CHAPTER 4. ELECTRICAL PRINCIPLES/ APPLY ELECTRICAL PRINCIPLES

4.1. Introduction of the Unit of Learning/Unit of Competency

Electrical Principles presents the basic theories and concepts taught at entry level in Tertiary Institutions. This series of content provides examples to trainers to enable them to develop a strong foundational knowledge of electrical and electronics engineering. The unit comprises of basic theory and practical lessons. Electrical principles link to other core units by providing knowledge in mathematics, physical sciences, mechanical sciences, workshop technology, and electrical machines.
This unit is designed to equip the trainee with the knowledge skills and attitude necessary to understand a wide range of Electrical Principles in their work. This includes basic electrical quantities, direct current (DC) circuits, alternating current (AC) circuits in electrical installation, use of earthing in electrical installation, apply lighting protection measures, apply electromagnetic field theory, apply electrodynamics, apply energy and momentum in electromagnetic field, apply electrical circuit analysis, use two port network, demonstration of refrigeration and air conditioning.

It is recommended that a trainee should have the following learning resources to help him/her in this unit: scientific calculators, relevant reference materials, stationeries, relevant practical materials, and computers with internet connections. Trainees are expected to adhere to the strict rules and regulations once inside the electrical workshops to avoid accidents. The trainee should also read and understand OSHA and WIBA rules and regulations.

In this unit the trainee will be engaged in learning activities such as oral questioning, class discussions, practical activities, supervised exercises, assignments, and written tests.

4.2. Performance Standard

Use electronic calculators when performing calculations in the unit, maintain the area of your working clean to avoid accidents in the workshop, identify

4.3. Learning Outcomes

4.3.1. List of Learning Outcomes

a) Use the concept of basic electrical quantities
b) Use the concepts of DC to AC circuits in electrical installation
c) Use basic electrical machines
d) Use power factor in electrical installation
e) Use earthing in electrical installation
f) Apply lightning protection measures
g) Apply electromagnetic field theory
h) Apply electrodynamics
i) Apply energy and momentum in electromagnetic field

j) Apply transients in electrical circuit analysis
k) Use two port network
l) Demonstrate understanding of refrigeration and air conditioning

4.3.2. Learning Outcome No 1: Use of Basic Electrical Machines

4.3.2.1. Learning Activities

Learning Outcome #No.1 Use of Basic Electrical Machines	
Learning Activities	Special Instructions
• State the Ohms Law • Compute electrical parameters such as power, current , voltage and resistance when given any two parameters • Set up an experiment to test the Ohms law	

4.3.2.2. Information Sheet No4/01

Introduction

An **electrical machine** is generally a device that converts mechanical energy into electrical energy and vice versa with the exception of an electrical transformer, which does the conversion of AC power from one voltage level to another. Other electrical machines are electrical generator and electrical motor.

Electric Generator: It is an electrical machine that converts mechanical energy into electrical energy. It operates on the principle of electromagnetic induction. It follows faraday's laws of electromagnetic induction, which states that whenever a conductor moves in a varying magnetic field, an electromotive force, emf, is induced within the conductor. It is also known as the generator action.

Electric Motor: It is an electrical machine that converts electrical energy into mechanical energy. The operating principle states that a current-carrying conductor experiences a torque (mechanical force) whenever it is put in a magnetic field. It is also known as the motoring action.

Transformers: It is a special type of machine because it does not convert any energy form one form to another. Instead, it transfers electrical power between circuits with different electrical voltage levels. Transformers increase (step-up) or decreases (step-down) voltages as it corresponds with the decrease or increase in current. In an ideal situation, the input and output power and frequency are the same.

Meaning of SI Unit: SI Units means the standard international unit which represents a complete metric system of units of measurements.

SI Units of various Types of electrical parameters

Table 3: SI Units of electrical parameters

Unit Name	Unit Symbol	Quantity
Ampere (amp)	A	Electric current (I)
Volt	V	Voltage (V, E) Electromotive force (E) Potential difference (Δφ)
Ohm	Ω	Resistance (R)
Watt	W	Electric power (P)
Decibel-milliwatt	dBm	Electric power (P)
Decibel-Watt	dBW	Electric power (P)
Volt-Ampere-Reactive	var	Reactive power (Q)
Volt-Ampere	VA	Apparent power (S)
Farad	F	Capacitance (C)
Henry	H	Inductance (L)
siemens / mho	S	Conductance (G) Admittance (Y)
Coulomb	C	Electric charge (Q)
Ampere-hour	Ah	Electric charge (Q)
Joule	J	Energy (E)
Kilowatt-hour	kWh	Energy (E)
Electron-volt	eV	Energy (E)
Ohm-meter	Ω·m	Resistivity (ρ)
siemens per meter	S/m	Conductivity (σ)
Volts per meter	V/m	Electric field (E)
Newtons per coulomb	N/C	Electric field (E)
Volt-meter	V·m	Electric flux (Φ_e)
Tesla	T	Magnetic field (B)
Gauss	G	Magnetic field (B)
Weber	Wb	Magnetic flux (Φ_m)
Hertz	Hz	Frequency (f)
Seconds	s	Time (t)
Meter / metre	m	Length (l)
Square-meter	m^2	Area (A)
Decibel	dB	
Parts per million	ppm	

Source: https://www.rapidtables.com/electric

Ohm' Law

Ohm's law states that "voltage or potential difference between two points is directly proportional to the current or electricity passing through the resistance, and inversely proportional to the resistance of the circuit."

The formula for Ohm's law is **V=I/R**.

Applications of Ohm's Law

Used in determination of voltage, current or impedance or resistance of a linear electric circuit

Calculations involving various Electrical parameters. (Power, Current, Voltage, Resistance)

Power can be calculated using formulas illustrated below:

$$P = I \times V = R \times I^2 = V^2 / R$$

Where P is power in Watts, V (voltage), I (current in amperes) (DC) and R is the resistance.

Note: in case of AC (alternating current), it is important to find power factor.

$PF = \cos \varphi$ Where φ is the power factor angle, the angle between the voltage and the amperage

From the above combined with ohms law,

Power (P)

$$P = V \times I = R \times I^2 = V^2 / R$$

Current (I)

$$I = V / R = P / V = \sqrt{(P / R)}$$

Voltage (V)

$$V = I \times R = P / I = \sqrt{(P \times R)}$$

Resistance (R)

$$R = V / I = P / I^2 = V^2 / P$$

Instruments used in measuring various types of electrical parameters

1. Analogue meter

Can be used to measure either one circuit value for instance voltage, resistance and current or measure of these at ago. They have a needle that swings indicating the value to be measured as illustrated below.

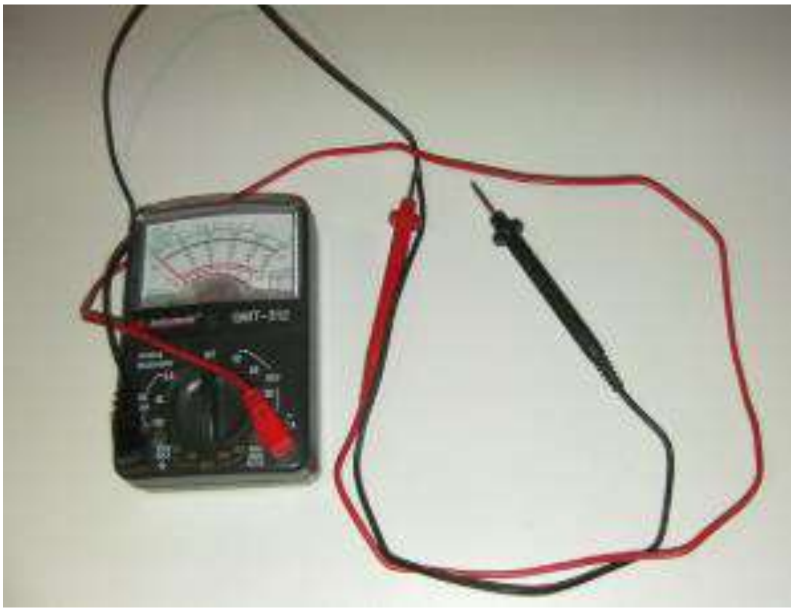


Figure 15 analogue meter

Source: https://en.wikipedia.org/wiki/Ohm#/media/File:Electronic_multi_meter.jpg

2. Digital meter

Such meters are accurate as they indicate real digital value unlike the analog meters subject to parallax errors while reading the measurement.

Figure 16: digital meter

Source: https://en.wikipedia.org/wiki/Ohm#/media/File:Electronic_multi_meter.jpg

An Experiment to conduct Ohms Law
Circuit diagram for ohms law

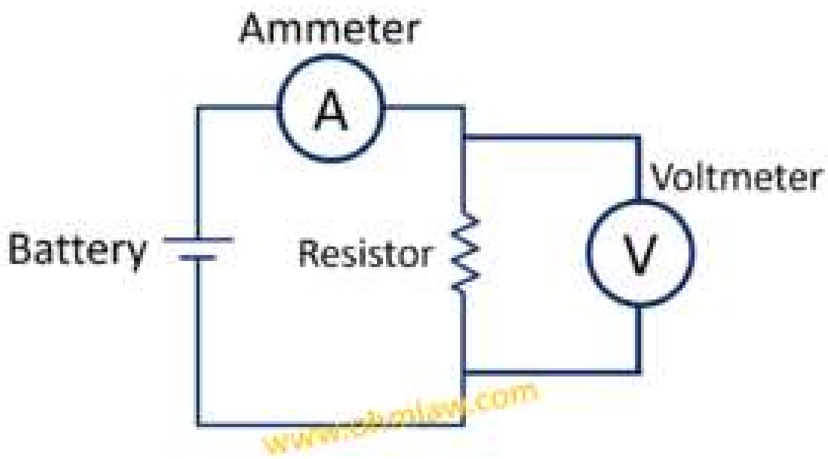


Figure 17: circuit diagram for ohms law

Source: www.ohmlaw.com

Experiment procedure

1. Connect the resistor on the breadboard.
2. Connect the source to the breadboard.
3. Connect the ammeter in series.
4. Connect the voltmeter in parallel.
5. Increase the voltage step-by-step from 0 to10 V and note the voltage/current.

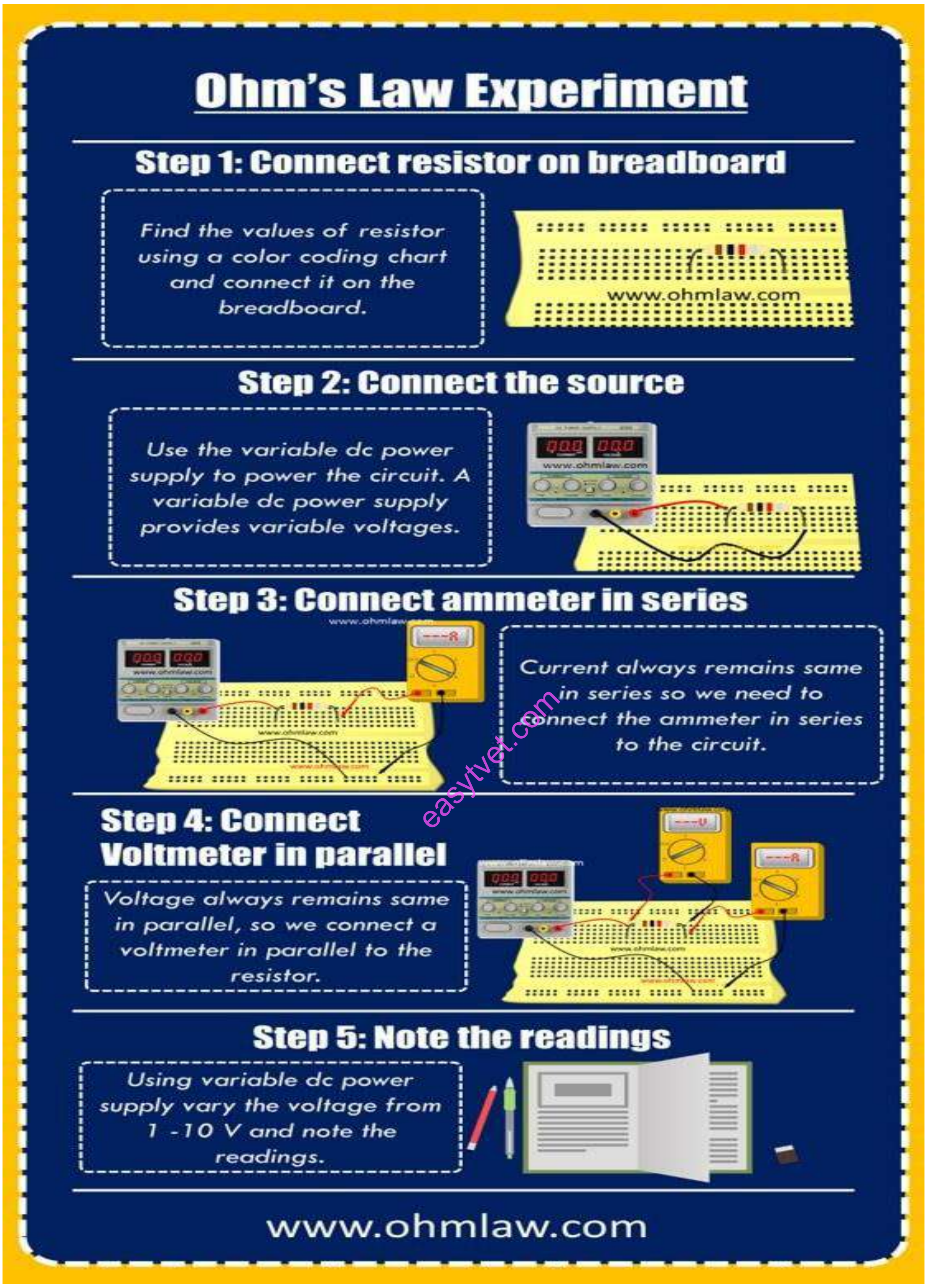


Figure 18: visual representation of steps

Source: (http://ohmlaw.com/ohms-law-experiment/)

4.3.2.3. Self-Assessment

a) Describe an electric generator and electric motor
b) Perform calculations on Voltage, current and voltage
c) State the Ohms Law
d) A generator is an electrical machine that converts electrical energy into mechanical energy. TRUE OR FALSE?
e) A transformer is a special type of machine because it does not convert any energy form one form to another. TRUE OR FALSE?
f) Conduct ohms experiment with ease
g) What types of losses occur in the magnetic frame of the transformer when the transformer is energized?
h) What information can be obtained from open circuit test of a transformer?
i) Why HV side is always kept open side in open circuit test?
j) What is the power factor of a transformer under no-load test situation?
k) How does no load current compare to full load current?

4.3.2.4. Tools, Equipment, Supplies and Materials for the specific learning outcome

- Scientific Calculators
- Relevant reference materials
- Stationeries
- Electrical workshop
- Relevant practical materials
- Computers with internet connection

4.3.2.4 References

1. Juha Pyrhonen, Tapani Jokinen, Valeria Hrabovcova, Design of Rotating Electrical Machines, New York, NY: John Wiley & Sons, 2013.
2. http://ohmlaw.com/ohms-law-experiment/

4.3.3. Learning Outcome No. 2. Use the concept of DC and AC circuits in electrical installation

4.3.3.1. Learning Activities

Learning Outcome No. 2 Use the concept of DC and AC circuits in electrical installation	
Learning Activities	Special Instructions
• Conduct an experiment to measure Kirchhoff's voltage/ current law • Carry out calculation involving parallel and series circuits	

4.3.3.2 Information Sheet No. 4/ LO2

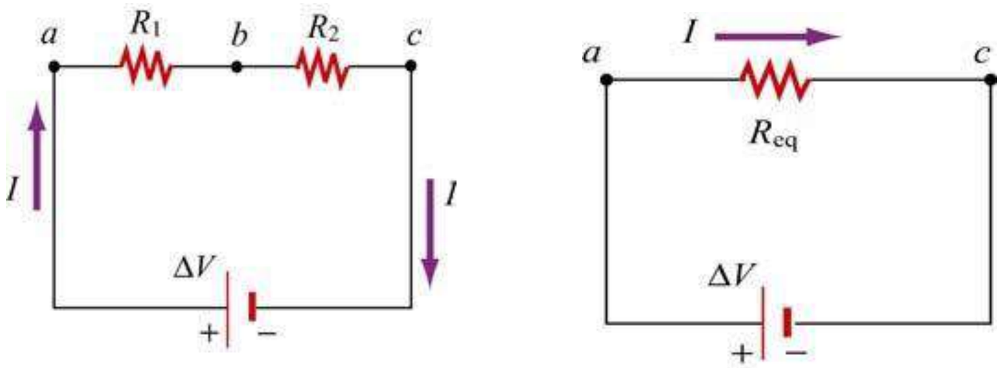
Introduction

Electrical circuits are used to connect loads to the power supply. Common loads are motors, resistors, lamps and heaters. A switch is used to close or open the path of electrical energy flow. Various loads are called circuit elements and can be in series or parallel. They are connected to the power supply using soldered wires called leads. A lead that connects several circuit elements is called a common lead.

