ELECTRICAL MACHINES

Laboratory Manual

2nd Year B.Tech.

Course Code: EE3P001

SCHOOL OF ELECTRICAL SCIENCES

Contents

SAFETY RULES

1. **SAFETY** is of paramount importance in the Electrical Laboratories.
2. Electricity NEVER EXCUSES careless persons. So, exercise enough care and attention in handling **electrical** equipment and follow **safety** practices in the laboratory. (Electricity is a good servant but a bad master).
3. Avoid direct contact with any voltage source and power line voltages. (Otherwise, any such contact may subject you to **electrical** shock).
4. Wear rubber-soled shoes. (To insulate you from earth so that even if you accidentally contact a live point, current will not flow through your body to earth and hence you will be protected from **electrical** shock).
5. Avoid loose clothing. (Loose clothing may get caught on an equipment/instrument and this may lead to an accident particularly if the equipment happens to be rotating machine)
6. Girl students should have their hair tied firmly or have it in a knot.
7. Do not wear any metallic rings, bangles, bracelets, wristwatches and neck chains. (When you move your hand/body, such conducting items may create a short circuit or may touch a live point and thereby subject you to **electrical** shock)
8. Be certain that your hands are dry and that you are not standing on wet floor. (Wet parts of the body reduce the contact resistance thereby increasing the severity of the shock)
9. Ensure that the power is OFF before you start connecting up the circuit. (Otherwise you will be touching the live parts in the circuit)
10. Get your circuit diagram approved by the staff member and connect up the circuit strictly as per the approved circuit diagram. You can use equipment issue slip available in Lab for this purpose.
11. Check power cords for any sign of damage and be certain that the chords use **safety** plugs and do not defeat the **safety** feature of these plugs by using underground plugs.
12. When using connection leads, check for any insulation damage in the leads and avoid such defective leads.
13. Do not defeat any **safety** devices such as fuse or circuit breaker by shorting across it.
    Safety devices protect YOU and your equipment.
14. Switch on the power to your circuit and equipment only after getting them checked up and approved by the staff member.
15. Take the measurement with one hand in your pocket.(To avoid shock in case you accidentally touch two points at different potentials with your two hands)
16. Do not make any change in the connection without the approval of the staff member.
17. In case you notice any abnormal condition in your circuit (like insulation heating up, resistor heating up etc.), switch off the power to your circuit immediately and inform the staff member.
18. After completing the experiment show your readings to the staff member and switch off the power to your circuit after getting approval from the staff member.
19. Some students have been found to damage meters by mishandling in the following ways:
    i. Keeping unnecessary material like books, lab records, unused meters etc. causing meters to fall down the table.
    ii. Putting pressure on the meter (especially glass) while making connections or while talking or listening somebody.

STUDENTS ARE STRICTLY WARNED THAT FULL COST OF THE METER WILL BE RECOVERED FROM THE INDIVIDUAL WHO HAS DAMAGED IT IN SUCH A MANNER.

Observe the safety rules yourself and help your friends to observe.

INDIAN INSTITUTE OF TECHNOLGY BHUBANESWAR

SCHOOL OF ELECTRICAL SCIENCES

Electrical Machines Laboratory

Course Outline

Course Instructors:

Course Contents:

Text Books:

1. Electrical Engg. Fundamentals by Del Toro
2. Electric Circuits by JW Nilsson
3. Basic Electrical Engineering by Nagrath and Kothari

