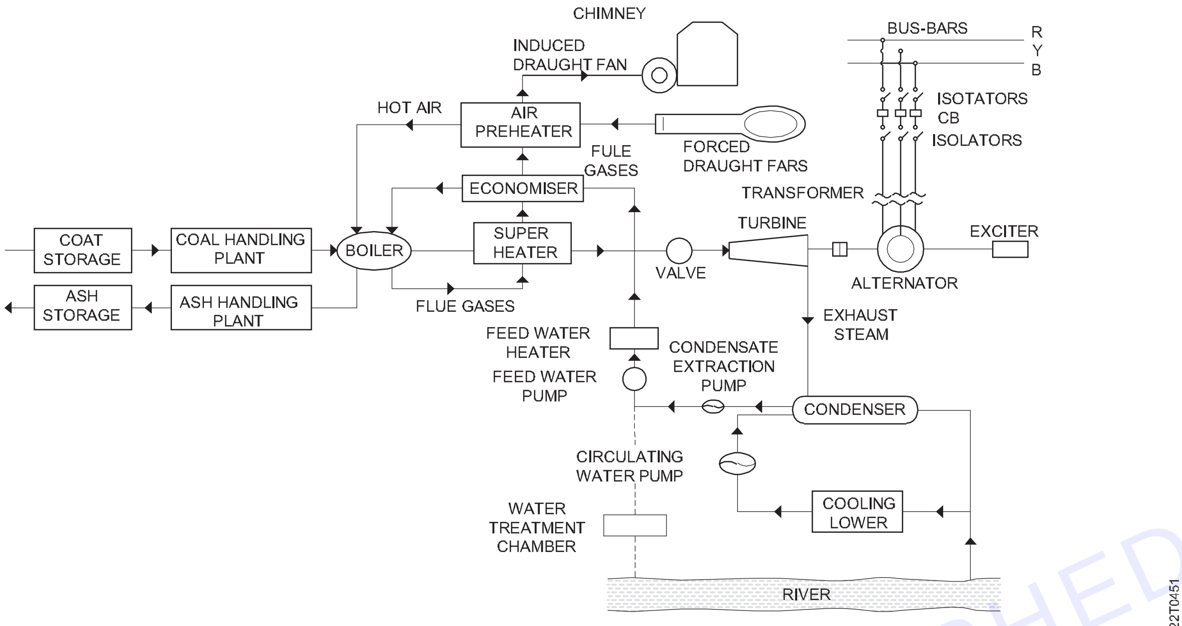
2 Less initial cost as compared to other generating stations.

3 It can be installed at any place irrespective of the existence of coal. The coal can be transported to the site of the plant by rail or road.

4 It requires less space as compared to the hydroelectric power station.

5 The cost of generation is lesser than that of the diesel power station.

Fig 1



SCHEMATIC ARRANGEMENT OF STEAM POWER STATION

Disadvantages

1 It pollutes the atmosphere due to the production of large amount of smoke and fumes.

2 It is costlier in running cost as compared to hydroelectric plant.

Thermal power plant

The schematic arrangement of a modern steam power station is shown in Figure. The whole arrangement can be divided into the following stages for the sake of simplicity

1 Coal and ash handling arrangement

2 Steam generating plant

3 Steam turbine

4 Alternator

5 Feed water

6 Cooling arrangement

1 Coal and ash handling arrangement

The coal is transported to the power station by road or rail and is stored in the coal storage plant. From the coal storage plant, coal is delivered to the coal handling plant where it is pulverized (i.e., crushed into small pieces) in order to increase its surface exposure, thus promoting rapid combustion without using large quantity of excess air. The pulverised coal is fed to the boiler by belt conveyors. The coal is burnt in the boiler and the ash produced after the complete combustion of coal is removed to the ash handling plant and then delivered to the ash storage plant for disposal. The removal of the ash from the boiler furnace is necessary for proper burning of coal.

2 Steam generating plant

The steam generating plant consists of a boiler for the production of steam and other auxiliary equipment for the utilisation of flue gases.

i **Boiler:** The heat of combustion of coal in the boiler is utilised to convert water into steam at high temperature and pressure. The flue gases from the boiler make their journey through super heater, economiser, air pre-heater and are finally exhausted to atmosphere through the chimney.

ii **Super heater:** The steam produced in the boiler is wet and is passed through a super heater where it is dried and super heated by the flue gases on their way to chimney. Superheating provides two principal benefits. Firstly, the overall efficiency is increased. Secondly, too much condensation in the last stages of turbine (which would cause blade corrosion) is avoided. The super heated steam from the super heater is fed to steam turbine through the main valve.

iii **Economiser:** An economiser is essentially a feed water heater and derives heat from the flue gases for this purpose. The feed water is fed to the economiser before supplying to the boiler. The economiser extracts a part of heat of flue gases to increase the feed water temperature.

iv **Air preheater:** An air preheater increases the temperature of the air supplied for coal burning by deriving heat from flue gases. Air is drawn from the atmosphere by a forced draught fan and is passed through air preheater before supplying to the boiler furnace. The air preheater extracts heat from flue gases and increases the temperature of air used for coal combustion.

3 Steam turbine

The dry and super heated steam from the super heater is fed to the steam turbine through main valve. The heat energy of steam when passing over the blades of turbine is converted into mechanical energy. After giving heat energy to the turbine, the steam is exhausted to the condenser which condenses the exhausted steam by means of cold water circulation.

4 Alternator

The steam turbine is coupled to an alternator. The alternator converts mechanical energy of turbine into electrical energy. The electrical output from the alternator is delivered to the bus bars through transformer, circuit breakers and isolators.

5 Feed water

The condensate from the condenser is used as feed water to the boiler. Some water may be lost in the cycle which is suitably made up from external source. The feed water on its way to the boiler is heated by water heaters and economiser. This helps in raising the overall efficiency of the plant.

6 Cooling arrangement

In order to improve the efficiency of the plant, the steam exhaust from the turbine is condensed by means of a condenser. Water is drawn from a natural source of supply such as a river, canal or lake and is circulated through the condenser. The circulating water takes up the heat of the exhausted steam and itself becomes hot. This hot water coming out from the condenser is discharged at a suitable location down the river. In case the availability of water from the source of supply is not assured throughout the year, cooling towers are used. During the scarcity of water in the river, hot water from the condenser is passed on to the cooling towers where it is cooled. The cold water from the cooling tower is reused in the condenser.

A modern steam power station is highly complex and has numerous equipment and auxiliaries. However, the most important constituents of a steam power station are

1 Steam generating equipment

2 Condenser

3 Prime mover

4 Water treatment plant

5 Electrical equipment

Steam generating equipment - This is an important part of steam power station. It is concerned with the generation of superheated steam and includes such items as boiler, boiler furnace, super heater, economiser, air pre-heater and other heat reclaiming devices

Boiler - A boiler is closed vessel in which water is converted into steam by utilising the heat of coal combustion. Steam boilers are broadly classified into the following two types:

a Water tube boilers

b Fire tube boilers

Water treatment plant - Boilers require clean and soft water for longer life and better efficiency. However, the source of boiler feed water is generally a river or lake which may contain suspended and dissolved impurities, dissolved gases etc. Therefore, it is very important that water is first purified and softened by chemical treatment and then delivered to the boiler. The water from the source of supply is stored in storage tanks. The suspended impurities are removed through sedimentation, coagulation and filtration. Dissolved gases are removed by aeration and degasification. The water is then 'softened' by removing temporary and permanent hardness through different chemical processes. The pure and soft water thus available is fed to the boiler for steam generation.

Electrical equipment - A modern power station contains numerous electrical equipment. However, the most important items are:

i **Alternators:** Each alternator is coupled to a steam turbine and converts mechanical energy of the turbine into electrical energy. The alternator may be hydrogen or air cooled. The necessary excitation is provided by means of main and pilot exciters directly coupled to the alternator shaft.

ii **Transformers:** A generating station has different types of transformers, viz.,

a main step-up transformers which step-up the generation voltage for transmission of power.

b station transformers which are used for general service (e.g., lighting) in the power station.

c auxiliary transformers which supply to individual unit-auxiliaries.

iii **Switchgear:** It houses such equipment which locates the fault on the system and isolate the faulty part from the healthy section. It contains circuit breakers, relays, switches and other control devices

Hydroelectric power station (Fig 2)

Generating station which utilises the potential energy of water at a high level for the generation of electrical energy is known as a hydro-electric power station. Hydro-electric power stations are generally located in hilly areas where dams can be built conveniently and large water reservoirs can be obtained. In a hydro-electric power station, water head is created by constructing a dam across a river or lake. From the dam, water is led to a water turbine. The water turbine captures the energy in the falling water and changes the hydraulic energy (i.e., product of head and flow of water) into mechanical energy at the turbine shaft. The turbine drives the alternator which converts mechanical energy into electrical energy. Hydro-electric power stations are becoming very popular because the reserves of fuels (i.e., coal and oil) are depleting day by day. They have the added importance for flood control, storage of water for irrigation and water for drinking purposes.

Advantages

i It requires no fuel as water is used for the generation of electrical energy.

ii It is quite neat and clean as no smoke or ash is produced.

iii It requires very small running charges because water is the source of energy which is available free of cost.

iv It is comparatively simple in construction and requires less maintenance.

v It does not require a long starting time like a steam power station. In fact, such plants can be put into service instantly.

vi It is robust and has a longer life.

vii Such plants serve many purposes. In addition to the generation of electrical energy, they also help in irrigation and controlling floods.

viii Although such plants require the attention of highly skilled persons at the time of construction, yet for operation, a few experienced persons may do the job well.

Disadvantages

i It involves high capital cost due to construction of dam.

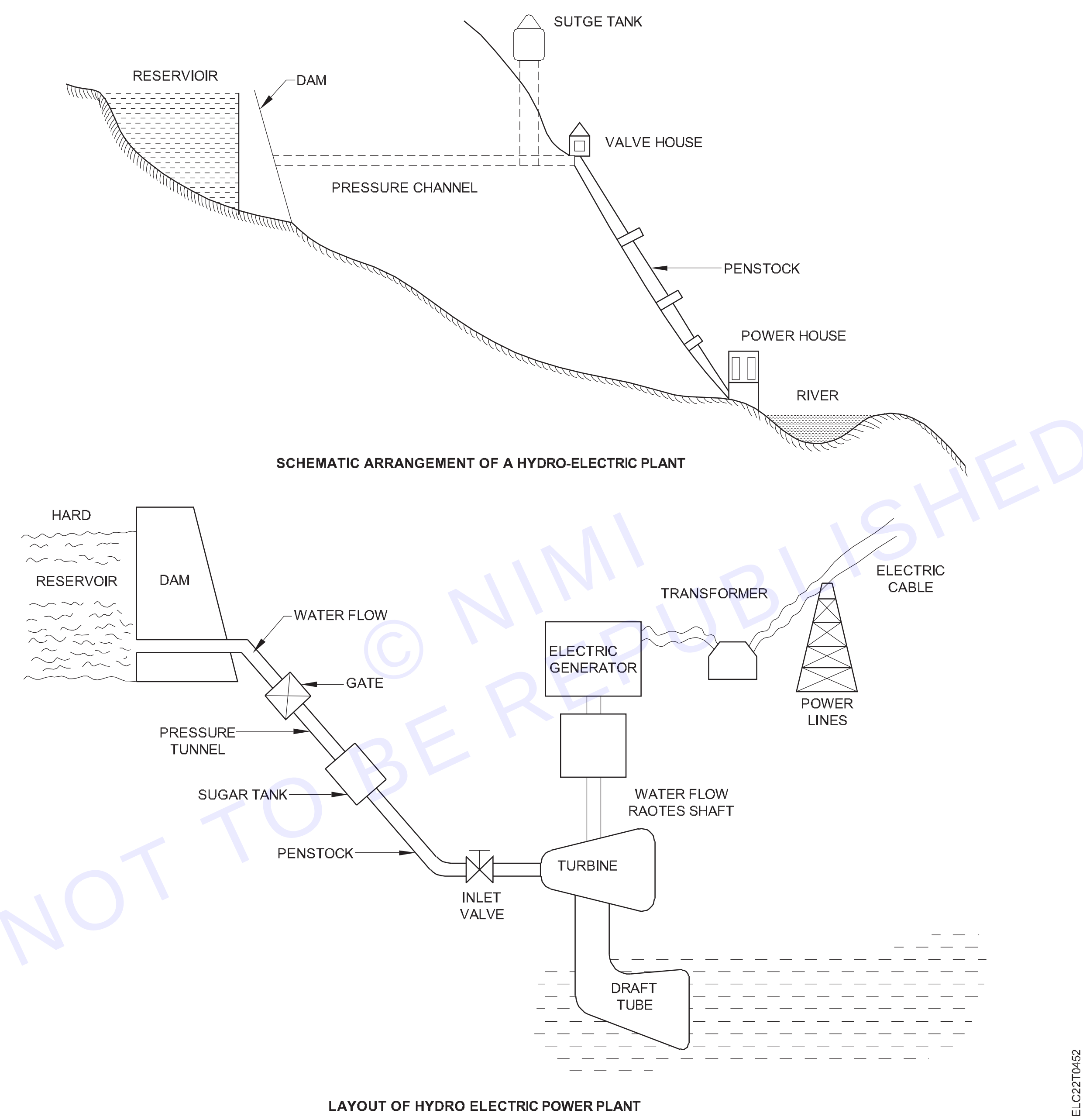
ii There is uncertainty about the availability of huge amount of water due to dependence on weather conditions.

iii Skilled and experienced hands are required to build the plant.

iv It requires high cost of transmission lines as the plant is located in hilly areas which are quite away from the consumers.

Although a hydro-electric power station simply involves the conversion of hydraulic energy into electrical energy, yet it embraces many arrangements for proper working and efficiency. The schematic arrangement of a modern hydro-electric plant is given below.

Fig 2



SCHEMATIC ARRANGEMENT OF A HYDRO-ELECTRIC PLANT

LAYOUT OF HYDRO ELECTRIC POWER PLANT

The dam is constructed across a river or lake and water from the catchment area collects at the back of the dam to form a reservoir. A pressure tunnel is taken off from the reservoir and water brought to the valve house at the start of the penstock. The valve house contains main sluice valves and automatic isolating valves. The former controls the water flow to the power house and the latter cuts off supply of water when the penstock bursts. From the valve house, water is taken to water turbine through a huge steel pipe known as penstock. The water turbine converts hydraulic energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.

A surge tank (open from top) is built just before the valve house and protects the penstock from bursting in case the turbine gates suddenly close due to electrical load being thrown off. When the gates close, there is a sudden stopping of water at the lower end of the penstock and consequently the penstock can burst like a paper log. The surge tank absorbs this pressure swing by increase in its level of water.

Choice of site for hydro electric power stations

The following points should be taken into account while selecting the site for a hydro-electric power station.

i **Availability of water:** Since the primary requirement of a hydro-electric power station is the availability of huge quantity of water, such plants should be built at a place (e.g., river, canal) where adequate water is available at a good head.

ii **Storage of water:** There are wide variations in water supply from a river or canal during the year. This makes it necessary to store water by constructing a dam in order to ensure the generation of power throughout the year. The storage helps in equalising the flow of water so that any excess quantity of water at a certain period of the year can be made available during times of very low flow in the river. This leads to the conclusion that site selected for a hydro-electric plant should provide adequate facilities for erecting a dam and storage of water.

iii **Cost and type of land:** The land for the construction of the plant should be available at a reasonable price. Further, the bearing capacity of the ground should be adequate to withstand the weight of heavy equipment to be installed.

iv **Transportation facilities:** The site selected for a hydro-electric plant should be accessible by rail and road so that necessary equipment and machinery could be easily transported. It is clear from the above mentioned factors that ideal choice of site for such a plant is near a river in hilly areas where dam can be conveniently built and large reservoirs can be obtained.

Constituents of hydro- electric power plant

The constituents of a hydro-electric plant are

1 Hydraulic structures

2 Water turbines

3 Eectrical equipment.

1 Hydraulic structures

Hydraulic structures in a hydro-electric power station include dam, spillways, headwork, surge tank, penstock and accessory works.

Dam: A dam is a barrier which stores water and creates water head. Dams are built of concrete or stone masonry, earth or rock fill. The type and arrangement depends upon the topography of the site. A masonry dam may be built in a narrow canyon. An earth dam may be best suited for a wide valley. The type of dam also depends upon the foundation conditions, local materials and transportation available, occurrence of earthquakes and other hazards. At most of sites, more than one type of dam may be suitable and the one which is most economical is chosen.

Spillways: There are times when the river flow exceeds the storage capacity of the reservoir. Such a situation arises during heavy rainfall in the catchment area. In order to discharge the surplus water from the storage reservoir into the river on the down-stream side of the dam, spillways are used. Spillways are constructed of concrete piers on the top of the dam. Gates are provided between these piers and surplus water is discharged over the crest of the dam by opening these gates.

Head works: The head works consists of the diversion structures at the head of an intake. They generally include booms and racks for diverting floating debris, sluices for by-passing debris and sediments and valves for controlling the flow of water to the turbine. The flow of water into and through head works should be as smooth as possible to avoid head loss and cavitation. For this purpose, it is necessary to avoid sharp corners and abrupt contractions or enlargements.

Surge tank: Open conduits leading water to the turbine require no protection. However, when closed conduits are used, protection becomes necessary to limit the abnormal pressure in the conduit. For this reason, closed conduits are always provided with a surge tank. A surge tank is a small reservoir or tank (open at the top) in which water level rises or falls to reduce the pressure swings in the conduit. A surge tank is located near the beginning of the conduit. When the turbine is running at a steady load, there are no surges in the flow of water through the conduit i.e., the quantity of water flowing in the conduit is just sufficient to meet the turbine requirements. However, when the load on the turbine decreases, the governor closes the gates of turbine, reducing water supply to the turbine. The excess water at the lower end of the conduit rushes back to the surge tank and increases its water level. Thus the conduit is prevented from bursting. On the other hand, when load on the turbine increases, additional water is drawn from the surge tank to meet the increased load requirement. Hence, a surge tank overcomes the abnormal pressure in the conduit when load on the turbine falls and acts as a reservoir during increase of load on the turbine.

Penstocks

Penstocks are open or closed conduits which carry water to the turbines. They are generally made of reinforced concrete or steel. Concrete penstocks are suitable for low heads (< 30 m) as greater pressure causes rapid deterioration of concrete. The steel penstock scan be designed for any head; the thickness of the penstock increases with the head or working pressure. Various devices such as automatic butterfly valve, air valve and surge tank (See Fig. 2.3) are provided for the protection of penstocks. Automatic butterfly valve shuts off water flow through the penstock promptly if it ruptures. Air valve maintains the air pressure inside the penstock equal to outside atmospheric pressure. When water runs out of a penstock faster than it enters, a vacuum is created which may cause the penstock to collapse. Under such situations, air valve opens and admits air in the penstock to maintain inside air pressure equal to the outside air pressure.

2 Water turbines

Water turbines are used to convert the energy of falling water into mechanical energy. The principal types of water turbines are

i Impulse turbines

ii Reaction turbines

i Impulse turbines

Such turbines are used for high heads. In an impulse turbine, the entire pressure of water is converted into kinetic energy in a nozzle and the velocity of the jet drives the wheel. The example of this type of turbine is the Pelton wheel. It consists of a wheel fitted with elliptical buckets along its periphery. The force of water jet striking the buckets on the wheel drives the turbine. The quantity of water jet falling on the turbine is controlled by means of a needle or spear placed in the tip of the nozzle. The movement of the needle is controlled by the governor. If the load on the turbine decreases, the governor pushes the needle into the nozzle, thereby reducing the quantity of water striking the buckets. Reverse action takes place if the load on the turbine increases.

ii Reaction turbines

Reaction turbines are used for low and medium heads. In a reaction turbine, water enters the runner partly with pressure energy and partly with velocity head. The important types of reaction turbines are:

a Francis turbines

b Kaplan turbines

A Francis turbine is used for low to medium heads. It consists of an outer ring of stationary guide blades fixed to the turbine casing and an inner ring of rotating blades forming the runner. The guide blades control the flow of water to the turbine. Water flows radially inwards and changes to a downward direction while passing through the runner. As the water passes over the “rotating blades” of the runner, both pressure and velocity of water are reduced. This causes a reaction force which drives the turbine.

A Kaplan turbine is used for low heads and large quantities of water. It is similar to Francis turbine except that the runner of Kaplan turbine receives water axially. Water flows radially inwards through regulating gates all around the sides, changing direction in the runner to axial flow. This causes a reaction force which drives the turbine.

3 Eectrical equipment

The electrical equipment of a hydro hydro-electric power station includes alternators, transformers, circuit breakers and other switching and protective devices.

Diesel power station

A generating station in which diesel engine is used as the prime mover for the generation of electrical energy is known as diesel power station. In a diesel power station, diesel engine is used as the prime mover. The diesel burns inside the engine and the products of this combustion act as the “working fluid” to produce mechanical energy. The diesel engine drives the alternator which converts mechanical energy into electrical energy. As the generation cost is considerable due to high price of diesel, therefore, such power stations are only used to produce small power. Although steam power stations and hydro-electric plants are invariably used to generate bulk power at cheaper cost, yet diesel power stations are finding favour at places where demand of power is less, sufficient quantity of coal and water is not available and the transportation facilities are inadequate. These plants are also used as standby sets for continuity of supply to important points such as hospitals, radio stations, cinema houses and telephone exchanges.

Advantages

1 The design and layout of the plant are quite simple

2 It occupies less space as the number and size of the auxiliaries is small.

3 It can be located at any place.

4 It can be started quickly and can pick up load in a short time.

5 There are no standby losses.

6 It requires less quantity of water for cooling.

7 The overall cost is much less than that of steam power station of the same capacity.

8 The thermal efficiency of the plant is higher than that of a steam power station.

9 It requires less operating staff.

DIsadvantages

1 The plant has high running charges as the fuel (i.e., diesel) used is costly.

2 The plant does not work satisfactorily under overload conditions for a longer period.

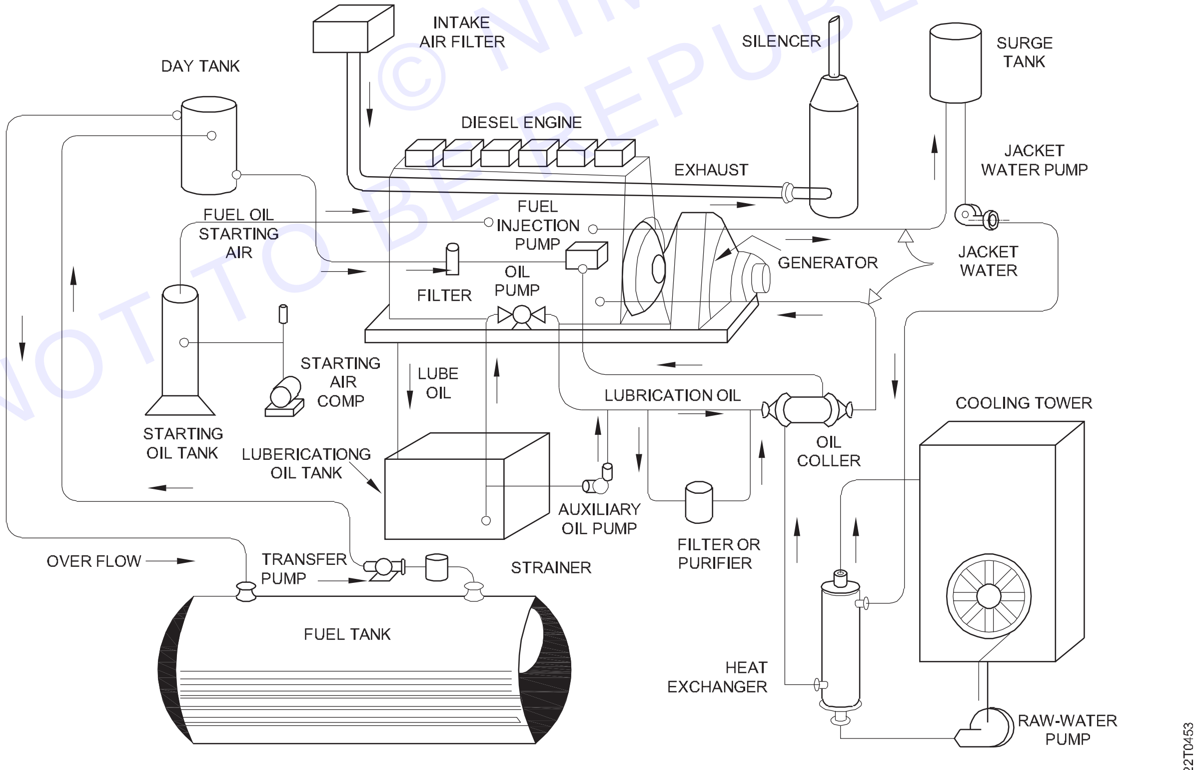
3 The plant can only generate small power.