Calculations Involving Parallel and Series Circuits

Resistors in Series and in Parallel

The two resistors R_1 and R_2 in Figure 7.3.1 are connected in series to a voltage source □*V*By current conservation, the same current *I* is flowing through each resistor.



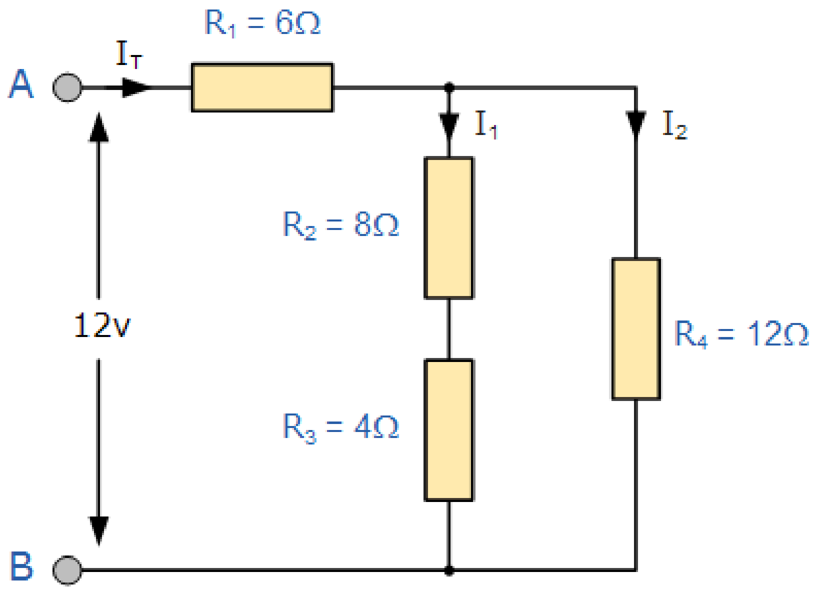


Figure 20: series calculation

Considering the above circuit, calculations of resistors in parallel and series can be calculated as follows

Series calculation

Resistors R1 and R2 are in series. The total resistance can be calculated as

$$R_2 + R_3 = 8\Omega + 4\Omega = 12\Omega$$

Replacing R1 and R2 result in the diagram below

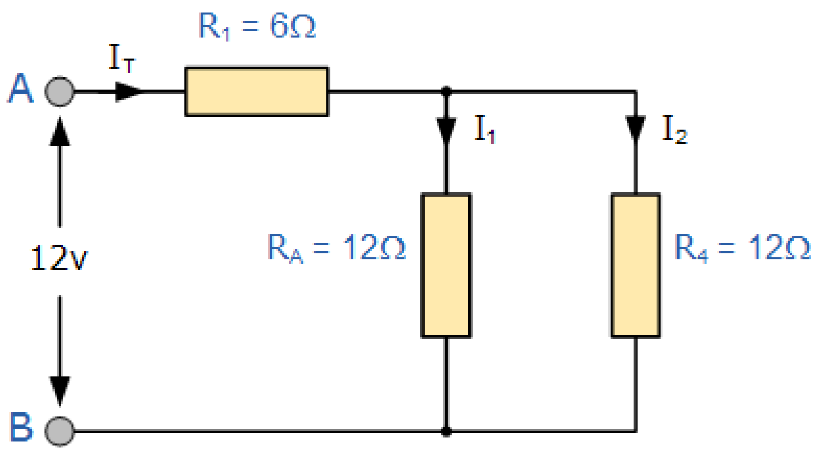


Figure 21: total resistance in circuit

Parallel calculation

From the above diagram RA is in parallel with R4

Using the resistor parallel equation, the total resistance can be calculated as :

$$R_{(combination)} = \frac{1}{R_A} + \frac{1}{R_4} = \frac{1}{12} + \frac{1}{12} = \frac{1}{R_{(com)}} = 6\Omega$$

The final resistive circuit can be illustrated as in the figure below.

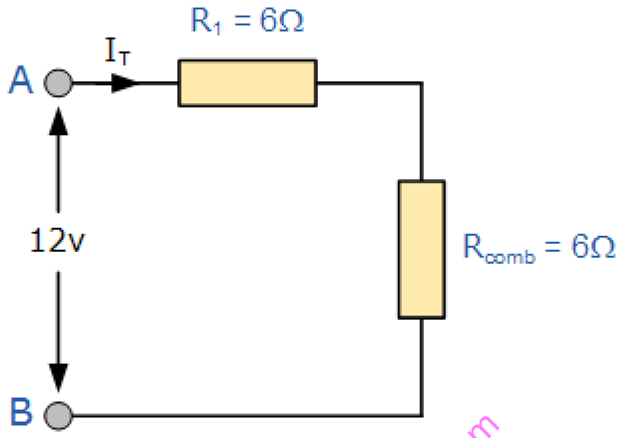


Figure 22: parallel calculation

Source :(https://www.electronics-tutorials.ws/resistor/res_5.html)

AC and DC network theorems

Electromotive Force

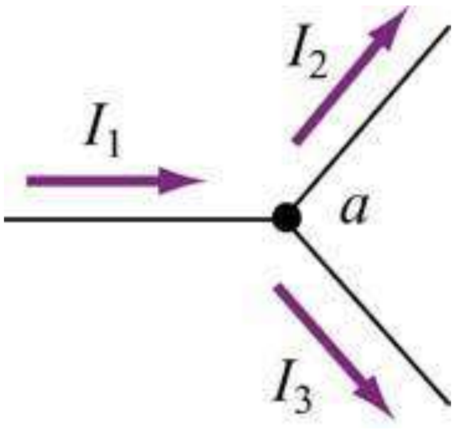
Electrical energy supply is necessary to maintain a constant current in a closed electrical circuit. The energy source is commonly referred to as electromotive force, emf. Popular emf sources are solar cells, batteries, and thermocouples. They are also considered as "charge pumps" since they push charges from areas of low potential to high one.

Kirchhoff's Circuit Rules

There are two fundamental rules used in analyzing electrical circuits, called Kirchhoff's Laws. They are two laws:

1. Kirchhoff's First Law: It states that at any junction of a circuit, the sum of currents coming into the junction is equal to the sum of currents leaving it. In other words, the sum of currents at a node is zero. It is also known as the Junction Rule or Kirchhoff's Current Law.

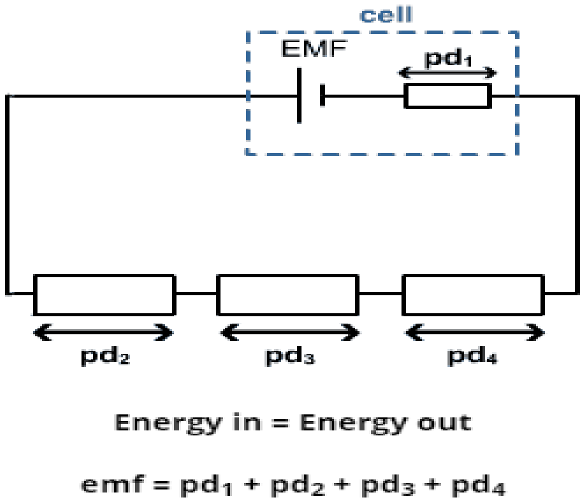
As an example, consider the figure below:



$I_1 = I_2 + I_3$ or $I_1 + I_2 + I_3 = 0$

2. Kirchhoff's Second Law: It states that the sum of voltage sources, emf, supplying a circuit loop is equal to the total energy absorbed by the elements in the circuit, potential differences, pd. In other words, the total amount of electrical energy put into a circuit is equal to the total amount of electrical energy taken out by the circuit elements. It is also known as Kirchhoff's Voltage Law.

As an example, consider the diagram below that shows a voltage source, emf and different loads with potential difference, Pd1, Pd2, Pd3 and Pd4.



Basic solar photovoltaic systems;

Materials that convert sunlight to electrical energy are known as photovoltaic. In attempt to boosting the output of the photovoltaic cells, they are interconnected to form large chains called panels/modules.

PV systems is made up of PV modules and arrays. Besides, the system is made up of mounting structures with pointing panels facing the sun and components that convert the produced direct current alternating current.

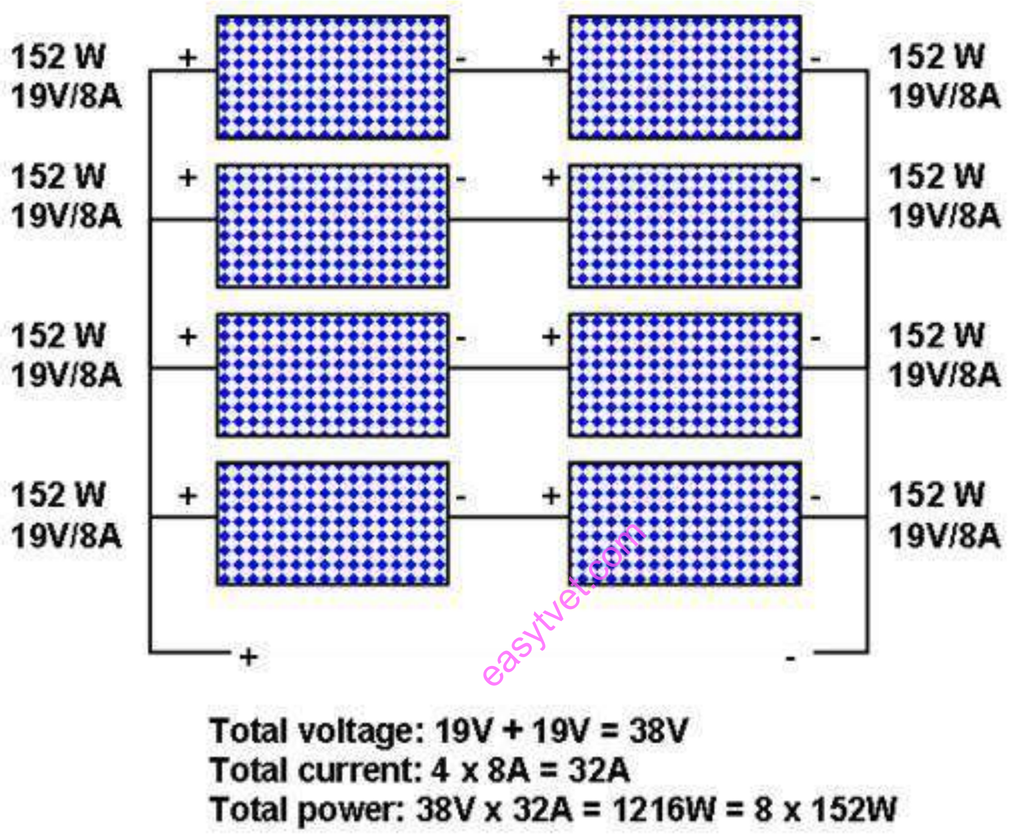


Figure 25: example of a PV solar panel

Experiment 2: Study Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law (KVL)

Apparatus:

3 AC Ammeters (0-10 amp)

3 AC Voltmeters (0-300 V)

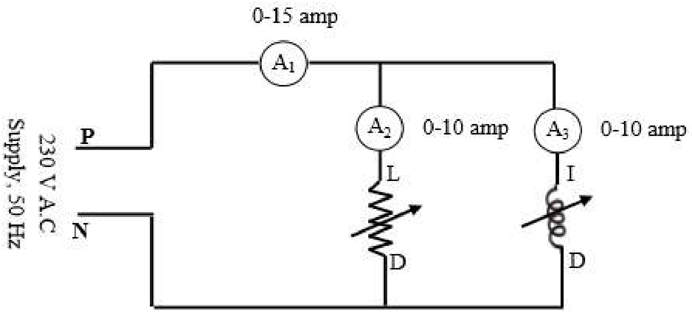
Rheostat

Inductive Load

Connecting wires

Procedure:

KCL:



Note down the initial readings of all ammeters A_1, A_2, and A_3 and all voltmeters V_1, V_2 and V_3.

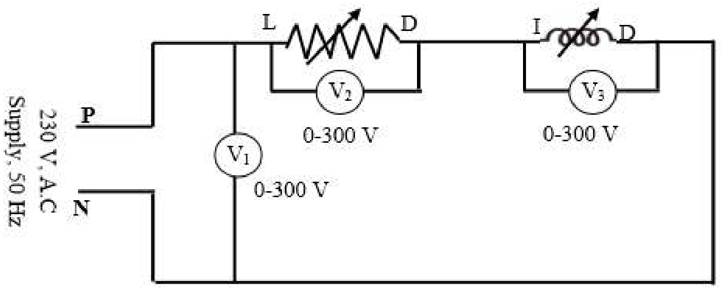
Connect the circuit as shown in the diagram

Vary both the resistive and inductive load and record the readings of the ammeters and voltmeters

Repeat procedure (3) with different values

Calculate percentage error.

KVL:



Connect the apparatus as shown in the circuit diagram

Vary both the rheostat and inductive load to obtain and note down the readings V_1, V_2, and V_3.

Repeat procedure (3) with different values

Calculate percentage error.

Precautions

Make the connections properly

Accurately note down the voltmeter and ammeter readings

Ensure the connections are tight.

Figure 26: example 2

Observation Table:

Table 4: Observation table

KVL

Sl.No.	V_1 in (Volts)	V_2 in (Volts)	V_3 in (Volts)	$V_1' = \sqrt{V_2^2 + V_3^2}$	% Error
1					
2					
3					

KCL

Sl.No.	A_1 in (Volts)	A_2 in (Volts)	A_3 in (Volts)	$A_1' = \sqrt{A_2^2 + A_3^2}$	% Error
1					
2					
3					

4.3.3.3. Self-Assessment

1. State Kirchhoff's voltage law
2. State Kirchhoff's current law
3. Kirchhoff's voltage Law states that at any junction of a circuit, the sum of currents coming into the junction is equal to the sum of currents leaving it. TRUE OR FALSE?
4. Materials that convert sunlight to electrical energy are known as photovoltaic. TRUE OR FALSE?
5. Perform an experiment to demonstrate Kirchhoff's law
6. Differentiate between calculations Involving Parallel and Series Circuits
7. What are the applications of the Kirchhoff's laws?

4.3.3.4. Tools, Equipment, Supplies and Materials for the specific learning outcome

- Scientific Calculators
- Relevant reference materials
- Stationeries
- Electrical workshop
- Relevant practical materials
- Dice
- Computers with internet connection

4.3.3.5. References

James W. Nilsson, Susan Riedel, Electric Circuits, New Jersey: Prentice Hall Press, 2010.