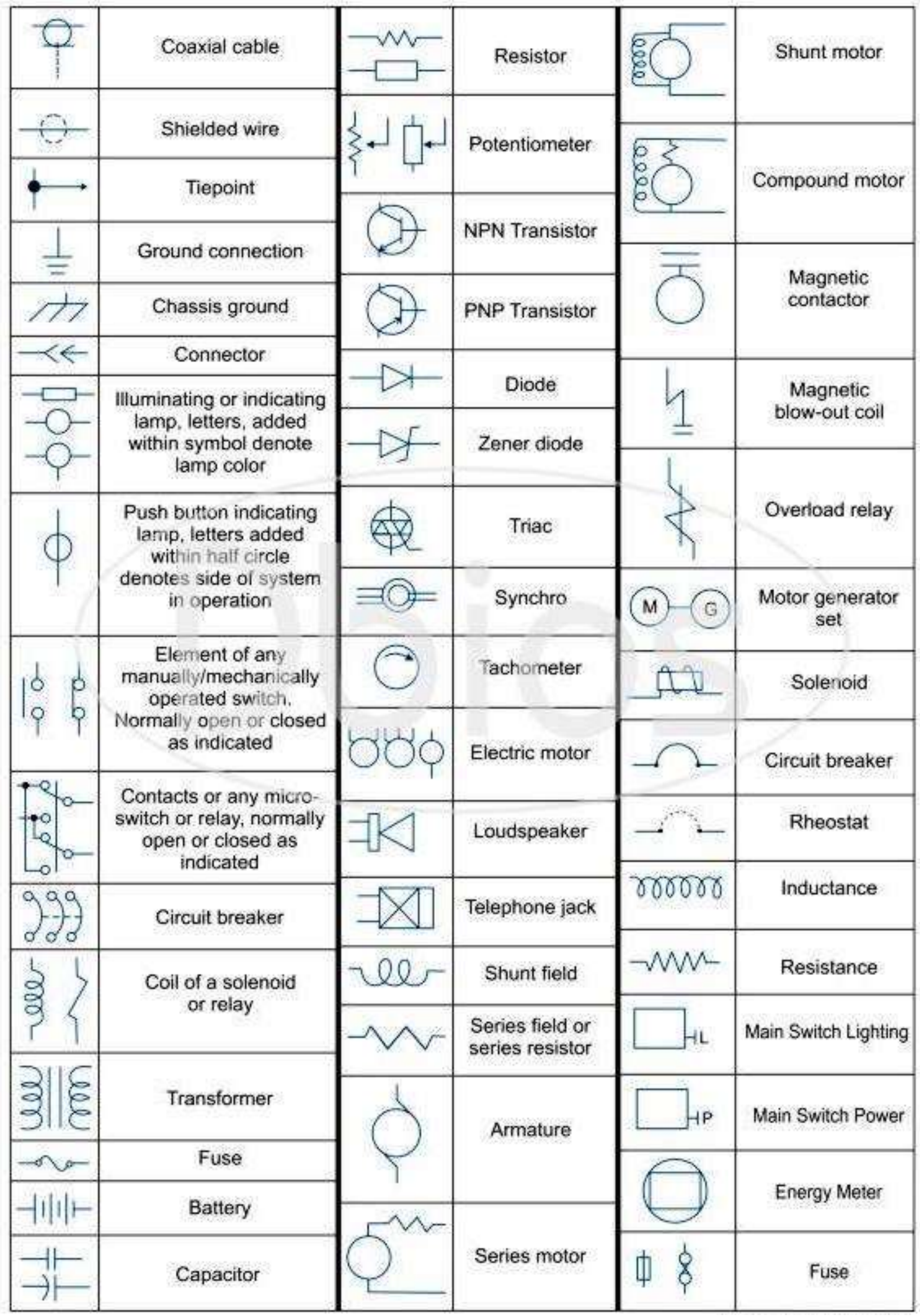
Instruction to Student

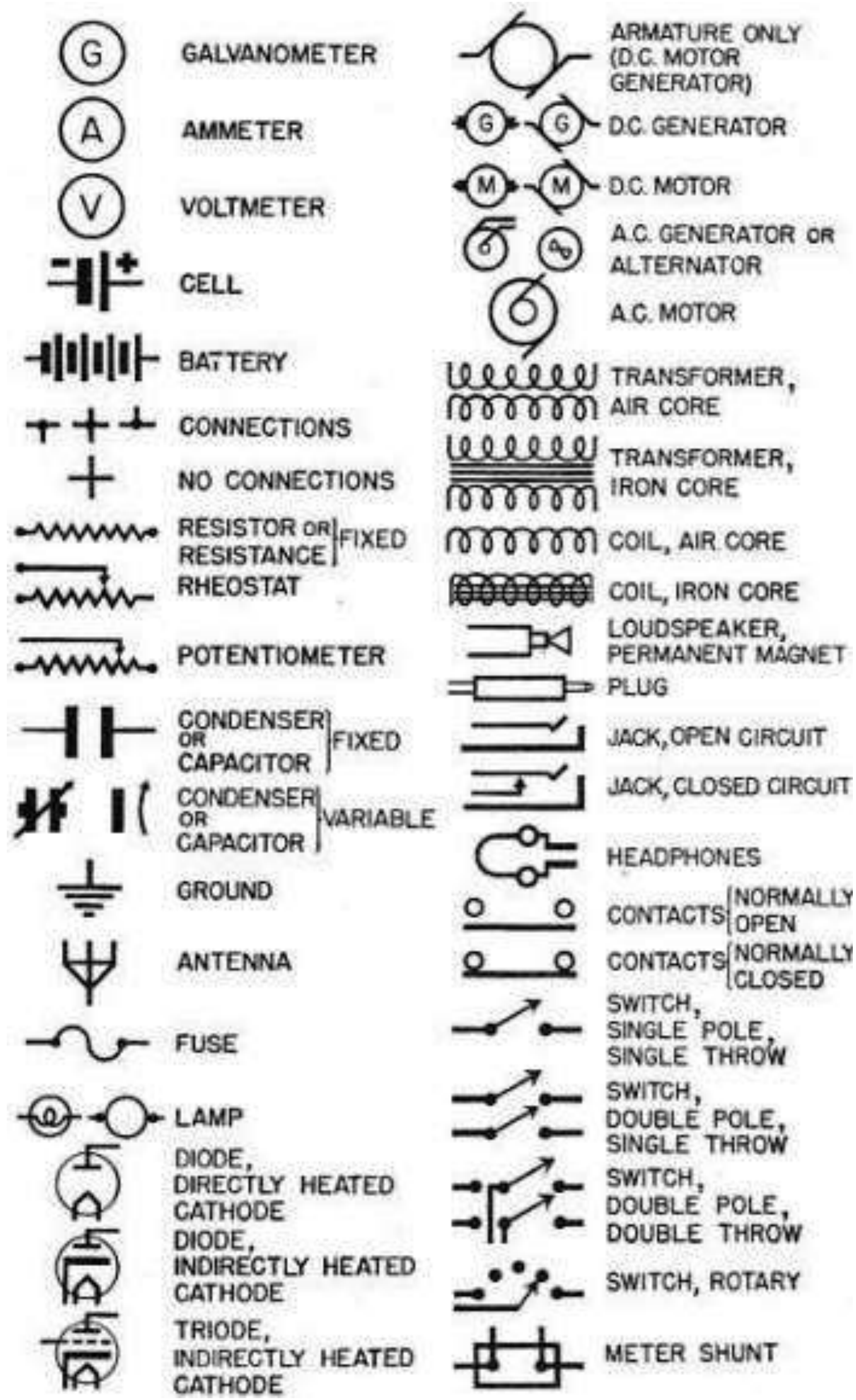
- You are required to know the location of the emergency trip switch in the laboratory.
- You are required to be familiar with basic safety procedures for electrical shock.
- You are required to dress safely. No loose garments, nothing that impedes your ability to work.
- During the lab class, it is required that one student of the group is always at the worktable, once the experiment has started.
- It is required that you take explicit permission if you have to leave during the class.
- Reports are due every week at the beginning of the lab class hour as per form decided by your instructor.
- Do not come to class carrying an infection take leave and make up your experiment.
- See to it that your laboratory partner knows your whereabouts. If you are unable to come class for any reason, inform him/her.
- Any other instructions as and when issued by the lab staff or instructor.

