EL 2010 – ELECTRO MECHANICAL SYSTEMS

LAB MANUAL

DEPARTMENT OF ELECTRICAL ENGINEERING,

FAST-NU, LAHORE

Created by: Mr. Umer Mumtaz, Mr. Ahmed Hassan, Ms. Rabia Khan

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Last Updated by: Mr. Syed Muhammad Ismail

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Approved by: Head of Electrical Engineering Department, Lahore Campus

Date:

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List of Equipment

Power Supplies

Sr. No.	Description
1	AC and DC Power Supply

Test Machines

Sr. No.	Name	P_N(W)	N (r/min)	U_{IN}(V)	I_{IN}(A)	U_F(V)	I_F(A)
1	1-Phase Transformer	200VA		127		50	
2	1-Phase Transformer	150VA		127		50	
3	3-Phase Transformer	100VA x3		127		50	
4	DC Excited Generator	120	1000	110	1.1	110	
5	DC Excited Motor	120	1000	110	1.58	110	
6	DC Excited Motor	120	1000	110	1.25	110	0.26
7	3-Phase Cage Asynchronous Motor	100	1420	220/Δ	0.5		
8	3-Phase Wound Motor	120	1380	220/ Δ	0.6		
9	3-Phase Synchronous Generator	170	1500	220/Y	0.45	14	1.2
10	3-Phase Synchronous Motor	90	1500	220/Y	0.35	10	0.8
11	1-Phase Capacitor Asynchronous Motor	120	1420	220	1		
12	3-Phase Dual Speed Cage Asynchronous Motor	120/90	2800/1400	220	0.6/0.6		
13	DC Power Gauge	250	1500	110	2.8		

14	DC Speed Measure Generator		1500	36			
15	Rotation Speed, Torque and Mechanical Power Meter						

Accessories

Sr. No.	Description
1	Variable Resistor 0-150 ohms, 150 W (1.0 A) (Module 7)
2	Resistor 500 Ohms 100 W (0.4A) (Module 7)
3	Variable Resistor 0-30 Ohms 100 W (1.8A) (Module 8)
4	Contactor KM1, KM2, KM3 (Module 9 & Module 10)
5	Thermal Relay FR1, FR2 (Module 10 and Module 11)
6	Intermediate Relay (Module 11)
7	Button SB1,SB2,SB3,SB4, emergency Stop Switch (Module 12 & Module 13)
8	Time Relay KT (Module 13)
9	Travel Switch (Module 13)
10	Low Voltage Transformer, Indicator Light, Light (Module 14)
11	3-Phase Knife Switch, Knife Switch x3 (Module 3 & Module 14)
12	Inductor L- 0.5H,1.0 A & Capacitor C- 50uf/400V (Module 3)

Instruments and Meters

Sr. No.	Description
1	DC Digital Voltmeters (Module 4)
2	DC Digital Ammeters (Module 4)
3	AC Digital Voltmeters (Module 5)

4	AC Digital Ammeters (Module 5)
5	AC Power Meters (Module 6)
6	AC Power Factor Meter (Module 6)

EXPERIMENT 1

INTRODUCTION TO ELECTROMECHANICAL SYSTEMS LAB AND EQUIPMENT

OBJECTIVE:

- To become familiar with different modules of EMS trainer and all other equipment and devices used in this lab

BACKGROUND:

1. AC AND DC SUPPLIES

The first three modules are the AC and DC supplies that are assembled in a single large module. These include the three-phase supply too, which is available in both separated three phases and the combined three phase supply with a single neutral. The ratings of the different supplies are indicated in the module. Three Phase and Single-Phase Power
Supply module available in lab is given in Figure 1.1

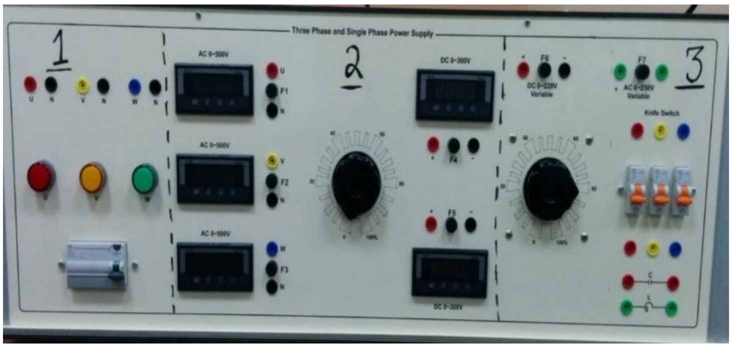


Figure 1.1: Three Phase and Single-Phase Supply

2. DC VOLTMETER AND DC AMMETER

The fourth module consists of DC voltmeters and DC Ammeters. One must keep in mind that Voltmeters are connected in parallel and the Ammeters are connected in series. DC Ammeter and DC Voltmeter module available in lab in shown in Figure 1.2

Figure 1.2: DC Voltmeter and Ammeter

3. AC POWER AND POWER FACTOR METER

As the name depicts, the AC Power and Power factor meter is used to determine these parameters of your circuit. One must know that the term power factor is defined only for AC. There are separate fuses which are attached to the devices in order to take care of the safety. The AC Power and Power factor meter available in lab is shown in Figure 1.3

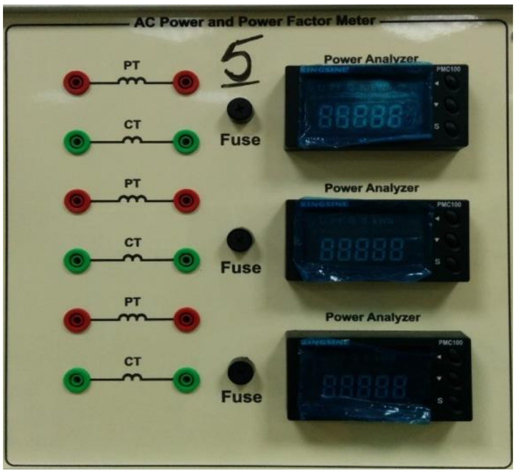


Figure 1.3: AC Power and Power Factor Meter

4. AC VOLTMETER AND AC AMMETER

This module consists of AC voltmeters and AC Ammeters. One must keep in mind that Voltmeters are connected in parallel and the ammeters are connected in series. Ratings of voltmeters and ammeters are mentioned on the respective modue. This module is shown in Figure 1.4

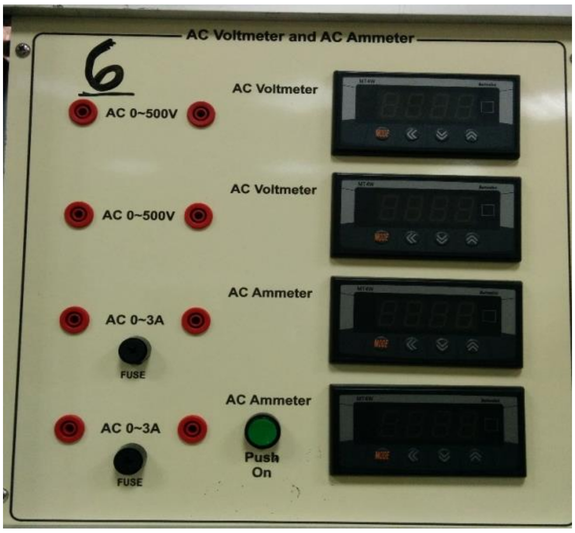


Figure 1.4: AC Voltmeter and AC Ammeter

5. THREE PHASE VARIABLE RESISTOR

The three-phase variable resistor is used where we need a resistance that can be varied so that we could observe the behavior of our parameters with respect to that of changing the resistor. The three-phase module is shown in Figure 1.5

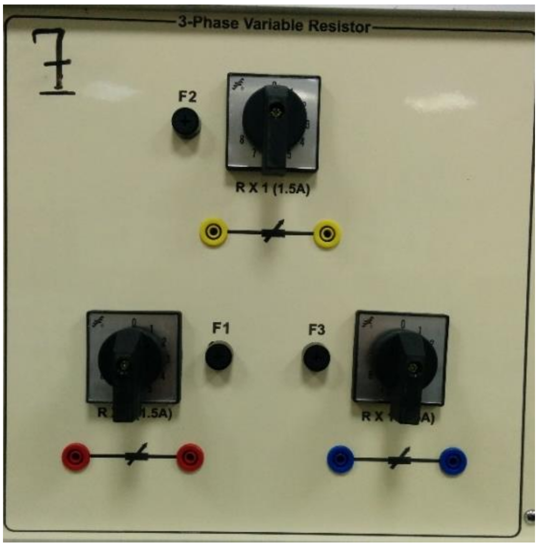


Figure 1.5: Three – Phase Variable Resistor

6. VARIABLE RESISTOR

The variable resistor is an important part of the circuitry which can be used for inserting an extra resistance and then varies it when required. Whenever you have to control the current you can insert a resistance. It could be variable of fixed depending on your requirements. Variable Resistor module is shown in Figure 1.6

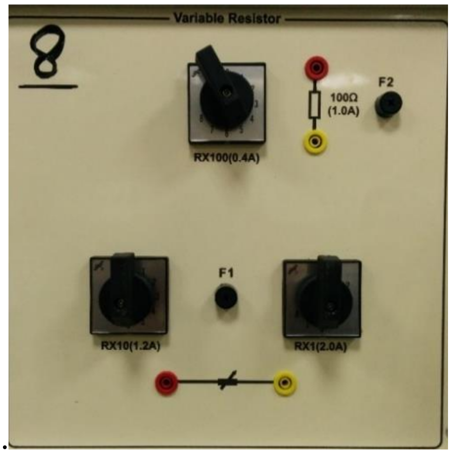


Figure 1.6: Variable Resistor

7. AC CONTACTORS

A contactor is an electrically controlled switch used for switching a power circuit similar to the relay except with the higher current ratings. Contactors typically have multiple contacts and those contacts are usually normally open, so that power to the circuit is shut off, when the coil is de-energized. They are used to control electric motors, lighting, heating, capacitor banks and other electric loads. The AC contactors module is shown in Figure 1.7

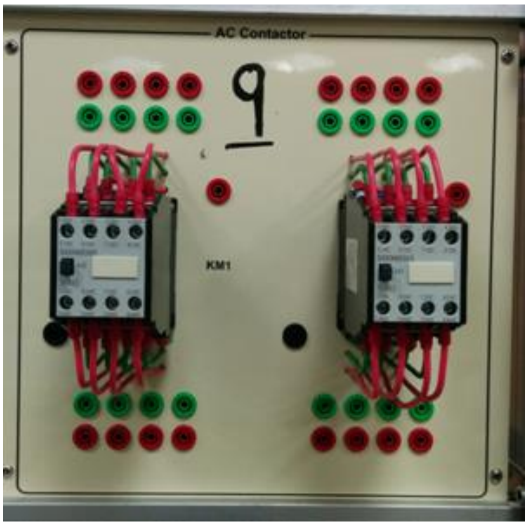


Figure 1.7: AC Contactor

8. THERMAL RELAY

Thermal relay is an electrical protection device which designed to disconnect the load from its power supply to avoid any damage by sensing the heat produced from the flow of current. It consists of bi metallic strip. The basic principle of thermal relay is that when it is heated by the coil carrying over current of the system, it bends and makes normally open contacts. Thermal Relay Module is shown in Figure 1.8

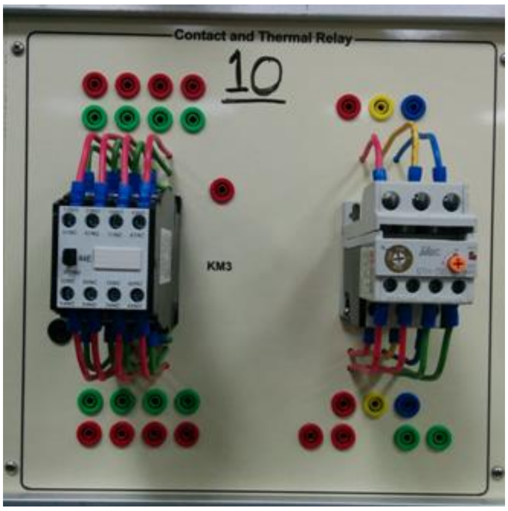


Figure 1.8: Contact and Thermal Relay

9. FUSE AND BUTTON SWITCH

A Fuse is a low resistance wire that acts as a sacrificial device to provide the over current protection. It interrupts the excessive current so that further damage from over current or heating can be prevented. Button switch is a simple switch used for controlling some aspects of machine or process. They are made of hard material such as plastic or metal and their surface is such that to accommodate the human finger or hand so that it can be easily pressed or pushed to make or break the circuit. This Module is shown in Figure 1.9

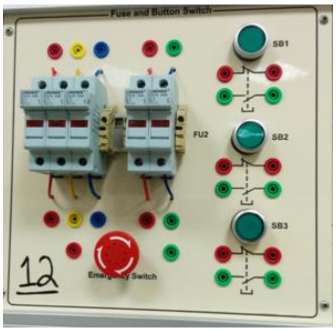


Figure 1.9: Fuse and Button Switch

10. TRAVEL SWITCH AND TIME RELAY

Time relay exhibit the property of time delay actuation. Sometimes, momentarily faults occur in the power system, which automatically vanishes after few seconds. Hence to avoid the tripping of circuit in case of the momentarily faults, time relays are used. Time-delay relay contacts must be specified not only as either normally-open or normally-closed, but whether the delay operates in the direction of closing or in the direction of opening. The Module comprising Travel Switch and Time Relay is shown in Figure 1.10

Figure 1.10: Travel Switch and Time Relay

11. SWITCH, FUSE, INDICATOR LIGHT AND LAMP

Switches used to connect or disconnect the circuit manually. A Fuse is a low resistance wire that acts as a sacrificial device to provide the over current protection. It interrupts the excessive current so that further damage from over current or heating can be prevented. Indicator light or lamp is a small device which shows whether the power is on or off. When the circuit is closed, it will glow, otherwise it will not. This Module is shown in Figure 1.11

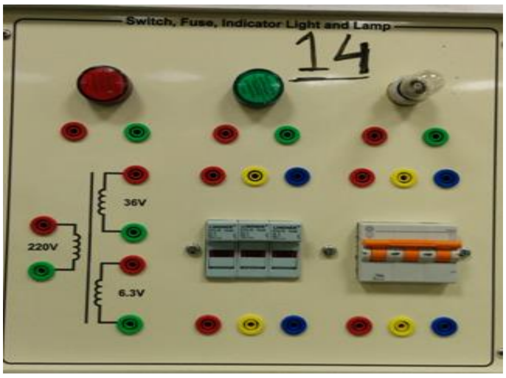


Figure 1.11: Switch, Fuse, Indicator Light and Lamp

POST LAB QUESTIONS:

1. What is the use of CTs and PTs?
2. How we can measure high DC voltages and currents?
3. Differentiate between fuse and circuit breaker?