4 The cost of lubrication is generally high.

5 The maintenance charges are generally high.

Schematic arrangement of diesel power station (Fig 3)

Fig 3



SCHEMATIC ARRANGEMENT OF DIESEL POWER PLANT

Apart from the diesel generator set, the plant has the following auxiliaries:

Fuel supply system: It consists of storage tank, strainers, fuel transfer pump and all day fuel tank. The fuel oil is supplied at the plant site by rail or road. This oil is stored in the storage tank. From the storage tank, oil is pumped to smaller all day tank at daily or short intervals. From this tank, fuel oil is passed through strainers to remove suspended impurities. The clean oil is injected into the engine by fuel injection pump.

Air intake system: This system supplies necessary air to the engine for fuel combustion. It consists of pipes for the supply of fresh air to the engine manifold. Filters are provided to remove dust particles from air which may act as abrasive in the engine cylinder.

Exhaust system: This system leads the engine exhaust gas outside the building and discharges it into atmosphere. A silencer is usually incorporated in the system to reduce the noise level.

Cooling system: The heat released by the burning of fuel in the engine cylinder is partially converted into work. The remainder part of the heat passes through the cylinder walls, piston, rings etc. and may cause damage to the system. In order to keep the temperature of the engine parts within the safe operating limits, cooling is provided. The cooling system consists of a water source, pump and cooling towers. The pump circulates water through cylinder and head jacket. The water takes away heat form the engine and itself becomes hot. The hot water is cooled by cooling towers and is recirculated for cooling.

Lubricating system: This system minimises the wear of rubbing surfaces of the engine. It comprises of lubricating oil tank, pump, filter and oil cooler. The lubricating oil is drawn from the lubricating oil tank by the pump and is passed through filters to remove impurities. The clean lubricating oil is delivered to the points which require lubrication. The oil coolers incorporated in the system keep the temperature of the oil low.

Engine starting system: This is an arrangement to rotate the engine initially, while starting, until firing starts and the unit runs with its own power. Small sets are started manually by handles but for larger units, compressed air is used for starting. In the latter case, air at high pressure is admitted to a few of the cylinders, making them to act as reciprocating air motors to turn over the engine shaft. The fuel is admitted to the remaining cylinders which makes the engine to start under its own power.

Nuclear power station: Generating station in which nuclear energy is converted into electrical energy is known as a nuclear power station. In nuclear power station, heavy elements such as Uranium (U235) or Thorium (Th232) are subjected to nuclear fission in a special apparatus known as a reactor. The heat energy thus released is utilised in raising steam at high temperature and pressure. The steam runs the steam turbine which converts steam energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy. The most important feature of a nuclear power station is that huge amount of electrical energy can be produced from a relatively small amount of nuclear fuel as compared to other conventional types of power stations. It has been found that complete fission of 1 kg of Uranium (U235) can produce as much energy as can be produced by the burning of 4,500 tons of high grade coal. Although the recovery of principal nuclear fuels (i.e., Uranium and Thorium) is difficult and expensive, yet the total energy content of the estimated world reserves of these fuels are considerably higher than those of conventional fuels, viz., coal, oil and gas. At present, energy crisis is gripping us and, therefore, nuclear energy can be successfully employed for producing low cost electrical energy on a large scale to meet the growing commercial and industrial demands. (Fig 4)

Advantages

1 The amount of fuel required is quite small. Therefore, there is a considerable saving in the cost of fuel transportation.

2 A nuclear power plant requires less space as compared to any other type of the same size.

3 It has low running charges as a small amount of fuel is used for producing bulk electrical energy.

4 This type of plant is very economical for producing bulk electric power.

5 It can be located near the load centres because it does not require large quantities of water and need not be near coal mines. Therefore, the cost of primary distribution is reduced.

6 There are large deposits of nuclear fuels available all over the world. Therefore, such plants can ensure continued supply of electrical energy for thousands of years.

7 It ensures reliability of operation.

Disadvantages

1 The fuel used is expensive and is difficult to recover.

2. The capital cost on a nuclear plant is very high as compared to other types of plants.

3 The erection and commissioning of the plant requires greater technical know-how.

4 The fission by-products are generally radioactive and may cause a dangerous amount of radioactive pollution.

5 Maintenance charges are high due to lack of standardisation. Moreover, high salaries of specially trained personnel employed to handle the plant further raise the cost.

6 Nuclear power plants are not well suited for varying loads as the reactor does not respond to the load fluctuations efficiently.

7 The disposal of the by-products, which are radioactive, is a big problem. They have either to be disposed off in a deep trench or in a sea away from sea-shore.

The schematic arrangement of a nuclear power station is shown in Figure. The whole arrangement can be divided into the following main stages:

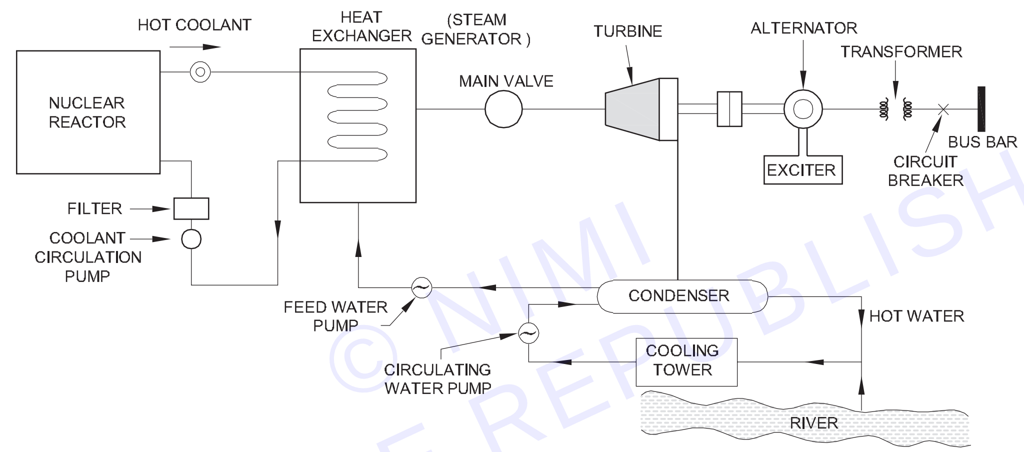
i Nuclear reactor

ii Heat exchanger

iii Steam turbine

iv Alternator

Fig 4



i Nuclear reactor

Is a cylindrical stout pressure vessel and houses, fuel rods of Uranium, moderator of graphite and control rods of cadmium material.

The graphite moderator slows down the neutrons before they bombard the fuel rods. Cadmium is strong neutron absorber and thus regulates the supply of neutrons for fission. By pulling out the control rods, power of the nuclear reactor is increased, whereas by pushing them in, it is reduced. The heat produced in the reactor is removed by the coolant, generally a sodium exchanger.

ii Heat exchanger

The coolant gives up heat to the heat exchanger which is utilized in raising the steam. After giving up heat, the coolant is again fed to the reactor.

iii Steam turbine

The steam produced in the heat exchanger is led to the steam turbine through a valve. After doing a useful work in the turbine, the steam is exhausted to condenser. The condenser condenses the steam which is fed to the heat exchanger through feed water pump.

iv Alternator

The steam turbine drives the alternator which converts mechanical energy into electrical energy. The output from the alternator is delivered to the bus-bars through transformer, circuit breakers and isolators.

Electrical power generation by non conventional methods

Objectives: At the end of this lesson you shall be able to:

- state the non - conventional energy
- explain the methods of generation power from bio-gas and tidal
- list out the merits and demerits of non-conventional power generation.

Non - conventional energy

Energy generated by using wind, tides, solar, geothermal heat and biomass including farm and animal waste is known as non-conventional energy. All these sources are renewable or inexhaustible and do not cause environmental pollution.

Merits of non - conventional over conventional sources of energy

1 Provide more energy

2 Reduce security risk associated with the use of nuclear energy.

3 Reduce pollutants

4 Less running and maintenance cost

5 Never destroyed

6 Despite the high initial investment and several limitations, use of solar energy to meet our ever increasing energy demand seems to be the only answer.

7 Green house effect and global warming is avoided

8 Less environment problems.

Demerits of non conventional over conventional sources of energy

1 Many non- conventional sources are still in their infant stages and required a lot of development efforts.

2 High initial cost

3 Less reliable and efficiency

4 Can not be used for base load demand.

Bio-gas power generation

The method of generating the electrical energy by using bio-gas is termed as bio-gas power generation.

Bio-gas

Biogas is a good fuel. Bio mass like animal excreta, vegetable wastes and seeds undergo decomposition in the absence of oxygen in a biogas plant and form a mixture of gases. This mixture is the biogas. Its main constituent is methane. This is used as a fuel for cooking and lighting.

Electricity generating plant

Generating plant fuelled by biomass uses conventional steam turbine as used in thermal power stations with modifications to the combustion chamber and fuel handling systems to handle the bulkier fuel. The schematic arrangement is in Fig 1.

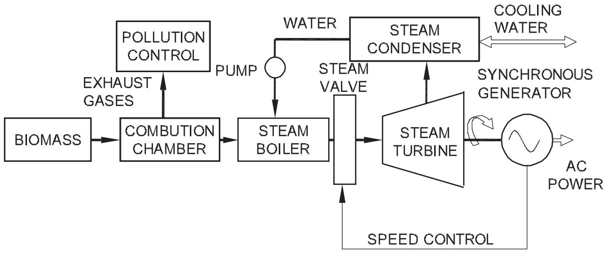
Co - generation

Because of the poor energy conversion efficiencies of biomass fuels, practical generating systems often employ a co-coal generation to achieve reasonable utilization of the generating plant.

Environmental issues

While biomass crops provide an environment friendly fuel source for generating electrical energy. The land used for disposing the slurry (waste) may be better employed for cultivation.

Fig 1



ELECTRICITY GENERATION POWERED BY BIOMASS

Tidal power generation

Objectives: At the end of this lesson you shall be able to:

- explain the features of tidal power generation
- state the system on which the tidal power generation works
- state the advantages and disadvantages of tidal power generation.

The generation of electricity using tidal power is termed as tidal power generation. It is basically the transformation of tidal power found in tidal motion of water in seas and oceans into electrical energy.

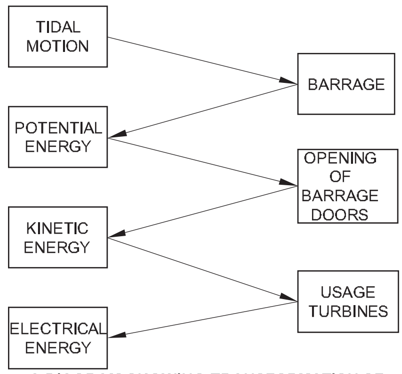
Tidal power

Tidal power is the power inherent in tides at sea or oceans, that is power of motion of water actuated by tides. Tides are defined as the increase and decrease in water levels due to the motion of water from one place to the other. Thus there is a renewable source of energy in the tidal motion of water at seas and oceans. This source of energy could be used to generate other types of energy that could be useful in industrial applications.

This is done using a very basic idea involving the use of a barrage or small dam built at the entrance of a bay where tides are known to reach very high levels of variation. This barrage will trap tidal water behind it creating a difference in water level, which will in turn create potential energy.

This potential energy will then be used in creating kinetic energy as doors in the barrage are opened and the water rush from the high level to the lower level. This kinetic energy will be converted into rotational kinetic energy that will rotate turbines giving electrical energy. Fig 1 shows the process in very simple terms.

Fig 1



A DIAGRAM SHOWING TRANSFORMATION OF TIDAL ENERGY TO ELETRICAL ENERGY

Working of tidal power generation system

In very simple terms a barrage is built at the entrance of a gulf and the water levels vary on both sides of the small dam. Passages are made inside the dam and water flows through these passage and turbines rotate due to this flow of water under head of water. Thus, electricity is created using the turbines. A general diagram of the system is in Fig 2.

The components of a tidal power station are :

1 **A barrage :** a barrage is a small wall built at the entrance of a gulf in order to trap water behind it. It will either trap it by keeping it from going into the gulf when water levels at the sea are high or it will keep water from going into the sea when water level at the sea is low.

2 **Turbines :** They are the components responsible for converting potential energy into kinetic energy. They are located in the passage ways that the water flows through when gates of barrage are opened.

3 **Sluices :** Sluice gates are the ones responsible for the flow of water through the barrage they could be seen Fig 2.

4 **Embankments :** They are caissons made out of concrete to prevent water from flowing at certain parts of the dam and to help maintenance work and electrical wiring to be connected or used to move equipment or cars over it.

Advantages of tidal power generation

There are many advantages of generating power from the tide; some of them are listed below.

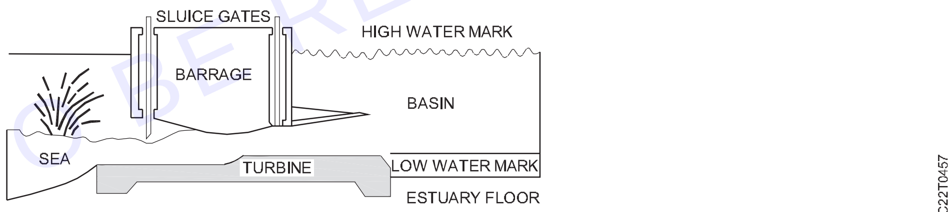
- Tidal power is a renewable and sustainable energy resource.
- It reduces dependence upon fossil fuels.
- It produces no liquid or solid pollution.
- It has little visual impact.
- Tidal power exists on a world wide scale from deep ocean waters.

Disadvantages and constraint to tidal power generation

Unfortunately, there are also disadvantages and limitations to generating tidal power. Some of these are;

- At the present time both tide and wave energy are suffering from orientation problems, in the sense that neither method is strictly economical (except in few locations throughout the world) on a large scale in comparison with conventional power sources.

Fig 2



GENERAL SCHEME OF THE TIDEL POWER STATION

Power generation by solar energy

Objectives: At the end of this lesson you shall be able to:

- explain the basic principle and construction of the solar cell.

Solar electricity

When sunlight strikes on photovoltaic (PV) solar panel, the electricity is produced. The method of generating the electrical energy from the solar panel (cells) is termed as solar energy generation.

Generation of electricity by using solar energy depends up on the photovoltaic effect in some specific materials. There are certain materials that produce electric current when these are exposed to direct sun light. This effect is seen in combination of two thin layers of semiconductor materials. One layer of this combination will have a depleted number of electrons.

When sunlight strikes on this layer, it absorbs the photons of sun light ray and consequently the electrons are excited and jump to the other layer. This phenomenon creates a charge difference between the layer and resulting to a tiny potential difference between them.

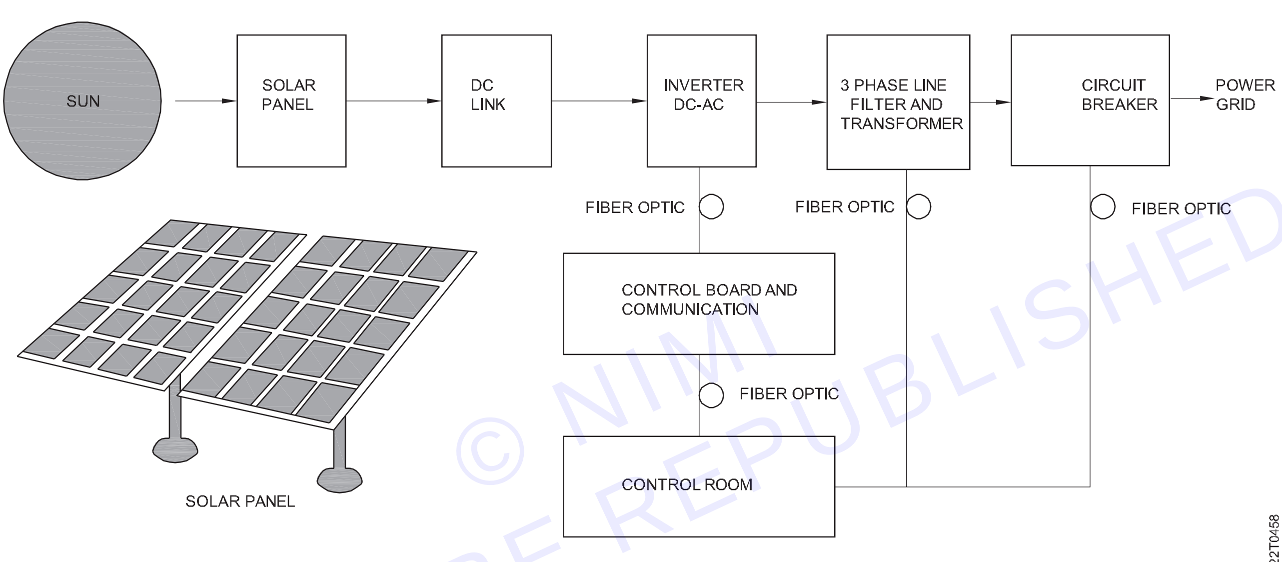
The unit of such combination of two layers of semi conductor materials, for producing electric potential difference in sunlight is called solar cell. Silicon is normally used as solar cell. For building cell, silicon material is cut into very thin wafers. Some of these wafers are doped with impurities. Then both doped and undoped wafers are sandwiched together to build solar cell. A metallic strip is attached to two extreme layers to collect current.

A desired number of solar cell are connected together in both parallel and series to form a solar module for producing desired electricity.

The solar cell can also work in cloudy weather as well as is moon light but the rate of production of electricity low as and it depends up on intensity of incident light ray.

Fig 1 describes the typical system of solar panels, controller, energy storage, inverter for converting DC into AC and how the system is connected to power grid.

Fig 1



SOLAR POWER PLANT

Assembling and installation of solar panels

A solar panel is a able to function using the solar energy which is derived from the sun. The solar panel installed on the roof top absorb sun's light (photons) from the sun.

Silicon and the conductors in use for solar panel converts the sunlight into direct current (DC) electricity flows into the inverter. It is an renewable energy. The process of converting sunlight to electrical energy and more efficient than other process.

Solar panel contains many different silicon cells (or) solar cells. The energy derived from the sun is connected into electricity with help of solar panels.

1 The solar panels installed on the roof top absorb sun's light from the sun.

2 The silicon and the conductor in the panel convert the sunlight into DC flows into inverter.

3 The inverter then converts DC to AC which can be used at home.

4 Excess electricity that is not used, can be feedback to the grid.

5 When the solar panels produce less power than required at home.

Process of connecting solar panel to electricity

Solar panels is used a special process of connecting photons to electrons to generate a current by making use of a special type of cell known as photovoltaic cell. These cells are commonly found on the front of calculation and small gadgets are connected together, called as solar panels (photovoltaic cells) are made up of semiconductor materials such as silicon, which absorb the light from the sun. The photons in the sunlight current the electron within the sunlight.

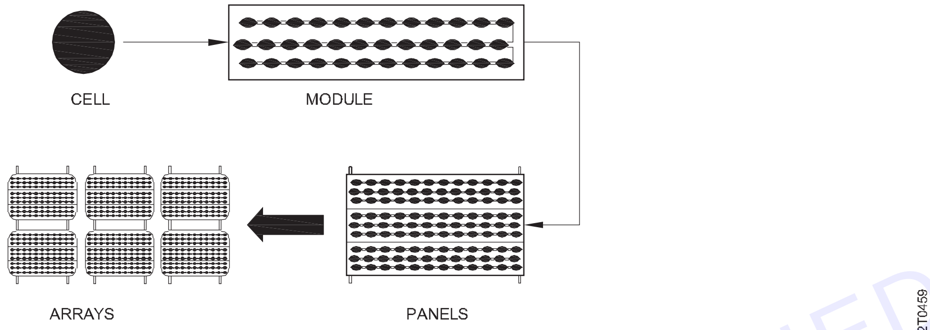
Basic idea of a solar module, array and balance of system (BOS)

Module

Solar cells are made in various shapes and sizes. The smallest of the cells can be seen in devices like an ordinary calculator, these type of devices are very little amount of power used in home lighting system needs more power to run on. The number of cells are put together to produce more power. The group of cells is packaged together in an enclosed space is called as a module.

It helps to give higher voltage, high power and protects the panel from rain, snow and wind etc. voltage and power output of module depend on the size and number of cells used. So, more number of modules are to be connected in a simple assembly of modules is known as array. (Fig 2)

Fig 2



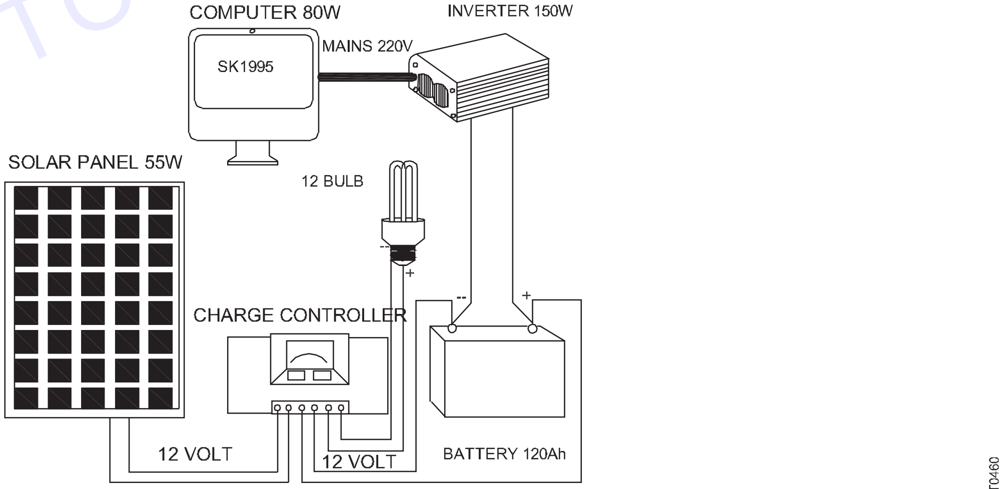
CELL MODULE PANEL AND ARRAY SYSTEM

Balance of system (BOS)

The cells modules and arrays are the power producing part, a small devices like radio, needs a small amount of power, can be directly connected to a small module. But most of the devices appliances need more power at night. The assembly of module, battery and an appliance is simple form a P.V system.

A module cannot be connected directly to a battery, so, a charge controller on charge regulator is used in between module and battery and inverter are required to operate AC appliances. So, the whole system excepts the module is known as balance of system (BOS). (Fig 3)

Fig 3



BALANCE OF SYSTEM(BOS)

The main components is BOS assembly are:

- Storage battery
- Charge controller
- Inverter
- Support structure
- Junction boxes
- Wire, cables and fuses
- Connections and switches

The functions of the above components are explained briefly below:

Storage battery

The most small systems used for lightening needs only 12V battery for longer system like refrigerator, 24V is used. If helps to keep the wire size small and system losses to a minimum. It needs to be handled carefully. If must not be over charged or fully discharged to prevent from damage.

Charge controller

If the battery is not able to control charge on its own. This work is done by a simple automatic device known as a charge controller in the following way.

- It senses the battery charge and switches ‘OFF’ the charging current and avoid from damage.
- It disconnects the appliances when the battery charge goes below a set limit.
- Prevents reverse current and protects from short circuit.

Inverter

A solar system produces only DC power. But home appliances need AC power. The device (example CFL) is required for this purpose to convert DC into AC is called as inverter.

Support structure

The solar module cannot be simply placed either on ground or roof. It needs to collect the sunshine at an angle. To keep the module safe from any strong winds support structure is used for solar PV system.