4.3.4. Learning Outcome No. 3. Use of basic electrical machines

4.3.4.1. Learning Activities

Learning Outcome No.3. Use of basic electrical machines	
Learning Activities	Special Instructions
• Identify AC and DC machines • Demonstrate the understanding of application of AC and Dc machines • Demonstrate motor starting methods	

4.3.4.2. Information Sheet No. 4/ Lo3

Introduction

Electrical Machines

Any devices that does the conversion of electrical energy to mechanical energy and vice versa is called an electrical machine. Transformer form part of electrical machines although they only convert voltage level from one level to another.

Types of Electrical machine

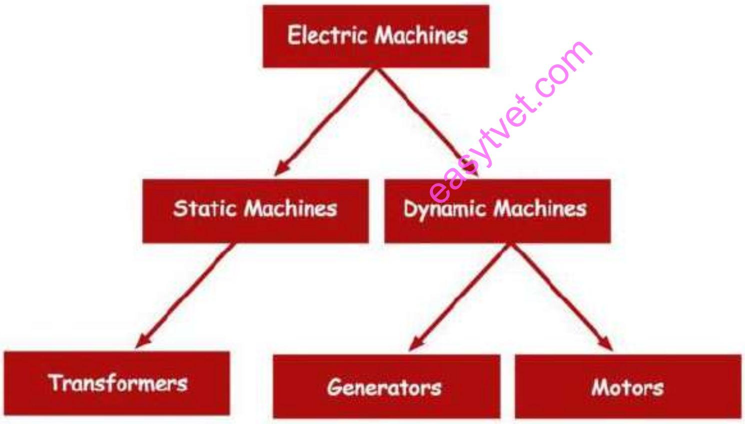


Figure 27: type of electrical machine

DC machines

Is a high versatile device that is likely to meet load demands requiring high acceleration and deceleration torques as well as high starting torque. The field winding for DC machines is located on the stator and windings of the armature is on the roto as shown below.

AC Single and three phase motors.

A motor is an electrical machine that converts electrical energy to mechanical energy.

Generators

Is an electrical machines that operates on the principal of electromagnetic induction hence converting mechanical energy to electrical energy? It is made up of a stator and a rotor. At the rotor, mechanical energy is provided through prime mover also called the turbine.

Transformers

Electrical machine that either steps up or down voltage suitable for consumption.

Working Principle of a Transformer

The basic principle of a transformer's operation is the phenomenon of mutual induction. The figure above shows the simplest form of a transformer. Basically a transformer It consists of two inductive coils; primary and secondary winding. Though the windings are electrically separated, they are magnetically linked.

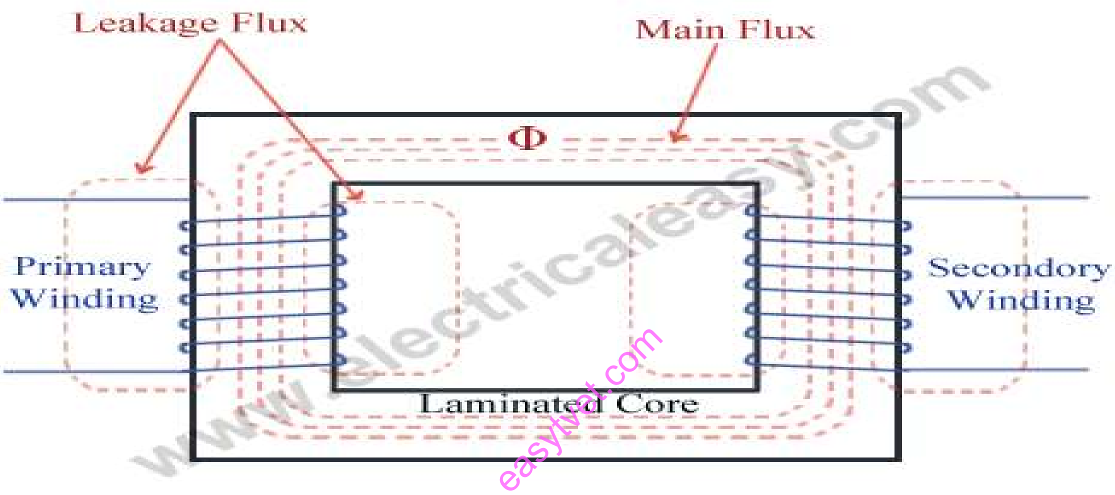


Figure 28: transformer

Source: www.electricaleasy.com

When the primary side is connected to an AC voltage supply, an alternating magnetic flux is produced around the primary winding. The laminated core provides magnetic path for the transfer of the flux on the primary side to the secondary winding. The flux that is successfully linked to the secondary side is called useful flux or main flux. The unlinked flux is known as leakage flux.

Since the induced flux is alternating, it forms a varying magnetic field, which meets the requirement of Faraday's law of electromagnetic induction. As a result, an emf is induced on the secondary winding called the mutually induced emf.

Types of Transformers

Transformers are broadly classified in terms of construction, purpose, type of power supply, use, and type of cooling.

Construction

Transformers fall into two categories based on their construction:

(i) Core type transformer

(ii) Shell type transformer

Core Type Transformer

The windings are wound in a cylindrical form then mounted on the core limbs. The windings are layered and the layers are insulated from each other using materials such as mica, paper and cloth. Low voltage windings are easier to insulate. Therefore, they are placed closest to the core.

Shell Type Transformer

The coils are wound in a rectangular or distributed form. They are also mounted in layers stacked with insulation between them.

- Purpose

1. Step up transformer: Increases the supply voltage with a corresponding decrease in current on the secondary side.
2. Step down transformer: Decreases supply voltage with a corresponding increase in current at the secondary side.

- Type of supply

1. Single phase transformer
2. Three phase transformer

- The use

1. Power transformer: Used in a power transmission network
2. Distribution transformer: Used in distribution network
3. Instrument transformer: Used in relay and protection purpose in different instruments in industries
   a) Current transformer (CT)
   b) Potential transformer (PT)

- Type of cooling
   a) Oil-filled self-cooled
   b) Oil-filled water cooled
   c) Air blast (air cooled)

Calculations involving single and three phase AC and DC transformers

Power Formulas in DC Circuits

- $P = V \times I$
- $P = I^2 \times R$
- $P = V^2 / R$

Where:

P = ***Power*** in ***Watts***

V = ***Voltage*** in ***Volts***

I = ***Current*** in ***Amperes***

R = ***Resistance*** in ***Ohms*** (Ω)

Power Formulas in Single Phase AC Circuits

- $P = V \times I \times \cos \Phi$
- $P = I^2 \times R \times \cos \Phi$
- $P = V^2 / R (\cos \Phi)$

Figure 29: single phase transformer calculations

Where:

P = ***Power*** in ***Watts***

V = ***Voltage*** in ***Volts***

I = ***Current*** in ***Amperes***

R = ***Resistance*** *in* ***Ohms*** *(Ω)*

Cos Φ = ***Power Factor***

Power Formulas in Three Phase AC Circuits

- $P = \sqrt{3} \times V_L \times I_L \times \cos \Phi$
- $P = 3 \times V_{Ph} \times I_{Ph} \times \cos \Phi$
- $P = 3 \times I^2 \times R \times \cos \Phi$
- $P = 3 (V^2 / R) \times \cos \Phi$

Where:

P = ***Power*** *in* ***Watts***

V = ***Voltage*** *in* ***Volts***

I = ***Current*** *in* ***Amperes***

R = ***Resistance*** *in* ***Ohms*** *(Ω)*

Cos Φ = ***Power Factor***

Three-phase Voltage and Current

Connection	Phase Voltage	Line Voltage	Phase Current	Line Current
Star	$V_P = V_L \div \sqrt{3}$	$V_L = \sqrt{3} \times V_P$	$I_P = I_L$	$I_L = I_P$
Delta	$V_P = V_L$	$V_L = V_P$	$I_P = I_L \div \sqrt{3}$	$I_L = \sqrt{3} \times I_P$

Figure 30: three-phase voltage and current

Source: V. Vodovozov,(2012)

Three-phase Transformer Line Voltage and Current

Primary-Secondary Configuration	Line Voltage Primary or Secondary	Line Current Primary or Secondary
Delta – Delta	$V_L \Rightarrow nV_L$	$I_L \Rightarrow \frac{I_L}{n}$
Delta – Star	$V_L \Rightarrow \sqrt{3}.nV_L$	$I_L \Rightarrow \frac{I_L}{\sqrt{3}.n}$
Star – Delta	$V_L \Rightarrow \frac{nV_L}{\sqrt{3}}$	$I_L \Rightarrow \sqrt{3}.\frac{I_L}{n}$
Star – Star	$V_L \Rightarrow nV_L$	$I_L \Rightarrow \frac{I_L}{n}$

Figure 31: three-phase line voltage and current

Source: (https://www.electronics-tutorials.ws/transformer/three-phase-transformer.html)

DC Machines

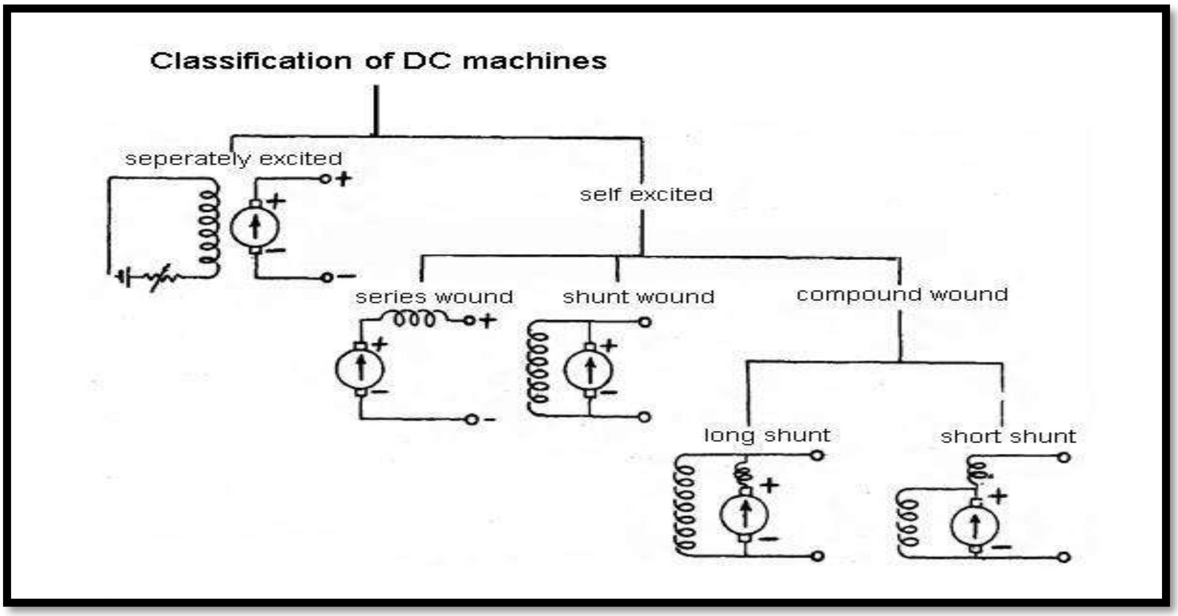


Figure 32: classification of DC machines

Source: (https://www.electronics-tutorials.ws/transformer/three-phase-transformer.html)

A DC machine can act as either a motor or a generator, which makes this classification suitable for both DC motors and DC generators. These machines are grouped into two broad categories based on the method of field excitation:

i) Separately excited DC Machines: The field and armature windings are powered by different power sources..

ii) Self-excited DC machines: The field and armature windings are interconnected in either series or parallel. They are further classified into:
   - Series Dc Machines: The field and the armature windings are connected in series. As a result, the field windings carry the entire load current.
   - Shunt Wound Dc machines: The field and armature windings are connected in parallel. As a result, the full voltage is applied on the field windings.
   - Compound Dc machines: There are two sets of field windings, one connected in series and another in parallel with the armature windings.

Motor Starting methods

- Direct-on-line starting

Refers to the connection of the motors directly to the supply at a specific voltage. It is suitably used stable supplies and shaft systems and pumps that are mechanically fit.
It simple and most commonly used. Temperature rise during starting is the lowest among other starting methods.

- Star-delta starting

It is mostly used induction motors to reduce the starting current. The current supplied to the windings of the stator is Y connected, later it is reconnected to the windings in delta connection when it gains speed.

- Auto-transformer starting

Applies auto transformer coupled in series connection with the motor when it starts.

- Soft starting

The device ensures soft starting of the motor. These are usually based on semi-conductors that aid in reducing the initial voltage of the motor resulting in a lower torque of the motor.

- Frequency converter starting

They can either be used to either continuously feed the motor or for start-up only. It makes it possible for use of low current for startup since motors have the ability to produce rated torque at rated current from zero till maximum speed.

Source: (https://automationforum.co/starting-methods-of-motor/
Advantages and disadvantages of motor starting methods

Special machines

Are machines with specific design to perform particular applications not possible to be performed by other conventional machines. To design a special machine, the electrical control design integrates with the hydraulic, mechanical and pneumatic system.

Examples include;

- Assembly Machines
- Process Machines
  - Semi – Automatic
  - Fully Automatic
- Stand Alone Systems
- Integrated Systems
- Lifts, Pick and place, Transfer tables, Gantries

Application of AC and DC machines

- AC Motor Application
- Fan
- Pumping Motor
- Coolers
- DC Motor Application
- Printer
- Toy
- Electric Train

Table 5: experiment 1

EXPERIMENT 1	Special Instructions
Objective: Perform open circuit test on a single phase transformer to Calculate: The circuit parameters in reference to the primary side of the transformer Transformer's open circuit loss/iron loss/core loss Apparatus Required: One A.C Wattmeter - (0- 250 W) One A.C Voltmeter - (0-250 V) One A.C ammeter - (0-2.5 A) Variac: 230 V, 10 A, 50 Hz, 1-Phase Single Phase Transformer (50 Hz) Connecting wires	Precautions ➢ All connections should be tight and clean ➢ Special care necessary when selecting meter ranges for open circuit tests ➢ Strict adherence to workshop rules and regulations

Voltmeter (V)	Ammeter (A)	Wattmeter (W)

Procedure:
Make the connections as per the circuit diagram.
Ensure that the secondary side of transformer is open
Ensure the variac is at zero position before switching on the power supply.
Switch on A.C power supply.
Apply full voltage supply (230V) to the primary side of the transformer by varying the position of the variac.
Note down the ammeter, voltmeter and wattmeter readings

Reset the Variance to zero position before switching off the power Supply.

4.3.4.3. Self-Assessment

1) Describe an electrical machine
2) Differentiate operation of various types of electrical machines
3) Explain the difference between DC and AC machines
4) Preform various motor starting methods
5) Describe special machines and their applications
6) Transformer form part of electrical machines although they only convert voltage level from one level to another. TRUE OR FALSE?
7) A generator is an electrical machine that converts electrical energy to mechanical energy. TRUE OR FALSE?
8) At the rotor, mechanical energy is provided through prime mover also called the turbine. TRUE OR FALSE?

4.3.4.4. Tools, Equipment, Supplies and Materials for the specific learning outcome

- Scientific Calculators
- Relevant reference materials
- Electrical workshop
- Relevant practical materials

4.3.4.5 References

V. Vodovozov, Electric Drive Systems and Operation, London: Ventus Publishers, 2012.
Cicuitglobe.com

4.3.5 Learning Outcome No. 4: Demonstrate Understanding of Three Phase Power Supply

4.3.5.1 Learning Activities

Learning Outcome No.4. Demonstrate Understanding Of Three Phase Power Supply	
Learning Activities	Special Instructions
• Measure reactive power in a three-phase circuit using this method • Conduct an experiment to measure the readings of two wattmeter's in this experiment, if the load is purely resistive	

4.3.5.2 Information Sheet No. 4/ L03

Three Phase System

Definition: The system which has three phases, i.e., the current will pass through the three wires, and there will be one neutral wire for passing the fault current to the earth is known as the three phase system.