EXPERIMENT 2

(A) CONSTRUCTION OF TRANSFORMER

(B) CONSTRUCTION OF AUTOTRANSFORMER

OBJECTIVE:

- To construct a 1:2 transformer.
- To study the construction and working of autotransformer

EQUIPMENT:

- Winding machine Single
- Bobbin
- Iron core stampings
- Insulating paper
- Laminated copper wire
- Nuts and bolts

BACKGROUND:

a) Transformer

A transformer is a device that converts one AC voltage to another. It's simply a device used for either stepping-up or stepping down an applied input AC through magnetic induction in between its two windings.
Basically, a transformer will have the following main components:

a) Iron core stampings (configured either as U/T or E/I, generally the latter is used more extensively).
b) Central plastic or ceramic bobbin surrounded by the above iron core stampings.
c) Two windings (electrically isolated and magnetically coupled) using super enameled copper wire made over the bobbin.
d) Normally the winding which is designated to receive the input supply is termed as the "Primary" and the winding which in response to this input produces the required induced voltage as the output is termed as the "secondary" winding.
e) Designing your own transformer as per a specific application can be interesting, but not feasible without calculating the various parameters typically involved with them. The following discussion will take you through a few important steps and formulas and explain how to make a transformer.

b) Autotransformer

The autotransformer is somewhat more efficient than transformers having separate windings because it has smaller core and copper losses. It is used primarily where a requirement exists for comparatively small increases or decreases in voltage; for example, to boost a power line voltage in order to compensate for losses caused by lengthy transmission lines or to reduce motor starting voltages, thus holding the starting currents within reasonable values. In industrial applications where several voltages are required for complex circuit systems a multi-tapped autotransformer would be used. The principal disadvantage of the autotransformer is the absence of isolation between windings. It is generally inadvisable to use it as a large ratio step-down device because, if the low voltage section of the winding should open up, the high voltage input would be placed across the low voltage load.

There is a special type of transformer, which physically has only one winding. Functionally, though, the one winding serves as both the primary and secondary. This type of transformer is called an autotransformer. When an autotransformer is used to step tip the voltage, part of the single winding acts as the primary and the entire winding acts as the secondary. When an autotransformer is used to step down the voltage, the entire winding acts as the primary and part of it acts as the secondary. Figure 2.1 below shows autotransformer connected for both step-up and step-down operation.

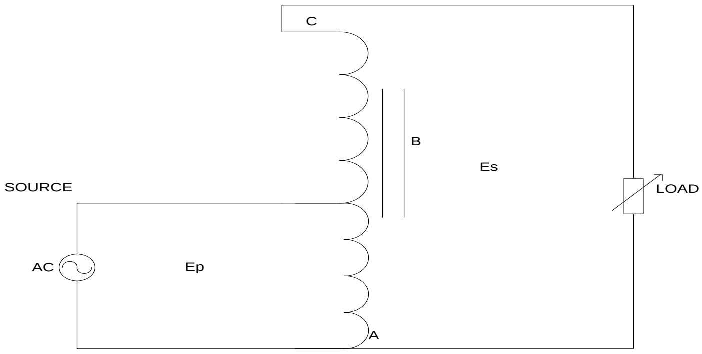


Figure 2.1: The Autotransformer

The action of the autotransformer is basically the same as the standard two-winding transformer. Power is transferred from the primary to the secondary by the changing magnetic field, and the secondary in turn, regulates the current in the primary to setup the required condition of equal primary and secondary power. The amount of step-up or step-down in voltage depends on the turn ratio between the primary and secondary, with each winding considered as separate, even though some turns are common to both the primary and secondary.
Voltages and currents in the various windings can be found by two simple rules:

a) Primary apparent power (VA; equals Secondary apparent power (VA)).
b) The primary (source) voltage and the secondary (load) voltage are directly proportional to the number of turns N.

These equations depend upon one important fact, that voltage E3 to E7 add in the same directionand do not oppose each other. We have assumed that the voltages are in phase. The load current, of course, cannot exceed the current carrying capacity of the winding. Once this is known it is relatively easy to calculate the VA load, which a particular autotransformer can supply.

A disadvantage of the autotransformer is the lack of isolation between the primary and secondary circuits, because the primary and secondary both use some of the same turns.

PROCEDURE:

a) Transformer

1. Calculate the number of turns for primary using the following formula and note down in Table – I

$$\text{PrimaryNumberofTurns} = \text{TPV} \times \text{PrimaryVoltage}$$

   Where TPV stands for Turns per Volt (Available wire in lab has 7.5 turns/V)
2. Calculate the number of turns for secondary using the following formula and note down in Table – I.

Secondary Number of Turns = TPV × secondary voltage

3. Make counter of winding machine to 0.
4. Take a bobbin of 1” * 1” (as shown in Figure2.2). At point 1 wrap insulating paper, take one end of primary winding out from point 2, mount the bobbin on winding machine then start winding copper wire around the bobbin. Until the desired number of turns for primary are completed. Cut the wire and take it out from point 3.

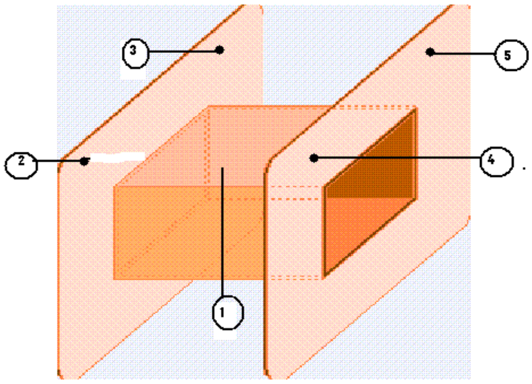


Figure 2.2: The bobbin

5. Wrap insulating paper on primary turns.
6. Take out one end of secondary from point 4 and start winding copper wire around the bobbin until the desired number of turns for secondary is completed. Cut the copper wire and take out other end of secondary from point 5.
7. The next step is assembling the core. Start inserting E laminations from alternating sides. After all E's have been inserted, the I's are slid into the voids. Align laminations with each other, and specially, align the screw holes of all the laminations.
8. Using nut and bolt tight the laminations. At this point, the transformer is truly ready for trying.

b) Autotransformer

1. Calculate the number of turns using the formula:

Total Number of Turns= TPV × Total Volts

Where TPV stands for Turns per (Available wire in lab has 7.5 turns/V)

2. Make counter of winding machine to 0.
3. Take a bobbin of 1’’ * 1” (as shown in Figure 2.2) at point 1 wrap insulating paper, take one end of winding out from point 2, mount the bobbin on winding machine then start winding copper wire around the bobbin. For creating taps of an autotransformer take out the copper wire of desirable length (don’t cut the copper wire) and after it again start winding until the desired number of turns are completed. Cut the wire and take it out from point 3.
4. Wrap insulating paper on windings.
5. The next step is assembling the core. Start inserting E laminations from alternating sides. After all E's have been inserted, the I's are slid into the voids. Align laminations with each other, and specially, align the screw holes of all the laminations.
6. Using nut and bolt tight the laminations. At this point, the transformer is truly ready for trying.

OBSERVATIONS:

TABLE – I (Voltage and Number of Turns in Primary and Secondary for Transformer and Auto Transformer)

	Transformer	Autotransformer
Primary Number of Turns		
Secondary Number of Turns		
Primary Voltage		
Secondary Voltage		

Connect the constructed autotransformer in step up and step-down mode and note down the voltages on primary and secondary side for both step-up and step-down mode in Table – II.

TABLE – II (Voltages on Primary and Secondary side in Step-Up and Step-Down Mode for Auto Transformer)

	Step - up mode	Step - down mode
Primary Voltage		
Secondary Voltage		

POST LAB QUESTIONS:

1. What is the effect of frequency on mutual induction of Transformer?
2. What is an autotransformer?
3. What are the advantages and disadvantages of an autotransformer?

EXPERIMENT 3

MODELING OF TRANSFORMER
(A) OPEN CIRCUIT TEST
(B) SHORT CIRCUIT TEST
(C) VOLTAGE REGULATION AND EFFICIENCY OF TRANSFORMER

OBJECTIVE:

- Modeling of a transformer.
- To find the core resistance and reactance by using open circuit test. (No Load Test).
- To perform short circuit test on transformer.
- To study the voltage regulation of the transformer.
- To study the efficiency of transformer.

EQUIPMENT:

- 1 Phase Transformer
- Single Phase Variable AC Supply
- Power Meter
- AC Voltmeter and Ammeter
- Load Box
- Connecting Wires

BACKGROUND:

The three quantities must be determined in order to describe the transformer model:

1. The equivalent resistance of Primary and Secondary side.
2. The equivalent reactance of Primary and Secondary side.
3. The resistance of the core R_c.
4. The reactance of the core (Magnetization Reactance) X_m.

After finding these values we can draw approximate equivalent circuit model of transformer. The equivalent circuit of transformer is shown in Figure 4.1

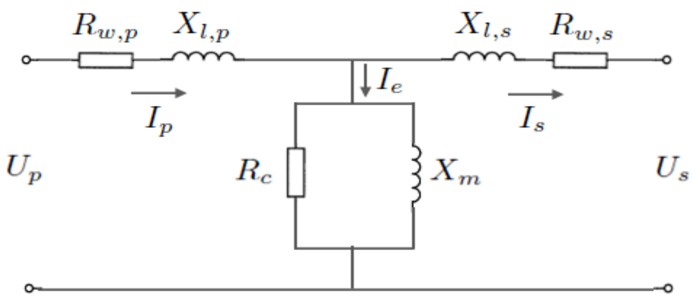


Figure 3.1: Equivalent Circuit of Transformer

Figure 4.2 shows the approximate equivalent circuit of transformer.

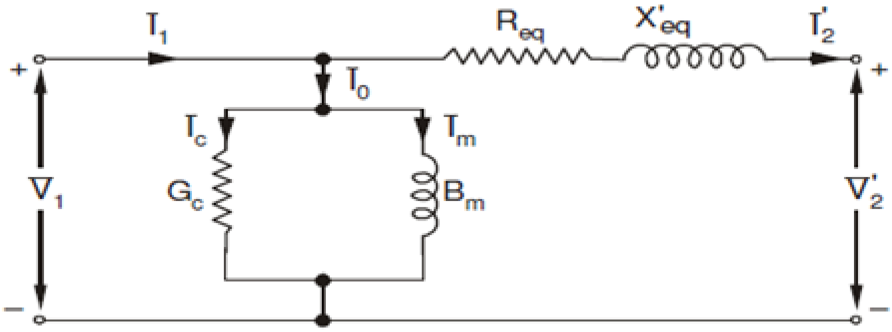


Figure 3.2: Approximate Equivalent Circuit of Transformer

The mentioned quantities can be determined by performing the following two tests:

1. Open-circuit test
2. Short circuit test.

An approximate method to determine the resistance of the core and the magnetization reactance one has to perform the open circuit.

Open Circuit Test:

The resistance and inductances in a transformer are necessary to find. It is really important that one would find out these values for modeling the approximate model of transformer. In order to perform the open circuit test of the transformer, the secondary side of the transformer is left open. The full rated line voltage is being applied at the primary side of transformer. If you look at the figure drawn above it is clear that in such a test, the input current flows through the excitation branch of the transformer. The equivalent resistance of the primary and secondary windings is too small as compared to the core ($R_c$and X_m) so they will not create significance difference. So, all the input voltage will drop at the excitation branch. The circuit diagram for open circuit test is shown in Figure 4.3

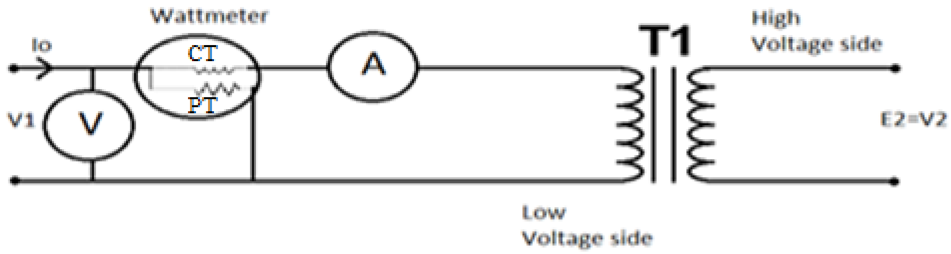


Figure 3.3: Open Circuit Test of Transformer

Short Circuit Test:

The short circuit test is performed by taking care of the applied voltage. In a short circuit test the secondary side is short circuited while the input voltage is applied to the primary side of the transformer. While applying input voltage, one must take precautions not to exceed it beyond a safe level. So, it is important to make it sure that the voltage applied should be within the limits otherwise the windings of the transformer can burn out. In the short circuit test the negligible current flows through the excitation branch so most of the current flow through primary and secondary windings.