Junction boxes

It is meeting point for many wires. These may be from a raw of modules are from modules to a battery bank. A junction box is made of an unbreakable material (ie) polycarbonate. It makes use of copper connectors for a high current flow. It protects the system from moisture.

Wires and fuses

This solar systems carry a low voltage but high current. So, the large diameter wire is needed. Fuses keep the solar equipment safe against the short circuit.

Mounting of charge controller

- Mount the controller to the wall into screws that fit to the wall material.
- Connect the battery cable assembly with fuse supplied along with the controller.
- Connect first controller and then battery and two modules
- Connect the wires to the load and only then to controller.

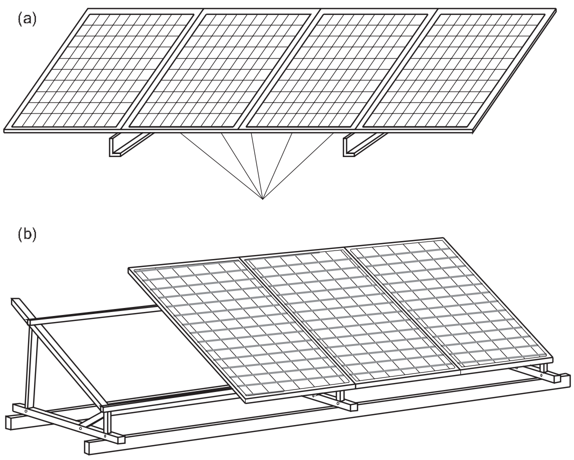
Electrical connection

- Connect the battery to the system only after getting fully charged.
- Do not switch ‘ON’ charged the loads for 2 - 3 days (when battery is ‘ON’ a full charged)
- Connect the array cable to charge controller with correct polarity.

- Keep the switch in ‘OFF’ position and connect the load cables and battery cables to charge controller.
- Switch ‘ON’ the load (ie) lamps for the normal operation.
- Test the solar panel installation for it’s functioning.

(Fig 4a & b) shows the installed solar panel with mid clamp and with frame mounted installation are illustrated.

Fig 4



Functionality of solar panel

Sunlight is the basic fuel for a solar panel. Sunshine is the cause to keep the panel for normal functioning. But the environment around the modules will affect it’s working.

The following few factors will affect it’s normal working cause for power loss.

- Tilt angle
- Dust
- Shading
- Light intensity
- Temperature
- Charge controller
- Semiconductor energy loss
- Cabling losses
- Improper connections

Tilt angle : The solar module must be installed in the proper path of sun and it is tilted properly at an angle, equal to the latitude of the place. If any error in the tilt angle will lead to same amount of power loss.

Dust : If the modules is not cleaned properly, dust will form on the modules surface in the dry season, and it may cause for high energy loss 5-10%.

Shading

Solar module faces the sun all day. Their shade should not be present on it. In such a place only it must be put up. But due to extended free transformer, T.V antennas etc, may cause to present shades.

A solar modules are made of a string of individual solar cells and connected in series with one another. Suppose as an example one cell from 36 cells in a module is fully shaded, the power output from the module will become zero due to high resistance. But if one cell is 50% shaded then the power output is reduced to 50% only offers high resistance.

Light intensity

More power is produced from the panel in bright sunlight. For 1000W/M2 of sunlight, the rated output power will be full. But, if it is 500W/M2 only the rated power output will be half. The output power is directly proportional with the increasing of solar in isolation.

Temperature

The higher the temperature the output power is reduced from a module, due to power loss. It is tested at standard temperature at 25°C. During the bright sunlight, cell may reach 70°C also. If crystalline silicon decrease from

0.4 to 0.5% per°C temperature increases above 25°C. Amorphous silicon module temperature coefficient is 0.2 to 0.25 % per°C of temperature increase.

Charge controller

If the charger controller is in continuous operation and draws a small current of about 5mA to 25mA, then the power loss is around 1%.

Semiconductor energy loss

The charge controller is having the components as MOSFET and blocking diodes, which is cause for heat energy loss.

Cabling loss

The cables are also cause for power loss, It can be minimized by choosing a large diameter of wire size.

Improper connection

If the electrical connections are not made properly, it results in less power is fed to the battery. It can be reduced by keeping clean, and tight connections.

Wind power generation

Objectives: At the end of this lesson you shall be able to:

- explain the features of wind power generation
- state the advantages and disadvantages of wind power generation.

The method of generating the electrical energy by using the wind is termed as wind power generation. Since the wind has velocity and kinetic energy, it can be used to produce electricity. For that, we can use windmills. The important part of a windmill is a structure with large leaves, fixed at the top of a high tower. The speed of leaves changes with the speed of the wind. If the rotation of the windmill is given to the rotor of a generator, then the electricity will be obtained from the generator. If the windmill is connected to a water pump, the leaves of the windmill rotate the pump and pumping out the water.

Wind power can be usefully exploited for the generation of electricity as there are large, coastal, hill and desert areas. Wind turbines comprising of machines with blade diameter of 17 m, which can generate about 100 kilowatts. A strike of blowing wind on specially designed blades of a windmill's rotor causes both to rotate. This rotation, which is the mechanical energy, when coupled to a turbine, drive the power generator.

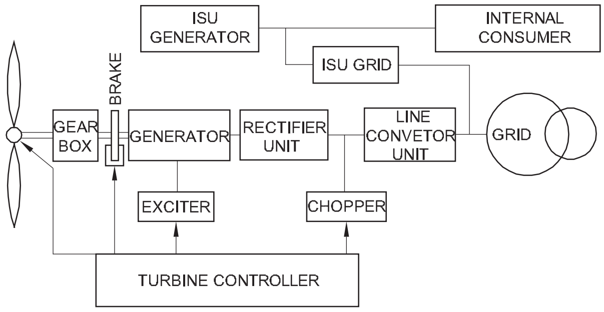
Operation

The schematic arrangement of wind power station is given in Fig 1.

When the wind strikes the rotor blades, blades start rotating. Rotor is directly connected to high speed gear box. Gear box converts the rotor rotation into high speed which rotates the electrical generator. An exciter is needed to give the required excitation to the coil so that it can generate required voltage. The exciter current is controlled by a turbine controller which senses the wind speed based on that it calculate the power what we can achieve at that particular wind speed.

The output voltage of electrical generator is given to a rectifier and rectifier output is given to line converter unit to stabilise the output ac that is fed to the grid by a high voltage transformer. An extra units is used to give the power to internal auxiliaries of wind turbine (like motor, battery etc), this is called internal supply unit. ISU can take the power from grid as well as from wind. Chopper is used to dissipate extra energy from the Rectifier Unit (RU) for safety purpose.

Fig 1



WIND POWER GENERATION

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Advantages

1 The wind energy is free, inexhaustible and does not need transportation.

2 Wind power plant on the other hand does not take long time to construct. Such wind mills will be highly desirable & economical to the rural areas which are far away from the existing grids.

3 There is a strong reason why wind power should be welcome by grids which have some hydroelectricity inputs in India. The water level in the hydel reservoir is at its lowest before the onset of the South West monsoon. If less water is drawn during the monsoon, a high level could be maintained for longer period. During the monsoon period wind energy can be used to feed the grid.

4 It is non polluting

5 It does not require high technology.

6 Electricity can be produced at a lower cost after installation.

Disadvantages

1 The major disadvantage associated in the wind power is that it is not constant and steady, which make the complications in designing the whole plant.

2 The rotor blades of wind turbine generators must sweep out large areas to produce worthwhile amount of power.

3 The wind is a very dangerous such storms can cause tremendous shear stresses which may spoil the whole plant within no time. To avoid this, special and costly designs and controls are always required.

4 Among all the disadvantages mentioned above, the cost factor is the major which has restricted the development of wind power on large scale for feeding to the existing grid. The estimated cost of wind electricity generation, storage & distribution system is over 1 lakh rupees which may be considered beyond the means of most Indian villages.

Modern wind machines are still wrestling with the problem of what to do when the wind is not blowing. Large turbines are connected to the utility power network some other type of generator picks up the load when there is no wind. Small turbines are often connected to diesel/electric generators or sometimes have a battery to store the extra energy they collect when the wind is blowing hard.

The wind energy is utilized by means of a wind mill or a series of wind mills. A wind mill consists of few vanes (normally 3 to 6) which rotate about their axis, when the wind blows against them. The rotational motion (i.e. mechanical energy) thus created is utilized for various applications, such as,

1 Lifting water from the well

2 Battery charging

3 Water pumping

4 Operating a simple machine

5 Wind energy is used for agricultural& rural applications such as grinding flour mills, wood cutting saw, stone crushers, mixers, water pumps and irrigation facility etc.

Electrical supply system - transmission and distribution

Objectives: At the end of this lesson you shall be able to:
- explain the electrical supply system and layout of AC power supply scheme
- explain single line diagram of substation
- explain the types of insulator and their used
- explain transmission and distribution by online - poles and towers
- explain circuit breaker relays lighting arrestor used in HT line.

Electrical supply system

The electrical energy generated from the power plants has to be supplied to the consumers. This is large network, which can be broadly divided into two stages, (ie.) Transmission and distribution.

The conveyance of electric power from a power station to the consumers / premises is called is Electrical supply system.

The Electrical power supply system consists of 3 main components viz (i) The power station / plant (ii) The transmission lines and (iii) The distribution systems. The power is produced at power plant which is away from the consumers, It has to be transmitted over long distances to load centres by transmission and to consumers through distribution network.

This supply system can be classified into

- DC or AC system
- Over head lines (or) underground system

Now a days, 3 phase, 3 -wire AC system is universally adopted as an economical proposition. In some places 3 phase - 4 wire AC system is adopted.

The underground system is more expensive than the over-head system, therefore in our country O.H system is almost adopted.

Types of power transmission system

Universally, 3 - phase - 3 wire AC system is adopted in most of the places. However other systems can also be used for transmission under special circumstances.

1 AC single phase system

- i Single-phase two wire
- ii Single - phase two wire with mid point earthed
- iii Single phase three wire

2 AC three phase system

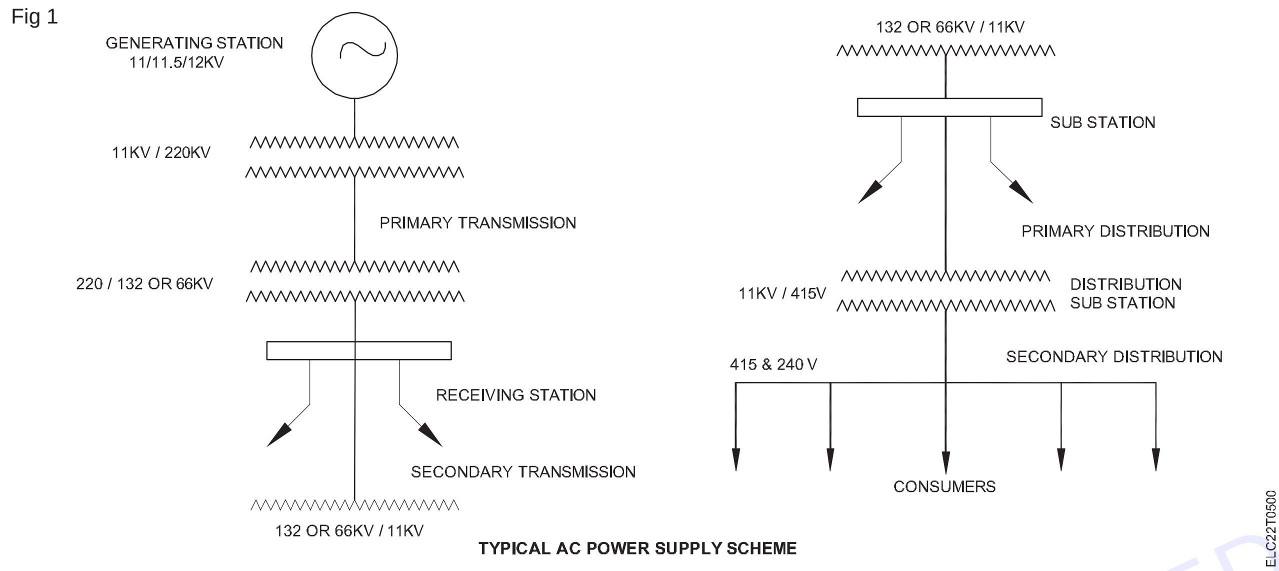
- i Three - phase - three wire
- ii Three - phase - four wire

The line network between generating station (Power station) and consumer of electric power can be divided into two parts.

- Transmission system
- Distribution system

This system can be categorized as primary transmission and secondary transmission. Similarly primary distribution and secondary distribution. This is in Fig 1.

Fig 1



TYPICAL AC POWER SUPPLY SCHEME

It is not necessary that the entire steps which are shown in the diagram must be included in the other power schemes. There may be difference, there is no secondary transmission in many, schemes, in some (small) schemes there is no transmission, but only distribution.

Various stages of a typical electrical power supply system, are as follows

1 Generating station

2 Primary transmission

3 Secondary transmission

4 Primary distribution

5 Secondary distribution

Generating station

The place where electric power produced by the parallel connected three phase alternators / generators is called generating station (i.e power plant).

he ordinary power plant capacity and generating voltage may be 11KV, 11.5 KV, 12KV or 13KV. But economically. It is good to step up the produced voltage from (11KV, 11.5KV or 12KV) to 132KV, 220KV, 400KV or 500KV or greater (in some countries, up to 1500KV) by step up transformer (power transformer).

Primary transmission

The electric supply (132KV, 220 KV, 500KV or greater) is transmitted to load center by three phase three wire (3 phase - 3 wires) overhead transmission system.

Secondary transmission

Area far from city (outskirt) which have connected with receiving station by line is called secondary transmission. At receiving station, the level of voltage reduced by step-down transformers up to 132KV, 66 or 33KV and electric power is transmitted by three phase three wire (3 phase - 3 wires) overhead system to different sub stations. So this is a secondary transmis**sion.**

Primary distribution

At a sub station, the level of secondary transmission voltage (132KV, 66 or 33KV) is reduced to 11KV by step down transformers.

Generally, electric supply is given to heavy consumer whose demands is 11KV, from these lines which carries 11KV (in three phase three wire overhead system) and they make a separate sub station to control and utilize this power.

In other cases, for heavier consumer (at large scale) their demand is about 132 KV or 33KV they take electric supply from secondary transmission or primary distribution (in 132KV, 66KV or 33KV) and then step down to the level of voltage by step -down transformers in their own sub station for utilization (i.e for electric traction etc).

Secondary distribution

Electric power is given to (from primary distribution line (i.e.) 11KV) distribution sub station. This sub station is located near by consumers area where the level of voltage reduced by step down transformers is 415V. These transformers are called distribution transformers, in

3 phase four wire system (3 phase - 4 wires), there is 415 volts (Three phase supply system) between any two phases and 240 volts (single phase supply) between neutral and any one of the phase (lives) wire.

Residential load (i.e. Fans, light, and TV etc) may be connected between any one phase and neutral wires, while three phase load may be connected directly to the three phase lines.

Elements of distribution system

Secondary distribution may be divided into three parts.

1 Feeders

2 Distributors

3 Service lines or service mains

Those electric lines which connect generating station (power station) or sub station to distributors are called feeders. Remember that current in feeders (in each point) is constant while the level of voltage may be different, the current flowing in the feeders depends on the size of conductor.

Distributors

Those tapings which extracted for supply of electric power to the consumers or those lines, from where consumers get electric supply is called distributors

Current is different in each section of the distributors while voltage may be same. The selection of distributors depends on voltage drop and may be designed according to voltage drop. It is because consumers get the rated voltage according to the rules. (Fig 2)

Service lines or service mains

The normal cable which is connected between distributors and consumer load terminal are called service line or service mains. A complete typical AC power supply system scheme is in Fig 3.

Comparison of DC and AC transmission

The electric power can be transmitted either by means of DC (or) AC. Each system has it's own merits and demerits. Some technical advantages and disadvantages of two systems are stated below.

AC transmission

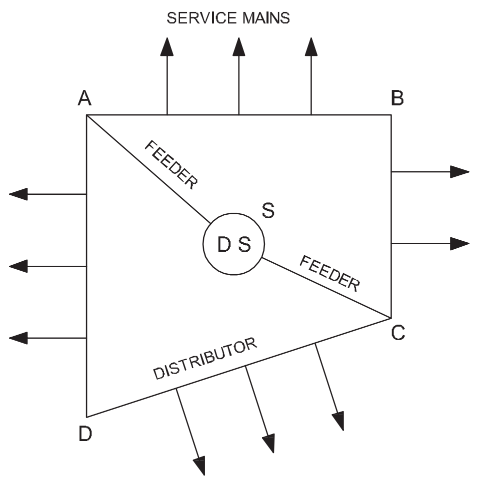
Some years ago, the transmission of electric power by DC has been receiving of the active consideration of engineers due to it's appreciable advantages.

Advantages of DC electric power transmission

1 It requires only two conductors

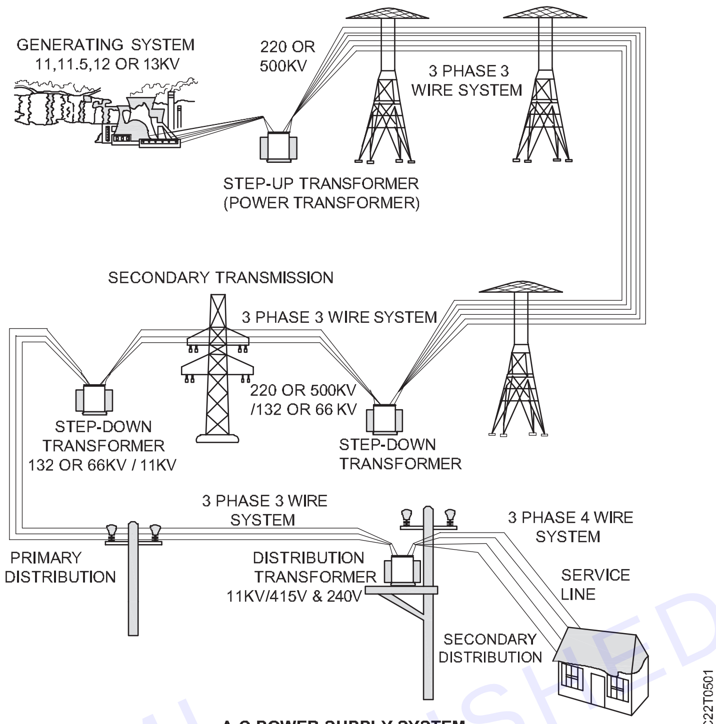
2 There is no problem of inductance, capacitance and phase displacement which is common in AC transmission.

Fig 2



DISTRIBUTION SYSTEM

Fig 3



A.C.POWER SUPPLY SYSTEM

3 For the same load and sending end voltage, the voltage drop in DC transmission lines is less than that in AC transmission.

4 As there is no skin effect on conductors, therefore entire cross - section of conductor is usefully utilized thereby affecting saving in material.

5 For the same value of voltage insulating material on DC lines experience less stress as compared to those on AC transmission lines.

6 A DC line has less corona loss and reduced interference with communication circuits.

7 There is no problem of system instability which is so common in AC transmission.

Disadvantages of DC transmission

1 Generation of power at high DC voltages is difficult due to commutation problems and cannot be usefully utilized at consumer ends.

2 Step up or step -down transformation of DC voltages is not possible in equipment like transformer.

Advantages of AC electric power transmission

1 Power can be generated at high voltages as there is no commutation problems.

2 AC voltages can be conveniently stepped up or stepped down by using transformers.

3 High voltage transmission of AC power reduces losses.

Disadvantages of AC electric power transmission

1 Problems of inductances and capacitances exist in transmission lines.

2 Due to skin effect, more copper is required.

3 Construction of AC transmission lines is more complicated as well as costly.

4 Effective resistance of AC transmission lines is increased due to skin effect.

From the above comparison, it is clear that high voltage DC transmission is superior to high voltage AC transmission. At present, transmission of electric power is carried by AC and effort is making towards DC transmission also. The convertor and inverter have made it possible to convert AC into DC and vice versa easily. Such devices can operate upto 30MW at 400KV in single units. The present day trend is towards AC for generation and distribution at high voltage DC for transmission.

The AC power at high voltage is fed to the convertor which convert AC to DC. The transmission of electric power is carried at high DC voltage. At the receiving emf DC is converted into AC with the help of invertors. The AC supply is stepped down to low voltage by receiving end transformer (T_R) for distribution.

Power transmission (Fg 4)

Introduction

Electrical energy is carried by conductors such as overhead transmission line and underground cables. The properties for several types of transmission lines are high voltage, low voltage, high power, low power, overhead and underground cables.

In order to provide electrical energy to consumers in usable form, a transmission and distribute on system must satisfy some basic requirements they are

i provide power at all times.

ii maintain a stable, nominal voltage does not vary by more than ± 10%.

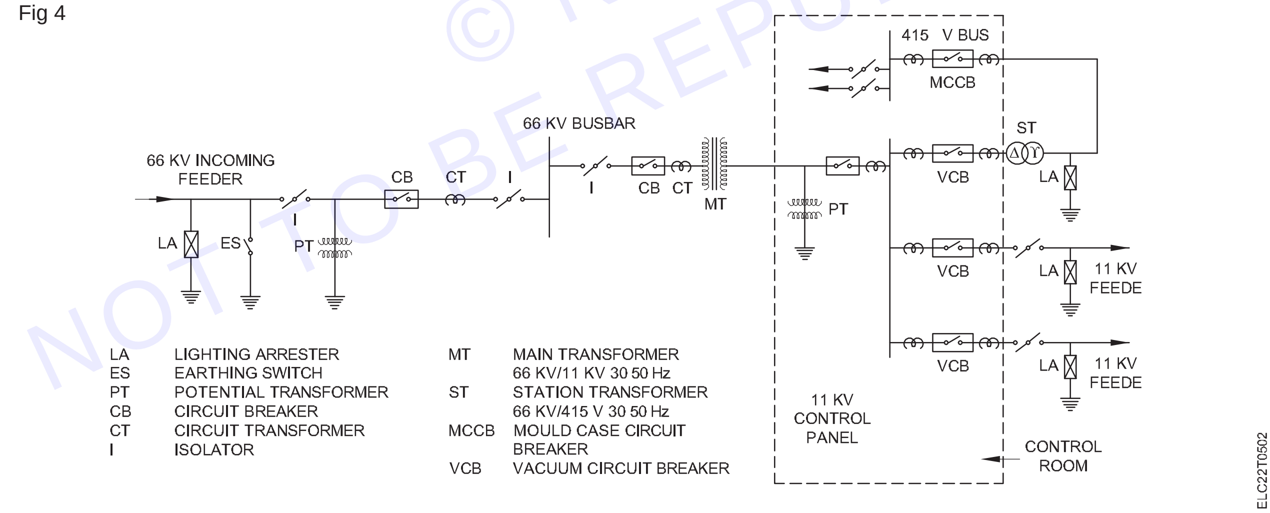
iii maintain a stable frequency that does not vary by more than ± 2Hz

iv supply energy at an acceptable price

v meet standards of safety

vi respect environmental standards

Fig 4



Tranmission substations

To change the line voltage by means of step up and step down transformers and regulate it by means of synchronous condensers or transformers with variable taps.

Distribution substations

Change the medium voltage to low voltage by means of step down transformers which may have automatic tap changing capability to regulate the low voltage.

Interconnecting substations

To increase the stability of the overall network it is essential to tie different power systems together to enable power exchange between them.

These substations also contain circuit breaker, fuses and lightning arrestors to protect expensive apparatus and provide quick isolation of faulted lines from the system.