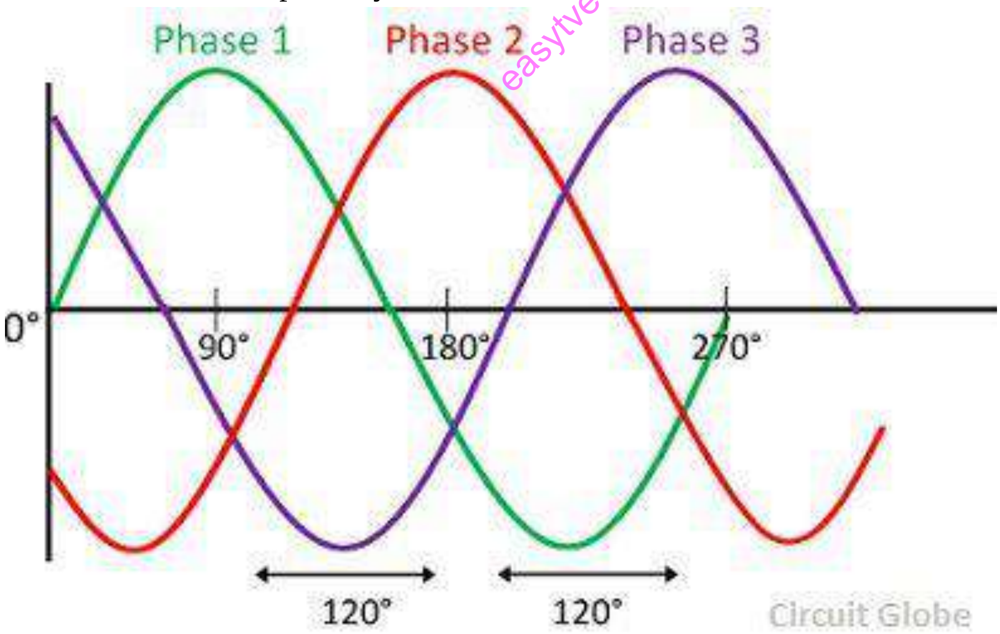


Figure 33: three phase system

Source: Source: (https://www.electronics-tutorials.ws/transformer/three-phase-transformer.html)

The 120º phase difference of the three phases is must for the proper working of the system. Otherwise, the system becomes damaged.

Types of Connections in Three-Phase System

Star Connection

The star connection requires four wires in which there are three phase conductors and one neutral conductor as shown below

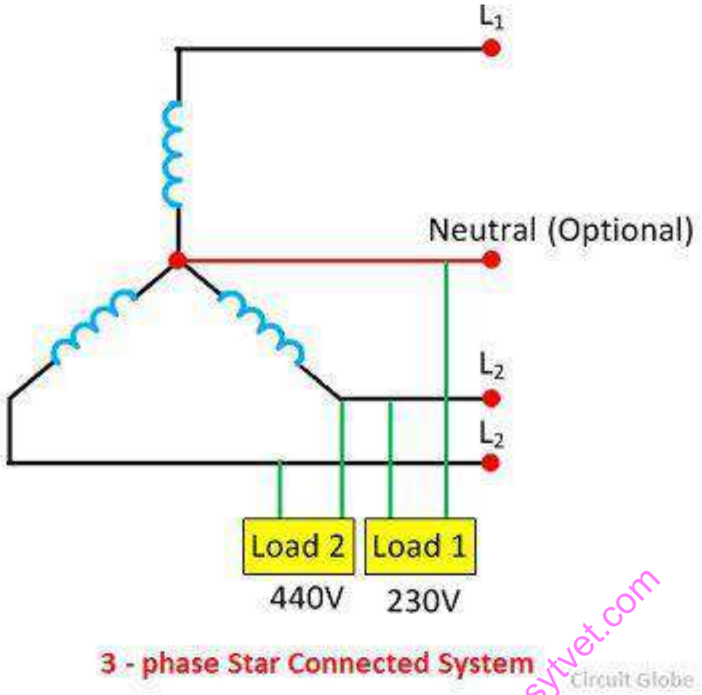


Figure 34: 3-phase star connected system

Source: circuit globe

The voltage between the single phase and the neutral is 230V, and the voltage between the two phases is equal to the 440V.

Delta Connection

The delta connection has three wires, and there is a no neutral point. The line voltage of the delta connection is equal to the phase voltage.

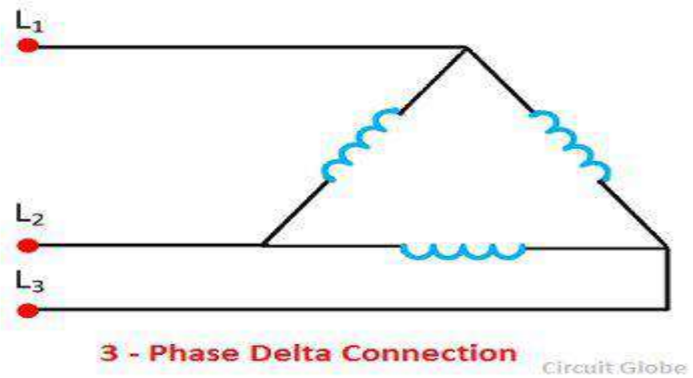
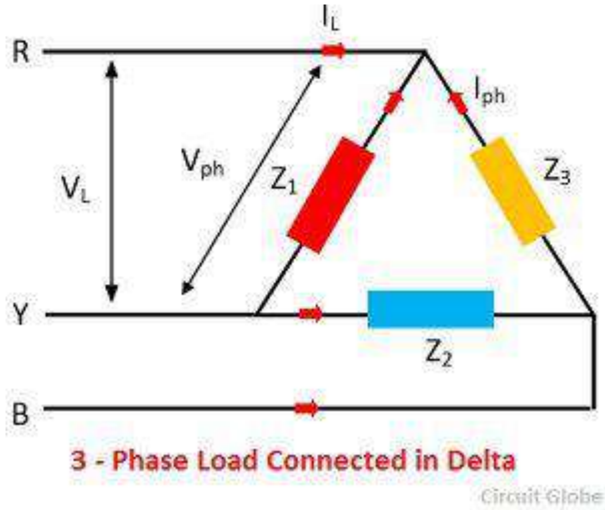


Figure 35:3-phase delta connection

Source: circuit globe

Connection of Loads in Three Phase System
The loads in the three-phase system may also connect in the star or delta. The three phase loads connected in the delta and star is shown in the figure below.



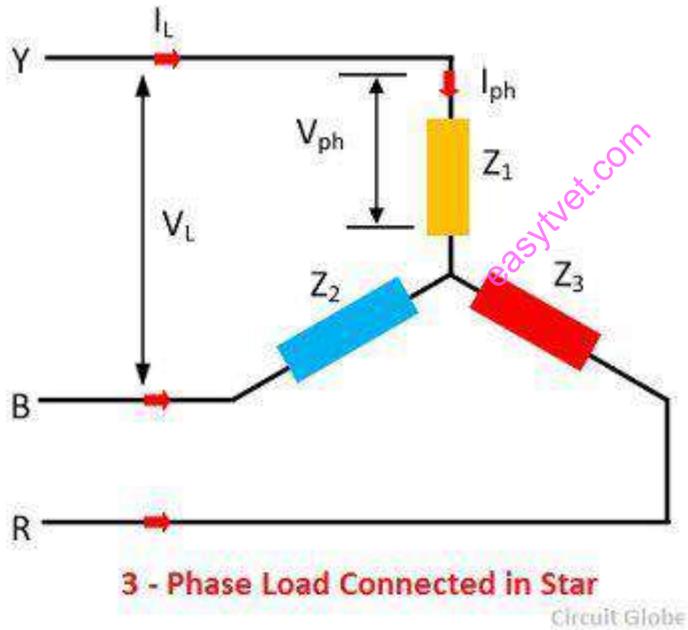


Figure 37: 3-phase load connected in star

Source: circuit globe

The three phase load may be balanced or unbalanced. Under balance condition, all the phases and the line voltages are equal in magnitude.

Review of Three-Phase Voltage System Properties

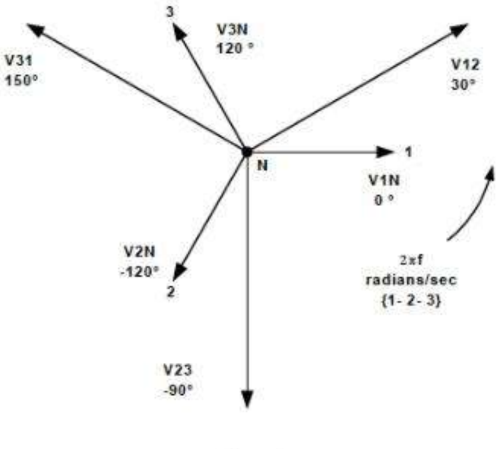


Figure 2
Three-Phase 4-Wire Wye System Voltage Phasors
Sequence {1-2-3}

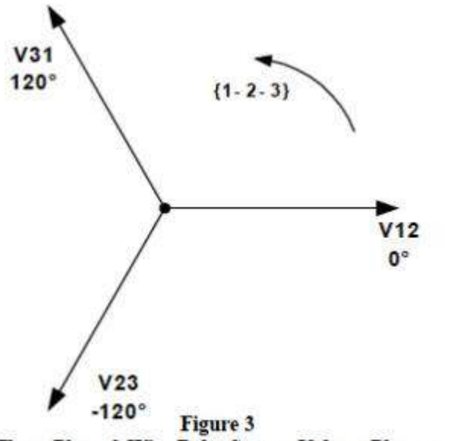


Figure 3
Three-Phase 3-Wire Delta System Voltage Phasors
Sequence {1-2-3}

Measurements of three phase power supply

1. Three watt meters method
2. Two watt meters method
3. Single wattmeter method.

The most common method is the three wattmeters method and it is used in measuring power in 3 phase, 4 wire system. The figure below describes connection for a star connected loads used in measuring power.

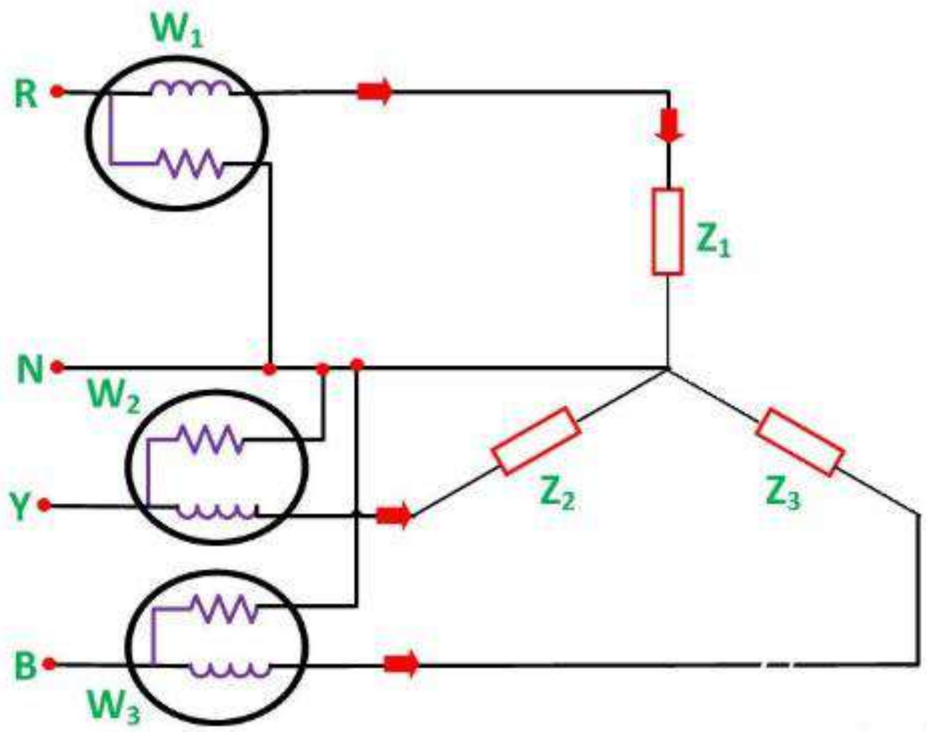


Figure 38: connection for a star connected loads used in measuring power

Source; circuit globe

$$\text{Total power } P = W_1 + W_2 + W_3$$

Where,

$W_1 = V_1 I_1$

$W_2 = V_2 I_2$

$W_3 = V_3 I_3$

Experiment 3: Measure power factor

Tabulation:

Table 6: measure power factor

Sl. No.	Condition	I_R	I_Y	I_B	V_R	V_Y	V_B	M.F.	W_1	W_2
1	Balanced Load									
2	Unbalanced Load									

To measure:

Three phase power and power factor in a balanced three-phase circuit by using two single-phase wattmeter.

Calculate the three phase power for unbalanced load condition.

Apparatus:

2 AC Wattmeters (0- 600 V, 750 W)

2 AC Voltmeters - 1 nos. (0-600 V)

3 AC Ammeters (0-5 A)

Load Box

Procedure:

Connect the apparatus as shown on the circuit diagram

Switch on AC power supply.

Note down the ammeter, Voltmeter and ammeter readings for balanced load conditions

Repeat procedure (3) but with unbalanced load condition

Switch off the AC power supply

Calculation:

Calculate P_M, Pc and % Error.

See Appendix 3 for the circuit diagram

Precautions:

Ensure the connections are tight and clean

Ensure the ammeter readings does not exceed the ammeter's current ratings

Reverse the connection of the measuring device in case of a negative deflection

Figure 39: circuit diagram

Source: circuit globe

4.3.5.3 Self-Assessment

Questions:

1. State reactive power
2. The delta connection requires four wires in which there are three phase conductors and one neutral conductor TRUE OR FALSE?
3. The loads in the three-phase system may also connect in the star or delta. TRUE OR FALSE?
4. Perform experiment on three phase power supply
5. Demonstrate three phase voltage system properties
6. Is it possible to measure reactive power in a three phase circuit using this method?
7. What would be the readings of two wattmeters in this experiment, if the load is purely resistive?
8. What would be the readings of two wattmeters in this experiment, if the load is purely inductive?
9. If one of the wattmeter reads zero, what is the power factor of the load?

4.3.5.4 Tools, Equipment, Supplies and Materials for the specific learning outcome

- Scientific Calculators
- Relevant reference materials
- Stationeries
- Electrical workshop
- Relevant practical materials
- Dice
- Computers with internet connection

4.3.5.5 References

1. V. Vodovozov, Electric Drive Systems and Operation, London: Ventus Publishers, 2012.
2. Circuitglobe.com

4.3.6 Learning Outcome No. 5. Use of Power Factor in Electrical Installation
4.3.6.1 Learning Activities

Learning Outcome No. 5. Use of Power Factor in Electrical Installation	
Learning Activities	Special Instructions
Demonstrate understanding of power factor Demonstrate understanding of power triangle Demonstrate understanding of power factor correction methods	

4.3.6.2. Information Sheet No. 4/L05
Power factor, active & reactive power basic concept
Power factor- In ac circuit there is often a phase difference between the current and voltage. Power factor or PF is the cosine of this angle phase difference, cos φ.
Power factor types-

- Leading power factor- Current leads voltage occurs in a capacitive load circuit,
- Lagging power factor- Current lags behind voltage. Occurs in inductive load circuit

Value of Power factor– As power factor is a cosine function its possible value ranges from -1 to +1
Active and reactive component of power factor
VI cosφ is called active or watt full component, whereas VI sinφ called reactive or watt less component.

