CHAPTER 2: ELECTRICAL PRINCIPLES

Unit of learning code ENG/CU/EI/CC/02/5

Relationship to Occupational Standards

This unit addresses the unit of competency: Apply Electrical Principles

2.1 Introduction

This unit describes the competencies required by a Solar PV installation technician in order to apply a wide range of Electrical principles in their work. Which includes; Use of the concept of basic Electrical quantities, use of the concepts of D.C and A.C circuits in electrical installation, use of basic electrical machine, demonstrating the understanding of three phase power supply systems, use of power factor in electrical installation, use of earthing in Electrical installations, apply lightning protection measures and apply Electromagnetic field theory

2.2 Summary of Learning Outcomes

1. Use the concept of basic Electrical quantities
2. Use the concepts of D.C and A.C circuits in electrical installation
3. Use of basic electrical machine
4. Demonstrate understanding of three phase power supply
5. Use of power factor in electrical installation
6. Use of earthing in Electrical installations
7. Apply lightning protection measures
8. Apply Electromagnetic field theory

2.2.1 Learning outcome 1: use the concept of basic electrical quantities

2.2.1.1 Introduction

To use the concept of basic electrical quantities, the learner need to identify basic SI units in electrical such as quantities of charge, force, work and power, perform calculations involving Ohm’s law i.e. current, resistance and voltage and other various electrical quantities and identify electrical quantities measuring instruments.

2.2.1.2 Performance Standard

2.2.1.2.1 Identify basic SI units in electrical systems
2.2.1.2.2 Identify quantities of charge, force, work and power
2.2.1.2.3 Perform calculations involving Ohm’s law i.e. current, resistance and voltage
2.2.1.2.4 Perform calculations involving various electrical quantities
2.2.1.2.5 Identify electrical quantities measuring instruments

2.2.1.3 Information Sheet

SI units

The system of units used in engineering and science is the System International unites (International system of units), usually abbreviated to SI units, and is based on the metric system. This was introduced in 1960 and is now adopted by the majority of countries as the official system of measurement. The basic units in the SI system are listed in table 1 with their symbols.

S/no.	Quantity	unit
1.	Length	Metre (m)
2.	Mass	Kilogram (kg)
3.	Time	Second(s)
4.	Electric current	Ampere (A)
5.	Thermodynamic temperature	Kelvin (K)
6.	Luminous intensity	Candela (cd)
7.	Amount of substance	Mole (mol)

Table 1 SI system and their symbols

Derived SI units use combinations of basic units and there are many of them. Two examples are:

a) Velocity – metres per second (m/s)

b) Acceleration – metres per second squared (m/s^2)

SI units may be made larger or smaller by using prefixes which denote multiplication or division by a particular amount. The six most common multiples, with their meaning, are listed in table 2

S/No.	Prefix	Name	Meaning
1.	M	mega	Multiply by 1,000,000 (i.e. $\times 10^6$)
2.	k	kilo	Multiply by 1,000 (i.e. $\times 10^3$)
3.	m	milli	divide by 1,000 (i.e. $\times 10^{-3}$)
4.	μ	micro	divide by 1,000,000 (i.e. $\times 10^{-6}$)
5.	n	nano	divide by 1,000,000,000 (i.e. $\times 10^{-9}$)
6.	p	pico	divide by 1,000,000,000,000 (i.e. $\times 10^{-12}$)

Table 2 Multiples and sub multiples of units

Standard electrical units of measure

The standard electrical units of measure are shown in table 3

Table 3 Standard units of measure

S/No.	Electrical Parameter	Measuring unit	Symbol	Description
1.	Voltage	Volt	V or E	Unit of Electrical Potential (**V = I × R**)
2.	Current	Ampere	I or i	Unit of Electrical Current (**I = V ÷ R**)
3.	Resistance	Ohm	R or Ω	Unit of DC Resistance (**R = V ÷ I**)
4.	Conductance	Siemen	G or ℧	Reciprocal of Resistance (**G = 1 ÷ R**)
5.	Capacitance	Farad	C	Unit of Capacitance (**C = Q ÷ V**)
6.	Charge	Coulomb	Q	Unit of Electrical Charge (**Q = C × V**)
7.	Inductance	Henry	L or H	Unit of Inductance ($V_L = -L(di/dt)$)
8.	Power	Watts	W	Unit of Power (**P = V × I** or $I^2 \times R$)
9.	Impedance	Ohm	Z	Unit of AC Resistance ($Z^2 = R^2 + X^2$)
10.	Frequency	Hertz	Hz	Unit of Frequency (**f = 1 ÷ T**)

Ohms law

Ohm's law states that the current flowing in a circuits is directly proportional to the applied voltage V and inversely proportional to the resistance R, provided the temperature remains constant. Thus,

$I = \frac{V}{R} \; or \; V = IR \; or \; R = \frac{V}{I}$

Question 1

The current flowing through a resistor is 0.8 A when a p.d. of 20 V is applied. Determine the value of the resistance.

From ohms law,

Resistance $R = \frac{V}{I} = \frac{20}{0.8} = 25\Omega$

Question 2.

Determine the p.d. which must be applied to a 2 KΩ resistor in order that a current of 10 mA may flow.

Resistance $R = 2K\Omega = 2 \times 10^3 = 2000\Omega$

Current $I = 10\ mA = 10 \times 10^{-3} A$

Question 3

A 100 V battery is connected across resistor and causes a current of 5 mA to flow. Determine the resistance of the resistor. If the voltage is now reduced to 25 V, what will be the new value of the current flowing?

Resistance $R = \frac{V}{I} = \frac{100}{5\times10^{-3}} = 20 \times 10^3 = 20K\Omega$

Question 4

A 100 W electric light bulb is connected to a 250 V supply. Determine

a) the current flowing in the bulb, and
b) the resistance of the bulb.

Power $P = V \times I$, from which, current $I = PV$

a) Current $I = \frac{100}{250} = 0.4\ A$
b) Resistance $R = \frac{V}{I} = \frac{250}{0.4} = 625\Omega$

Question 5

Calculate the power dissipated when a current of 4 mA flows through a resistance of 5kΩ.

Power P= $I^2R = 4\times 10^{-3} \times 5 \times 10^3 = 80\times 10^{-3}$

$= 0.80W\ or\ 80mW$

Electrical Measurement & Instrument

Basically, measurement is an essential act to determine the electrical measuring unit. It performs from the comparing unknown quantity's unit and standard unit of an electronic device.

Definition:

A measuring devices which use to measure or compare unknown quantity with standard quantity is called as 'Measuring Instrument'

In simple words, sometimes, the measuring instrument called as **'Meter'**.

Ammeter, Voltmeter, Ohmmeter, and wattmeter are the example of the electrical measuring instrument. These instruments calculate or measure the value of electrical quantities (current, voltage, resistance, electric power.

Classification of Electrical Measuring Instrument

The classification of an electrical measuring instrument is based on the nature of the operation, function, purpose, uses and many other terms. Generally, it is classified into two categories.

a) Direct Measuring Instrument
b) Comparison Measuring Instrument

A direct measuring instrument measures the electrical unit by reading and deflection. Ammeter, voltmeter, wattmeter are types of direct measuring instruments.

It is mostly used in engineering practical study especially electrical and electronics stream. It is simple and inexpensive as compared to the comparison instrument. It is also classified into two different parts like,

i. Absolute Instrument
ii. Secondary Instrument

You can easily understand the classification of an instrument through the block chart shown in figure

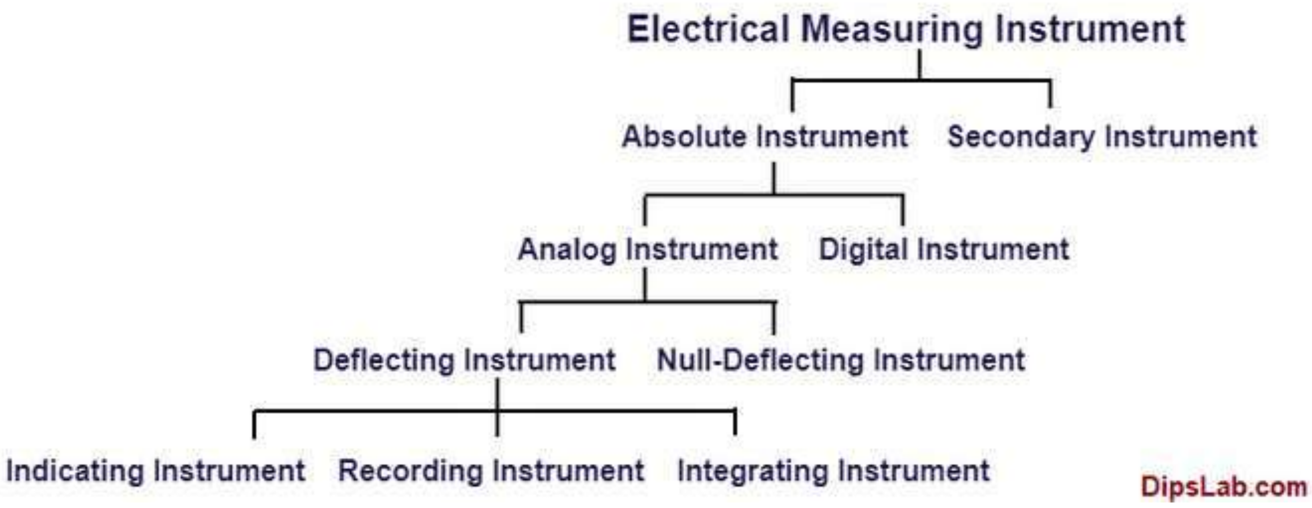

Figure 12: Classification of instruments

Multimeter

Multi-meters can be used to make various electrical measurements, they can be used to measure AC and DC voltage, AC and DC current, and resistance. It is known as multi-meter because it can do the functions of various meters such as voltmeter, ammeter, and ohm-meter. Multi-meters can also be used to check the continuity. **Multimeter** are a popular type of electrical measuring instrument. Like its name, it works like an ammeter, voltmeter, and ohmmeter to measure current, voltage, and resistance, respectively

The multimeter is available into two different forms, like-

i. Analog type Multimeter
ii. Digital type Multimeter

In this advanced technology, both types of meter are needed as per requirement. A signal Multimeter performs all standard analog and digital meters measurement units or functions for AC and DC.

Advantages of Digital Multimeter over the Analog Multimeter

a) The analog type of multimeter shows the continuous signal. It detects and displays the electrical reading by using the moving pointer. Whereas, digital type of multimeter shows the discrete signal. And it measures and displays the numeric measuring unit or value. So, digital multimeter (DMM) gives a more accurate, fast response and readable digital output over analog multimeter.
b) Digital meter is also called as '**Smart Meters** 'or '**Advance Meters'.** With this single smart meter, you can measure multiple units. Instead of buying separate meters to measure current, voltage, resistance, and so on, you buy digital a multimeter.

Ammeter

An ammeter is an instrument which is used to measure the electric current in amperes in a branch of an electric circuit. In order to measure the current it must flow through the ammeter, so the ammeter must be placed in series with the measured branch and it must have very low resistance so that the alteration of the current can be avoided which is measured. Instruments which is used to measure smaller currents are micro-ammeter. The ammeter is connected in series to the device which is to be measured because objects in series have the same current.

Types of ammeter

Moving iron ammeter

In a moving iron, ammeter can measure the AC and DC, it has an iron piece instead of the spring and pointer system of the galvanometer. The iron will act by the magnetic field created in the coil.

Zero center ammeter

Zero center ammeters are used where the voltage needs to be monitored in two directions and they are used along with a battery. In this the charging of battery deflects the needle in one direction and discharging of the battery deflects the battery in the other.

Galvanometer

Galvanometer was the first type of ammeter; it is used to detect and measure electric current. It is an analog electromechanical transducer which makes a rotary deflection in response to the electric current flowing through the coil. A galvanometer can read direct current flow, the magnetic field created as current flows through a coil acts on a spring, which will move the needle indicator.

Shunt

A shunt can be used in ammeters to measure large currents, shunt acts as a resistor the known quantity of resistance is used to obtain an accurate reading. Digital ammeters use analog to digital converter to measure the current across the shunt.

Clamp meter

Clamp meters are used to measure the current flowing through a conductor, AC clamp meters have a current transformer in it. With the help of the current transformer the reading will be taken. There are two types of clamp meters AC clamp meter which is used to measure the AC and the DC clamp meter which is used to measure the DC.

Voltmeter

The voltmeter can be considered as a kind of galvanometer, which can be used to measure the voltage potential of an electrical circuit or the potential difference between two points. A voltmeter can also be considered as an ammeter they also measure the current, voltage is only measured when the current is transmitted in a circuit through resistance. Voltmeters are capable to measure the current, voltage and resistance. Voltmeters are also termed as high resistance ammeters they can also measure DC and AC. A voltmeter can measure the change in voltage by two points in an electrical circuit and they are connected in parallel with the portion of the circuit on which the measurement is made. Voltmeters must have high resistance so that it won't have any effect on the current or voltage associated with the circuit.

Types of voltmeter

Digital voltmeter

Digital voltmeters can measure the AC and DC voltages and it displays the result in converted digital form with decimal point and polarity. It can provide accurate details about the current draw and current continuity and this will help the users to troubleshoot erratic loads.

What are the advantages of digital voltmeter?

a. Outputs are accurate without any error
b. Readings are taken quickly
c. Versatile and accurate
d. Less power consumption
e. Portable instrument

Electrostatic voltmeter

These voltmeters are instruments that can accurately measure the voltage without any charge transfer. Whereas conventional voltmeter needs charge transfer to the voltmeter and it will lead to loading and adjustment of the source voltage. The main advantage of an electrostatic voltmeter is that it can do the surface potential measurement on any type of material without any physical contact.

Ohmmeter

An ohmmeter is an instrument that is used to measure the resistance and they can measure the value of resistance accurately. According to their measurement and construction, these instruments are classified into the series type and shunt type ohmmeter. It can be used to check the continuity of the electrical circuits and components. Series type ohmmeters are used to measure the high resistance values while the shunt type is used to measure low resistance values.

Potentiometer

Potentiometers are instruments that can be used to measure the unknown voltage. The known voltage will be supplied from a standard cell or any other known voltage reference source. Potentiometer measurement has high accuracy because the measurement is done by the comparison method and the obtained result is not by the deflection of the pointer. Potentiometers can be used to compare the E.M.F of the two cells, it can be used to determine the E.M.F of a cell, it can be used to determine the internal resistance of a cell and to calibrate the voltmeter and ammeter.

Wattmeter

Watt-meters are used to measure power, these instruments are similar in design and construction of an ammeter. It can be used to measure the average electric power in watts. Wattmeter has two coils they are current and pressure coil. Wattmeter can be used to measure the gain in amplifiers, bandwidth in filters.

Necessity or Uses of Electrical Measuring Instruments

The main functions of the measurement system are indicating, recording, detecting, controlling and testing the electrical units. Apart from that, here are some important used.

i. It helps to control and monitoring the operation in an electrical system.
ii. You can find out the error in the measuring unit with the help of standard values.
iii. In generating power stations, instruments are used for data recording, measuring the value, fault detecting and many more purpose.
iv. It helps to detect and protect from hazard conditions.
v. Measuring instrument uses for the analysis of experimental data in an electrical system.
vi. It is essential for displaying accurate numerical values. Digital multimeter is one of them.
vii. Mostly, it utilizes in testing in the lab, industrial environment, science, and engineering study, building an electrical and electronics project, etc.

3.1.1.3. Learning Activities

Project/workshop

Practical activity	Knowledge	Special instruction
1. Identification of basic SI units in electrical systems	SI units	Write down the SI units of electrical systems
2. Identification of quantities of charge, force, work and power.	Quantities	Write the units for measuring charge, force, work and power
3. Measure current, Voltage and resistance		Perform calculations using the measured quantities.
4. Measure various electrical quantities		Perform calculations using the measured quantities.
5. Identify electrical quantities measuring instruments	Measuring instruments	Record the measured readings

3.1.1.4. Self-Assessment Questions

1) What does 'SI units' mean? **(3 Marks)**
2) Which electrical instrument would you use to measure current in an electric circuit? **(2 Marks)**

3) A charge of 240 Coulombs is transferred in 2 minutes in an electric circuit, what is the amount of current flowing through it? **(2 Marks)**

4) What is Ohms law? **(3 Marks)**

5) What is the power dissipated by a resistor of 10 Ω when a current of 2 A passes through it? **(2 Marks)**

6) A current of 2 A flows for 10 h through a 100 resistor. What is the energy consumed by the resistor? **(3 Marks)**

3.1.1.5.Tools, Equipment and Materials

Recommended Resources

Tools and equipment	Materials and supplies
i. Cable Strippers ii. Pliers iii. Screw drivers iv. Hammers v. Chisels vi. Allen keys vii. Electrician knives viii. Crimping tools ix. Bending springs x. Bending machine xi. Steel tapes xii. Draw wires xiii. Hack saws xiv. Drilling tools xv. Stock and die xvi. Bench vice xvii. Machine vice xviii. PPE – hand gloves, dust coats, dust masks, helmets, ear muffs, industrial boots	i. Stationery ii. Cables iii. Light fittings iv. Accessories v. Conduits and fittings vi. Cable trays vii. Cable ducts viii. Trunkings ix. Computers x. Drawing instruments xi. Screws

3.1.1.6.References

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3. J.Hyde. (1994). *Electrical Installation Principles and Practices.* London: Maccmillan education Ltd.
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5. Walters, J. (2013). Trade Electrician, motor control. In J. Walters, *Trade Electrician* (pp. 34-36). dublin, Ireland: Solas.
6. IEE regulations
7. Occupational safety and health act (OSHA)
8. Work injury benefits act (WIBA)
9. Manufacturers' catalogues
10. British standards
11. KEBS standards

3.1.1.7. Model answers to self-assessment Questions

1. **'SI units' mean** **(3 Marks)**

   The system of units used in engineering and science, which is based on the metric system. This was introduced in 1960 and is now adopted by the majority of countries as the official system of measurement.

2. **Electrical instrument used to measure current in an electric circuit** **(2 Marks)**
   a) An ammeter
   b) Clamp metre

3. **The amount of current flowing through the electric circuit in which a charge of 240 Coulombs is transferred in 2 minutes** **(2 Marks)**

$$Q = It \qquad I = \frac{Q}{t}$$

$$I = \frac{240C}{2x60\ sec}$$

$$= 2\ Amperes$$

4. **Ohms law** **(3 Marks)**

   Ohms law states that the current I flowing through a conductor in a circuit is directly proportional to the applied voltage V provided that temperature and other physical condition are kept constant

5. **The power dissipated by a resistor of 10 Ω when a current of 2 A passes through it.** **(2 Marks)**

$$P = I^2R$$

$$2^2 \times 10 = 40\ Watts$$

6. **The energy consumed by a 100 Ω resistor when a current of 2 A flows for 10 h through.**

(3 Marks)

$$Energy = Power \times time$$
$$= I^2 R \times 10\ hours$$
$$= 2^2 \times 100 \times 10\ hours$$
$$= 4000 watts$$

3.1.2. Use the concepts of D.C and A.C circuits in electrical installation

3.1. Introduction

To use the concepts of D.C and A.C circuits in Electrical installation, the learner should perform calculations involving parallel and series circuits, perform calculations involving Network theorems e.g. Kirchhoff's laws, superposition, Thevenin's, Norton's ; identify photovoltaic solar system and perform AC to Dc and DC to AC conversion.

3.1.2.1. Performance Standard

1. Perform calculations involving parallel and series circuits
2. Perform calculations involving Network theorems e.g. Kirchhoff's laws, Superposition, Thevenin's, Norton's etc.
3. Identify Photovoltaic solar system
4. Perform AC to DC and DC to AC conversion

3.1.2.2. Information Sheet

Definition of terms

Resistance: - opposition to current flow.

Inductive reactance (X_L):- the opposition to an $a.c.$ current in an inductive circuit.

Capacitive reactance (X_C): - the opposition to an a.c. current in a capacitive circuit.

Impedance (Z):-the total opposition to current flow in an $a.c.$ circuit

A phasor: -straight line, having definite length and direction, which rep-resents to scale the magnitude and direction of a quantity such as a current, voltage or impedance

Circuit: – a circuit is a closed loop conducting path in which an electrical current flows.

Path: – a single line of connecting elements or sources.

Node – a node is a junction, connection or terminal within a circuit were two or more circuit elements are connected or joined together giving a connection point between two or more branches. A node is indicated by a dot.

Branch – a branch is a single or group of components such as resistors or a source which are connected between two nodes.

Loop – a loop is a simple closed path in a circuit in which no circuit element or node is encountered more than once.

Mesh – a mesh is a single closed loop series path that does not contain any other paths. There are no loops inside a mesh.

Series and parallel networks

Series networks

Figure 2 shows three resistors R_1, R_2 and R_3 connected end to end, i.e., in series, with a battery source of V volts.

Since the circuit is closed a current, I will flow and the $p.d.$ across each resistor may be determined from the voltmeter readings V_1, V_2 and V_3.

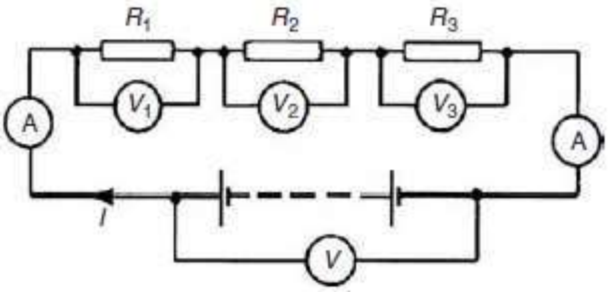

Figure 13: series circuit

In a series circuit

a) the current I is the same in all parts of the circuit and hence the same reading is found on each of the ammeters shown, and

b) the sum of the voltages $V1$, $V2$ and $V3$ is equal to the total applied voltage, V,

i.e. $\boldsymbol{V = V_1 + V_2 + V_3}$

From Ohm's law: $\boldsymbol{V_1} = IR_1, \boldsymbol{V_2} = IR_2, \boldsymbol{V_3} = IR_3$ and

$V = IR$ where R is the total circuit resistance. Since

$V = V_1 + V_2 + V_3$ then $IR = IR_1 + IR_2 + IR_3$. Dividing throughout by I gives

$\boldsymbol{R = R_1 + R_2 + R_3}$

Thus, for a series circuit, the total resistance is obtained by adding together the values of the separate resistance's.

