A Laboratory Manual for

Basics Electrical Engineering (BE01R00051)

B.E. Semester-II (All Branches)

Directorate of Technical Education, Gandhinagar, Gujarat

Government Engineering College, Bhuj
Certificate

This is to certify that Mr./Ms. ____ Enrollment No. _________________ of B.E. Semester II _________________ Engineering of this Institute (GTU Code: 015) has satisfactorily completed the Practical work for the subject **Basics Electrical Engineering (BE01R00051)** for the academic year ___________

Place: ___________
Date: ___________

Name and Sign of Faculty member

Head of the Department

Preface

Main motto of any laboratory/practical work is for enhancing required skills as well as creating ability amongst students to solve real time problem by developing relevant competencies in psychomotor domain. By keeping in view, GTU has designed competency focused outcome-based curriculum for engineering degree programs where sufficient weightage is given to practical work. It shows importance of enhancement of skills amongst the students and it pays attention to utilize every second of time allotted for practical amongst students, instructors and faculty members to achieve relevant outcomes by performing the experiments rather than having merely study type experiments. It is must for effective implementation of competency focused outcome-based curriculum that every practical is keenly designed to serve as a tool to develop and enhance relevant competency required by the various industry among every student. These psychomotor skills are very difficult to develop through traditional chalk and board content delivery method in the classroom. Accordingly, this lab manual is designed to focus on the industry defined relevant outcomes, rather than old practice of conducting practical to prove concept and theory.

By using this lab manual students can go through the relevant theory and procedure in advance before the actual performance which creates an interest and students can have basic idea prior to performance. This in turn enhances pre-determined outcomes amongst students. Each experiment in this manual begins with competency, industry relevant skills, course outcomes as well as practical outcomes (objectives). The students will also achieve safety and necessary precautions to be taken while performing practical.

This manual also provides guidelines to faculty members to facilitate student centric lab activities through each experiment by arranging and managing necessary resources in order that the students follow the procedures with required safety and necessary precautions to achieve the outcomes. It also gives an idea that how students will be assessed by providing rubrics.

This laboratory manual is designed to supplement the theoretical knowledge gained in the Basics Electrical Engineering course. It provides practical hands-on experience to reinforce concepts such as Ohm's Law, Various laws and theorems, AC/DC circuits, Electrical Machines and safety & protection. The manual includes step-by-step instructions for conducting experiments, as well as detailed explanations of the underlying principles and equations. The experiments in this manual have been carefully selected to cover the key topics in Basics Electrical Engineering and to help students develop critical thinking, problem-solving, and troubleshooting skills. This manual is an essential resource for any student studying electrical engineering, as it provides a practical approach to understanding the theoretical concepts learned in class.

Practical – Course Outcome matrix

Course Outcomes (COs):

CO-1 : Apply fundamental electrical laws and circuit theorems to electrical circuits.

CO-2 : Analyze single phase and three phase AC circuits.

CO-3 : Describe operating principle and applications of static and rotating electrical machines.

CO-4 : Understand the LT switchgear, earthing and safety of electrical appliances.

CO-5 : Comprehend illumination system, batteries, electrical consumption & billing and electrical measuring instruments.

Sr. No.	Objective(s) of Experiment	CO1	CO2	CO3	CO4	CO5
1.	To verify the Kirchhoff's laws for the given network	√				
2.	To verify the Superposition theorem for the given network	√				
3.	To verify the Thevenin's theorem for the given network	√				
4.	To demonstrate B-H curve			√		
5.	To determine resistance, inductance, power and power factor of series R-L circuit		√			
6.	To verify the current and voltage relationships in three phase star and delta connections		√			
7.	To measure power in three phase circuit using two watt-meter method		√			
8.	To study BLDC motors.			√		
9.	To demonstrate the working of miniature circuit breaker (MCB)				√	
10.	To study different types of batteries and its applications.					√

Industry Relevant Skills

The following industry relevant competency are expected to be developed in the student by undertaking the practical work of this laboratory.

1. By performing experiments in Basic Electrical Engineering, students can develop a systematic approach to identify and troubleshoot faults in electrical systems.
2. Students can get aware about elementary electrical safety by following the safety guidelines while performing experiments in the lab.
3. By working in a team and presenting their experimental results, students can develop effective communication skills.
4. Students can develop analytical skills by analyzing the experimental data and drawing meaningful conclusions.
5. By documenting their experimental results, students can develop documentation skills that are essential in the industry.

Guidelines for Faculty members

1. Teacher should provide the guideline with demonstration of practical to the students with all features.
2. Teacher shall explain basic concepts/theory related to the experiment to the students before starting of each practical
3. Involve all the students in performance of each experiment.
4. Teacher is expected to share the skills and competencies to be developed in the students and ensure that the respective skills and competencies are developed in the students after the completion of the experimentation.
5. Teachers should give opportunity to students for hands-on experience after the demonstration.
6. Teacher may provide additional knowledge and skills to the students even though not covered in the manual but are expected from the students by concerned industry.
7. Give practical assignment and assess the performance of students based on task assigned to check whether it is as per the instructions or not.
8. Teacher is expected to refer complete curriculum of the course and follow the guidelines for implementation.

Instructions for Students

1. Students are expected to carefully listen to all the theory classes delivered by the faculty members and understand the COs, content of the course, teaching and examination scheme, skill set to be developed etc.
2. Students shall organize the work in the group and make record of all observations.
3. Students shall develop maintenance skill as expected by industries.
4. Student shall attempt to develop related hand-on skills and build confidence.
5. Student shall develop the habits of evolving more ideas, innovations, skills etc. apart from those included in scope of manual.
6. Student shall refer technical magazines and data books.
7. Student should develop a habit of submitting the experimentation work as per the schedule and s/he should be well prepared for the same.

Government Engineering College, Bhuj
Institute Vision and Mission

Vision

To optimize perseverance, quality and ethics in the higher technical education and research as can groom the learners into the owners of global trends in engineering.

Mission

- To facilitate the learners with fundamental and advanced technical knowledge in theory and practice
- To facilitate the learning with concerned industrial exposure to the obtaining technology
- To help the learners acquire professional ethics, acumen and zeal for research and entrepreneurship

Government Engineering College, Bhuj
Electrical Engineering Department
Department Vision and Mission, PEOs and PSOs

Vision

To empower Electrical Engineers with technical expertise, social responsibility and adaptability to vibrant industries.

Mission

M1: To provide sound fundamental knowledge and skill of electrical engineering field.

M2: To provide platform for higher study, entrepreneurship and placement.

M3: To produce Electrical Engineers with an attitude to adapt themselves to changing technological environment.

M4: To create lifelong learning environment in department.

Program Educational Objectives (PEOs)

Within few years after Graduation, the Student will be able:

PEO1: To implant a strong foundation in the Electrical Engineering fundamentals to solve and analyze the Electrical Engineering problems. (Core Technical)

PEO2: To produce graduates who are well placed in the field of Electrical Engineering and contributing towards nation development. (Placement and Entrepreneurship)

PEO3: Building a professional culture within the department community that embodies the ethics and honesty. (Ethics)

Program Specific Outcomes (PSOs)

PSO 1: Graduates will be able to demonstrate fundamental knowledge of electrical power system, electrical machines, power electronics using appropriate concepts.

PSO 2: Graduates will be able to design electrical machines, transmission lines and Power apparatus.

PSO 3: Graduates will be able to develop support system based on renewable and sustainable energy sources.

Government Engineering College, Bhuj
Electrical Engineering Department
LAB ASSESSMENT RUBRICS

Subject Code: BE01R00051
Subject Name: BASIC ELECTRICAL ENGINEERING

Criteria for laboratory assessment:

Criterion	**Rubric for regular laboratory work and lab file submission**				
	Assessment of Criterion ***(Note: Assigned score within a range is assessment of degree criterion is met.)***				
	Excellent (5)	***Very Good (4)***	***Good (3)***	***Fair (2)***	***Needs more work (1)***
Meeting Performance					
knowledge	• Always well-prepared and organized	• Usually prepared and organized	• Sometimes prepared and organized	• Rarely prepared and organized	• Never prepared and organized
Calculation	• Excellent analytical and concluding abilities based on results.	• Very good analytical and concluding abilities based on results.	• Average analytical and concluding abilities based on results.	• Poor analytical and concluding abilities based on results.	• No analytical and concluding abilities based on results.
Participation	• Always a willing participant • Responds frequently to questions • Routinely volunteers point of view	• Often a willing participant • Responds occasionally to questions • Occasionally volunteers point of view	• Sometimes a willing participant • Rarely able to respond to questions • Rarely volunteers point of view	• Rarely a willing participant • Rarely able to respond to questions • Rarely volunteers point of view	• Never a willing participant • Never able to respond to questions • Never volunteers point of
Journal work and submission	• Excellent write-up, ethical practices and on time submission.	• Very good write-up, ethical practices and on time submission.	• Average write-up, low ethical practices and on time submission.	• Poor write-up, partial copy with poor understanding but timely submission.	• Poor write-up, high copy content with very less/no understanding and delayed submission

Rubrics	**knowledge**	**Calculation**	**Participation**	**Journal work and submission**	**Total**
Marks					

Index
(Progressive Assessment Sheet)

Sr. No.	Objective(s) of Experiment	Page No.	Date of performance	Date of submission	Assessment Marks	Sign. of Teacher with date	Remarks
1.	To verify the Kirchhoff's laws for the given network						
2.	To verify the Superposition theorem for the given network						
3.	To verify the Thevenin's theorem for the given network						
4.	To demonstrate B-H curve						
5.	To determine resistance, inductance, power and power factor of series R-L circuit						
6.	To verify the current and voltage relationships in three phase star and delta connections						
7.	To measure power in three phase circuit using two watt-meter method						
8.	To study BLDC motors.						
9.	To demonstrate the working of miniature circuit breaker (MCB)						
10.	To study different types of batteries and its applications.						

Experiment No: 1
To verify the Kirchhoff's law for the given network

Date:

Competency and Practical Skills: Knowledge of Kirchhoff's laws, Familiarity with the network components, Ability to measure voltage and current

Objectives: (a) To know the basic principles of Kirchhoff's laws and their significance in circuit analysis.
(b) To measure the currents at different nodes in the circuit and then compare them with the sum of the currents entering and leaving the node.
(c) To measure the voltages across different elements in the circuit and then compare them with the sum of the voltages in the closed loop.
(d) To solve the circuit using KCL and KVL and find the unknown currents and voltages.

Equipment/Instruments: Resistors , Ammeters, Voltmeters, Regulated DC power supply, Connecting probes.

Theory: Kirchhoff's laws Kirchhoff's laws are particularly useful (a) in determining the equivalent resistance of a complicated network and (b) for calculating the currents flowing in the various conductors.

- **KIRCHHOFF'S VOLTAGE LAW :**

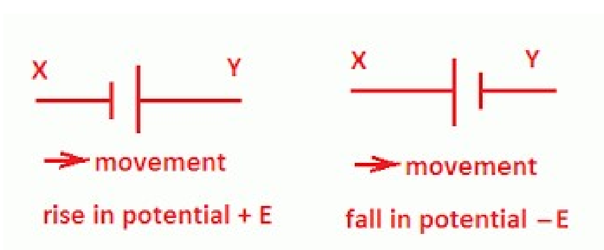
It states that "the algebraic sum of products of currents and resistances in each of the conductors in any closed path in a network plus the algebraic sum of the e.m.fs in that path is zero". In other words,

$$\sum IR + \sum e.m.f. = 0$$

It should be noted that algebraic sum is the sum which takes into account the polarities of the voltage drops. Following sign convention is suggested:

SIGN CONVENTIONS :

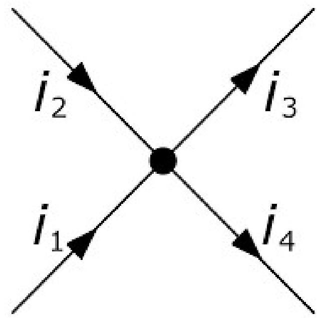
a) **battery e.m.f.:** A rise in voltage should be given a + ve sign and a fall in voltage a –ve sign. Keeping this in mind, it is clear that as we move from negative terminal of source to positive terminal, there is a rise in potential, hence this voltage should be given a +ve sign. If, on the other hand, we move from +ve terminal to –v terminal of voltage source, then there is a fall in potential, hence it is to be considered as –ve.



b) Sign of IR Drop: Whenever we move in the direction of current there is a drop in voltage, Since the current always flows from point at higher potential to the point at lower potential. Hence Voltage drop in the current direction is taken as –ve. However, if we go in a direction opposite to that of the current, then there is a rise in voltage.

- **KIRCHHOFF'S CURRENT LAW (KCL) :**

It states that "in any electrical network, algebraic sum of the currents meeting a point is zero". In another way, it simply means that the total current leaving a unction is equal to the total current entering that junction. It is obviously true because there is no accumulation or depletion of current at any junction of the network. Consider the case of a few conductors meeting at a node as in fig.

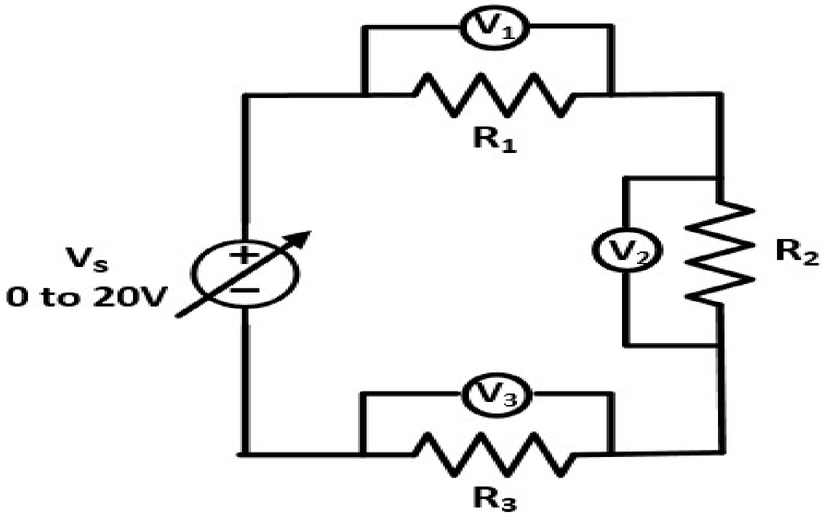


$$i_1 + i_2 = i_3 + i_4$$

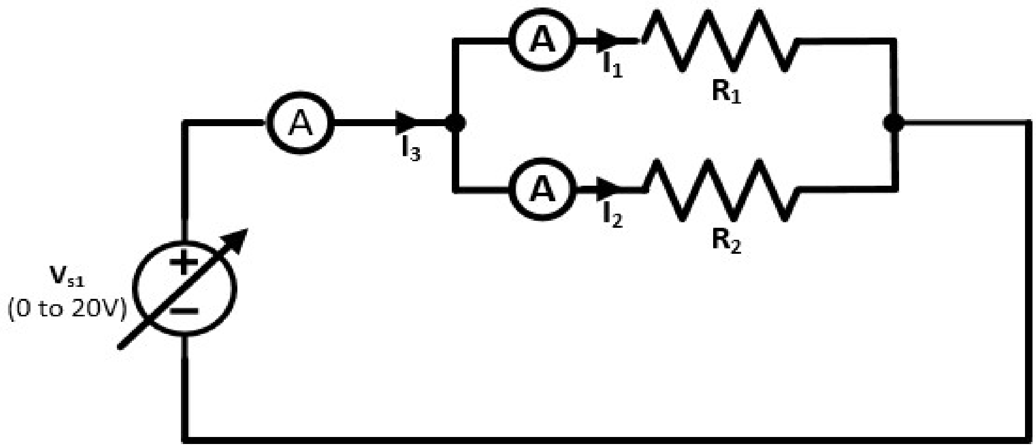
Some conductors have currents leading to node whereas some have currents leading away from node. Assuming the incoming currents to be positive and the outgoing currents negative, applying KCL at node we have,

I1 + I2 -I3 -I4 = 0 OR I1 + I2 = I3 + I4

Set up diagram:



KVL



KCL

Safety and necessary Precautions:
1. Wear protective gear
2. Ensure proper wiring
3. Use appropriate voltage
4. Use appropriate measuring equipment
5. Avoid touching the circuit
6. Handle components with care
7. Follow laboratory guidelines

Procedure:
1. Connect the circuit as per circuit diag.
2. Switch on the DC voltage supply, Adjust the voltage to any suitable value.
3. Take the reading of all the ammeters for KCL experiment and measure the voltages across all the resistors for KVL experiment.
4. Changed the voltage of power supply and repeat step (3) and verify laws.