Types power lines

a Low tension - operating at 1000V or less

b High tension - voltage is up to 11 KV.

c Super tension - 22Kv to 33 KV

d Extra high tension - 33 to 66 KV

e Extra super voltage conductor - beyond 132 KV

Advantages of high voltage transmission

1 It reduces volume of conductor material

2 Increases transmission efficiency

3 Decreases percentage line drops

Disadvantages of high voltage transmission

1 Increased cost of insulating the conductor

2 Because of increased cost of transformer switch gears are used.

Advantages of high voltage DC transmission

1 It requires only two conductors

2 No inductance, capacitance and phase difference.

3 No skin effect.

4 Insulation stress is less

5 Less corona loss

6 Dielectric loss is less suitable for cable

7 No stability problems and synchronizing difficulties

8 DC transmission line has better voltage regulation

9 Advantages of high voltage DC transmission

Disadvantages of high voltage DC transmission

1 Electric power cannot be generated at high DC voltage

2 DC cannot be stepped up

3 Dc switches and circuit breakers have their own limitations

Advantages of high voltage AC transmission

1 Power can be generated at high voltage.

2 Maintenance of AC stations is easy and cheaper.

3 It can be stepped up or stepped down by transformer with ease and efficiency

Disadvantages of high voltage AC transmission

1 Require more copper or conductor

2 AC transmission line is more complicated

3 Skin effect

4 Has capacitance and there for continuous loss of power due to charging

Various transmission systems

1 Overhead transmission system

2 Underground transmission system

Overhead transmission system

1 Types of OH lines

 i Line in horizontal

 ii Line in vertical

2 Materials used in oh system

 i Poles
 ii Cross arm brackets
 iii Wires
 iv Insulators
 v Stay rods and stay wires
 vi Guards

Poles

The selection of a particular type depends on the number and weight of wires used type of ground and type of work.

Type of poles used are

1 **Wooden pole –** This type of poles is used for temporary electric lines. The length of wooden pole is kept 6-9 meters out of which 1-2 meters buried in the ground.

2 **Cement concrete pole –** he length of the pole is kept7-10 meters out of which 1.5 – 2.5 meters length is buried in the ground

3 **Steel pole –** These poles are made in different shapes they are

 a Rail line type pole
 b Tubular pole
 c Compound pole
 d Tower

Tower

For EHT lines lattice structured towers are used. Their height is kept more than the other type poles and they are constructed by joining a number of angle iron pieces

3 Cross arm brackets

The wires and the insulators are balanced on both sides of cross arm brackets. They are fitted on the top side of the pole. The 3 length of a cross arm brackets should be kept such that the wires may not touch each other due to wind and storm. The brackets are fitted with I type clamps made of iron.

4 Wires

Aluminum, copper and steel wires are used for installation of overhead lines. The use of single conductor wire is limited to 6 SWG and the wires thicker than this are always of stranded type. The strength of stranded cable can be increased by 10 times by using one steel wire. This type wire is known as ACSR wire and mostly used for EHT lines.

5 Insulators

Porcelain or glass insulators are mounted on the cross arm so as to isolate the wires from the cross arm, pole etc. The wires are tied on the insulators. Polished porcelain insulators are preferred because of their increased insulation strength.

The insulators are mounted in required shapes they are

Pin insulator

These are screwed on the cross arm at a pin. The single shed type insulators are used for low voltage lines, double shed types are used for 33 KV line.

Shackle insulator

These are porcelain insulator, which are used in the overhead lines of factories and workshops. They are preferred at the starting and terminating ends and at the bends of a low or medium voltage line.

Suspension insulator

These insulators are made of glass or porcelain in the form of disc which can be fastened together in any number as per the requirement a wire is tied at the bottom end. They are used in EHT voltage line normally one disc on 11 KV, 3 discs on 33KV and 12 discs on 132 KV are used.

Egg or stay wire insulator

These insulators are used in stay wires to avoid any leakage of current in them from the line wires.

6 Stay wire or stay rods

Stay wires are necessary for the poles installed at bends. An egg insulator is mounted at a height of 3m in the stay wire. A stay wire is always tied in an opposite direction to that of the tension of the line.

7 Guard

All overhead lines are provided with proper guards at crossings.

The guarding methods are

i Cradle guarding

ii Cage guarding

iii Bird guarding

iv Bead guarding

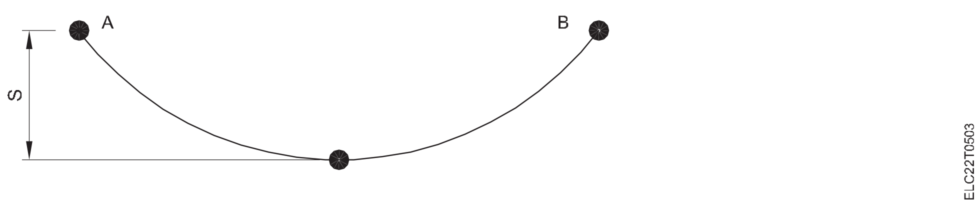
v Trolly guarding

Sag in overhead lines (Fig 5)

- While erecting an overhead line, it is very important that conductors are under safe tension.
- If the conductors are too much stretched between supports to save conductor material, the stress in the conductor may reach unsafe value and in certain cases the conductor may break due to excessive tension.
- In order to permit safe tension in the conductors, they are not fully stretched but are allowed to have a dip or sag.
- The difference in level between points of supports and the lowest point on the conductor is called sag.
- The sag should be so adjusted that tension in the conductors is within safe limits.
- The tension is governed by conductor weight, effects of wind, ice loading and temperature variations.
- It is a standard practice to keep conductor tension less than 50% of its ultimate tensile strength.

  Sag αl^2 Sag $\alpha 1/T$

Fig 5



Overhead versus underground system

Public safety

The underground system is more safe than overhead system because all distribution wiring is placed underground and there are little chances of any hazard.

Initial cost

The underground system is more expensive due to the high cost of trenching, conduits, cables, manholes and other special equipment. The initial cost of an underground system may be five to ten times than that of an overhead system.

Flexibility

The overhead system is much more flexible than the underground system. In the latter case, manholes, duct lines etc., are permanently placed once installed and the load expansion can only be met by laying new lines. However, on an overhead system, poles,wires, transformers etc., can be easily shifted to meet the changes in load conditions.

Corona effect

When the applied voltage exceeds a certain value (critical disruptive voltage) the conductors are surrounded by a faint violet glow called corona. This is occurred by the ionization of air surrounded by a hissing sound. When the surface is even the effect of corona is less.

Advantages of corona

1 Acting as valve for the surges

2 Effect of transients produced by surges is reduced

3 Electrostatic stress is reduced

Disadvantages of corona

1 Power loss and radio interference

2 Produce ozone layer, hissing noise.

3 Insulation damage

Methods of reducing corona

1 By increasing conductor size

2 By increasing conductor spacing

3 By using bundled conductor

Skin effect

Skin effect is a tendency for alternating current to flow mostly near the outer surface of a conductor. This effect become more and more apparent as the frequency increases. This effect is most pronounced in radio frequency system and transmission lines.

Factors affecting

The skin effect in an ac system depends on a number of factors

1 Shape of conductor

2 Type of material

3 Diameter of the conductor

4 Operational frequency

Ferranti effect

In all electrical systems current flows from the region of higher potential to the region of lower potential to compensate for the electrical potential difference that exist in the system. In medium distance transmission line or long distance transmission line in case of light loading or no load operation of transmission system the receiving at voltage often increases beyond the sending end voltage, leading to phenomena known as Ferranti effect. A long transmission line can be considered to compost a high amount of capacitance and inductance distributed across the entire length of the line.

This voltage can be controlled by placing shunt reactors at the receiving ends of the lines. Shunt reactor is an inductive current element connected between line and neutral to compensate the capacitive current from transmission lines.

Protective relays

Protective relay is a device that detects the fault and initiates the operation of the circuit breaker to isolate the defective element from the rest of the system.

Primary winding of a current transformer(C.T.) which is connected in series with the line to be protected. Secondary winding of C.T. and the relay operating coil.Tripping circuit which may be either AC or DC. It consists of a source of supply, the trip coil of the circuit breaker and the relay stationary contacts.

Requirements of protective relaying (Fig 6)

- **Selectivity:** It is the ability of the protective system to select correctly that part of the system in trouble and disconnect the faulty part without disturbing the rest of the system.
- **Speed:** The relay system should disconnect the faulty section as fast as possible.
- **Sensitivity:** It is the ability of the relay system to operate with low value of actuating quantity.
- **Reliability:** It is the ability of the relay system to operate under the pre-determined conditions.
- **Simplicity.** The relaying system should be simple so that it can be easily maintained.
- **Economy.** The most important factor in the choice of a particular protection scheme is the economic aspect.

Basic relays (Fig 7)

Relays are classified in to two

1 Electromagnetic attraction

2 Electromagnetic induction.

Fig 6

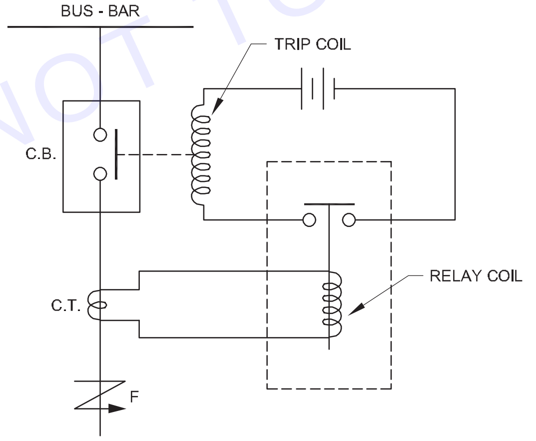
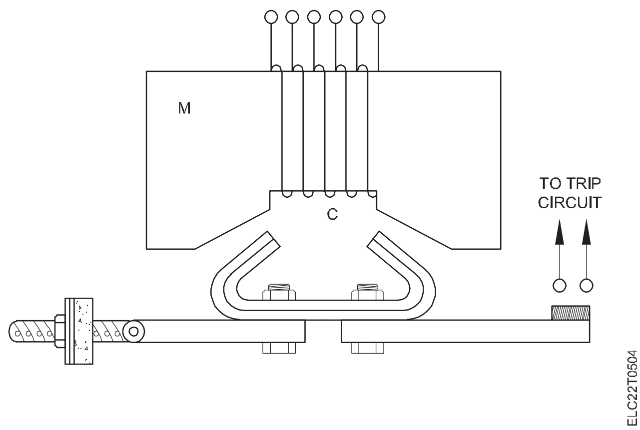


Fig 7



Pick-up current

It is the minimum current in the relay coil at which the relay starts to operate. So long as the current in the relay is less than the pick-up value, the relay does not operate and the breaker controlled by it remains in the closed position.

Current setting

Usually achieved by the use of tapping's on the relay operating coil.

Pick-up current = Rated secondary current of C.T x Current setting

Plug-Setting Multiplier (P.S.M.)

It is the ratio of fault current in relay coil to the pick-up current i.e.

$$\text{P.S.M.} = \frac{\text{Fault current in relay coil}}{\text{Pick - up current}}$$

Functional relays

- Induction type overcurrent relays
- Induction type reverse power relays
- Distance relays
- Differential relays
- Translay scheme

Equipments used in substations

Circuit breaker

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by over current or short circuit. Its basic function is to interrupt current flow after protective relays detect a fault. A circuit breaker can be reset (either manually or automatically) to receive normal operation.

Once a fault is detected, a circuit breaker contact must open to interrupt the circuit, some mechanically stored energy contained within the breaker is used to separate the contacts, although some of the energy required may be obtained from the fault current itself. The contacts must carry the load current without excessive heating and must also withstand the heat of arc produced when interrupting the circuit.

Different types of breakers use vacuum, air, insulating gas(SF6) or oil as the arc quenching medium.

Lightning arrestor

A lightning arrestor is a device used on power systems above 1000 V to protect other equipment from lightning and switching surges. It is essentially a collection billions of microscopic junctions of metal oxide grains that turn ON and OFF in micro seconds to form a current path from the top terminal to the ground terminal of the arrestor.

Underground cables

1 These cables give greater safety to the public and better out look to the city.

2 These are used in submarine crossings.

3 These cables provide less interference with amenities.

1 Classification of cables

a The type of insulating material used by the manufacturer.

b The voltage for which they are used manufactured.

2 Types of cables for three phase service

In practice underground cables are generally used to deliver 3-phase power. For the purpose three core cable or three single core cables may be used. For voltage up to 66kv 3-core cable is preferred due to economic reasons.

The following cables are generally used for three phase service are:

a Belted cables – up to 11kv.

b screened cables – from 22kv to 66kv.

c pressure cables – beyond 66kv.

3 Advantages and disadvantages (Fig 8)

Advantages

1 Less subject to damage from severe weather conditions (mainly lightning, wind and freezing).

2 Underground cables pose no hazard to low flying aircraft or to wildlife.

3 Much less subject to conductor theft, illegal connections, sabotage, and damage from armed conflict.

Disadvantages

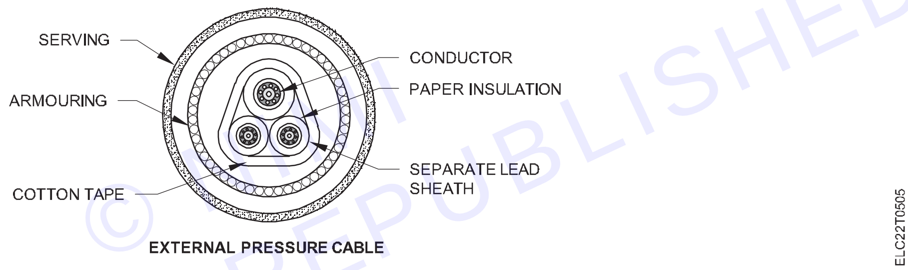
1 Underground cable locations are not always obvious, which can lead to unwary diggers damaging cables or being electrocuted.

2 Operations are more difficult since the high reactive power of underground cables produces large charging currents and so makes voltage control more difficult.

Undergrounding is more expensive, since the cost of burying cables at transmission voltages is several times greater than overhead power lines, and the life-cycle cost of an underground power cable is two to four times the cost of an overhead power line

Underground cables offer an affordable and justifiable solution for critical parts, and in some cases the entire length, of overhead high voltage power lines. With appropriate technology used in appropriate places, the environmental impact of underground cables can be minimised.

Fig 8



Line insulators

Objectives: At the end of this lesson you shall be able to

- explain the types of insulators and their uses.

Line insulators

The aim of using a line insulator in an overhead line is to hold the live conductor to prevent leakage of current from the conductor to the pole. These are made of porcelain clay and are thoroughly glazed to avoid the absorption of moisture from the atmosphere.

Properties of insulators

i High mechanical strength in order to withstand conductor load, wind load etc.

ii High electrical resistance of insulator material in order to avoid leakage currents to earth.

iii High relative permittivity of insulator material in order that dielectric strength is high.

iv The insulator material should be non - porous, free from impurities and cracks otherwise the permittivity will be lowered.

v High ratio of puncture strength to flash over.

The most commonly used material for insulators of overhead line is porcelain but glass, steatite and special composition materials are also used to a limited extent.

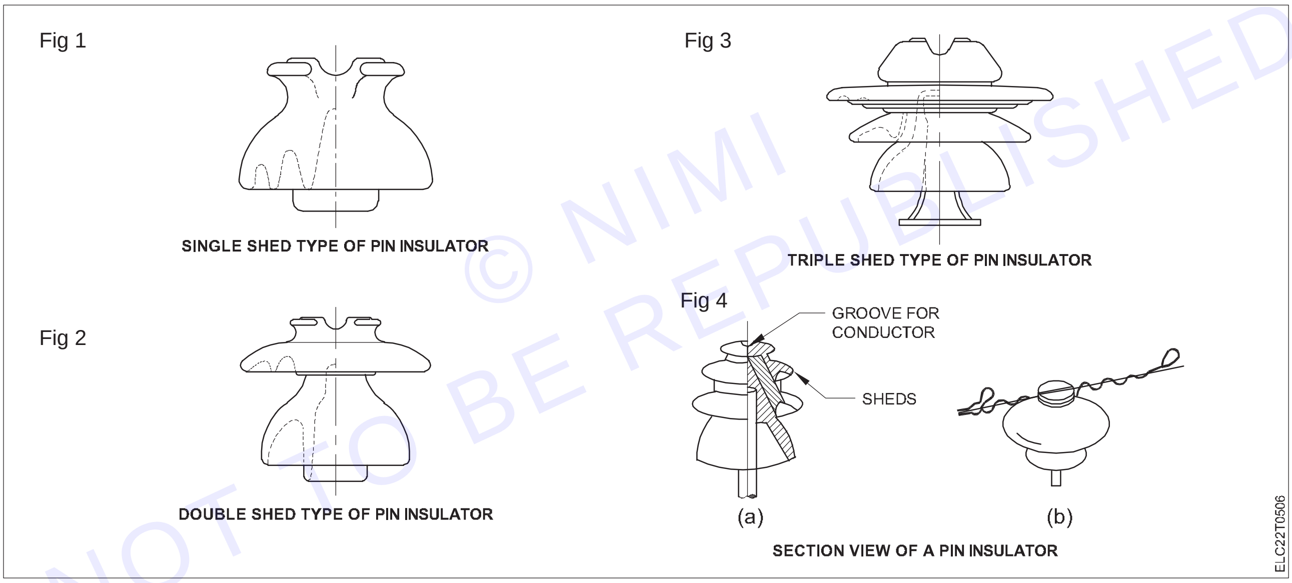
Fig 4

The following are the common types of insulators in use.

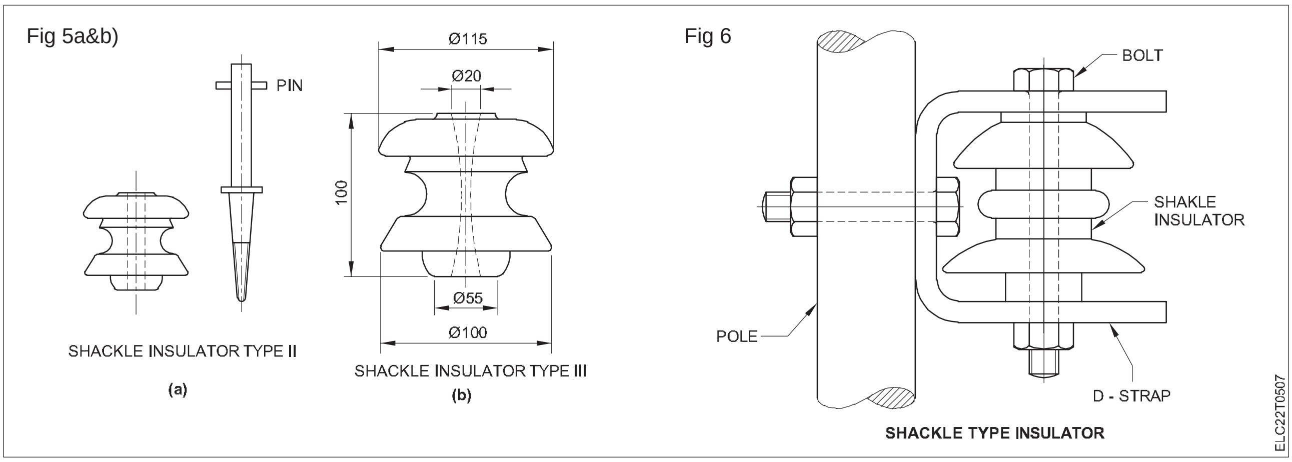
- Pin type insulator
- Shackle insulator
- Suspension insulator
- Strain insulator
- Post insulator
- Stay insulator
- Disc insulator

Pin Insulators: Pin insulators are used for holding the line conductors on straight running of poles. Pin insulators are three types. i.e single shed (Fig 1) double shed (Fig 2) and triple shed (Fig 3) The single -shed pin insulators are used for low and medium voltage lines. The double and triple shed pin insulators are used for over 3000V. These sheds are used to drip off the rain water.

The part section of a pin type insulator is in Fig 4a & 4b As the name suggest, the pin type insulator is secured to the cross - arm on the pole. There is a groove on the top of the insulator for housing the conductor. The conductor passes through this groove and is bound by the annealed wire of the same material as the conductor.



Shackle insulators : Shackle insulators are generally used for terminating on corner poles. These insulators are used for medium voltage line only. (Fig 5a & 5b)

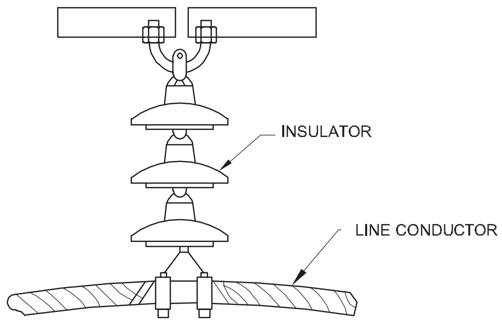


But now a days, they are frequency used for low voltage distribution lines. Such insulators can be used either in horizontal position or in a vertical position. They can be directly fix to the pole with a bolt or to the cross arm. Fig 6 shows a shackle insulator fixed to the pole. The conductor in the groove is fixed with a soft binding wire.

Suspension type insulators

The cost of pin type insulator increases rapidly as the working voltage is increased. Therefore, this type of insulator is not economical beyond 33 KV. For high voltage (>33KV), it is a usual practice to use suspension type insulators as in Fig 7. They consist of a number of porcelain discs connected in series by metal links in the form of a string. The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross- arm of the tower. Each unit or disc is designed for low voltage, say 11KV. The number of discs in series would obviously depend upon the working voltage. For instance, if the working voltage is 66KV, then six discs in series will be provided on the string.

Fig 7



SUSPENSION INSULATOR

Advantages

1 Suspension type insulators are cheaper than pin type insulators for voltage beyond 33 KV.

2 Each unit or disc of suspension type insulator is designed for low voltage, usually 11KV. Depending upon the working voltage, the desired number of discs can be connected in series.

3 If any one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.

4 The suspension arrangement provides greater flexibility to the line. The connection at the cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.

5 In case of increased demand on the transmission line it is found more satisfactory to supply the greater demand by raising the line voltage than to provide another set of conductors. The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.

6 The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross arm of the tower, therefore, this arrangement provides partial protection from lighting.

Strain insulators

When there is a dead end of the line or there is corner or sharp curve, the line is subjected to greater tension. In order to relieve the line of excessive tension, the strain insulators are used. For low voltage lines (<11KV) shackle insulators are used as strain insulators. However for high voltage transmission lines, strain insulator consists of an assembly of suspension insulators. The discs of strain insulators are used in the vertical plane. When the tension in the lines is excessively high, as at long river spans, two or more strings are used in parallel.

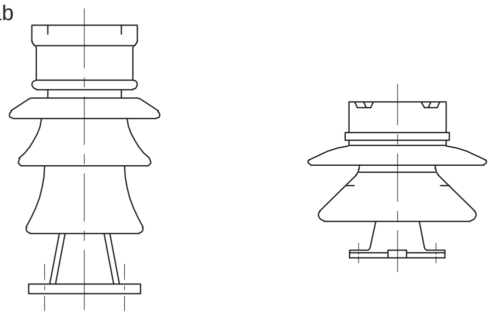
Post insulators

Cap and pin type: Such insulators can be used for mounting of buses, dropout fuses, line conductors, G.O.A.B (Gang Operated Air Break) switches. These are of outdoor type and are available in 11, 22 and 33KV ranges. (Fig 8a&b)

Stay insulators (Fig 9): Stay insulators are also known as strain insulators and are generally used up to 33 KV line. These insulators should not be fixed below three metres from the ground level. These insulators are also used where the lines are strained.

The supporting wire which is used in the opposite direction of tension on the pole due to overhead conductors is known as 'stay wire'. It prevents the bending of the pole due to tension of the conductor. These stay wires consist of 4 to 7 strands of GI wire is in Fig 10. The correct size to be used depends upon the tension on the pole.

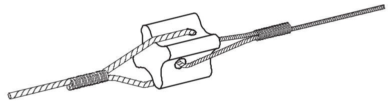
Fig 8a&b



a) CAP AND PIN INSULATOR FOR GOAB SWITCH

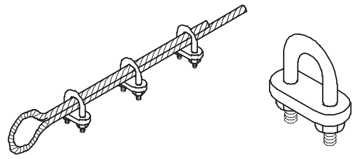
b) ANOTHER DESIGN OF CAP AND PIN INSULATOR FOR GOAB SWITCH

Fig 9



STAY INSULATOR

Fig 10



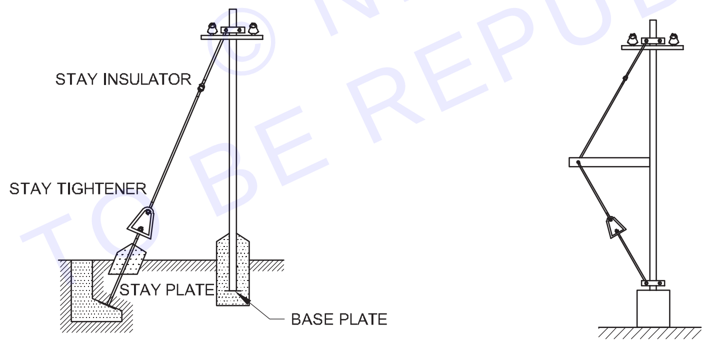
GI STAY WIRE & CLAMP

ELC22T0509

Stays and struts: Stays and struts are the different types of supporting wires for the pole. Stays are generally used for angle and terminating poles to prevent the bending of the pole whereas struts are used where space for stay is very limited. Fig 11 shows both the stay and the strut.