Potential divider

The voltage distribution for the circuit shown in Fig. 3 is given by:

$\boldsymbol{V_1} = \left(\frac{\boldsymbol{R_1}}{\boldsymbol{R_1+R_2}}\right)\boldsymbol{V}$ **and** $\boldsymbol{V_2} = \left(\frac{\boldsymbol{R_2}}{\boldsymbol{R_1+R_2}}\right)\boldsymbol{V}$

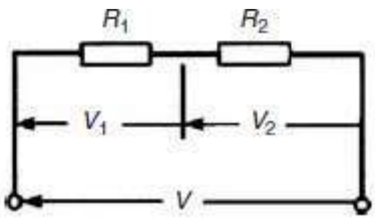

Figure 14: Voltage distribution circuit

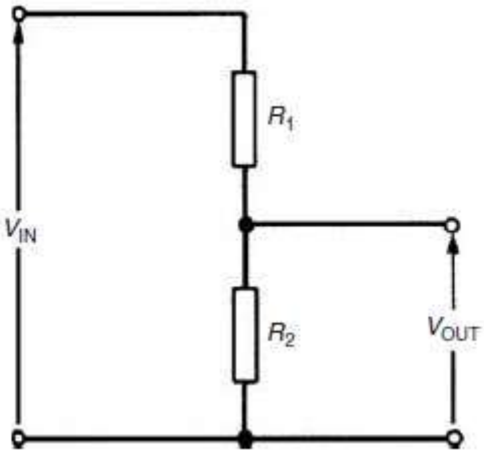

Figure 15: Potential divider

The circuit shown in Fig. 4 is often referred to as a **potential divider** circuit. Such a circuit can consist of a number of similar elements in series connected across a voltage source, voltages being taken from connections

$$\boldsymbol{V_{OUT}} = \left(\frac{\boldsymbol{R_2}}{\boldsymbol{R_1} + \boldsymbol{R_2}}\right)\boldsymbol{V_{IN}}$$

A potential divider is the simplest way of producing a source of lower $e.m.f.$ from a source of higher e.m.f., and is the basic operating mechanism of the **potentiometer**, a measuring device for accurately measuring potential differences.

Parallel networks

Figure 5 shows three resistors, *R*1, *R*2 and *R*3 connected across each other, i.e. in parallel, across a battery source of *V* volts.

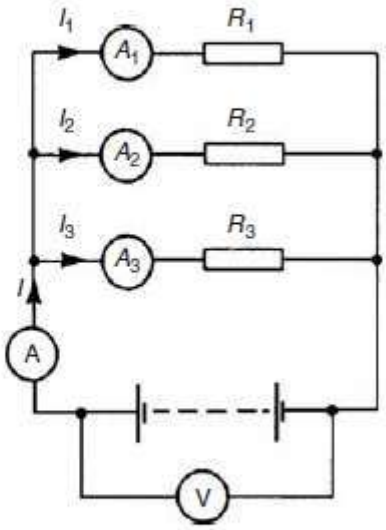

Figure 16: Resistors connected in parallel

In a parallel circuit:

a) The sum of the currents $\boldsymbol{I_1}$, $\boldsymbol{I_2}$ and $\boldsymbol{I_3}$ is equal to the total circuit current, *I*, i.e. $\boldsymbol{I} = \boldsymbol{I_1} + \boldsymbol{I_2} + \boldsymbol{I_3}$ and

b) The source $p.d.$, *V* volts, is the same across each of the resistors.

From Ohm's law:

$$I_1 = \frac{V}{R_1},\ I_2 = \frac{V}{R_2}\ ,\ I_3 = \frac{V}{R_3}\ and\ \ I = \frac{V}{R}$$

Where R is the total circuit resistance. Since $I = I_1 + I_2 + I_3$ then $\frac{V}{R} = \frac{V}{R_1} = \frac{V}{R_2} = \frac{V}{R_3}$

Dividing throughout by V gives: $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

This equation must be used when finding the total resistance R of a parallel circuit. For the special case of **two resistors in parallel**

$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1 R_2}$

Hence $R = \frac{R_1 R_2}{R_1 + R_2} \left(i.e \frac{Product}{sum} \right)$

Current division

For the circuit shown in Fig. 6, the total circuit resistance, RT is given by $R_T = \frac{R_1 R_2}{R_1 + R_2}$

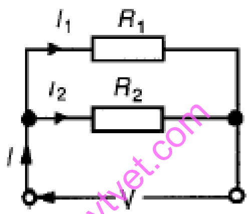

Figure 17: Current division circuit

Alternating current theory

Commercial quantities of electricity for industry, commerce and domestic use are generated as a.c. in large Power Stations and distributed around the United Kingdom on the National Grid to the end user. The D.C. electricity has many applications where portability or an emergency stand-by supply is important but for large quantities of power it has to be an a.c. supply because it is so easy to change the voltage levels using a transformer. Rotating a simple loop of wire or coils of wire between the poles of a mag-net such as that shown simplified in Fig. 7 will cut the north south lines of magnetic flux and induce an a.c. voltage in the loop or coils of wire as shown by the display on a cathode ray oscilloscope. This is an a.c. supply, an alternating current supply. The basic principle of the a.c. supply generated in a Power Station is exactly the same as shown in Figure 7 except that powerful electromagnets are used and the power for rotation comes from a steam turbine.

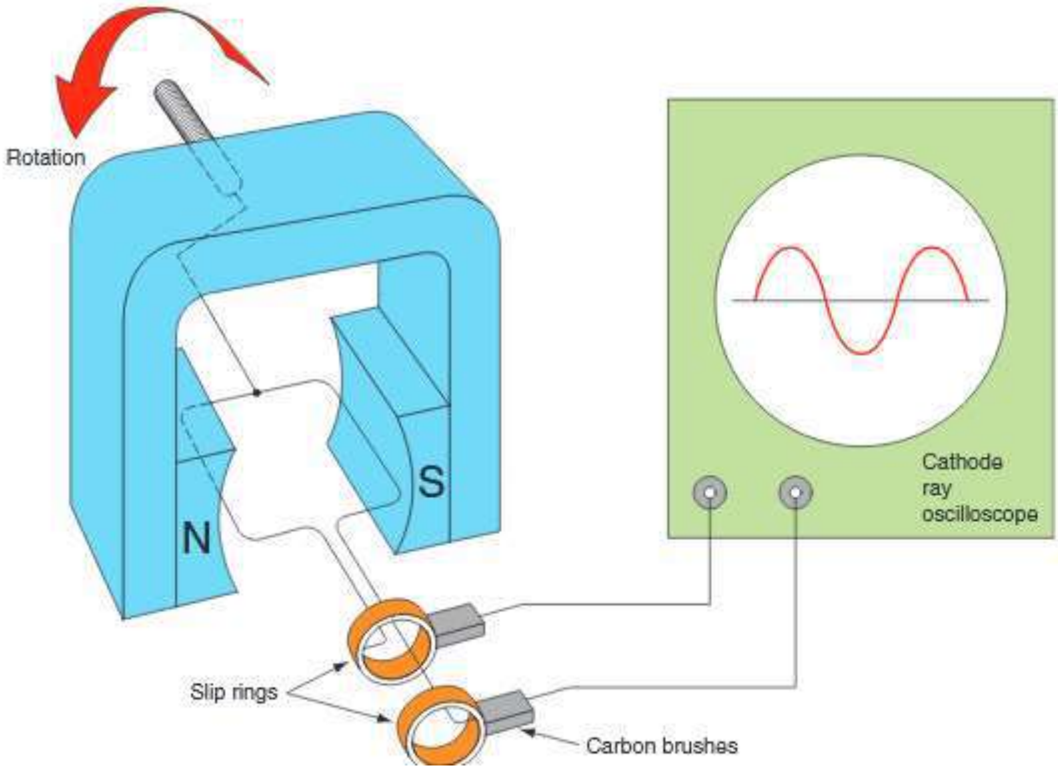

Figure 18: Simple generator/alternator

Resistance

From Ohm's law:

$$R = \frac{V_R}{I_R} (\Omega)$$

However, in an $a.c.$ circuit, resistance is only part of the opposition to cur-rent flow. The inductance and capacitance of an $a.c.$ circuit also cause an opposition to current flow, which we call reactance.

Inductive reactance (X_L)

It causes the current in the circuit to lag behind the applied voltage, as shown in Fig. 8. It is given by the formula:

$$X_L = 2\pi f L \ (\Omega)$$

where

$\pi = 3.142$ a constant

$f =$ the frequency of the supply

$L =$ the inductance of the circuit or by

$$X_L = \frac{V_L}{I_L}$$

Capacitive reactance (X_C)

It causes the current in the circuit to lead ahead of the voltage, as shown in Fig. 8. It is given by the formula:

$$X_C = \frac{1}{2\pi fC} \ (\Omega)$$

Where π and f are defined as before and C is the capacitance of the circuit. It can also be expressed as:

$$X_C = \frac{V_C}{I_C}$$

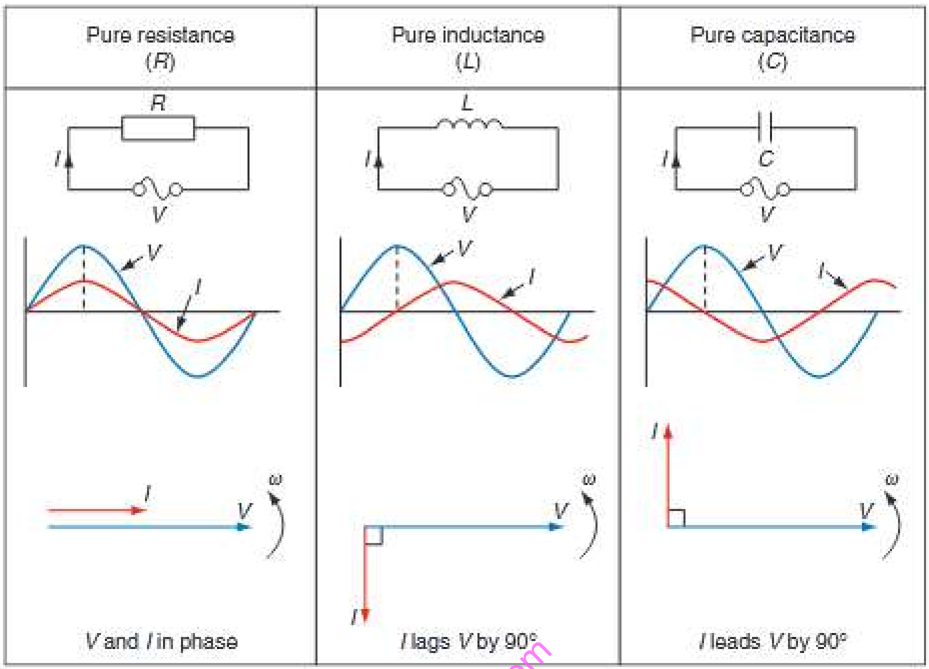

Figure 19: Voltage and current relationships in resistive, capacitive and inductive circuits

Impedance (Z)

Impedance is the combined opposition to current flow of the resistance, inductive reactance and capacitive reactance of the circuit and can be calculated from the formula:

$$Z = \sqrt{R^2 + X^2} \ (\Omega)$$

or

$$Z = \frac{V_T}{I_T}$$

Resistance, inductance and capacitance in an a.c. circuit

When a resistor only is connected to an a.c. circuit the current and voltage waveforms remain together, starting and finishing at the same time. We say that the waveforms are in phase. When a pure inductor is connected to an a.c. circuit the current lags behind the voltage waveform by an angle of 90°. We say that the current lags the voltage by 90°. When a pure capacitor is connected to an a.c. circuit the current leads the voltage by an angle of 90°. These various effects can be observed on an oscilloscope, but the circuit diagram, waveform diagram and phasor diagram for each circuit are shown in Fig. 8.

Phasor diagrams

Phasor diagrams and a.c. circuits are an inseparable combination. Phasor diagrams allow us to produce a model or picture of the circuit under consideration which helps us to understand the circuit.

To find the combined effect of two quantities we combine their phasors by adding the beginning of the second phasor to the end of the first. The combined effect of the two quantities is shown by the resultant phasor, which is measured from the original zero position to the end of the last phasor. The figure 9 shows phasor addition of currents A and B.

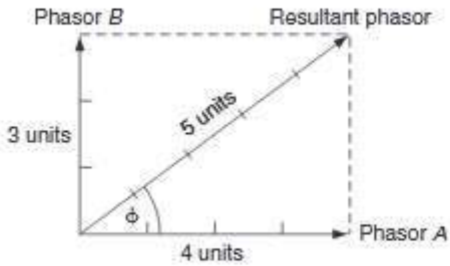

Figure 20: The Phasor addition of currents A and B

Phase angle φ

In an $a.c.$ circuit containing resistance only, such as a heating circuit, the voltage and current are in phase, which means that they reach their peak and zero values together, as shown in Fig. 10. In an a.c. circuit containing inductance, such as a motor or discharge lighting circuit, the current often reaches its maximum value after the volt-age, which means that the current and voltage are out of phase with each other, as shown in Fig. 10. The phase difference, measured in degrees between the current and voltage, is called the phase angle of the circuit, and is denoted by the symbol φ, the lower-case Greek letter phi. When circuits contain two or more separate elements, such as RL, RC or RLC, the phase angle between the total voltage and total current will be neither 0° nor 90° but will be determined by the relative values of resistance and reactance in the circuit. In Fig. 11 the phase angle between applied voltage and current is some angle φ.

Alternating current series circuits

In a circuit containing a resistor and inductor connected in series as shown in Fig. 11, the current I will flow through the resistor and the inductor causing the voltage V_R to be dropped across the resistor and V_L to be dropped across the inductor. The sum of these voltages will be equal to the total voltage V_T but because this is an a.c. circuit the voltages must be added by phasor addition. The result is shown in Fig. 11, where V_R is drawn to scale and in phase with the current and V_L is drawn to scale and leading the current by 90°. The phasor addition of these two voltages gives us the magnitude and direction of V_T, which leads the current by some angle φ .In a circuit containing a resistor and capacitor connected in series as shown in Fig. 12, the current I will flow through the resistor and capacitor causing voltage drops V_R and V_C. The voltage V_R will be in phase with the current and V_C will lag the current by 90°. The phasor addition of these voltages is equal to the total voltage V_T which, as can be seen in Fig. 12, is lagging the current by some angle φ.

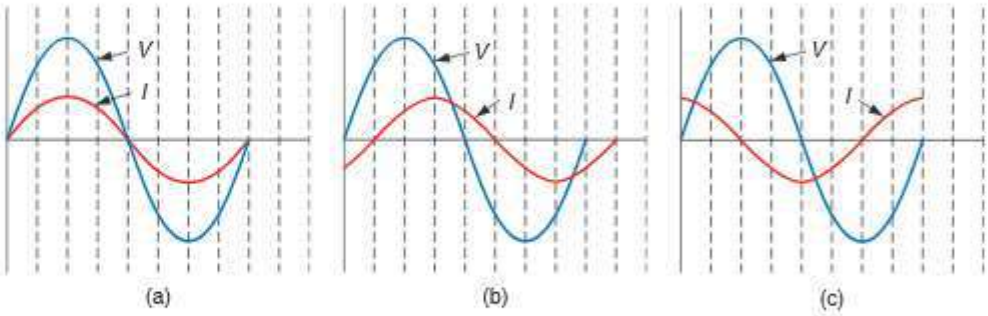

Figure 21: phase relationship of ac waveform

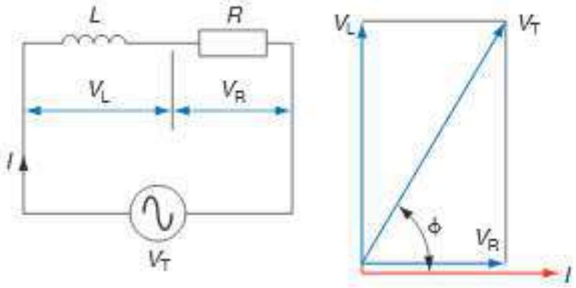

Figure 22: Series RL circuit and phasor diagram

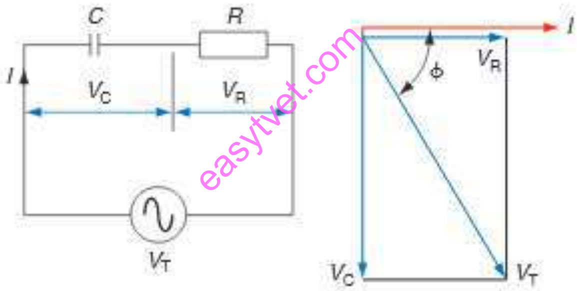

Figure 23: Series RC and phasor diagram

The impedance triangle

We have now established the general shape of the phasor diagram for a series a.c. circuit. Figures 10.5 and 10.6 show the voltage phasors, but we know that $V_R = IR$, $V_L = IX_L$,, $V_C = IX_C$, and $V_T = IZ$ therefore the phasor diagrams (a) and (b) of Fig. 13 must be equal. From Fig. 13(b), by the theorem of Pythagoras, we have:

$$(IZ)^2 = (IR)^2 + (IX)^2$$

$$I^2Z^2 = I^2R^2 + I^2X^2$$

If we now divide throughout by I2 we have:

$$Z^2 = R^2 + X^2$$

$$\text{or } Z = \sqrt{R^2 + X^2}\ \Omega$$

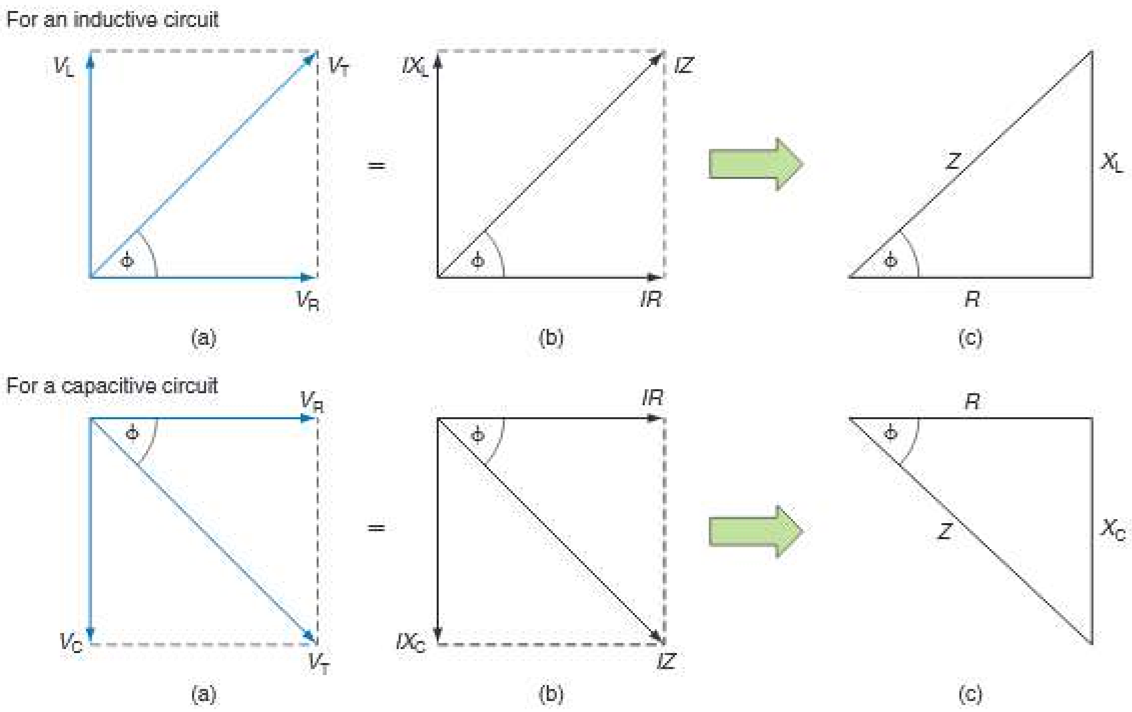

Figure 24: Phasor diagram and impedance triangle

Network Theorems

Thevenin's theorem and Norton theorem

The Thévenin and Norton networks shown in Fig. 19 are equivalent to each other. The resistance 'looking-in' at terminals AB is the same in each of the networks, i.e. *r*

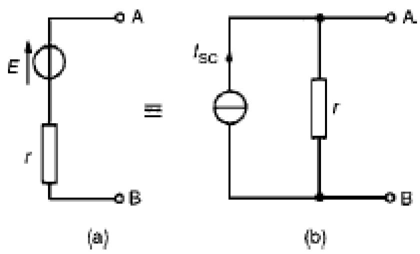

Figure 25: Norton's and Thevenin's networks

If terminals AB in Fig. 19(a) are short-circuited, the short-circuit current is given by *E/r*. If terminals AB in Fig. 19(b) are short-circuited, the short-circuit current is I_{SC}. For the circuit shown in Fig. 19(a) to be equivalent to the circuit in Fig. 19(b) the same short-circuit current must flow. Thus $I_{SC} = E/r$.

Figure 20 shows a source of $e.m.f.$ *E* in series with a resistance *r* feeding a load resistance *R*

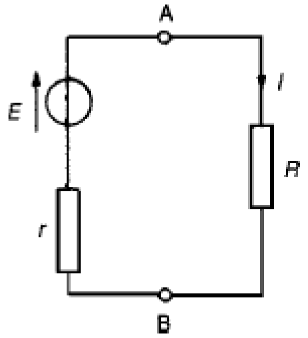

Figure 15: Source of $\boldsymbol{e.m.f}$ *in series with resistance*

From Fig. 20,

$$I = \frac{E}{r+R} = \frac{E/r}{(r+R)/r} = \left(\frac{r}{r+R}\right)\frac{E}{r}$$

i.e. $$I = \left(\frac{r}{r+R}\right) I_{SC}$$

From Fig. 21 it can be seen that, when viewed from the load, the source appears as a source of current I_{SC} which is divided between *r* and *R* connected in parallel

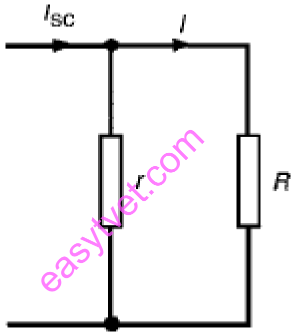

Figure 26: Source current divided

Thus the two representations shown in Fig. 20 are equivalent.

Superposition Theorem

Superposition states that the voltage across (or current through) an element in a linear circuit is the algebraic sum of the voltage across (or currents through) that element due to EACH independent source acting alone.-The principle of superposition helps us to analyze a linear circuit with more than one independent source by calculating the contribution of each independent source separately.-Steps to Apply Superposition Principle:

1. Turn off all independent sources except one source. Find the output (v or i) due to that active source.
2. Repeat Step 1 for each of the other independent sources.
3. Find Total contribution by adding all contributions from independent sources.

Note: In Step 1, this implies that we replace every voltage source by 0 V (or a short circuit), and every current source by 0 A (or an open circuit). Dependent sources are left intact because they are controlled by others.