Observations:

1) KVL:

Measured:

SR No	Voltage V_1 (V)	Voltage V_2 (V)	Voltage V_3 (V)	Total Voltage $V = V_1 + V_2 + V_3$

2) KCL:

Measured:

SR No	Brach Current I_1 (A)	Brach Current I_2 (A)	Source Current I_3 (A)

Calculation:

Results:

KVL:

	Theoretical	Measured
SR No	Total Voltage $V= V_1+ V_2 + V_3$	Total Voltage $V= V_1+ V_2 + V_3$
1		
2		
3		

KCL:

	Theoretical	Measured
SR No	Total Current $I3= I_1+ I_2$	Total Current $I3= I_1+ I_2$
1		
2		
3		

Conclusion:

Quiz:

1. State kirchhoff's laws in context of DC circuit.

2. Any closed path formed by the branches in a network is called a______________.
3. In network having N nodes, the number of independent equations required to solve the network, with ground is as the reference node, is___________
4. Differentiate loop and Mesh.

Suggested Reference:

1. "Engineering Circuit Analysis" by William H. Hayt and Jack E. Kemmerly, The McGraw Hill
2. "Basic Electrical Engineering" by T. K. Nagsarkar and M. S. Sukhija, Oxford university press.
3. http://vlabs.iitkgp.ernet.in/be/exp4/index.html, Basic Electronics Virtual Laboratory(IIT KHARAGPUR)

References used by the students:

Rubric wise marks obtained:

5=Excellent 4=Very Good 3=Good 2=Fair 1=Needs more work					
Rubrics	**knowledge**	**Calculation**	**Participation**	**Journal work and submission**	**Total**
Marks					

Experiment No: 2
To verify the superposition theorem for the given network.

Date:

Competency and Practical Skills: Knowledge of superposition law, Familiarity with the network components, Ability to measure voltage and current

Objectives: (a) To construct a circuit containing multiple sources (such as voltage sources or current sources) and resistors.
(b) To measure the response (voltage or current) at a specific point in the circuit using a multimeter.
(c) To verify that the total response of the circuit when all sources are turned on is equal to the algebraic sum of the responses measured when each source is turned on individually
(d) To compare the experimental results with the theoretical predictions based on the superposition theorem

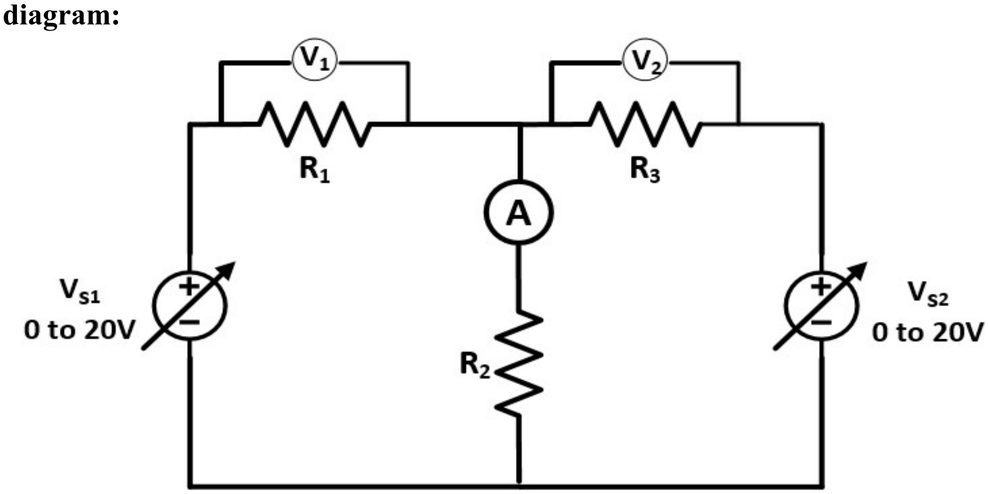
Equipment/Instruments: Resistors , Ammeters, Voltmeters, Regulated DC power supply, Connecting probes.

Theory: The Superposition Theorem is a fundamental principle in electrical engineering that states that the response of a linear circuit to a set of multiple inputs can be calculated by considering the individual responses of the circuit to each input, taken separately.

More specifically, the theorem states that in a linear circuit containing multiple sources (such as voltage or current sources), the total response at any point in the circuit is the sum of the responses due to each individual source acting alone, with all other sources turned off. In other words, the contribution of each source to the final response is calculated independently and then added together to obtain the total response.

The Superposition Theorem is based on the principle of linearity, which states that a linear system's response to a sum of inputs is equal to the sum of the responses to each individual input. The theorem can be applied to any linear circuit, regardless of its complexity, and it is a powerful tool for simplifying circuit analysis and understanding circuit behavior. However, it can only be applied to circuits with linear components, and it assumes that all the sources are independent of each other.

Set up diagram:



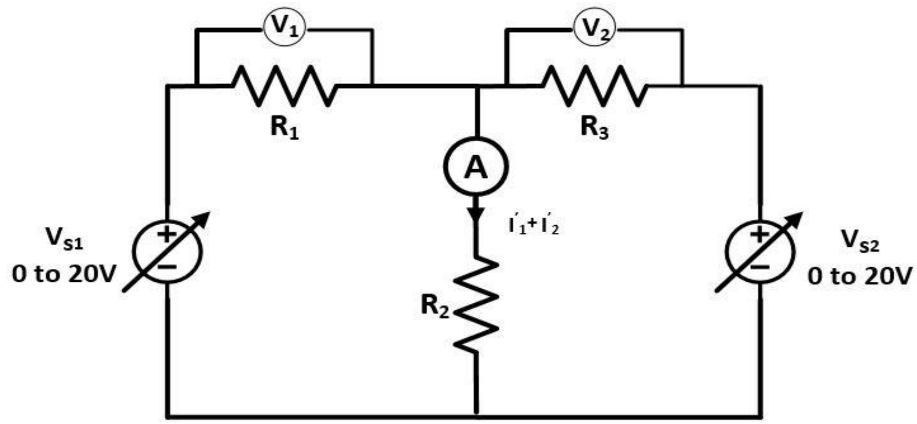
Safety and necessary Precautions:

1. Wear protective gear
2. Ensure proper wiring
3. Use appropriate voltage
4. Use appropriate measuring equipment
5. Avoid touching the circuit
6. Handle components with care
7. Follow laboratory guidelines

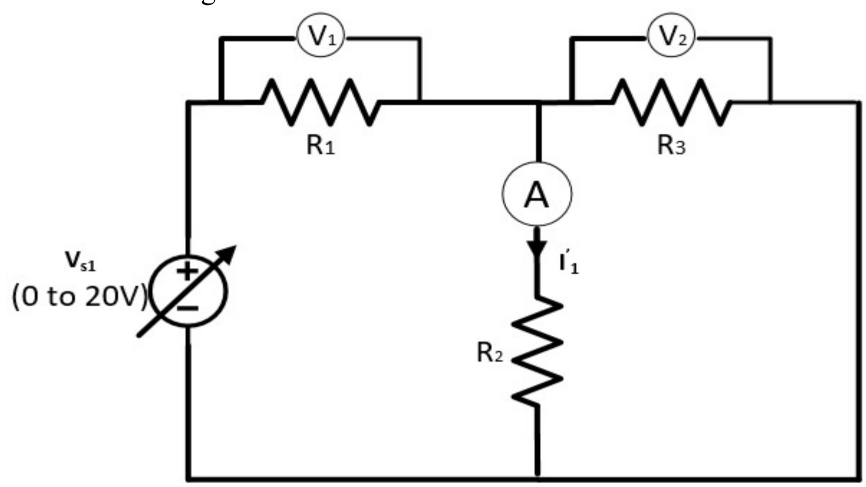
Procedure:

Connection are made as per the circuit diagram shown in figure given above.

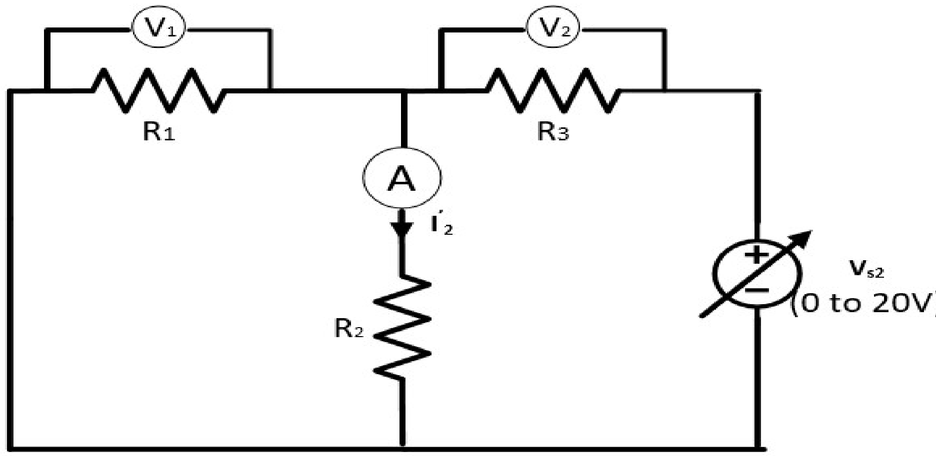
1. Vary the supply voltage V_{S1} & V_{S2} and take the corresponding reading ($I'_1 + I'_2$)from the ammeter.



2. Now VS2 is short circuited. Vary VS1 & take the corresponding reading I'_1 from the ammeter as shown in figure



3. Now VS1 is short circuited. Vary VS2 & take the corresponding reading I'_2 from the ammeter as shown in figure .



4 Finally Verify whether $I = \pm I'_1 \pm I'_2$

Observations:

	Measured Value
When both V_{s1} and V_{s2} are acting (I'_1+I'_2)	
When only V_{s1} is acting (I'_1)	
When only V_{s2} is acting (I'_2)	

Calculation:

Result:

	Current Through R_2	
	Theoretical Value	**Measured Value**
When both V_{s1} and V_{s2} are acting (I'_1+I'_2)		
When only V_{s1} is acting (I'_1)		
When only V_{s2} is acting (I'_2)		

Conclusion:

Quiz:

1. State superposition theorem.

2. What is Node and super Node?

3. What are limitations of super position theorem?

4. Superposition theorem is applicable for linear network or nonlinear network? Justify your answer.

Suggested Reference:

1. "Engineering Circuit Analysis" by William H. Hayt and Jack E. Kemmerly, The McGraw Hill
2. "Basic Electrical Engineering" by T. K. Nagsarkar and M. S. Sukhija, Oxford university press.
3. **http://vlabs.iitkgp.ernet.in/asnm/exp5/index.html**, Analog Signals, Network and Measurement Laboratory(IIT KHARAGPUR)

References used by the students:

Rubric wise marks obtained:

5=Excellent 4=Very Good 3=Good 2=Fair 1=Needs more work					
Rubrics	**knowledge**	**Calculation**	**Participation**	**Journal work and submission**	**Total**
Marks					

Experiment No: 3
To verify Thevenin's Theorem for given network.

Date:

Competency and Practical Skills: Knowledge of Thevenin's law, Familiarity with the network components, Ability to measure voltage and current

Objectives: At the end of this experiment, student will be able to

(a) Know about the Thevenin's Law.

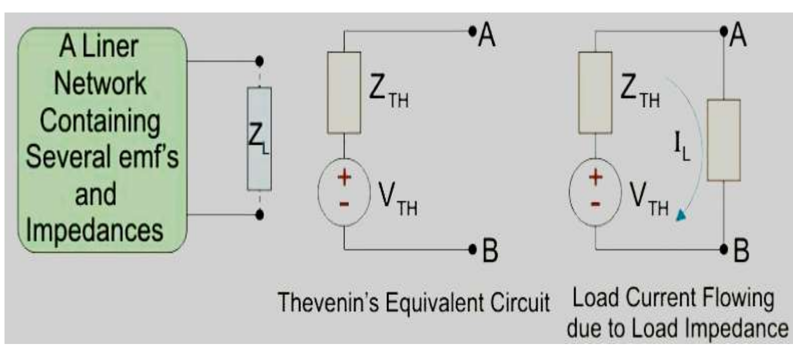
(b) Determine voltage across and current through any branch of circuits.

Equipment/Instruments: Resistors , Ammeters, Voltmeters, Regulated DC power supply, Connecting probes.

Theory: Thevenin's theorem states that any linear circuit can be replaced by an equivalent circuit containing a single voltage source and a single series resistor, known as the Thevenin equivalent circuit. This equivalent circuit has the same voltage-current characteristics as the original circuit between two terminals, also known as the load terminals.

To experimentally verify Thevenin's theorem, you can follow these steps:

- Identify the circuit for which you want to find the Thevenin equivalent circuit.
- Disconnect any load or resistor connected to the circuit.
- Measure the open-circuit voltage across the load terminals. This voltage is the Thevenin voltage (Vth).
- Determine the equivalent resistance of the circuit seen from the load terminals. To do this, short-circuit the voltage source and measure the current flowing through the load terminals. This current is the short-circuit current (Isc). The equivalent resistance (Rth) is given by Rth = Vth/Isc.
- Connect the Thevenin voltage source (Vth) in series with the equivalent resistance (Rth) to form the Thevenin equivalent circuit.
- Verify that the Thevenin equivalent circuit provides the same voltage-current characteristics as the original circuit between the load terminals. One can do this by connecting different resistive loads to the load terminals and measuring the resulting currents and voltages. The values should match those obtained from the original circuit.



.

Figure given above illustrates concept of thevenin's theorem. Figure shows that given network is replaced by thevenins equivalent which contains a voltage source Voc or Vth and a thevenins equivalent resistance R_{TH}.

V_{oc} orV_{th}:

This voltage is called open circuit voltage .It is the voltage between open circuited load terminals. So $V_{oc}=V_{th}=V_{AB}$ with Z_L open circuited.