The short circuit test is used to find the equivalent resistance and reactance of the primary and secondary windings. The circuit diagram for short circuit test is shown in Figure 4.4

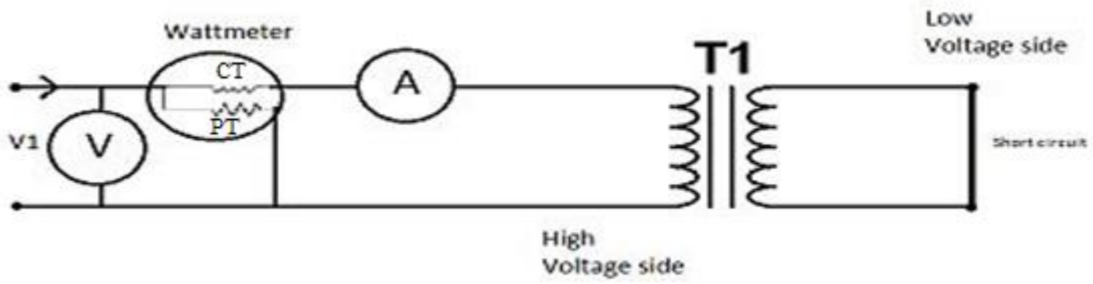


Figure 3.4: Short Circuit Test of Transformer

Voltage regulation:

An ideal transformer has no series impedance in it. But in case of real transformer there is the series impedance within it. The output voltage of a transformer varies with the load even if the input voltage remains constant. So, to conveniently compare transformers in this respect, it is customary to define a quantity called as voltage regulation. Full load voltage regulation is the quantity that compares the output voltage of a transformer at no load with the output voltage at full load.

$$\mathbf{VR} = \frac{\mathbf{V_{s,nl}} - \mathbf{V_{s,fl}}}{\mathbf{V_{s,fl}}} * \mathbf{100}$$

The voltage regulation can be found mathematically by using another formula.

$$\mathbf{VR} = \frac{\frac{\mathbf{V_p}}{\mathbf{a}} - \mathbf{V_{s,fl}}}{\mathbf{V_{s,fl}}}$$

For an ideal transformer VR = 0%. In case of real transformer, the voltage regulation is not equal to zero. It varies depending on the kind of load.
The circuit diagram for finding Voltage Regulation is shown in Figure 4.5

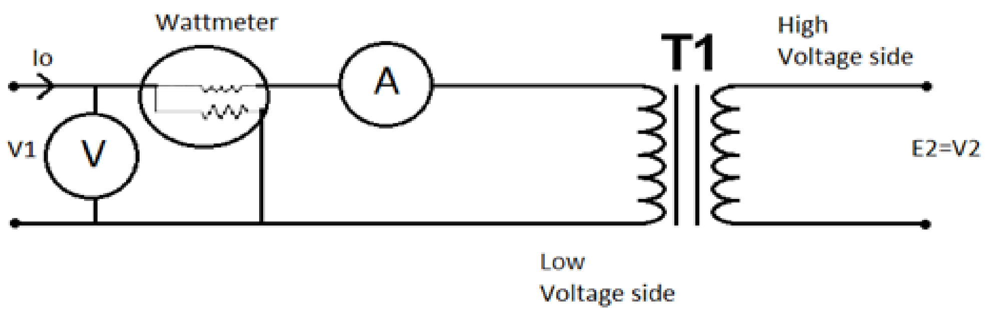


Figure 3.5: Voltage regulation

Efficiency

Transformers are also compared and judged depending on their efficiencies. The efficiency of a device is defined by the following formula.

$$\eta = \frac{P_{out}}{P_{in}} * 100$$

Since the input power comprises of both the output power along with losses so it is quite evident that we have to include the losses to evaluate the efficiency of transformer. There are two kinds of losses in a transformer. These losses include the core losses and the copper losses. When we include both of these losses the expression gets changed. The new expression for the efficiency of transformer is given below.

$$\eta = \frac{V_s * I_s * \mathrm{Cos}\theta}{P_{cu} + P_{core} + V_s * I_s * \mathrm{Cos}\theta} * 100$$

$$P_{cu} = {I_s}^2 * R_{eq}$$

$$P_{core} = \frac{\left(\frac{Vp}{a}\right)^2}{R_c}$$

$$a = \frac{Vs}{Vp} = \frac{Ns}{Np}$$

PROCEDURE:

Open Circuit Test:

1. Make the connection as show in diagram carefully.
2. Apply the full line voltage to the primary side of the transformer.
3. Measure the input voltage, input current and the power of the transformer.
4. Determine the power factor of input current by using the following formula.

$$\mathrm{Cos}\theta = \frac{P_{oc}}{V_{oc} * I_{oc}}$$

5. Measure the magnitude and angle of excitation impedance.

$$Y = \frac{1}{Rc} - j\frac{1}{Xm}$$

6. The admittance is calculated by using $V_{oc}$and I_{oc}.

$$Y = \frac{I_{oc}}{V_{oc}}$$

Short Circuit Test:

1. Apply the line voltage to the primary side of the transformer and increase the voltage until the current through the secondary windings is equal to its rated value.
2. Measure the input voltage, input current and the power of the transformer.
3. Determine the power factor of input current by using the following formula.

$$\mathbf{Cos\ \theta = \frac{P_{sc}}{V_{sc} * I_{sc}}}$$

4. Measure the magnitude and angle of excitation impedance.

$$\mathbf{Z_{se} = R_{eq} + jX_{eq}}$$

5. The short circuit impedance is calculated by using the measured values of $V_{sc}$and I_{sc}.

$$\mathbf{Z_{se} = \frac{V_{sc}}{I_{sc}}}$$

Voltage Regulation:

1) Using your Transformer Trainer connect the circuit as shown in Figure 4.5. Turn on the power supply and adjust for exactly rated V_{ac} as indicated by volt-meter V_1.
2) Apply the rated Voltage on the low voltage side of transformer.
3) Place all of the Resistance Module switches in their open position for zero load current.
4) Measure and record the output voltage E_2which is the voltage at no load
5) Now switch the resistance modules in such a way that the maximum load is being applied at the transformer.
6) Note down the value of E_2 at this load. This is equal to full load voltage.
7) Calculate the transformer regulation using the no load and full load output voltages.

Efficiency:

1. Using your Transformer Trainer connect the circuit as shown in Figure 4.5.
2. Connect an ammeter on the high voltage side to measure the Current Is.
3. Switch all of the Resistance Module switches to give a constant load.
4. Turn on the power supply and adjust for exactly rated V_{ac}as indicated by volt-meter V_1
5. Apply the rated Voltage on the low voltage side of transformer.
6. Measure and record the output voltage E_2= $V_s$which is the voltage at a specified load.
7. Measure and record the output current I_s which is the current at a specified load.
8. Power factor is dependent on the type of load.
9. Calculate the specified copper losses and core losses.
10. Calculate the transformer efficiency by using calculated values

MEASUREMENTS AND CALCULATIONS:

Open Circuit Test

V_{oc}= -----------------------------
$I_{oc=}$ ------------------------------
P_{oc}= -----------------------------

Short Circuit Test

V_{sc} =-----------------------------
I_{sc} = -----------------------------
P_{sc} = ----------------------------

Parameters found are:
R_c = ------------------- .
X_m = ------------------
R_{eq} = ------------------
X_{eq} = ------------------

Voltage Regulation

$V_{s,nl}$ = -------------------------
$V_{s,fl}$ =-------------------------
$V.R$ =-------------------------

Efficiency

V_s = -----------------------------
I_s = ------------------------------
$\cos\theta$ = -------------------------
η =------------------------------

Parameters found are:
VR = ----------------------------
η = ------------------------------

POST LAB QUESTIONS:

1. What is voltage regulation? Why voltage regulation is important? What are the factors that affect the secondary voltage of a transformer? At ideal cases what will be the percent of regulation?

EXPERIMENT 4

THREE PHASE TRANSFORMERS

OBJECTIVE:

- To connect transformers in Δ and Y configurations

EQUIPMENT:

- 3 Phase Transformer
- Three Phase AC Variable Supply
- AC Voltmeter
- Connecting Wires

BACKGROUND:

Single-phase transformers can be connected to form three-phase transformer banks for raising or lowering the voltages of three-phase systems. Four common methods of connecting three transformers for three-phase transformations are the delta-delta, wye-wye, wye-delta, and delta-wye connections. The three-phase transformer is shown below in Figure 3.1.

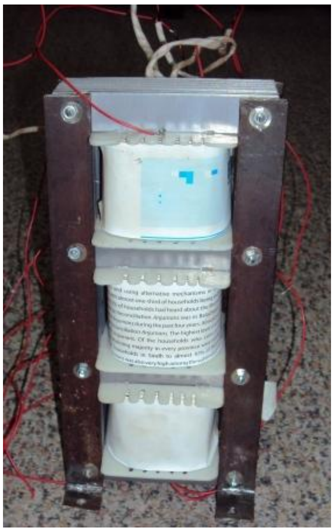


Figure 4.1: Three Phase Transformer

An advantage of the delta-delta connection is that if one transformer becomes damaged or is removed from service, the remaining two can be operated in what is known as the open-delta or V connection. By being operated in this way, the bank still delivers three phase currents and voltages in their correct phase relationship, but the capacity of the bank is reduced to 57.7 percent ($1/\sqrt{3}$)of what it was with all three transformers in service.In the wye-wye connection only 57.7 percent of the line voltage is impressed upon each winding, but full line current flows in each transformer winding. The wye-wye connection is seldom used.

The delta-wye connection is well adapted for stepping up voltages since the voltage is increased by the transformer ratio multiplied by the factor$\sqrt{3}$**.** The wye-delta connection can be used for stepping down voltages. The high-voltage windings of most transformers are wye-connected.
The three-phase transformer may be a single transformer' or three separate single-phase transformers

connected in *delta* or *wye.* Sometimes only two transformers are used.

Commercial three-phase voltage from the power lines is generally 380 volts, and the standard values of single-phase voltage (220V) can be supplied from the line as shown in Figure 3.2.

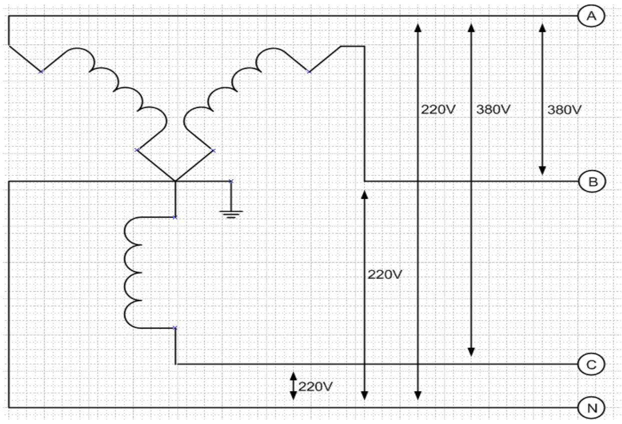


Figure 4.2: Phase and Line voltages of a three-phase transformer

The windings a, b and c represent the three wye-connected transformer secondary windings. The three-phase lines are designated *A*, *B* and *C* and the single-phase connections are from *A*, *B* or *C* to neutral (ground). Three-phase transformers must be properly connected to threes lines in order to operate. Four of the most widely used transformer connections are given below:

a) Primary windings in delta, secondary windings in delta, or delta-delta (Δ-Δ).
b) Primary windings in wye, secondary windings in wye, or wye-wye (Y-Y).
c) Primary windings in wye, secondary windings in delta, or wye-delta (Y- Δ).
a) Primary windings in delta, secondary windings in wye, or delta-wye (Δ-Y).

Of these four combinations, the one used most extensively is the last one listed i.e. *delta-wye.*

PROCEDURE:

Part I

a) The circuit shown in Figure 3.3 has three transformers connected in a delta- delta configuration.

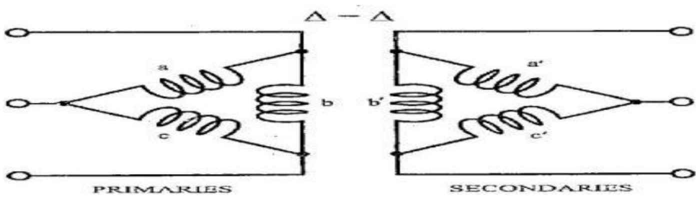


Figure 4.3: Delta – Delta (Δ- Δ)

b) Record the values in Table – I.

For Δ-connection,

$$V_L = V_\phi$$

Input Voltage =70V

TABLE – I (Primary and Secondary side Phase and Line Voltages for Δ – Δ configuration)

	Primary	Secondary
$V_{Ø(\text{Measured})}$		
$V_{L(\text{Measured})}$		
$V_{Ø(\text{Calculated})}$		
$V_{L(\text{Calculated})}$		

Part II

a) The circuit shown in Figure 3.4 has three transformers connected in a delta wye configuration.

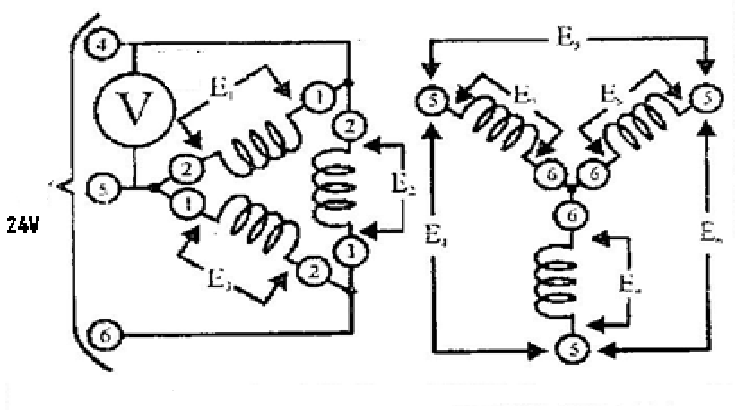


Figure 4.4: Delta-Wye (Δ-Y)

b) Record the values in Table – II.
For Y-connection:

$$V_L = \sqrt{3}.V_Ø$$
$$V_Ø = V_L/\sqrt{3}$$

For Δ-connection:

$$V_L = V_Ø$$

Input Voltage =70

TABLE – II (Primary and Secondary side Phase and Line Voltages for Δ – Y configuration)

	Primary	Secondary
$V_{Ø(\text{Measured})}$		
$V_{L(\text{Measured})}$		
$V_{Ø(\text{Calculated})}$		
$V_{L(\text{Calculated})}$		

Part III

a) The circuit shown in Figure 3.5 has three transformers connected in a wye delta configuration.

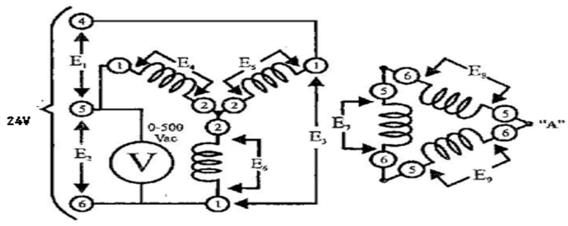


Figure 4.5: Wye-Delta (Y-Δ)

b) Record the values in Table – III.

For Y-connection

$$V_L = \sqrt{3}.V_Ø$$
$$V_Ø = V_L/\sqrt{3}$$

For Δ-connection $V_L = V_Ø$

Input Voltage =70V

TABLE – III (Primary and Secondary Phase and Line Voltages for Y – Δ Configuration)

	Primary	Secondary
$V_{Ø(Measured)}$		
$V_{L(Measured)}$		
$V_{Ø(Calculated)}$		
$V_{L(Calculated)}$		

Part IV

The circuit shown in Figure 3.6 has three transformers connected in a wye – wye configuration.