Kirchhoff's Circuit Law

Kirchhoff's Circuit Laws allow us to solve complex circuit problems by defining a set of basic network laws and theorems for the voltages and currents around a circuit a single equivalent resistance, (RT) can be found when two or more resistors are connected together in either series, parallel or combinations of both, and that these circuits obey Ohm's Law. However, sometimes in complex circuits such as bridge or T networks, we cannot simply use Ohm's Law alone to find the voltages or currents circulating within the circuit. For these types of calculations, we need certain rules which allow us to obtain the circuit equations and for this we can use Kirchhoffs Circuit Law. In 1845, a German physicist, Gustav Kirchhoff developed a pair or set of rules or laws which deal with the conservation of current and energy within electrical circuits. These two rules are commonly known as: Kirchhoffs Circuit Laws with one of Kirchhoff's laws dealing with the current flowing around a closed circuit, Kirchhoffs Current Law, (KCL) while the other law deals with the voltage sources present in a closed circuit, Kirchhoffs Voltage Law, (KVL).

Kirchhoff's First Law – The Current Law, (KCL)

Kirchhoff's Current Law or KCL, states that the "*total current or charge entering a junction or node is exactly equal to the charge leaving the node as it has no other place to go except to leave, as no charge is lost within the node*". In other words the algebraic sum of ALL the currents entering and leaving a node must be equal to zero, $I_{(exiting)} + I_{(entering)} = 0$. This idea by Kirchhoff is commonly known as the Conservation of Charge. The figure 22 illustrates the Kirchhoff's current law.

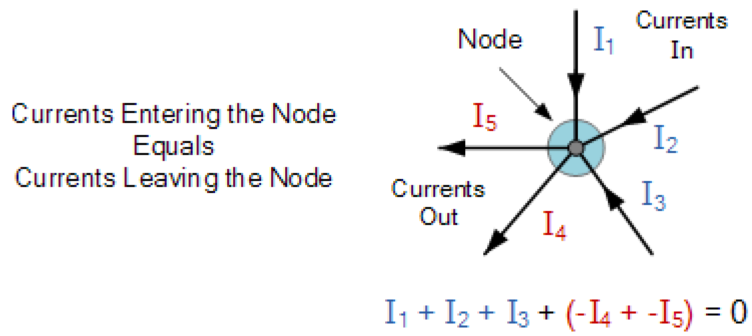

Figure 277: Kirchhoff's current law

Here, the three currents entering the node, I_1, I_2, I_3 are all positive in value and the two currents leaving the node, I_4 and I_5 are negative in value. Then this means we can also rewrite the equation as;

$I_1 + I_2 + I_3 – I_4 – I_5 = 0$

The term Node in an electrical circuit generally refers to a connection or junction of two or more current carrying paths or elements such as cables and components. Also for current to flow either in or out of a node a closed circuit path must exist. We can use Kirchhoff's current law when analyzing parallel circuits.

Kirchhoff's Second Law – The Voltage Law, (KVL)

Kirchhoff's Voltage Law or KVL, states that "*in any closed loop network, the total voltage around the loop is equal to the sum of all the voltage drops within the same loop*" which is also equal to zero. In other words the algebraic sum of all voltages within the loop must be equal to zero. This idea by Kirchhoff is known as the Conservation of Energy.

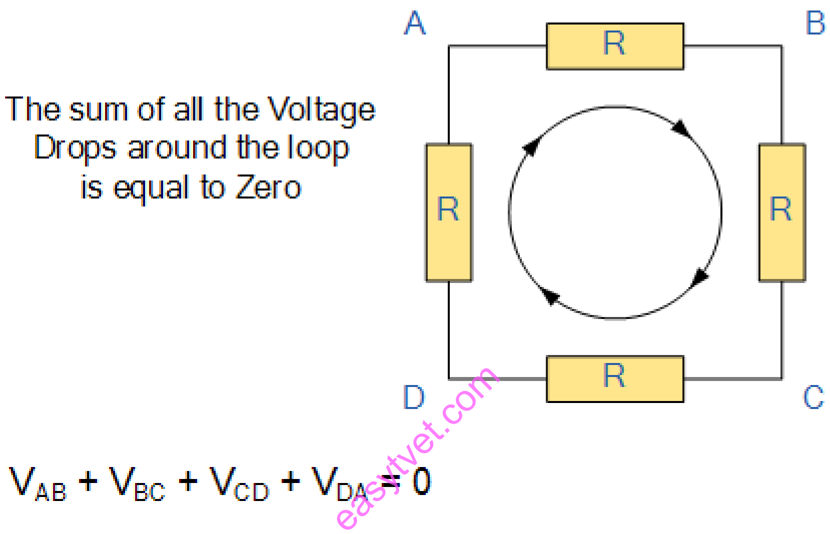

Figure 18: Kirchhoff's voltage law

Starting at any point in the loop continue in the same direction noting the direction of all the voltage drops, either positive or negative, and returning back to the same starting point. It is important to maintain the same direction either clockwise or anti-clockwise or the final voltage sum will not be equal to zero. We can use Kirchhoff's voltage law when analyzing series circuits.

When analyzing either DC circuits or AC circuits using Kirchhoff's Circuit Laws a number of definitions and terminologies are used to describe the parts of the circuit being analyzed such as: node, paths, branches, loops and meshes. These terms are used frequently in circuit analysis so it is important to understand them.

Norton theorem

Norton's theorem states that a linear two-terminal circuit can be replaced by an equivalent circuit consisting of a current source I_N in parallel with a resistor R_N, where I_N is the short-circuit current through the terminals and R_N is the input or equivalent resistance at the terminals when the independent sources are turned off.

Thus, the circuit in Fig.(a) can be replaced by the one in Fig. (b)

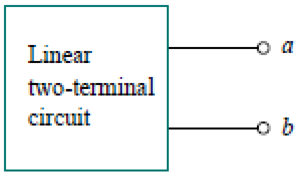

Figure19. (a) Original circuit

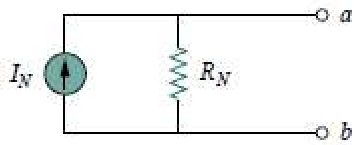

Figure19. (b) Norton equivalent circuit

We find R_N in the same way we find R_{Th}. In fact, from what we know about source transformation, the Thevenin and Norton resistances are equal; that is,

$$R_N = R_{Th}.$$

To find the Norton current I_N,we determine the short-circuit current flowing from terminal *a* to *b* in both circuits in Fig. 4.37. It is evident that the short-circuit current in Fig. (b) is I_N. This must be the same short-circuit current from terminal *a* to *b* in Fig. (a), since the two circuits are equivalent. Thus,

$$I_N = i_{SC}$$

As shown in the fig below.

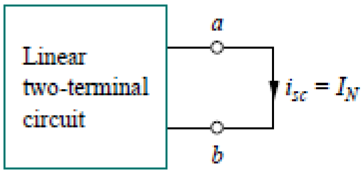

Figure 20: Finding Norton current I_N

Dependent and independent sources are treated the same way as in Thevenin's theorem.
Observe the close relationship between Norton's and Thevenin's theorems: $R_N = R_{\text{Th}}$ and $I_N = \frac{V_{\text{Th}}}{R_{\text{Th}}}$

This is essentially source transformation. For this reason, source transformation is often called Thevenin-Norton transformation. Since V_{Th}, I_N, and R_{Th} are related; to determine the Thevenin or Norton equivalent circuit requires that we find:

a. The open-circuit voltage v_{oc} across terminals *a* and *b*.
b. The short-circuit current i_{sc} at terminals *a* and *b*.
c. The equivalent or input resistance R_{in} at terminals *a* and *b* when all independent sources are turned off.

We can calculate any two of the three using the method that takes the least effort and use them to get the third using Ohm's law. Since,

$$V_{\text{Th}} = v_{oc}$$
$$I_N = i_{SC}$$
$$R_{\text{Th}} = \frac{V_{oc}}{i_{SC}} = R_N$$

AC to DC conversion

The process of obtaining unidirectional currents and voltages from alternating currents and voltages is called rectification. Automatic switching in circuits is achieved using diodes. Half-wave rectification using a single diode, D, as shown in figure 19, half-wave rectification is obtained. When P is sufficiently positive with respect to Q, diode D is switched on and current i flows. When P is negative with respect to QT diode D is switched off. Transformer T isolates the equipment from direct connection with the mains supply and enables the mains voltage to be changed. Thus, an alternating, sinusoidal waveform applied to the transformer primary is rectified into a unidirectional waveform. Unfortunately, the output waveform shown in Figure 19 is not constant (i.e. steady), and as such, would be unsuitable as a $d.c.$ power supply for electronic equipment. It would, however, be satisfactory as a battery charger. Full-wave rectification using a centre-tapped transformer two diodes may be used as shown in Figure 20 to obtain full-wave rectification where a centre-tapped transformer T is used. When P is sufficiently positive with respect to Q, diode D1 conducts and current flows (shown by the broken line in Figure 20). When S is positive with respect to Q, diode D2conducts and current flows (shown by the continuous line in figure 20)

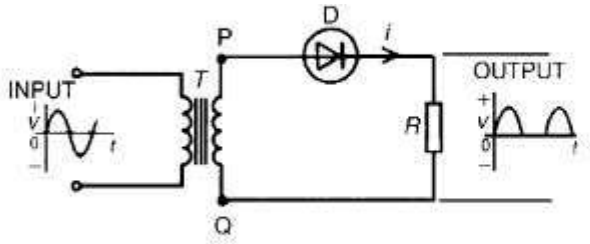

Figure 21: half wave rectification

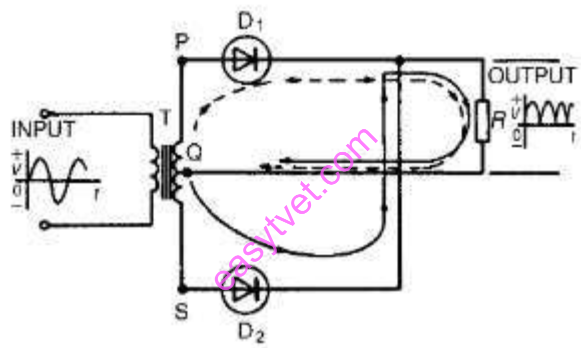

Figure 22: Full wave rectifier

The current flowing in the load R is in the same direction for both half-cycles of the input. The output waveform is thus as shown in figure 20. The output is unidirectional, but is not constant; however, it is better than the output waveform produced with a half-wave rectifier. A disadvantage of this type of rectifier is that centre-tapped transformers are expensive. Full-wave bridge rectification four diodes may be used in a bridge rectifier circuit, as shown in Figure 21 to obtain full-wave rectification. (Note, the term 'bridge' means a network of four elements connected to form a square, the input being applied to two opposite corners and the output being taken from the remaining two corners). As for the rectifier shown in Figure. 20 the current flowing in load R is in the same direction for both half cycles of the input giving the output waveform shown. Following the broken line in figure 21:

When P is positive with respect to Q, current flows from the transformer to point E, through diode D4 to point F, then through load R to point H, through D2 to point G, and back to the transformer. Following the full line in figure 27: When Q is positive with respect to P, current flows from the transformer to point G, through diode D3to point F, then through load R to point H, through D1to point E, and back to the transformer. The output waveform is not steady and needs improving; a method of smoothing is explained in the next section.

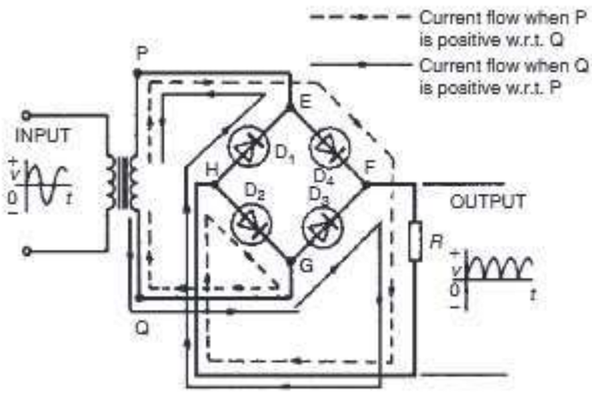

Figure 23: Bridge rectifier

DC to AC Converters

Converts DC to AC power by switching the DC input voltage (or current) in a pre-determined sequence so as to generate AC voltage (or current) output. The figure 27 show the image and the block representation of DC to AC inverters

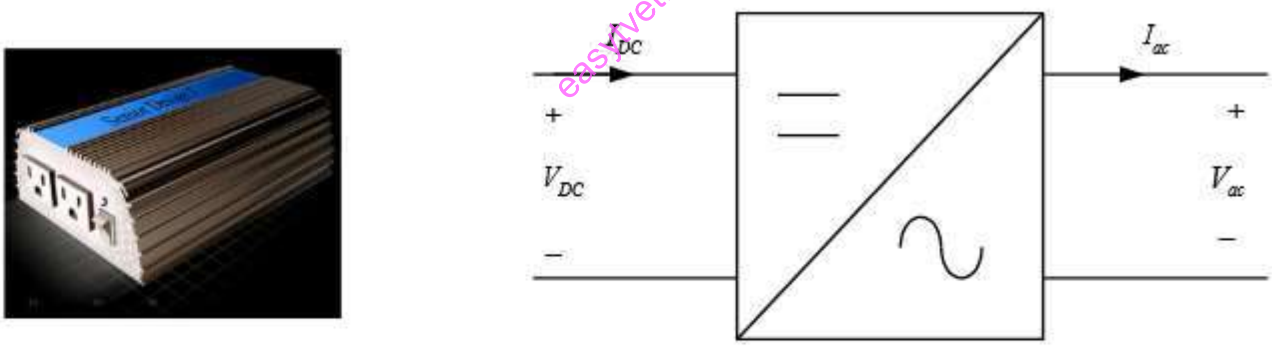

Figure 24: Dc to Ac inverters

3.1.2.2. Self-Assessment Questions

1. State the Norton's Theorem
2. What is the difference between power and energy?
3. An EMF of 50 v is applied in turn to the following resistors: 22 Ω,820 Ω,330 Ω and 27 MΩ calculate the current flow in each case
4. What are the four major components of a solar PV system?

3.1.2.3. Tools, Equipment and Materials

These includes;

Tools and equipment	Materials and supplies
i. Cable Strippers ii. Pliers iii. Screw drivers iv. Hammers v. Chisels vi. Allen keys vii. Electrician knives viii. Crimping tools ix. Bending springs x. Bending machine xi. Steel tapes xii. Draw wires xiii. Hack saws xiv. Drilling tools xv. Stock and die xvi. Bench vice xvii. Machine vice xviii. PPE – hand gloves, dust coats, dust masks, helmets, ear muffs, industrial boots	i. Stationery ii. Cables iii. Light fittings iv. Accessories v. Conduits and fittings vi. Cable trays vii. Cable ducts viii. Trunkings ix. Computers x. Drawing instruments xi. Screws
Reference materials • IEE regulations • Occupational safety and health act (OSHA) • Work injury benefits act (WIBA) • Manufacturers' catalogues • British standards • KEBS standards	

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3.1.2.5.Model Answers to self-assessment Questions

1. Norton's theorem states: The current that flows in any branch of a network is the same as that which would flow in the branch if it were connected across a source of electrical energy, the short-circuit current of which is equal to the current that would flow in a short-circuit across the branch, and the internal resistance of which is equal to the resistance which appears across the open-circuited branch terminals

2. Energy is the ability to do work while power is the rate of doing work

3. 50/22=2.2 7A, (b)5/82=0.06 A (c)50/ (330x1000)=0.0002A

4. What are the four major components of a solar PV system?
   - Solar module
   - Solar battery
   - Charge controller
   - Inverter

Use of basic electrical machine

3.1.1.0.Introduction

In order to use basic electrical machine, identify various electrical machines, perform operations involving single phase and three phase AC and DC motors, perform operations involving single phase and three phase transformers, perform operations involving single phase and three phase generators and apply AC and DC machines. .

3.1.1.1.Performance Standards

1. Identify types of various electrical machines
2. Perform operations involving single phase and three phase AC and DC motors
3. Perform calculations involving single phase AC and DC transformers.
4. Perform operations involving single and three phase generators
5. Apply AC and DC machines are as per their functions

3.1.1.2.Information Sheet

Direct current motors

All electric motors work on the principle that when a current carrying conductor is placed in a magnetic field it will experience a force. An electric motor uses this magnetic force to turn the shaft of the electric motor. If a current carrying conductor is placed into the field of a permanent magnet as shown in Figure 50(c) a force F will be exerted on the conductor to push it out of the magnetic field.

Figure 50(a) shows the magnetic field due to the current carrying conductor only. Figure 50(b) shows the magnetic field due to the permanent magnet in which is placed the conductor carrying no current. Figure 50(c) shows the effect of the combined magnetic fields which are distorted and, because lines of magnetic flux never cross, but behave like stretched elastic bands, always trying to find the shorter distance between a north and south pole, the force F is exerted on the conductor, pushing it out of the permanent magnetic field.

This is the basic motor principle, and the force F is dependent upon the strength of the magnetic fi the conductor I and the length of conductor within the magnetic field l.

The following equation expresses this relationship:

$F = BIL(N)$ Where B is in tesla, l is in metres, I is in amperes and F is in Newtons.

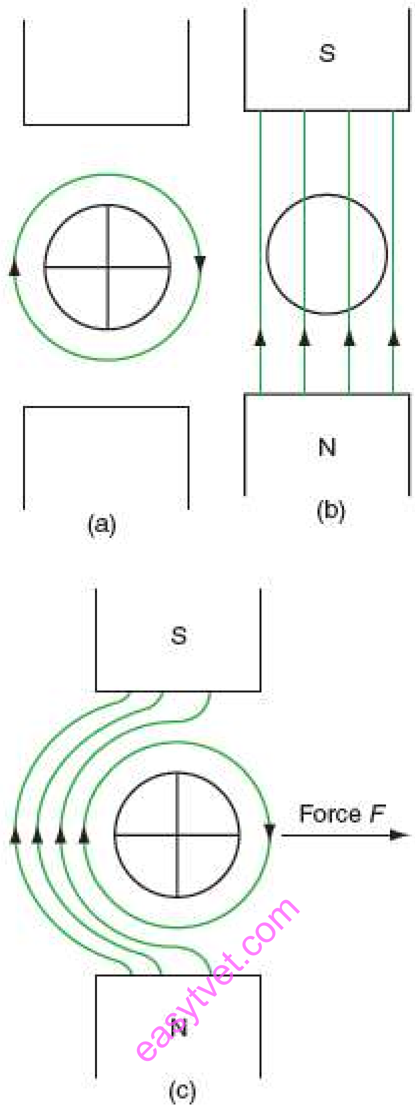


Figure 25: Magnetic fields

DC generators

D.C. generators are classified according to the method of their field excitation. These groupings are:

i. Separately-excited generators, where the field winding is connected to a source of supply other than the armature of its own machine.

ii. Self-excited generators, where the field winding receives its supply from the armature of its own machine, and which are sub-divided into

   I. shunt,

   II. series, and

   III. compound wound generators

Practical $d.c.$ motors

Practical motors are constructed as shown in Figure 51 all d.c. motors contain a field winding wound on pole pieces attached to a steel yoke. The armature winding rotates between the poles and is connected to the commutator. Contact with the external circuit is made through carbon brushes rubbing on the commutator segments. Direct current motors are classified by the way in which the field and armature windings are connected, which may be in series or in parallel.

Series motor

The field and armature windings are connected in series and consequently share the same current. The series motor has the characteristics of a high starting torque but a speed which varies with load. Figure 52 shows series motor connections and characteristics. For this reason the motor is only suitable for direct coupling to a load, except in very small motors, such as vacuum cleaners and hand drills, and is ideally suited for applications where the machine must start on load, such as electric trains, cranes and hoists. Reversal of rotation may be achieved by reversing the connections of either the field or armature windings but not both. This characteristic means that the machine will run on both a.c. or d.c. and is, therefore, sometimes referred to as a 'universal' motor.

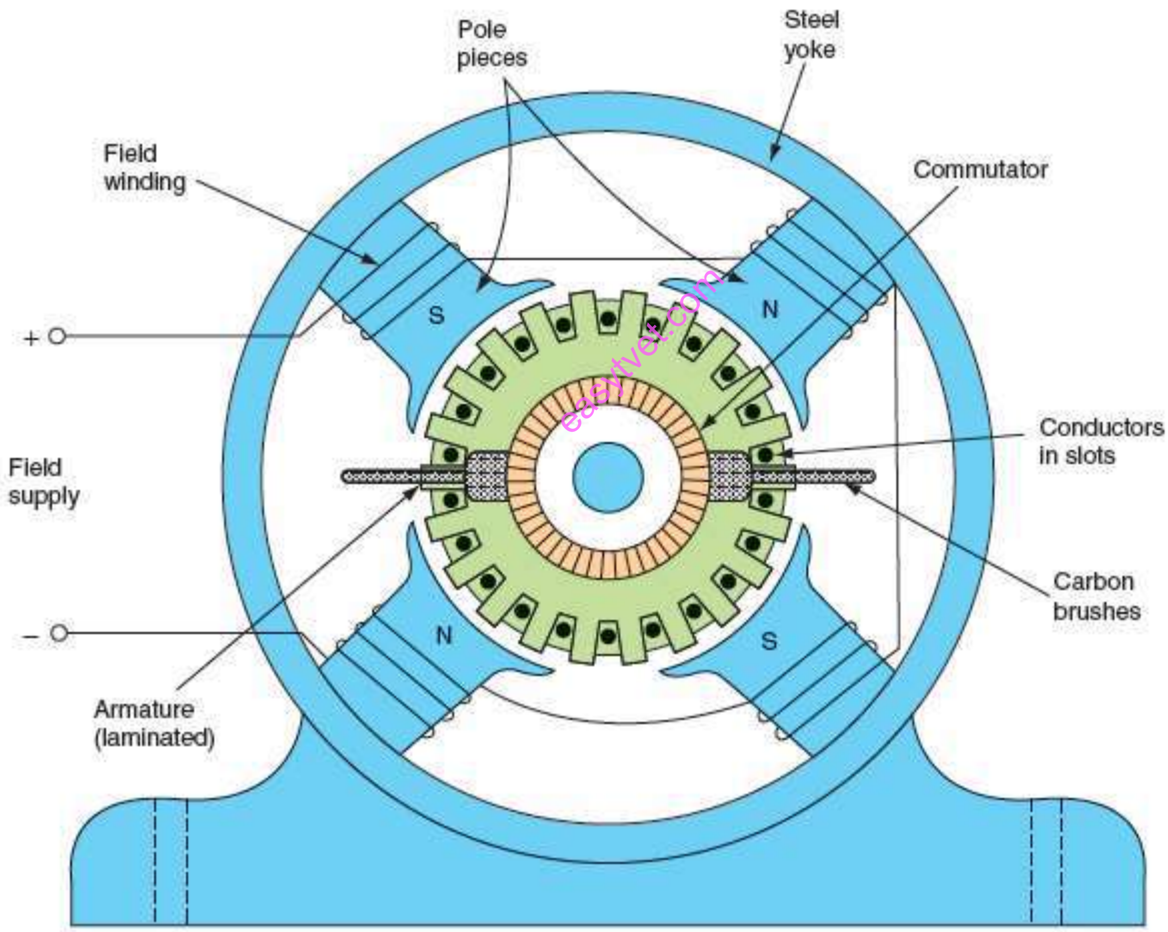


Figure 26: Practical motors

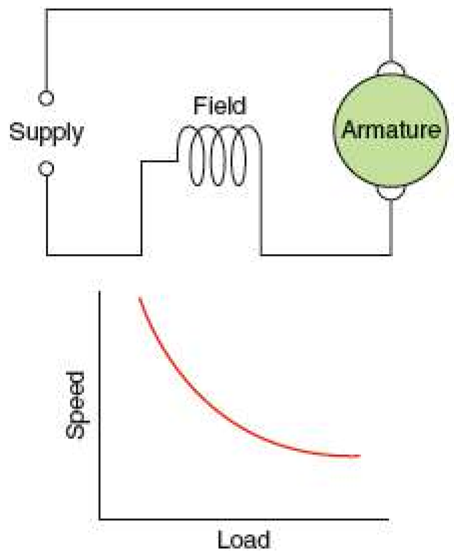


Figure 27: Series motor connection and characteristics

Single-phase $a.c.$ motors

A single-phase $a.c.$ supply produces a pulsating magnetic field, not the rotating magnetic field produced by a three-phase supply. All $a.c.$ motors require a rotating field to start. Therefore, single-phase a.c. motors have two windings which are electrically separated by about 90°. The two windings are known as the start and run windings. The magnetic fields produced by currents flowing through these out-of-phase windings create the rotating field and turning force required to start the motor. Once rotation is established, the pulsating field in the run winding is sufficient to maintain rotation and the start winding is disconnected by a centrifugal switch which operates when the motor has reached about 80% of the full load speed.