Set up diagram:

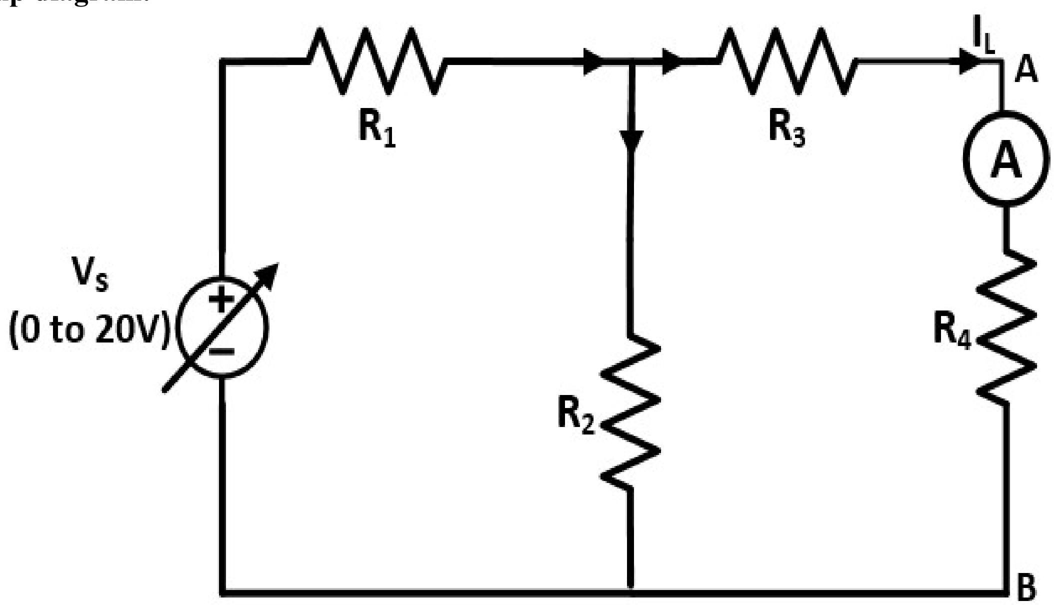


Fig.1

Safety and necessary Precautions:

1. Wear protective gear
2. Ensure proper wiring
3. Use appropriate voltage
4. Use appropriate measuring equipment
5. Avoid touching the circuit
6. Handle components with care
7. Follow laboratory guidelines

Procedure:

1. Connect the circuit as per fig.1.
2. Adjust the output voltage of the regulated power supply(Vs) to an appropriate value.
3. Note down the response (current) through the branch of interest i.e. AB (ammeter reading).
4. Reduce the output voltage of the regulated power supply to 0V and switch-off the supply.
5. Disconnect the circuit and connect circuit as per the fig.2.

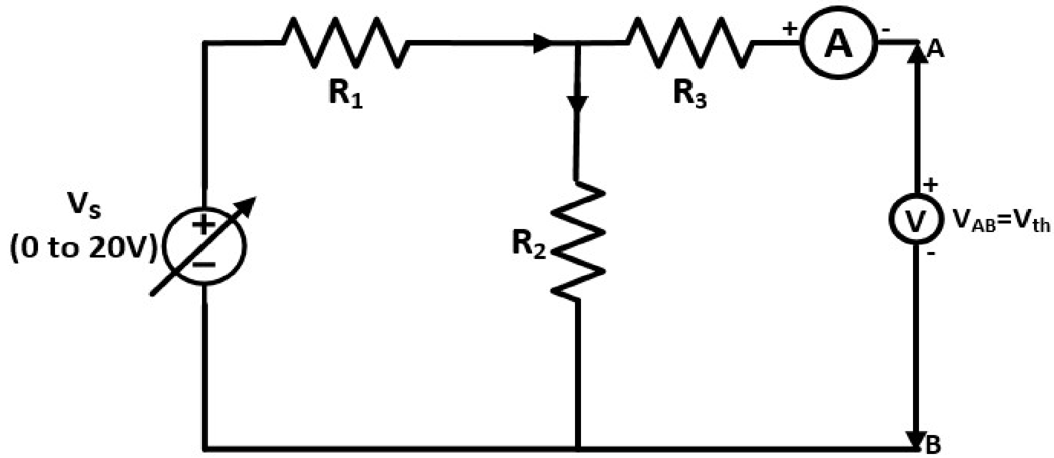


Fig.2

6 Adjust the output voltage of the regulated power supply(V_s) to an appropriate value.
7 Note down the voltage across the load terminals AB (Voltmeter reading) that gives V_{th}.
8 Reduce the output voltage of the regulated power supply to 0V and switch-off the supply.
9 Disconnect the circuit and connect circuit as per the fig.3.

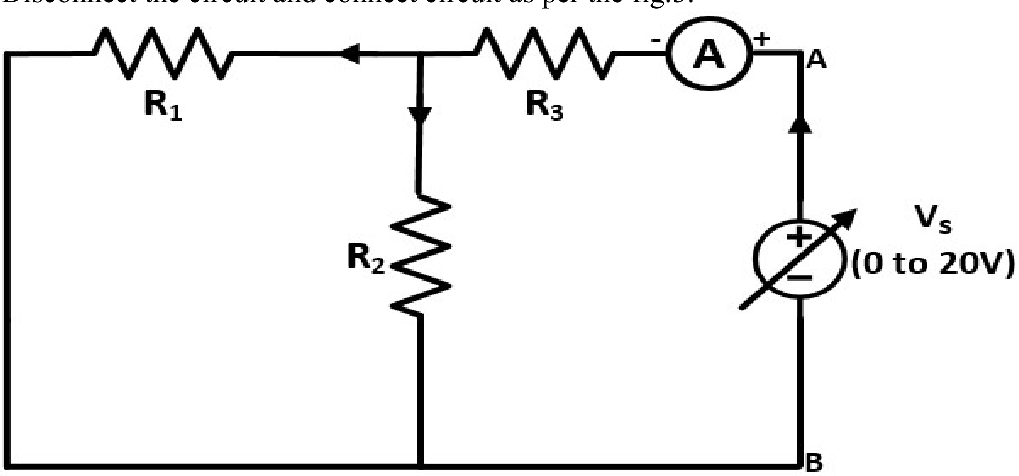


Fig.3

10 Adjust the output voltage of the regulated power supply to an appropriate value.
11 Note down the current (I) supplied by the source (ammeter reading).
12 The ratio of V_s and I gives the R_{th} (Thevenin's Resistance).

Observations:

SR No	Measured Value
1	**R_{th}=**
2	**V_{th} =**
3	**I_L =**

Calculation:

Result:

Theoretical Value	Measured Value
R_{th}=	**R_{th}=**
V_{th} =	**V_{th} =**
I_L =	**I_L =**

Conclusion:

Quiz:

1. State Thevenin's Theorme.

2. Draw the equivalent circuit for thevenin's theorem.

3. What is the other name of thevenin's theorem?

4. Thevenin's theorem can be applied to networks containing active elements only. True/false?

Suggested Reference:

1. "Engineering Circuit Analysis" by William H. Hayt and Jack E. Kemmerly, The McGraw Hill
2. "Basic Electrical Engineering" by T. K. Nagsarkar and M. S. Sukhija, Oxford university press.
3. **http://vlabs.iitkgp.ernet.in/asnm/exp3/index.html**, Analog Signals, Network and Measurement Laboratory(IIT KHARAGPUR)

References used by the students:

Rubric wise marks obtained:

5=Excellent 4=Very Good 3=Good 2=Fair 1=Needs more work					
Rubrics	**Knowledge**	**Calculations**	**Participation**	**Journal work and submission**	**Total**
Marks					

Experiment No: 4
To demonstrate B-H curve

Date:

Competency and Practical Skills: Knowledge of Electromagnetism, Familiarity with the Equipment, Basic Knowledge of DSO/CRO Ability to measure voltage and current

Objectives: (a) To determine the magnetic properties of a material.
(b) To study the hysteresis phenomenon.
(c) To analyze the magnetic behavior of a material.
(d) To compare different materials.

Equipment/Instruments: B-H Curve Kit, CRO/DSO, Connecting probes.

Theory: The flux density B is the ratio of the total no of lines of force existing in the magnetic field (in webers) and the area (in m^2) . Thus,
B=Total no. of lines of force (wb)/ Area (m^2)
The permeability (μ) is the ratio of the change in flux density to the change in field intensity.
μ=change in flux density / change in field intensity = $\Delta B / \Delta H$
Materials like cobalt, nickel, iron which posses a value of y much greater than unity are called ferromagnetic materials. Materials with m less than unity are called diamagnetic while materials with μ values slightly greater than unity are termed as paramagnetic. For vacuum, the value of the permeability is unity. When an alternating current is allowed to flow through an air core coil the variation of flux density (B) with magnetising force (H), the flux density increses in phase with the magnetising force.
Similarly the flux density decreases with the magnetising force in phase. However, for an iron cored
Coil or a coil consisting of a core of ordinary steel, the B-H or magnetization curve is exhibit. Due to residual magnetism, the B-H curve or magnetization curve of the Iron core forms a loop called the Hysteresis loop.
Saturable reactors normally use cores of nickel iron or silicon iron alloys. These materials may be of(a) high permeability type (mumetal or permalloy) and (b) grain oriented alloys. Normally saturable reactors employ
a)Thin laminations to reduce eddy current loss
b)Construction without gap to minimise flux leakage.

RETENTIVITY, COERCIVITY AND HYSTERSIS:

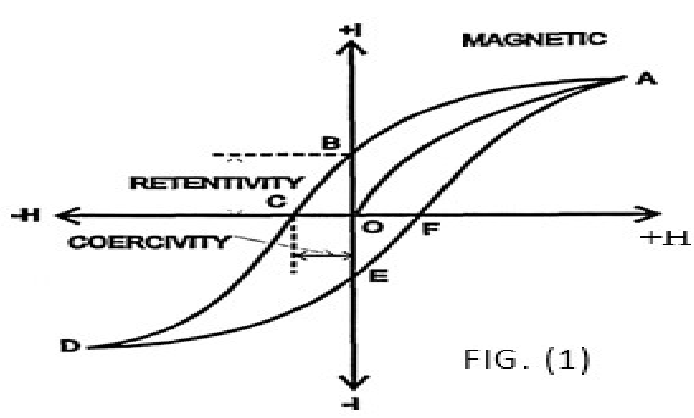


FIG. (1)

Ferromagnetic materials contain large no. of small regions, called domain. In each domain, all the atomic magnets are fixed in rigid parallelism. Thus each domain has a net magnetization in a particular direction distributed randomly. When a specimen of ferromagnetic material is placed in a magnetizing field (H), the specimen is magnetized by induction. As the magnetizing field (H) is varied, the intensity of magnetization of the specimen, 'I' changes. The variation in 'I' with variation in H is shown in Figure (1). The point O represents an initially unmagnetised specimen and a zero magnetizing field. As H is increased, 'I' also increases but not uniformly. When all the domains are aligned in the field direction, the magnetization of specimen gets saturated at A. Any further increase in H result no more increase in 'I'.

If H is now decreased, 'I' also decreases but following a path AB. Thus 'I' lags behind H. When H becomes zero, 'I' still has a value equal to OB. This amount of magnetization is called the "residual magnetism" or "retentivity" of the specimen. Thus the retentively of a specimen is a measure of the intensity of magnetisation remaining in the specimen when the magnetising field is removed. If the magnetising field H be now increased in the reverse direction, the value of 'I' further decreases, still lagging behind H and becomes zero when H has a value equal to OC. This value of the magnetising field is called the "coercive force" or "coercivity" of the specimen. Thus coercivity is a measure of the magnetising field required to destroy the residual magnetism of the specimen.

As H is increased beyond OC, the specimen is increasingly magnetized in the negative direction, until the magnetic saturation is reached at D. By taking H back from its negative saturation value, through zero, to its original positive saturation value, a similar curve DEFA is obtained.

It is thus found that the intensity of magnetization 'I' always lags behind the magnetising field H, when H changes. The lagging of I behind H is called "hysteresis". The closed curve ABCDEFA which represents a cycle of magnetization of the specimen is known as the 'hysteresis 'curve' of the specimen. A graph between magnetic induction B and magnetising field H is similar in shape with the only difference that B never becomes constant but always increases with H. Hence in the B-H curve, the corners A and D are not straight but sloping.

Set up diagram:

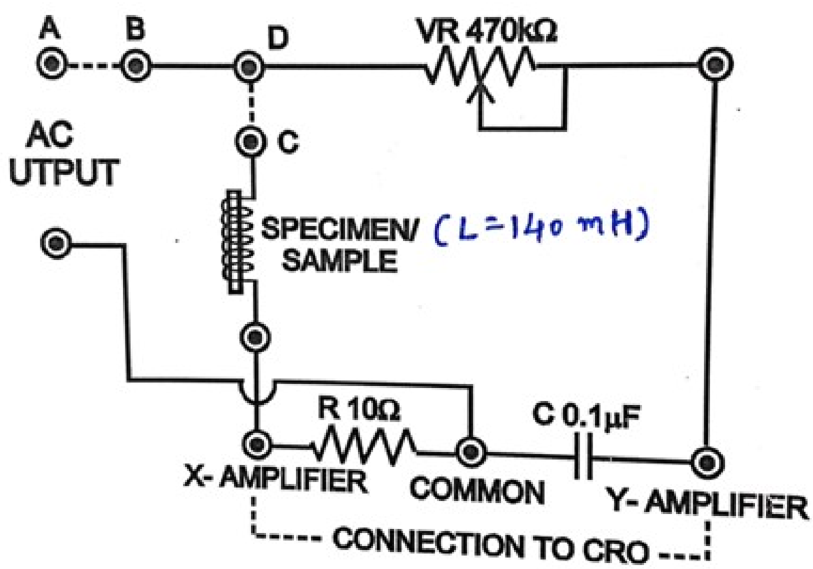


Fig.2

Safety and necessary Precautions:

1 Wear protective gear

2 Ensure proper wiring
3 Use appropriate voltage
4 Use appropriate measuring equipment
5 Avoid touching the circuit
6 Handle components with care
7 Follow laboratory guidelines

Procedure:

1 Arrange the connections as Shown in Fig. (2) i.e. by Connecting the dotted A, B & C, D points through patchcords. Connect X,Y and common points of CRO to points marked On the front panel. Set the AC output between 3V-15V. Throw the sample select switch Towards internal position so that FIG. (2) internal sample connects in the Circuit.
2 Switch ON the instrument using ON/ OFF toggle switch provided on the front panel.
3 To get the proper loop vary the resistance (V_R) & adjust the horizontal and vertical gain controls (G_h and G_v) of the CRO to obtain proper shape and size of the waveform (Hystersis Loop) as shown in Fig. (1).
4 Observe the Coercivity and Retentivity on CRO as shown in Fig. (1).
5 Tracing of B-H Curve: After obtaining a curve of suitable shape on CRO, a tracing paper is put on the screen. Now, set the vertical gain G_v to zero (with maximum horizontal gain) to obtain a straight line on the paper which marks the H-axis and then set the horizontal gain G_h (vertical gain G_v is not zero) to zero to get a straight line which marks B-axis. Now, adjust horizontal and vertical gain controls to their original position to obtain a curve of suitable shape. Trace this curve on the paper.

Observations:

Conclusion:

Quiz:

1. The unit of magnetic field intensity is _________________
2. Magnetic circuit obeys
   a) Kirchoff's Law b) Thevenin's theorem c) Nortorn's theorem d) None of these
3. The word "Hysteresis" means________________________
4. The unit of H x B is _______________________

Suggested Reference:

1. "Basic Electrical Engineering" by T. K. Nagsarkar and M. S. Sukhija, Oxford university press.

References used by the students:

Rubric wise marks obtained:

5=Excellent 4=Very Good 3=Good 2=Fair 1=Needs more work					
Rubrics	**Knowledge**	**Calculations**	**Participation**	**Journal work and submission**	**Total**
Marks					

Experiment No: 5
To determine resistance, inductance, power and power factor of series R-L circuit

Date:

Competency and Practical Skills: Knowledge of circuit theory, Familiarity with electrical components, Understanding of measuring instruments, Familiarity with safety measures, Analytical and troubleshooting skills, Ability to construct circuits.