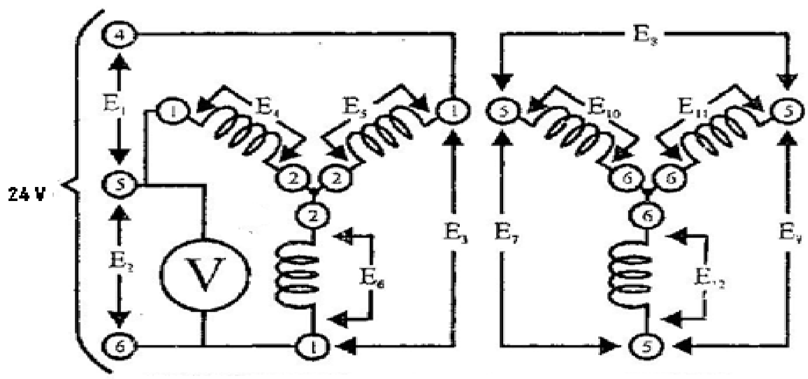


Figure 4.6: Wye-Wye (Y-Y)

b) Record the values in Table – IV.

For Y-connection

$$V_L = \sqrt{3}.V_Ø$$
$$V_Ø = V_L/\sqrt{3}$$

Input Voltage =70V

TABLE - IV (Primary and Secondary Phase and Line Voltages for Y – Y configuration)

	Primary	Secondary
$V_{\text{Ø(Measured)}}$		
$V_{L\text{(Measured)}}$		
$V_{\text{Ø(Calculated)}}$		
$V_{L\text{(Calculated)}}$		

POST LAB QUESTIONS:

1. Which type of transformer connections are used at the distribution side?

EXPERIMENT 5

NO LOAD AND LOAD CHARACTERISTICS OF SELF EXCITED DC SHUNT GENERATOR

OBJECTIVE:

- To observe the no load characteristics of separately exited DC shunt generator (open circuit characteristics curve O.C.C).
- To draw the load characteristics curve of self-excited D.C shunt generator

EQUIPMENT:

- DC Excited Generator
- Variable DC Supply
- Variable Resistor
- DC Voltmeter and Ammeter

BACKGROUND:

(A) No Load Characteristics:

The Generators in which field magnets are energized by the current supplied by them are called Self excited generators. In these types of generators, field coils are internally connected with the armature. Due to residual magnetism, some flux is always present in the poles. When the armature is rotated, some emf is induced; hence some induced current is produced. This small current flows through the field coil as well as the load and thereby strengthening the pole flux. As the pole flux strengthened, which will produce more armature emf, which cause further increase of current through the field. This increased field current further raises armature emf and this phenomenon continues until the excitation reaches its rated value.

The magnetization characteristics also known as **“No load”** or **“Open circuit”** characteristics are the relation between emf generated and field current at a given speed.

Due to residual magnetism in the poles, some emf is generated even when filed current is zero. Hence the curve starts a little way up. It is seen that the first part of the curve is practically straight. This is due the fact that at low flux densities reluctance of iron path is being negligible, total reluctance is given by air gap reluctance which is constant. Hence the flux and consequently the generated emf are directly proportional to exciting current. However, at high flux densities iron path reluctance is being appreciable and straight relation between emf and field current no longer holds good. In other words, saturation of poles starts. The circuit diagram for No Load characteristics is shown in Figure 5.1

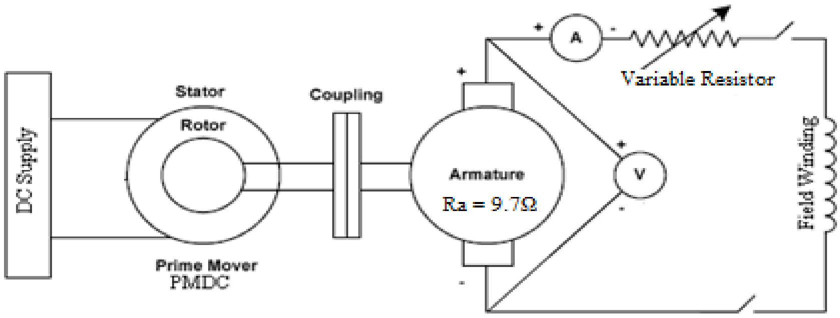


Figure 5.1: Circuit Diagram for No Load Characteristics

(B)Load Characteristics:

Load characteristic curve is the graphical representation which shows change in terminal voltage with respect to change in load. After building up of voltage, if a shunt generator is loaded then terminal voltage drops with increase in load current. There are three main reasons for the drop of terminal voltage for a shunt generator under load.

i) Armature reaction

Armature reaction is the effect of magnetic field set up by the armature current on the distribution of flux under main poles of a generator. Due to demagnetizing effect of armature reaction, pole flux is weakened and so induced emf in the armature is decreased.

ii) Armature resistance

As the load current increases, more voltage is consumed in the resistance of armature circuit. Hence the terminal voltage ($V_t = E - I_a R_a$) is decreased where “E” is the emf induced in armature under load condition.

iii) Drop in terminal voltage

The drop in terminal voltage (V_t) due to armature resistance and armature reaction results in decreased field current, which further reduces emf induced.
For a shunt generator

$$Ra = 9.7\ \Omega$$
$$I_a = I_L + I_F$$
$$E = V_t + I_a R_a$$

The circuit diagram for Load Characteristics is shown in Figure 5.2

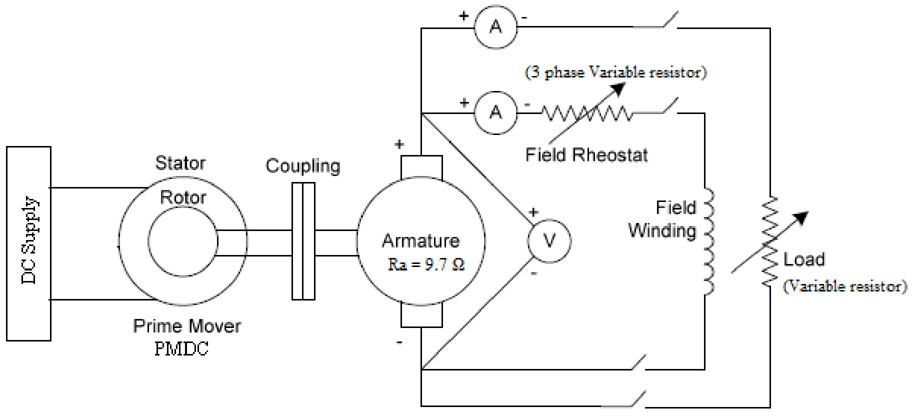


Figure 5.2: Circuit Diagram for Load Characteristics

PROCEDURE:

(A) No Load Characteristics:

1. Connect the shunt field to armature terminal through the ammeter, switch and rheostat as shown in Figure 5.1.
2. Connect the multi-range voltmeter across the terminals of armature.
3. Increase the voltage of permanent magnet DC (PMDC) motor (prime mover) by the help of power supply until it reaches at normal speed (i.e. 110V DC).
4. Note the reading of voltmeter which indicates the voltage due to residual magnetism.
5. Close field switch and excite the field at low current.
6. Increase the field current in steps and note the voltage each time.
7. Take at least 5 readings.
8. Tabulate the readings in Table - I and draw the curve between armature induced emf and field Current.

(B) Load Characteristics:

1. Make the connections as shown in Figure 5.2.
2. Increase the voltage of permanent magnet DC (PMDC) motor (prime mover) by the help of power supply until it reaches at normal speed (i.e. 110V DC).
3. Increase the voltage of permanent magnet DC (PMDC) motor (prime mover) by the help of power supply until it reaches at normal speed.
4. When motor reaches rated speed, close the shunt field switch.
5. Now connect load to the armature terminals through ammeter.
6. Close the switch of load and vary the load current by means of load rheostat.
7. Note down the meter readings from all meters carefully and note them in Table – II.

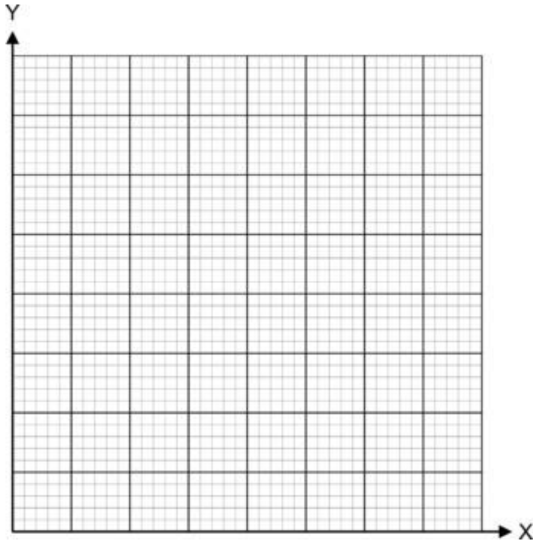
OBSERVATIONS:

(A) No Load Characteristics

TABLE – I (Internal Generated Voltage corresponding to Field Current)

Sr.No.	Field Current I_F (A)	Internally Generated or Terminal Voltage E_A/ V_T(V)
1		
2		
3		
4		
5		

No Load Characteristics Curve:

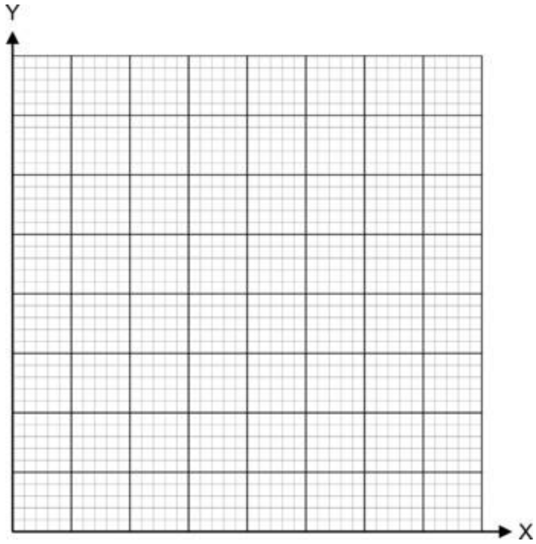


(B) Load Characteristics

TABLE – II (Terminal Voltages corresponding to Load current and Field current)

Sr. No.	I_f(A)	I_L(A)	I_a=I_f + I_L(A)	V_T(V)	V_D=$I_a R_a$(V)
1					
2					
3					
4					
5					

Load Characteristics Curve:



POST LAB QUESTIONS:

1. Why the curve starts somewhat above the origin?
2. The voltage increases rapidly at first and then changes a little in value at higher excitations.
3. At which point terminal voltage of DC shunt Generator was maximum and why?

EXPERIMENT 6

INTERNAL AND EXTERNAL CHARACTERISTICS OF SEPARATELY EXCITED DC GENERATOR

OBJECTIVE:

- To draw the internal and external characteristics of separately excited DC shunt generator.

EQUIPMENT:

- DC Excited Generator
- Variable DC Supply
- Variable Resistor
- DC Voltmeter and Ammeter

BACKGROUND:

The generators in which field coils are excited from some external source for e.g. batteries, are called separately excited DC generators. They are of low voltage and high current rating. They are used in Electroplating, Electro traction and Electro Refining of Metals. The load or external characteristic of a generator is the relation between the terminal voltageV_t and load current I_L. The characteristic expressed the manner in which the voltage across the load varies with I, the value of load current. The internal or total characteristic of a generator is the relation between the emf actually induced in the generator E_a and the armature current I_a. The internal characteristic of the generator, which is separately excited, can be obtained as below:

Let:

V_t = Terminal voltage, I_a = Armature current, R_a = Armature resistance

Then,

$$\mathbf{E = V_t + I_a R_a}$$
$$\mathbf{I_a = I_L}$$

Therefore, if we add drop of armature (I_aR_a) to terminal voltage V_t we get actually induced emf (E). The three main reasons for decrease in terminal voltage of Shunt Generator under load condition are armature reaction, armature resistance and drop in terminal voltage as discussed above. The circuit diagram for determining Internal and External Characteristics is shown in Figure 6.1

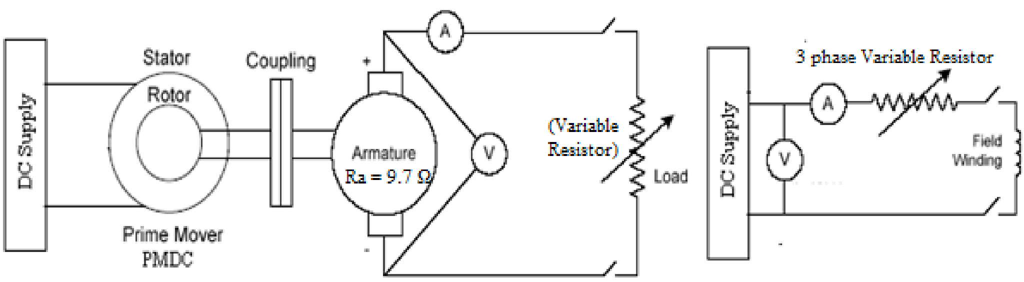


Figure 6.1: Circuit Diagram for Internal and External Characteristics

PROCEDURE:

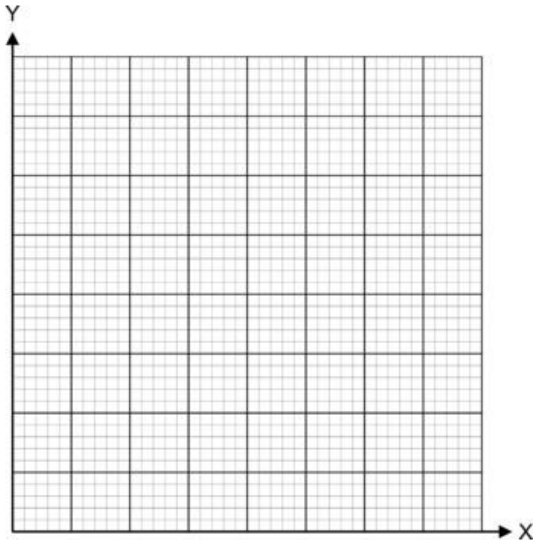
1. Make the circuit as shown in circuit diagram in Figure 6.1.
2. Increase the voltage of permanent magnet DC (PMDC) motor (prime mover) with the help of DC power supply until it reaches at normal speed.
3. When motor reaches rated speed, close the shunt field switch.
4. Now connect load to the armature terminals through ammeter.
5. Close the switch of load and vary the load current by means of load rheostat.
6. Note down the meter readings from all meters carefully and note them in Table - I

OBSERVATIONS:

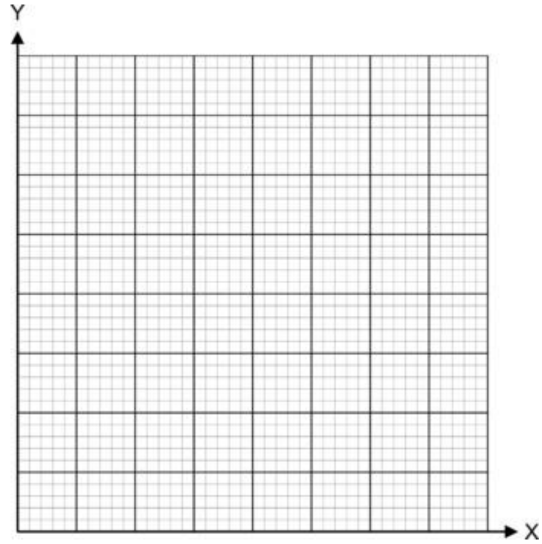
TABLE – I (Terminal Voltage corresponding to Field and Load Current)

Sr. No.	I_L (A)	I_F (A)	V_T (V)	$E_a = V_t + I_a R_a$ (V)
1				
2				
3				
4				
5				

Internal Characteristics:



External Characteristics:



POST LAB QUESTIONS:

1. Why the terminal voltage across DC shunt generator decreases as the load increases?
2. What conclusion you have reached from the above experiment?