A cage rotor is used on single-phase a.c. motors, the turning force being produced in the way described previously for three-phase induction motors and shown in figure 53 because both windings carry currents which are out of phase with each other, the motor is known as a 'split-phase' motor. The phase displacement between the currents in the windings is achieved in one of two ways:

- by connecting a capacitor in series with the start winding, as shown in figure 53(a), which gives a 90° phase difference between the currents in the start and run windings;
- by designing the start winding to have a high resistance and the run winding a high inductance, once again creating a 90° phase shift between the currents in each winding, as shown in Figure 53(b).

When the motor is first switched on, the centrifugal switch is closed and the magnetic fields from the two coils produce the turning force required to run the rotor up to full speed. When the motor reaches about 80% of full speed, the centrifugal switch clicks open and the machine continues to run on the magnetic flux created by the run winding only.

Split-phase motors are constant speed machines with a low starting torque and are used on light loads such as fans, pumps, refrigerators and washing machines. Reversal of rotation may be achieved by reversing the connections to the start or run windings, but not both.

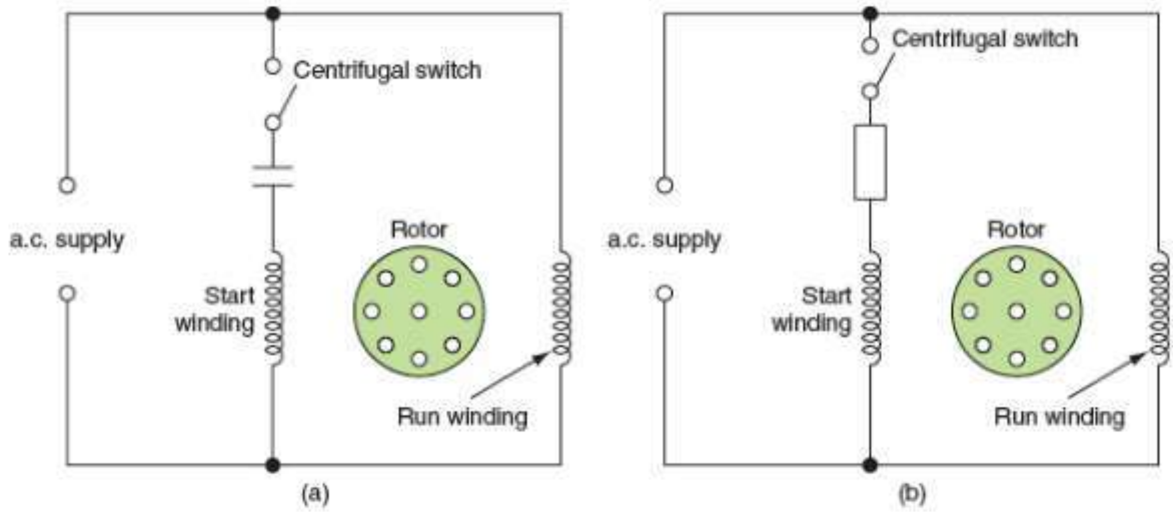


Figure 28: circuit diagram of : (a) capacitor split phase motors and (b) Resistance split phase motors

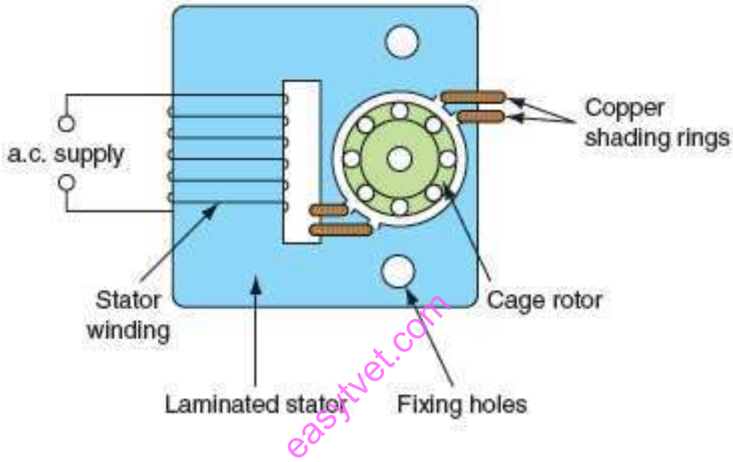


Figure 29: Shaded pole motor

Shaded pole motors

The shaded pole motor is a simple, robust single-phase motor, which is suitable for very small machines with a rating of less than about 50 W. Figure 54 shows a shaded pole motor. It has a cage rotor and the moving field is produced by enclosing one side of each stator pole in a solid copper or brass ring, called a shading ring, which displaces the magnetic field and creates an artificial phase shift.

Shaded pole motors are constant speed machines with a very low starting torque and are used on very light loads such as oven fans, record turntable motors and electric fan heaters. Reversal of rotation is theoretically possible by moving the shading rings to the opposite side of the stator pole face. However, in practice this is often not a simple process, but the motors are symmetrical and it is sometimes easier to reverse the rotor by removing the fixing bolts and reversing the whole motor.

There are more motors operating from single-phase supplies than all other types of motor added together. Most of them operate as very small motors in domestic and business machines where single-phase supplies are most common.

Transformers

A transformer is an electrical machine which is used to change the value of an alternating voltage. They vary in size from miniature units used in electronics to huge power transformers used in power stations. A transformer will only work when an alternating voltage is connected. It will not normally work from a $d.c.$ supply such as a battery.

A transformer, as shown in Fig. 55, consists of two coils, called the primary and secondary coils, or windings, which are insulated from each other and wound on to the same steel or iron core. An alternating voltage applied to the primary winding produces an alternating current, which sets up an alternating magnetic flux throughout the core.

This magnetic flux induces an $e.m.f$ in the secondary winding, as described by Faraday's law, which says that when a conductor is cut by a magnetic field, an $e.m.f$ is induced in that conductor. Since both windings are linked by the same magnetic flux, the induced $e.m.f$ per turn will be the same for both windings. Therefore, the $e.m.f$ in both windings is proportional to the number of turns. In symbols

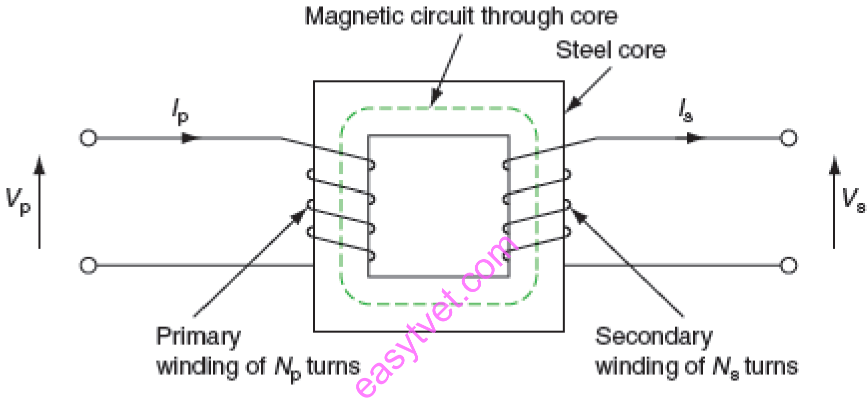


Figure 30: Simple transformer

$$\frac{V_p}{N_p} = \frac{V_s}{N_s}$$

Where V_p = the primary voltage

V_s = the secondary voltage

N_p = the number of primary turns

N_s = the number of secondary turns

Moving the terms around, we have a general expression for a transformer:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

Types of transformer

Step down Transformers are used to reduce the output voltage, often for safety reasons. Figure 10.22 shows a step down transformer where the primary winding has twice as many turns as the secondary winding. The turns ratio is 2:1 and, therefore, the secondary voltage is halved.

Step up Transformers are used to increase the output voltage. The electricity generated in a power station is stepped up for distribution on the National Grid Network. Figure 56 shows a step up transformer where the primary winding has only half the number of turns as the secondary winding.

The turns ratio is 1:2 and, therefore, the secondary voltage is doubled.

Instrument Transformers are used in industry and commerce so that large currents and voltage can be measured by small electrical instruments.

A Current Transformer (or CT) has the large load currents connected to the primary winding of the transformer and the ammeter connected to the secondary winding. The ammeter is calibrated to take account of the turns ratio of the transformer, so that the ammeter displays the actual current being taken by the load when the ammeter is actually only taking a small proportion of the load current.

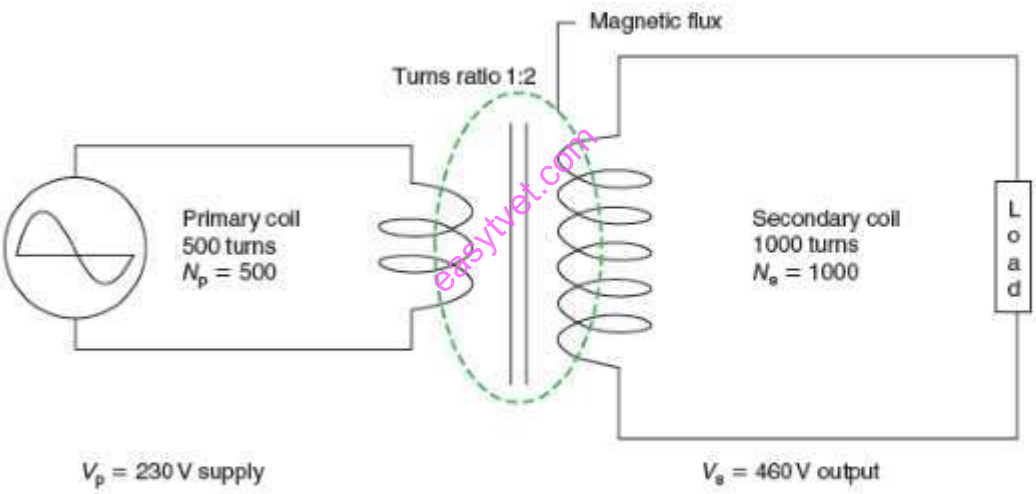


Figure 31: Step up transformer

A Voltage Transformer (or VT) has the main supply voltage connected to the primary winding of the transformer and the voltmeter connected to the secondary winding. The voltmeter is calibrated to take account of the turns ratio of the transformer, so that the voltmeter displays the actual supply voltage.

Separated Extra-low Voltage (SELV) Transformers If the primary winding and the secondary winding of a double wound transformer have a separate connection to earth, then the output of the transformer is effectively isolated from the input since the only connection between the primary and secondary windings is the magnetic flux in the transformer core. Such a transformer would give a very safe electrical supply which might be suitable for bathroom equipment such as shaver sockets and construction site 110 V tools, providing that all other considerations are satisfied, such as water ingress, humidity, IP protection and robust construction.

Electrical machines

Electrical machines are energy converters. If the machine input is mechanical energy and the output electrical energy then that machine is a generator, as shown in Fig. 56(a). Alternatively, if the machine input is electrical energy and the output mechanical energy then the machine is a motor, as shown in Fig. 56(b) .An electrical machine may be used as a motor or a generator, although in practice the machine will operate more efficiently when operated in the mode for which it was designed.

Simple $a.c.$ generator or alternator

If a simple loop of wire is rotated between the poles of a permanent magnet, as shown in Fig. 57, the loop of wire will cut the lines of magnetic flux between the north and south poles. This flux cutting will induce an $e.m.f$ in the wire by Faraday's law which states that when a conductor cuts or is cut by a magnetic field, an $e.m.f$ is induced in that conductor. If the generated $e.m.f$ is collected by carbon brushes at the slip rings and displayed on the screen of a cathode ray oscilloscope, the waveform will be seen to be approximately sinusoidal. Alternately changing, first positive and then negative, then positive again, giving an alternating output. This simple arrangement produces a very bumpy $d.c.$ output. In a practical machine, the commutator would contain many segments and many windings to produce a smoother $d.c.$ output. Similar to the unidirectional battery supply shown in Fig. 58.

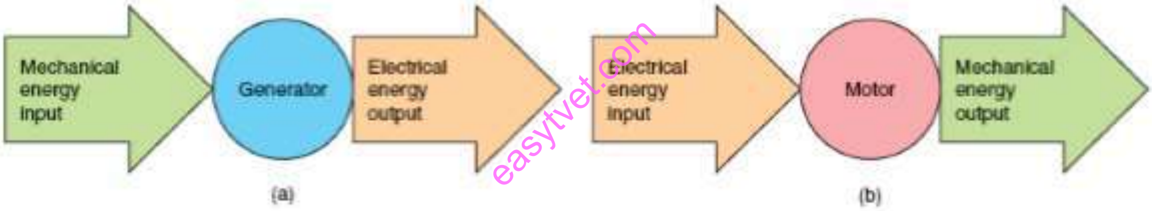


Figure 32: Electrical machines as energy converters

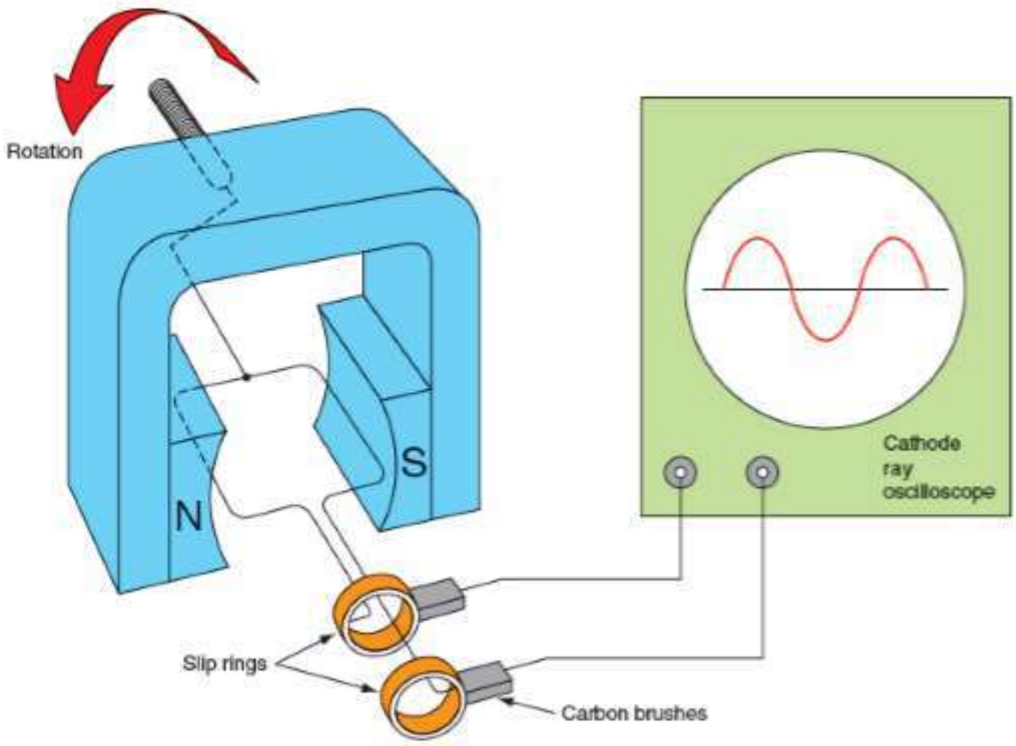


Figure 33: Simple AC generator or alternator

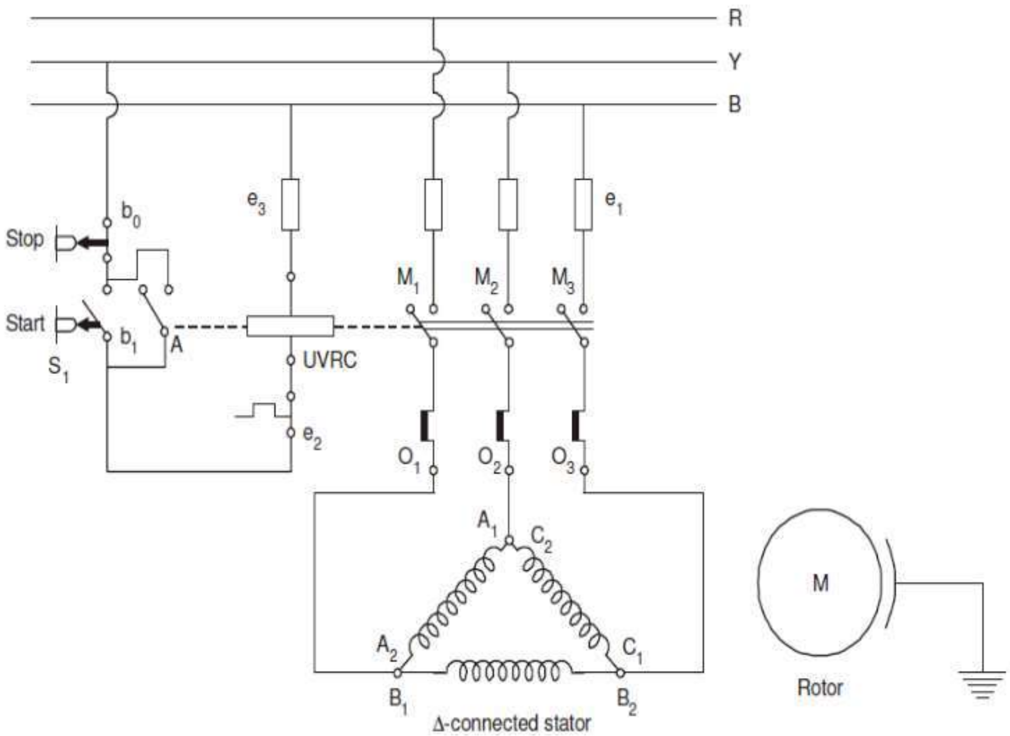
Starting methods of three phase induction motors

An induction motor is similar to a poly-phase transformer whose secondary is short circuited. Thus, at normal supply voltage, like in transformers, the initial current taken by the primary is very large for a short while. Unlike in DC motors, large current at starting is due to the absence of back e.m.f. If an induction motor is directly switched on from the supply, it takes 5 to 7 times its full load current and develops a torque which is only 1.5 to 2.5 times the full load torque. This large starting current produces a large voltage drop in the line, which may affect the operation of other devices connected to the same line. Hence, it is not advisable to start induction motors of higher ratings (generally above 25kW) directly from the mains supply. Various starting methods of induction motors are described below.

Direct-on-line (DOL) starters

Small three phase induction motors can be started direct-on-line, which means that the rated supply is directly applied to the motor. But, as mentioned above, here, the starting current would be very large, usually 5 to 7 times the rated current. The starting torque is likely to be 1.5 to 2.5 times the full load torque. Induction motors can be started directly on-line using a DOL starter which generally consists of a contactor and a motor protection equipment such as a circuit breaker. A DOL starter consists of a coil operated contactor which can be controlled by start and stop push buttons. When the start push button is pressed, the contactor gets energized and it closes all the three phases of the motor to the supply phases at a time. The stop push button de-energizes the contactor and disconnects all the three phases to stop the motor. In order to avoid excessive voltage drop in the supply line due to large starting current, a DOL starter is generally used for motors that are rated below 5kW. The figure 59 shows a direct online starters

Figure 34: Direct online starters



a) Auto-transformers:

Auto-transformers are also known as auto-starters. They can be used for both star connected and delta connected squirrel cage motors. It is basically a three phase step down transformer with different taps provided that permit the user to start the motor at, say, 50%, 65% or 80% of line voltage. With auto-transformer starting, the current drawn from supply line is always less than the motor current by an amount equal to the transformation ratio. For example, when a motor is started on a 65% tap, the applied voltage to the motor will be 65% of the line voltage and the applied current will be 65% of the line voltage starting value, while the line current will be 65% of 65% (i.e. 42%) of the line voltage starting value. This difference between the line current and the motor current is due to transformer action. The internal connections of an auto-starter are as shown in the figure. At starting, switch is at "start" position, and a reduced voltage (which is selected using a tap) is applied across the stator. When the motor gathers an appropriate speed, say up to 80% of its rated speed, the auto-transformer automatically gets disconnected from the circuit as the switch goes to "run" position.

The switch changing the connection from start to run position may be air-break (small motors) or oil-immersed (large motors) type. There are also provisions for no-voltage and overload, with time delay circuits on an autostarter.