One end of the stay is fixed at the top of the pole and its other end is grouted in the concrete foundation.

Fig 11



STAY TYPE SUPPORT

STRUT TYPE SUPPORT

ELC22T0510

Disc insulators: Disc insulators are made of glazed porcelain or tough glass and are used as insulators at dead ends, or on straight lines as suspension type for voltages 3.3 kV and above. (Figs 12, 13 and 14)

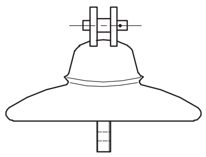
These are available in four designs:

Tongue and clevis type (Fig 12): A round pin with a cotter pin is used to hold the tongue of one unit in the clevis of the other.

Ball and socket type (Fig 13): In this case insulators are assembled by sliding the ball of one insulator from the side. A cotter pin is slipped in from the back of the socket so that the ball cannot slide out. These are used at dead ends.

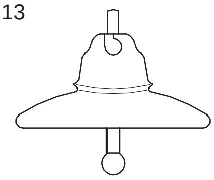
Insulators for cold climate (Fig 14): For cold climate the depth of the lower cap is increased to get creepage distance which becomes necessary in cold climates. Two designs known as fog type and anti-fog types are available.

Fig 12



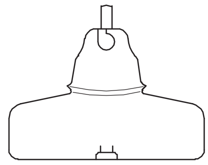
DISC INSULATOR TONGUE AND CLEVIS TYPE

Fig 13



DISC INSULATOR BALL AND SOCKET TYPE

Fig 14



DISC INSULATOR COLD AND CLIMATE TYPE

ELC22T0511

Overhead poles and method of joining aluminium conductors

Objectives: At the end of this lesson you shall be able to

- state transmission and distribution by O.H lines
- list out the main components and explain each of them
- state the types of power lines with respect to the classification of voltage
- state sag in O.H lines.

Overhead lines: Electric power, which is generated from generating plant / station to the consumer end is transmitted and distributed either by means of overhead lines (O.H) or by under ground cables (U.G. cables).

Main components used in O.H lines

An overhead line may be used to transmit or distribute electric power.

i Conductors which carry electric power from the sending end station to the receiving end station.

ii Supports which may be poles or towers and keep the conductors at a suitable level above the ground.

iii Insulators which are attached to supports and insulate the conductors from the ground.

iv Cross arms which provide support to the insulators.

v Miscellaneous items such as phase plates, danger plates, lightning arrestors, anti-climbing wires etc.

Commonly used conductor materials

The most commonly used conductor material for overhead lines are copper, aluminium, steel reinforced aluminium, galvanized steel and cadmium copper.

All conductors used for overhead lines are preferably stranded in order to increase the flexibility. In stranded conductors, there is generally one central wire and round this, successive layers of wires containing 6, 12, 18, 24...

Line Supports: The supporting structures for overhead line conductors are various types of poles and towers called line supports. In general, the line supports should have the following properties:

i High mechanical strength to withstand the weight of conductors and wind loads etc.

ii Light in weight without the loss of mechanical strength

iii Cheap in cost and economical to maintain.

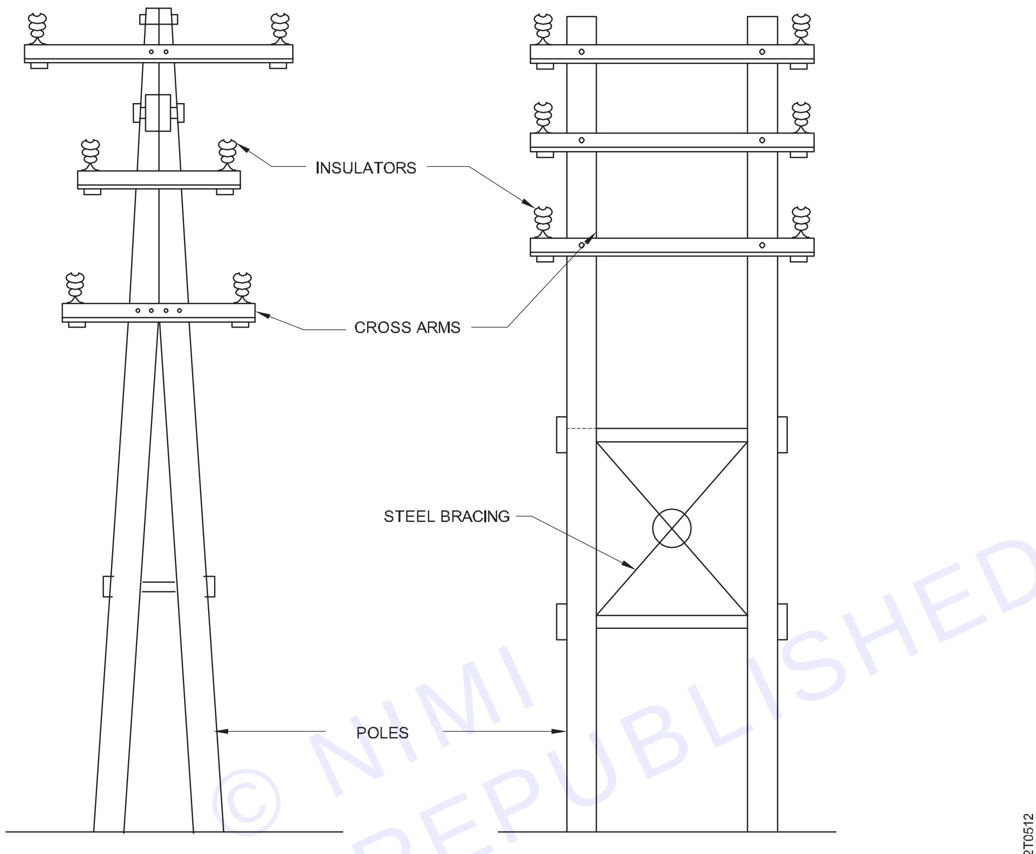
iv Longer life

v Easy accessibility of conductors for maintenance

The line supports used for transmission and distribution of electric power are of various types including wooden, poles, steel poles, R.C.C poles and lattice steel towers.

Wooden poles (Fig 1): These are made of seasoned wood (sal or ehir) and are suitable for lines of moderate cross sectional area and of, relatively shorter spans, say up to 50 metres. Such supports are cheap, easily available, provide insulating properties and, therefore are widely used for distribution purposes in rural areas as an economical proposition.

Fig 1



WOODEN POLES

Steel poles: The steel poles are often used as a substitute for wooden poles. They possess greater mechanical strength, longer life and permit longer spans to be used. Such poles are generally used for distribution purposes in the cities. This type of supports need to be galvanized or painted in order to prolong its life. The steel poles are of three types viz (i) rail poles (ii) tubular poles and (iii) rolled steel joints.

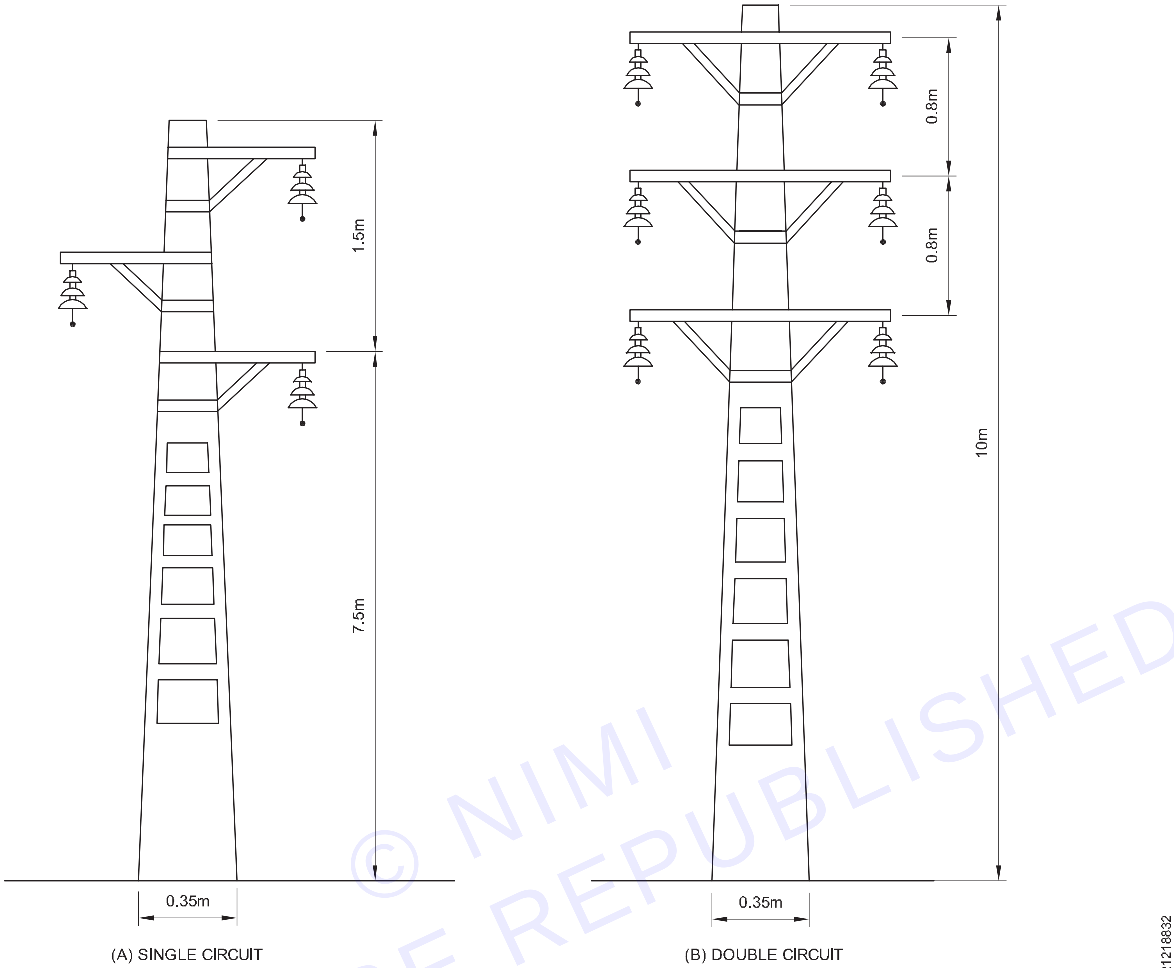
RCC Poles: The reinforced cement concrete (RCC) poles have become very popular as line supports in recent years. They have greater mechanical strength, longer life and permit longer spans than steel poles. Moreover, they give good outlook, require little maintenance and have good insulating properties. Fig 2 shows R.C.C poles for single and double circuit. The holes in the poles facilitate the climbing of poles and at the same time reduce the weight of line supports.

Steel towers

In practice, wooden, steel and reinforced concrete poles are used for distribution purpose at low voltages, say upto 11 KV. However for long distance transmission at higher voltage, steel towers are invariably employed. Steel towers have greater mechanical strength, longer life, can withstand more severe climatic conditions and permit the use of longer spans. The risk of interrupted service due to broken or punctured insulation is considerably reduced owing to longer spans. Tower footings are usually grounded by driving rods into the earth. This minimizes the lightning troubles as each tower acts as a lightning conductor.

Fig 3(a) shows a single circuit tower. However, at a moderate additional cost, double circuit tower can be provided as shown in Fig 3(b). The double circuit has the advantage that it ensures continuity of supply. In case there is breakdown of one circuit, the continuity of supply can be maintained by the other circuit.

Fig 2



RCC POLES

The electric supply is transmitted at different voltages through over head lines and the types of power lines are furnished below:

a Low voltage line (should not exceed 250V)

b Medium voltage line (should not exceed 650V)

c High voltage line (should not exceed 33000V (33 KV)

d Extra high voltage line (above 33KV)

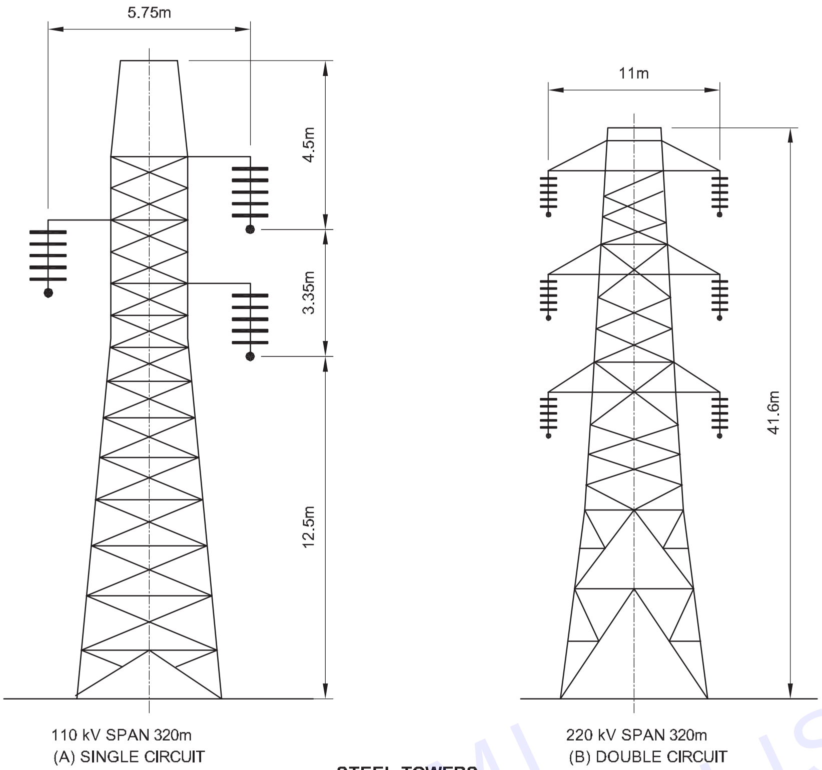
Sag in Overhead Lines: The difference in level between points of supports and the lowers point on the conductor is called 'Sag'.

Fig 4 (a) shows a conductor suspended between two equal level supports A and B. The conductor is not fully stretched but is allowed to have a dip. The lowest point of the conductor is O and the sag is S. Fig 4(b) shows unequal level supports.

Conductor sag and tension: This is an important consideration in the mechanical design of overhead lines. The conductor sag should be kept to a minimum in order to reduce the conductor material required and to avoid extra pole height for sufficient clearance above ground level.

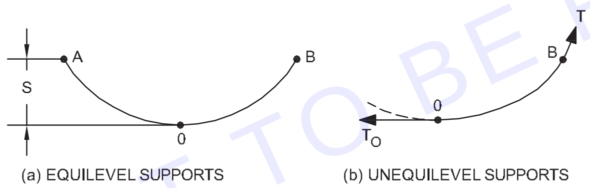
Method of erection of poles: The poles to be erected may be brought to the pit location by manual labour or by improvised carts. Then the pole may be erected in the pit. Wooden support poles may be utilized to facilitate lifting of the pole at the pit locations as in Fig 5.

Fig 3



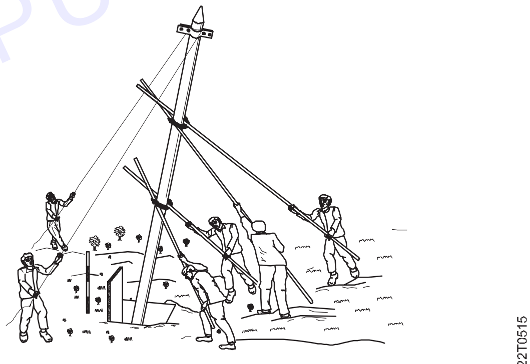
STEEL TOWERS

Fig 4



SAG

Fig 5



ERECTION OF POLES

Before the pole is placed into the pit, RCC padding or alternatively a suitable base plate maybe given below the pole to increase the surface contact between the pole and the soil. The padding will distribute the density of the pressure due to the weight of the pole on the soil.

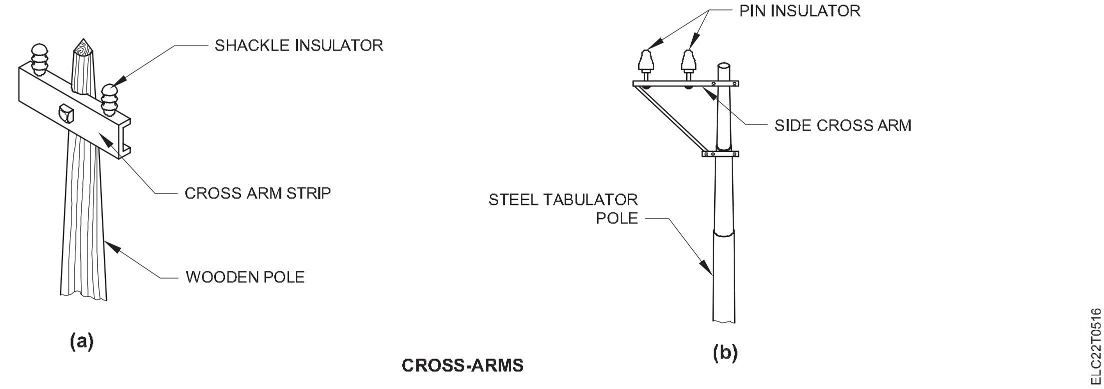
Having lifted the pole, the same should be kept in a vertical position with the help of Manila /sisal ropes of 20/25 mm dia. using the rope as a temporary anchor. As the poles are being erected, say, from an anchor point to the next angle point, the alignment of the poles are to be checked and set right by visual check. The verticality's of the poles are to be checked with a spirit level on both transverse and longitudinal directions.

Having satisfied that the vertical and longitudinal alignment are all right, earth filling is to be done. In some soils the poles are to be concreted up to ground level of the pit. After the poles have been set, the temporary anchors are to be removed.

Use of cross - arms : These are also known as insulator supports and are made of either wood or angle iron. Cross- arms are installed at the top of the pole for holding the insulators on which conductors are fastened. They are also known according to their relative position on the poles. If the cross - arm is fixed in the centre of the poles then it is called a cross - arm (Fig 6a) and if installed on one side of the pole, then it is termed as side cross -arm (Fig 6b) U-shaped cross - arms are specially used for three phase lines.

Channel iron cross-arms fabricated from channels of size 75 mm x 40 mm x 5.7 kg/m or size 100mm x 50 mm x 7.9 kg/m are used for H.T. lines, and those made from angle irons of size 50 mm x 50 mm x 6 mm are used for L.T lines.

Fig 6



CROSS-ARMS

Joining of aluminium conductors

Objectives: At the end of this lesson you shall be able to

- state the type of joints
- explain the type and use of connectors used to joining conductors
- explain the steps to testing of O.H lines
- state the preliminary safety procedure for OH line erection.

Joining accessories in O.H lines: Normally connectors are used for joining the O.H. aluminium conductors. Connectors maybe of several types of which few are described below.

1 Sleeved joints

2 Straight through connectors / taps

3 Vice - clamp connectors /taps with parallel grooves

4 Nut and bolt connector

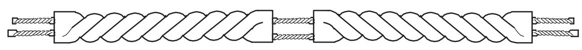
Sleeved joints

Twisted joints: Oval shaped aluminium sleeves are inserted over the conductors to be joined and then twisted as in Fig 1. Only one sleeve is sufficient for all aluminium conductors whereas two concentric sleeves are used for ACSR conductors. One each for the aluminium and steel portions. Twisting joints are recommended for conductors up to 15 mm diameter. Only special wrenches should be used for twisting the sleeves.

Compression joints: ACSR conductors are joined by compression joints having two sleeves as in Fig 2. The larger sleeve is of aluminium , fitting over the entire conductor, and the smaller one is of steel fitted on the steel portion of the wire eccentrically. Conductors to be joined are inserted into the sleeves one after the other and compressed either by hand or by hydraulic compressors. Compression joints for all aluminium conductors consist of aluminium sleeve only .

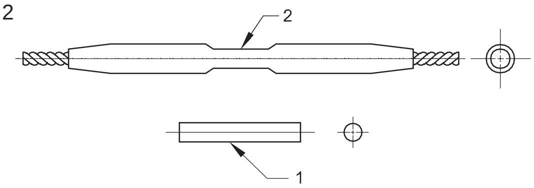
Straight through connectors / taps: Two types of connectors are used to join two straight through run of wires in such locations where mass concrete foundations are to be adopted to avoid collapse of foundation in the black cotton soil.

Fig 1



TWISTED JOINT

Fig 2

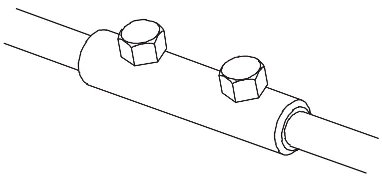


COMPRESSION JOINT FOR ASCR

Straight sleeve and nut connector: This is in Fig 3. It has a sleeve (round or oval in section) made of cadmium plated brass or aluminium. The conductors are inserted into the sleeve and tightened by the nuts.

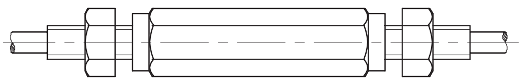
Compression connector: In this, the conductors are wrapped at both ends and then compressed with nuts as in Fig 4.

Fig 3



STRAIGHT SLEEVE AND NUT

Fig 4



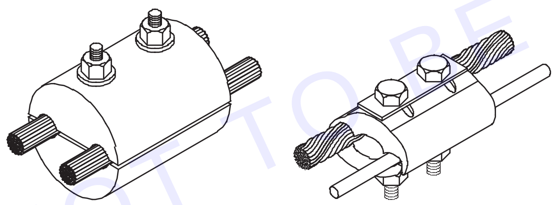
COMPRESSION CONNECTOR

Vice-clamp connectors/taps with parallel grooves (PG): There are several types as explained below.

Standard P.G. clamps: This clamp as in Fig 5 consists of two aluminium halves, having two semi-circular parallel grooves in each half. After inserting the conductors to be joined, the galvanized steel nuts are tightened. As the grooves are of the same size, it is useful only when the joining conductors are also of the same size.

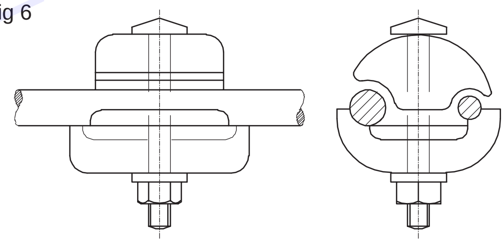
Universal P.G. clamp: This is in Fig 6. It has grooves of slightly different shape to accommodate different sizes of conductors, and has only one bolt. This clamp is not for heavy duty service but can be used for tapping connections from the distribution line to individual consumers through aluminium conductors.

Fig 5



P.G. VICE CONNECTOR

Fig 6

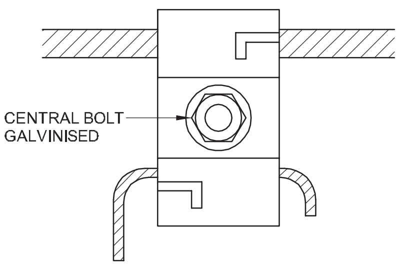


U.P.G. CLAMP

Bimetallic universal parallel groove clamps (B.M.P.G. clamps): This clamp is in Fig 7. It has a brass body with cadmium plating. The two halves are tightened by a galvanised bolt. This is used for connecting copper wire to aluminium conductors in the case of consumer service connections.

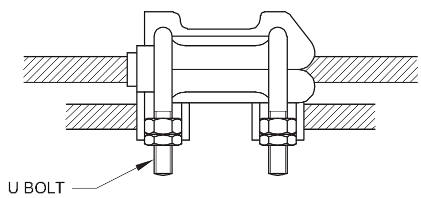
U bolt clamps: This is in Fig 8. It uses 'U' bolts as these bolts exert 4 times more pressure than the conventional straight bolts. Such clamps are suitable for heavy duty conductors.