EXPERIMENT 7

DESIGN A SPEED CONTROL CIRCUIT FOR DC SHUNT MOTOR (OPEN ENDED LAB)

OBJECTIVE:

- Design a control circuit to operate the DC Shunt motor in a range of speed

PROBLEM STATEMENT:

You have to design a control circuit that operates the DC Shunt Motor in a range between its Rated Speed (S_{Rated}) and Speed (S_2). You have to select the value of Speed (S_2) by putting your Section no and last two digits of your Registration no in the given formula:

$$S_2 = S_{Rated} + 100 * section\_no + Last\ 2\ digits\ of\ your\ registration\ no$$

You are required to use only the following resistors or a combination of these to achieve your desired value of resistor
4.7Ω, 10Ω, 47Ω, 100Ω, 220Ω, 1kΩ, 2.2kΩ, 4.7kΩ, 10kΩ, 12kΩ

You are required to design a value of resistor for the following values of speeds specified in Table – I

TABLE – I (Designed Resistors corresponding to speeds)

Speed	**Speed**	**Resistor**
S_2 - 50		
S_2 - 100		
S_2 - 150		

Implement the circuit in lab after designing a resistor.
Measure the speed using a Tachometer.
Calculate the error between measured and desired speed interpret the difference.
Make a valid conclusion.

NOTE:
Rated Voltage of DC MOTOR=110 V
Rated Field current =0.26 A
Rated Speed=1000 RPM

EXPERIMENT 8

SPEED CONTROL OF DC SERIES MOTOR

OBJECTIVE:

- Speed control of a DC series motor by using flux control method.
- Speed control of a DC series motor by using armature resistance control method.

EQUIPMENT:

- DC Excited Motor
- Variable DC Supply
- Variable Resistor
- DC Voltmeter and Ammeter

BACKGROUND:

(A) Using Flux Control

Dc series motor gets their name from the way that their armature and field winding are connected together in a series circuit. Their prominent characteristics are high starting torque and poor speed regulation. Their main disadvantage is that they cannot operate safely in an unloaded condition. They are widely used for starting heavy industrial high torque loads such as cranes, elevators, trolleys etc.

In flux control method, a variable resistance also called flux diverter is connected in parallel with the field winding. Its purpose is to divide some portion of line current from series field winding, there by weakening the flux and increasing the speed since speed is inversely proportional to flux ($N \propto 1/\emptyset$). The lowest speed obtainable is that corresponding to zero current in the diverter and it is also the normal speed of the motor. Consequently, this method can only provide speed above the normal speed of motor. The circuit diagram for speed control of series motor using Flux Control Method is shown in Figure 8.1

CIRCUIT DIAGRAM:

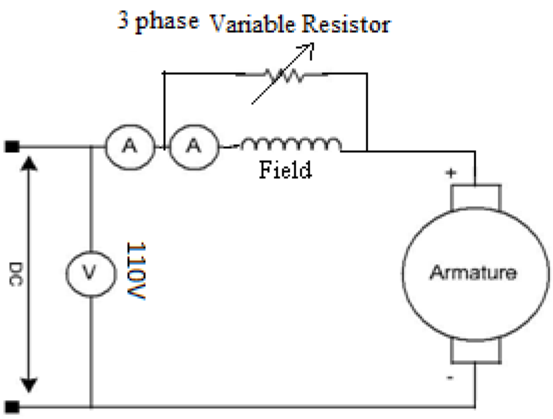


Figure 8.1: Speed control of DC series motor using flux control

(B) Using Armature Resistance Control

Dc series motor gets their name from the way that their armature and field winding are connected together in a series circuit. Their prominent characteristics are high starting torque and poor speed regulation. Their main disadvantage is that they cannot operate safely in an unloaded condition. They are widely used for starting heavy industrial high torque loads such as cranes, elevators, trolleys etc.

In Armature resistance control method, a variable resistance is directly connected in series with the supply to the motor. This reduces the voltage available across the armature and hence the speed falls. By changing the value of variable resistance, any speed below the normal speed can be obtained. This is the most common method to control the speed of DC series motor. Although this method has poor speed regulation, but this has no significance in case of series motors, because they are used in varying speed regulations. The loss of power in series resistance for many applications of series motors is not too serious, since in these applications the control is utilized for large portion of time for reducing speed under light load conditions and is only used intermittently when the motor is carrying full load. The circuit diagram for speed control of series motor using Armature Control Method is shown in Figure 8.2

CIRCUIT DIAGRAM:

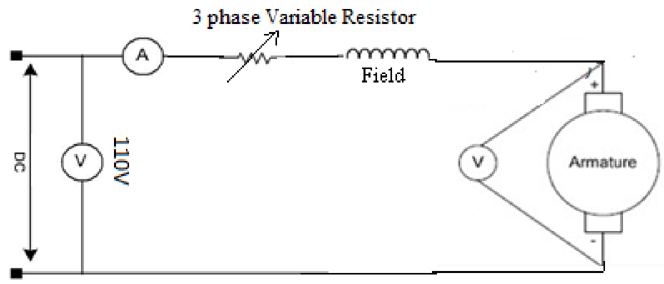


Figure 8.2: Speed control of DC series motor using armature resistance control

PROCEDURE:

(A) Using Flux Control:

1. Make connections as shown in the Figure 8.1 by placing a variable resistance in parallel with the field winding.
2. Keep the motor starting rheostat at its maximum position and field rheostat at its minimum position while starting motor.
3. Start the motor by pressing switch "ON" without load and provide 40 volts approx.
4. Adjust the motor start rheostat to its minimum value.
5. Increase the value of field flux diverter step by step and take readings of field current and speed from digital tachometer at every step and note them in Table - I. Adjust the flux diverter to note the maximum speed at which motor can be operated safely.

(B) Using Armature Resistance Control:

1. Make connections as shown in Figure 8.2 by placing a variable resistance in series with the armature and field winding.
2. Keep the motor starting rheostat at its maximum position and field rheostat at its minimum position while starting motor.
3. Start the motor by pressing switch "ON" without load and provide 40 volts approx.
4. Adjust the motor start rheostat to its minimum value.
5. Increase the value of rheostat step by step and take readings of armature voltage and speed from digital tachometer at every step and note them in Table - II. Adjust the rheostat to note the minimum speed at which motor can be operated safely.

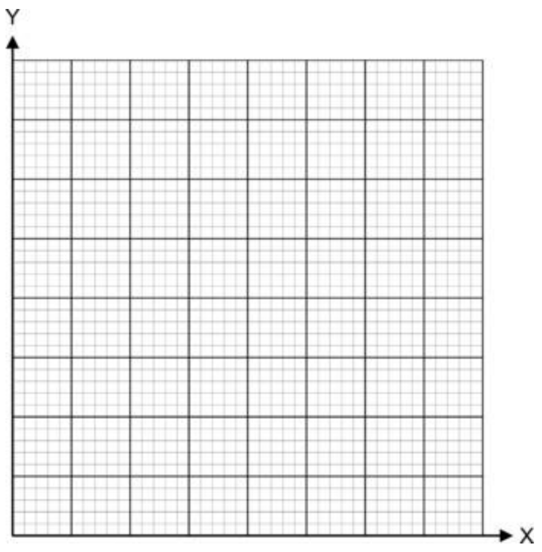
OBSERVATIONS:

(A) Using Flux Control

TABLE – I (Speed corresponding to change in field current)

Sr.No.	Armature Current I_A (A)	Field Current I_f (A)	Speed N (rpm)
1			
2			
3			
4			
5			

Graph between Field Current and Speed:

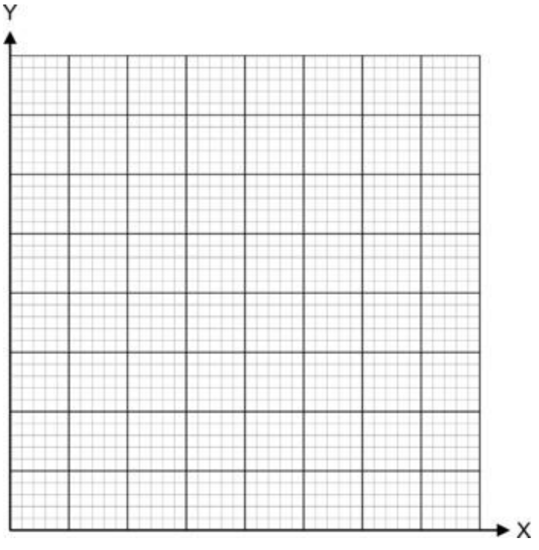


(B) Using Armature Resistance Control

TABLE – II (Speed corresponding to Armature Voltage)

Sr. No	**Armature Voltage (V)**	**Speed (RPM)**
1		
2		
3		
4		
5		

Graph between Armature Voltage and Speed:



<u>POST LAB QUESTIONS:</u>

1. Why it is not suitable to start the DC series without load?
2. If the rated speed of DC series motor is 15000 rpm and you want to run the motor on a speed of 1000 rpm, which method would you choose to achieve the desired speed and why?
3. What are the factors on which the speed of DC series motor depends?

EXPERIMENT 9

VOLTAGE REGULATION OF SYNCHRONOUS GENERATOR

OBJECTIVE:

- To get familiarize with voltage regulation of synchronous generator

EQUIPMENT:

- 3 Phase Synchronous Generator
- Load Box
- AC Voltmeter
- PMDC Motor as a prime mover
- Variable DC Supply

BACKGROUND:

It is clear that when change in load occurs, there is a change in terminal voltage of alternator. Magnitude of this change not only depends on the load but also on the load power factor. Voltage regulation of an alternator is defined as the "Rise in voltage when full load is removed (field excitation and speed remaining the same) divided by the rated terminal voltage.

$$\textbf{\% voltage regulation} = \frac{Eo-V}{V} * 100$$

(E_o-V) is the arithmetical difference.
The circuit diagram for determination of synchronous generator is shown in Figure 9.1

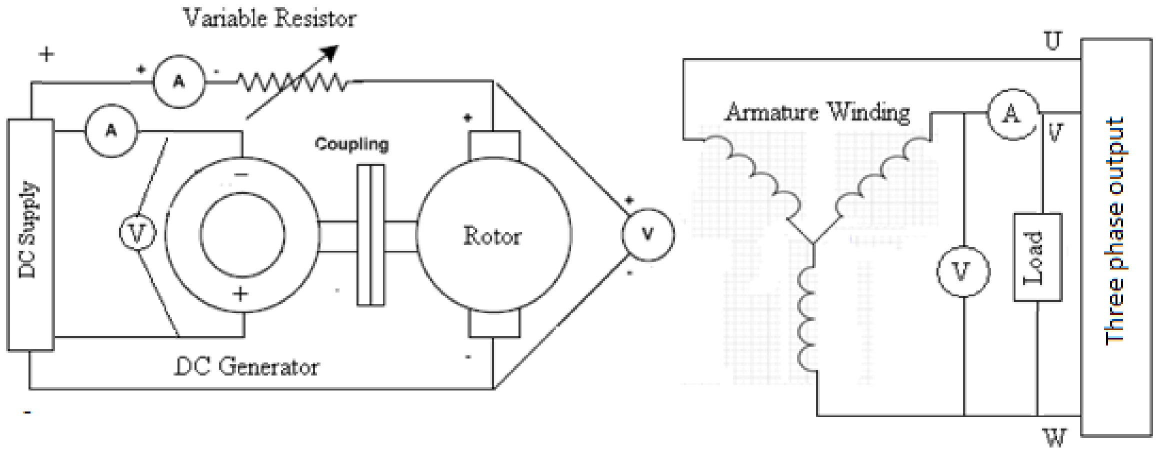


Figure 9.1: Voltage regulation of synchronous generator

PROCEDURE:

In case of small machines, the regulation may be found by direct loading procedure is as follows:

1. Connect the circuit as shown in Figure 9.1.
2. The No Load voltage is set to be 110V using field current rheostat.
3. The alternator is driven at synchronous speed and the terminal voltage is adjusted to its rated value V.

4. The load is varied until the wattmeter and ammeter (connected for purpose) indicate the rated values at defined P.F.
5. Then the entire load is thrown off while the speed and field excitation are kept constant. The open circuit or no-load voltage E_o is read. So, voltage regulation can be calculated using formula given above. Note all the values in Table – I.

OBSERVATIONS:

Rated Voltage =
Rated Load Current =
Rated Power =
RPMs =
Power Factor =

TABLE – I (Voltage Regulation corresponding to different values of Field Current)

Sr.No.	No load Phase Voltage (V)	Full Load Phase Voltage (V)	Field Current (I_f)	Voltage Regulation (V.R)
1				
2				
3				
4				
5				

POST LAB QUESTIONS:

1. What is meaning of V.R?
2. What is significance of V.R.?
3. What should be the value of V.R. in ideal cases?

EXPERIMENT 10

MODELING OF SYNCHRONOUS GENERATOR

OBJECTIVE:

- To find the equivalent circuit of the synchronous generator by finding its parameter.
- To learn how to find out the resistance of armature winding.
- To draw magnetization curve of synchronous generator
- To perform short circuit test on synchronous generator.

EQUIPMENT:

- 3 Phase Synchronous Generator
- Load Box
- AC Voltmeter
- Variable Resistor
- PMDC Motor as a prime mover
- Variable DC Supply
- DC Voltmeter and Ammeter

BACKGROUND:

The three quantities must be determined in order to describe the generator model:

1. The relationship between field current and flux (and therefore between the field current I_F and the internal generated voltage E_a.
2. The synchronous reactance X_s.
3. The armature resistance R_a.