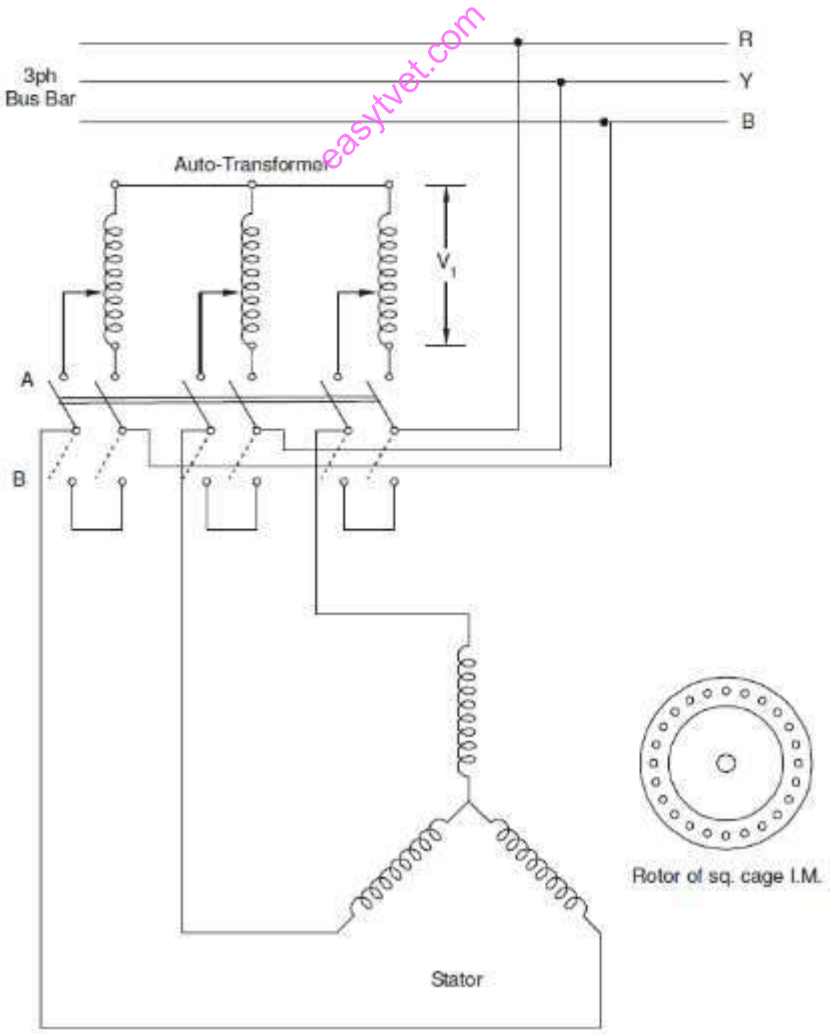


Figure 35: Autotransformer starting method

b) Star-delta starter

The stator winding of the motor is designed for delta operation and is connected in star during the starting period. When the machine is up to speed, the connections are changed to delta. The circuit arrangement for star-delta starting is shown in Fig. The six leads of the stator windings are connected to the changeover switch as shown. At the instant of starting, the changeover switch is thrown to ―Start‖ position which connects the stator windings in star. Therefore, each stator phase gets V 3 volts where V is the line voltage. This reduces the starting current. When the motor picks up speed, the changeover switch is thrown to ―Run‖ position which connects the stator windings in delta. Now each stator phase gets full line voltage V.

The disadvantages of this method are:

i. With star-connection during starting, stator phase voltage is 1/root3 times the line voltage. Consequently, starting torque is (1/root3)2 or 1/3 times the value it would have with D-connection. This is rather a large reduction in starting torque.
ii. The reduction in voltage is fixed. This method of starting is used for medium-size machines (up to about 25 H.P.).

Figure 61 shows star delta starter. Figure 62 shows the star and delta connections

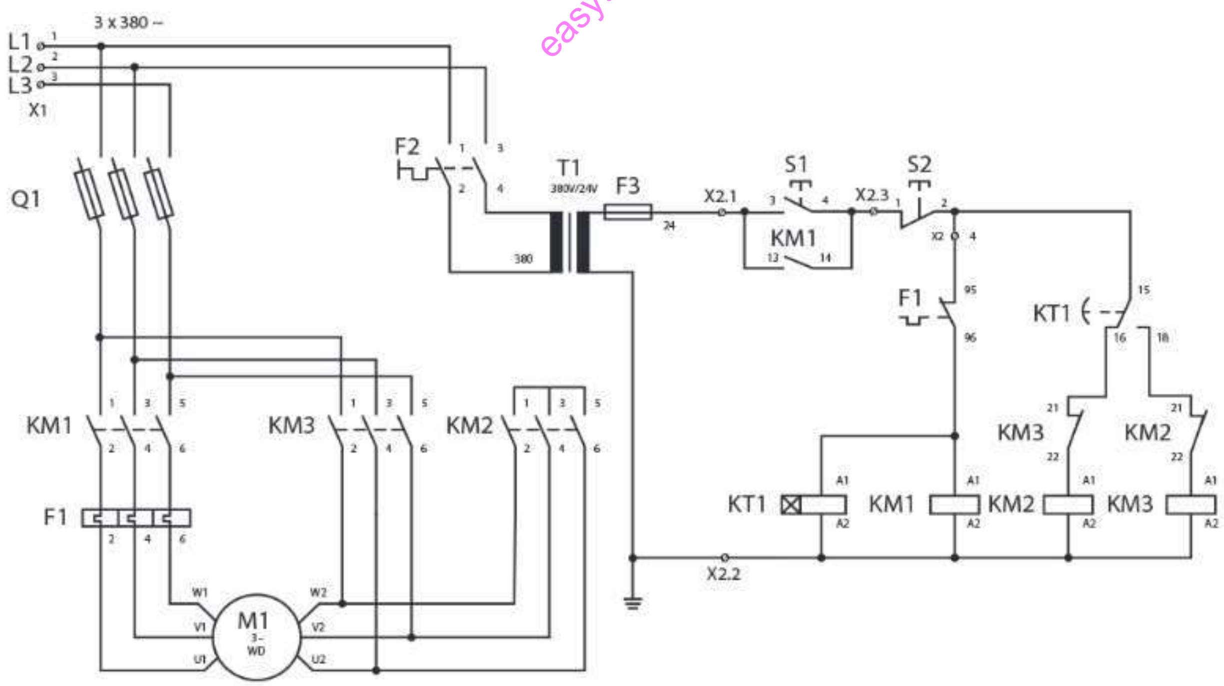


Figure 36: Star delta starter

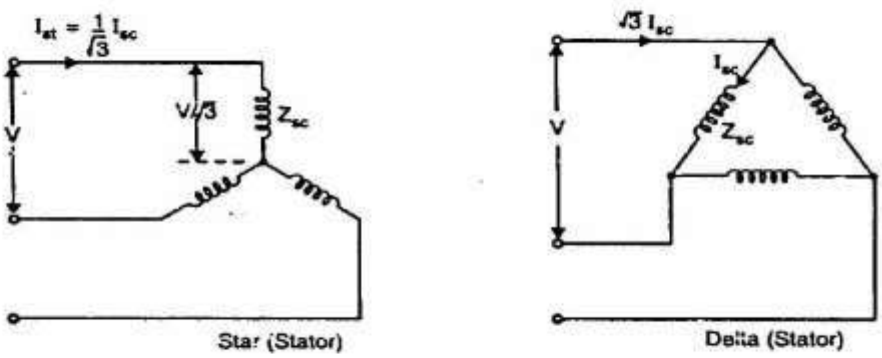


Figure 37: star and delta connections

3.1.3.3.Learning Activities

Workshop Practice

Practical activities	Knowledge	Special instruction
1. Identify types of various electrical machines		
2. Perform operations involving single phase and three phase AC and DC motors		
3. Perform calculations involving single phase and three phase AC and DC transformers		
4. Perform operations involving single and three phase generators.		
5. Apply AC and DC machines as per their functions		

3.1.3.4.Self-Assessment Questions

1. One application for an $a.c.$ induction motor is:
   - A. an electric train
   - B. a microwave oven
   - C. a central heating pump
   - D. an electric drill.

2. One application for a shaded pole a.c. motor is:

A. an electric train.

B. a microwave oven.

C. a central heating pump

D. an electric drill.

3. A step down transformer has 1000 turns on the primary winding and 500 turns on the secondary winding. If the input voltage was 230 V the output voltage will be:

A. 11V

B. 115 V

C. 200 V

D. 460 V.

4. An electromagnetic switch operated by a solenoid is one definition of: a.

A. a transformer

B. an a.c. motor

C. an relay

D. an inductive coil.

3.1.3.5. Tools, Equipment and Materials

Recommended Resources

Tools and equipment	**Materials and supplies**
i. Cable Strippers ii. Pliers iii. Screw drivers iv. Hammers v. Chisels vi. Allen keys vii. Electrician knives viii. Crimping tools ix. Bending springs x. Bending machine xi. Steel tapes xii. Draw wires xiii. Hack saws xiv. Drilling tools xv. Stock and die xvi. Bench vice	i. Stationery ii. Cables iii. Light fittings iv. Accessories v. Conduits and fittings vi. Cable trays vii. Cable ducts viii. Trunkings ix. Computers x. Drawing instruments xi. Screws

xvii. Machine vice xviii. PPE – hand gloves, dust coats, dust masks, helmets, ear muffs, industrial boots	
Reference materials I. IEE regulations II. Occupational safety and health act (OSHA) III. Work injury benefits act (WIBA) IV. Manufacturers' catalogues V. British standards VI. KEBS standards	

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3.1.3.6.Model Answers to self-assessment Question

1. One application for an a.c. induction motor is:
   - A. An electric train
   - B. A microwave oven
   - **C. A central heating pump**
   - D. An electric drill.
2. One application for a shaded pole a.c. motor is:
   - A. An Electric Train.
   - B. **A Microwave Oven**.
   - C. A Central Heating Pump
   - **D.** An Electric Drill.
3. **3.** A step down transformer has 1000 turns on the primary winding and 500 turns on the secondary winding. If the input voltage was 230 V the output voltage will be:
   - A. 11V
   - **B. 115 V**
   - C. 200 V
   - D. 460 V.
4. An electromagnetic switch operated by a solenoid is one definition of: a.
   - A. A Transformer
   - B. An A.C. Motor
   - **C. An Relay**
   - **D.** An Inductive Coil.

Demonstrate understanding of three phase power supply

3.1.2.0.Introduction

To demonstrate understanding of three phase power supply, perform connections of three phase power supply as per the standard operating procedure, perform calculations involving three phase power supply, perform measurements of three phase power supply and perform interconnections of three phase power supply as per the nature of load.

3.1.2.1. Performance Standards

1. Perform connections of three phase power supply as per the standard operating procedure,
2. perform calculations involving three phase power supply
3. Perform measurements of three phase power supply
4. Perform interconnections of three phase power supply as per the nature of load.

Information Sheet

Star and delta connections

The three-phase windings of an $a.c.$ generator may be star connected or delta connected as shown in Fig. 63 The important relationship between phase and line currents and voltages is also shown. The square root of 3 is simply a constant for three-phase circuits, and has a value of 1.732. The delta connection is used for electrical power transmission because only three conductors are required. Delta connection is also used to connect the windings of most three-phase motors because the phase windings are perfectly balanced and, therefore, do not require a neutral connection. Making a star connection at the local sub-station has the advantage that two voltages become available – a line voltage of 400 V between any two phases, and a phase voltage of 230 V between line and neutral which is connected to the star point. In any star-connected system currents flow along the lines (IL), through the load and return by the neutral conductor connected to the star point. In a balanced three-phase system all currents have the same value and when they are added up by phasor addition, we find the resultant current is zero. Therefore, no current flows in the neutral and the star point is at zero volts. The star point of the distribution transformer is earthed because earth is also at zero potential. A star-connected system is also called a three-phase four-wire system and allows us to connect single-phase loads to a three-phase system.

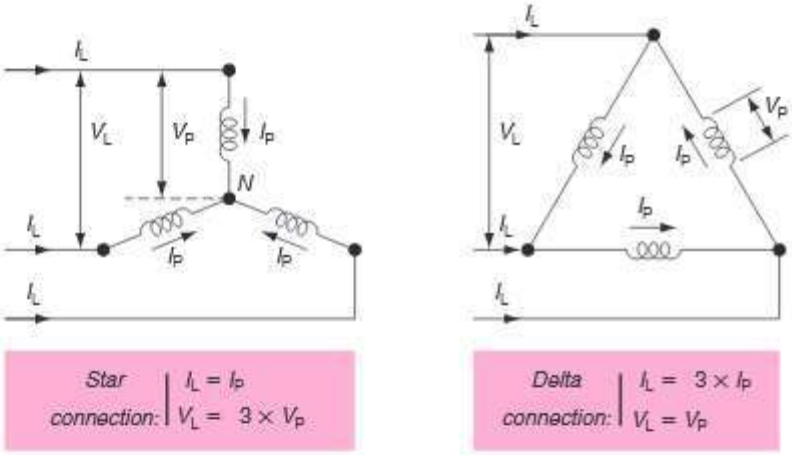

Figure 38: Star and delta connections

Three-phase power We know from our single-phase alternating current theory in Chapter 10 that power can be found from the following formula: Power cos (W) VIcos φ In any balanced three-phase system, the total power is equal to three times the power in any one-phase.

Voltage, current and power calculation

Three similar coils, each having resistance of 8Ω and an inductive reactance of 8Ω are connected

(a) In star and

(b) In delta, across a 415V, 3-phase supply. Calculate for each connection the readings on each of two wattmeters connected to measure the power by the two-wattmeter method.

(a) **Star connection:** $V_L = \sqrt{3}\, V_p$ and $I_L = I_p$

Phase voltage, $V_p = \dfrac{V_L}{\sqrt{3}} = \dfrac{415}{\sqrt{3}}$

and phase impedance,

$$Z_p = \sqrt{R_p^2 + X_L^2} = \sqrt{8^2 + 8^2} = 11.31\ \Omega$$

Hence phase current,

$$I_p = \frac{V_p}{Z_p} = \frac{\frac{415}{\sqrt{3}}}{11.31} = 21.18\ \text{A}$$

Total power,

$$P = 3I_p^2 R_p = 3(21.18)^2(8) = 10\,766\ \text{W}$$

If wattmeter readings are P_1 and P_2 then:

$$P_1 + P_2 = 10\,766 \qquad (1)$$

Since $R_p = 8\ \Omega$ and $X_L = 8\ \Omega$, then phase angle $\phi = 45°$ (from impedance triangle).

$$\tan\phi = \sqrt{3}\left(\frac{P_1 - P_2}{P_1 + P_2}\right)$$

hence $\tan 45° = \dfrac{\sqrt{3}(P_1 - P_2)}{10\,766}$

from which

$$P_1 - P_2 = \frac{(10\,766)(1)}{\sqrt{3}} = 6216\,\text{W} \qquad (2)$$

Adding Equations (1) and (2) gives:

$2P_1 = 10\,766 + 6216 = 16\,982\,\text{W}$

Hence $P_1 = 8491\,\text{W}$

From Equation (1), $P_2 = 10\,766 - 8491 = 2275\,\text{W}$.

When the coils are star-connected the wattmeter readings are thus 8.491 kW and 2.275 kW

(b) **Delta connection:** $V_L = V_p$ and $I_L = \sqrt{3}\,I_p$

Phase current, $I_p = \frac{V_p}{Z_p} = \frac{415}{11.31} = 36.69\,\text{A}$.

Total power,

$P = 3I_p^2R_p = 3(36.69)^2(8) = 32\,310\,\text{W}$

Hence $P_1 + P_2 = 32\,310\,\text{W} \qquad (3)$

$$\tan\phi = \sqrt{3}\left(\frac{P_1 - P_2}{P_1 + P_2}\right) \text{ thus } 1 = \frac{\sqrt{3}(P_1 - P_2)}{32\,310}$$

from which,

$$P_1 - P_2 = \frac{32\,310}{\sqrt{3}} = 18\,650\,\text{W} \qquad (4)$$

Adding Equations (3) and (4) gives:

$2P_1 = 50\,960$ from which $P_1 = 25\,480\,\text{W}$.

From Equation (3), $P_2 = 32\,310 - 25\,480 = 6830\,\text{W}$

When the coils are delta-connected the wattmeter readings are thus 25.48 kW and 6.83 kW

Measurement of power in three phase systems

Power in three-phase loads may be measured by the following methods:

a) One-wattmeter method for a balanced load

Wattmeter connections for both star and delta are shown in Fig. 64

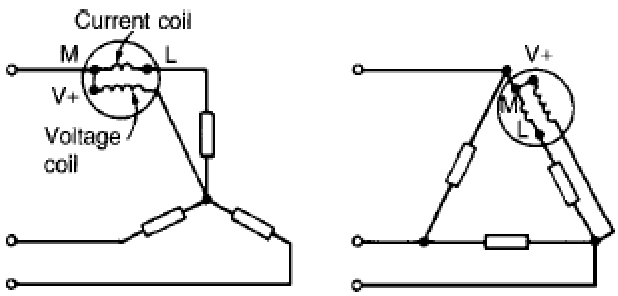

Figure 39: One wattmeter method

Total power = $3X wattmeter\ reading$

b) Two-wattmeter method for balanced or unbalanced loads

A connection diagram for this method is shown in Fig. 65 for a star-connected load. Similar connections are made for a delta-connected load.

Total power = sum of wattmeter readings

$=P_1 + P_2$

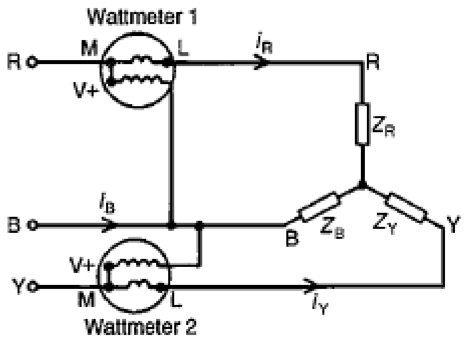

Figure 40: Two wattmeter method

The power factor may be determined from: $\tan \emptyset = \sqrt{3}\left(\frac{P_1 - P_2}{P_1 + P_2}\right)$

It is possible, depending on the load power factor, for one wattmeter to have to be 'reversed' to obtain a reading. In this case it is taken as a negative reading

c) Three-wattmeter method for a three-phase, 4- wire system for balanced and unbalanced loads

Total Power = $P_1 + P_2 + P_3$

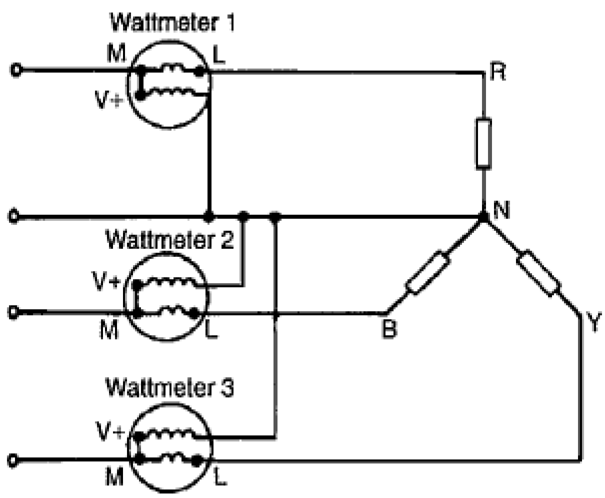

Figure 41: Three wattmeter method

3.1.2.2. Learning Activities

Industrial attachment/workshop practice/project

Practical activities	knowledge	Special instructions
1. Performed connections of three phase power supply as per the standard operating procedure.	Connections of 3 phase power supplies	
2. Performed calculations involving three phase power supply connections	Three phase power calculations	
3. Performed measurements of three phase power supply	Measurements of three phase power supply	
4. Performed interconnections of three phase power supply	Interconnection of three phase power supply	

3.1.2.3. Self-Assessment Questions

1. Which are the ways in which phases of a three-phase supply can be interconnected to reduce the number of conductors used compared with three single-phase systems?
2. State the relationships between line and phase currents and line and phase voltages or a star-connected system
3. By what methods may power be measured in a three-phase system?
4. State the national standard phase sequence for a three-phase supply

3.1.3.0. Tools, Equipment and Materials

Recommended Tools, Equipment and Materials

Tools and equipment	Materials and supplies
i. Cable Strippers	i. Stationery
ii. Pliers	ii. Cables
iii. Screw drivers	iii. Light fittings
iv. Hammers	iv. Accessories
v. Chisels	v. Conduits and fittings
vi. Allen keys	vi. Cable trays
vii. Electrician knives	vii. Cable ducts
viii. Crimping tools	viii. Trunkings
ix. Bending springs	ix. Computers
x. Bending machine	x. Drawing instruments

xi. Steel tapes xii. Draw wires xiii. Hack saws xiv. Drilling tools xv. Stock and die xvi. Bench vice xvii. Machine vice xviii. PPE – hand gloves, dust coats, dust masks, helmets, ear muffs, industrial boots	xi. Screws
Reference materials a) IEE regulations b) Occupational safety and health act (OSHA) c) Work injury benefits act (WIBA) d) Manufacturers' catalogues e) British standards f) KEBS standards	

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3.1.3.1. Model Answer to self-assessment Questions

1. Ways in which phases of a three phase supply can be interconnected to reduce the number of conductors used compared with three single-phase systems
    i. **Star**
    ii. **Delta**
2. **Relationships between line and phase currents and line and phase voltages or a star-connected system**

$$\mathbf{V_L = \sqrt{3}\,V_p}$$

$$\mathbf{I_L = I_P}$$

3. **Methods in which power may be measured in a three-phase system**
    a) One wattpower method
    b) Two wattpower method
    c) Three wattpower method
4. **National standard phase sequence for a three-phase supply**

    RYBN

3.1.5. USE OF POWER FACTOR IN ELECTRICAL INSTALLATION

Introduction

Performance Standard

1. Identify power triangle i.e. active, apparent and reactive power
2. Perform use of power factor
3. Perform calculations involving power factor correction
4. Apply methods of power factor correction

Information Sheet

Power and power factor

Power factor ($p.f.$) is defined as the cosine of the phase angle between the current and voltage:

$$\text{p.f.} = \cos\phi$$

If the current lags the voltage as shown in Fig. 10.5, we say that the $p.f.$ is lagging, and if the current leads the voltage as shown in Fig. 10.6, the $p.f.$ is said to be leading. From the trigonometry of the impedance triangle shown in Fig. 10.7,$p.f.$ is also equal to:

$$\text{p.f.} = \cos\phi = \frac{R}{Z} = \frac{V_R}{V_T}$$

The electrical power in a circuit is the product of the instantaneous values of the voltage and current. Figure 67 shows the voltage and current waveform for a pure inductor and pure capacitor. The power waveform is obtained from the product of *V* and *I* at every instant in the cycle. It can be seen that the power waveform reverses every quarter cycle, indicating that energy is alternately being fed into and taken out of the inductor and capacitor. When considered over one complete cycle, the positive and negative portions are equal, showing that the average power consumed by a pure inductor or capacitor is zero. This shows that inductors and capacitors store energy during one part of the voltage cycle and feed it back into the supply later in the cycle. Inductors store energy as a magnetic field and capacitors as an electric field.