Objectives: (a) To understand the basic concepts of resistance, inductance, power, and power factor in R-L series circuits and how they are related to each other.
(b) To learn how to measure the resistance and inductance of a circuit using appropriate equipment and techniques, such as mustimeters.
(c) To investigate the relationship between the voltage, current, and phase angle in an R-L series circuit and to determine the power factor of the circuit..
(d) To understand the practical applications of R-L series circuits in electrical engineering, such as in AC power transmission and electric motors.

Equipment/Instruments: Rheostat, Ammeters, Voltmeters, Wattmeter, single phase AC Supply, Inductive coil, Connecting probes.

Theory: The series R-L circuit comprises a resistor and an inductor connected in series with a voltage source. When an AC voltage is applied to the circuit, it causes a current to flow through the circuit. Due to the presence of inductance, the current lags behind the voltage by an angle. The phase angle between the voltage and the current is known as the power factor.

The power factor of a circuit is defined as the ratio of the real power (P) to the apparent power (S). The real power is the power consumed by the circuit, while the apparent power is the product of the voltage and current. The power factor ranges from 0 to 1, with a power factor of 1 indicating a purely resistive circuit.

The resistance (R) and inductance (L) of the circuit can be calculated using various electrical measuring instruments, such as a voltmeter, an ammeter, and a wattmeter.

A choke coil can be considered as a series combination of resistance r and self-inductance L. Choke coil is connected in series with a non – inductive resistance R (lamp-bank) across a 230 V, 50 Hz AC supply. As per the fig.1,

$$Z_{ckt} = \frac{V_S}{I} \qquad (1)$$

$$Z_{coil} = \frac{V_{coil}}{I} \qquad (2)$$

$$R = \frac{V_R}{I} \qquad (3)$$

Where Z_{ckt} — Impedance of Total circuit

Z_{coil} — Impedance of choke coil

R — Resistance of Rheostat

V_s – Supply Voltage

V_R – Voltage across Rheostat

r – Resistance of choke coil

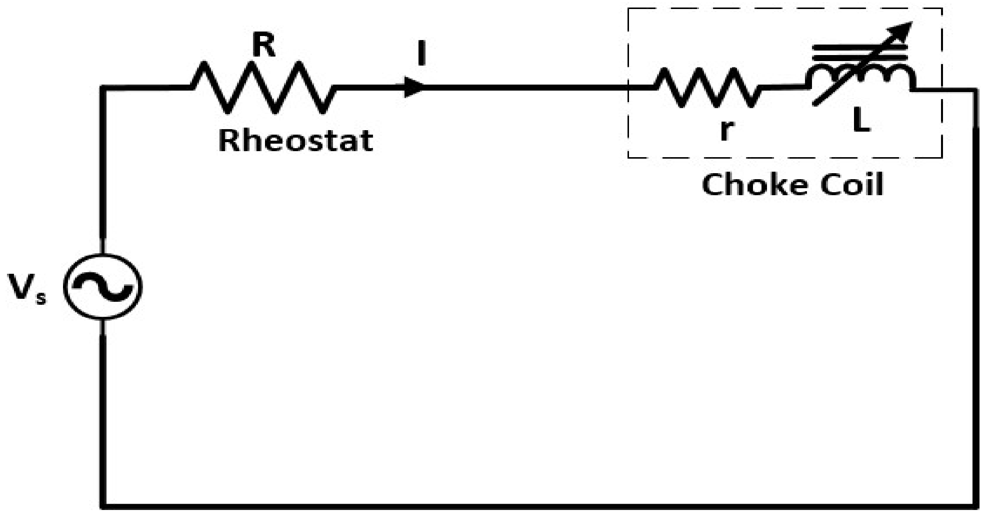


fig.1

It is evident that $$(R+r)^2 + X^2 = Z^2_{ckt} \quad (4)$$

$$R^2 + 2Rr + r^2 + X^2 = Z^2_{ckt}$$

But $$Z^2_{coil} = r^2 + X^2$$

$$\omega L = X$$

$$R^2 + 2Rr + Z^2_{coil} = Z^2_{ckt}$$

$$r = \frac{Z^2_{ckt} - Z^2_{coil} - R^2}{2R} \quad (5)$$

Now, $$Z^2_{coil} = r^2 + X^2$$

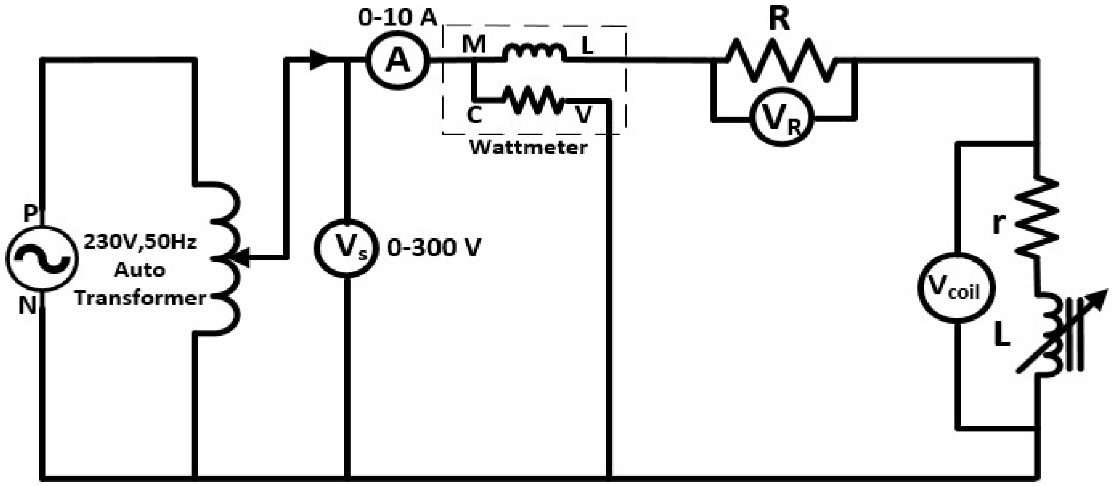
$$X = \sqrt{Z^2_{coil} - r^2} \quad (6)$$

But, $$\omega L = X$$

$$L = \frac{X}{\omega} = \frac{X}{2\pi f} H$$

Thus, resistance and inductance of choke coil can be calculated.

Set up diagram:



Safety and necessary Precautions:

1 Wear protective gear
2 Ensure proper wiring
3 Use appropriate voltage
4 Use appropriate measuring equipment
5 Avoid touching the circuit
6 Handle components with care
7 Follow laboratory guidelines

Procedure:

1. Set up the series R-L circuit by connecting the rheostat and choke coil in series.
2. Connect the voltmeter across the resistor to measure the voltage (V_R).
3. Connect the ammeter in series with the circuit to measure the current (I).
4. Connect the wattmeter to measure the power consumed by the circuit.
5. Switch on the AC voltage supply, Adjust the voltage to any suitable value
6. Record the readings of voltage, current, and power.
7. Repeat the measurements for different values of voltages.
8. Calculate the resistance (r), inductance (L), power (P), and power factor (PF).

Observations:

Sr. No.	Supply voltage V_s (volts)	Voltage across rheostat V_R (volts)	Voltage across coil V_{coil} (volts)	Current I (amps)	Power P (watts)
1.					
2.					
3.					

Calculation:
(Reading-1)

(1) $Z_{ckt} = \frac{V_s}{I} =$ $Z_{coil} = \frac{V_{coil}}{I} =$ $R = \frac{V_R}{I} =$

(2) $r = \frac{Z_{ckt}^2 - Z_{coil}^2 - R^2}{2R} =$ $X^2 = Z_{coil}^2 - r^2 =$ $L = \frac{X}{2\pi f} H =$

(3) $\cos\phi = \frac{R + r}{Z_{ckt}} =$ Power $P = V_s I \cos\phi =$

(Reading-2)

(1) $Z_{ckt} = \frac{V_s}{I} =$ $Z_{coil} = \frac{V_{coil}}{I} =$ $R = \frac{V_R}{I} =$

(2) $r = \frac{Z_{ckt}^2 - Z_{coil}^2 - R^2}{2R} =$ $X^2 = Z_{coil}^2 - r^2 =$ $L = \frac{X}{2\pi f} H =$

(3) $\cos\phi = \frac{R + r}{Z_{ckt}} =$ Power $P = V_s I \cos\phi =$

(Reading-3)

(1) $Z_{ckt} = \frac{V_s}{I} =$ $Z_{coil} = \frac{V_{coil}}{I} =$ $R = \frac{V_R}{I} =$

(2) $r = \frac{Z_{ckt}^2 - Z_{coil}^2 - R^2}{2R} =$ $X^2 = Z_{coil}^2 - r^2 =$ $L = \frac{X}{2\pi f} H =$

(3) $\cos\phi = \dfrac{R+r}{Z_{ckt}}$ = Power $P = V_s I \cos\phi$ =

Result:

Sr. No	**R**	**Z_{ckt}**	**Z_{coil}**	**Resistance of coil *(r)* Ω**	**Inductance of coil (L) H**	**Inductive reactance of coil (X) Ω**	**Power (P) Watt**	**Power factor (cosΦ)**
1.								
2.								
3.								

PHASOR DIAGRAM:

1. Select the scale 1 cm = _______ volts.
2. Draw the current (I) as a reference phasor OE as shown in Fig. 1.
3. Draw the phasor OB (=VR) to the scale in phase with the current phasor OE.
4. From the point B, draw an arc of radius equal to Vcoil (to the scale).
5. From the point O, draw an arc of radius equal to Vs (to the scale) such that it intersects the previous arc at A.
6. Thus, phasor BA represents the voltage across the coil and phasor OA represents the supply voltage.
7. Draw the perpendicular from the point A intersecting the current phasor at D.
8. Phasor BD represents the voltage across the resistance of the coil. Hence BD = Ir.
9. Phasor AD represents the voltage across the inductive reactance of the coil. Hence AD = I_X
10. Determine r and L from the phasor diagram. Compare the results.

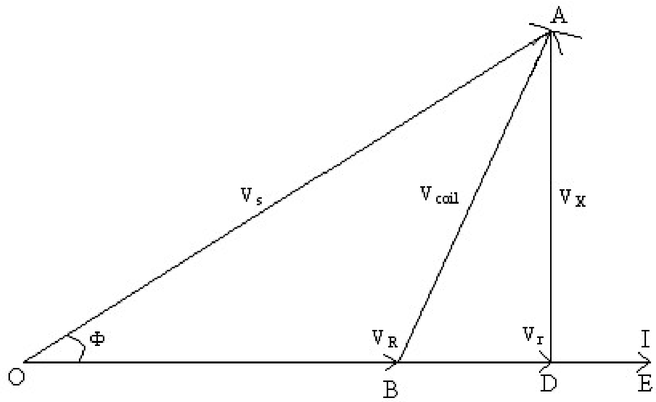


fig.2

Conclusion:

Quiz:

1. Define RMS value.

2. What is phasor?

3. What is impedance triangle?

4. State advantages of sinusoidal alternating quantity.

Suggested Reference:

1. "Basic Electrical Engineering" by T. K. Nagsarkar and M. S. Sukhija, Oxford university press.
2. **https://vlab.amrita.edu/?sub=1&brch=75&sim=332&cnt=1**

References used by the students:

Rubric wise marks obtained:

5=Excellent 4=Very Good 3=Good 2=Fair 1=Needs more work					
Rubrics	**Knowledge**	**Calculations**	**Participation**	**Journal work and submission**	**Total**
Marks					

Experiment No: 6
To verify the current and voltage relationships in three phase star and delta connections.

Date:

Competency and Practical Skills: Understanding of Three-Phase Systems, Knowledge of Star and Delta Connections, Familiarity with Electrical Instruments, Practical Skills in Wiring, Analytical and Problem-Solving Skills, Safety and Lab Etiquette

Objectives: (a) To understand the concepts of three-phase power systems, star and delta connections, and their applications in practical scenarios.
(b) To verify the relationship between line and phase voltages and currents in three-phase star and delta connections using various measuring instruments such as voltmeters, ammeters, and wattmeters
(c) To understand the importance of safety measures when working with electrical circuits and equipment.

Equipment/Instruments: 3-phase Auto Transformer, AC voltmeters and Ammeters, lamp load, Connecting wires.

Theory: Three-phase power systems are widely used in electrical power distribution. The three-phase system consists of three conductors carrying alternating currents that are 120 degrees out of phase with each other. The most common configurations for three-phase systems are star and delta connections. In this write-up, we will discuss the current and voltage relationships in both star and delta connections and the methods to verify them.

Star Connection:

In a three-phase star connection, three-phase windings of a transformer or an electrical machine are connected together at a common point called the neutral. The three-phase conductors are connected to the remaining ends of the windings, and the voltage between any two of these conductors is known as the line voltage. The current flowing in each winding is known as the phase current.

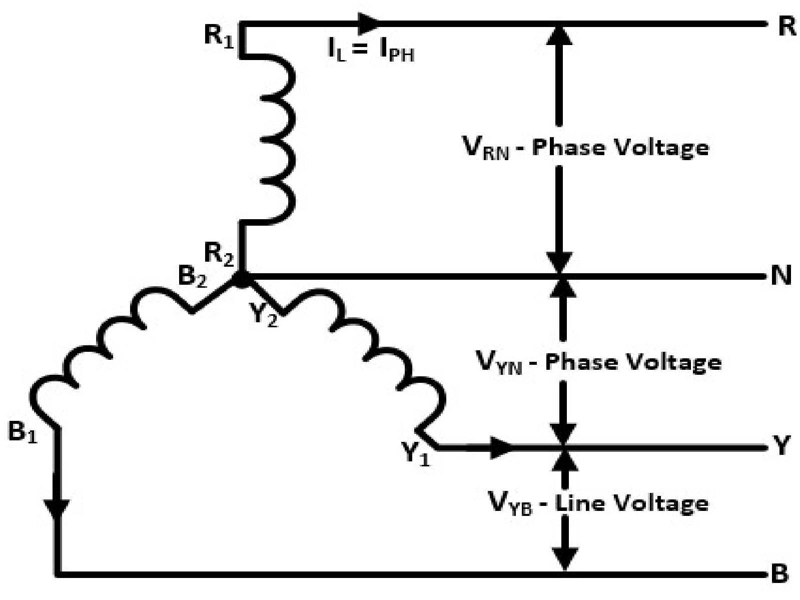


Fig.1

In the three-phase system, where all the three phases wires are connected to a common point. This common point is known as the neutral point. And this type of connection is known as Star

Connection. The star connection will be called a three-phase three-wire system when only three live wires are used. And the star connection will be called a three-phase four-wire system when all the three phases and the neutral wire is used. The neutral wire is connected to the neutral point where all three phases are connected. As the star connection looks like the English letter 'Y', it is also known as wye connection.

- In the star connection, all three phases are connected to a neutral point. If the voltage across all the phases and the current in each phase are equal, the voltage of the neutral point will be zero.
- In the star connection, the line voltage and phase voltage are different. Line voltage is root 3 times of phase voltage. Line voltage is measured between any two phases whereas phase voltage is measured between any one phase and neutral.
- In a star connection, we can have two different voltages, so we can connect it with two different circuits operated at two different voltages. For example, from a 440V three-phase system, we can get two different voltages such as 440V and 230V.
- In the star connection, the line current is equal to the phase current.
- In the star connection, less insulation is required for each phase as the phase voltage is less than the line voltage.

As the line and phase voltage is different for the star connection,

So relationship of line voltage with phase voltage is,

$$V_L = \sqrt{3} * V_{PH}$$

Line Voltage = $\sqrt{3}$ * Phase Voltage

The relationship of line current in the star connection is

$$I_L = I_{PH}$$

Line Current = Phase Current

Delta Connection:

In a three-phase delta connection, the three-phase windings are connected in a closed loop. Each winding is connected to the next winding in the sequence, and the end of the third winding is connected back to the beginning of the first winding. The voltage between any two of the windings is known as the phase voltage, and the current flowing in each winding is known as the phase current.