AC Circuit Power Triangle

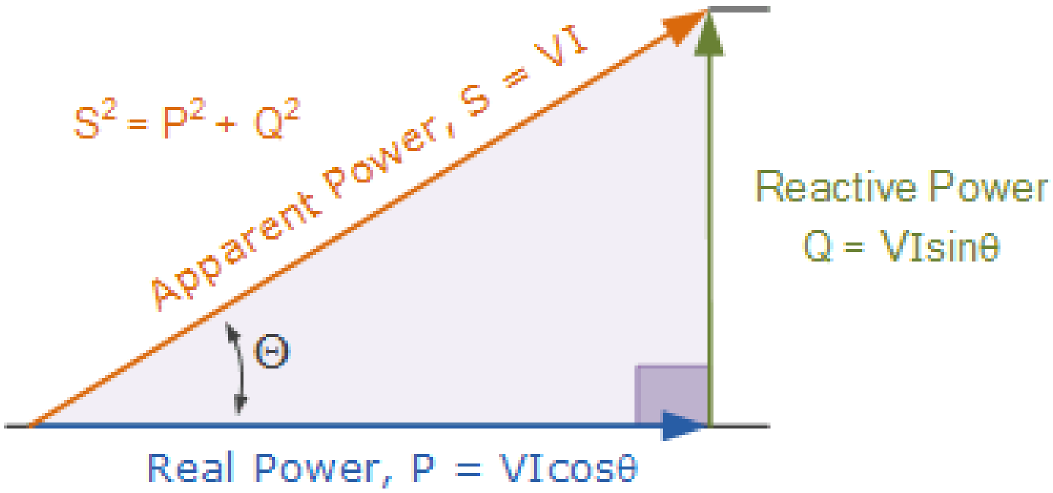


Figure 40: AC Circuit power triangle

Source: circuit globe

Where:

- P is the Real power that performs work measured in watts, W
- Q is the Reactive power measured in volt-amperes reactive, VAr
- S is the Apparent power measured in volt-amperes, VA
- θ is the phase angle in degrees. The larger the phase angle, the greater the reactive power
- Cos(θ) = P ÷ S = W/VA = power factor, p.f.
- Sin(θ) = Q ÷ S = VAr/VA
- Tan(θ) = Q ÷ P = VAr/W

The power factor is calculated as the ratio of the real power to the apparent power because this ratio equals cos (θ).

EXPERIMENT 4: To measure power factor in a single phase AC circuit by using three ammeters.

Table 7 to measure power factor in a single phase AC

Apparatus: 1 AC Wattmeter. (0- 250 V, 0- amp) 1 AC Ammeter (0-10 A) 2 AC Ammeter (0-5 A) 1 AC Voltmeter (0-300 V) Variance: 1-Phase, 230 V, 10 A, 50 Hz Resistor: 450 ohm R-L Load Box Connecting wires Procedure Connect the circuit as shown in the circuit diagram Ensure the variance is at zero position before starting the experiment Switch on AC supply. Set the supply voltage by varying the position of the Variance Vary the RL load to obtain different readings of ammeters, and wattmeter. Repeat step 5 and note down the readings. Reset the Variance to zero position before switching off the power supply Calculation: Calculate the value of P, cos Ø.	Precautions: All connection should be neat and tight The current should not exceed ammeter rating

See Appendix 4 for circuit diagram and tabulation table	

Appendix 4

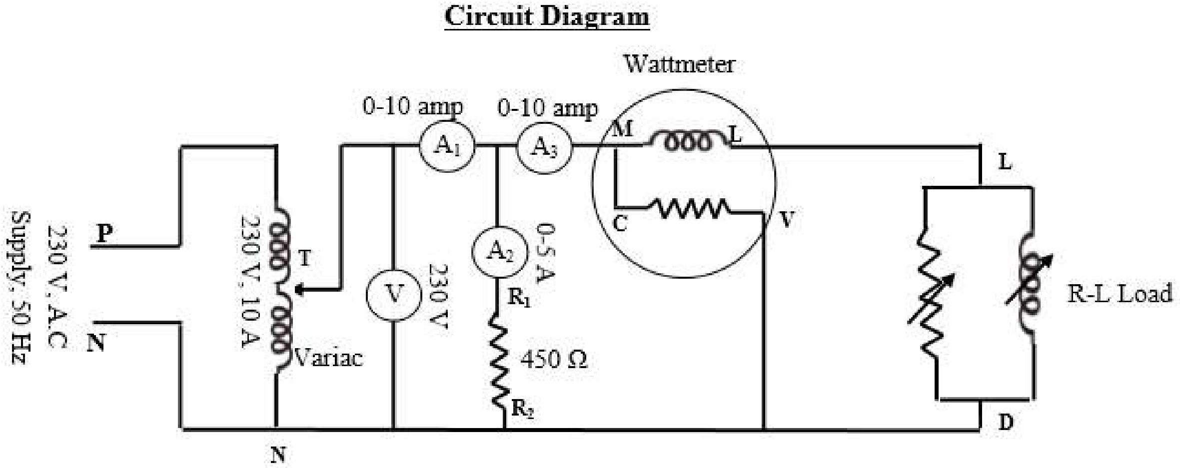


Figure 41: circuit diagram

Phasor Diagram

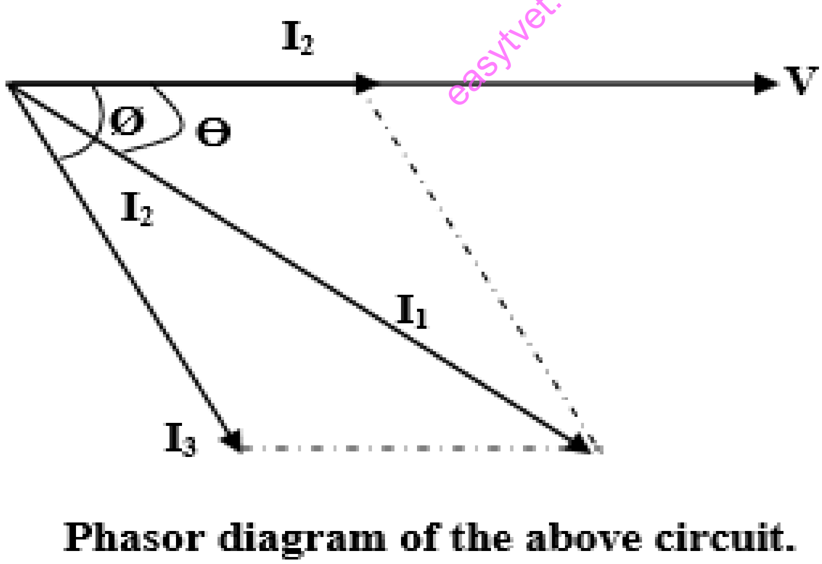


Figure 42: phasor diagram

Source; circuit globe

4.3.5.3 Self-Assessment

1. In an a.c. circuit which power is more apparent or real and why?
2. What is the basic difference between an inductive load and purely inductive load?
3. The practical loads are purely inductive or inductive?
4. Perform calculations on power factor correction methods?
5. Explain power factor
6. Differentiate active & reactive power
7. Demonstrate understanding of power triangle
8. Describe power factor correction methods
9. Lagging power factor- Current leads voltage occurs in a capacitive load circuit. TRUE OR FALSE?
10. Leading power factor- Current lags behind voltage. Occurs in inductive load circuit. TRUE OR FALSE?

4.3.5.4. Tools, Equipment, Supplies and Materials for the specific learning outcome

- Scientific Calculators
- Relevant reference materials
- Stationeries
- Electrical workshop
- Relevant practical materials
- Dice
- Computers with internet connection

4.3.5.5 References

1. S. P. Chandra, Principles of electric machines and power electronics. John Wiley & Sons, 2007.

4.3.7. Learning Outcome No. 6. Use of Earthing in Electrical Installation
4.3.7.1 Learning Activities

Learning Outcome No. 6. Use of Earthing In Electrical Installation	
Learning Activities	Special Instructions
• Connect earthing cable	

4.3.6.2 Information Sheet No5/L05

Introduction
Earthing is the process of connecting electric currents to the earth, purposely for safety. Electrical wiring is directed to the earth so that in case of exposure of the live wire or any other insulation mishaps, there is no immediate danger to the surrounding and the circuit. Live electric currents can cause extensive damages as it spreads faster and has devastating effects. The idea behind this action is neutralizing the electric currents in case they stray due to human neglect or equipment malfunctioning.
Earthing is done through embedding a metallic rod or plate into the ground. The process by which the metallic rode – earth electrode – is placed into the ground is technically called Earth Resistance, and is measured in Ohms.

Importance of Earth in Electrical Networking

1. The exercise helps in saving human beings from electrocution in case there is a fuse blow. Earthing neutralizes the electric currents by creating alternative current paths.
2. Helps to neutralize the effects of lightning or short circuits
3. If there is any faulty equipment or machinery connected to the network, earthing prevents it from being destroyed by the live currents.
4. Prevents friction from occurring in case of static electricity
5. Earthing stabilizes electric currents in electronics. Different equipment needs a certain voltage to function optimally, hence earthing regulates the amount of current passing through to avoid damage.

Functions of Electric Earthing Systems
1. To prevent the destruction of lives and properties in case of exposure to a live current
2. Keep the voltage of any electrical gadget in check
3. Create a harmless alternative path in case there is a faulty electric current

Types of Earthing

Earthing is divided into two:

1. System/Neutral, and
2. Equipment

System or neutral earthing is achieved by stabilizing the voltage to match that produced by the ground. It is designed to shield electrical equipment from being short-circuited. It is done by connecting part of the current of the plant to the ground. The ground provides a low-voltage path that prevents any live current from causing harm. As for the neutral earthing, the current is connected to the ground which acts as the central electric panel. As the neutral conductor, the ground should have an identical voltage to stabilise the current flow.

Equipment earthing maintains the current flow against harming people or things that are non-conductors. Its main target is people who are closer to live currents. This is done by connecting frames of these equipment to the earth.

The two types of earthing are enjoined so that the harmless (fault) current passing through its systems reduces the probability of someone or something being destroyed. It also maintains the potential gradient of current at the processing substation. If the systems have to work differently, the cons will be a higher current on short-circuiting, a reduced intensity of current flows and expenses in terms of materials used to relay earthing into the ground. If the two systems are integrated, the cost of implementation and efficiency gained will be worthwhile.

Experiment 5: *Measurement of Earth Resistance by use of Earth Tester by Three Point method or Fall Potential Test*

The fall potential is the most popular method of measuring the earth resistance of a grounding system.

Take measurement in different directions as shown in below fig.

Procedure

1. Connect C1 and P1 terminals on the test set to the earth electrode.
2. Drive a probe into the earth 100 to 200 feet from the center of the electrode and connect to terminal C2.This probe should be driven to a depth of 6 – 12 inches.
3. Drive another probe into the earth midway between the electrodes and probe C2 and connect to terminal P2. This probe should be driven to a depth 6 – 12 inches.
4. Record the resistance measurement.
5. Move the potential probe 10 feet farther away from the electrode and make a second measurement.
6. Move the potential probe 10 feet closer to the electrode and make a third measurement.

7. If the three measurements agree with each other within a few percent of their average, then the average of the three measurements may be used as the electrode resistance.
8. If the three measurements disagree by more than a few percent from their average, then additional measurement procedures are required.

4.3.6.3. Self-Assessment

1. **State earthing**
2. **Describe the importance of earthing**
3. **Differentiate various types of earthing**
4. **What is a Building Protection and Grounding System?**
5. **What existing objects are included in a Building Protection and Grounding System Design?**
6. **How does a Building Protection and Grounding System work?**
7. Electrical wiring is directed to the earth so that in case of exposure of the live wire or any other insulation mishaps, there is no immediate danger to the surrounding and the circuit. TRUE OR FALSE?
8. If there is any faulty equipment or machinery connected to the network, earthing prevents it from being destroyed by the live currents. TRUE OR FALSE?
9. The process by which the metallic rode – earth electrode – is placed into the ground is technically called Earth Resistance, and is measured in Ohms. TRUE OR FALSE?

4.3.6.4. Tools, Equipment, Supplies and Materials for the specific learning outcome

- Scientific Calculators
- Relevant reference materials
- Stationeries
- Electrical workshop
- Relevant practical materials
- Dice
- Computers with internet connection

4.3.6.5 References

1. T. Linsley, Basic Electrical Installation Works, Routledge, 2018.

4.3.8 Learning Outcome No. 7. Apply Lightning Protection Measures

4.3.8.1 Learning Activities

Learning Outcome No. 7. Apply Lightening Protection Measures	
Learning Activities	Special Instructions
ACTIVITY • Set up earthing equipment and materials • Carry out the earthing procedure PROCEDURE • Provide down conductor tapes in locations as indicated on the drawings. • Down conductors shall be either: Installed surface on the structure concealed behind the cladding OR Reinforcing bars within the concrete structure. 1. Down conductor tapes shall terminate on to dedicated reinforcing bars which shall be utilized as the final connection to earth via the pile foundations. The Contractor shall include for supervising and testing the installation of the reinforcing bars including all joints prior to the concrete being poured. 2. Down conductors to be connected at roof level to a common loop tape. Provide horizontally mounted conductor tapes at levels indicated on the drawings. These shall provide a common connection for all down conductors, structure, cladding, steelwork and exposed metalwork	

4.3.7.2. Information Sheet No 4/LO7

Lightning physics, effects, and risk assessment

Definition of Key Words

Lightning Flash/Discharge – it is the discharge of electrical currents in the atmosphere occasioned by two charged clouds. The cumulonimbus clouds often form these oppositely charged regions, and the flash comes about by when it touches the earth surface.

Lightning Flash Density – this is the frequency by which a specific type of lightning flashes in an area over a given period of time. It is measured yearly, documenting the number of times the flash discharge in a particular area.

Lightning Protection System – these are components designed from conductors that are installed to reduce the damaging effect of lightning.

Lightning Strike – this is the action or effect caused as a result of the lightning flash on or at a given point.
Lightning Strike attachment Point – this is the contact point where the lightning strike touches. It may be on the ground on a structure.
Lightning stroke – this is a single current impulse at the contact point from the lightning strike.
Thunderday – this is a presumptive date or day in a calendar year when thunder is recorded in a given location.
Zone of Protection – an area protected from the lightening by the lightning protection system.

Types of lightning strikes

- Direct strike: This type occurs when lightning strikes an individual
- Side flash: It occurs in case lighting strikes a tall object and part of strikes extends to individuals close to it.
- Ground current: Is in form of dissipated strikes that results from objects being transferred to the ground. The dissipated energy can possibly electrocute individuals that are near the point of focus.
- Conduction: Occurs in case an individual is in contact with a metal material that has been struck by lightning.

Components of lightening protection systems;
Copper air terminals are usually made up of either copper or aluminum. The air terminals are connected through cable with minimal two ground rods buried 10 feet below the grade.

- copper cable
- copper clad ground rods
- surge suppressors

Application of lightning systems

- Lightning protection system (LPS)
- Lightning arrester

Maintenance of lightening system

4.3.7.3. Self-Assessment

1. Define lightning
2. Describe the procedure for testing lightning system
3. Describe the various methods used in earthing in domestic installation
4. What are the applications of lightning systems?
5. Differentiate the various components of lightening protection systems
6. Lightning Flash Density is the frequency by which a specific type of lightning flashes in an area over a given period of time. TRUE OR FALSE

7. Zone of Protection is an area protected from the lightening by the lightning protection system. TRUE OR FALSE?

4.3.7.4. Tools, Equipment, Supplies and Materials for the specific learning outcome

- Scientific Calculators
- Relevant reference materials
- Stationeries
- Electrical workshop
- Relevant practical materials
- Dice
- Computers with internet connection

4.3.7.5. References

1. T. Linsley, Basic Electrical Installation Works, Routledge, 2018.

4.3.9. Learning Outcome No. 8. Apply Electromagnetic Field Theory
4.3.9.1 Learning Activities

Learning Outcome No. 7. Apply Electromagnetic Field Theory	
Learning Activities	Special Instructions
• Conduct the hertz experiment	

4.3.8.2 Information Sheet No4/LO8
Electromagnetic Field Theory
An electromagnetic field is a typical field produced when charged particles (electrons) are charged. Any particles charged electrically are surrounded by electric field. The charged particles produce magnetic field. In case of change in velocity of charged particle, and electromagnetic field is produced.