After finding these values we can draw synchronous generator equivalent model as given in Figure 10.1

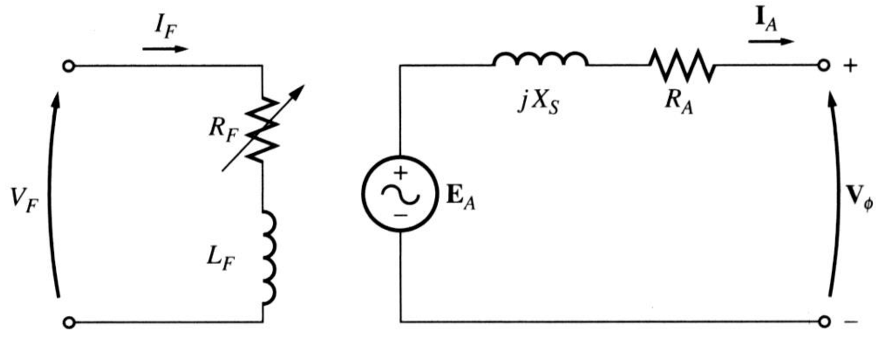


Figure 10.1: Per-Phase Equivalent Circuit

Since – for balanced loads – the three phases of a synchronous generator are identical except for phase angles, so per-phase equivalent circuits are often used.

The above-mentioned quantities can be determined by performing the following three tests:

1. DC test
2. Open circuit test
3. Short circuit test

(A) DC Test (To find the Armature resistance)

The purpose of the DC test is to determine Ra. A variable DC voltage source is connected between two stator terminals.

The DC source is adjusted to provide approximately rated stator current, and the resistance between the two stator leads is determined from the voltmeter and ammeter readings.
Then,

$$\mathbf{R_{dc}} = \frac{\mathbf{V_{dc}}}{\mathbf{I_{dc}}}$$

If the stator is Y-connected, the per phase stator resistance is

$$\mathbf{R_a} = \frac{\mathbf{R_{dc}}}{\mathbf{2}}$$

If the stator is delta-connected, the per phase stator resistance is

$$\mathbf{R_a} = \frac{\mathbf{3}}{\mathbf{2}}\mathbf{R_{dc}}$$

The circuit diagram for DC Test when the stator is connected in Y-connected is shown in Figure 10.2

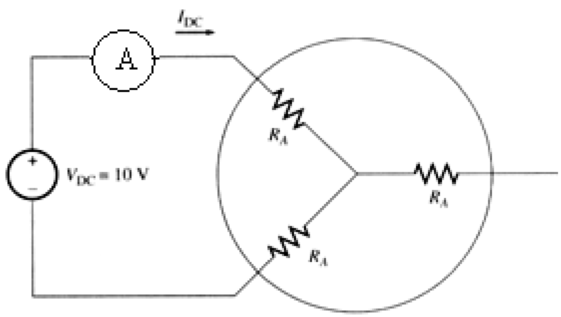


Figure 10.2: DC test

(B) Open Circuit Test (Effect of Field Current on Internal Generated Voltage)

The magnitude of internal generated voltage induced in a given stator is

$$\mathrm{Ea} = \mathrm{K}\Phi\ \omega$$

Where K is a constant, Φ $is\ flux\ \omega$ is rotation speed of rotor.

Since flux in the machine depends on the field current through it, the internal generated voltage is a function of the rotor field current.
The generator is rotated at the rated speed, all the terminals are disconnected from loads, the field current is set to zero first. Next, the field current is increased in steps and the phase voltage (which is equal to the internal generated voltage E_A since the armature current is zero) is measured.

Therefore, it is possible to plot the dependence of the internal generated voltage on the field current – the open-circuit characteristic (OCC) of the generator

Since the unsaturated core of the machine has a reluctance thousands of times lower than the reluctance of the air-gap, the resulting flux increases linearly first. When the saturation is reached, the core reluctance greatly increases causing the flux to increase much slower with the increase of the mmf. The circuit diagram for open circuit test is shown in Figure 10.3

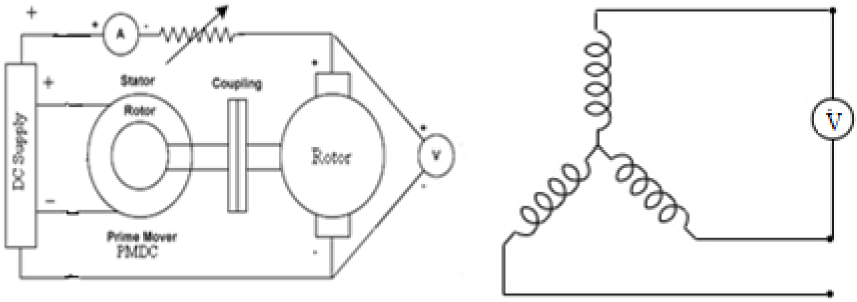


Figure 10.3: Open circuit test

(C) Short Circuit Test

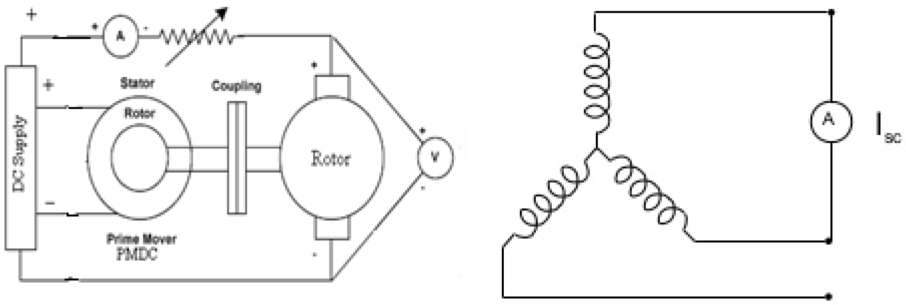


Figure 10.4: Short circuit test

PROCEDURE:

(A) DC Test:

1. Connect the armature in star connection as shown in Figure 10.2.
2. Make connections according to circuit diagram.
3. Apply V_{dc} across two phases of armature and note down the current I_{dc} Table – I.
4. Calculate armature resistance using formula given above and note down in Table – I.
5. Take average.

(B) Open Circuit Test:

1. Make the connection as show in Figure 10.3 carefully.
2. Run the rotor with help of prime mover at rated speed (PMDC).
3. Note down the line voltage at zero excitation. If there exist any voltage, this is due to residual magnetism.
4. Now increase the field excitation step by step and note down the corresponding values of generated voltage in Table – II.
5. Draw a graph between generated voltage and field current.

(C) Short Circuit Test:

1. Make connections as shown in Figure 10.4
2. The generator is rotated at the rated speed.
3. All the terminals are short-circuited through ammeters.
4. The field current is set to zero first. Next, the field current is increased in steps and the Armature current I_A is measured as the field current is increased. Note the Armature Current corresponding to Field Current in Table – III.
5. Plot the graph between armature current (or line current) and the field current. The graph is a straight line for the short circuit terminals. The magnitude of the armature current is

$$\mathbf{Ia} = \frac{\mathbf{Ea}}{\sqrt{\mathbf{Ra^2} + \mathbf{Xs^2}}}$$

OBSERVATIONS:

(A) DC Test

TABLE – 1 (Armature Resistance corresponding to Applied Voltage)

Sr. No.	Applied Voltage (V)	Current (A)	DC Resistance (R_{dc})	Armature Resistance (Ra)
1				
2				
3				
4				
5				

$$\mathbf{Average\ Armature\ resistance} = \frac{\mathbf{Ra1 + Ra2 + Ra3 + Ra4 + Ra5}}{\mathbf{5}}$$

So average armature resistance = …………………

(B) Open Circuit Test

TABLE – II (Phase Voltage corresponding to field current)

Sr. No.	Field Current(A)	Phase Voltage(V)	Speed (RPM)
1			
2			
3			
4			
5			

(C)Short Circuit Test

TABLE – III (Synchronous Reactance)

Sr. No.	RPM	Phase Voltage (V)	Field Current (A)	Armature Current (A)	Xs
1					
2					
3					
4					
5					

An approximate method to determine the synchronous reactance X_S at a given field current:

1. Get the internal generated voltage E_A from the OCC at that field current.
2. Get the short-circuit current $I_{A,\,SC}$ at that field current from the SCC.
3. Find X_S from

$$\boldsymbol{Xs \approx \frac{Ea}{Ia, sc}}$$

Results

Parameters found are:

Ra=…………...

Xs=…………...

<u>POST LAB QUESTIONS:</u>

1. How AC resistance differs from DC resistance?

EXPERIMENT 11

STARTING METHODS OF SYNCHRONOUS MOTOR

OBJECTIVE:

- Learn how to start a synchronous motor. And why we need these methods to start synchronous motor.

EQUIPMENT:

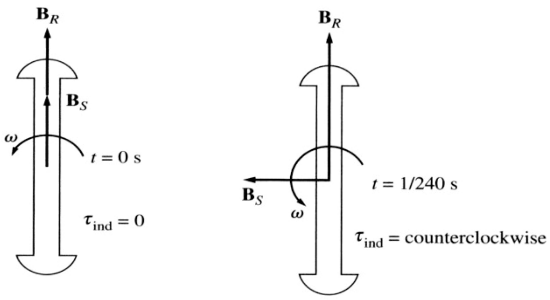
- 3 Phase Synchronous Motor
- Knife Switch
- PMDC Motor as a prime mover
- Variable DC Supply
- AC and DC Voltmeter and Ammeter
- Variable Resistor

BACKGROUND:

Consider a 60 Hz synchronous motor.
When the power is applied to the stator windings, the rotor (and, therefore its magnetic field B_R) is stationary. The stator magnetic field B_S starts sweeping around the motor at synchronous speed.

Note that the induced torque on the shaft (τ_{ind}= kB_R*Bs) is zero at t = 0 since both magnetic fields are aligned.

At t = 1/240 s the rotor has barely moved but the stator magnetic field B_S has rotated by 90^0. Therefore, the torque on the shaft is non-zero and counter-clockwise.

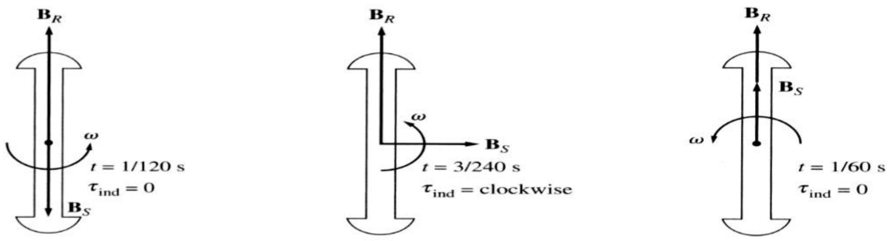


At t = 1/120 s the rotor and stator magnetic fields point in opposite directions, and the induced torque on the shaft is zero again.

At t = 3/240 s the stator magnetic fields point to the right, and the induced torque on the shaft is non-zero but clockwise.

Finally, at t = 1/60 s the rotor and stator magnetic fields are aligned again, and the induced torque on the shaft is zero.

During one electrical cycle, the torque was counter-clockwise and then clockwise, and the average torque is zero. The motor will vibrate heavily and finally overheats



Three basic approaches can be used to safely start a synchronous motor:

1. Reduce the speed of the stator magnetic field to a low enough value that the rotor can accelerate and two magnetic fields lock in during one half-cycle of field rotation. This can be achieved by reducing the frequency of the applied electric power (which used to be difficult but can be done now).
2. Use an external prime mover to accelerate the synchronous motor up to synchronous speed, go through the paralleling procedure, and bring the machine on the line as a generator. Next, turning off the prime mover will make the synchronous machine a motor.
3. Use damper windings or Amortisseur windings.

We will use $2^{nd}$and 3^{rd}method in the lab to start the synchronous motor.

(A) Method 1- Using Damper Winding:

The torque acting on a synchronous machine is counter-clockwise and then clockwise during one electrical cycle, and the average torque is zero. The motor will vibrate heavily and finally overheats.

So, a synchronous machine cannot be started by direct applying the two supplies i.e. 3-phase supply to Armature winding and DC supply to field winding. So, for this purpose synchronous machines are always provided with Damper winding also known as Amortisseur winding.
Damper windings are special bars laid into notches carved in the rotor face and then shorted out on each end by a large shorting ring. Figure 11.1 is showing Damper Winding in a machine.

Figure 11.1: Damper Winding

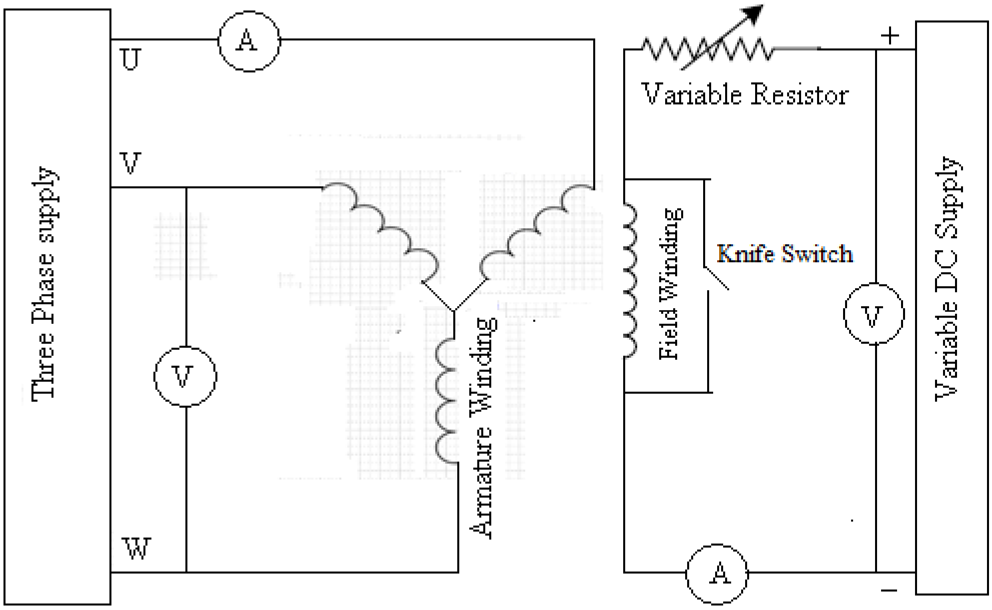


Figure 11.2: Starting of synchronous motor by damper winding

(B) Method 2- Using Prime Mover:

To use an external prime mover to accelerate the rotor of synchronous motor near to its synchronous speed and then supply the rotor as well as stator. Care should be taken to ensure that the direction of rotation of the rotor as well as that of the rotating magnetic field of the stator is the same. This method is usually followed in the laboratory- the synchronous machine is started as a generator and is then connected to the supply mains by following the synchronization or paralleling procedure. Then the power supply to the prime mover is disconnected so that the synchronous machine will continue to operate as a motor.