In an electric circuit more power is taken from the supply than is fed back into it, since some power is dissipated by the resistance of the circuit, and therefore:

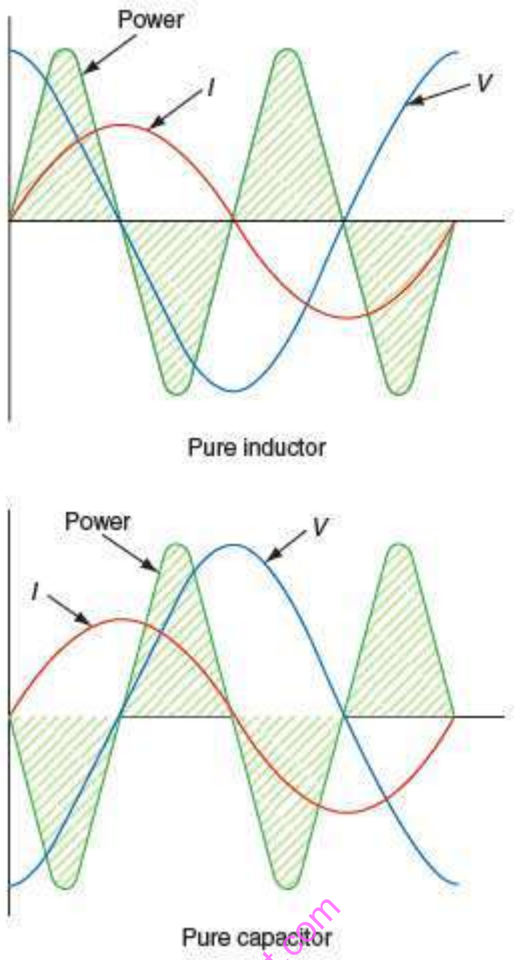

Figure 42: waveform for the ac power in purely inductive and purely capacitive circuit

$P = I^2R\,(\mathrm{W})$

In any $d.c.$ circuit the power consumed is given by the product of the voltage and current, because in a $d.c.$ circuit voltage and current are in phase In an $a.c.$ circuit the power consumed is given by the product of the current and that part of the voltage which is in phase with the current. The in-phase component of the voltage is given by $V\cos\varphi,$ and so power can also be given by the equation:

The power factor of most industrial loads is lagging because the machines and discharge lighting used in industry are mostly inductive. This causes an additional magnetizing current to be drawn from the supply, which does not produce power, but does need to be supplied, making supply cables larger.

Power Triangle

Power Triangle is the representation of a right angle triangle showing the relation between active the power, reactive power and apparent power. When each component of the current that is the active component ($Icos\phi$) or the reactive component ($Isin\phi$) is then multiplied by the voltage V, a power triangle is obtained shown in the figure 68.

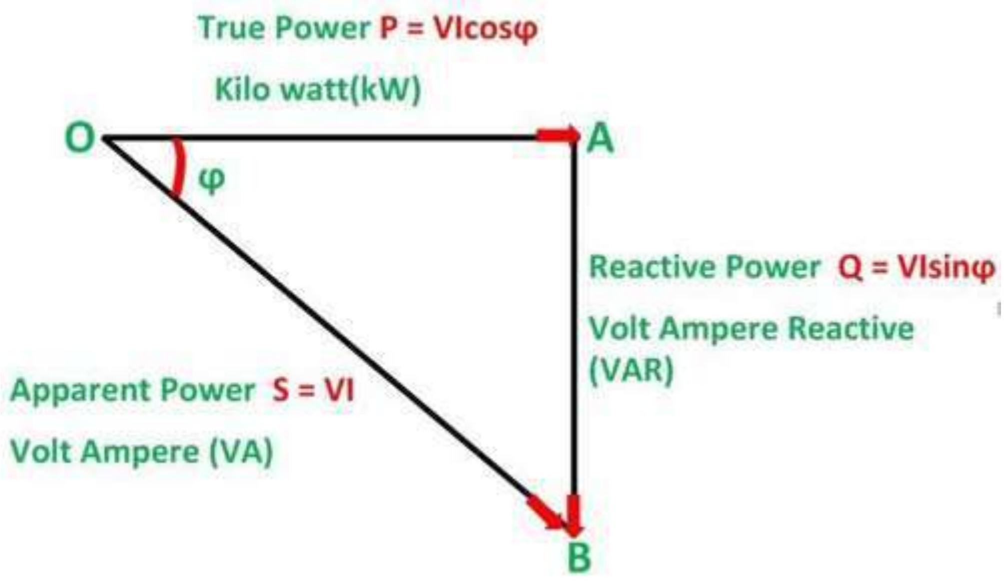

Figure 43: Power triangle

The power which is actually consumed or utilized in an AC Circuit is called True power or Active Power or real power. It is measured in kilowatt (kW) or MW. The power which flows back and forth that means it moves in both the direction in the circuit or reacts upon it, is called Reactive Power. The reactive power is measured in kilovolt-ampere reactive (kVAR) or MVAR. The product of root means square (RMS) value of voltage and current is known as Apparent Power. This power is measured in KVA or MVA.

The following point shows the relationship between the following quantities and is explained by graphical representation called Power Triangle shown above.

i. When an active component of current is multiplied by the circuit voltage V, it results in active power.it is this power which produces torque in the motor, heat in the heater, etc. This power is measured by the wattmeter.
ii. When the reactive component of the current is multiplied by the circuit voltage, it gives reactive power. This power determines the power factor, and it flows back and froths in the circuit.
iii. When the circuit current is multiplied by the circuit voltage, it results in the apparent power.
iv. From the power triangle shown above the power, the factor may be determined by taking the ratio of true power to the apparent power.

$$\text{Power factor } (\cos\varphi) = \frac{Active\ Power}{Apparent\ Power} = \frac{kW}{kVA}$$

As we know simply power means the product of voltage and current but in AC circuit except for pure resistive circuit, there is usually a phase difference between voltage and current and thus VI does not give real or true power in the circuit

Power factor correction

Most installations have a low or bad power factor because of the inductive nature of the load. A capacitor has the opposite effect of an inductor, and so it seems reasonable to add a capacitor to a load which is known to have a lower or bad power factor, for example, a motor.

Figure 69(a) shows an industrial load with a low power factor. If a capacitor is connected in parallel with the load, the capacitor current I_C leads the applied voltage by 90°. When this capacitor current is added to the load current as shown in Fig 69(b) the resultant load current has a much improved power factor. However, using a slightly bigger capacitor, the load current can be pushed up until it is 'in phase' with the voltage as can be seen in Fig. 69(c). Capacitors may be connected across the main busbars of industrial loads in order to provide power factor improvement, but smaller capacitors may also be connected across an individual piece of equipment, as is the case for fluorescent light fittings.

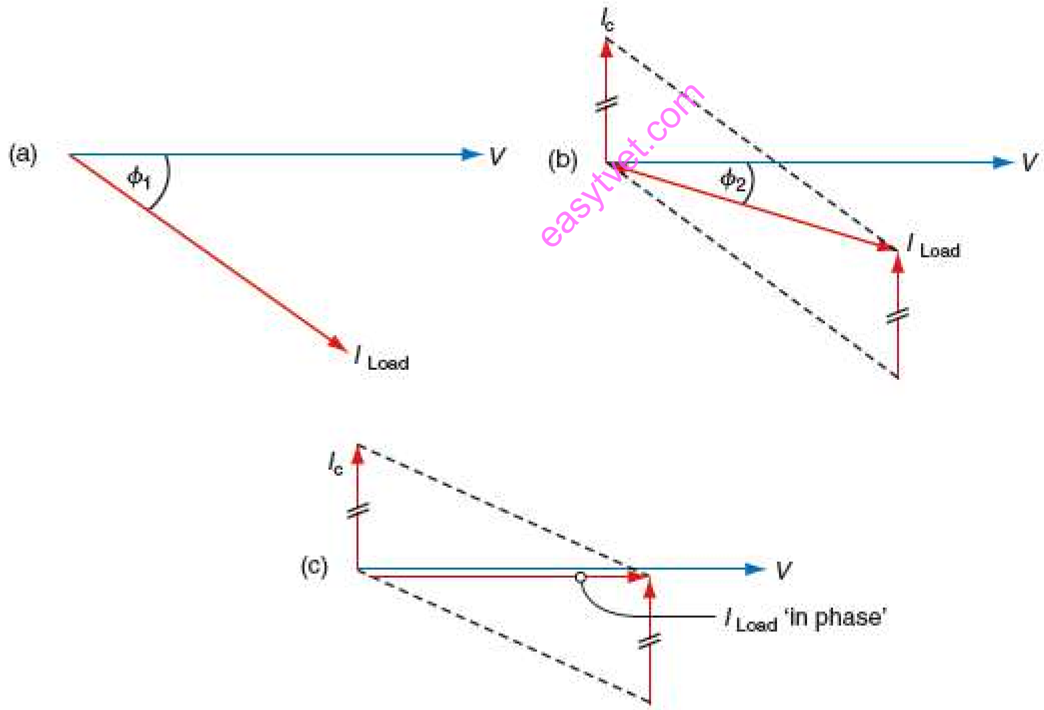

Figure 44: Power factor improvement using capacitors

Causes of low power factor

a) Most of the $a.c$ motors are induction type which have low lagging power factor. These motors work at a power factor which is extremely small on light load (0.2 to 0.3) and rises to 0.8 to 0.9 at full load

b) Arc lamps, electric discharge lamps and industrial heating furnaces operate at low power factor.

c) The load on the power system is varying; being high during morning and evening and low at other times. During low load period, supply voltage is increased which increases the magnetization current thus decreased power factor.

Ways of improving a low power factor

i. Use of static capacitor-capacitor is connected in parallel with the equipment operating at a lagging power factor. The capacitor draws a leading current and partly or completely neutralizes the lagging reactive component of load current and thus raises power factor

ii. Synchronous condenser-takes a leading current when overexcited and thus behaves like a capacitor. An overexcited synchronous motor running on no load is known as synchronous condenser. When connected in parallel with the supply, it takes a leading current which partly neutralizes the lagging reactive component of the load hence improving the power factor.

iii. Phase Advancers-This provides exciting current from another ac source since the low power factor is as a result of stator winding drawing exciting current which lags behind the supply voltage by 90^o.

Calculation involving power factor correction

A Three phase motor connected to 400V, 50Hz takes 31.7A at a power factor of 0.7 lagging. Calculate the capacitance required in parallel with the motor to raise the power factor to 0.9 lagging.

Solution:

The circuit and phasor diagrams are shown in Figs. 6.8 and 6.9 respectively. Here

Motor *M* is taking a current *IM* of 31·7A. The current *IC* taken by the capacitor must be such that when combined with *IM*, the resultant current *I* lags the voltage by an angle φ where cos φ = 0·9.

Referring to the phasor diagram in

Active component of *IM* = *IM* cos φ *M* = 31·7 × 0·7 = 22·19A

Active component of *I* = *I* cos φ = *I* × 0·9

These components are represented in the phasor diagram

$I = \frac{22.19}{0.9}$= 24·65A

Reactive component of *IM* = *IM* sin φ*M* = 31·7 × 0·714* = 22·6A

Reactive component of *I* = *I* sin φ = 24·65 $\sqrt{1-(0.9)}2$

= 24·65 × 0·436 = 10·75 A

It is clear from the phasor diagram:

IC = Reactive component of *IM* − Reactive component of *I*

= 22·6 − 10·75 = 11·85A

But $I_C = \frac{V}{Xc} = VX2\pi fc$

$or\ 11{\cdot}85 = 400 \times 2\pi \times 50 \times C$

$$\therefore C = 94{\cdot}3 \times 10{-}6\ \text{F} = \mathbf{94{\cdot}3}\ \mu\boldsymbol{F}$$

$$\Rightarrow \sin \phi_m = \sqrt{1 - cos^2\phi_m}$$

$$= \sqrt{1 - 0.7^2}$$

$$= \mathbf{0.714}$$

3.1.5.3. Learning Activities

Industrial attachment

Practical activities	**Knowledge**	**Special instruction**
1. Identify power triangle i.e. active apparent d reactive power		
2. Perform the use of power factor		
3. Perform calculations involving power factor correction		
4. Apply methods of power factor correction		

Self-Assessment Questions

1. What does the term power factor mean? **(2 Marks)**
2. What are the causes of low power factors? **(4 Marks)**
3. Which are the ways used to improve the power factor of a system? **(4 Marks)**
4. A 230 V supply feeds three 1.84 kW loads with power factors of 1, 0.8 and 0.4. Calculate the current at each power factor. **(5 Marks)**

3.1.5.5. Tools, Equipment and Materials

Recommended Resources

Tools and equipment	**Materials and supplies**
i. Cable Strippers ii. Pliers iii. Screw drivers iv. Hammers v. Chisels	i. Stationery ii. Cables iii. Light fittings iv. Accessories v. Conduits and fittings

vi. Allen keys vii. Electrician knives viii. Crimping tools ix. Bending springs x. Bending machine xi. Steel tapes xii. Draw wires xiii. Hack saws xiv. Drilling tools xv. Stock and die xvi. Bench vice xvii. Machine vice xviii. PPE – hand gloves, dust coats, dust masks, helmets, ear muffs, industrial boots	vi. Cable trays vii. Cable ducts viii. Trunkings ix. Computers x. Drawing instruments xi. Screws
Reference materials i. IEE regulations ii. Occupational safety and health act (OSHA) iii. Work injury benefits act (WIBA) iv. Manufacturers' catalogues v. British standards vi. KEBS standards	

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3.1.5.7. Response to self-assessment

1. **Power factor** **(2 Marks)**

   Power factor ($p.f.$) is defined as the cosine of the phase angle between the current and voltage:

   $$\text{p.f.} = \cos\phi$$

2. **Causes of low power factors** **(4 Marks)**

   (a) Most of the $a.c$ motors are induction type which have low lagging power factor. These motors work at a power factor which is extremely small on light load (0.2 to 0.3) and rises to 0.8 to 0.9 at full load

   (b) Arc lamps, electric discharge lamps and industrial heating furnaces operate at low power factor.

   (c) The load on the power system is varying; being high during morning and evening and low at other times. During low load period, supply voltage is increased which increases the magnetization current thus decreased power factor.

3. **Ways used to improve the power factor of a system** **(4 Marks)**

   a. Use of static capacitor-capacitor is connected in parallel with the equipment operating at a lagging power factor. The capacitor draws a leading current and partly or completely neutralizes the lagging reactive component of load current and thus raises power factor

b. Synchronous condenser-takes a leading current when overexcited and thus behaves like a capacitor. An overexcited synchronous motor running on no load is known as synchronous condenser. When connected in parallel with the supply, it takes a leading current which partly neutralizes the lagging reactive component of the load hence improving the power factor.

c. Phase Advancers-This provides exciting current from another ac source since the low power factor is as a result of stator winding drawing exciting current which lags behind the supply voltage by 90°.

4. **A 230 V supply feeds three 1.84 kW loads with power factors of 1, 0.8 and 0.4. (5 Marks)**

i. Current at 1.0 power factor.

The current is given by: $I = \frac{P}{V\cos\emptyset}$

Where $P = 1.84$ kW $= 1840$ W and $V = 230$ V

$\therefore$ Current at 1.0 power factor, $I = \frac{1840\ W}{230V \times 1} = 8.0$ A

ii. Current at 0.8 power factor.

$I = \frac{1840\ W}{230\text{V} \times 0.8} = 10.0$ A

iii. Current at 0.8 power factor.

$I = \frac{1840\ W}{230\text{V} \times 0.4} = 20.0$ A

It can be seen from these calculations that a 1.84 kW load supplied at a power factor of 0.4 would require a 20 A cable, while the same load at unity power factor could be supplied with an 8 A cable. There may also be the problem of higher voltage drops in the supply cables. As a result, the supply companies encourage installation engineers to improve their power factor to a value close to unity (1.0) and sometimes charge penalties if the power factor falls below predetermined value, say 0.8

3.1.6. Use of earthing in electrical installation

3.1.6.0. Introduction

To use earthing in electrical installations, one need to identify the earthing types, identify earthing points in electrical installation, perform calculation involved in determining the earthing type and perform test on earthing system in line with IEE regulations.

3.1.6.1. Performance Standard

1. Identify the earthing types,
2. Identify earthing points in electrical installation,
3. Perform calculation involved in determining the earthing type and
4. Perform test on earthing system in line with IEE regulations

Information Sheet

Earthing system

Terms in earthing

Current rating of a fuse – it is the current the fuse will carry continuously without blowing or deteriorating.

Rated minimum fusing current – it is the minimum current at which the fuse will blow at a specified time. This may vary between 1.25 - 2.5 the current rating of the fuse.

Fusing factor –The relationship between the rated minimum fusing current and the current rating is called the fusing factor**.**

Overcurrent – Any current beyond the current rating of a fuse

Discrimination – relate to the time current characteristic of protection devices sustained. This is the ability of a fuse to distinguish between a transient and high current e.g. motor starting current and continuous fault current

Reasons for earthing

(a) To maintain the potential of any part of an electrical system at a definite value with respect to earth.

(b) To allow fault current to flow to earth in the event of an earth fault so that the protective gears operates to isolate the faulty circuit.
(c) So that in the event of a fault, apparatus normally 'dead' cannot reach a dangerous potential with respect to earth.

Methods used to achieve earthing of an installation

i. Connection to the metal sheath of armoring of supply authority underground cable (concentric earthing system)
ii. Connection to the continuous earth wire provided by Supply authority where the distribution of energy is by overhead lines.
iii. Connection to the earth electrode sunk into the ground for the purpose
iv. Installation of automatic earth fault protection device e.g. ELCB

Fuses.

A fuse element consists essentially of a piece of copper or tin-lead alloy wire which will melt when carrying a predetermined current. This element with contact carrier, and base is called a fuse. It is placed in series with the circuit or sub-circuit to be protected, and automatically breaks the circuit when overloaded. In general, the regulations regarding fuses require that fuses shall be accessible, and shall be fitted either on the front of a switch board or in a protecting case. In most cases in installation work the fuses are fitted in a distribution board.

The current rating or normal current-carrying capacity of a fuse should not exceed the current rating of the smallest conductor in the circuit protected by the fuse, account being taken of the class of excess- current protection provided by the fuse, coarse or close. For electric motors, a higher fuse rating is allowable. The fusing values of normal duty fuses vary from 160 to 200 percent of the carrying capacity.

Types of fuses

a. Rewireable fuses.

In this type, fuse wire is placed in a removable fuse link. The fuse link may be of porcelain or other suitable insulating materials, it is so constructed that there is no danger to the operator in removing the fuse link. The fuse wire is connected between two terminals and passes through an asbestos tube or is in intimate contact with a sheet of asbestos. The fuse link is push-fitted into the fuse base to make the connection through suitable contacts. Although the material cost of replacing a blown fuse wire in a Rewirable fuse is negligible, nevertheless this fuse had disadvantages, the chief being the deterioration of the fuse wire over a period, and another the possibility of renewal by the wrong size of fuse wire.

b. Cartridge fuses

The cartridge fuse consists of a sealed tube with metal end caps. The fuse wire passes through the tube from cap to cap and is welded or soldered to the inside of the cap. There is sometimes a blowout device in the side of the tube to indicate when the fuse is blown. When the fuse is blown the whole cartridge must be replaced. Cartridge fuses only are used in fused plugs, such as the common ring-circuit 13 –A plug.

c. High breaking and High rapturing capacity fuses.

The H.B.C fuse consists of a ceramic tube with metal end caps and fixing tags. The fuse is a silver strip of special shape with a low melting point rivet in the centre. The strip is entirely surrounded by chemically purified silica. When an overload occurs breaking the fuse element, the silica prevents the formation of an arc, thus preventing overheating of the fuse and its surroundings.

Figure 28 HRC fuses

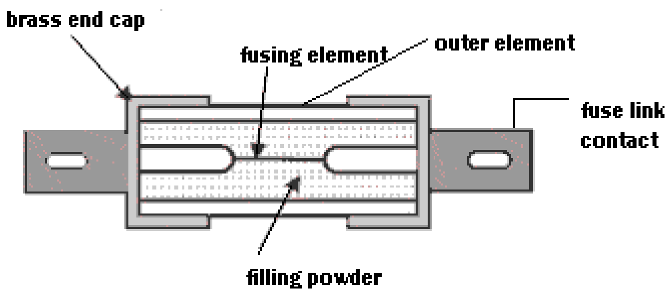

Figure 45: Construction of HRC fuse

Distribution boards.

By definition, the distribution board is an assemblage of parts, including one or more fuses or circuit-breakers arranged for the distribution of electrical energy to final sub–circuits or to other distribution boards.

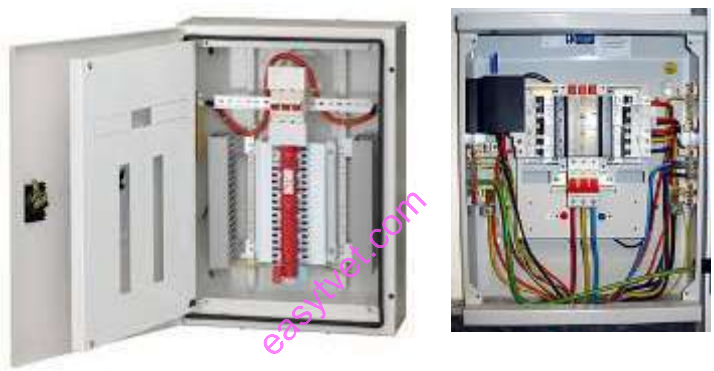

Figure 46: Distribution board

The boards are usually metal-cased in sheet steel, or hardwood- cased in oak, teak, or mahogany. The doors may be solid or glazed, and the case if fitted with an earthing terminal. Figure 1.38 shows a 1-pole and neutral, 6-way, distribution board with sheet steel body, fitted with Rewirable or H.B.C fuses. There is one fuse bank only, on the live side. One end of each of the six fuses is rigidly connected to a busbar, and the other end is arranged for connection to the circuit wire. The neutral wire of the circuit is connected to the neutral bar.

The regulations require that the neutral conductors for the different sub- circuits shall be connected in the same order as the live conductors to the fuses. Some distribution boards are designed to contain circuit – breakers instead of fuses. These however are more expensive than the equivalent Rewirable or H.B.C fuses.

Miniature circuit- breakers

These are being increasingly used to provide *close excess - current* protection in single phase, 250 V circuits.