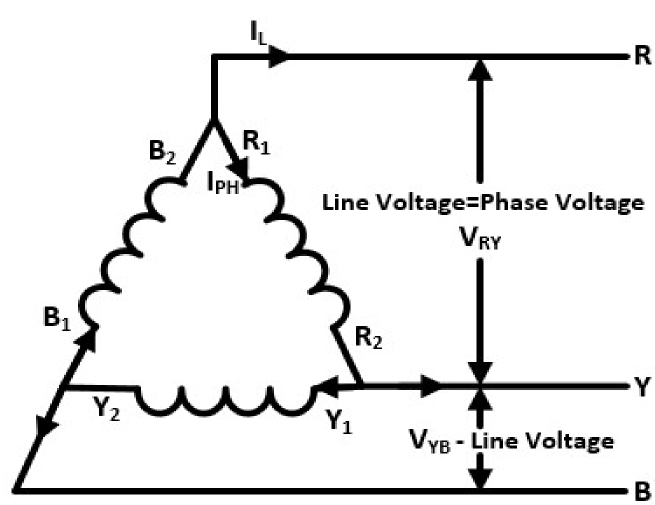


Fig.2

- There is no neutral point in the delta connection.
- In the delta connection, phase voltage is equal to the line voltage.
- In the delta connection, the line current is root three times the phase current.
- Delta connection provides a single voltage. Here, you can not get two different voltages like the star connection.

As the line and phase current is different for the delta connection,
So relationship of line current is,

$$I_L = \sqrt{3} * I_{PH}$$

Line Current = $\sqrt{3}$ * Phase Current

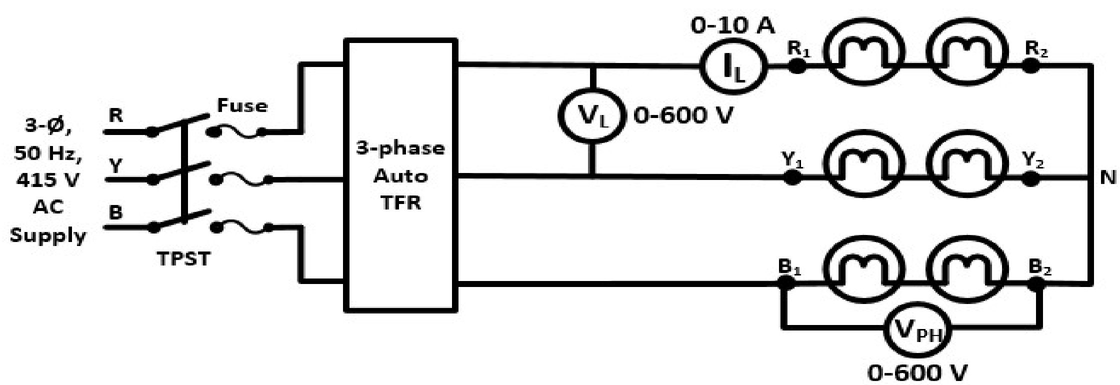
The relationship of line voltage in the delta connection is

$$V_L = V_{PH}$$

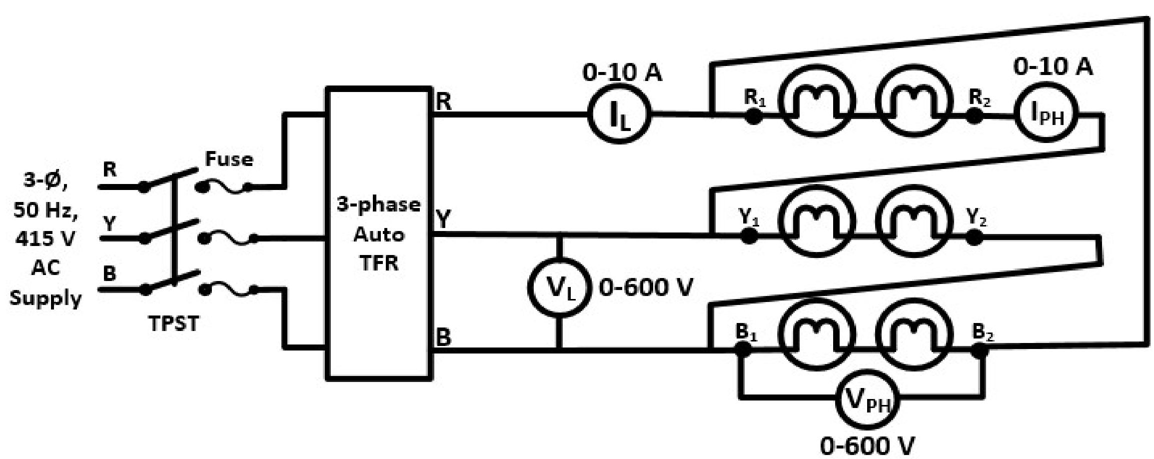
Line Voltage = Phase Voltage

Set up diagram:

<u>Star Connection:</u>



<u>Delta Connection:</u>



Safety and necessary Precautions:

1. Wear protective gear
2. Ensure proper wiring
3. Use appropriate voltage
4. Use appropriate measuring equipment
5. Avoid touching the circuit
6. Handle components with care

7 Follow laboratory guidelines

Procedure:

Star Connected Load

a. Connect the circuit of star connection as per circuit diagram shown above.
b. Switch on the AC voltage supply by keeping the autotransformer in minimum position.
c. Vary the auto transformer voltage and set at appropriate value.
d. Note down corresponding readings of ammeter and voltmeters.
e. Verify $V_{PH} = \frac{V_L}{\sqrt{3}}$ and $I_L = I_{PH}$
f. Repeat the above procedure for different value of voltages.
g. Bring back the auto transformer to minimum position. Switch off the supply and remove all connections.

Delta Connected Load

a. Connect the circuit of delta connection as per circuit diagram shown above.
b. Switch on the AC voltage supply by keeping the autotransformer in minimum position.
c. Vary the auto transformer voltage and set at appropriate value.
d. Note down corresponding readings of ammeter and voltmeters.
e. Verify $V_L = V_{PH}$ and $I_{PH} = \frac{I_L}{\sqrt{3}}$
f. Repeat the above procedure for different value of voltages.
g. Bring back the auto transformer to minimum position. Switch off the supply and remove all connections.

Observations:

Star Connection:

SR No	Line Voltage V_L (V)	Phase Voltage V_{PH} (V)	Line Current I_L (A)	Phase Current I_{PH} (A)	$V_{PH} = V_L/\sqrt{3}$

Delta Connection:

SR No	Line Voltage V_L (V)	Phase Voltage V_{PH} (V)	Line Current I_L (A)	Phase Current I_{PH} (A)	$I_{PH} = I_L/\sqrt{3}$

Calculation:

Conclusion:

Quiz:

1. What are advantages of 3-Ø supply over 1-Ø supply?

2. What do you mean by balanced system?

3. Write the formula of Active power for 3-Ø delta connected load.

4. Phase angle between line voltage and phase voltage in star connected load is__________

Suggested Reference:

1. B. L. Theraja, "Electrical Technology – Part I and II", S. Chand and Co. 2012
2. Basic Electrical Engineering - Nagsarkar and Sukhija, Oxford University Press

References used by the students:

Rubric wise marks obtained:

5=Excellent 4=Very Good 3=Good 2=Fair 1=Needs more work					
Rubrics	**Knowledge**	**Calculations**	**Participation**	**Journal work and submission**	**Total**
Marks					

Experiment No: 7
To Measure power in three phase circuit by two wattmeter method.

Date:

Competency and Practical Skills: Knowledge of three-phase power systems, Knowledge of Wattmeters, Familiarity with two-wattmeter method, Understanding of safety precautions,

Objectives: (a) To understand the principle of operation of the two-wattmeter method.
(b) To learn the connection of wattmeters in a three-phase circuit
(c) To verify the theory of two-wattmeter method by calculating power in three-phase circuit.
(d) To observe the phase angle between the voltage and current in a three-phase circuit and to determine the power factor of the circuit.
(e) To compare the power calculated by the two-wattmeter method with the power calculated by the three-wattmeter method and to evaluate the accuracy of the two-wattmeter method

Equipment/Instruments: 3-phase Auto Transformer, AC voltmeters and Ammeters, lamp load, Connecting wires.

Theory: Power in a three phase system with balanced or unbalanced load can be measured by two wattmeter method. The load may be star or delta connected. Here we have considered star connected load as shown in fig, although it can be equally applied to a delta connected load.
Two wattmeter methods is the most common method for the measurement of power in 3- phase system. The current coils are of two wattmeters are connected in series in any two lines and the potential coils are connected between these lines and the third line in which the current coil is not connected. It can be proved that the sum of instantaneous values of power indicated by these wattmeters equal s the total power absorbed by the 3-phase load.
Let us consider two wattmeters connected to measure power in three phase circuit as shown in circuit diagram.

Instantaneous reading of P_1 wattmeter, $P_1 = I_{1.} (V_1 - V_3)$

Instantaneous reading of P_2 wattmeter, $P_2 = I_{2.} (V_2 - V_3)$

Sum of instantaneous readings of two wattmeter's, $P = P_1 + P_2$

$= I_1 (V_1 - V_3) + I_{2.} (V_2 - V_3)$

$= V_1 I_1 + V_2 I_2 - V_3 (I_1 + I_2)$

From Kirchoff's law, $I_1 + I_2 + I_3 = 0$ OR $I_3 = - (I_1 + I_2)$
Therefore, the sum of instantaneous readings of two wattmeters, $V_1 I_1 + V_2 I_2 + V_3 I_3$
Therefore the sum of 2 wattmeter readings is equal to the power consumed by the load. This is irrespective of whether the load is balanced or unbalanced.

For balanced star connected load

ABBREVIATIONS:

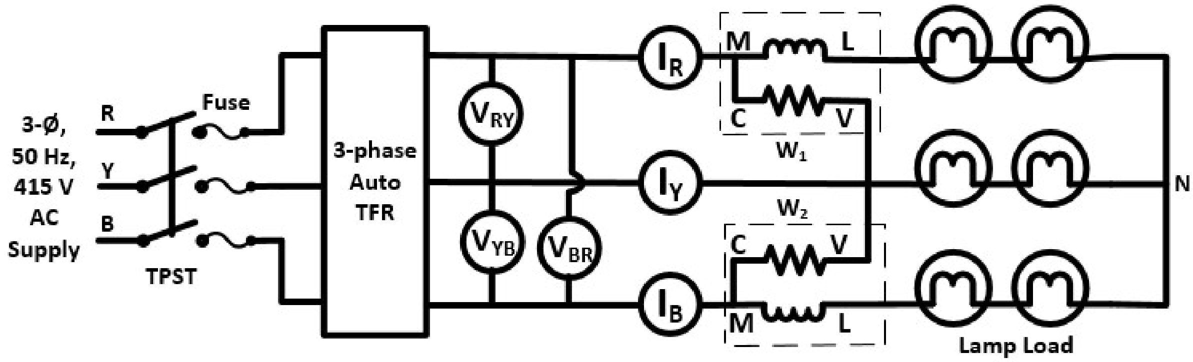
Line Voltage $(V_L) = \sqrt{3}$ Phase Voltage (V_{PH})

Line Voltage $(V_L) = V_{RY} = V_{YB} = V_{BR} = V_L = \sqrt{3}\, V_{PH}$

Phase Voltage $(V_{PH}) = V_R = V_Y = V_B = V_{PH} = V$

Line Current (I_L) = Phase Current $(I_{PH}) = I$

Set up diagram:



Safety and necessary Precautions:

1. Wear protective gear
2. Ensure proper wiring
3. Use appropriate voltage
4. Use appropriate measuring equipment
5. Avoid touching the circuit
6. Handle components with care
7. Follow laboratory guidelines

Procedure:

1. Make connections as per circuit diagram.
2. Keep operating dial of 3-phase variac at its null ('0') position & then switch ON 3-phase input a.c. supply.
6. By controlling the operating dial of 3-phase variac, set the input phase voltage (V) at appropriate value making sure that the 3-phase supply is balanced.
7. Gradually increase the load equally in all phases and note down various readings
8. Note line voltages and line currents of respective lines.
9. Note readings of wattmeter (W_1) and wattmeter (W_2).
10. Calculate $\emptyset = (\sqrt{3}\frac{W1-W2}{W1+W2})$

Observations:

Sr. No.	Observation Table								Calculations	
	Line Voltage			Line Current			Wattmeter Reading		3 ϕ Active Power (= P)	
	V_{RY}	V_{YB}	V_{BR}	I_R	I_Y	I_B	W_1	W_2	$P = W_1 + W_2$	$P = \sqrt{3}\, V_L I_L \cos\phi$
1.										
2.										
3.										

Calculation:

3- ϕ Active Power $P = \sqrt{3}\, V_L\, I_L \cos\phi$ = ________

3-ϕ Re active Power $Q = \sqrt{3}\, V_L\, I_L \sin\phi$ = ________

Apparent Power $S = \sqrt{3}\, V_L\, I_L$ = ________

Conclusion:

Quiz:

1. Define power factor.

2. Two wattmeter method is applicable for star connected system or delta connected system or both? Justify your answer.

3. Total number of phase sequence in 3-Ø AC system is___________
4. In the two wattmeter method of measuring power in 3-Ø circuit, the two wattmeter will show equal readings when the power factor angle is equal to______

Suggested Reference:

1. A. Chakrabarti, Circuit Theory (Analysis and Synthesis). Fifth Edition : 2006, Dhanpat Rai and Co.

2. Basic Electrical Engineering - Nagsarkar and Sukhija, Oxford University Press

3. http://vlabs.iitkgp.ernet.in/asnm/exp7/index.html Analog Signals, Network and Measurement Laboratory(IIT KHARAGPUR)

References used by the students:

Rubric wise marks obtained:

5=Excellent 4=Very Good 3=Good 2=Fair 1=Needs more work					
Rubrics	**Knowledge**	**Calculations**	**Participation**	**Journal work and submission**	**Total**
Marks					

Experiment No: 8
To Study BLDC Motors

Date:

Competency and Practical Skills: Basic Electrical Knowledge, Reading and Understanding Electrical Diagrams, Knowledge of safety precautions.

Objectives: (a) To understand the constriction of BLDC Motors.
(b) To familiarize with BLDC Motors terminologies.
(c) To study working principle of BLDC Motors.

Equipment/Instruments: Cut section of DC Motors.

Theory: Brushless DC motors (BLDCs) have been a primary focus for numerous motor manufacturers, as they are becoming the preferred choice in a growing number of applications, particularly in the field of motor control technology. BLDC motors possess numerous advantages over brushed DC motors, such as the capacity to operate at high velocities, improved heat dissipation, and high efficiency. They are indispensable elements of contemporary drive technology, and they are frequently employed in actuating motors, machine tools, electric propulsion, robotics, computer peripherals, and even electrical power generation. In terms of reliability, size, and total system cost, these electric motors have become highly effective as a result of the advancements in sensor-less technology and digital control.

A brushless DC motor (BLDC) is a permanent magnet synchronous electric motor powered by direct current (DC) electricity, utilising an electronically controlled commutation system—where commutation refers to the process of generating rotational torque by altering phase currents at precise intervals—rather than a mechanical commutation system.

BLDC motors are also known as trapezoidal permanent magnet motors. In contrast to traditional brushed DC motors, which utilise brushes to establish mechanical contact with the rotor's commutator, thereby creating an electrical connection between a DC power source and the rotor's armature windings, a BLDC motor utilises electrical commutation with a permanent magnet rotor and a stator featuring a series of coils.