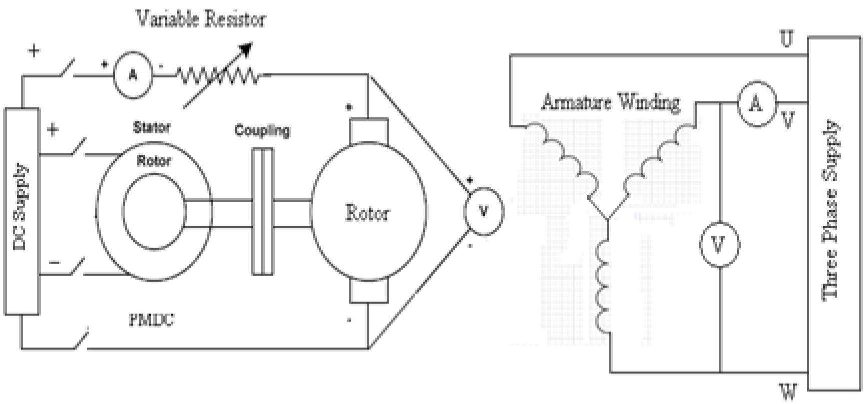


Figure 11.3: Starting of synchronous motor using prime mover

PROCEDURE:

(A) Method 1- Using Damper Winding:

1. Connect circuit as shown in Figure 11.2
2. First, main filed winding is short circuited.

3. Reduced voltage approximately 70V AC with is applied across stator terminals. The motor starts up.
4. When it reaches a steady state speed a weak dc excitation i.e. 50V is applied by removing the short circuit on the main filed winding. If excitation is sufficient, the machine will be pulled into synchronism.
5. Full supply voltage is applied across stator terminals.
6. The motor may be operated at any desired P.F by changing the D.C excitation.

(B) Method 2- Using Prime Mover:

1. Connect circuit as shown in Figure 11.3
2. Apply 3-phase supply to armature circuit.
3. Rotate the armature with help of prime mover at rated speed.
4. Apply field excitation.
5. Vary field excitation until machine runs at constant speed. At that instant machine interlocks electrically.

POST LAB QUESTIONS:

1. What do you mean by rated value i.e. rated voltage, rated current, rated power, rated speed etc.
2. What happens when field circuit of synchronous motor is disconnected?
3. What is the difference between induction machine and synchronous machine?

EXPERIMENT 12

CHARACTERISTIC CURVES OF SYNCHRONOUS MOTOR

OBJECTIVE:

- To learn how armature current varies with its field current.
- To have the understanding of torque and speed of synchronous motor.

EQUIPMENT:

- 3 Phase Synchronous Motor
- Knife Switch
- Variable DC Supply
- AC and DC Voltmeter and Ammeter
- Variable Resistor

BACKGROUND:

(A) Construction of V Curve (Effect of Field Excitation on Armature Current)

The V-curves of a synchronous motor show how armature current varies with its field current when motor input is kept constant. These are obtained by plotting A.C. armature current against D.C. field current while motor input is kept constant and are so called because of their shapes.
The magnitude of I_a varies with excitation. Current has large value for both low and high values of excitation (though it is lagging for low and leading for higher excitation). In between it has minimum value corresponding to certain excitation.

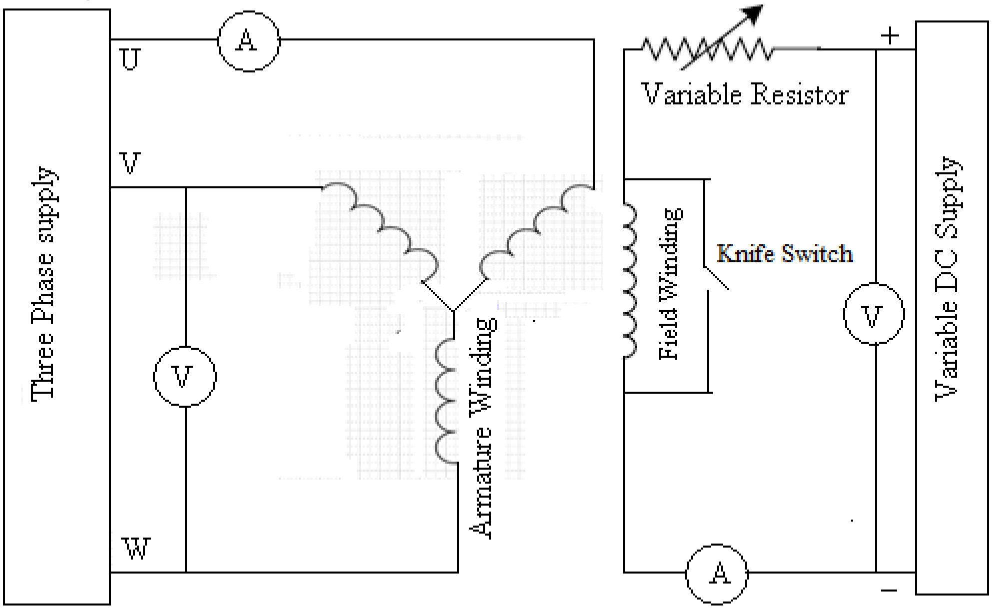


Figure 12.1: Construction of V curve

(B) Torque Speed Curve

Steady state speed of synchronous motor is constant from no load to maximum torque that motor can supply (pullout torque).

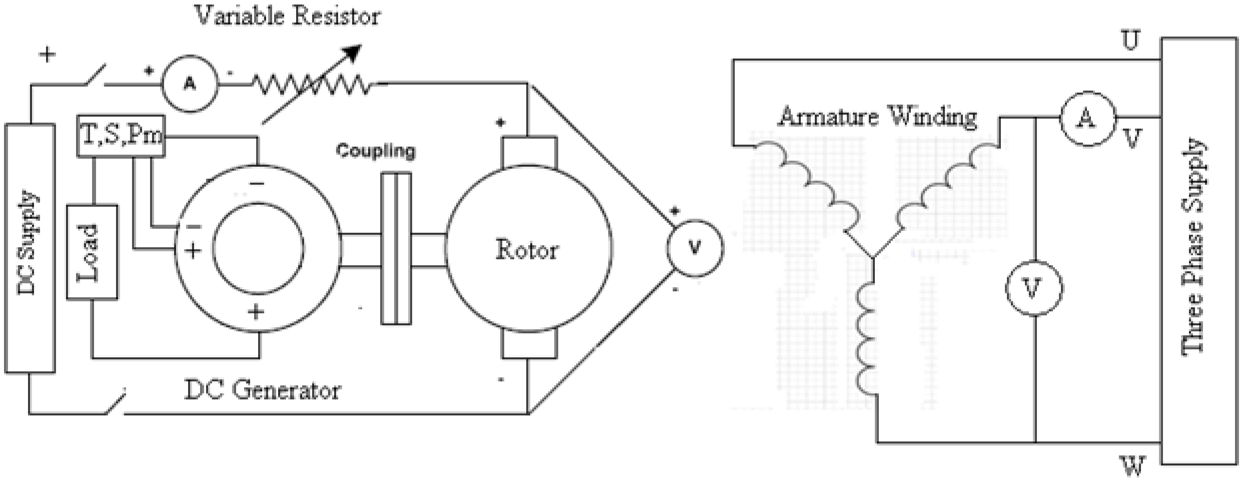


Figure 12.2: Torque speed curve

PROCEDURE:

(A) Construction Of V-Curve

Connect the circuit as shown in Figure 12.1. To draw these curves experimentally the motor is run from constant voltage and constant frequency bus bars. Power input to motor is kept constant at a definite value. Next, field current is increased in small steps and corresponding armature currents are noted in Table – I. When plotted, we get V curves for a particular constant motor input.

(B) Torque Speed Curve

1. Couple synchronous motor with PMDC generator mechanically as shown in Figure 12.2.
2. Run synchronous motor using any of above-mentioned methods.
3. Now start increasing load on the generator in small steps.
4. Note down corresponding values of torque and speed in Table – II.
5. Make a plot between torque and speed

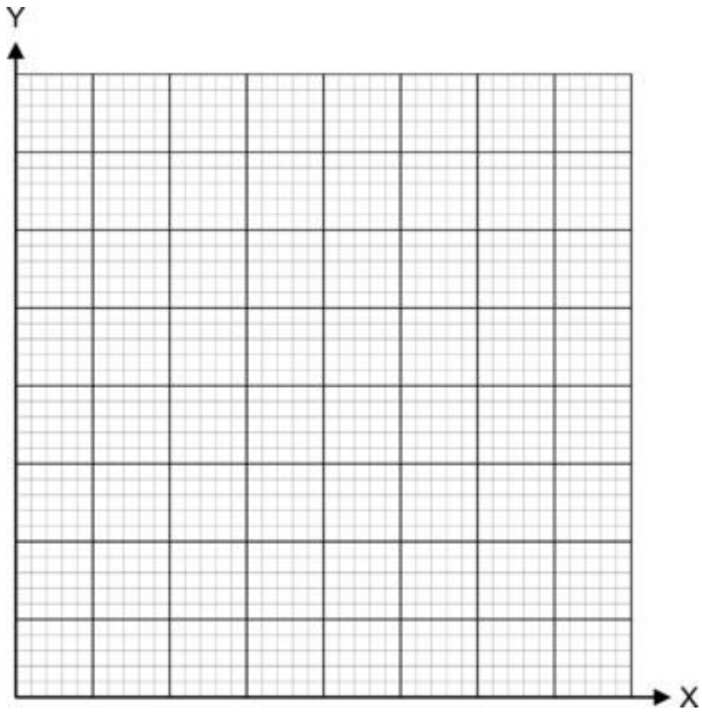
OBSERVATIONS:

(A) Construction of V Curve

TABLE – I (Armature current corresponding to Field current)

Sr.No.	Field Current I_f (A)	Armature Current I_a (A)
1		
2		
3		
4		
5		
6		

Curve between Field Current and Armature Current (V Curve):

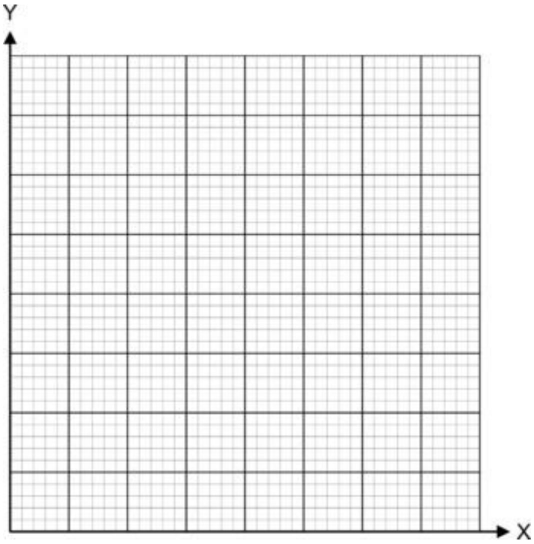


(B) Torque Speed Curve

TABLE – II (Torque and Speed corresponding to Load)

Sr.No.	Load	Torque (N)	Speed (ω)
1			
2			
3			
4			
5			

Curve between Torque and Speed (Torque Speed Curve):



POST LAB QUESTIONS:

1) What is the significance of V characteristics of synchronous motor?
2) What is the effect of dc excitation on power factor?
3) What is the effect of increasing load on torque? What is the effect of increasing load on speed?

EXPERIMENT 13

THREE PHASE INDUCTION MOTOR (CAGE ROTOR)

OBJECTIVE:

- To study the torque speed curve of the induction motor (Cage Rotor)

EQUIPMENT:

- Three Phase Asynchronous Cage Rotor Motor
- Three phase variable AC Supply
- AC and DC Voltmeter and Ammeter
- Load Box
- PMDC Motor

BACKGROUND:

The cage rotor induction motor is quite different from the synchronous motor so its behavior will also vary. The induction machine is the one which has only the Amortisseur windings. The machine is called as an induction machine because the voltage is being induced in the rotor of the induction machine rather than being supplied by the external source. The torque of the machine varies by changing the load. The behavior of an induction machine is being observed in this experiment.

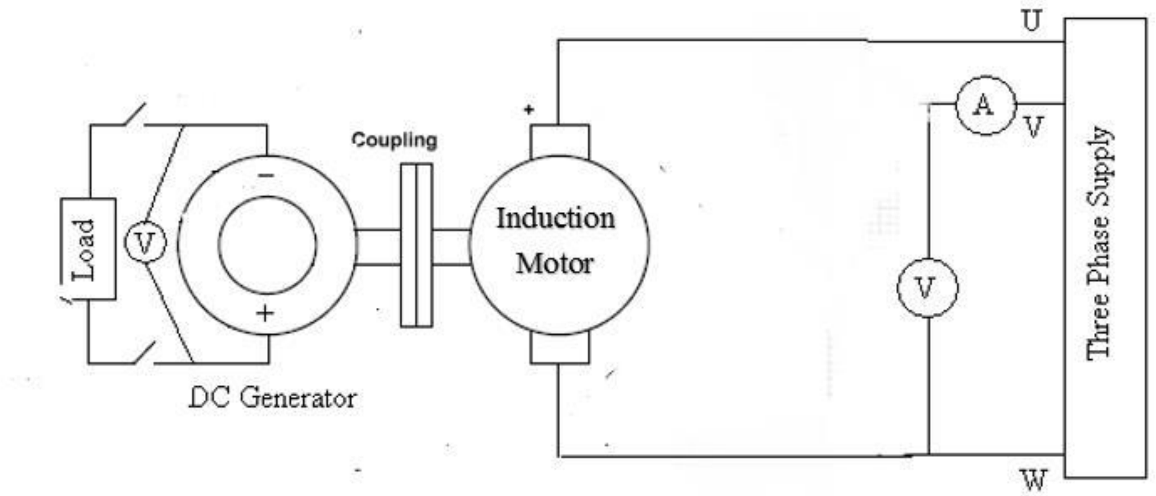


Figure 13.1: Torque speed curve of Induction motor (Cage rotor)

PROCEDURE:

1. According to the given diagram in Figure 13.1 connect the different electrical wires.
2. Supply the Three phase voltage to the 3 Phase cage asynchronous Motor.
3. In order to take necessary precautions, connect a relay and thermal connector between the two.
4. The 3 Phase cage Asynchronous motor is coupled to the DC motor that acts as a generator.
5. Connect the generator to the Torque Power Measurement gauge.
6. The load is connected to the Generator through an ammeter.