Fig 7



CENTRAL BOLT IS OF GALVANISED IRON

Fig 8



U BOLT CLAMP

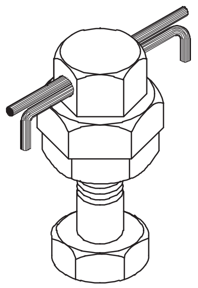
Nut and bolt connectors are of two types

Nut connector

This is in Fig 9. It has a transverse hole through which the conductors to be joined are inserted and then tightened by the bolt.

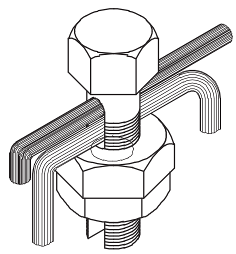
Split bolt connector: This is in Fig 10. It is split at the stem. The conductors to be joined are to be inserted into the split and then tightened by the external nut.

Fig 9



NUT CONNECTOR

Fig 10



SPLIT BOLT CONNECTOR

ELC22T0521

Types of relays and its operation

Objectives: At the end of this lesson you shall be able to

- state the classification of relays
- list the types of relays and their uses
- explain the principle of operation of over current, differential, earth fault, distance and non directional relays
- state the characteristics of relays
- explain the principle of operation of a over voltage under voltage relay
- state the necessity of time multiplier setting of relay.

Introduction

The relays is the element that senses as abnormal condition in the circuit and commands the operation of the breaker. It interpret the fault quantities ie, CT output current and PT output voltage and sending the command to the tripping circuits of breaker for operation in accordance with the characteristic set in the relay and the value of the time multiplier setting.

Classification of Relays

Relays are classified mainly in three categories; they are according to:

1 **Quantity sensed:** Current, Voltage, active power, reactive power & impedance

2 **Tripping:** Instantaneous trip, delayed trip inverse time response and definite time

3 **Operating principle:** Electro magnetic relays, Induction relays, Thermal relays and static or digital relays

Types or relays: Various types of relays are used as per the requirement; they are:

1 Over current relay

2 Over voltage relay

3 Under voltage relay

4 Differential relay

5 Earth fault relay

6 Distance relay

7 Impedance relay

8 Admittance relay

9 Reactance relay

Relay is one of the main device used for switch gear protection networks to protect the transmission lines, transmission equipments and sub station equipments. The equipments used for transmission and in substation for distribution such as transformers, lightening arrestors,earth switches, isolators, CTs & PTs etc; are very costly and needs continuous protection from damage. Replacement or repairs are not easy and to provide an uninterrupted supply to consumers. So, protection of these devices/equipments are very essential

Reasons for over current, Over voltage and under voltage fault:

Many reasons constituted for over current, over and under voltage or earth faults; type of fault and the cause effect is listed in Table 1.

Table 1

Sl No	Type of Fault	Cause	Effect
1	Phase to neutral short	- Insulation failure - Components failure - Human error`	- High current flow in line. - Fire
2	Phase to phase short in transmission lines	- Tree branches falls on line - Snakes crossing on tower lines and - Birds falls - Strong winds - Natural calamities - Riots, and human made faults	- Very high current flows - Fire - Extensive damage of equipments
3	Phase to ground fault	- Insulation failure - Component failure	- High current flow in line - Fire - Low voltage
4	Lightening storm etc;	- Natural calamities	- Very high current flows - Fire - High voltage spikes
5	Sudden removal of heavy load	- Fuse failure	- High voltage
6	Increasing Load beyond the rated level	- Human Error	- Low voltage in line - Over loading the line

Sensors used for Relays

The relay cannot accept the total line voltage or load current. A small part of the electrical quantity is supplied to the relay through sensors. A current transformer popularly known as CT and a potential transformer PT, is serves the purpose of sensors in current relay and voltage relay. Various input and output ratios are in practice to supply the sensing quantity to the relays according to the load conditions.

Working principle of current relay

The electro magnetic relay widely using in the substation and transmission lines are serves the protection from the disaster conditions. The latest version of modern static or digital relays are now a days out dated the conventional electro magnetic relays, because of their many of advancements compare to electro magnetic relay. (Fig 1)

Fig 2 shows the front panel setting of a electric magnetic relay.

1 Time multiplier setting (TMS)

2 Trip flag

3 Aluminium rotating disc

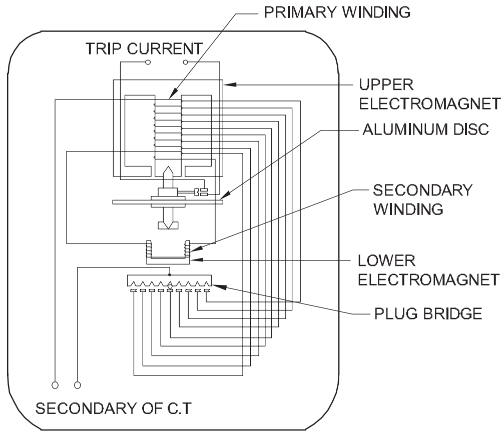
4 Percentage fault quantity time reference dial

5 Tap setting plug

6 Input fault quantity (VONI)

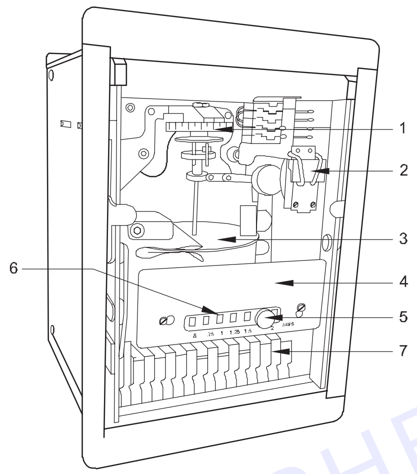
7 Contact plug terminals

Fig 1



INDUCTION TYPE NON-DIRECTIONAL OVERCURRENT RELAY

Fig 2



ELECTRO - MECHANICAL RELAY

ELC22T0522

An induction type over current relay giving inverse time operation with a definite minimum time characteristic is in Fig 1. It consists essentially of an ac energy meter mechanism with slight modification to give required characteristics. The relay has two electromagnets. The upper electromagnet has two windings, one of these is primary and is connected to the secondary of a CT in the line to be protected and is tapped at intervals.

The tappings are connected to a plug setting bridge by which the number of turns in use can be adjusted, thereby giving the desired current setting. The plug bridge is usually arranged to give seven sections of tappings to give over current range from 50% to 200% in steps of 25%. If the relay is required to response for earth fault the steps are arranged to give a range from 10% to 70% or 20 to 80% in steps of 10%. The values assigned to each tap are expressed in terms of percentage of full-load rating of CT with which the relay is associated and represents the value above which the disc commences to rotate and finally closes the trip circuit.

Thus pick-up current equals the rated secondary current of CT multiplied by current setting. For example suppose that an over current relay having a current setting of 150% is connected to a supply circuit through a CT of 500/5A. The rated secondary current of CT is 5 A and, therefore, the pick-up value will be 1.5 x 5i.e., 7.5 A. It means that with above current setting, the relay will actually operate for a relay current equal to or greater than 7.5 A.

Similarly for current settings of 50, 100 and 200% the relay will operate for relay currents of 2.5A, 5 A and 10 A respectively. Adjustment of current setting is made by inserting a pin between the spring loaded jaws of the bridge socket at the tap value required. When the pin is

withdrawn for the purpose of changing the setting value while the relay in service, the relay automatically adopts higher setting, thus the CT's secondary is not open-circuited.

Time multiplier setting

This setting is helps the relay to shorten the time selected without change of any other settings made in the relay. Time multiplier helps the relay to activate fast the breaker in case the fault quantity is more than 50% of the fault quantity selected by the tap setting.

Differential protection relay

Differential protection is a very reliable method of protecting generators, transformers, busbar and transmission lines from the effects of internal faults. In normal operating conditions the current through the CTs is the same. So the relay sense no differential current. This is also the case for external faults. Differential protection can be used for protecting generators from faults to ground. Differential protection of busbars in substations uses one CT for each incoming line. All incoming currents are added up and compared to the sum of all out going currents.

General schematic diagram of differential protection relay is in Fig 3.

The installation of differential relay for protection of power transformers used in transmission line is in Fig 4.

Distance relays / Admittance relay

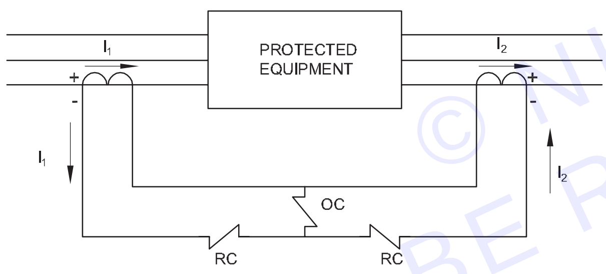
The impedance of a transmission line is proportional to its length, for distance measurement it is appropriate to use a relay capable of measuring the impedance of a line up to a predetermined point (the reach point) Such a relay is described as a distance relay and is designed to operate only for faults occurring between the relay location and the selected reach point thus giving discrimination for faults that may occur in different line sections

Reactance relays (or) Shaded pole type non directional relay

The reactance relay is a straight line characteristic that responds only to the reactance (XL) of the protected line . It is non directional and is used to supplement the admittance relay as a tripping relay to make the overall protection independent of resistance. It is particularly useful on short lines where the fault arc resistance is the same order of magnitude as the line length.

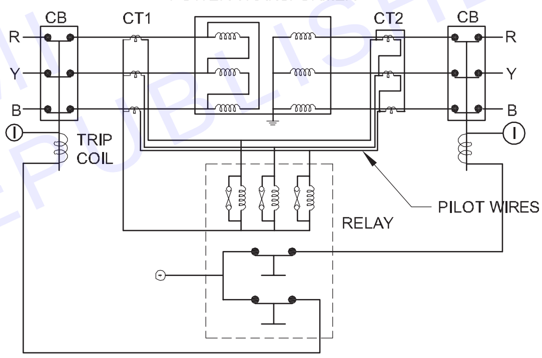
The relay serves an important part in switchgear protection. The electromagnetic relay is the first generation of protective relays and it has many moving parts and working in the principles of induction. Electromagnetic relay can carry one function ie., over current, over voltage or under voltage at a time. This draw back is overcome by the use of static or digital relay which can use for multi function, as well as more accurate than electromagnetic relays.

Fig 3



DIFFERENTIAL RELAY

Fig 4



DIFFRENTIAL PROTECTION IN TRANSFORMER

ELC22T0523

Circuit breakers - parts - functions- tripping mechanism

Objectives: At the end of this lesson you shall be able to

- state about circuit breaker
- list the various types of circuit breakers
- explain the parts of each circuit breakers
- explain the principle of operation of circuit breaker
- explain the application and uses of circuit breaker.

Circuit breaker

Circuit breakers are the electrical device (or) equipment, which makes or breaks the electrical circuit. In a 240 volt single phase system a low rated single pole switch can use the circuit to break or make. But in this case the resultant spark at the contacts are negligible and this will not make any fire, in the circuit or contacts since the current is very low.

But in the case of heavy loads; say some hundreds, of ampere are flowing in a circuit the resultant spark at contact are heavy and this leads to electrical fire. To overcome this problem the sparks at the contacts are to be controlled or quenched, when any load makes or breaks. The equipment or device used to make or break a circuit under control at the same time it prevents or quenching the resultant fire is called as a circuit breaker. The breakers are named after the quenching medium used to control the fire such (1) air circuit breaker, (2) oil circuit breaker, (3) vaccum circuit breaker and (4) Sulphur hexafluoride (SF6) circuit breaker.

Air circuit breaker (ACB): A circuit breaker which uses the either natural air or blast air as an Arc quenching medium is termed as Air-circuit breakers.

ACB is widely used upto 15KV in place of oil circuit breaker because there is no chance of the fire due to the quenching oil as in case of OCB.

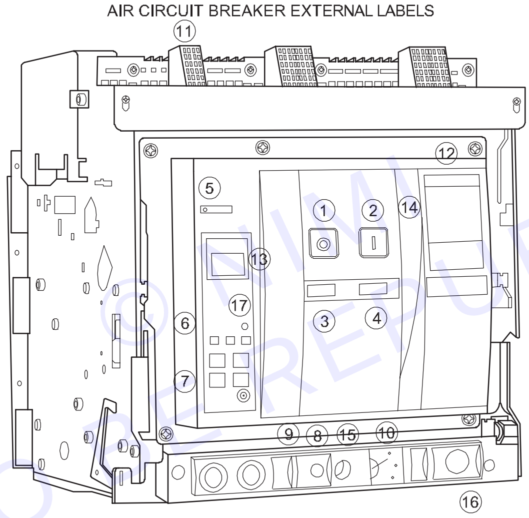
Air- Circuit breakers are widely used in industries as well as power system for controlling and protection of different section of the circuit like, Transformers, Motors, Generators / Alternator etc and leads the system stable and reliable. Other components are also associated with circuit breakers like fuses, relays, switches etc.

Construction of air - circuit breaker

External lables / parts of ACB in Fig 1

Fig 1

AIR CIRCUIT BREAKER EXTERNAL LABELS



EXTERNAL VIEW OF ACB

1 OFF button (O)

2 ON button (I)

3 Main contact position indicator

4 Energy storage mechanism status indicator

5 Reset button

6 LED indicators

7 Controller

8 “Connection” “Test” and “isolated” position latching /locking mechanism

9 User padlock

10 Connection, “Test”, and isolated position indication

11 Connection test and isolated position indication contacts

12 Name plate

13 Digital displays

14 Energy storage handle

15 Draw out /in hole

16 Rocker repository

17 Trip reset button

Internal construction of air circuit breaker

The internal parts of an ACB in Fig.2

1 Sheet steel supporting structure

2 Current transformer for protection trip unit

3 Pole group insulating box

4 Horizontal rare terminals

5 Plate for fixed main contacts

6 Plates for fixed arcing contacts

7 Plate for main moving contacts

8 Plates for moving arcing contacts

9 Arcing chamber

10 Terminal box for fixed version - sliding contacts for withdrawable version

11 Protection trip unit

12 Circuit breaker closing and opening control

13 Closing springs

14 Spring loading arrangement

15 Manual releasing lever

Principle of operation of air circuit breaker

- When the circuit breaker opens the circuit either under the normal condition or in the fault condition, some Arc is produced between the main contacts and some current flows to the load, called transition current through the arc.
- This Arc and the current should be suppressed /eliminated especially during the fault condition otherwise the severity of the fault level will be more and damages the circuit which leads to the electric fire.
- During the period of Arc some voltage appears across the main contacts called transition voltage, which will be more than the rated system / supply voltage.
- To quench the Arc, this transition voltage should be reduced or the Arc voltage to be increased. The minimum voltage required to maintain the arc is called as Arc voltage. In ACB, the Arc voltage is increased in the following three ways.
- Arc voltage can be increased by cooling arc plasma by air. The temperature of arc plasma is reduced, more voltage will be required to maintain the arc.
- By splitting the arc into a number of series in Arc chute will increases the arc voltage.
- Arc voltage can be increased by lengthening the arc path. As length of arc path is increased its resistance of the arc path will increase hence the arc voltage is increased.

Some ACB contains two pairs of contact . The main pair carries the current and the made of copper. An additional pair of contact (Arc contact) is made of carbon. When the breaker is opened, the main contact opens first. and the arc contact remains in touch. The arcing gets initiated when arc contacts are separated.

Hence transition voltage will be reduced.

Application and uses of air circuit breaker

- It is used for protection of plants
- It is used for common protection of electrical machines
- Air circuit breaker is also used in electricity sharing system upto 15KV
- Also used in low as well as high voltage and current applications.
- It is used for protection of transformers, capacitors and generators.

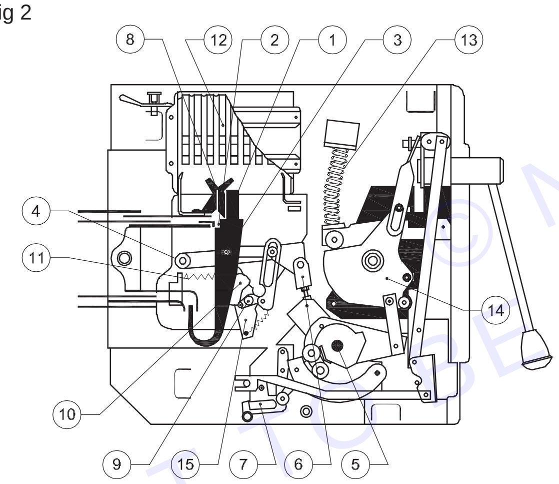
Types of air circuit breaker

- Plain air circuit breaker
- Air blast circuit breaker

Plain air circuit breaker: In this circuit breaker a chamber is fitted surrounding the contact. The chamber is known as **"arc chute"**. The arc chute will help in achieving cooling. Arc chute is made from some refractory material.

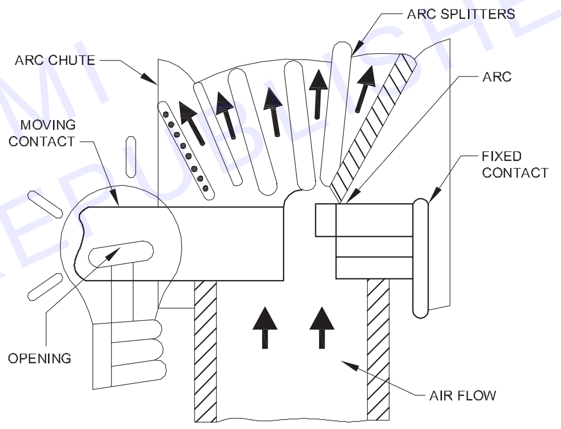
The arc chute is divided into a number of small compartments by using metallic separation plates called **arc splitters** and behave as a mini arc chute as in Fig 3. Initial arc will split into a series of arcs and make the arc voltages higher than system voltage. They are preferable choice in low voltage application.

Fig 2



INTERNAL VIEW OF CIRCUIT BREAKER

Fig 3



AIR BLAST CIRCUIT BREAKER

ELC22T0525

Oil circuit breakers (OCB)

Circuit breakers which uses the insulating oil (e.g transformer oil) as an arc quenching medium is called as oil circuit breaker. The main contacts of the OCB are opened under the oil and an arc is struck between them. The heat of the arc evaporates the surrounding oil and dissociates it into gaseous of hydrogen at high pressure.

The hydrogen gas occupies a volume about one thousand times that of the oil decomposed. The oil is, therefore, pushed away from the arc and an expanding hydrogen gas bubble surrounds the arc region of the contacts. The arc extinction is completed by two processes. Firstly, the hydrogen gas has high heat conductivity and cools the arc, thus aiding the de-ionization of the medium between the contacts.

Secondly, the gas sets up turbulence in the oil and forces it into the space between contacts, thus eliminating the arc as in Fig 4. The result is that arc is extinguished and circuit current is interrupted.

The advantages of oil as an arc quenching medium

i It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.

ii It acts as an insulator and permits smaller clearance between main contacts.

iii The surrounding oil presents the cooling surface in close proximity to the arc.

The disadvantages of oil as an arc quenching medium.

i It is inflammable and there is a risk of a fire.

ii It may form an explosive mixture with air.

iii The arcing products (e.g. carbon) remain in the oil and it deteriorates the quality of insulating oil.

iv Periodic checking and replacement of the insulating oil is required.

Types of oil circuit breakers

i Plain break oil circuit breakers

i Arc control oil circuit breakers.

iii Low oil circuit breakers

Plain break oil circuit breakers: In plain- break oil circuit breaker the main contacts are placed under the whole oil in the tank. There is no special system for arc control other than the increase in length of separation of the contacts. The arc extinction occurs when a critical gas is reached between the contacts.

The plain - break oil circuit breaker is the oldest type and has a very simple construction. It consists of fixed and moving contacts enclosed in a strong weather- tight earthed tank containing transformer oil upto a certain level and an air cushion above the oil level.

The air cushion provides sufficient room to arc gases without the generation of unsafe pressure in the circuit breaker. It also absorbs the upward oil movement. Fig 5 shows a double break plain oil circuit breaker. It is called a double break because it provides two breaks in series.

Fig 4

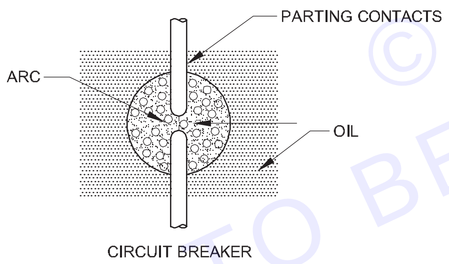
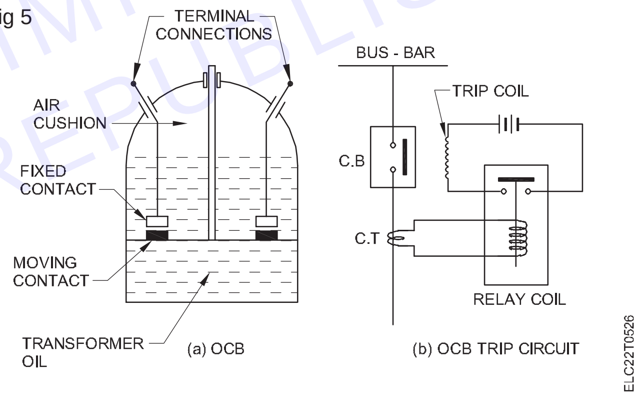


Fig 5



Principle of working

Under normal operating conditions, the fixed and moving contacts remain closed and carries the normal circuit current. When a fault occurs, the moving contacts are pulled down by the tripping mechanism and an arc is produced which vaporizes the oil into hydrogen gas. The arc extinction is completed by the following processes.

i The hydrogen gas bubble generated around the arc, cools the arc.

ii The gas sets up turbulence in the oil and helps in eliminating the arc.

iii As the arc lengthens due to the separation of contacts, the Arc voltage is increased.

The result is at some critical gap, the arc is extinguished and the circuit current is interrupted.

Disadvantages

i There is no special control over the arc other than the increase in gap length.

ii These breakers have long and inconsistent arcing times.

iii The speed of interruption is less.

Due to these disadvantages, plain - break oil circuit breakers are used only for low - voltage not exceeding 11 KV applications where high breaking- capacities are not important.

Vacuum circuit breaker (VCB)

Circuit breaker which uses vacuum as an arc quenching medium is called as vacuum circuit breaker.

Vacuum offers the highest insulating strength and have the superior arc quenching properties than any other medium. When the contacts of a breaker are opened in vacuum, the interruption occurs instantly as the dielectric strength between the contacts are many times higher than the other circuit breakers.

The technology is only suitable for medium voltage application. For higher voltage application, the vacuum technology has been developed.

Principle of vacuum circuit breaker

- When the contacts of the breaker are opened in vacuum (107 to 105 torr), an arc is produced between the contacts by the ionisation of metal vapours i.e, combination of electrons and ions of contacts. However, the arc is quickly extinguished because the metallic vapours, rapidly cools resulting quick recovery of dielectric strength.
- The salient feature of vacuum is, as soon as the arc is produced in vacuum, it is quickly extinguished due to the rapid recovery of dielectric strength of vacuum.

Construction of vacuum circuit breaker

Fig 6 shows the typical parts of vacuum circuit breaker

- It consists of the fixed contact, moving contact and arc shield mounted inside a vacuum chamber.
- The movable member is sealed by a stainless steel bellows, is connected to the control mechanism . This enables the permanent sealing of the vacuum chamber, to eliminate the possibility of leak.
- A glass vessel or ceramic vessel is used as the outer insulating body.
- The arc shield prevents the metallic vapours falling on the inside surface of the outer insulating cover.

Working of vacuum circuit breaker

- When the breaker opens, the moving contact is separated from the fixed contact and an arc is produced between the contacts. The production of arc is due to the ionisation of metal ions and depends upon the material of contacts.
- The arc is quickly extinguished because the metallic vapours , are diffused in a short time and condensed on the surfaces of moving and fixed members and arc shields.
- Since vacuum has rapid Arc recovery rate of dielectric strength, the arc extinction in a vacuum breaker occurs with a short separation (say 0.625 cm) of contacts.