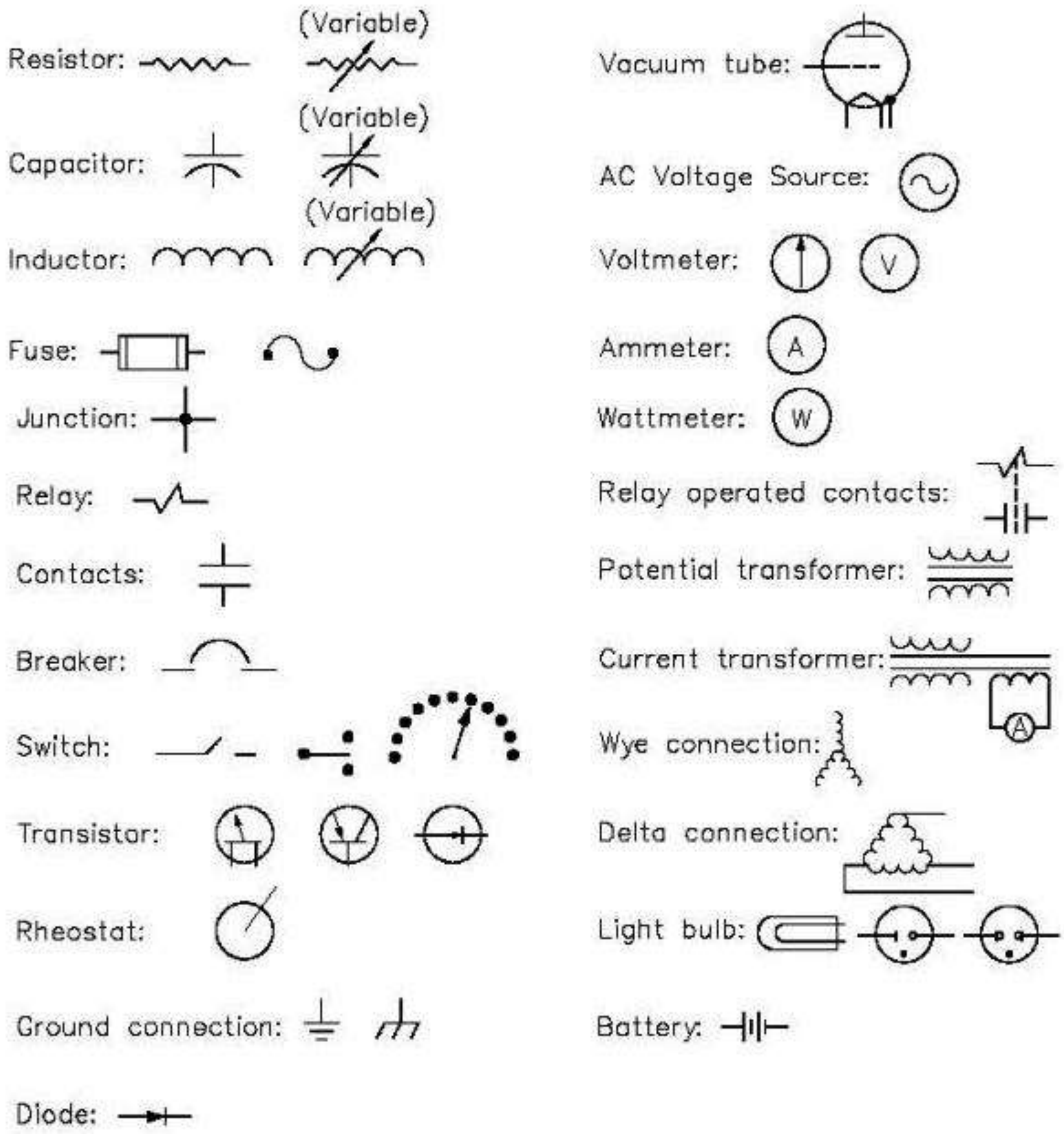
POINTS FOR MAINTAINING LAB RECORDS

1. Maintain the contents properly giving experiment date & submission date clearly.
2. Draw the circuit diagram clearly using HB pencil.
3. Write the specification of machines (wherever required) & other devices (such as Variac, Rheostat, Load box, Isolating Switch etc.) properly.
4. Use Pro-circle for drawing all meters & rotating machines.
5. Note down the range & type of meters used in circuit diagram.
6. Name different supply & their range clearly as mentioned below-
   a) A.C supply should be clearly indicated by Ph. & N. with frequency.
   b) D.C supply should be clearly indicated with polarity (+ & -).
   c) 3 ϕ AC supply should be clearly indicated with proper phase sequence (R, Y, B or $L_{1,}$ L_2 $L_{3)}$ and frequency.
7. Graph should be pasted at left gutter position.
8. Don't fraction (whenever not required) the Axis when you draw the graph.
9. Resistor & Inductor should be drawn properly. (i.e., Inside two invisible parallel lines should be clear).
10. All the calculation part should be on left side (plane side) of record.

ELECTRIC SYMBOLS




GALVANOMETER
AMMETER
VOLTMETER
CELL
BATTERY
CONNECTIONS
NO CONNECTIONS
RESISTOR OR RESISTANCE FIXED
RHEOSTAT
POTENTIOMETER
CONDENSER OR CAPACITOR FIXED
CONDENSER OR CAPACITOR VARIABLE
GROUND
ANTENNA
FUSE
LAMP
DIODE, DIRECTLY HEATED CATHODE
DIODE, INDIRECTLY HEATED CATHODE
TRIODE, INDIRECTLY HEATED CATHODE
ARMATURE ONLY (D.C. MOTOR GENERATOR)
D.C. GENERATOR
D.C. MOTOR
A.C. GENERATOR OR ALTERNATOR
A.C. MOTOR
TRANSFORMER, AIR CORE
TRANSFORMER, IRON CORE
COIL, AIR CORE
COIL, IRON CORE
LOUDSPEAKER, PERMANENT MAGNET
PLUG
JACK, OPEN CIRCUIT
JACK, CLOSED CIRCUIT
HEADPHONES
CONTACTS NORMALLY OPEN
CONTACTS NORMALLY CLOSED
SWITCH, SINGLE POLE, SINGLE THROW
SWITCH, DOUBLE POLE, SINGLE THROW
SWITCH, DOUBLE POLE, DOUBLE THROW
SWITCH, ROTARY
METER SHUNT


Resistor:
(Variable)
Capacitor:
(Variable)
Inductor:
(Variable)
Fuse:
Junction:
Relay:
Contacts:
Breaker:
Switch:
Transistor:
Rheostat:
Ground connection:
Diode:
Vacuum tube:
AC Voltage Source:
Voltmeter:
V
Ammeter:
A
Wattmeter:
W
Relay operated contacts:
Potential transformer:
Current transformer:
A
Wye connection:
Delta connection:
Light bulb:
Battery:

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Electrical Machines Laboratory

LABORATORY EQUIPMENT ISSUE SLIP

Group No.- Date:

Aim/Objective:

Circuit Diagram: (Use back side of this page)

Apparatus Required:

Instruments/Equipments:

Sl. No.	Instrument/Equipment	Type	Specification	Quantity
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

Machine Specification:

Sl. No.	Machine	Specification	Quantity
1.			

<table>
<tr><th>Sl. No.</th><th>Roll No.</th><th>Name</th><th>Signature</th><th>Signature of Instructor/T.A.</th></tr>
<tr><td>1.</td><td></td><td></td><td></td><td rowspan="2"></td></tr>
<tr><td>2.</td><td></td><td></td><td></td></tr>
<tr><td>3.</td><td></td><td></td><td></td><td>Signature of Staff</td></tr>
<tr><td>4.</td><td></td><td></td><td></td><td rowspan="2"></td></tr>
<tr><td>5.</td><td></td><td></td><td></td></tr>
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Undertaking

I have read and understand the rules and procedures set forth for the ELECTRICAL MACHINES LABORATORY.I agree to abide by these rules and procedures at all times while using these facilities. I understand that failure to follow these rules and procedures will result in my immediate dismissal from the laboratory and additional disciplinary action may be taken according to the Institute policies.