The circuit- breaker is essentially a switch which may be:

i. Opened and closed by hand

ii. Opened automatically when overloaded

The tripping action may be either magnetic or thermal. In general both these actions are used in this type of circuit-breaker. Protection against sustained over current is given by the bending of a bi-metal strip with its time-lag affect, while high speed protection against a short- circuit is given by magnetic operation.

The circuit-breaker replaces both switch and fuses in the various circuits in which it is used. It can be obtained with plug-in contacts for insertion into a fuse base in a distribution board in place of a plug-in fuse carrier.

Main switch and fuses

The consumer's main switch and fuses may be combined in one case. With this type of switch and fuse gear, the switch cannot be operated when the case is open, nor can the case be opened while the switch is closed.

Consumer's control unit

In a single-phase installation whose current rating is not greater than 60A, the consumer's main switch and fuse may be combined with the distribution board as one combined unit. The unit comprises a 60A 2-pole main switch and up to 12 single-pole circuit fuses (12 way consumer unit). The fuses vary in size, e.g 5A, 15 A and 30 A.

Obviously the maximum current to be taken from the unit at any one time must not exceed 60 A. either cartridge or Rewirable fuses may be employed. In addition to the fuses a neutral bar and an earthing bar are fitted. The whole is fitted in a suitable sheet steel case, or in a moulded case; figure 1.39 shows a connection diagram for this unit.

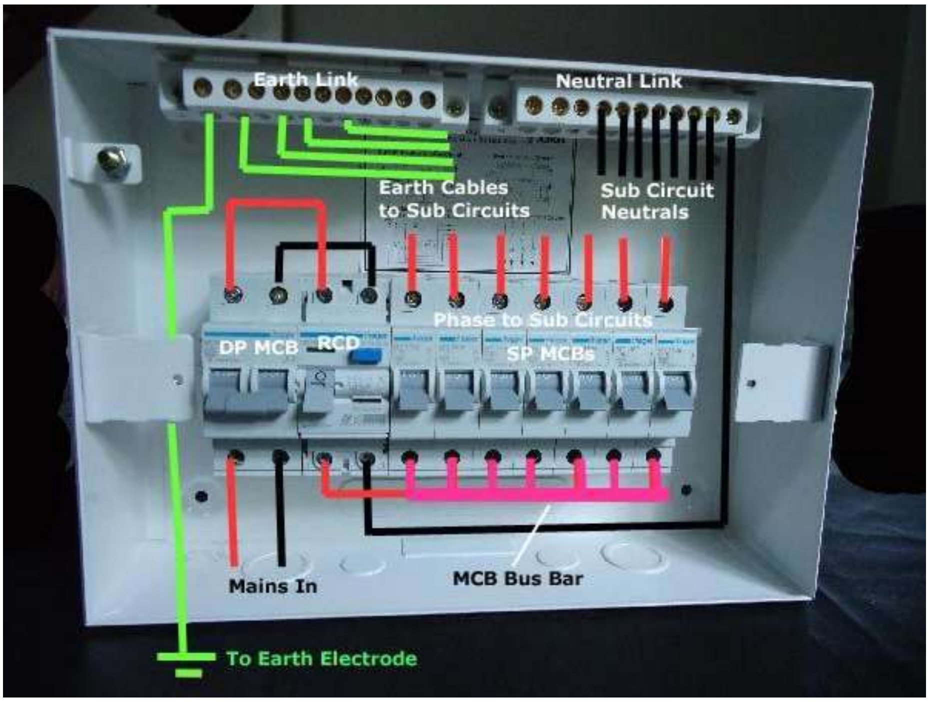

Figure 47: Consumer control unit

Effectiveness of earthing tests

The purpose of this test is:-

a) To measure the resistance of the earth continuity conductor.
b) To check that the earth continuity heavy leakage currents.
c) To ensure that the earth electrode is effectively connected to the general mass of earth.

Earth Continuity

Earth continuity is making sure that should there be an electrical fault, all exposed metalwork in a building is bonded together and connected to the earth block in the consumer unit, leaking the current to earth and automatically disconnecting the supply. An earth continuity test will verify that exposed metalwork in a building is bonded together and connected to the earthing block in the consumer unit.

The ohmmeter leads are connected between the points being tested, between simultaneously accessible conductive parts e.g. pipe works, sinks etc. This test will verify that the conductor is sound.

Earth fault loop test

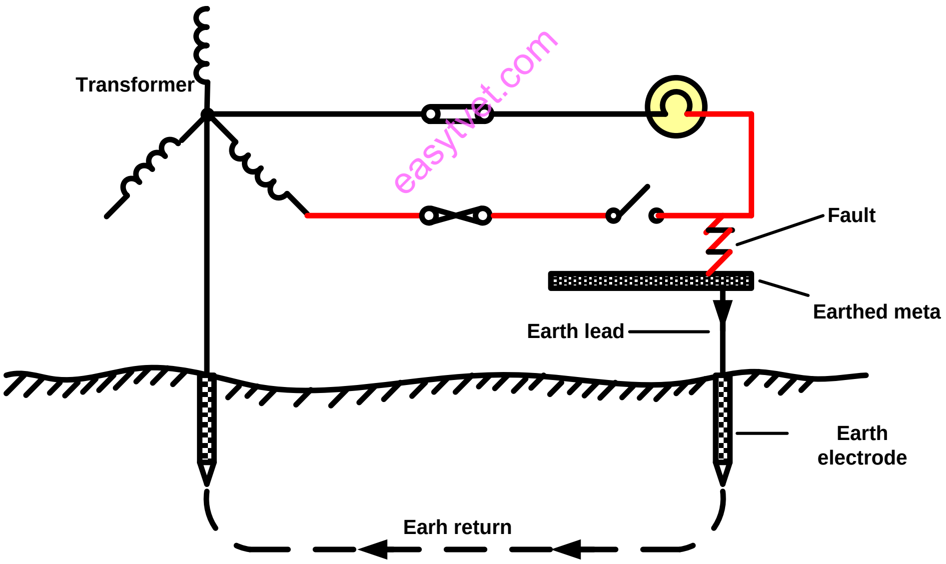

Figure 48: Earth loop test

The earth fault loop is the path which the leakage current will take back to the supply transformer when there is an earth leakage in an installation. The path is as shown below.

The test must be carried out on an new or largely modified installations where earth-leakage protection relies on the operation of fuses or excess current circuit – breakers.

a) The leakage current flows from the faulty conductor into the earth continuity conductor.
b) It then flows along the earth continuity conductor to the earthing lead.
c) The earthing lead carries the current to the earth electrode.
d) The leakage current now takes the shortest path back to the earthed neutral of the supply transformer.

The purpose of this test is to show that the earth fault loop is capable of carrying heavy leakage currents so that the protective gear (e.g. fuses) will operate when leakages occur between the line conductor and the earthed metalwork of the installation.

Apparatus: Line-earth loop tester (Megger).

Method

The Line-earth loop tester, operating on fall mains voltage, passes a short duration current of approximately 20A from the line conductor, through the consumer's earth continuity conductor and the earth return path to the neutral of the supply transformer. This instrument measures the value of the loop in Ohms.

Readings

The minimum permissible reading depends on the operating conditions but the two main factors are:-

Operating current of fuse or circuit breaker protecting circuit.

Supply voltage.

Example

If the circuit fuse operated at 50A and the supply voltage is 240V then the resistance of the earth fault loop must not be more than $\frac{240\,V}{60\,A} = 4\boldsymbol{\Omega}$. If the resistance is higher than this value the fuse will not open under serious fault conditions.

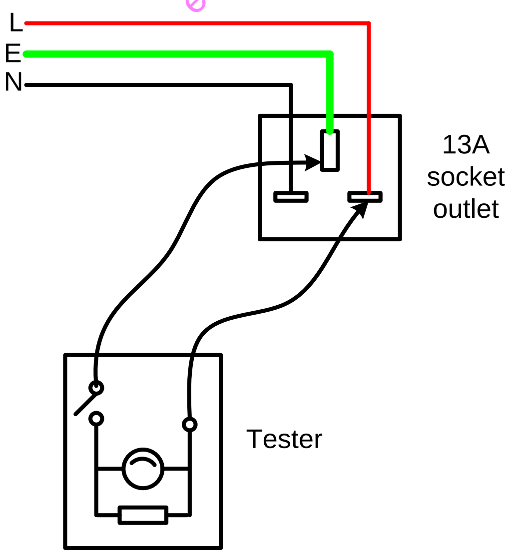

Figure 49: circuit of megger line-earth loop tester

Factors determining resistance of earth fault loop are as follows.

i. The continuity of the metallic circuit up to the earth electrode (the earth continuity conductor and the earthing lead).

ii. The resistance of the body of earth surrounding the earth electrode.

Earthing Lead – The minimum size of copper earthing lead is 1mm^2. The earthing lead connecting an earth –leakage circuit-breaker to an earth electrode need not exceed 2.5mm^2. the earthing lead should be protected against mechanical damage and corrosion and the clamp used for connecting the earth lead to the earth electrode should be non-ferrous and should be accessible for inspection.

The resistance area is the name given to the resistance of the body of earth surrounding the earth electrode.

The resistance area is measured using

i. An alternating current (at a maximum pressure of 40V) is connected between the main earth electrode A and an auxiliary electrode B, placed about 30m from A. An ammeter is placed in series with the supply to measure the current through the circuit.

ii. A second auxiliary electrode C is placed between A and B and the voltage (potential difference) is measured between A and C. the resistance of the resistance area is found by taking various readings from point A towards point B. Outside the resistance area the resistance is constant .

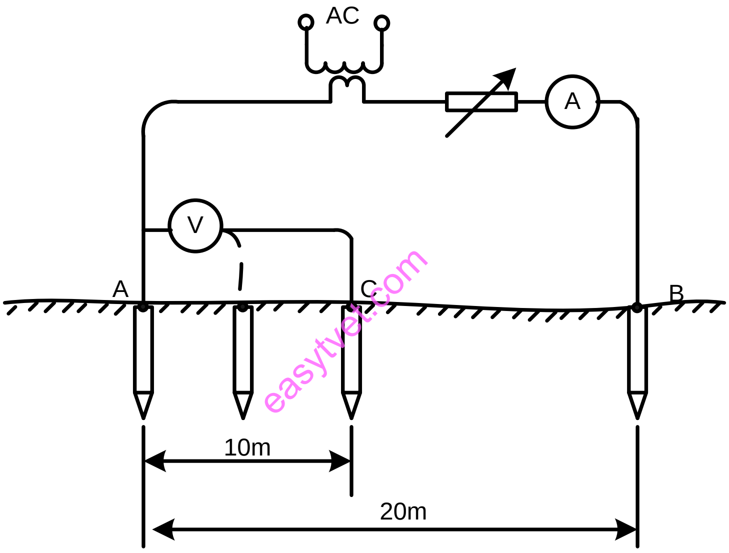

Figure 50: Earth electrode resistance test

Figure 51: resistance area measurement

$$R = \frac{Voltage\ between\ \ A\ and\ C}{Current}$$

3.1.6.2.Learning Activities

Industrial attachment/workshop Practice

Practical activities	knowledge	Special instruction
1. Identify earthing types		
2. Identify earthing points in electrical installation		
3. Perform calculation involved in determining the earthing type		
4. Perform test on earthing system in line with IEE regulations		

3.1.6.3. Self-Assessment Questions

1. What is the meaning of the following terms with reference to earthing:- **(10 Marks)**
   i. Current rating of a fuse?
   ii. Rated minimum fusing current?
   iii. Fusing factor?
   iv. Overcurrent?
   v. Discrimination?
2. What are the reasons for earthing? **(6 Marks)**
3. Which methods can be used to achieve earthing of an installation? **(6 Marks)**
4. Which tests related to earthing should be carried out in a completed electrical installation? **(3 Marks)**

3.1.6.4.Tools, Equipment and Material

Recommended Resources

Tools and equipment	Materials and supplies
i. Cable Strippers	i. Stationery

ii. Pliers iii. Screw drivers iv. Hammers v. Chisels vi. Allen keys vii. Electrician knives viii. Crimping tools ix. Bending springs x. Bending machine xi. Steel tapes xii. Draw wires xiii. Hack saws xiv. Drilling tools xv. Stock and die xvi. Bench vice xvii. Machine vice xviii. PPE – hand gloves, dust coats, dust masks, helmets, ear muffs, industrial boots	ii. Cables iii. Light fittings iv. Accessories v. Conduits and fittings vi. Cable trays vii. Cable ducts viii. Trunkings ix. Computers x. Drawing instruments xi. Screws
Reference materials I. IEE regulations II. Occupational safety and health act (OSHA) III. Work injury benefits act (WIBA) IV. Manufacturers' catalogues V. British standards VI. KEBS standards	

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3.1.6.6.Model Answers to self-assessment Questions (10 Marks)

1. What is the meaning of the following terms with reference to earthing
   i. **Current rating of a fuse:** – it is the current the fuse will carry continuously without blowing or deteriorating.
   ii. **Rated minimum fusing current:** – it is the minimum current at which the fuse will blow at a specified time. This may vary between 1.25 − 2.5 the current rating of the fuse.

iii. **Fusing factor:** –The relationship between the rated minimum fusing current and the current rating is called the fusing factor.

iv. **Overcurrent:** – Any current beyond the current rating of a fuse

v. **Discrimination:** – relate to the time current characteristic of protection devices sustained. This is the ability of a fuse to distinguish between a transient and high current e.g. motor starting current and continuous fault current.

2. **Reasons for earthing** **(6 Marks)**

a) To maintain the potential of any part of an electrical system at a definite value with respect to earth.

b) To allow fault current to flow to earth in the event of an earth fault so that the protective gears operates to isolate the faulty circuit.

c) So that in the event of a fault, apparatus normally 'dead' cannot reach a dangerous potential with respect to earth.

3. **Methods used to achieve earthing of an installation** **(6 Marks)**

i. Connection to the metal sheath of armoring of supply authority underground cable (concentric earthing system)

ii. Connection to the continuous earth wire provided by Supply authority where the distribution of energy is by overhead lines.

iii. Connection to the earth electrode sunk into the ground for the purpose

iv. Installation of automatic earth fault protection device e.g. ELCB

4. **Tests related to earthing which should be carried out in a completed electrical installation** **(3 Marks)**

a. Earth electrode resistance test

b. Earth continuity conductor test

c. Earth loop impedance test

3.1.7. Apply lightning protection measures

3.1.7.0. Introduction

To apply lightning protection measures, identify types of lightning strokes, identify components of lightning protection system, establish tests to be carried out in lightning protection system and determine application of lightning protection system.

Performance Standard

1. Identify types of lightning strokes.
2. Identify components of lightning protection system.
3. Establish tests to be carried out in lightning protection system.
4. Determine application of lightning protection system.

Information Sheet

Lightning protection

Lightning is a sudden electrostatic discharge that occurs during a thunderstorm. This discharge occurs between electrically charged regions of a cloud (called intra-cloud lightning or IC), between two clouds (CC lightning), or between a cloud and the ground (CG lightning).

Types of strikes and lightning

i. Different types of strikes
ii. Cloud to cloud
iii. Ground to cloud
iv. Cloud to cloud

Types of lightning

a. Normal lightning
b. Sheet lightning
c. Heat lightning
d. Ball lightning
e. Red sprite
f. Blue jet

Colors of lightning

a) Blue lightning within a cloud indicates the presence of hail
b) Red lightning within a cloud indicates the presence of rain
c) Yellow/orange lightning occurs when there is a large concentration of dust in the air
d) White lightning is a sign of low humidity, white is the colour of lightning that most often ignites forest fires

Effects of lightning

i. Physical damage - Fire, explosion, mechanical destruction
ii. Injuries/death to living being

Lightning protection components

a. Air termination or termination network

I. For a spire or chimney, this will consist of one or more vertical conductors positioned just above the highest point.
II. For a small building, this will consist of a single horizontal conductor along the ridge of the roof.
III. For roofs of larger dimensions this will consist of a system of horizontal conductors

NB

No part of the roof should be more than 9m from the nearest horizontal conductor and all metallic projections such as vent pipes, railing gutters etc., on or above the roof of the main building should be bonded to the conductor to form part of air termination.

b. Down conductors

The number of down conductors required is determined by the area covered by the structured. A structure with a base area not exceeding $100m^2$ needs only one down conductor. Base areas greater than $100m^2$ require one for every additional $300m^2$ or part thereof.

Test joints

These are provided in down conductors so that resistance measurements of sections can be made.

c. Earth termination or termination network

This is the part of the lightning protection system intended to discharge current into general mass of earth. All points below the lowest test point in a down conductor are included in this term. Figure x shows the components of a lightning protection system.

d. Earth electrode

This is the part of the earth termination which makes electrical contact with earth.

NB

Roof and down conductors are generally annealed copper strips, as are any interconnections. Down conductors are secured to the building by 'holdfast' fixings made from gunmetal. Earth electrodes can be copper rods or copper plates.

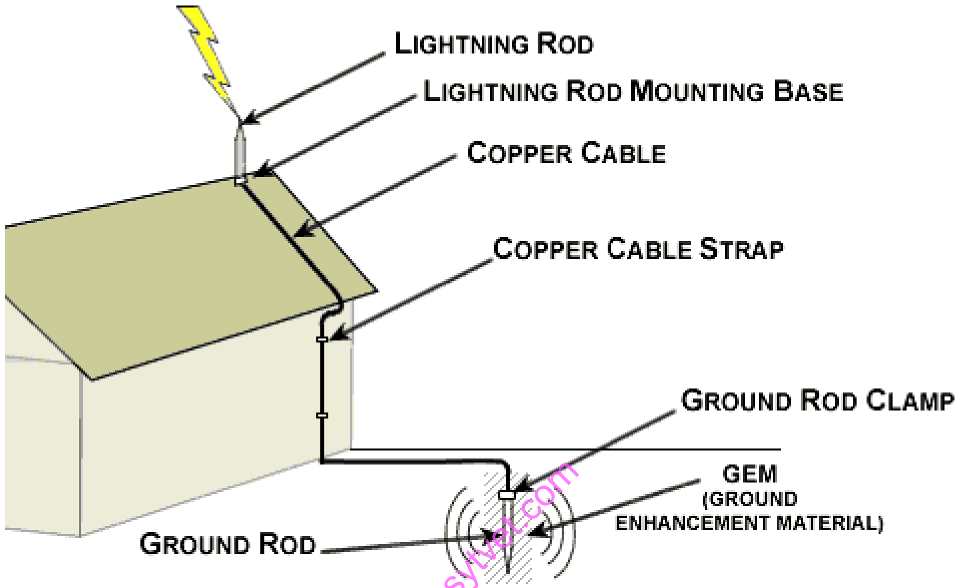

Figure 52: Lightning protection components

Testing

All lightning protection systems should be inspected and tested after completion and at intervals of twelve months (six months if explosives are stored in the building) the tests should verify electrical continuity of the system and the resistance to the general mass of earth. This must not exceed 10 ohms using the electrode testing method.

Record test should be kept on site by the person responsible for maintaining the installation.

Lightning rod maintenance

Lightning rods must undergo periodic inspections and maintenance, as indicated by national and international regulations (UNE21186, NF-C 17 102, IEC EN 62305). These periodic inspections of the lightning rod allow the detection of deviations from the reference standards or anomalies in the installation caused by environmental conditions such as corrosion, incorrect handling such as sectioning or robberies, or other circumstances such as expansions of the building where the lightning rod is located.

The inspection of the lightning protection system must be part of the maintenance routine of the buildings and the annual action plans.

Why is maintenance of lightning rods necessary?

All lightning protection systems should have routine maintenance and monitoring carried out. If the lightning rod is not properly maintained, there is a risk that lightning strikes are not controlled nor their current conducted and dispersed in a safe manner. The different elements of the lightning protection system can be deteriorated over time, reducing safety levels of the system if they are not properly maintained.

For a lightning protection system to work optimally each and every part needs to be in good condition:

a. The lightning rods, or air terminals must work correctly. In the case of the early streamer emission (ESE), the element that emits the upward leader should be fully operational in order to maintain the time of advance of the ESE air terminal that has been measured in the laboratory.
b. Down conductors must maintain continuity at all times and be well fixed to avoid sparks and breakage.
c. Ground resistance must remain below 10 ohms so the lightning current dissipates quickly, minimizing the return currents and the contact voltages, which that can be very dangerous for people.

How is the lightning rod revision carried out?

The procedure for the lightning rod maintenance consists of two types of verifications:

Visual inspection in the maintenance of lightning protection systems

Check that:

i. There is no damage due to lightning strikes.
ii. The lightning rod keeps all its elements in good state.
iii. The continuity of the conductors is correct.
iv. The fixings are in good condition.
v. There are no parts damaged by corrosion.
vi. The state of the equipotential bonding is correct.

Complete verification in the maintenance of the lightning protection system. The complete verification includes the visual inspections described above as well as other measures. It is necessary to verify the electrical continuity of the down conductors and the correct performance of the lightning rod according to the specifications indicated by the manufacturer.

In the case of ESEs, the correct operation of the air terminals must also be checked. The lightning rods are installed at the highest point of the structure, always two meters above any element to be protected and usually on a six-meter mast. Therefore, in most cases it is difficult to have access these air terminals and puts the operator is put in danger when carrying these inspections.

To make this maintenance task easier, a remote tester has been incorporated to the ESE terminal DAT CONTROLER REMOTE. By doing so, it is not necessary to physically access the air terminal, since it has a system that daily checks its state and sends the result to a web application where the updated data can be consulted at any time.

Regarding the earthing system, it is essential to measure the earth resistance, as it could vary with time. It is also important to ensure that it remains below 10 Ω. It is recommended to check the earthing annually. In fact, in many countries there is a regulation that requires this. If high earth values are recorded, it will be necessary to use a ground enhancing product such as Conductiver Plus or adapt the system to include more earth rods.

Likewise, the inspection must verify that the electrical lines which require protection against overvoltages are protected with adequate surge protection devices.

After having carried out the inspections described and when deterioration or anomalies in the system are detected, it is essential to repair or carry out the necessary corrective measures in the shortest time possible to ensure optimum protection.

In both periodic inspection (visual and complete) the person in charge of the maintenance actions must elaborate a report which informs the inspections that have been carried out, providing data and photographs.

Figure 53: Lightning rod image

When should we carry out an inspection of a lightning rod?

According to the standards, lightning protection systems must undergo an inspection whenever the structure of the building is modified or repaired and also when the structure has been struck by lightning. Therefore, it is very useful to have a lightning event counter that informs about the number of lightning strikes on the structure. For more information about the functioning of the lightning event counter check the technical data sheet for the ATLOGGER, a device which also records the information of the day and time of the strike.