Key Differences Between a BLDC Motor and a Brushed DC Motor

Aspect	Brushed DC Motor	Brushless DC (BLDC) Motor
Commutation Method	**Mechanical Commutation**: Uses a commutator and brushes for switching current in the windings.	**Electronic Commutation**: Uses an electronic controller to switch current in the windings.
Commutator	Contains a physical **commutator and brushes** to transfer current to the rotor windings.	Does not have a commutator; relies on electronic circuits to control current flow.
Maintenance	Requires periodic maintenance due to wear of brushes and commutator.	Low maintenance as there are no brushes or commutator.
Efficiency	Less efficient due to friction and power loss in the brushes.	More efficient due to reduced friction and precise electronic control.

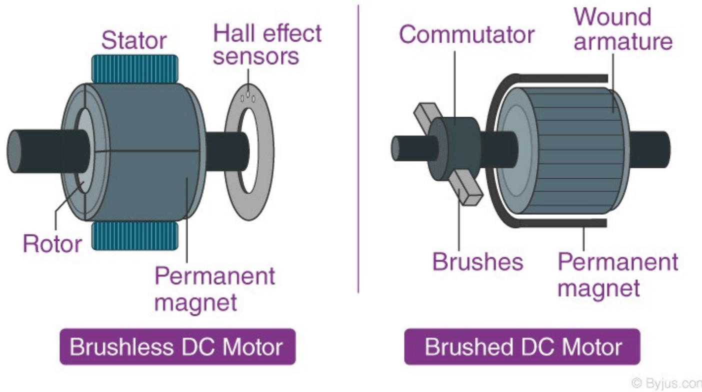


Figure 1*Difference between Brushless and Brushed DC Motor*

Principle of Operation of a BLDC Motor

A Brushless DC (BLDC) motor operates based on the interaction between magnetic fields produced by the stator and rotor. The stator contains coils (windings) arranged in phases, which create a rotating magnetic field when current flows through them. The rotor, which has permanent magnets, aligns itself with the stator's magnetic field due to magnetic attraction and repulsion. As the stator's magnetic field rotates, the rotor follows, producing continuous rotational motion. This interaction ensures smooth torque generation and efficient operation, making the BLDC motor highly reliable and widely used in various applications.

In this motor, the permanent magnet (or field poles) spins while the current-carrying conductors remain stationary. The armature coils are electrically switched by transistors or silicon-controlled rectifiers at the appropriate rotor location, ensuring that the armature field is in spatial quadrature with the rotor field poles. Consequently, the force exerted on the rotor induces its rotation. Hall sensors or rotary encoders are predominantly employed to detect the rotor's position and are situated around the stator. The rotor position data from the sensor facilitates the determination of the appropriate timing for switching the armature current.

Electronic Commutation in a BLDC Motor

Conventionally in brushed DC motors, the commutator mechanically reverses the current direction in the rotor windings as the rotor turns, ensuring continuous torque in one direction. The physical contact between brushes and commutator causes wear, friction, and electrical noise, limiting efficiency and lifespan. To overcome this, electronic commutation was introduced. The electronic controller senses the rotor's position (using Hall sensors or back EMF) and switches the current in the stator windings at the right time to maintain rotation and torque. It eliminates physical wear, increases efficiency, enables precise control of speed and torque, and allows for quieter operation.

Thus, unlike traditional brushed motors, BLDC motors use electronic commutation to control the energizing of the stator phases. In this process, sensors (such as Hall sensors) detect the rotor's position and send feedback to the motor controller. Based on this feedback, the controller switches the current between the motor's phases in a precise sequence to ensure that the stator's magnetic field remains synchronized with the rotor's position.

The stator phases are energized in pairs (e.g., A-B, B-C, C-A), with one phase acting as the positive terminal, another as the negative terminal, and the third phase left unenergized in each step. This sequence repeats as the rotor moves, ensuring continuous rotation.

Consider the following configuration of three windings in the stator, which are denoted by the letters A, B, and C. For the purpose of clarity, let us replace the rotor with a single magnet. The application of current through a coil generates a magnetic field, with the

Figure 1 Generalized Block Diagram of BLDC Motor

orientation of the field lines, or the poles of the resultant magnet, determined by the direction of the current flow through

Field system

The function of the field system is to produce uniform magnetic field within which the armature rotates. Field coils are mounted on the poles and carry the dc exciting current. The field coils are connected in such a way that adjacent poles have opposite polarity. The m.m.f. developed by the field coils produces a magnetic flux that passes through the pole pieces, the air gap, the armature and the frame. Practical d.c. machines have air gaps ranging from 0.5 mm to 1.5 mm.

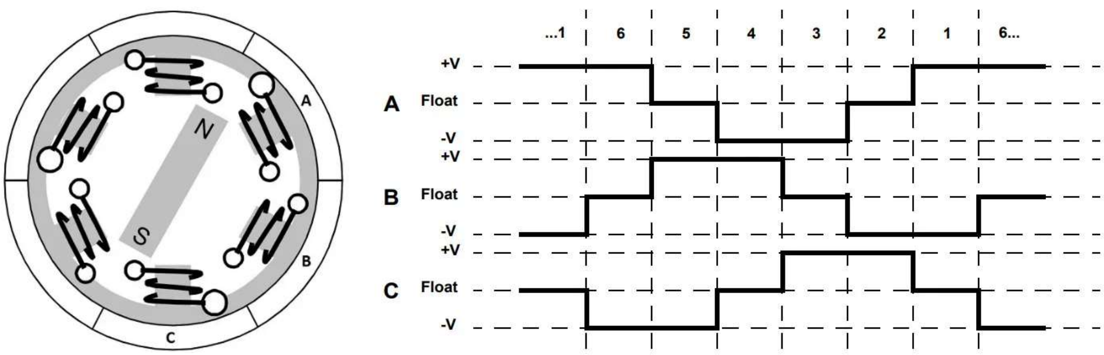


Figure 2BLDC Motor Winding Arrangement and Stator Winding Supply Voltage Waveform

By applying this principle, supplying current to coil A will generate a magnetic field that attracts the rotor magnet. The rotor magnet's position will shift slightly clockwise to align with A. Passing current through coils B and C sequentially will result in the rotor magnet rotating in a clockwise direction. To enhance efficiency, we can utilise a single coil to wind the opposing coils, thereby achieving double attraction. To enhance efficiency, it is possible to energise two coils simultaneously, allowing one coil to attract the magnet while the other repels it. At this time, the third will remain inactive.

Based on the diagram presented, it can be confirmed that at any given moment, one phase is positive, one phase is negative, and the third phase remains idle (or floating). Based on the inputs from the Hall Sensors, two phases are switched according to the diagram provided above.

In a full 360° rotation of the rotor magnet, there are six applicable combinations of coils A, B, and C, as illustrated in the subsequent timing diagram.

Thus, this electronic commutation system replaces the commutator and brushes in a DC motor, resulting in enhanced reliability and reduced noise during operation. BLDC motors can operate at high speeds due to the lack of brushes. BLDC motors often exhibit an efficiency of 85 to 90 percent, while brushed DC motors have an efficiency of 75 to 80 percent. A diverse array of BLDC motors exists, encompassing minor power ranges, fractional horsepower, integral horsepower, and enormous power ranges.

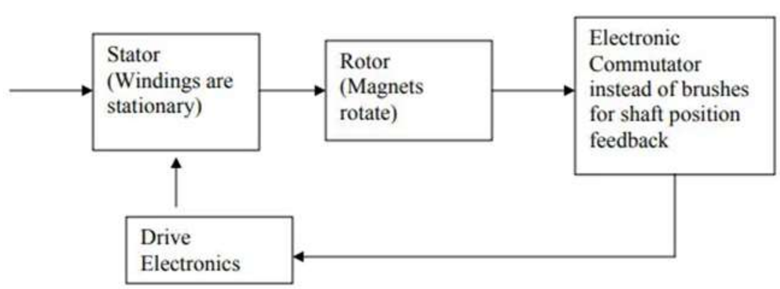


Figure 3 Generalized Block Diagram of BLDC Motor

Construction

The construction of BLDC motors can take place in a variety of various physical layouts. These can be constructed as single-phase, two-phase, or three-phase motors (depending on the stator windings), depending on the configuration. Three-phase brushless direct current (BLDC) motors with permanent magnet rotors are the most prevalent type of motors utilised. The construction of this motor has similarities with three phase induction motor and conventional DC motor.

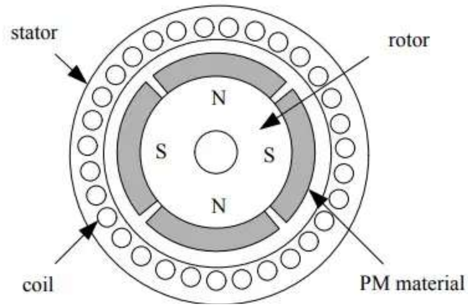


Figure 4 Cross section view of BLDC Motor

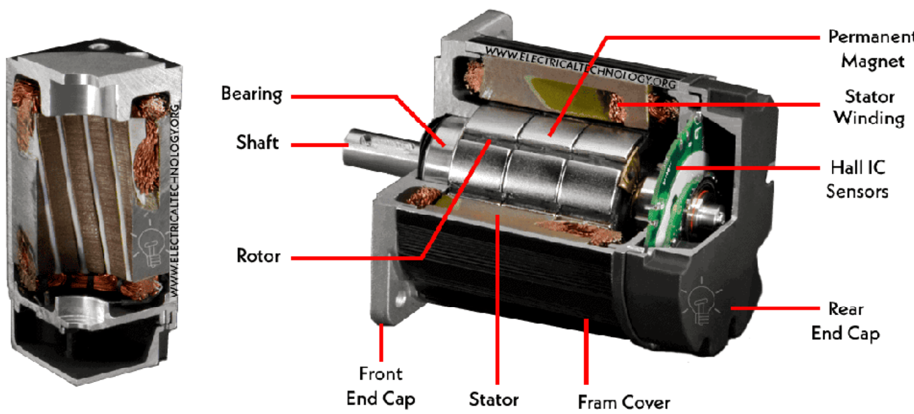


Figure 5 Parts of the BLDC Motor

According to power supply capacity, the stator must have the right voltage rating. 48 V or less BLDC motors are best for robotics, automotive, and small actuation applications. Whereas industrial and automation systems employ 100 V or higher motors.

A Brushless DC (BLDC) motor consists of the following main components:

Stator

The stator is the stationary part of the motor that generates a rotating magnetic field. It is made of laminated steel sheets to reduce eddy current losses. The stator has concentrated windings or distributed windings, arranged in specific patterns (e.g., star or delta configuration). The windings are energized sequentially by an electronic controller to produce a rotating magnetic field, which interacts with the rotor. in a Brushless DC (BLDC) motor.

The materials used for the stator and rotor are carefully chosen to enhance performance, efficiency, and durability. The stator, which is the stationary part of the motor, is typically made from laminated steel sheets to reduce energy losses caused by eddy currents. These steel laminations are coated with insulation to minimize electrical losses. The stator windings are made of copper, which is preferred for its excellent electrical conductivity, ensuring efficient current flow and strong magnetic field generation

Rotor

The rotor, which is the rotating part of the motor, is usually made of a solid steel core to provide mechanical strength. Permanent magnets, typically made from materials like neodymium-iron-boron (NdFeB) or ferrite, are attached to or embedded within the rotor. Neodymium magnets are preferred in high-performance applications due to their strong magnetic properties, while ferrite magnets are used for cost-effective designs.

The rotor is the rotating part of the motor, driven by the interaction with the stator's magnetic field. It is typically made of steel to support the magnets and ensure mechanical strength. Hence, permanent magnets are mounted on the rotor, and their polarity interacts with the stator's magnetic field to generate torque. The number of poles can range from two to eight, with North (N) and South (S) poles arranged in an alternating pattern, depending on the application. The poles are arranged in three distinct ways in the image below. The magnets are positioned on the rotor's outer periphery in the initial scenario

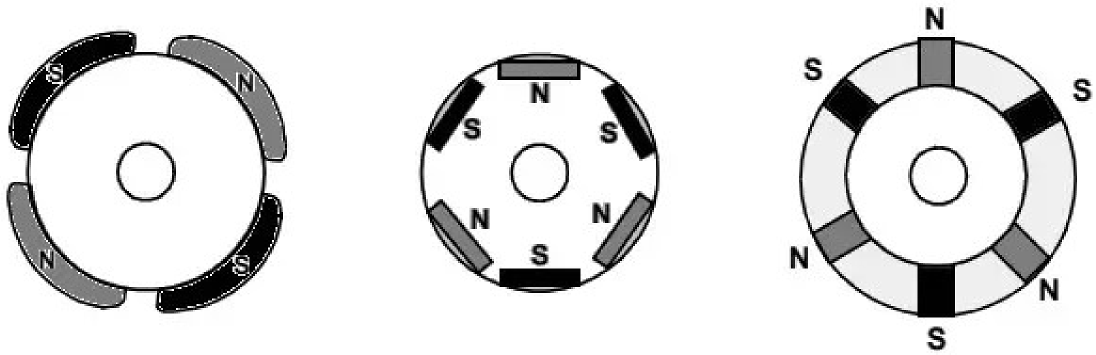


Figure 3Different Arrangements of the Permanent Magnets on the Rotor of BLDC Motor

Thus, there are two main types based on magnet placement:

- **Surface-mounted**: Magnets are placed on the surface of the rotor.
- **Interior-mounted**: Magnets are embedded within the rotor.

Permanent Magnets

Magnets are critical in creating the interaction between the rotor and stator. Typically made of rare earth materials like neodymium, ferrite, or samarium-cobalt for high magnetic strength. The magnets on the rotor provide a consistent magnetic field, which aligns with the stator's field to produce motion.

Using permanent magnets in Brushless DC (BLDC) motors offers several advantages, making them highly efficient, reliable, and suitable for a wide range of applications. These advantages stem from the unique properties of permanent magnets, such as their ability to generate a strong and consistent magnetic field. Below are the key benefits:

The permanent magnets-

-offer a consistent magnetic flux, reducing energy input and rotor losses, resulting in improved efficiency compared to induction or wound-rotor motors.

-provide high torque-to-weight and power-to-weight ratios. Smaller, lighter motors with the same power output are appropriate for space-constrained applications like electric cars and drones.

-offer reliable magnetic fields, eliminating frictional losses and rotor copper losses, unlike brushed DC motors and induction motors.

-reduce core losses, enhancing thermal efficiency.

-can be used without electrical stimulation or mechanical commutation, decreasing wear. No maintenance is needed to replace brushes and commutators without brushes.

-reduce rotor inertia, allowing for high-speed operation and improved dynamic responsiveness.

-generate less heat than electrically stimulated motors due to no losses in rotor magnetic field generation. Reduced heating enhances motor longevity and dependability. BLDC motors have a simpler rotor without windings, slip rings, or brushes. It streamlines production and enhances durability.

-provide fine speed and torque control, making BLDC motors appropriate for automotive (electric cars, power steering), robotics, and automation. Aerospace, drones, HVAC, pumps, compressors, etc.

Windings

Windings are copper wires wound around the stator poles. When energized by the electronic controller, they create electromagnetic fields. Three-phase windings are most common in BLDC motors. The windings are activated sequentially to produce a rotating magnetic field. BLDC motors use two main types of winding configurations based on the back-EMF waveform they generate:

Trapezoidal Winding Configuration: The windings are designed to produce a trapezoidal back-EMF waveform. The stator windings are concentrated in such a way that the magnetic field distribution results in a trapezoidal shape. This configuration requires simpler control logic (often called six-step commutation). It is ideal for cost-sensitive and less precision-critical applications, such as cooling fans, pumps, and household appliances.