Sources of Electromagnetic Fields
Solar radiation/ natural radiation: Are radiations that originates from the sun

Artificial radiation: Originates from a remote sensing system
Terrestrial radiation: Are radiations emitted by the Earth's surface

Detectors of Electromagnetic radiation
1. X-ray machines,
2. radios
3. cell phones

Application of Electromagnetic waves
1. Communication
2. Heating water
3. Cooking
4. Detecting of fodged bank notes

Electromagnetics Laws
- Faraday's Law

It states that when the magnetic flux linking a circuit changes, an electromotive force is induced in the circuit proportional to the rate of change of the flux linkage.
- Lenz's law

It states that the direction of an induced current is always such as to oppose the change in the circuit or the magnetic field that produces it.
- Fleming's Laws

Fleming's Left Hand Rule

It states "Hold out your left hand with the forefinger, second finger and thumb at the right angle to one another. If the forefinger represents the direction of the field and the second finger represents that of the current, then thumb gives the direction of the force."

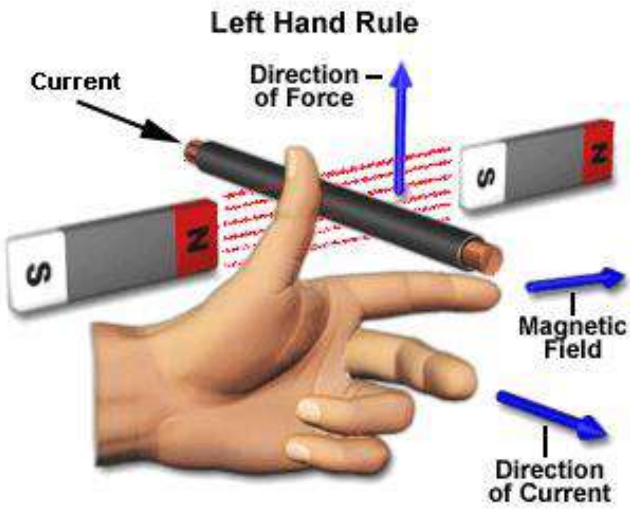


Figure 43: Fleming's left hand rule

Source: circuit globe

Fleming's Right Hand Rule

This rule states "Hold out the right hand with the first finger, second finger and thumb at the right angle to each other. If forefinger represents the direction of the line of force, the thumb points in the direction of motion or applied force, then second finger points in the direction of the induced current".

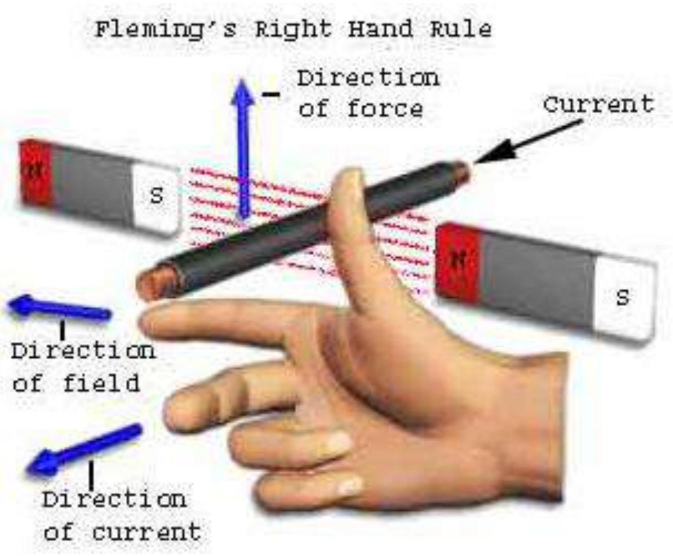


Figure 44: Fleming's right hand rule

Source: circuit globe

Properties and Effects of Electromagnetic waves

1. Energy and Momentum

Electromagnetic waves have energy and momentum that are both associated with their wavelength and frequency.

2. Energy

The energy (E) of a photon can be related to its frequency (f) by Planck's constant (h):

$$E=hf=hc/\lambda$$

The ratio of speed of light (c) to wavelength (λ) can be substituted in place off to give the same equation to energy in different terms. Note that energy cannot take any value: it can only exist in increments of frequency times Planck's constant (or Planck's constant time's c divided by wavelength). Energy of a wave is therefore "quantized."

3. Momentum

Momentum is classically defined as the product of mass and velocity and thus would intuitively seem irrelevant to a discussion of electromagnetic radiation, which is both massless and composed of waves.

However, Einstein proved that light can act as particles in some circumstances, and that a wave-particle duality exists. And, given that he related energy and mass (E=mc2), it becomes more conceivable that a wave (which has an energy value) not only has an equation to mass but a momentum as well.

And indeed, Einstein proved that the momentum (p) of a photon is the ratio of its energy to the speed of light.

Wave Characteristics and Shielding

An electromagnetic wave shield reduces the energy of electromagnetic waves by means of the reflection, absorption, and multiple reflection of the waves. By attenuating the electromagnetic waves, the shield avoids disruptions to precision equipment.

Skin Effect

It states that the tendency of a high-frequency alternating current to flow through only the outer layer of a conductor

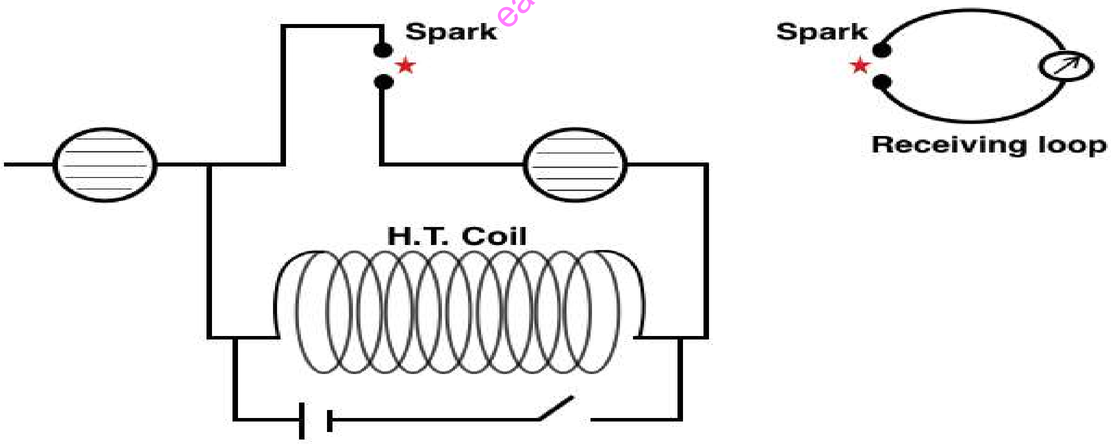
The hertz experiment

Description:

Hertz experiment was the first to prove the existence of electromagnetic waves. He also concluded that electromagnetic waves do not require a medium to travel.

Apparatus

1. High tension coil.
2. Polished brass knobs.
3. Receiving loop.



Working

Hertz used the high-tension coil to generate large amount of potential difference across the circuit. When the high potential difference was gained and propagated to the brass knobs, there appeared a spark between the knobs. Spark indicates that there was electron jump between the knobs.

As soon as the spark was observed between the knobs in the circuit, a spark was also seen between the knobs of the receiving loop.

4.3.8.3. Self-Assessment

a) Explain shielding
b) Explain sources of terrestrial radiation
c) Describe detectors of electromagnetic radiation
d) Differentiate various electromagnetic laws
e) Describes Flemings Left and Right-hand Rules
f) What is the importance of Flemings Rules?
g) Define Skin effect.
h) The charged particles produce magnetic field. TRUE OR FALSE?
i) Electromagnetic waves have energy and momentum that are both associated with their wavelength and frequency. TRUE OR FALSE?

4.3.8.4. Tools, Equipment, Supplies and Materials for the specific learning outcome

- Scientific Calculators
- Relevant reference materials
- Stationeries
- Electrical workshop
- Relevant practical materials
- Dice
- Computers with internet connection

4.3.8.5. References

1. J. C. T. Adolf, Engineering Electromagnetic Fields and Waves, New York: John Wiley and Sons, Inc., 1975.

4.3.10 Learning Outcome No. 9. Apply Electrodynamics
4.3.10.1 Learning Activities

Learning Outcome No. 9. Apply Electrodynamics	
Learning Activities	Special Instructions
• Determine factors that affect electrodynamics	

4.3.9.2. Information Sheet No. 4/ LO9

Meaning of Electrostatics Is the study of stationary electric charges.
A rod of plastic rubbed with fur or a rod of glass rubbed with silk will attract small pieces of paper and is said to be electrically charged.

Meaning of terms in magnetostatics

- Magnetic field or Magnetic Induction (B)

The field where the magnet attracts or repels magnetic materials
F=q x v x B

Where;
F= Force,
V = Speed of Particles,
B = magnitude of the field.

- Magnetic Field Strength (H)

The amount of magnetizing force (how much force it has to magnetize, magnetic materials
The SI unit of Magnetic Field Strength is Ampere/meter (A/m)
H=NI/1c
Where 1c = magnetic path in meter.

- Magnetic Flux (Φ)

Magnetic Flux which is denoted by Φ or Φm or ΦB. Or it is the amount of magnetic field or magnetic lines of force passing through a surface like conducting area, space, air, etc. The SI Unit of magnetic flux is Wb (Weber).
Φ=BAc
Where
Ac=area in m2

- Magnetization (M)

It is the density of permanent magnet or electromagnet dipole moments in magnetic materials. The SI Unit of Magnetization is Ampere/meter (A/m) and it is also a vector quantity. The SI formula for Magnetization is

M=m/V

Where,

m = Total magnetic moment

And V= volume in m3

Introduction

The earliest recorded study on the concept of electromagnetic induction gives credit to Henry (American) and Faraday (English). The two did independent research on this subject in the 19^{th} century. Faraday, received the full credit because his publication earlier than Henry.

What is electromagnetism Induction?

It is the phenomenon whereby a fluctuating magnetic flux through a coil of wire generates an *emf* (electromotive force) in the wire. It is the basic principle behind the generation of electricity to date.

Emf generated depends on:

i. The strength of the magnetic flux, $\Delta\Phi_B$

ii. The number of loops in the coil of wire, N

iii. The rate at which the flux fluctuates, Δt

$$\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$$

<u>Apparatus:</u> bar magnet; coil of magnet wire (20 or 22 awg); three rectangular ceramic magnets; a spring system; slot weight system; two large binder clips; Pasco Science Workshop software and interface Voltage leads Motion sensor <u>Procedure:</u> <u>Part I - Lenz's Law and the Induced Current</u> Boot up the computer (if necessary) and logon. Open Science Workshop. Take a good look at your experimental setup. You will need to return it to this arrangement later in the experiment (step 8). But for now, unhook your spring from the lab stand and lay the entire assembly (spring, binder clips, magnets and slot weight hanger) on your lab table out of the way. Goto file/open and then choose to look on the t: drive. Open the setup file frdy1-1 which you will find in the 151 Lab folder on the t:drive. Now grab the bar magnet so that the red end (north pole) points downward, as though it were an arrow head on an arrow. Start the data collection by double clicking REC. Now center the magnet above the loops and thrust the magnet downward toward the loops from above. (The north end of the magnet should be approaching the plane of the loops first.) Watch the computer monitor as you do this. You should see a voltage peak displayed on your screen. Now pull the magnet upward and watch the display again. Repeat this down and up motion of the magnet several times, being careful to note the polarity of the voltage peak when you move the magnet down	

and up. Stop the data collection by double clicking on STOP. Now record what you have observed in the provided data chart at the end of this handout Redo step 4 above, focusing on the silver end (south pole) of the magnet. Record your Observations. Analyze your table and conclude on the direction the induced current will flow in the loops when compared to the direction that the magnetic flux was changing. Begin the data collection by and move the magnet up and down as in steps 4 and 5. Have an alternating exercise whereby you move the magnets faster then slowly as you make observations. Conclude the data collection. Skeam through the data. Do you note anything about the magnitude of the induced voltage in comparison with the speed with which you moved the magnet? Tabulate your result and then make a bold conclusion. Do you agree with the findings of Henry and Faraday?	

Experiment 8: *To investigate electromagnetic induction and determine the factors that affect it*

Mass (g)	Period (s)	Frequency (Hz)	Peak Voltage (V)
50			
150			
250			
350			
450			

ANALYSIS:

1. Close Science Workshop and open up Vernier's Graphical Analysis software. If you are doing this somewhere other than Penn State's physics lab, you may use a spreadsheet software or some other graphing software.
2. Enter your data from steps 8 - 22 into the graphing software. Put the frequency value in the X data column and the peak voltage in the Y data column.
3. Do a linear curve fit and print out your graph.
4. Assuming the number of loops in your coil of wire was about 80, and using your graph you just printed out as needed, calculate the magnetic flux change that was occurring as you oscillated the magnets back and forth in steps eight through twenty two. Show your calculation and explain your reasoning step by step.

4.3.9.3. Self-Assessment

a) Explain Electrostatics
b) Perform calculations in magnetostatics
c) Explain electromagnetic Induction
d) What are the various applications of Electrostatics?
e) Perform calculations involving electromagnetic Induction
f) Magnetic field or Magnetic Induction (B) is the field where the magnet attracts or repels magnetic materials. TRUE OR FALSE?
g) The SI Unit of Magnetization is Ampere/meter (A/m) and it is also a vector quantity. TRUE OR FALSE?

4.3.9.4. Tools, Equipment, Supplies and Materials for the specific learning outcome

- Scientific Calculators
- Relevant reference materials
- Stationeries
- Electrical workshop
- Relevant practical materials
- Dice
- Computers with internet connection

4.3.9.5. References

1. J. C. T. Adolf, Engineering Electromagnetic Fields and Waves, New York: John Wiley and Sons, Inc., 1975.

4.3.11 Learning Outcome No. 10. Apply energy and momentum in electromagnetic field

4.3.10.1. Learning Activities

Learning Outcome No. 10. Apply energy and momentum in electromagnetic field	
Learning Activities	Special Instructions
Apply energy and momentum in electromagnetic field	

4.3.10.2. Information Sheet No. 4/ LO10

Energy conservation theorem:

- Poyntings' Theorem

The Poynting Theorem is in the nature of a statement of the conservation of energy for a configuration consisting of electric and magnetic fields acting on charges. Consider a volume V with a surface S. Then "the time rate of change of electromagnetic energy within V plus the net energy flowing out of V through S per unit time is equal to the negative of the total work done on the charges within V."

Momentum Energy Flow

Describing Fluid Flow

There are various mathematical models that describe the movement of fluids and various engineering correlations that can be used for special cases. However, the most complete and accurate description comes from *partial differential equations* (PDEs). For instance, a flow field is characterized by balance in mass, momentum, and total energy described by the continuity equation, the Navier-Stokes equations,

The solution to the mathematical model equations gives the velocity field, pressure, *p*; and temperature, *T*; of the fluid in the modeled domain. In principle, this set of equations is able to describe flows from the creeping flow in a microfluidic device to the turbulent flow in a heat exchanger and even the supersonic flow around a jet fighter. However, solving Equation for a case such as the jet plane shown below is not feasible and while it is possible to solve the whole of Equation for a microfluidic device, it is a lot of work down the drain. Much of computational fluid dynamics (CFD) is therefore devoted to selecting suitable approximations to Equation so that accurate results are obtained with a reasonable computational cost.

Electromagnetic Energy flow

Electromagnetic radiation, in classical physics, the flow of energy at the universal speed of light through free space or through a material medium in the form of the electric and magnetic fields that make up electromagnetic waves such as radio waves, visible light, and gamma rays. In such a wave, time-varying electric and magnetic fields are mutually linked with each other at right angles and perpendicular to the direction of motion.

An electromagnetic wave is characterized by its intensity and the frequency ν of the time variation of the electric and magnetic fields. In terms of the modern quantum theory, electromagnetic radiation is the flow of photons (also called light quanta) through space. Photons are packets of energy hν that always move with the universal speed of light.