Even if these situations do not occur, the inspection of the lightning protection system should be made periodically. As part of the maintenance protocol, the following types of verifications are carried out:

a. Visual verification: Annual revision for levels of protection I and II. For levels III and IV, the visual verification needs to be done at least every two years.
b. Complete verification: For levels of protection I and II, the complete verification will be done at least every two years. For protection levels III and IV, the verification will be done at least every 4 years.
c. Complete verification of the critical systems: This verification needs to be done at least once a year for all of the protection levels.

In some countries where the rainy season has high rates of precipitation and is concentrated in a very short period of the year. In these cases, it is very important to carry out the maintenance of lightning rods before the beginning of this period of the year. Contact a specialist to perform necessary lightning protection system inspection and receive appropriate advice.

3.1.7.3.Learning Activities

Industrial attachment/workshop Practice

Practical activities	knowledge	Special instruction
1. Identify types of lightning strokes.		
2. Identify components of lightning protection system.		
3. Establish tests to be carried out in lightning protection system.		
4. Determine application of lightning protection system.		

3.1.7.4. Self-Assessment Questions

1. What is the meaning of the term lightning?
2. Which types lightning strokes do you know?
3. What are the structures of air termination or termination network used in buildings?
4. What are the components of lightning protection system?

3.1.7.5. Tools, Equipment and Material

Recommended Resources

Tools and equipment	**Materials and supplies**
i. Cable Strippers ii. Pliers iii. Screw drivers iv. Hammers v. Chisels vi. Allen keys vii. Electrician knives viii. Crimping tools ix. Bending springs x. Bending machine xi. Steel tapes xii. Draw wires xiii. Hack saws xiv. Drilling tools xv. Stock and die xvi. Bench vice xvii. Machine vice xviii. PPE – hand gloves, dust coats, dust masks, helmets, ear muffs, industrial boots	i. Stationery ii. Cables iii. Light fittings iv. Accessories v. Conduits and fittings vi. Cable trays vii. Cable ducts viii. Trunkings ix. Computers x. Drawing instruments xi. Screws
Reference materials i. IEE regulations	

ii. Occupational safety and health act (OSHA) iii. Work injury benefits act (WIBA) iv. Manufacturers' catalogues v. British standards vi. KEBS standards	

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3.1.7.7.Model Answers to Self-Assessment Questions

1. **Lightning** **(2 Marks)**

   Lightning is a sudden electrostatic discharge that occurs during a thunderstorm. This discharge occurs between electrically charged regions of a cloud (called intra-cloud lightning or IC), between two clouds (CC lightning), or between a cloud and the ground (CG lightning).

2. Lightning strokes **(3 Marks)**
   i. Different types of strikes
   ii. Cloud to cloud
   iii. Ground to cloud
   iv. Cloud to cloud

3. **The structures of air termination or termination network used in buildings**
   (a) For a spire or chimney, this will consist of one or more vertical conductors positioned just above the highest point.
   (b) For a small building, this will consist of a single horizontal conductor along the ridge of the roof.
   (c) For roofs of larger dimensions this will consist of a system of horizontal conductors **(6 Marks)**

4. **The components of lightning protection system** **(4 Marks)**
   a. Air termination or termination network
   b. Down conductors
   c. Earth termination or termination network
   d. Earth electrode

3.1.8. Apply electromagnetic field theory

3.1.8.0. Introduction

Apply electromagnetic field theory, identify electromagnetic radiation sources, determine detectors of electromagnetic radiations, apply electromagnetic waves, identify electromagnetic laws and establish behaviours and effects of electromagnetic waves.

3.1.1.1. Performance Standard

1. Apply electromagnetic field theory,
2. Identify electromagnetic radiation sources

3. Determine detectors of electromagnetic radiations,
4. Apply electromagnetic waves,
5. Identify electromagnetic laws and establish behaviours and effects of electromagnetic waves.

3.1.1.2. Information Sheet

Electromagnetic field

A property of space caused by the motion of an electric charge. A stationary charge will produce only an electric field in the surrounding space. If the charge is moving, a magnetic field is also produced. An electric field can be produced also by a changing magnetic field. The mutual interaction of electric and magnetic fields produces an electromagnetic field, which is considered as having its own existence in space apart from the charges or currents (a stream of moving charges) with which it may be related. Under certain circumstances, this electromagnetic field can be described as a wave transporting electromagnetic energy. Figure 80 shows frequency ranges of electromagnetic fields.

Figure 54: Frequency ranges of electromagnetic fields

Electromagnetic fields are a combination of invisible electric and magnetic fields of force. They are generated by natural phenomena like the Earth's magnetic field but also by human activities, mainly through the use of electricity.

Mobile phones, power lines and computer screens are examples of equipment that generates electromagnetic fields.

Most man-made electromagnetic fields reverse their direction at regular intervals of time, ranging from high radio frequencies (mobile phones) through intermediate frequencies (computer screens) to extremely low frequencies (power lines).

The term static refers to fields that do not vary with time (i.e. with a frequency of 0 Hz). Static magnetic fields are used in medical imaging and generated by appliances using direct current.

Typical sources of electromagnetic fields

Frequency range	Frequencies	Some examples of exposure sources
Static	0 Hz	video display units; MRI (medical imaging) and other diagnostic or scientific instrumentation; industrial electrolysis; welding devices
ELF [Extremely Low Frequencies]	0-300 Hz	power lines; domestic distribution lines; domestic appliances; electric engines in cars, trains and tramways; welding devices
IF [Intermediate Frequencies]	300 Hz - 100 kHz	video display units; anti-theft devices in shops; hands-free access control systems, card readers and metal detectors; MRI; welding devices
RF [Radio Frequencies]	100 kHz - 300 GHz	mobile telephones; broadcasting and TV; microwave ovens; radar and radio transceivers; portable radios; MRI
THz technologies	300 GHz – 20 THz	Applications are still in development, but currently mostly telecommunication applications and body scanners are considered.

Detectors/sensors for Electromagnetic Radiation:

Radio waves, microwaves, infra-red, visible light, ultraviolet, X- and γ-rays are all examples of electromagnetic radiation. They are waves with electric and magnetic components which travel at the speed of light in a vacuum, approximately 300 million m/s. The electric and magnetic fields oscillate at right angles to each other and combined waves move in a direction perpendicular to both of the electric and magnetic field oscillations. Like all waves, they have a frequency, which is the number of crests per second, and a wavelength, which is the distance between successive crests. These values are used to categorize the radiation into the types shown above. The examples here are given in order of increasing frequency and decreasing wavelength. FM radio, for instance, is transmitted at frequencies around 100 MHz, have wavelengths of 3 m and can be detected by an aerial. The eye can detect wavelengths in the region of 380-750 nm, less than a thousandth of a millimetre. Electromagnetic radiation, with even higher frequencies, and therefore smaller wavelengths, is ionizing, which means that a large enough exposure can damage DNA and cause cancer. The frequency of UV radiation is around ten million times higher than that of FM radio.

A variety of sensors are required for detecting the different ranges of electromagnetic radiation. Aerials are suitable for detecting radio waves and microwave transmissions as used by Wi-Fi and Bluetooth devices for example. Optical sensors such as photodiodes and charge-coupled devices are used for the infra-red and visible wavelengths. Geiger-Müller tubes use the ionizing properties of the higher frequencies to produce a current pulse which can be used to generate an audible click Scintillators fluoresce when they detect ionizing radiation. Microwave sensors are recently proven successfully over the range of 1-300 GHz to suit various industrial applications including non-invasive real-time monitoring of the oil and water pipe line constituents, passive radiometer and radar applications for mapping, imaging and tomography. Recent and future development of such sensors having high accuracy and reliability in health care applications including detection of tumours, alcohol, drugs and sugar in the blood stream. A new development has emerged in the use of optical imaging in radiotherapy that by measuring the patient movements very accurately which will have a tremendous potential for the health care industry. Future sensors will emerge in the form of nanoscale with hybrid multi-functionality sensors meeting the demands of many challenging applications.

Applications of electromagnetic waves

(a) Microwave oven

Microwave oven is most familiar as the energy source for cooking food. It generate microwave radiation of appropriate frequency in the working space of the oven where food is kept. The energy is not wasted in heating up the vessel as in conventional method. The energy is directly delivered to water molecules which are shared by the entire food.

(b) Radar

Radar is acronym for Radio Detection And Ranging. Radar is an electromagnetic system, used for sensing, detecting, and locating the object present in the ambience. Used to detect direction, speed, velocity, range, altitude of an object with the help of radio waves. Radar find applications in various systems such as air traffic control to track planes both on and off the grounds it is also used to track satellites.

(c) **Wireless Communication**

Wireless communication is the transfer of information between two or more points that are not connected by an electrical conductor. The term is commonly used in the telecommunications industry to refer to telecommunications systems (e.g., radio transmitters and receivers, remote controls, etc.) that use some form of energy (e.g., radio waves, acoustic energy, etc.) to transfer information without the use of wires. Information is transferred in this manner over both short and long distances. Wireless operations permit services, such as long-range communications, that are otherwise impossible (or impractical) to implement with the use of wires e.g from earlier technologies such as GSM, CDMA and GPRS, to 3G networks such as W-CDMA, EDGE or CDMA2000, another popular supporting technology is Wi-Fi, a wireless local area network that enables portable computing devices to connect easily to the Internet.

Electromagnetic laws

i. Faraday's law

Faraday's law of induction states that the emf induced in a circuit is equal to the rate of change of magnetic flux through the circuit:

$$\mathcal{E} = -\frac{d\Phi_B}{dt}.$$

$$\mathcal{E} = -N\frac{d\Phi_B}{dt}.$$

ii. Lenz's law

The minus sign in Faraday's law gives the direction of the induced $e.m.f$: A current produced by an induced $e.m.f$ moves in a direction so that the magnetic field it produces tends to restore the changed field or: An induced $e.m.f$ is always in a direction that opposes the original change in flux that caused it.

$$\mathcal{E} = -N\frac{d\Phi_B}{dt}.$$

iii. Fleming's laws

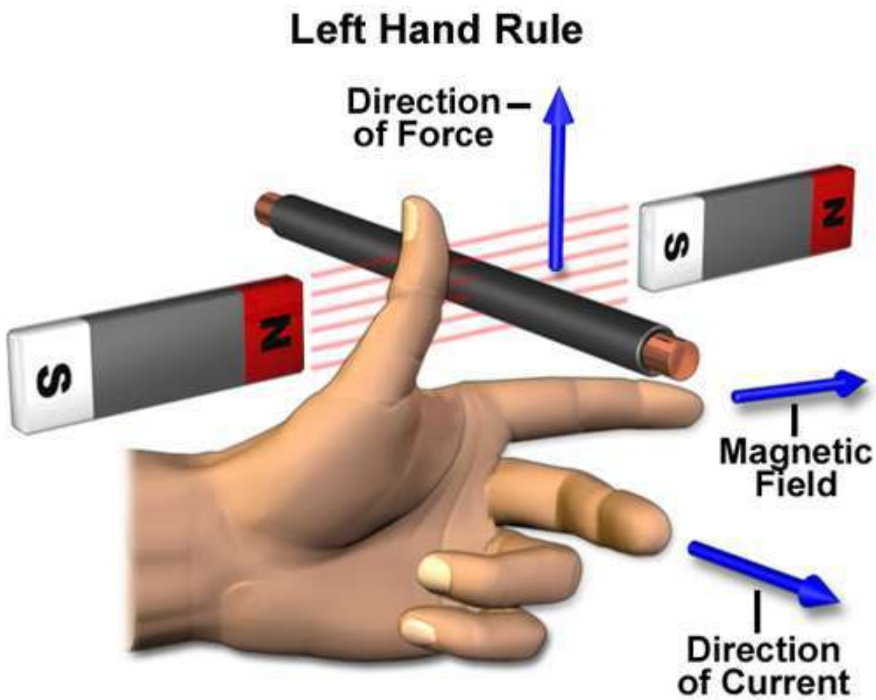
a) Right hand rule

The Right Hand Rule, illustrated at left, simply shows how a current-carrying wire generates a magnetic field. If you point your thumb in the direction of the current, as shown, and let your fingers assume a curved position, the magnetic field circling around those wires flows in the direction in which your four fingers point.

Right hand rule.

Left hand rule

The Left Hand Rule shows what happens when an electrical current enters a magnetic field. You need to contort your hand in an unnatural position for this rule, illustrated below. As you can see, if your index finger points in the direction of a magnetic field, and your middle finger, at a 90 degree angle to your index, points in the direction of the current, then your extended thumb (forming an L with your index) points in the direction of the force exerted upon that particle. This rule is also called Fleming's Left Hand Rule, after English electronics pioneer John Ambrose Fleming, who came up with it.



Common properties

Electromagnetic waves are members of a family of waves with **common properties** called the electromagnetic spectrum.

All electromagnetic waves:

i. are transverse waves;
ii. can travel through a vacuum;
iii. Travel at exactly the same speed in a vacuum, the speed of light, 300,000,000 m/s.

Like all waves, electromagnetic waves:

a. transfer energy from one place to another;
b. can be reflected;
c. Can be refracted.

Differences

Each type of wave in the electromagnetic spectrum has different:

a. wavelength;

b. Frequency.

Characteristics of Waves:

All waves share certain characteristics:

Amplitude

- The maximum distance the molecules are displaced from their starting place
- As energy ↑, amplitude ↑

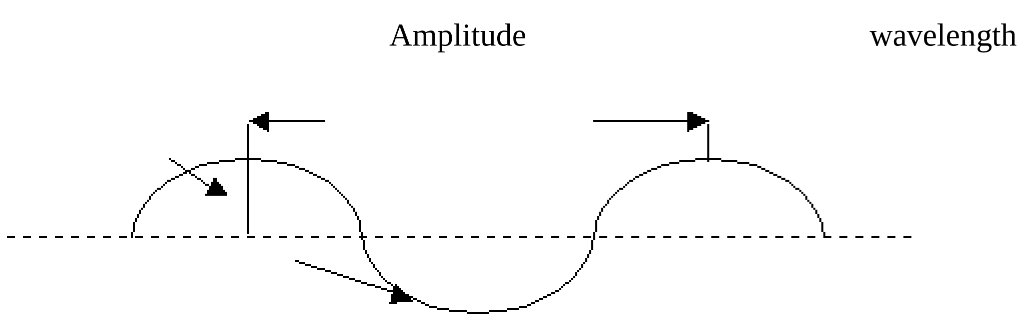
Wavelength

The distance between 2 consecutive crests or troughs

Frequency

The number of cycles per unit time

- Transverse – crests (troughs)/second
- Compression – compressions (rarefactions)/second
- Unit is the hertz (Hz) 1Hz = 1wave/second



Speed of Waves:

The speed of a wave is determined by the number of waves passing a point per second and the length of the wave.

· Speed in any given medium is constant.

· Speed = frequency × wavelength ($f \times \lambda$)

- If f ↑,λ↓ or f ↓, λ ↑

Electromagnetic shielding

Electromagnetic shielding is the practice of reducing the electromagnetic field in a space by blocking the field with barriers made of conductive or magnetic materials. Shielding is typically applied to enclosures to isolate electrical devices from their surroundings, and to cables to isolate wires from the environment through which the cable runs. Electromagnetic shielding that blocks radio frequency (RF) electromagnetic radiation is also known as RF shielding.

The shielding can reduce the coupling of radio waves, electromagnetic fields, and electrostatic fields. A conductive enclosure used to block electrostatic fields is also known as a Faraday cage. The amount of reduction depends very much upon the material used, its thickness, the size of the shielded volume and the frequency of the fields of interest and the size, shape and orientation of holes in a shield to an incident electromagnetic field.

Materials used

Typical materials used for electromagnetic shielding include sheet metal, metal screen, and metal foam. Common sheet metals for shielding include copper, brass, nickel, silver, steel, and tin. Shielding effectiveness, that is how well a shield reflects or absorbs/suppresses electromagnetic radiation, is affected by the physical properties of the metal. These may include conductivity, solderability, permeability, thickness, and weight. A metal's properties are an important consideration in material selection. For example, electrically dominant waves are reflected by highly conductive metals like copper, silver, and brass, while magnetically dominant waves are absorbed/suppressed by a less conductive metal such as steel or stainless steel. Further, any holes in the shield or mesh must be significantly smaller than the wavelength of the radiation that is being kept out, or the enclosure will not effectively approximate an unbroken conducting surface.

Another commonly used shielding method, especially with electronic goods housed in plastic enclosures, is to coat the inside of the enclosure with a metallic ink or similar material. The ink consists of a carrier material loaded with a suitable metal, typically copper or nickel, in the form of very small particulates. It is sprayed on to the enclosure and, once dry, produces a continuous conductive layer of metal, which can be electrically connected to the chassis ground of the equipment, thus providing effective shielding.
Electromagnetic shielding is the process of lowering the electromagnetic field in an area by barricading it with conductive or magnetic material. Copper is used for radio frequency (RF) shielding because it absorbs radio and other electromagnetic waves. Properly designed and constructed RF shielding enclosures satisfy most RF shielding needs, from computer and electrical switching rooms to hospital CAT-scan and MRI facilities

Skin effect

Skin effect is the tendency of an alternating electric current (AC) to become distributed within a conductor such that the current density is largest near the surface of the conductor and decreases exponentially with greater depths in the conductor. The electric current flows mainly at the "skin" of the conductor, between the outer surface and a level called the skin depth. Skin depth depends on the frequency of the alternating current; as frequency increases, current flow moves to the surface, resulting in less skin depth. Skin effect reduces the effective cross-section of the conductor and thus increases its effective resistance. Skin effect is caused by opposing eddy currents induced by the changing magnetic field resulting from the alternating current. At 60 Hz in copper, the skin depth is about 8.5 mm. At high frequencies the skin depth becomes much smaller.

Increased AC resistance caused by the skin effect can be mitigated by using specially woven litz wire. Because the interior of a large conductor carries so little of the current, tubular conductors such as pipe can be used to save weight and cost. The skin effect has practical consequences in the analysis and design of radio-frequency and microwave circuits, transmission lines (or waveguides), and antennas. It is also important at mains frequencies (50–60 Hz) in AC electrical power transmission and distribution systems. It is one of the reasons for preferring high-voltage direct current for long distance power transmission.

Causes of skin effect

Conductors, typically in the form of wires, may be used to transmit electrical energy or signals using an alternating current flowing through that conductor. The charge carriers constituting that current, usually electrons, are driven by an electric field due to the source of electrical energy. A current in a conductor produces a magnetic field in and around the conductor. When the intensity of current in a conductor changes, the magnetic field also changes. The change in the magnetic field, in turn, creates an electric field which opposes the change in current intensity. This opposing electric field is called “counter-electromotive force” (back EMF). The back EMF is strongest at the center of the conductor, and forces the conducting electrons to the outside of the conductor.

Regardless of the driving force, the current density is found to be greatest at the conductor's surface, with a reduced magnitude deeper in the conductor. That decline in current density is known as the *skin effect* and the *skin depth* is a measure of the depth at which the current density falls to 1/e of its value near the surface. Over 98% of the current will flow within a layer 4 times the skin depth from the surface. This behavior is distinct from that of direct current which usually will be distributed evenly over the cross-section of the wire.

An alternating current may also be *induced* in a conductor due to an alternating magnetic field according to the law of induction. An electromagnetic wave impinging on a conductor will therefore generally produce such a current; this explains the reflection of electromagnetic waves from metals. Although the term "skin effect" is most often associated with applications involving transmission of electric currents, the skin depth also describes the exponential decay of the electric and magnetic fields, as well as the density of induced currents, inside a bulk material when a plane wave impinges on it at normal incidence

3.1.1.3.Learning Activities

Industrial attachment/workshop Practice

Practical activities	**knowledge**	**Special instruction**
1. Apply electromagnetic field theory,		

2. Identify electromagnetic radiation sources		
3. Determine detectors of electromagnetic radiations,		
4. Apply electromagnetic waves,		
5. Identify electromagnetic laws and establish behaviours and effects of electromagnetic waves		

3.1.1.4. Self-Assessment Questions

1. What are the sources of electromagnetic fields? **(4 Marks)**
2. Which detectors can be used to sense electromagnetic waves? **(4 Marks)**
3. What are the applications of Electromagnetic waves? **(3 Marks)**
4. What are the properties of Electromagnetic waves? **(4 Marks)**

3.1.1.5.Tools, Equipment and Material

These includes:

Tools and equipment	**Materials and supplies**
i. Cable Strippers ii. Pliers iii. Screw drivers iv. Hammers v. Chisels vi. Allen keys vii. Electrician knives viii. Crimping tools ix. Bending springs x. Bending machine xi. Steel tapes xii. Draw wires xiii. Hack saws xiv. Drilling tools xv. Stock and die xvi. Bench vice xvii. Machine vice xviii. PPE – hand gloves, dust coats, dust masks, helmets, ear muffs, industrial boots	i. Stationery ii. Cables iii. Light fittings iv. Accessories v. Conduits and fittings vi. Cable trays vii. Cable ducts viii. Trunkings ix. Computers x. Drawing instruments xi. Screws
Reference materials a) IEE regulations	

b) Occupational safety and health act (OSHA) c) Work injury benefits act (WIBA) d) Manufacturers' catalogues e) British standards f) KEBS standards	

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3.1.1.7. Model Answers to self-assessment Questions

1. Sources of electromagnetic fields **(4 Marks)**

a) Static
b) ELF (extremely low frequencies)
c) IF(intermediate frequencies)

d) RF (radio frequencies)

2. **Detectors which can be used to sense electromagnetic waves** **(4 Marks)**
   (a) Optical sensors
   (b) Photodiodes
   (c) IR
   (d) Microwave sensors
3. **Applications of Electromagnetic waves** **(3 Marks)**
   i. Microwave oven
   ii. Radar
   iii. Wireless communication
4. **Properties of Electromagnetic waves** **(4 Marks)**
   i. Transverse
   ii. Travel through a vacuum
   iii. Can be reflected
   iv. can be refracted

CHAPTER 1 ENGINEERING MATHEMATICS

Unit of learning code: ENG/AUT/CC/1/5

Related Unit of Competency in Occupational Standard: Apply Engineering Mathematics

1.1 Introduction to the unit of learning

This unit describes the competencies required by an automotive technician in order to apply engineering mathematics. It involves use concepts of arithmetic in solving work problems, applying algebra, applying trigonometry and hyperbolic functions, applying complex numbers, applying coordinate geometry, carrying out binomial expansion, applying calculus, solving ordinary differential equations, carrying out mensuration, applying power series, applying statistics, applying numerical methods, applying vector theory, applying matrix, solving partial differential equations, applying Laplace transforms and applying Fourier series.

1.2 Summary of Learning Outcomes

10. Use concepts of arithmetic in solving work problems
11. Use common formula and algebraic expressions for work
12. Use trigonometry to solve practical engineering problems