Sinusoidal Winding Configuration: The windings are designed to produce a sinusoidal back-EMF waveform. The stator windings are distributed to ensure that the magnetic field in the air gap is sinusoidal. Requires advanced electronic controllers to perform sinusoidal commutation (e.g., Field Oriented Control, FOC). Such winding is employed in BLDC motors used in high-precision and noise-sensitive applications, such as electric vehicles, robotics, and drones.

The choice of winding configuration in a BLDC motor depends on the application's requirements for smoothness, noise, cost, and control complexity. Trapezoidal windings are preferred for simple and cost-effective solutions, while sinusoidal windings are used for precision and performance-critical applications.

Position Sensors

In a Brushless DC (BLDC) motor, Hall sensors or other position sensors play a crucial role in detecting the rotor's position, which is necessary for the motor’s operation. Unlike traditional brushed DC motors that rely on mechanical brushes for commutation, BLDC motors use electronic commutation to control the energizing of stator windings. The position sensors rovide feedback to the motor controller about the rotor's orientation relative to the stator. This information ensures that the correct stator winding is energized at the right time, maintaining synchronization between the rotor and the stator's magnetic fields. This synchronization minimizes torque ripple, enhances efficiency, and ensures smooth and reliable operation of the motor.

In addition to Hall sensors, advanced sensors such as optical encoders and resolvers are used in applications that require high precision or operate in harsh environments. Alternatively, sensorless control methods, which estimate rotor position based on back-EMF, are also popular for cost-sensitive or high-speed applications. These position-detection techniques enable key motor functions like speed control, torque production, and direction management. For first-year engineering students, understanding the role of position sensors in BLDC motors lays the foundation for exploring electronic commutation, motor control, and real-world applications such as robotics, electric vehicles, and industrial automation systems.

Losses in BLDC Motor:

In a Brushless DC (BLDC) motor, there are several types of losses that occur during its operation, which affect its overall efficiency. Understanding these losses is essential for first-year engineering students as it helps in designing more efficient motors for various applications.

Copper Losses (I^2R Losses):

Copper losses occur due to the resistance of the copper windings in the stator. When current flows through the stator windings to create a magnetic field, some of the electrical energy is lost as heat due to the resistance of the copper wire. These losses increase with higher currents and contribute to motor heating, reducing efficiency. The thicker the copper wire, the lower the resistance and the smaller the copper losses.

Iron Losses (Core Losses):

Iron losses, also known as core losses, occur in the stator due to the alternating magnetic field. The core material (typically steel) experiences magnetization and demagnetization as the stator's magnetic field changes direction. This causes energy to be lost in the form of heat. Iron losses in BLDC motor can further be subdivided as:

- **Hysteresis Loss:** Loss due to the friction of magnetic domains in the steel when they change direction.
- **Eddy Current Loss:** Loss due to circulating currents induced in the core material by the changing magnetic field.

These losses are dependent on the frequency of the alternating magnetic field and the properties of the core material.

Mechanical Losses:

Mechanical losses occur due to friction in the bearings, air resistance (windage losses), and any other moving parts. Even though BLDC motors do not have brushes (which contribute to friction in brushed motors), mechanical losses still occur in the form of friction between the rotor and bearings or resistance from the airas the rotor spins. Mechanical losses increase with higher speeds and contribute to the overall energy loss in the motor.

Stray Losses:

Stray losses are the result of factors that are not easily categorized, such as leakage flux or non-ideal motor design. These losses may arise from imperfect magnetic field interactions or imperfections in the materials used. These losses are typically small but still contribute to the overall inefficiency of the motor.

Switching Losses:

In BLDC motors, the switching of the power transistors (such as MOSFETs or IGBTs) in the electronic commutation process also results in energy losses. Each time the transistors switch on or off, there is a small amount of energy lost due to the voltage and current changes. Switching losses are more noticeable at higher speeds and switching frequencies.

Applications of BLDC Motor:

Brushless DC (BLDC) motors are widely used in many everyday applications due to their high efficiency, reliability, and low maintenance requirements. Here are some common applications of BLDC motors in daily life:

- **Electric Vehicles (EVs):** BLDC motors are commonly used in electric cars, e-bikes, and electric scooters for propulsion. Their high efficiency and smooth operation make them ideal for these applications.
- **Drones and UAVs:** Drones and unmanned aerial vehicles (UAVs) use BLDC motors because of their lightweight, high power-to-weight ratio, and precise control, which are crucial for stable flight.

Household Appliances:

- **Fans:** BLDC motors are used in ceiling fans, table fans, and exhaust fans for their energy efficiency and quiet operation.
- **Vacuum Cleaners:** Many modern vacuum cleaners use BLDC motors to provide powerful suction while keeping noise levels low.
- **Washing Machines:** Some washing machines use BLDC motors for smooth operation, reduced vibration, and higher energy efficiency.

Computer Cooling Fans: BLDC motors are used in computer cooling fans because of their efficiency, reliability, and the ability to run at variable speeds, which helps in controlling the temperature of computer components.

HVAC Systems: BLDC motors are used in heating, ventilation, and air conditioning (HVAC) systems, especially in air handlers and blowers, due to their energy-saving potential and smooth operation.

Power Tools: Cordless power tools like drills, saws, and screwdrivers often use BLDC motors because they provide higher efficiency, longer battery life, and less maintenance compared to brushed motors.

Conclusion:

Quiz:

1. **What is the main difference between a BLDC motor and a brushed DC motor?**

   a) BLDC motors use brushes, while brushed DC motors do not.
   b) BLDC motors have higher losses compared to brushed DC motors.
   c) BLDC motors use electronic commutation instead of mechanical brushes.
   d) Brushed DC motors are more efficient than BLDC motors.

2. **Which material is commonly used for the windings in a BLDC motor?**
   a) Aluminium
   b) Copper
   c) Iron
   d) Steel

3. **What is the role of position sensors in a BLDC motor?**
   a) To detect the speed of the motor.
   b) To detect the position of the rotor for electronic commutation.
   c) To reduce noise during operation.
   d) To increase the motor's torque output.

4. **Describe the principle of operation of a BLDC motor.**

5. **What are the common rotor configurations in a BLDC motor?**

6. **Explain the importance of electronic commutation in a BLDC motor.**

Suggested Reference:

1. "Basic Electrical Engineering" by T. K. Nagsarkar and M. S. Sukhija, Oxford university press.

2.https://www.electricaltechnology.org/2016/05/bldc-brushless-dc-motor-construction-working-principle.html
3. https://www.electronicshub.org/brushless-dc-motor-bldc-motor/

References used by the students:

Rubric wise marks obtained:

5=Excellent	4=Very Good	3=Good	2=Fair	1=Needs more work	
Rubrics	**Knowledge**	**Calculations**	**Participation**	**Journal work and submission**	**Total**
Marks					

Experiment No: 9
To demonstrate the working of miniature circuit breaker (MCB)

Date:

Competency and Practical Skills: Knowledge of electrical circuits, Familiarity with MCBs, Understanding of measuring instruments, Practical skills in wiring and circuit assembly, Knowledge of safety precautions.

Objectives: (a) To understand the operating principles of miniature circuit breakers and their role in electrical circuit protection.
(b) To plot the current vs. time characteristics of the MCB for different levels of overcurrent and to observe the trip time of the MCB.
(c) To identify the limitations and applications of MCBs and to appreciate their importance in electrical safety.

Equipment/Instruments: Ammeter, Voltmeter, Single phase supply, MCB, Connecting Wires.

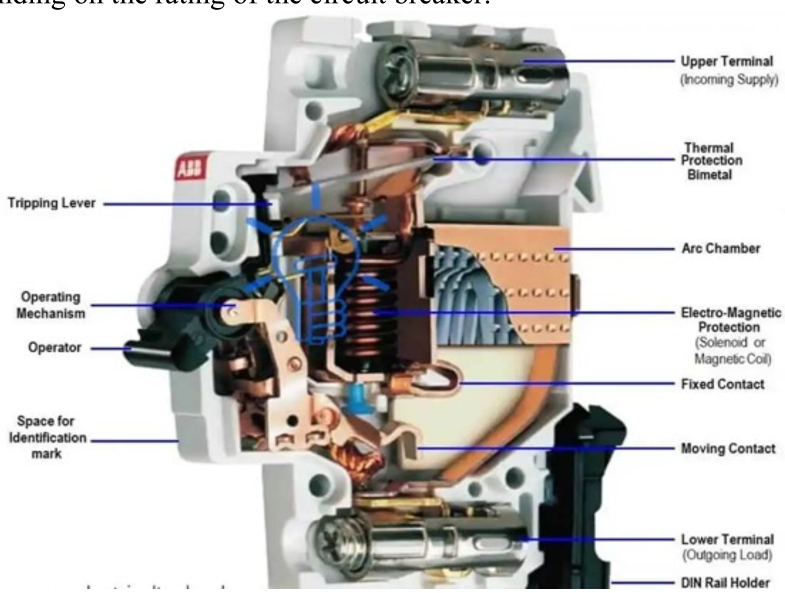
Theory: The theory behind the laboratory experiment to plot the characteristics of miniature circuit breaker (MCB) involves understanding the operation and behavior of the MCB under different abnormal conditions.

An MCB is a type of circuit breaker that is commonly used in low-voltage electrical systems to protect against overcurrents and short circuits. It is designed to trip and open the circuit when the current exceeds a certain value, which is known as the tripping current.

Construction of MCB:

MCB embodies a complete enclosure in a moulded insulating material. This provides mechanically strong and insulated housing.

The switching system consists of a fixed and a moving contact to which incoming and outgoing wires are connected. The metal or current carrying parts are made up of electrolytic copper or silver alloy depending on the rating of the circuit breaker.



As the contacts are separated in the event of an overload or short circuit situation, an electric arc is formed. All modern MCBs are designed to handle arc interruption processes where arc energy extraction and its cooling are provided by metallic arc splitter plates.

These plates are held in a proper position by an insulating material. Also, arc runner is provided to force the arc that is produced between the main contacts.

The operating mechanism consists of both magnetic tripping and thermal tripping arrangements.

The magnetic tripping arrangement essentially consists of a composite magnetic system that has a spring loaded dashpot with a magnetic slug in a silicon fluid, and a normal magnetic trip. A current carrying coil in the trip arrangement moves the slug against spring towards a fixed pole piece. So the magnetic pull is developed on the trip lever when there is a sufficient magnetic field produced by the coil.

In case of short circuits or heavy overloads, strong magnetic field produced by the coils (Solenoid) is sufficient to attract the armature of the trip lever irrespective of the position of the slug in the dashpot.
The thermal tripping arrangement consists of a bimetallic strip around which a heater coil is wound to create heat depending on the flow of current.

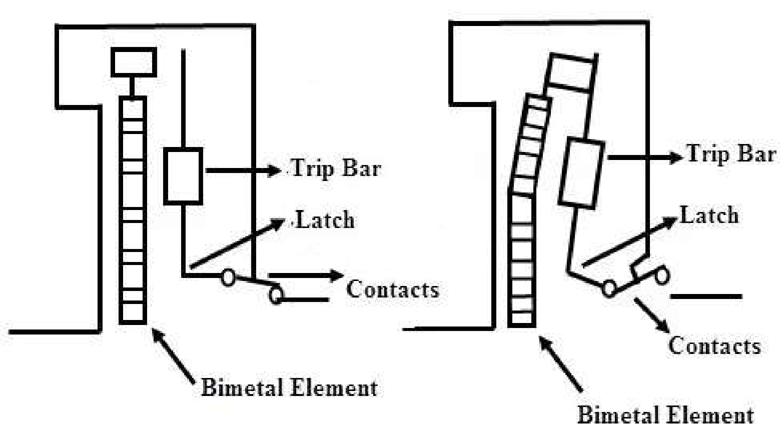
The heater design can be either direct where current is passed through a bimetal strip which affects part of electric circuit or indirect where a coil of current carrying conductor is wound around the bimetallic strip. The deflection of a bimetallic strip activates the tripping mechanism in case of certain overload conditions.

The bimetal strips are made up of two different metals, usually brass and steel. These metals are riveted and welded along their length. These are so designed such that they will not heat the strip to the tripping point for normal currents, but if the current is increased beyond rated value, the strip is warmed, bent and trips the latch. Bimetallic strips are chosen to provide particular time delays under certain overloads.

Working & Operation of MCB

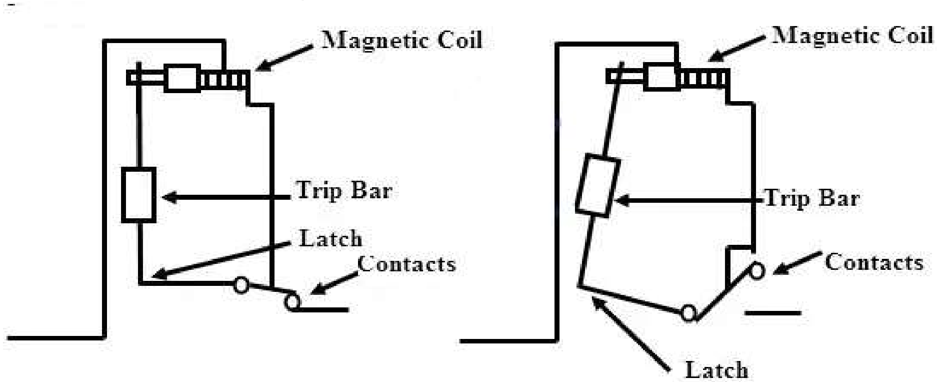
Under normal working conditions, MCB operates as a switch (manual one) to make the circuit ON or OFF. Under overload or short circuit condition, it automatically operates or trips so that current interruption takes place in the load circuit.

The visual indication of this trip can be observed by automatic movement of the operating knob to OFF position. This automatic operation MCB can be obtained in two ways as we have seen in MCB construction; those are magnetic tripping and thermal tripping.



Under overload conditions, the current through the bimetal causes it to raise the temperature of it. The heat generated within the bimetal itself is enough to cause deflection due to thermal expansion of metals. This deflection further releases the trip latch and hence contacts get separated.

In some MCBs, the magnetic field generated by the coil causes it to develop pull on bimetals such that deflection activates the tripping mechanism.



Under short circuit or heavy overload conditions, magnetic tripping arrangement comes into the picture. Under normal working conditions, the slug is held in a position by a light spring because the magnetic field generated by the coil is not sufficient to attract the latch.

When a fault current flows, the magnetic field generated by the coil is sufficient to overcome the spring force holding the slug in position. And hence slug moves and then actuate the tripping mechanism.

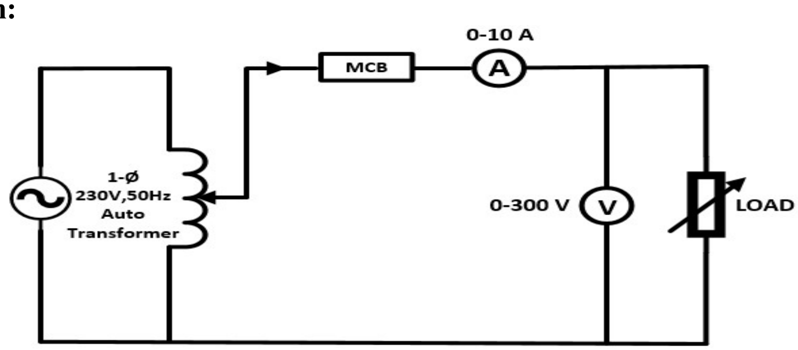
A combination of both magnetic and thermal tripping mechanisms are implemented in most miniature circuit breakers. In both magnetic and thermal tripping operations, an arc is formed when the contacts start separating. This arc is then forced into arc splitter plates via arc runner.