Student's Signature Date-

Name-

RollNo.-

INDIAN INSTITUTE OF TECHNOLGY BHUBANESWAR

SCHOOL OF ELECTRICAL SCIENCES

Electrical Machines Laboratory

List of Experiments

Cycle-1

1. Perform Scott connection on two single phase transformers.
2. Leakage Impendence of a Single phase three winding Transformer.
3. To study the power factor improvement of a 3-Phase load by capacitor bank.
4. To draw the equivalent circuit and phasor diagram per phase of a Single phase Transformer by back to back test.
5. To perform parallel operation of two single phase Transformer.
6. To study of dissectible Machines.

Cycle-2

7. To determine regulation of 3 phase alternator by synchronous impedance method using Open -Circuit &Short- Circuit test.
8. To determine Direct Axis & Quadrature Axis Synchronous Reactance of a 3-Phase Alternator.
9. To determine regulation of 3-Phase alternator by Zero Power Factor (ZPF) method.
10. To determine Negative sequence & zero sequence impedance of a Three phase Alternator.
11. To perform No load and Block rotor test of a 3-� Induction motor and draw Circle diagram.
12. To determine operation characteristics of a 3-ph. Squirrel Cage Induction Motor by using dissectible machine set up.

Familiarization with Lab. Equipments and Basic Measurements

Laboratory Works:

In the first class, please note that: Your lab group has been formed. One/two table has been assigned to each experiment, so check which table is meant for what experiment.

0.1 You should have the following with you:

- Report of previous class.
- Ensure that along with your report, you have rough lab note which contains the data original signed by the instructor or the Lab technician in the previous class.
- Graph sheets.
- Pen/paper/graph sheet/pencil/calculator.
- The lab manual.

0.2 You should know the following:

- The experiment that you are about to conduct.
- The location of the experiment table.
- The location of the emergency trip switches.
- Basis safety procedures as given in the handout to you.
- Do not switch on the circuit/experiment until you get it checked once by Technician/ Research Scholar / Instructor.

0.3 At the end of the class hour:

- Clean up your table.
- Switch of all equipment.
- Hand in all components issued to you for the lab session.
- See that the Instructor/Grad asst/Lab Technician have signed your data sheet of the experiment done on that day.

Get your table checked by the technician before you leave.

Indian Institute of Technology Bhubaneswar
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Electrical Machines Laboratory

Experiment No- 1

SCOTT CONNECTION OF SINGLE PHASE TRANSFORMERS

AIM OF THE EXPERIMENT:

Perform Scott connection on two single phase transformers.

APPARATUS REQUIRED:

Instruments/Equipments:

Sl. No	Instruments/Equipments	Type	Specification	Quantity
1	Ammeter	MI	0 – 5 A	5 Nos
2	Voltmeter	MI	0 – 600 V	1 No
3	Voltmeter	MI	0 - 300 V	2 Nos
4	Load Box	Resistive	4 kW, 250 V	2 Nos
5	3-Φ variac	Iron core	10 A, 415 V	1 No
6	Connecting Wires	Cu	1.5 sq. mm	As required

Machines Required:

Sl.No	Machine	Specification	Quantity
1.	1- Φ Transformer having 50% & 86.6% tapping.	3 kVA, 220/110 V	2 Nos

THEORY:

Three phase to two-phase conversion or vice-versa is essential under the following circumstances.

(i) To supply power to two phase electric furnaces.
(ii) To supply power to two phase apparatus from a 3-ϕ source.
(iii) To interlink three phase system and two phase systems.
(iv) To supply power to three phase apparatus from a two-phase source.

The common type of connection which can achieve the above conversion is normally called Scott-connection. Two single-phase transformers of identical rating with suitable tapping provided on both, are required for the Scott connection. The two transformers used for this conversion must have the following tappings on their primary windings.

Transformer A – 50 percent tapping and is called the main transformer.

Transformer B- 86.6 percent tapping and is called the teasure transformer.

CIRCUIT DIAGRAM:

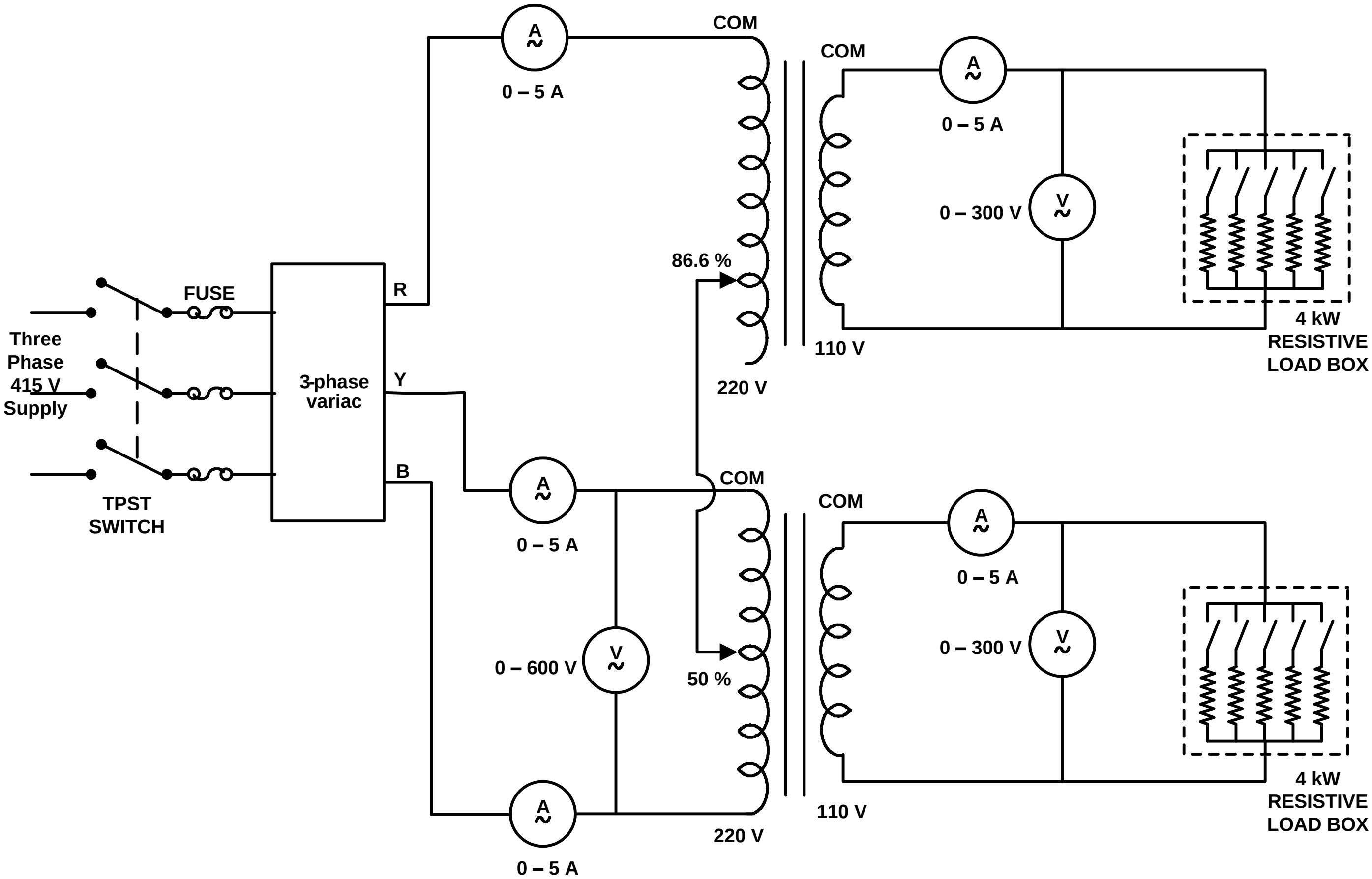

Fig- Circuit Diagram for Scott connection

PRECAUTION:

1. Connection should be right and tight.
2. Check the circuit connection thoroughly before switching on the supply.
3. Instruments should be connected in proper polarity and range.
4. Do not touch any non-insulated part of any instrument or equipment.
5. Be ensured the zero setting of instrument is on right position. Avoid parallax error.
6. Before switching on the supply set the 3-Φ variac at its minimum position and all load switches in off position.

PROCEDURE:

1. Connect the circuit as per the circuit diagram.
2. Adjust the 3-ϕ Variac for minimum voltage in output circuit.
3. Close the TPST switch and apply rated voltage across the primaries of the transformers.
4. Note down the no-load readings with $I_{2T} = I_{2M} = 0$.
5. Apply load on the teasure transformer and note down the readings.
6. Repeat step-6 for various load condition.
7. Similarly apply load and take reading for various load condition on the main transformers.

8. Apply load on both secondaries adjust equal loading for both secondaries, Record the readings of all the meters.
9. Repeat step-9 for various equal loading condition on the two secondaries.
10. Repeat step-9 for various unequal loading conditions on the two secondaries.
11. Switch off the load from both the secondaries and switch off the main supply.
12. With load circuit removed, connect the two secondary windings in series and observe the resultant voltage $V_R = \sqrt{2}\ V_{2T} = = \sqrt{2}\ V_{2M}$

OBSERVATION:

Table-1

Sl.No	I_R	I_Y	I_B	I_{2M}	I_{2T}	V_{2M}	V_{2T}
No load condition							
When load on main transformer							
When load on teasure transformer							
When equal load on main & teasure transformer							
When unequal load on main & treasure transformer							

Table-2

V_{2T}	V_{2M}	V_R (Measured)	V_R calculated i.e. $V_R = \sqrt{2}\ V_{2T} = = \sqrt{2}\ V_{2M}$	% Error

Data Processing and Analysis:

1. Draw the phasor diagrams at equal & unequal load conditions.

CALCULATIONS:

DISCUSSION:

1. Why is it essential that 86.6% tapping must be there in teasure transformer?
2. What tapping should be available on the main transformer and why?
3. What is the advantages and disadvantages of Scott connection over Open-Delta connection?