Electron deflection tube: using an electric field Demonstration The deflection tube allows you to show the parabolic path of an electron beam passing through a uniform electric field. The graduated scale allows you to take measurements if you wish. This is the main advantage of the deflection tube over the fine beam tube. Most of the qualitative ideas of this experiment can be shown using the experiment Deflecting an electron beam. Apparatus and materials Power supply, EHT, 1 (or 2 if a second one is available) Power supply, 6.3 V, AC, for the heater filament (this is often included on the HT supply) Magnadur magnets, 2 (optional) Electron deflection tube and stand Health & Safety and Technical notes The tubes are fragile (and expensive!) and should be handled carefully. They will implode if broken. Use the stands specifically designed for holding them. Read our standard health & safety guidance Set the tube up according to the manufacturer's instructions. Ensure that you can identify the following: The 6.3 V supply to the cathode heater, if you connect the wrong voltage to the heater you can easily damage the tube beyond repair. The EHT supply for the anode. Set this to zero. The cathode is often one of the heater terminals. The terminals for the deflecting plates. Procedure a Set up the deflection tube in its special stand. b Connect the 6.3 V supply to the filament. Make sure you connect the 6.3 V supply to the filament. (See technical note 2 above.)	

c Start with the deflection plates connected together and also connected to the anode on the tube. d Connect the negative terminal of the EHT supply to the filament and the positive terminal to the anode. e Set the EHT to zero volts, and switch on the 6.3 V supply to the heater filament. f With no output from the EHT supply, the light from the filament produces a line on the inclined fluorescent screen where the light strikes it. g Increase the potential difference (p.d.) to about 3 kV: a fluorescent line appears. This is the path of the electron beam. Point out that the electron beam travels in a straight horizontal line. h Then, while one plate is left connected to the anode, connect the other plate to the negative terminal of the EHT supply. This produces a vertical electric field between the plates, deflecting the beam into a parabolic path. i If you have not shown an electron beam being deflected by magnets, you could do it here. (See Deflecting an electron beam.)	

1 This experiment is best demonstrated to the students in groups of four to five in a darkened room if full value is to be obtained.
2 Always reduce the anode to zero volts when not actually observing the beam, because the tube has a finite life time
3 The beam is deflected, which shows there is a force on it. The force is consistent with the beam being made of negatively charged particles.
4 The beam is deflected by a finite amount. So it must be made of something with mass. This seems obvious now, but, it is an important piece of deduction. We can deduce that the beam is made of particles with some mass and a negative charge.
5 The beam stays intact as it is deflected. At first glance, this suggests that all the particles are the same. However, the mathematics shows that the shape of the curve is independent of the charge and mass of the particles. This is because, if the charge

increases, the acceleration will increase in both the electron gun and between the deflection plates.

Likewise, any changes in mass will produce the same proportional change in acceleration in both the electron gun and the deflecting field (see Guidance note Deflection in electric fields).

6 The beam travels at a uniform horizontal velocity and so the horizontal displacement varies linearly with time. It also experiences a constant vertical force, so it has a constant vertical acceleration, *a*. The vertical displacement, s_v, varies as the square of time, *t*. ($s_v=0.5at^2$). Hence the path of the beam is a parabola (see Guidance note Deflection in electric fields).

7 The fluorescent screen has a gratitude on it, and the shape of the parabolic path for different accelerating voltages can be recorded.
8 This is analogous to a ballistic experiment in a uniform gravitational field. Whenever you throw something on the surface of the Earth, it traces out a parabola because the vertical *acceleration* is constant and the horizontal *velocity* is constant.

4.3.10.3 Self-Assessment

a) Explain Energy conservation theorem
b) Describe Poyntings' Theorem
c) Perform calculations on fluid flow calculations
d) Describe electromagnetic radiation
e) The most complete and accurate description comes from *partial differential equations* (PDEs). TRUE OR FALSE?
f) An electromagnetic wave is characterized by its intensity and the frequency ν of the time variation of the electric and magnetic fields. TRUE OR FALSE?
g) Photons are packets of energy hν that always move with the universal speed of light. TRUE OR FALSE?

4.3.10.4 Tools, Equipment, Supplies and Materials for the specific learning outcome

- Scientific Calculators
- Relevant reference materials
- Stationeries
- Electrical workshop
- Relevant practical materials
- Dice
- Computers with internet connection

4.3.10.5 References

1. J. C. T. Adolf, Engineering Electromagnetic Fields and Waves, New York: John Wiley and Sons, Inc., 1975.

4.3.12. Learning Outcome No. 11. Apply Transients in Electrical Circuit Analysis

4.3.12.1. Learning Activities

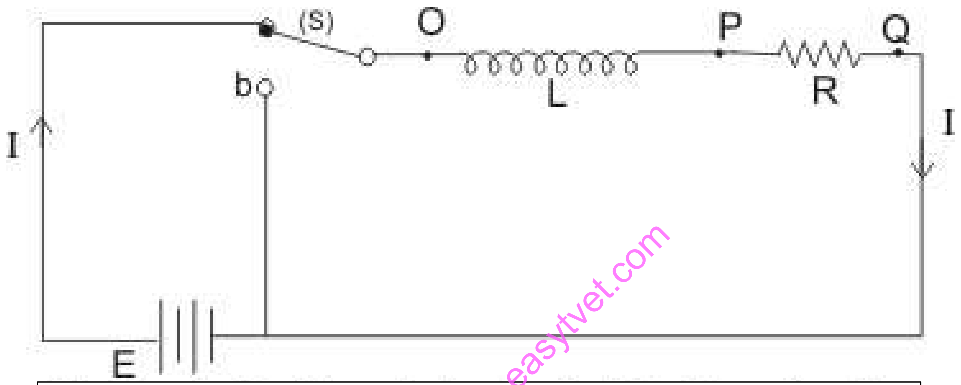
Learning Outcome #No. 11. Apply Transients In Electrical Circuit Analysis	
Learning Activities	Special Instructions
• Apply Transients in Electrical Circuit Analysis	

4.3.12.2. Information Sheet No. 4/ LO11

Meaning of Growth and decay in R-L & R-C circuits

(A) Growth of current

- Suppose in the beginning we close the switch in the up position as shown in below in the figure



Switch is now closed and battery E, inductance L and resistance R are now connected in series

- Because of self-induced emf current will not immediately reach its steady value but grows at a rate depending on inductance and resistance of the c circuit
- Let at any instant I be the c current in the circuit increasing from 0 to a maximum value at a rate of increase dI/dt
- Now the potential difference across the inductor is

  $V_{op}=LdI/dt$

  and across resistor is

  $V_{pq}=IR$

  Since

  $V=V_{op}+V_{pq}$

  so we have,

  $$V = L\frac{dI}{dt} + IR \qquad \text{----(6)}$$

  Thus rate of increase of current would be,

  $$\frac{dI}{dt} = \frac{V - IR}{L} \qquad \text{---(7)}$$

- In the beginning at t=0 when circuit is first closed current begins to grow at a rate,

  $$\left(\frac{dI}{dt}\right)_{t=0} = \frac{V}{L}$$

  from the above relation we conclude that greater would be the inductance of the inductor, more slowly the current starts to increase.
- When the current reaches its steady state value I ,the rate of increase of current becomes zero then from equation (7) we have,
  0=(V-IR)/L
  or,
  I=V/R
  From this we conclude that final steady state current in the circuit does not depend on self-inductance rather it is same as it would be if only resistance is connected to the source
- Now we will obtain the relation of current as a function of time Again consider equation (6) and rearrange it so that

  $$\frac{dI}{\left(\frac{V}{R}\right) - I} = \frac{R}{L}dt$$

  let V/R= I_{max} ,the maximum current in the circuit .so we have

  $$\frac{dI}{I_{max} - I} = \frac{R}{L}dt \qquad \text{----(8)}$$

- Integrating equation (8) on both sides we have

  $$-\ln(I_{max} - I) = \frac{R}{L}t + C \qquad \text{---(9)}$$

  where C is a constant and is evaluated by the value for current at t=0 which is i=0
  so,
  C=-ln(V/R)=-ln I_{max}
  putting this value of C in equation (9) we get,

  $$\ln\left(\frac{I_{max} - I}{I_{max}}\right) = -\frac{R}{L}t$$

  Or,

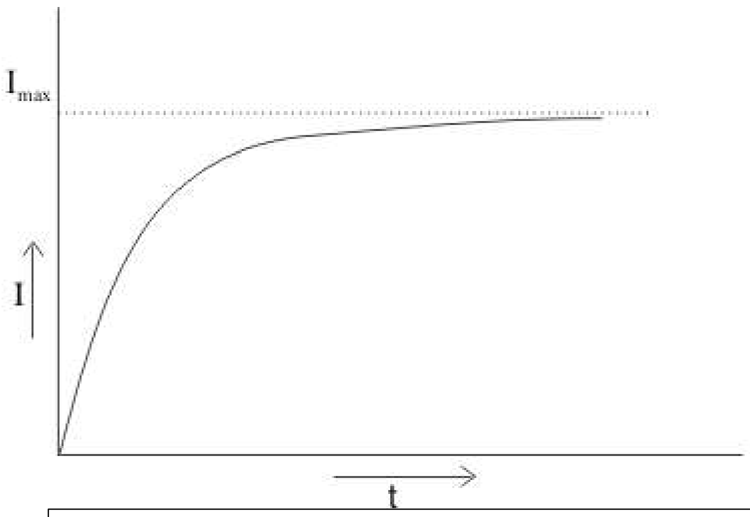
  $$\frac{I_{max} - I}{I_{max}} = e^{-\frac{R}{L}t}$$

  Or,

  $$I = I_{max}(1 - e^{-\frac{R}{L}t}) \qquad \text{---(10)}$$

This equation shows the exponential increase of current in the circuit with the passage of time

Figure below shows the plot of current versus time



- If we put $t=\tau_L=L/R$ is equation 10 then,

  $$I = I_{max}(1-\frac{1}{e}) = .63I_{max}$$

  Hence, the time in which the current in the circuit increases from zero to 63% of the maximum value of I_{max} is called the constant or the decay constant of the circuit.
- For LR circuit, decay constant is,

  $\tau_L=L/R$ ---(11)
- Again from equation (8),

  $$\frac{dI}{dt} = \frac{R}{L}(I_{max} - I_0) = \frac{I_{max} - I_0}{\tau_L}$$

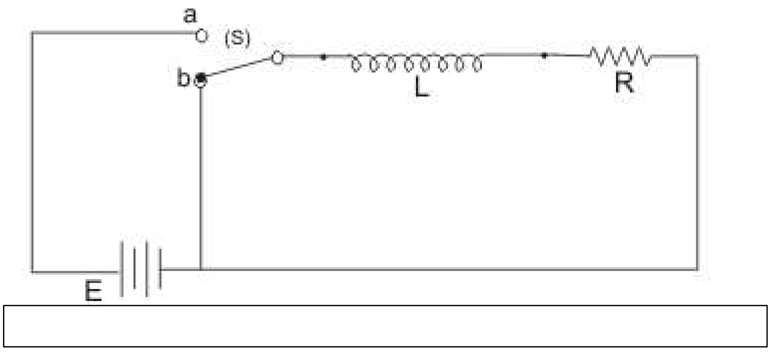
  Or,

  $$\frac{dI}{dt} \alpha \frac{1}{\tau_L}$$

  This suggests that rate of change current per sec depends on time constant.
- Higher is the value of decay constant, lower will be the rate of change of current and vice versa.

(B) Decay of current

- When the switch S is thrown down to b as shown below in the figure ,the L-R circuit is again closed and battery is cut off



- In this condition the current in the circuit begins to decay
- Again from equation (8) since V=0 this time, so the equation for decay is

$$L\frac{dI}{dt} + RI = 0$$

Or,

$$\frac{dI}{I} = \frac{-R}{L}dt$$

Integrating on both sides

$$\int\frac{dI}{I} = \frac{-R}{L}\int dt$$

Or,

$$\ln I = \frac{-R}{L}t + C_1 \quad \text{----(12)}$$

In this case initially at time t=0 current $I=I_{max}$ so
$C_1=\ln I_0$
Putting this value of C_1 in equation (12)

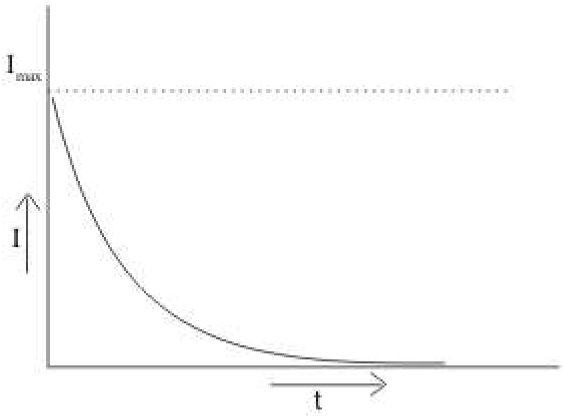
$$\ln I = \frac{-R}{L}t + \ln I_{max}$$

Or,

$$I = I_{max}e^{-\frac{R}{L}t} \quad \text{---(13)}$$

Hence current decreases exponentially with time in the circuit in accordance with the above equation after the battery are cutoff from the circuit.

Figure below shows the graph between current and time



- If in equation (13)
  $t=\tau_L=L/R$
  then
  $I=I_{max}e^{-1}=.37I_{max}$
  hence the time in which the current decrease from the maximum value to 37% of the maximum value I_{max} is called the time constant of the circuit
- From equation (13) it is clear that when R is large ,current in the L-R circuit will decrease rapidly and there is a chance of production of spark
- To avoid this situation L is kept large enough to make L/R large so that current can decrease slowly
- For large time constant the decay is slow and for small time constant the decay is fast

Application of Growth and decay in R-L & R-C Circuits

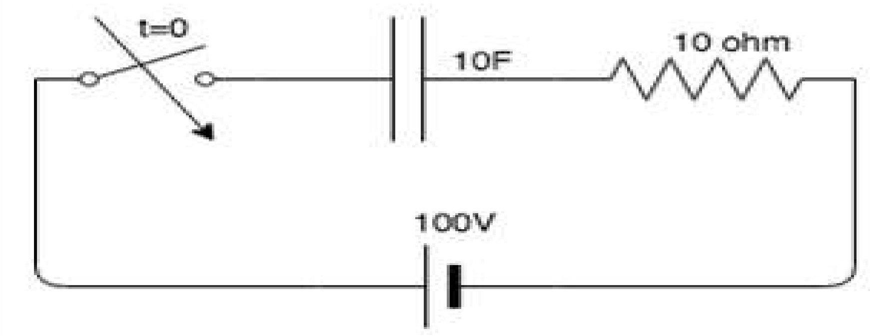
- Series Inductor Resistor
- Oscillator
- Capacitors

4.3.12.3. Self-Assessment

a) Differentiate R-L & R-C circuits
b) Perform calculations on R-L & R-C circuits
c) Describe growth of current in R-L & R-C circuits
d) the time in which the current in the circuit increases from zero to 63% of the maximum value of I_{max} is called the constant or the decay constant of the circuit. TRUE OR FALSE?
e) Higher is the value of decay constant,lower will be the rate of change of current and vice versa. TRUE OR FALSE?
f) Describe decay current in R-L & R-C circuits

g) What are the applications of Growth and decay in R-L & R-C Circuits?

If the switch is closed at t=0, what is the current in the circuit?



4.3.12.4.Tools, Equipment, Supplies and Materials for the specific learning outcome

- Scientific Calculators
- Relevant reference materials
- Stationeries
- Electrical workshop
- Relevant practical materials
- Dice
- Computers with internet connection

4.3.12.5. References

1. James W. Nilsson, Susan Riedel, Electric Circuits, New Jersey: Prentice Hall Press, 2010.

4.3.13. Learning Outcome No. 12. Use two port networks
4.3.13.1 Learning Activities

Learning Outcome No. 12. Use two port networks	
Learning Activities	Special Instructions
Apply Transients in Electrical Circuit Analysis	

4.3.13.2. Information Sheet No. 4/ LO12

Meaning of passive networks
A passive network is a type of computer network in which each node works on a predefined function or process.
Passive networks don't execute any specialized code or instruction at any node and don't change their behavior dynamically.