7. Switch on the 3 Phase power supply and measure the Torque, Speed, Power and current at no load
8. Now increase the load by a single step and note down the readings in the given table.
9. You can measure the speed through a tachometer.
10. Find the torque using formula of $P = \zeta * \omega$. Keep in mind that w is the speed in radians per second.
11. Plot the graph of Torque vs. Speed from the data recorded in the Table – I.

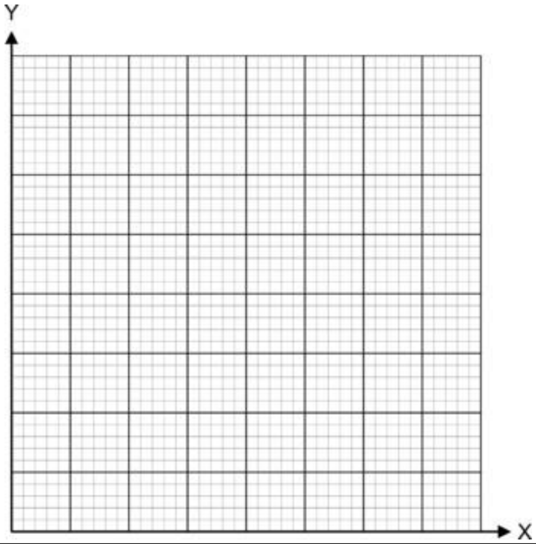
OBSERVATIONS:

TABLE – I (Power, Torque and Speed corresponding to Load)

Sr. No	R_{load} (Ω)	Speed (rpm)	Power (W)	Torque (Nm)	Current(A)
1					
2					
3					
4					
5					

POST LAB QUESTIONS:

1. Draw a graph between Torque and Speed from the above noted values.
2. How much torque can an induction motor supply at the starting conditions?
3. How does the speed of an induction motor vary as the load gets changed? Explain it with respect to the graph you plotted.
4. What is the difference between cage rotor and wound rotor?



EXPERIMENT 14

STARTING AND TORQUE SPEED CHARACTERISTICS OF THREE PHASE INDUCTION MOTOR (WOUND ROTOR)

OBJECTIVE:

- To observe the torque speed characteristics of the induction motor(Wound Rotor)
- To observe the starting of the induction motor (Wound Rotor)

EQUIPMENT:

- Three Phase Asynchronous Wound Rotor Motor
- Three phase variable AC Supply
- AC and DC Voltmeter and Ammeter
- Variable Resistor
- PMDC Motor

BACKGROUND:

(A) Torque Speed Characteristics

A wound rotor has a complete set of three phase windings that are mirror images of stator windings. The wound rotor induction motor is quite different form cage rotor just because of its construction of rotor. The wound rotor induction motor has a slightly different behavior as compared to that of cage rotor. The torque of a motor depends on a number of factors. In this experiment we will discuss the torque speed curve of the induction motor.

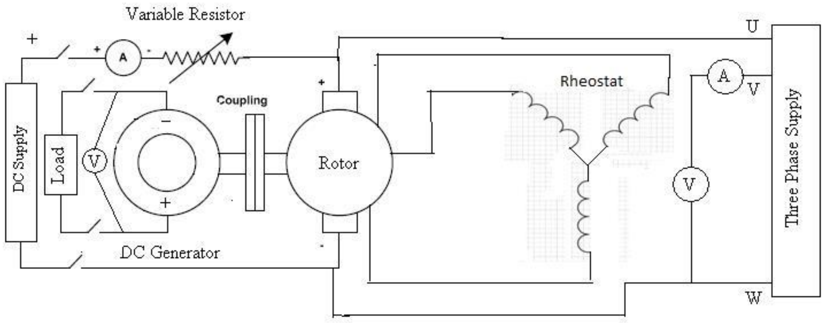


Figure 14.1: Torque speed curve of Induction motor

(B) Starting of 3 Phase Induction Motor (Wound Rotor)

3 Phase asynchronous motor is also called as an induction motor. Induction motors do not present the types of starting problems that synchronous motors do. In many cases, induction motors can be started by simply connecting them to the power line. However, there are sometimes good reasons for not doing so. For wound rotor motors the starting current can be achieved at very low currents by inserting extra resistance in the rotor circuit during starting. This extra resistance not only increases the starting torque but also reduces the starting current.

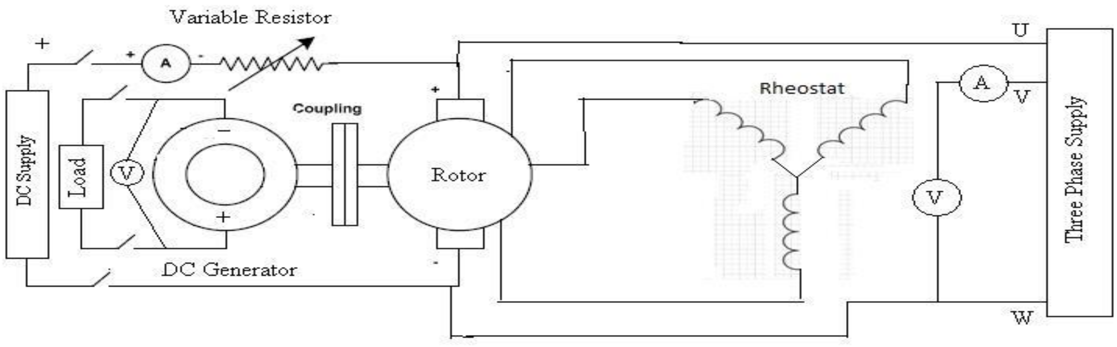


Figure 14.2: Starting of Induction motor

PROCEDURE:

(A) Torque Speed Characteristics

1. According to the given diagram shown in Figure 14.1 connect the different electrical wires.
2. Supply the Three phase voltage to the 3 Phase cage asynchronous Motor.
3. In order to take necessary precautions, connect a relay and thermal connector between the two.
4. The 3 Phase cage Asynchronous motor is coupled to the DC motor that acts as a generator.
5. Connect the generator to the Torque Power Measurement gauge.
6. The load is connected to the Generator through an ammeter.
7. The rotor that is Y-connected internally should be connected to a rheostat in a Y-connection
8. Switch on the 3 Phase power supply and keep the connection of Y-connected rheostat to the rotor for 20 seconds
9. After 20 seconds, remove the rheostat and short the windings of the rotor.
10. Observe the behavior of asynchronous motor.
11. Measure the Torque, Speed, Power and Currentat no load.
12. Now increase the load by a single step and note down the readings in the given table.
13. You can measure the speed through a tachometer.
14. Find the torque using formula of $P = \zeta * \omega$. Keep in mind that w is the speed in radians per second.
15. Plot the graph of Torque vs. Speed from the data recorded in the Table – I

(B) Starting of 3 Phase Induction Motor:

1. According to the given diagram shown in Figure 14.2 connect the different electrical wires.
2. Supply the Three phase voltage to the 3 Phase cage asynchronous Motor.
3. In order to take necessary precautions, connect a relay and thermal connector between the two.
4. The 3 Phase cage Asynchronous motor is coupled to the DC motor that acts as a generator.
5. Connect the generator to the Torque Power Measurement gauge.
6. The load is connected to the Generator through an ammeter.
7. The rotor that is Y-connected internally should be connected to a rheostat in a Y-connection
8. Switch on the 3 Phase power supply and keep the connection of Y-connected rheostat to the rotor for 20 seconds

9. After 20 seconds, remove the rheostat and short the windings of the rotor.
10. Observe the behavior of asynchronous motor.
11. Measure the Torque, Speed, Power and Current at no load.

OBSERVATIONS:

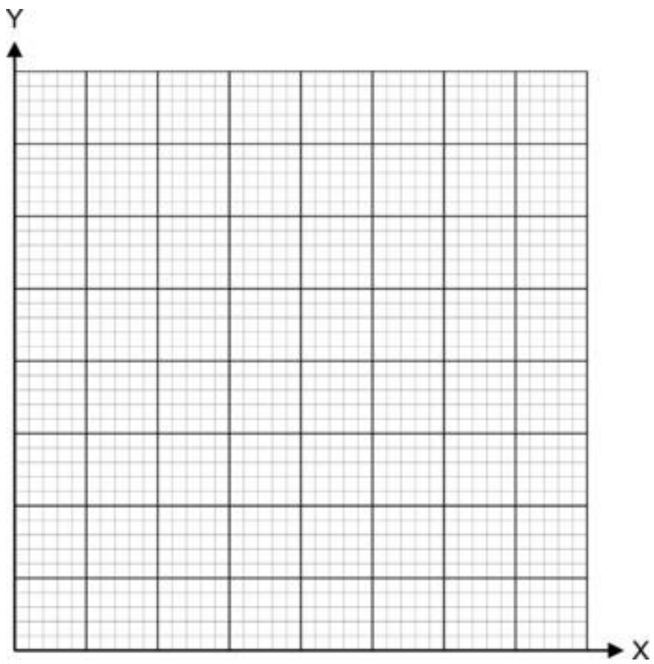
(A) Torque Speed Characteristics

TABLE – I (Speed, Power and Torque corresponding to Load)

Sr. No	R_{load}	Speed	Power	Torque	Current
1.					
2.					
3.					
4.					
5.					

(B) Starting of 3 Phase Induction Motor

Torque:________________________
Speed: ________________________
Power: ________________________
Current:_______________________



POST LAB QUESTIONS:

1. Draw a graph between Torque and Speed from the above noted values.
2. Write the relation between torque and Power. How are they related?
3. What is the speed of an induction motor at the synchronous speed?
4. What do you know about the pullout torque or break down torque? Can you identify this term in your own graph?
5. Why the starting torque on the motor is slightly larger than the full-load torque?
6. Why the extra resistance is being added for the starting of the induction motor?
7. On what parameters does the starting current of an induction motor depend?
8. Is there any other method for starting the induction motor besides adding resistance? If yes then explain it?

Appendix A: Lab Evaluation Criteria

Labs with projects

1. Class Participation 10%
2. Lab Work 40%
3. Quiz (2) 20%
4. Project 30%
   a. Project Demonstration 20%
   b. Project Report 5%
   c. Project Quiz 5%

Labs without projects

1. Class Participation 10%
2. Lab Work 40%
3. Quiz (2) 20%
4. Lab Final 30%
   a. Lab Final (Practical) 20%
   b. Lab Final (Written) 10%

Appendix B: Safety around Electricity

In all the Electrical Engineering (EE) labs, with an aim to prevent any unforeseen accidents during conduct of lab experiments, following preventive measures and safe practices shall be adopted:

- Remember that the voltage of the electricity and the available electrical current in EE labs has enough power to cause death/injury by electrocution. It is around 50V/10 mA that the “cannot let go” level is reached. “The key to survival is to decrease our exposure to energized circuits.”
- If a person touches an energized bare wire or faulty equipment while grounded, electricity will instantly pass through the body to the ground, causing a harmful, potentially fatal, shock.
- Each circuit must be protected by a fuse or circuit breaker that will blow or “trip” when its safe carrying capacity is surpassed. If a fuse blows or circuit breaker trips repeatedly while in normal use (not overloaded), check for shorts and other faults in the line or devices. Do not resume use until the trouble is fixed.
- It is hazardous to overload electrical circuits by using extension cords and multi-plug outlets. Use extension cords only when necessary and make sure they are heavy enough for the job. Avoid creating an “octopus” by inserting several plugs into a multi-plug outlet connected to a single wall outlet. Extension cords should ONLY be used on a temporary basis in situations where fixed wiring is not feasible.
- Dimmed lights, reduced output from heaters and poor monitor pictures are all symptoms of an overloaded circuit. Keep the total load at any one time safely below maximum capacity.
- If wires are exposed, they may cause a shock to a person who comes into contact with them. Cords should not be hung on nails, run over or wrapped around objects, knotted or twisted. This may break the wire or insulation. Short circuits are usually caused by bare wires touching due to breakdown of insulation. Electrical tape or any other kind of tape is not adequate for insulation!
- Electrical cords should be examined visually before use for external defects such as: Fraying (worn out) and exposed wiring, loose parts, deformed or missing parts, damage to outer jacket or insulation, evidence of internal damage such as pinched or crushed outer jacket. If any defects are found the electric cords should be removed from service immediately.
- Pull the plug not the cord. Pulling the cord could break a wire, causing a short circuit.
- Plug your heavy current consuming or any other large appliances into an outlet that is not shared with other appliances. Do not tamper with fuses as this is a potential fire hazard. Do not overload circuits as this may cause the wires to heat and ignite insulation or other combustibles.
- Keep lab equipment properly cleaned and maintained.
- Ensure lamps are free from contact with flammable material. Always use lights bulbs with the recommended wattage for your lamp and equipment.
- Be aware of the odor of burning plastic or wire.
- ALWAYS follow the manufacturer recommendations when using or installing new lab equipment. Wiring installations should always be made by a licensed electrician or other qualified person. All electrical lab equipment should have the label of a testing laboratory.
- Be aware of missing ground prong and outlet cover, pinched wires, damaged casings on electrical outlets.
- Inform Lab engineer / Lab assistant of any failure of safety preventive measures and safe practices as soon you notice it. Be alert and proceed with caution at all times in the laboratory.
- Conduct yourself in a responsible manner at all times in the EE Labs.

- Follow all written and verbal instructions carefully. If you do not understand a direction or part of a procedure, ASK YOUR LAB ENGINEER / LAB ASSISTANT BEFORE PROCEEDING WITH THE ACTIVITY.
- Never work alone in the laboratory. No student may work in EE Labs without the presence of the Lab engineer / Lab assistant.
- Perform only those experiments authorized by your teacher. Carefully follow all instructions, both written and oral. Unauthorized experiments are not allowed.
- Be prepared for your work in the EE Labs. Read all procedures thoroughly before entering the laboratory. Never fool around in the laboratory. Horseplay, practical jokes, and pranks are dangerous and prohibited.
- Always work in a well-ventilated area.
- Observe good housekeeping practices. Work areas should be kept clean and tidy at all times.
- Experiments must be personally monitored at all times. Do not wander around the room, distract other students, startle other students or interfere with the laboratory experiments of others.
- Dress properly during a laboratory activity. Long hair, dangling jewelry, and loose or baggy clothing are a hazard in the laboratory. Long hair must be tied back, and dangling jewelry and baggy clothing must be secured. Shoes must completely cover the foot.
- Know the locations and operating procedures of all safety equipment including fire extinguisher. Know what to do if there is a fire during a lab period; “Turn off equipment, if possible and exit EE lab immediately.”