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Experiment No- 02

LEAKAGE IMPEDANCE OF A SINGLE PHASE THREE WINDING TRANSFORMER

AIM OF THE EXPERIMENT:

To measure the leakage impedance of a single phase three winding transformer.

EQUIPMENTS REQUIRED:

Instruments/Equipments:

Sl.No	Instruments/Equipments	Type	Specification	Quantity
1.	Volt meter	MI	(0-75/150/300)V	1
2.	Ammeter	MI	(0-5)A	1
			(0-10)A	1
			(0-15)A	1
3.	Wattmeter	UPF	5/10A,0-75/150/300V	1
4.	1-φ Autotransformer	Iron Core		1
5	Connecting wires	Cu	1.5 sq. mm	As required

Machines Required:

Sl. No.	Name of the machine	Specification
1.	Single Phase Three Winding Transformer	1.5kVA Primary:-415V, 3.6A Secondary:-230V,6.5A Tertiary:-110V,13.64A

CIRCUIT DIAGRAM:

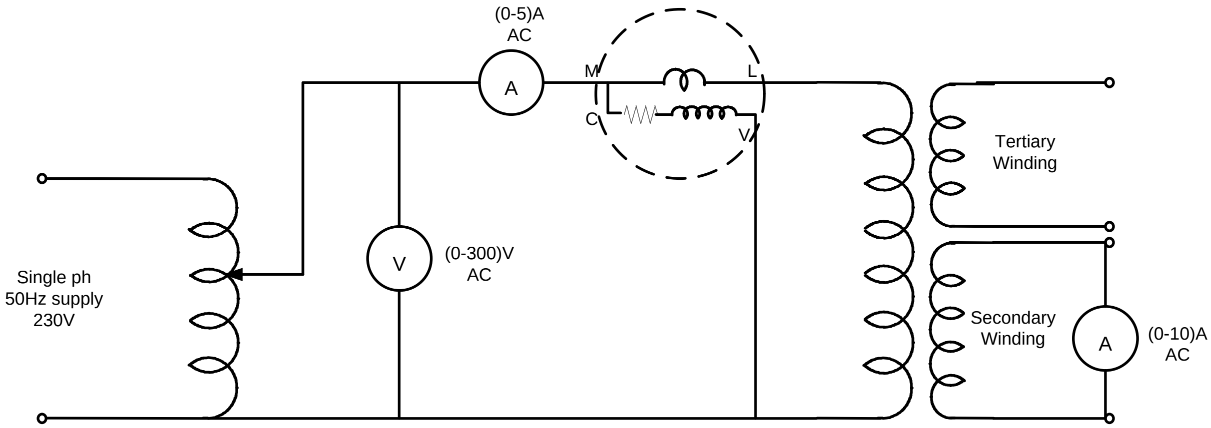


Figure 1:- Circuit Diagram for measurement of leakage impedance (Zps)

Similarly circuit can be connected for Zpt and Zst.

THEORY:

Generally, large power transformers have three windings. The third winding is known as a tertiary winding which may be used for the following purposes:

1. To supply a load at a voltage different from the secondary voltage.
2. To provide a low impedance for the flow of certain abnormal currents, such a third harmonic currents.
3. To provide for the excitation of a regulating transformer.

While both the primary and secondary winding of a two winding transformer have the same KVA rating, all the three windings of a three winding transformer may have different KVA ratings. The p.u. impedance in the impedance diagram should therefore be expressed on a common KVA basis.

When one winding is left open, the three winding transformer behaves as two winding transformer and standard short circuit tests can be used to evaluate per unit leakage impedances which are defined as follows:

Zps = per unit leakage impedance measured from primary with secondary shorted and tertiary open.

Zpt = per unit leakage impedance measured from primary with tertiary shorted and secondary open.

Zst = per unit leakage impedance measured from secondary with tertiary shorted and primary open.

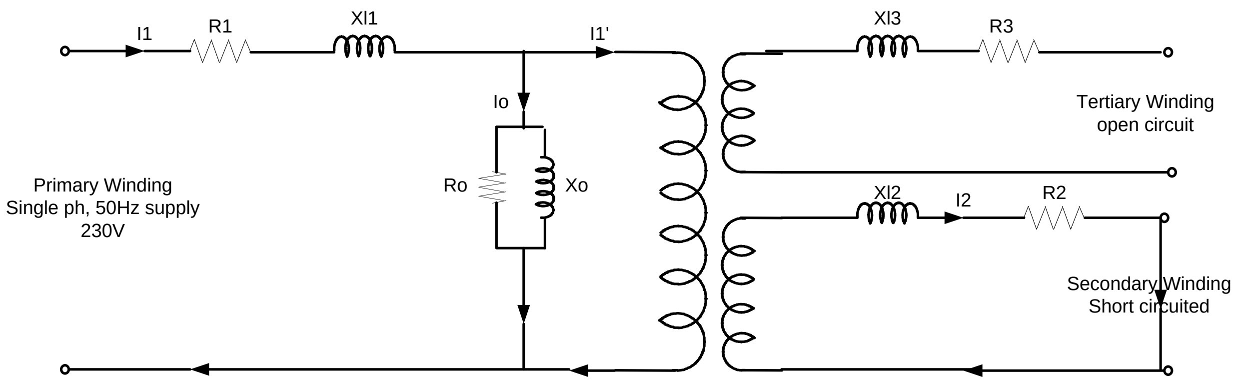
Let consider measurement of Zps, so the supply is given to primary, secondary is short circuited and tertiary is open. Now the three winding transformer behave as two winding transformer with primary and secondary. The equivalent circuit is like