These arc splitter plates are also called arc chutes where arc is formed into a series of arcs and at the same time energy extracted and cools it. Hence this arrangement achieves the arc extinction.

To plot the characteristics of an MCB, the experiment typically involves measuring the tripping current of the MCB under different conditions. This can be done by connecting the MCB in series with a power source and a load, and then introducing different levels of fault current by varying the load or introducing a short circuit.

The experiment involve measuring the tripping current at different time intervals to observe the behavior of the MCB over time. This can help to determine the tripping characteristics of the MCB, such as the time-delay characteristics and the instantaneous trip characteristics.

Set up diagram:



Safety and necessary Precautions:
1. Wear protective gear
2. Ensure proper wiring
3. Use appropriate voltage
4. Use appropriate measuring equipment
5. Avoid touching the circuit
6. Handle components with care
7. Follow laboratory guidelines

Procedure:
1. Connect the circuit as per circuit setup diag.
2. Switch on 1-Ø AC supply and set appropriate voltage.
3. Gradually vary the load until MCB gets tripped.
4. Note down the tripping current.

Observations:
Tripping Current=

Conclusion:

Quiz:
1. What is the function of MCB?

2. State difference between MCB and MCCB.

3. What is the difference between fuse and MCB?

Suggested Reference:

1. "Switchgear and protection" by Sunil S Rao, Dhanpat rai.
2. **MCB (Miniature Circuit Breaker) - Construction, Types & Working (electricaltechnology.org)**

References used by the students:

Rubric wise marks obtained:

5=Excellent 4=Very Good 3=Good 2=Fair 1=Needs more work					
Rubrics	**Knowledge**	**Calculations**	**Participation**	**Journal work and submission**	**Total**
Marks					

Experiment No: 10
To study different types of batteries and its applications.

Date:

Competency and Practical Skills: Knowledge of basic chemistry, Familiarity with electrical circuits, Understanding of battery technology.

Objectives: (a) To understand the basic principles of battery operation.
(b) To identify the differences between primary and secondary batteries, and their respective advantages and disadvantages.
(c) To explore the various types of primary batteries, such as alkaline, lithium, and zinc-carbon batteries, and their unique properties and applications.
(d) To investigate the different types of secondary batteries, such as lead-acid, nickel-cadmium, and lithium-ion batteries, and their specific characteristics and uses.

Equipment/Instruments: Batteries.

Theory: A battery is a collection of one or more cells that go under chemical reactions to create the flow of electrons within a circuit. There is lot of research and advancement going on in battery technology, and as a result, breakthrough technologies are being experienced and used around the world currently. Batteries came into play due to the need to store generated electrical energy. As much as a good amount of energy was being generated, it was important to store the energy so it can be used when generation is down or when there is a need to power standalone devices which cannot be kept tethered to the supply from the mains. Here it should be noted that only DC can be stored in the batteries, AC current can't be stored.

Battery cells are usually made up of three main components;

1. The Anode (Negative Electrode)
2. The Cathode (Positive Electrode)
3. The electrolytes

The anode is a negative electrode that produces electrons to the external circuit to which the battery is connected. When batteries are connected, an electron build-up is initiated at the anode which causes a potential difference between the two electrodes. The electrons naturally then try to redistribute themselves, this is prevented by the electrolyte, so when an electrical circuit is connected, it provides a clear path for the electrons to move from the anode to the cathode thereby powering the circuit to which it is connected. By changing the arrangement and material used to build the Anode, Cathode and Electrolyte we can achieve many different types of battery chemistries enabling us to design different types of battery cells.

Types of Batteries

Batteries generally can be classified into different categories and types, ranging from chemical composition, size, form factor and use cases, but under all of these are two major battery types;

1. Primary Batteries
2. Secondary Batteries

1. Primary Batteries

Primary batteries are batteries that **cannot be recharged** once depleted. Primary batteries are made of electrochemical cells whose electrochemical reaction cannot be reversed.

Primary batteries exist in different forms **ranging from coin cells to AA batteries**. They are commonly used in standalone applications where charging is impractical or impossible. A good example of which is in military grade devices and battery powered equipment. It will be impractical to use rechargeable batteries as recharging a battery will be the last thing in the mind of the soldiers. Primary batteries always have high specific energy and the systems in which they are used are always designed to consume low amount of power to enable the battery last as long as possible.

Some other **examples of devices using primary batteries include**; Pace makers, Animal trackers, Wrist watches, remote controls and children toys to mention a few.

The most popular type of primary batteries are **alkaline batteries**. They have a high specific energy and are environmentally friendly, cost-effective and do not leak even when fully discharged. They can be stored for several years, have a good safety record and can be carried on an aircraft without being subject to UN Transport and other regulations. The only downside to alkaline batteries is the low load current, which limits its use to devices with low current requirements like remote controls, flashlights and portable entertainment devices.

2. Secondary Batteries

Secondary batteries are batteries with electrochemical cells whose chemical reactions can be reversed by applying a certain voltage to the battery in the reversed direction. Also referred to as **rechargeable batteries**, secondary cells unlike primary cells can be recharged after the energy on the battery has been used up.

They are typically used in high drain applications and other scenarios where it will be either too expensive or impracticable to use single charge batteries. Small capacity secondary batteries are used to power portable electronic devices like **mobile phones**, and other gadgets and appliances while heavy-duty batteries are used in powering diverse **electric vehicles** and other high drain applications like load levelling in electricity generation. They are also used as standalone power sources alongside **Inverters to supply electricity**. Although the initial cost of acquiring rechargeable batteries is always a whole lot higher than that of primary batteries but they are the most cost-effective over the long-term. Secondary batteries can be further classified into several other types based on their chemistry**.** This is very important because the chemistry determines some of the attributes of the battery including its specific energy, cycle life, shelf life, and price to mention a few.

The following are the **different types of rechargeable batteries** that are commonly used.

1. Lithium-ion(Li-ion)
2. Nickel Cadmium(Ni-Cd)
3. Nickel-Metal Hydride(Ni-MH)
4. Lead-Acid

1. Nickel-Cadmium Batteries

The nickel–cadmium battery (NiCd battery or NiCad battery) is a type of rechargeable battery which is developed using nickel oxide hydroxide and metallic cadmium as electrodes. Ni-Cd batteries excel at maintaining voltage and holding charge when not in use. However, NI-Cd batteries easily fall a victim of the dreaded "memory" effect when a partially charged battery is recharged, lowering the future capacity of the battery.

In comparison with other types of rechargeable cells, Ni-Cd batteries offer good life cycle and performance at low temperatures with a fair capacity but their most significant advantage will be their ability to deliver their full rated capacity at high discharge rates. They are available in different sizes including the sizes used for alkaline batteries, AAA to D. Ni-Cd cells are used individual or assembled in packs of two or more cells. The small packs are used in portable devices, electronics and toys while the bigger ones find application in aircraft starting batteries, Electric vehicles and standby power supply.

Some of the properties of Nickel-Cadmium batteries are listed below.

- Specific Energy: 40-60W-h/kg
- Energy Density: 50-150 W-h/L
- Specific Power: 150W/kg
- Charge/discharge efficiency: 70-90%
- Self-discharge rate: 10%/month
- Cycle durability/life: 2000cycles

2. Nickel-Metal Hydride Batteries

Nickel metal hydride (Ni-MH) is another type of chemical configuration used for rechargeable batteries. The chemical reaction at the positive electrode of batteries is similar to that of the nickel–cadmium cell (NiCd), with both battery type using the same nickel oxide hydroxide (NiOOH). However, the negative electrodes in Nickel-Metal Hydride use a hydrogen-absorbing alloy instead of cadmium which is used in NiCd batteries

NiMH batteries find application in high drain devices because of their high capacity and energy density. A NiMH battery can possess two to three times the capacity of a NiCd battery of the same size, and its energy density can approach that of a lithium-ion battery. Unlike the NiCd chemistry, batteries based on the **NiMH chemistry are not susceptible to the "memory"** effect that NiCads experience.

Below are some of the properties of batteries based on the Nickel-metal hydride chemistry;

- Specific Energy: 60-120h/kg
- Energy Density: 140-300 Wh/L
- Specific Power: 250-1000 W/kg
- Charge/discharge efficiency: 66% - 92%
- Self-discharge rate: 1.3-2.9%/month at 20^{o}C
- Cycle Durability/life: 180 -2000

3. Lithium-ion Batteries

Lithium-ion batteries are one of the most popular types of rechargeable batteries. There are many **different types of Lithium batteries**, but among all the lithium-ion batteries are the most commonly used. You can find these lithium batteries being used in different forms popularly among electric vehicles and other portable gadgets. If you are curious to know more about batteries used in Electric vehicles, you can check out this article on Electric Vehicle Batteries. They are found in different portable appliances including mobile phones, smart devices and several other battery appliances used at home. They also find applications in aerospace and military applications due to their lightweight nature.

Lithium-ion batteries are a type of rechargeable battery in which lithium ions from the negative electrode migrate to the positive electrode during discharge and migrate back to the negative electrode when the battery is being charged. Li-ion batteries use an intercalated lithium compound as one electrode material, compared to the metallic lithium used in non-rechargeable lithium batteries.

Lithium-ion batteries generally possess high energy density, little or no memory effect and low self-discharge compared to other battery types. Their chemistry alongside performance and cost vary across different use cases, for example, Li-ion batteries used in handheld electronic devices are usually based on lithium cobalt oxide ($LiCoO_2$) which provides high energy density and low safety risks when damaged while Li-ion batteries based on Lithium iron phosphate which offer a lower energy density are safer due to a reduced likelihood of unfortunate events happening are widely used in powering electric tools and medical equipment. Lithium-ion batteries offer the best performance to weight ratio with the lithium sulphur battery offering the highest ratio.

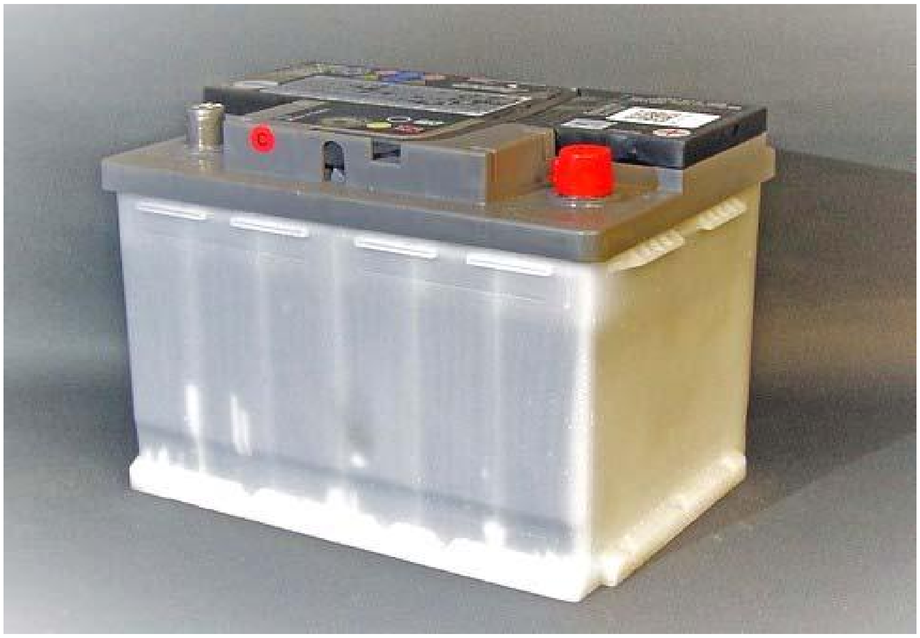
Some of the attributes of lithium-ion batteries are listed below;

- Specific Energy: 100: 265W-h/kg
- Energy Density: 250: 693 W-h/L
- Specific Power: 250: 340 W/kg
- Charge/discharge percentage: 80-90%
- Cycle Durability: 400: 1200 cycles
- Nominal cell voltage: NMC 3.6/3.85V

4. Lead-Acid Batteries

Lead-acid batteries are a low-cost reliable power workhorse used in heavy-duty applications.

They are usually very large and because of their weight, they're always used in non-portable applications such as solar-panel energy storage, vehicle ignition and lights, backup power and load levelling in power generation/distribution. The lead-acid is the oldest type of rechargeable battery and still very relevant and important into today's world. Lead-acid batteries have very low energy to volume and energy to weight ratios but it has a relatively large power to weight ratio and as a result, can supply huge surge currents when needed. These attributes alongside its low cost make these batteries attractive for use in several high current applications like powering automobile starter motors and for storage in backup power supplies.



Selecting the right battery for your application

One of the main problems hindering technology revolutions like IoT is power, battery life affects the successful deployment of devices that require long battery life and even though several power management techniques are being adopted to make the battery last longer, a compatible battery must still be selected to achieve the desired outcome.

Below are some factors to consider when selecting the right type of battery for your project.

1. **Energy Density:** The energy density is the total amount of energy that can be stored per unit mass or volume. This determines how long your device stays on before it needs a recharge.

2. Power Density: Maximum rate of energy discharge per unit mass or volume. Low power: laptop, i-pod. High power: power tools.

3. Safety: It is important to consider the temperature at which the device you are building will work. At high temperatures, certain battery components will breakdown and can undergo exothermic reactions. High temperatures generally reduces the performance of most batteries.

4. Life cycle durability: The stability of energy density and power density of a battery with repeated cycling (charging and discharging) is needed for the long battery life required by most applications.

5. Cost: Cost is an important part of any engineering decisions you will be making. It is important that the cost of your battery choice is commensurate with its performance and will not increase the overall cost of the project abnormally.

Some important characteristics of batteries include:

Capacity: This refers to the amount of energy that a battery can store and deliver. The unit of measurement for capacity is ampere-hours (Ah) or milliampere-hours (mAh), and it determines how long a battery can power a device before it needs to be recharged.

Voltage: This is the electrical potential difference between the positive and negative terminals of a battery. It determines the amount of electrical energy that can be delivered by the battery and is typically measured in volts (V).

Chemistry: The chemical composition of a battery determines its performance characteristics, such as its capacity, voltage, and discharge rate. Different types of batteries use different chemical compositions, including alkaline, lithium-ion, lead-acid, and nickel-cadmium.

Discharge rate: This refers to how quickly a battery can deliver its energy. It is usually measured in amperes (A) or milliamperes (mA) and can be affected by factors such as the temperature, load, and age of the battery.

Cycle life: This is the number of charge and discharge cycles that a battery can go through before its performance starts to degrade. It is influenced by factors such as the chemistry of the battery, its usage patterns, and the quality of its construction.

Self-discharge rate: This refers to the rate at which a battery loses its charge when it is not in use. It can vary depending on the chemistry of the battery and its storage conditions.

Temperature range: The performance of a battery can be affected by the temperature at which it is used and stored. Different types of batteries have different temperature ranges for optimal performance.
Overall, these characteristics are important to consider when selecting a battery for a particular application, as they can impact the battery's performance, lifespan, and overall cost-effectiveness.

Conclusion:

Quiz:

1. What is primary cell and secondary cell?

2. Do temperature have effect on battery?

3. Mercury cell is primary cell. True/False? Justify your answer.

Suggested Reference:

1. https://nptel.ac.in/courses/113105102
3. **Different Types of Batteries and their Applications (circuitdigest.com)**

References used by the students:

Rubric wise marks obtained:

5=Excellent 4=Very Good 3=Good 2=Fair 1=Needs more work					
Rubrics	**Knowledge**	**Calculations**	**Participation**	**Journal work and submission**	**Total**
Marks					