Typically, this behavior is related to each network router nod

- Types of Passive network

Resistors
A resistor is taken as a passive element since it cannot deliver any energy to a circuit.

Inductors
An inductor is also considered as passive element of circuit, because it can store energy in it as a magnetic field, and can deliver that energy to the circuit, but not in continuous basis.

Capacitors
A capacitor is considered as a passive element because it can store energy in it as electric field.

Transformers
A transformer is also a passive electronic component. Although this can seem surprising since transformers are often used to raise voltage levels – remember that power is kept constant.

Characteristic impedance in T & pie networks
Transforming from Pi to T and vice versa

Any pi network can be transformed to an equivalent T network. This is also known as the Wye-Delta transformation, which is the terminology used in power distribution and electrical engineering. The pi is equivalent to the Delta and the T is equivalent to the Wye (or Star) form.

The impedances of the pi network (Za, Zb, and Zc) can be found from the impedances of the T network with the following equations:

$Za = ((Z1*Z2)+(Z1*Z3)+(Z2*Z3)) / Z2$

$Zb = ((Z1*Z2)+(Z1*Z3)+(Z2*Z3)) / Z1$

$Zc = ((Z1*Z2)+(Z1*Z3)+(Z2*Z3)) / Z3$

Note the common numerator in all these expressions which can prove useful in reducing the amount of computation necessary.

The impedances of the T network (Z1, Z2, Z3) can be found from the impedances of the equivalent pi network with the following equations:

$Z1 = (Za * Zc) / (Za + Zb + Zc)$

$Z2 = (Zb * Zc) / (Za + Zb + Zc)$

$Z3 = (Za * Zb) / (Za + Zb + Zc)$

Note the common denominator in these expressions.

In the case where all the impedances are reactive (i.e. they are all in the form jX), it is handy to note that the -1 factors from squaring j*j on the top cancels the -1 from bringing the j in the denominator up top.

Synthesis of pi and T networks to transform resistances and create phase shifts

Assuming that the desired port impedances are purely resistive (i.e. real), you can design a T or pi network with purely reactive components both to produce a desired phase shift (beta) and transform the impedances with the following equations. Note that beta can be any value, except for zero or pi.

$Z1 = -j * (R1 *cos(beta) - sqrt(R1 * R2))/ sin (beta)$

$Z2 = -j * (R2 *cos(beta) - sqrt(R1 * R2))/sin(beta)$

$Z3 = -j * sqrt(R1*R2) / sin(beta)$

$Za = j *R1*R2 * sin(beta) / (R2 * cos(beta) - sqrt(R1 * R2))$

$Zb = j * R1*R2 * sin(beta) / (R1 * cos(beta) - sqrt(R1 * R2))$

$Zc = j * sqrt(R1 * R2) * sin (beta)$

Beta is the phase lag passing through the network from either port 1 to port 2 or vice versa. Note that if beta is 0 or pi, these expressions break down, except if R1=R2. If you need to transform resistive impedances and you don't want any phase shift, you have to use a transformer.

In many practical applications, the load or generator impedances may be reactive (i.e. Z (port 1) and Z (port 2) are some general R+jX). This can be accomodated by absorbing the external reactive impedance into the network, reducing or increasing the series or shunt impedance as requred. For instance, if a T network is required to connect between two impedances: 50+j0 and 100-j20 with 45 degrees of phase shift:

First, calculate the Z's assuming resistive impedances: R1=50, R2= 100

Z1 = -j * (50 * .707 - sqrt(50*100))/.707 = +j 50 ohms
Z2 = -j * (100 * .707 - sqrt(50*100))/.707 = 0 ohms
Z3 = -j * sqrt(50 * 100) / .707 = -j 100 ohms
(the example is somewhat contrived, and it winds up creating an L network for the resistive case).

Now, a reactive component is added to Z2 to exactly cancel the external reactive component. This changes Z2 from 0 ohms to +j20 ohms. The final network is then:
Z1 = +j50, Z2= +j20, Z3 = -j100 ohms
If you are working with a pi network, you would want to transform the external impedances into their corresponding shunt forms first, so that the reactive component is a shunt value, which would be absorbed (or combined) with the corresponding shunt component of the pi network.

Cascade ABCD two-port networks

Telephone subscriber lines have become a topic of intense interest for organizations attempting to transmit Internet signals on telephone lines. Basic loop standards exist, and tables of twisted-pair primary constants extending to 20 MHz are in the literature. Asymmetric digital-subscriber lines (ADSLs) are now available for high-speed Internet service. The telephone industry has always used two-port networks in the form of ABCD matrices to cascade sections of telephone cable. These configurations allow you to join the sections by matrix multiplication. However, because the elements in the matrices are complex numbers and several sections make up a chain, you need to organize the process of matrix multiplication. A short computer program performs this task (Listing 1). You enter the number of matrices in the chain and then enter the real and imaginary parts for each A, B, C, and D element. The product then appears on the screen.

A represents the open-circuit transfer function, B represents the short-circuit transfer impedance, C represents the open-circuit transfer admittance, and D represents the short-circuit current ratio. You can find the ABCD matrix for a ladder network composed of RLC elements by slicing the network into series and shunt matrices. You then multiply the product of the first two by the third, and the progression continues with additional subscripts identifying the components. In the final product, the elements A, B, C, and D—with all their component symbols—may become quite cumbersome. To avoid these complicated expressions in the matrix for the ladder network, don't use them. Rather, enter the numerical values for the series and shunt components along with the necessary 0,0s and 1,0s. You can use this concept for any network comprising passive components that you can separate into isolated two-port sections. You can also use the method to predict the degradation a bridged tap produces in a telephone cable.

The progression of entering values for cascaded networks is normally from left to right, or from source to load with the current pointing toward the load. If you reverse the progression, the direction of the current is usually reversed, and the location of elements

A and D is reversed to conform to the reciprocity theorem. The matrices for a single series component and a single shunt component are as follows:

You can use these simple matrices to represent RLC components, transformers, and bridged taps in telephone cables. However, for a telephone cable, you must consider the reflected wave. Thus, you must express the A, B, C, D elements by the following hyperbolic functions:

Where the propagation constant, =+, d is the electrical length of the cable, and Z0 is the characteristic impedance. In the United States, the nominal value for Z0 is 100V, which is also the specified value for the source and load impedance. Because is a complex number, A, B, C, and D are also complex numbers, or the polar equivalent thereof. These numbers are not difficult to calculate; however, the parameters depend on the application (References 1 and 2). The following example shows how to enter the data and read the results:

Within the solid bars, N1 through N4 show the entered data for the components. The bottom line shows the matrix product as it appears on the screen. For this network, the matrix elements are A=43+j0, B=0–j25, C=0+j12, and D=7+j0. The open-circuit voltage ratio is V1/V2=A= 43. The open-circuit transfer admittanceI1/V2=C= 0+j12. The input impedance isZN=A/C=0–j(43/12). Listing 1 uses easy-to-read and-compile QuickBasic. (DI #2455)

4.3.13.3. Self-Assessment

a) Describe passive networks
b) Explain the operation of various types of passive network
c) Explain characteristic impedance in T & pie networks
d) Passive networks don't execute any specialized code or instruction at any node and don't change their behavior dynamically. TRUE OR FALSE?
e) .Asymmetric digital-subscriber lines (ADSLs) are now available for high-speed Internet service. TRUE OR FALSE?
f) Describe Cascade ABCD two-port networks
g) Perform calculations on passive networks
h) What are the applications of passive networks?

4.3.13.4.Tools, Equipment, Supplies and Materials for the specific learning outcome

- Scientific Calculators
- Relevant reference materials
- Stationeries
- Electrical workshop

4.3.13.5. References

1. James W. Nilsson, Susan Riedel, Electric Circuits, New Jersey: Prentice Hall Press, 2010.

4.3.14. Learning Outcome No. 13. Demonstrate understanding of refrigeration and air conditioning

4.3.14.1. Learning Activities

Learning Outcome No. 13. Demonstrate understanding of refrigeration	
Learning Activities	Special Instructions
• Demonstrate understanding the operation principle of a refrigerator and an air conditioner • Demonstrate understanding of the differences between refrigerator and an air conditioner	

4.3.14.2 Information Sheet No. 4/LO13

Meaning of Refrigeration and Air Conditioning

Key differences in the design and operation.

Supply

A major difference between refrigeration and air conditioning is the point of supply for the gases. Refrigeration systems have gas installed in a series of tubes. Air conditioning systems use built-in chemicals, but also air from the room or rooms being heated.

Circulation

Air conditioners have circulation systems designed to project cool air away from the units while refrigeration units have circulation systems designed to retain coolant in a confined space. Air conditioners, while also employing tubes in the coolant system, have fans for the dispersal of air. Unlike refrigeration systems, which keep gases contained to a pre-determined space, air conditioning systems disperse cool air throughout areas of unknown volume.

Vaporization

Both air conditioning and refrigeration units depend on converting liquid to gas in the cooling process, but the manner in which they achieve this is different for each system. Air conditioners use something called an evaporator to convert a liquid to a gas. Vaporization is the process of converting a liquid to a gas and can be accomplished one of two ways: boiling or evaporation. Thus air conditioning units vaporize liquid through evaporation while refrigeration systems do so through boiling

Operation of Refrigeration and Air conditioning

Refrigeration system

The refrigeration system must have 4 parts. A condenser, an evaporator, compressor and an expansion device. Starting with the compressor, refrigerant gas is compressed to a higher pressure. After passing through the compressor, it passes to the condenser. The high pressure gas transfers its heat to the surrounding air and condenses. It then passes through the expansion device, which is a restriction separating the high side from the low side. After passing through the expansion device, the pressure is reduced because the compressor is removing gas from the end of the evaporator. This lowers the boiling temperature of the refrigerant. The lower temperature absorbs heat from the air passing over the evaporator and boils the liquid to a gas. The gas then passes into the compressor and the cycle repeats.

Air conditioners

Air conditioners use refrigeration to chill indoor air, taking advantage of a remarkable physical law: When a liquid converts to a gas (in a process called phase conversion), it absorbs heat. Air conditioners exploit this feature of phase conversion by forcing special chemical compounds to evaporate and condense over and over again in a closed system of coils.

The compounds involved are refrigerants that have properties enabling them to change at relatively low temperatures. Air conditioners also contain fans that move warm interior air over these cold, refrigerant-filled coils. In fact, central air conditioners have a whole system of ducts designed to funnel air to and from these serpentine, air-chilling coils.

When hot air flows over the cold, low-pressure evaporator coils, the refrigerant inside absorbs heat as it changes from a liquid to a gaseous state. To keep cooling efficiently, the air conditioner has to convert the refrigerant gas back to a liquid again. To do that, a compressor puts the gas under high pressure, a process that creates unwanted heat. All the extra heat created by compressing the gas is then evacuated to the outdoors with the help of a second set of coils called condenser coils, and a second fan. As the gas cools, it changes back to a liquid, and the process starts all over again. Think of it as an endless, elegant cycle: liquid refrigerant, phase conversion to a gas/ heat absorption, compression and phase transition back to a liquid again.

Plant layout of Refrigeration and Air conditioning system
Air conditioner layout

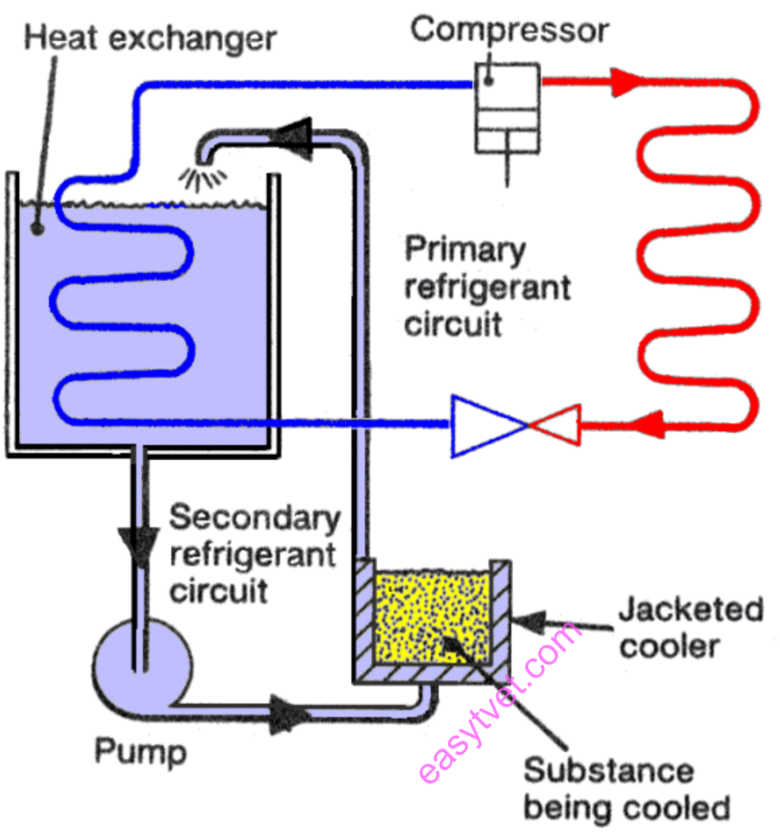


Figure 46: Refrigeration and air conditioning

4.3.15.3 References;

Air Conditioning - Basic Refrigeration Cycle. (n.d.). Retrieved from https://www.swtc.edu/Ag_Power/air_conditioning/lecture/basic_cycle.htm

How Air Conditioners Work. (2011, June 28). Retrieved from https://home.howstuffworks.com/ac1.htm

4.3.14.3. Self-Assessment

a) Define the terms refrigeration systems, air conditioning and vaporization
b) Illustrate various refrigeration plant layouts
c) Describe Refrigeration and Air Conditioning
d) Differentiate between Refrigeration and Air Conditioning
e) Explain operational Principe between a Refrigerator and Air Conditioner
f) What is the importance of Refrigeration and Air Conditioning?
g) Describe Plant layout of Refrigeration and Air conditioning system

h) A major difference between refrigeration and air conditioning is the point of supply for the gases. Refrigeration systems have gas installed in a series of tubes. TRUE OR FALSE?
i) The compounds involved are refrigerants that have properties enabling them to change at relatively low temperatures. TRUE OR FALSE?
j) Define the terms refrigeration systems, air conditioning and vaporization
k) Describe Refrigeration and Air Conditioning
l) Differentiate between Refrigeration and Air Conditioning
m) Explain operational Principe between a Refrigerator and Air Conditioner
n) What is the importance of Refrigeration and Air Conditioning?
o) Describe Plant layout of Refrigeration and Air conditioning system
p) To keep cooling efficiently, the air conditioner has to convert the refrigerant gas back to……..
    a) Solid
    b) Semi solid
    c) Liquid
    d) Gas
q) When hot air flows over the cold, low-pressure………….., the refrigerant inside absorbs heat as it changes from a liquid to a gaseous state.
    a) Condenser coil
    b) evaporator coils
    c) heating coils
r) ………… is the process of converting a liquid to a gas and can be accomplished one of two ways: boiling or evaporation
    a) Circulation
    b) Vaporization
    c) Cooling
s) A major difference between refrigeration and air conditioning is the point of supply for the gases. Refrigeration systems have gas installed in a series of tubes.
    a) True
    b) False
t) The compounds involved are refrigerants that have properties enabling them to change at relatively low temperatures.
    a) True
    b) False

Practical exercise

a) Demonstrate understanding the operation principle of a refrigerator and an air conditioner
b) Demonstrate understanding of the differences between refrigerator and an air conditioner
c) Draw and illustrate various refrigeration plant layouts

4.3.14.2.Tools, Equipment, Supplies and Materials for the specific learning outcome

- Scientific Calculators
- Relevant reference materials
- Stationeries
- Electrical workshop
- Relevant practical materials
- Dice
- Computers with internet connection

4.3.14.5. References

1. James W. Nilsson, Susan Riedel, Electric Circuits, New Jersey: Prentice Hall Press, 2010.