Application of VCB

- Vacuum circuit breakers are employed for outdoor applications ranging from 22KV to 66KV.
- They are suitable for majority of applications in rural areas.

Sulphur hexafluoride (SF_6) circuit breaker

Circuit breakers which uses the sulphur hexafluoride gas (SF_6) as an arc quenching medium is called as SF_6 circuit breaker.

The sulphur hexafluoride gas (SF_6) is an electronegative gas and has a strong tendency to absorb the free electrons. When the contacts of the breaker are opened in a high pressure sulphur hexafluoride (SF_6) gas medium and an arc is struck between them.

The SF_6 gas capture the conducting free electrons in the arc and form immovable negative ions. This loss of conducting electrons in the arc quickly improve the insulation strength to extinguish the arc.

The sulphur hexafluoride (SF_6) circuit breakers are very effective for high power and high voltage applications.

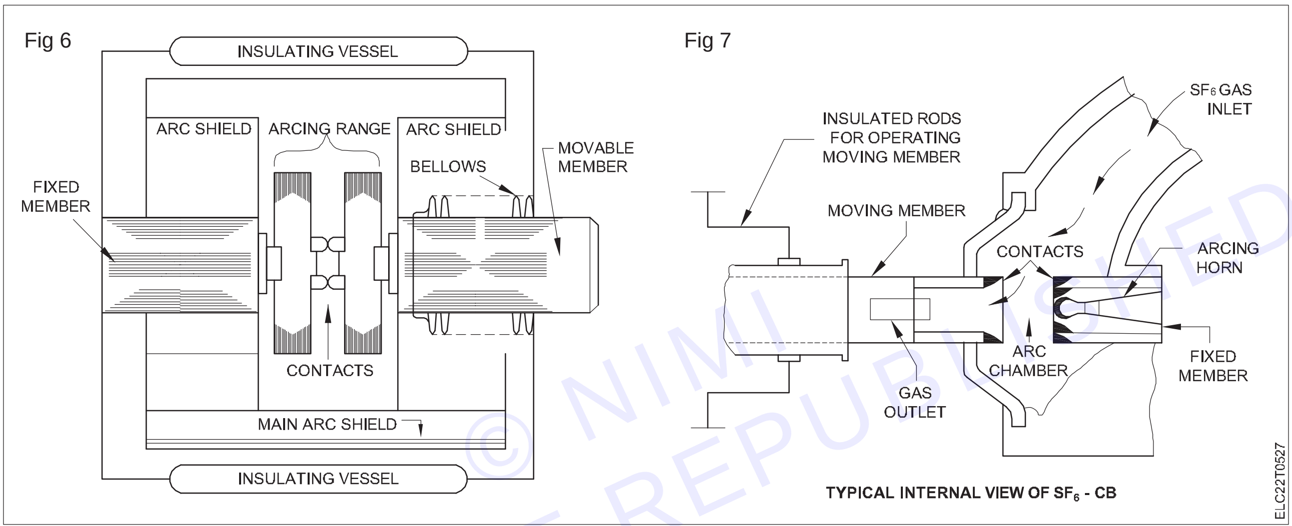
Construction of SF_6 circuit breaker

A sulphur hexafluoride (SF_6) circuit breaker consists of fixed and moving contacts enclosed in a chamber as in Fig 7. The chamber is called arc interruption chamber which contains the sulphur hexafluoride (SF_6) gas and it is connected to sulphur hexafluoride (SF_6) gas reservoir.

When the contacts of breaker are opened, the valve mechanism permits a high pressure sulphur hexafluoride (SF_6) gas from the reservoir to flow towards the arc interruption chamber.

The fixed contact is a hollow cylindrical contact fitted with an arc horn. The moving contact is also a hollow cylinder with rectangular holes in the sides. The holes permit the sulphur hexafluoride gas (SF_6) to let out through them after flowing along and across the arc.

The tips of fixed contact, moving contact and arcing horn are coated with copper - tungsten arc resistant material. Since sulphur hexafluoride gas is costly, it is reconditioned and reclaimed using suitable auxiliary system after each operation of breaker.



Working of SF_6 circuit breaker

In the closed position of the breaker, the contacts remain surrounded by SF_6 gas at a pressure of about 2.8 kg/cm². When the breaker opens, the moving contact is pulled apart and an arc is struck between the contacts. The movement of the moving contact is synchronized with the opening of a valve which permits SF6 gas at 14kg /cm² pressure from the reservoir to the arc interruption chamber.

The high pressure flow of SF_6 gas rapidly absorbs the free electrons in the arc path to form immovable negative ions which are ineffective as charge carriers. The result is that the medium between the contacts rapidly improve the dielectric strength and causes the extinction of the arc. After the breaker operation (i.e. after arc extinction), the valve mechanism is closed by a set of springs.

Advantage of SF_6 circuit breaker

Due to the superior arc quenching properties of SF_6 gas, the sulphur hexafluoride gas circuit breakers have many advantages over oil or air circuit breakers. Some of them are listed below.

1 Such circuit breakers have very short arcing time.

2 Since the dielectric strength of SF_6 gas is 2 to 3 times more than the air, such breakers can interrupt much larger currents.

3 SF_6 circuit breaker gives noiseless operation due to its closed gas circuit and no exhaust to the atmosphere unlike the air blast circuit breaker.

Tripping mechanism of circuit breakers

Objectives: At the end of this lesson you shall be able to

- state the necessity of tripping mechanism
- state the types of tripping mechanism.

Tripping mechanism of circuit breakers

Trip mechanism: Trip mechanism is incorporated in the circuit breaker to switch off the circuit breaker at faulty condition either automatically or manually at the desired time.

Fig 1 shows the arrangement. When the circuit breaker is closed, the mechanism is locked in position by a system of linkages. This lock can be released by lifting the trip bar.

Trip bar is attached to the tripping lever which in turn can be operated manually. The tripping lever is generally kept locked. When the trip bar is lifted the mechanism opens the breaker contacts.

Trip coils: When remote operation is desired, trip coils are used. The trip coils are small solenoids either operated by AC or DC supplies. Fig 2 shows the general arrangement of the trip coil mechanism. A plunger moves freely inside the solenoid. When the solenoid is energised by the trip switch the plunger moves up and release the lock which holds the trip bar. Further the trip coils are also actuated by short circuit /overload and under -voltage relays as described in the following paragraphs.

Shunt trip coils: The shunt trip coil requires an auxiliary supply, a C.T and a relay. The relay can be set to give time-graded protection. The relay closes the trip coil circuit when the load current exceeds the stipulated value. This relay is in Fig 3.

Fig 1

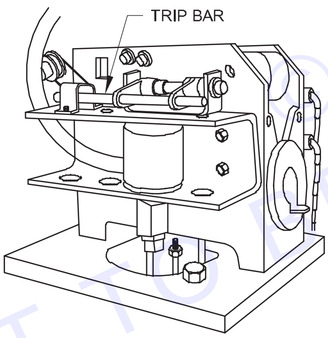


Fig 2

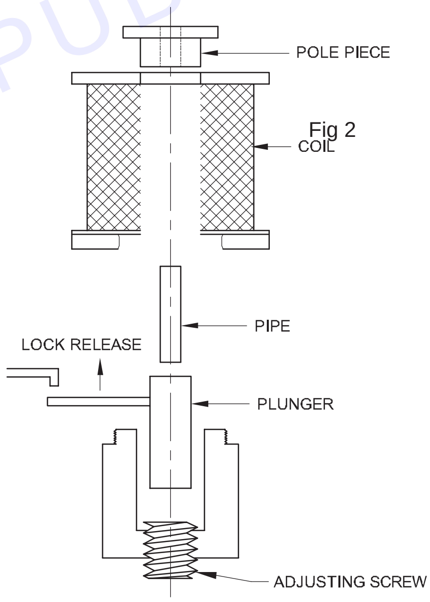
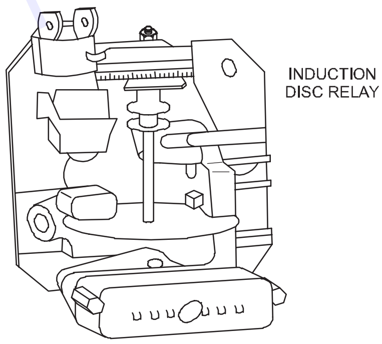


Fig 3



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Series trip coil: The series trip coil mechanism is in Fig 4 consists of a series solenoid with a plunger controlled by a spring. When current in the load become excessive the plunger rises and trips the mechanism.

The current necessary to trip the circuit breaker is regulated by a screw which adjusts the tension of the spring controlling the plunger. Time-lag can be adjusted by the position of the dash pot which holds the piston of the plunger in the oil bath.

In three-phase circuit breakers, there are three series trip coils, three dash pots, three plungers. They can operate the trip mechanism together or independently.

Under voltage release coils: The under-voltage release coil is used in installations where detection and isolation of abnormally low voltage is required. The construction of the under-voltage trip coil is in Fig 5 is similar to the trip coils discussed above except that the plunger is held away from the pole piece by a coiled spring. Under normal operating conditions, the solenoid is energised and the plunger is held down against the force of the spring. When the supply voltage falls, the under - voltage release coil will not be in a position to hold the plunger down against the spring tension. Thus the plunger moves up and pushes the trip bar to trip the circuit breaker.

Fig 4

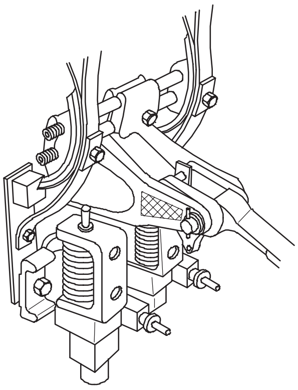
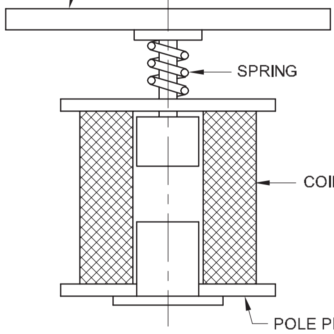


Fig 5



Repair and maintenance of CBs

Objectives: At the end of this lesson you shall be able to

- explain the procedure to carry out maintenance and repair of a OCB
- state the method to adopt checking and maintenance/repair of ACB & VCB
- explain the procedure of the condition of SF_6 circuit breakers and their repair and maintenance.

Any circuit breaker has the fundamental operation is to make and break the circuit. The design and operating procedure depends on the breaking/making load current in the circuit. Selection of quenching medium (oil, air, vacuum or gas) and the volume is involved main factors and proper maintenance is very important to keep the breaker accurate performance and long life.

Maintenance & repair of oil breaker

It is the first generation of circuit breaker used in the electrical protection circuit and it is still in use. High insulated oil is the main quenching medium and the oil storage maintenance is quite difficult. Frequent purification, reconditioning, refilling and leak proof storage etc. keeps the breaker always healthy. Due to this oil storage, recondition and refilling problem, oil circuit breakers are replaced by modern vacuum circuit breaker. Troubleshooting chart at this end will help to carryout smooth maintenance and repair of OCB.

Maintenance & repair of ACB, & VCB

Air circuit breaker are found in variety of applications such as very low, low, medium and high current applications. Natural air with arc chutes in chamber found useful in very low and low to medium circuit breaker. Very high voltage to EHT lines the VCB are used very extensively.

Natural air or forced air used for ACBs arc chutes are common in both ACB chamber, but in high voltage ACB forced or compressed air blow is used. To produce compressed air, air chamber, air compressor is necessary in order to operate ACB.

Maintenance is also required at fixed and moving contacts of OCB. Alloy metals are used to make the tips of contacts part in conductors. But in usage these contacts are partially melted or damaged or repaired frequently otherwise quenching time will increase rapidly.

The tension of loading springs and manual operating levers are to be checked and rectified if any mechanical part is found defective. The coils, electromagnets and other electrical parts are to be checked for its effectiveness. A comprehensive service flow chart is attached for detailed repair and maintenance.

Maintenance & repair of SF_6 circuit breaker

It is a advanced version and compact to use mainly for indoor substation. Since the SF_6 gas is poisonous proper protective gadgets are to be used while handling SF_6 circuit breaker.

The loading, tripping mechanism almost same as that of VCB and air blast ACB. The maintenance and repair mentioned may have to follow in this case also.

The main maintenance requirement in SF_6 circuit breaker are handling gas or charging gas. No recondition is possible the SF_6 total replacement is required in case of any gas failure. More cycle of operation will cause the reduction of gas strength and reducing gas pressure also will be the reason of SF_6 circuit breaker failure.

The SF_6 chart illustrate the relevant failure/repair of the circuit breaker.

Troubleshooting chart - 1

Sl.No.	Type of fault	Cause	Effects/remedy
1	Excessive heat in oil	- Poor dielectric strength	- Heavy spark inside the tank in long duration - Change the oil
2	Oil level diminishing fast	- Leak in tank	- Arrest the leak
3	Sledge deposit in bottom of tank	- Adultered oil, very old oil filled	- No proper contacts in the bottom of tank - Filter the oil
4	Spark continuing in the electrode contact after making circuit	- Conductor tip damaged - No proper contact - Pressure spring defect	- Increased oil temperature - Leads to breakage of the tank - Rectify spring (or) contact tip
5	Manual breaking not functioning	- Loading spring defect - Loading mechanism defective	- No breaking is possible - Rectify
6	No tripping in fault condition	- Defective tripping mechanism - Defective tripping coil	- Fault condition will continue - Damage the machine connected in line
7	Very loud noise in ACB while operation	- Insufficient air flow air pressure in chamber	- Continuous vibration once it is operated. - Maintain air pressure
8	Moving contact broken	- Excessive heat - Excess spring tension - Miss alignment	- Moving contact fail to make contact with fixed contact - Change the contact
9	Melting of electrode tip	- Excessive current produces heavy spark - Substandard alloy metal - Arc quenching is extended beyond the set values	- Check the source of excessive current - Use standard alloy metal - Maintain arc quenching medium in good condition
10	Intermittent tripping of breaker	- Wrong setting in relay - Deflective or faulty loading spring - Faulty moving mechanism	- Correct the setting - Repair spring and loading mechanism
11	Shock in the breaker	- Earth fault	- Do proper earth connection

MODULE 19 : EV Charging

LESSON 117-119 : EV Scenario in India EV charging

Objectives

At the end of this lesson you shall be able to:

- explain about EV scenario in India
- state the basic theory of EV charging batteries
- state the safety requirement for EV charging.

EV Scenario in india and upcoming growth

With the increase in global warming, making environmentally friendly choices and preventing climate change are essential. Electric vehicle (EVs) is one such ecologically friendly choice. A paradigm change is currently taking place in the global automotive sector as it attempts to transition to alternative, less energy-intensive options. One of the primary drivers behind India's recent measures to accelerate the transition to e-mobility is the increase in prices for oil imports, rising pollution, and international pledges to battle global climate change. As a result, India committed to an aspirational goal of having at least 30% of private automobiles as EVs by 2030 at the Conference of the Parties 26 (COP26) Summit.

Current status and future aspirations of India in the EV sector

- The Indian automobile sector ranks fifth globally and is expected to rise to third by 2030. India is the world's largest producer of two and three-wheelers, the second-largest manufacturer of buses, and the biggest producer of vehicles like tractors
- Currently, the automobile industry contributes 7.1% of India's Gross Domestic Product (GDP) and 49% of its manufacturing GDP. This means that this significantly impacts the nation's economy. This suggests that, as they follow the trends, numerous auto ancillaries and associated sectors will grow along with the EV industry in the upcoming years.
- India's automotive industry is worth around %222 Bn, while the EV market in India is estimated to be valued at $2 Bn by 2023 and $7.09 Bn by 2025. Further, the automotive industry accounts for 8% of all national exports. This sector accounts for 40% of the total $31 Bn of global research and development spend [Research and Development (R&D wing)]
- There are a total of 13, 92,265 EVs on Indian roads as on August 2022 (data by Ministry of Road Transport and Highways, India). By 2030, this will likely increase by 45–50 Mn EVs on the road.
- Currently, the automotive sector employs around 37 Mn people, and by 2030, it aspires to generate 50 Mn direct and indirect jobs.
- By 2030, the EV market is anticipated to reach 10 Mn annual sales, growing at a Compound Annual Growth Rate (CAGR) of 49% between 2022 and 2030
- Between April 2000 and March 2022, the sector attracted equity inflows from Foreign Direct Investment (FDI) of $ 32.84 Bn, or 6% of all FDI in equities during that time.

Government initiatives and achievements in this sector

Following are a few steps taken to boost the growth of the EV sector in India.

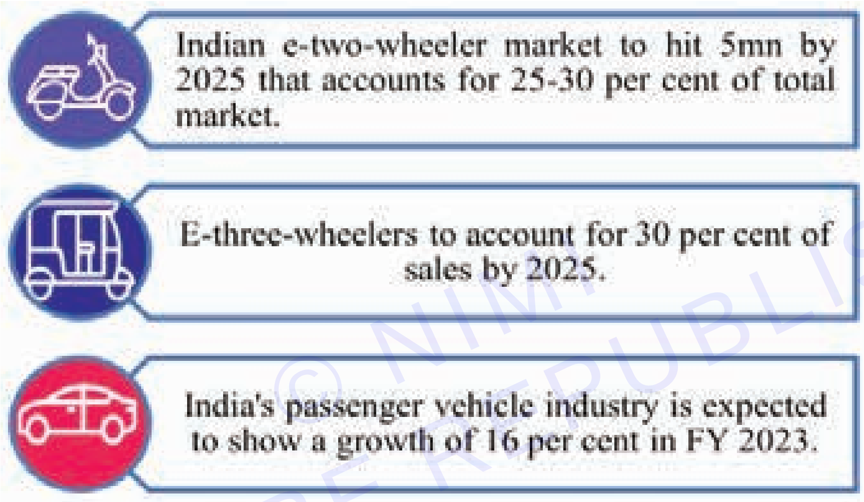
Firstly, many conventional automotive players and oil companies are investing heavily to boost EV demand to reach the aspirational goal. To name a few, Skoda revealed its plan to produce EVs locally in India in 2021, and Indian Oil Corporation stated its plans to create 22,000 EV charging stations over three to five years.

Secondly, the Indian government has also been implementing several programmes to encourage the growth of electric mobility, including 100 per cent FDI through the automotive route in the EV space, incubator programmes, shared facilities for prototyping and small-scale manufacturing, financial support through the Credit Guarantee Scheme for Start-ups (CGSS), tax breaks, and subsidies for consumers.

Thirdly, in 2021, investment into EV startups reached a record high, rising by about 255 per cent to reach $ 444 Mn. For example, Ola Electric ($ 253 Mn), Blusmart ($ 25 Mn), Simple Energy ($ 21 Mn), Revolt ($ 20 Mn), and Detel ($ 20 Mn) were the EV firms that received the most financing in 2021. About 500 startups spanning the whole EV value chain make up the Indian EV ecosystem, with 63 per cent of those startups solely dedicated to manufacturing.

Fourthly, the Production linked incentive (PLI) scheme (with a $ 3.5 Bn budget) for the automotive industry suggests financial incentives of up to 18 per cent to encourage domestic production of high-tech automotive products and draw capital to the industry's value chain. The PLI scheme promotes the domestic manufacture of EV batteries and less reliance on imports. This will considerably lower the cost of EVs and provide the necessary infrastructure to support the EV sector.

India has already achieved one of the benchmarks in the EV sector. The highway between Delhi and Chandigarh is the first in the nation to be made e-vehicle friendly by Bharat Heavy Electricals Limited (BHEL), successful commissioning 20 Solar Based EV Chargers. India's total number of charging stations climbed by 285 per cent year over year in the financial year (FY) 2022; strong government measures are projected to accelerate the expansion to 4 lakh stations by FY 2026.



Why is the EV sector in India a good investment opportunity?

The EV industry's importance and impending growth are already attracting investments in the sector. In 2021, it had around $6 Bn investments, which is expected to increase to $20 Bn by 2030.

The Automotive Mission Plan (AMP) 2016–26 encapsulates the goals shared by the Indian government and the automotive sector. According to the AMP 2016-26, the industry is expected to contribute more than 12% of the nation's GDP, of which 7.1% has been achieved until now. It also aspires to constitute at least 40% of the manufacturing sector by the end of 2026. The automobile industry and India will change if these targets are met.

Another essential factor is that the nation's internal lithium-ion battery production plans could lower EVs' costs, reducing dependence and unsettling import duties. Hence, there will soon be a significant market in India.

India's EVs are considered the key to the auto industry's future. With the current climate change and worries about it, EVs are set to take over as the industry's mainstay in the years to come.

Given that India's EV business appears to have a bright future. By 2030, India's focused efforts to promote shared, electric, and connected mobility may enable our country to reduce carbon dioxide emissions by one gigatonne.

Many private equity and venture capitalist investors have also invested in this sector, which grew from $181 Mn to $1.7 Bn. Several mutual funds like Mirae Asset Global Electric and Autonomous Vehicles exchange-traded fund (ETFs) Fund of Fund is an investment opportunity that invests in schemes like lithium and battery technology.

India's auto industry has had significant growth and is expected to continue experiencing exponential expansion. In terms of how the market is doing, the pandemic has sparked a demand for goods that help reduce pollution levels, and EVs are a remarkable way to do so.

India launched the e-AMRIT portal in November 2021 as a one-stop destination for all EV-related information like charging location, investment opportunities, policies and subsidies in the sector.

EV Charging standards

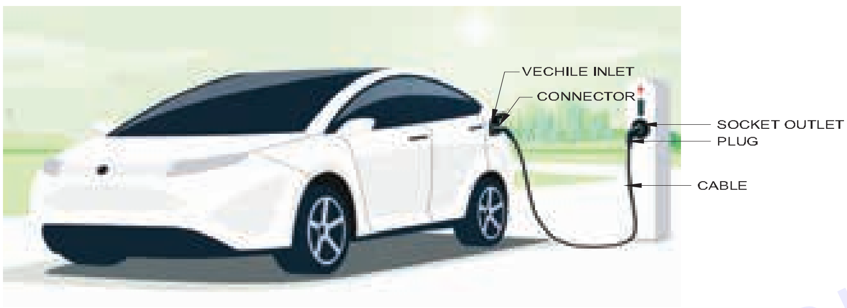
A Charging stations provide connectors that conform to a variety of international standards. DC charging stations are commonly equipped with multiple connectors to be able to charge a wide variety of vehicles that utilize competing standards.

Public charging stations are typically found street-side or at retail shopping centers, government facilities, and other parking areas. Private charging stations are typically found at residences, workplaces, and hotels.

Standards

Multiple standards have been established for charging technology to enable interoperability across vendors. Standards are available for nomenclature, power, and connectors. Notably, Tesla has developed proprietary technology in these areas, and built its charging networking starting in 2012.

Nomenclature



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Charging station and vehicle terminology. In 2011,the European Automobile Manufacturers Association (ACEA) defined the following terms:

- **Socket outlet:** the port on the electric vehicle supply equipment (EVSE) that supplies charging power to the vehicle
- **Plug:** the end of the flexible cable that interfaces with the socket outlet on the EVSE. In North America, the socket outlet and plug are not used because the cable is permanently attached.
- **Cable:** a flexible bundle of conductors that connects the EVSE with the electric vehicle
- **Connector:** the end of the flexible cable that interfaces with the vehicle inlet
- **Vehicle inlet:** the port on the electric vehicle that receives charging power

The terms “electric vehicle connector” and “electric vehicle inlet” were previously defined in the same way under Article 625 of the United States National Electric Code (NEC) of 1999. NEC-1999 also defined the term “electric vehicle supply equipment” as the entire unit “installed specifically for the purpose of delivering energy from the premises wiring to the electric vehicle”, including “conductors ... electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets, or apparatuses”.

Tesla, Inc uses the term charging station as the location of a group of chargers, and the term connector for an individual EVSE

Voltage and power

Early standards

NEC(1999) levels

Method	Maximum supply		
	Current (A)	**Voltage (V)**	**Power (kW)**
Level 1 (1-phasea AC)	12	120	1.44
	16	120	1.92
	24	120	2.88
Level 2 (1-phase AC)	32	208/240	7.68
Level 3 (3-phase AC)	400	480	332.6

The National Electric Transportation Infrastructure Working Council (IWC) was formed in 1991 by the Electric Power Research Institute with members drawn from automotive manufacturers and the electric utilities to define standards in the United States; early work by the IWC led to the definition of three levels of charging in the 1999 National Electric Code (NEC) Hand book.

Under the 1999 NEC, Level 1 charging equipment (as defined in the NEC handbook but not in the code) was connected to the grid through a standard NEMA5-20R 3-prong electrical outlet with grounding, and a ground-fault circuit interrupter was required within 12 in (300 mm) of the plug. The supply circuit required protection at 125% of the maximum rated current; for example, charging equipment rated at 16 amperes ("amps" or "A") continuous current required a breaker sized to 20 A.

Level 2 charging equipment (as defined in the handbook) was permanently wired and fastened at a fixed location under NEC-1999. It also required grounding and ground-fault protection; in addition, it required an interlock to prevent vehicle startup during charging and a safety breakaway for the cable and connector. A 40 A breaker (125% of continuous maximum supply current) was required to protect the branch circuit.[5]:9 For convenience and speedier charging, many early EVs preferred that owners and operators install Level 2 charging equipment, which was connected to the EV either through an inductive paddle (Magne Charge) or a conductive connector (Avcon).

Level 3 charging equipment used an off-vehicle rectifier to convert the input AC power to DC, which was then supplied to the vehicle. At the time it was written, the 1999 NEC handbook anticipated that Level 3 charging equipment would require utilities to upgrade their distribution systems and transformers.

SAE

SAE J1772(2017) levels

Method	Maximum supply		
	Current (A)	Voltage (V)	Power (kW)
AC Level 1	12	120	1.44
	16	120	1.92
AC Level 2	80	208–240	19.2
DC Level 1	80	50–1000	80
DC Level 2	400	50–1000	400

The Society of Automotive Engineers (SAE International) defines the general physical, electrical, communication, and performance requirements for EV charging systems used in North America, as part of standard SAE J1772, initially developed in 2001. SAE J1772 defines four levels of charging, two levels each for AC and DC supplies; the differences between levels are based upon the power distribution type, standards and maximum power.

Alternating current (AC)

AC charging stations connect the vehicle's onboard charging circuitry directly to the AC supply.

- **AC Level 1:** Connects directly to a standard 120 V North American outlet; capable of supplying 6–16 A (0.7–1.92 kilowatts or "kW") depending on the capacity of a dedicated circuit.
- **AC Level 2:** Utilizes 240 V (single phase) or 208 V (three phase) power to supply between 6 and 80 A (1.4–19.2 kW). It provides a significant charging speed increase over AC Level 1 charging.

Direct Current (DC)

Commonly, though incorrectly, called "Level 3" charging based on the older NEC-1999 definition, DC charging is categorized separately in the SAE standard. In DC fast-charging, grid AC power is passed through an AC-to-DC converter in the station before reaching the vehicle's battery, bypassing any AC-to-DC converter on board the vehicle.

- DC Level 1: Supplies a maximum of 80 kW at 50–1000 V.
- DC Level 2: Supplies a maximum of 400 kW at 50–1000 V.

Additional standards released by SAE for charging include SAE J3068 (three-phase AC charging, using the Type 2 connector defined in IEC 62196-2) and SAE J3105 (automated connection of DC charging devices).

IEC

In 2003, the International Electro technical Commission (IEC) adopted a mwwajority of the SAE J1772 standard under IEC 62196-1 for international implementation.

IEC 61851-1 modes

Mode	Type	Maximum supply		
		Current (A)	Voltage (V)	Power (kW)
1	1Φ AC	16	250	4
	3Φ AC	16	480	11
2	1Φ AC	32	250	7.4
	3Φ AC	32	480	22
3	1Φ AC	63	250	14.5
	3Φ AC	63	480	43.5
4	DC	200	400	80

The IEC alternatively defines charging in modes (IEC 61851-1):

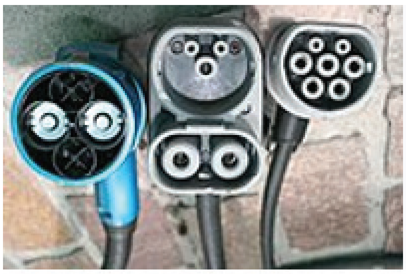
- **Mode 1:** slow charging from a regular electrical socket (single- or three-phase AC)
- **Mode 2:** slow charging from a regular AC socket but with some EV-specific protection arrangement (i.e. the Park & Charge or the PARVE systems)
- **Mode 3:** slow or fast AC charging using a specific EV multi-pin socket with control and protection functions (i.e. SAE J1772 and IEC 62196-2)
- **Mode 4:** DC fast charging using a specific charging interface (i.e. IEC 62196-3, such as CHAdeMO)

The connection between the electric grid and "charger" (electric vehicle supply equipment) is defined by three cases (IEC 61851-1):

- **Case A:** any charger connected to the mains (the mains supply cable is usually attached to the charger) usually associated with modes 1 or 2.
- **Case B:** an on-board vehicle charger with a mains supply cable that can be detached from both the supply and the vehicle – usually mode 3.
- **Case C:** DC dedicated charging station. The mains supply cable may be permanently attached to the charge station as in mode 4.

Connectors

Common charging connectors



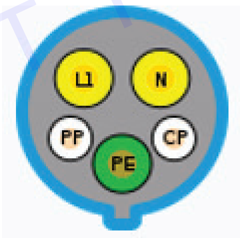
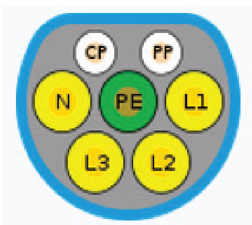
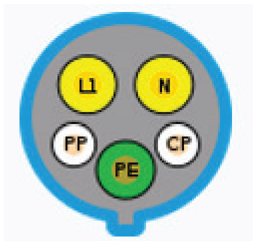
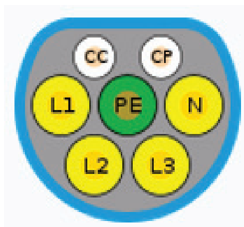
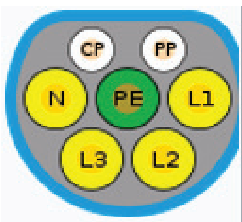
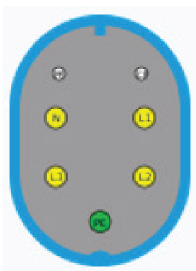
IEC Type 4/CHAdeMO (left); CCS Combo 2 (center); IEC Type 2 outlet (right)

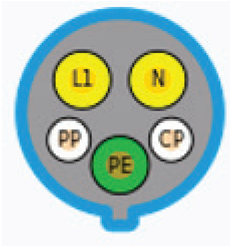
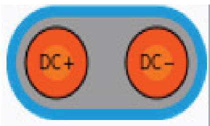
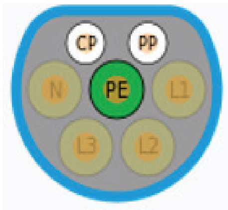
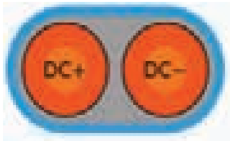
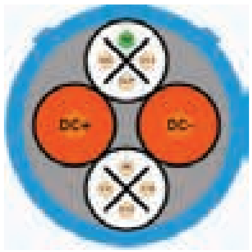
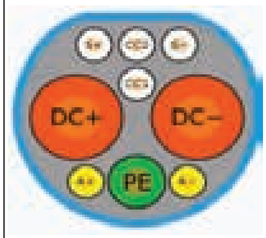
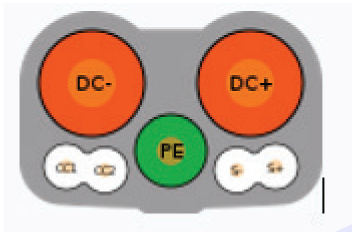
IEC Type 1/SAE J1772 inlet (left); NACS (center); IEC Type 2 connector outlet (right)

Common connectors include Type 1 (Yazaki), Type 2 (Mennekes), Type 3 (Scame), CCS Combo 1 and 2, CHAdeMO, and Tesla.[29][30][31] Many standard plug types are defined in IEC 62196-2 (for AC supplied power) and 62196-3 (for DC supplied power):

- **Type 1:** single-phase AC vehicle coupler – SAE J1772/2009 automotive plug specifications
- **Type 2:** single- and three-phase AC vehicle coupler – VDE-AR-E 2623-2-2, SAE J3068, and GB/T 20234.2 plug specifications
- **Type 3:** single- and three-phase AC vehicle coupler equipped with safety shutters – EV Plug Alliance proposal
- **Type 4:** DC fast charge couplers
  - i Configuration AA: CHAdeMO
  - ii Configuration BB: GB/T 20234.3
  - iii Configurations CC/DD: (reserved)
  - iv Configuration EE: CCS Combo 1
  - v Configuration FF: CCS Combo 2

Connector designs listed in IEC 62196-2 and -3

Power supply	United States	European Union	Japan	China
1-phase AC (62196.2)	Type 1(SAE J1772) 	Type 2 (DE, UK) 	Type 1 (SAE J1772) 	Type 2 (GB/T 20234.2) 
3-phase AC (62196.2)	Type 2 (SAE J3068) 	Type 3 (IT, FR; now deprecated) 		

DC (62196.3)	EE (CCS Combo 1)	FF (CCS Combo 2)	AA (CHAdeMO)	BB (GB//T 20234.3)
	 	 		
				

EV scenario in India and EV charging

Objectives: At the end of this exercise you shall be able to

- explain about EV scenario in India
- state the basic theory of EV charging batteries
- state the safety requirements for EV charging.

Introduction to Electric Vehicle

In recent years, green house gas problem increases and also the gasoline fuel rate also increases days by day in India and global wide so that public also suffer financially due to this reason, automobile manufacture and new companies put their effort to convert the conventional vehicle into electric vehicle that provide reliable solution.

Electric vehicle is propelled with electric motors and draw power from on board electric source in an electric vehicle, it is more durable and mechanically simpler than gasoline vehicle. It gives more fuel efficiency that gasoline because it does not produce emission like internal combustion engine. However, automobile industry is not completely moving towards pure electric vehicle production, because there is in here problem of existing batteries technology for storing the electric energy.

However now a days increasing the usage of hybrid and electric vehicle in our country and globalise.

Electric Vehicle: This type of vehicle uses one or more electric motor for propulsion. Electric vehicle are the automobiles that are propelled by one or more electric motors using the energy stores in batteries.

India need to reduce dependency on a fossil-fuel based economy. India's crude oil imports for 2021-22 was 163.91 billion dollars approximately 13,000,00 crore rupees.

Air quality indices related to India indicate that the air in many cities of India is no longer healthy. Automobile related pollution has been one of the causes for this.

People living in some of Indian cities are being affected by noise pollution. Some of the Indian cities have the worst noise pollution levels in the world Electric Vehicles may contribute to a reduction in noise pollution levels in the cities.

Current Status of EV in India

The Indian Electric Vehicles (EV) market is at a very initial stage comprising of only 2% of the total automobile sales. 95% of the Indian EV market is dominated by 2 and 3 wheelers. The EV market in India is set to see the entry of a flurry of new players of foreign and domestic origin in the 2 and 3 wheeler segments.

In 2012 the National Electric Mobility Mission Plan (NEMMP) 2020 was established to promote hybrid and Electric Vehicles. In early 2018 the Ministry of Power launched the New National Electric Mobility Programme to focus on creating the charging infrastructure and a policy frame work to set a target of more than 30% electric vehicles by 2030.

EV Charging Basic Theory

EV charging is the process of using EV charging equipment to deliver electricity to the Car's battery AM EV charging stations taps into electrical grid to charge an EV. The technical term for EV charging stations is Electric Vehicle Supply Equipment (EVSE).

Methods of Charring an EV

Three methods of charging an EV (Electric Vehicle)

i Trickle charging method

ii AC charging method (charging from AC mains)

iii DC charging method

Types of Electric Vehicle

i Battery Electric Vehicles (BEVs)

ii Plug-in Hybrid Electric Vehicles (PHEVs)

iii Hybrid Electric Vehicles (HEVs)

Electric traction motor is used in EV. Most EVs can take in about 32 amps adding around 25 miles of Range Per Hour of charging so a 32 amp charging station is a good choice for many vehicles.

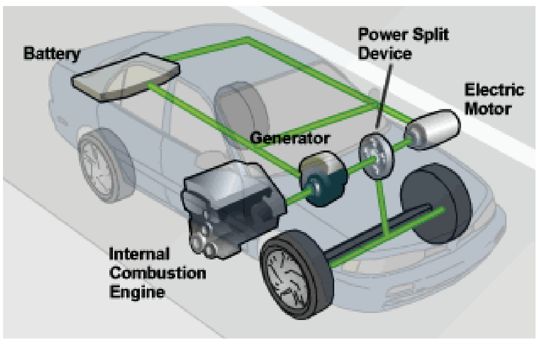
Generally electric Cars charged at home use about 7200 watts of electricity which can vary depending on the mode and home charger.

A charging station also known as a charge point or Electric Vehicle Supply Equipment (EVSE) is a piece of equipment that supplies electrical power for charging plug in electric vehicles (including electrical Cars, electrical trucks, electric buses, neighborhood electric vehicles and plug in hybrids).

Hybrid Electric Vehicles (HEVs)

Today's Hybrid Electric Vehicles (HEVs) are powered by an internal combustion engine in combination with one or more electric motors that use energy stored in batteries. HEVs combine the benefits of high fuel economy and low tailpipe emissions with the power and range of conventional vehicles. (Fig 1)

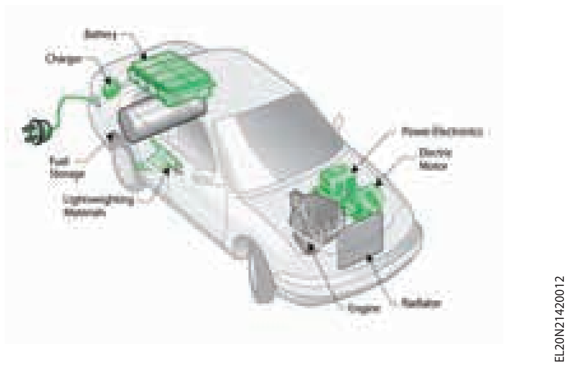
Fig 1



Plug-In Hybrid Electric Vehicles (PHEVs)

Plug-in Hybrid Electric Vehicles (PHEVs) use batteries to power an electric motor and another fuel, such as gasoline to power in Internal Combustion Engine (ICE). The vehicle typically runs on electric power until the battery is nearly depleted and then the car automatically switches over to use the internal combustion engine. (Fig 2)

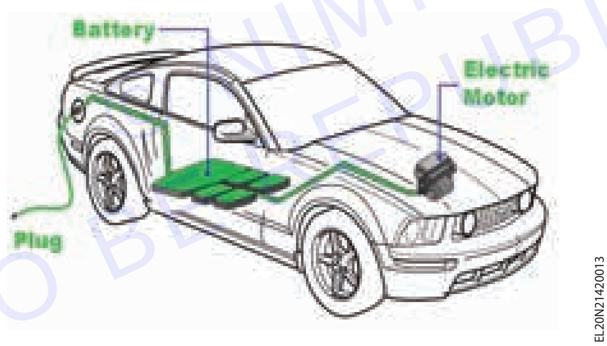
Fig 2



Battery Electric Vehicles (BEVs)

A Battery Electric Vehicles (BEVs), pure electric vehicle, only electric vehicle or all electric vehicle is a type of electric vehicle (EV) that exclusively uses chemical energy stores in rechargeable battery packs, with no secondary source of propulsion (e.g. hydrogen fuel cell, combustion engine etc) (Fig 3)

Fig 3



EV Basic Working Principle

An electric vehicle works on a basic principle of conversion of Electrical energy into mechanical energy. There is a motor used in the electric system to carry on this duty of conversion.

Main Components of EV Chargers

- Battery
- Power Conversion System
- Software

EV battery voltage is 12V for the lead acid battery any typically some where between 400-800 V for the lithium-ion battery pack. Lithium-ion battery capacity is measures in KWH (Kilo Watt Hours). The average capacity is around 40 kwh, but some Cars now have upto a 100 kwh capacity.

EV batteries are projected to last between 1,00,000 and 2,00,000 miles or about 15 to 20 years.

An electric current is a flow of charges particles. The size of an electric current is the rate of flow of charge

Quantity of Charge (Q) = Current (I) x Time (t)

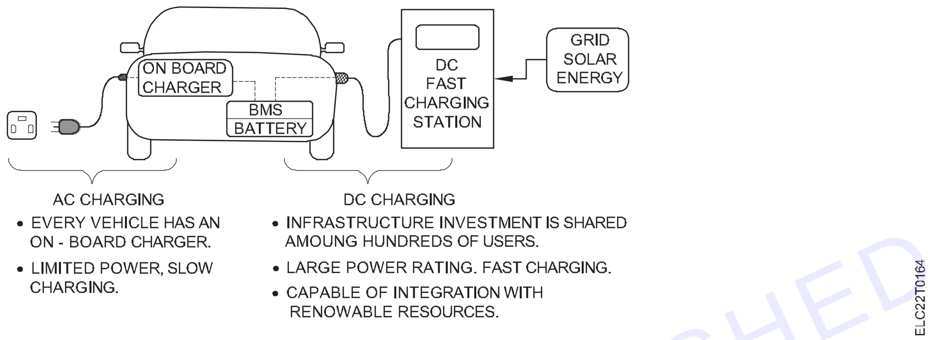
(Q) = It

In rainy season there is no issue regards to driving your EV. Plus even in the worst case there are many protective layers to a car and battery will remain safe and separate itself if at all water come in.

Working of Public charging Stations

- Electricity from the grid is delivered as Alternating Current (AC) but the EV require Direct Current (DC). A rectifier needs to sit between the grid and the battery to convert one of the other. For home and third party public charging this AC-to-DC conversion is done by EV, on-board rectifier. AC current at charge port is converted to DC for the battery by the rectifier.
- Supercharges deliver high voltage, high current DC electricity directly to the EV's battery, by passing the on-board rectifier. This allows the supercharger to push electricity into the battery as fast as the battery can take it- typically ten times faster than home charging. (Fig 4)

Fig 4



- Using induction, which is more energy efficient, the taxis can be charged as they wait in what's known as a taxi rank, or a slow-moving queue where cans line up to wait for passengers.
- The project aims to install wireless charging using induction technology. charging plates are installed in the ground where the taxi is parked and a receiver is installed in the taxi. This allows for charging up to 75 kilowatts.
- The project will be the first wireless fast-charging infrastructure for electric taxis anywhere in the world, and will also help the further development of wireless charging technology for all EV drivers.
- Fortnum charge & Drive has long been working with the taxi industry to enable electrification of the taxi fleet.

Public charging station (Fig 5)

EV charging Safety Requirements

The global safety standards are marked as following:

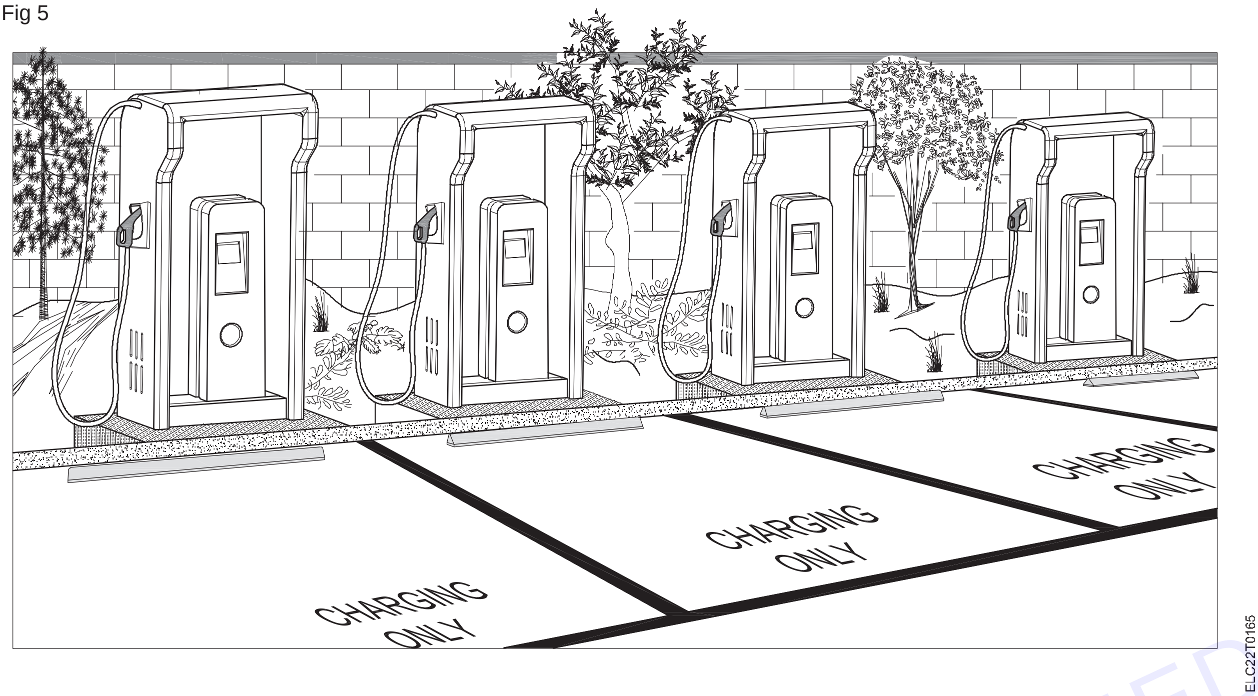
1 Unintended Vehicle Movement

- Indication to driver when vehicle is first put into “active driving possible mode”.
- Signal to driver when exciting the vehicle if the vehicle is still in “active driving possible mode”.
- Indication to driver of vehicle drive direction

2 Shock Protection

- Protection against direct contact
- Physical barrier/access protection
- Marking (enclosures/electrical protection barriers and colour coding of high voltage wires/cables)
- Protection against indirect contact
- Minimum isolation resistance
- Fuel cell isolation resistance monitoring
- Protection against water effects

Fig 5



3 **Elimination Explosive Events**

- Vibration (Component test)
- Over Charge Protection
- Over Discharge Protection
- Over Temperature Protection
- Over Current Protection

4 **"Rechargeable Energy Storage System (REESS)"**

- Installation Integrity/Protection
- Restricts mounting locations for impact protection.
- REESS placed/shielded from contact with road debris
- Shall remain attached and not enter the passenger compartment
- Battery placement management

Indian Safety standards of Electric Vehicles

Some Basic electric Vehicle safety requirement are as follows

- Occupant protection from electric shock
- Safety requirement for rechargeable energy storage systems
- Electrical isolation
- Battery integrity
- Best practices or guidelines for manufactures and/ or emergency responders.

Advantages of Electric Vehicles

1 **ECO friendly -** Because electric vehicles do not utilise fuel for combustion, there are no emissions or gas exhaust.

2 **Renewable Energy Source -** Electric vehicles run on renewable power, where as conventional auto- mobiles function on the combustion of fossil fuels which reduces the world's fuel stocks.

3 **Less Noise and Smoother motion -** Electricity is far less expensive than fuel such as gasoline and diesel which are subject to regular price increases.

4 **Low maintenance -** Because electric cars have fewer moving components, wear and tear is reduced when compared to traditional auto parts.

5 **Government Support -** Governments thought the world have granted tax breaks to encourage people to drive electric vehicles as part of green program.

Disadvantages of Electric Vehicles

1 **High Initial Cost -** Electric Vehicles continue to be quite expensive and many buyers believe they are not as in expensive as traditional automobiles.

2 **Charging Station Limitations-** People who need to travel long distances are concerned about finding adequate charging stations in the middle as their journey which are not always accessible.

3 **Recharging Takes Time -** Unlike conventional automobiles which require only a few minutes to replenish their gas tanks, charging an electric vehicles takes many hours.

4 **Limited Options -** Currently there are not many electric car models to pick from in terms of appearances style or customized variations.

5 **Less Driving Range -** When compared to conventional automobiles electric vehicles have a shorter driving range.