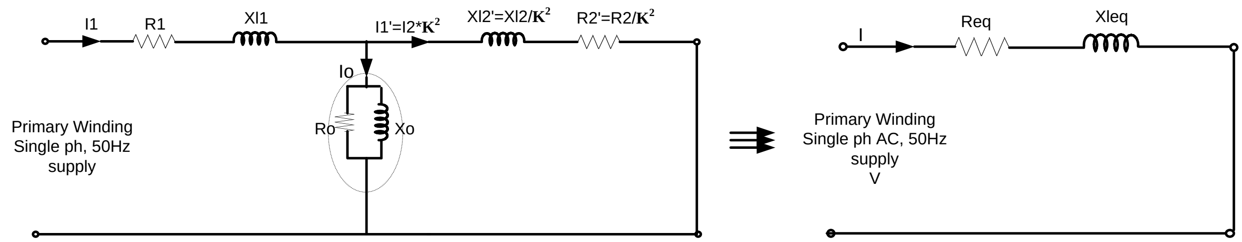
R_1 =Resistance of primary winding, X_{l1} =Leakage reactance of primary winding

R_2 =Resistance of secondary winding, X_{l2} =Leakage reactance of secondary winding

R_1 =Resistance of tertiary winding, X_{l3} =Leakage reactance of tertiary winding

I_0= magnetizing current. (It is 0.02% of rated current. so it can be neglected when finding equivalent circuit)





Let Z_{ps}, Z_{pt}, and Z_{st} are leakage impedance of the primary, secondary and tertiary windings referred to primary circuit. Then from transformer theory, we have -

$Zps = Zp + Zs/K^2$ …………... (a)
$Zpt = Zp + Zt/K^2$ …………… (b)
$Zst = Zs + Zt/K^2$ ……………..(c)

Where Zp, Zs, and Zt : the impedances of primary, secondary and tertiary. $K=V_2/V_1$
Solving these equations we find

$Zp = ½ (Zps + Zpt - Zst)$ …….. (d)
$Zs = ½ (Zps + Zst - Zpt)$ ……. . (e)
$Zt = ½ (Zpt + Zst – Zps)$ …… (f)

These equations can be used to evaluate the per unit series impedances Zp, Zs, and Zt of three winding transformer equivalent circuit from the per unit impedances Zps, Zpt and Zst which in turn are determined from short circuit tests.

PRECAUTION:

1. Connection should be right and tight.
2. Check the circuit connection thoroughly before switching on the supply.
3. Instruments should be connected in proper polarity and range.
4. Do not touch any non-insulated part of any instrument or equipment.
5. Be ensured the zero setting of instrument is on right position. Avoid parallax error.
6. Before switching on the supply, be sure that variable point of Variac should be at zero.

PROCEDURE:

Measurement of leakage impedances:-

These are obtained experimentally from three independent short circuit measurements. Experimental procedure for the measurement of leakage impedances for a single phase three winding transformer. All impedances are referred to same KVA base and to a same voltage base generally referred to primary circuit.

Measurement 1: Obtain leakage impedance Z_{ps} in p.u. measured in primary with secondary short circuited and tertiary open.

Measurement 2: Obtain leakage impedance Z_{pt} in p. u. measured in primary with tertiary short circuited and secondary open.

Measurement 3: Obtain leakage impedance Z_{st} in p. u. measured in secondary with tertiary short circuited and primary open.

- Connect the circuit as shown in figure 1(circuit for calculating $Z_{ps,\ similarly}$ connect for other two cases).
- Give the supply to primary (Z_{ps}) through variac.
- Gradually increase the supply voltage by variac, so that rated current will flow through the short circuit side (secondary side for Z_{ps}).
- Record the voltmeter and ammeter reading

OBSERVATIONS:

Table 1

SL. NO.	Winding	Rated voltage (Line to line KV)	Rated KVA (Three phase)
1.	Primary		
2.	Secondary		
3.	Tertiary		

Table 2

Sl. No.	Impedance to be measured	Impedance measured w.r.t winding	Winding short circuited	Winding open	Impedance(pu)
1	Z_{ps}	Primary	Secondary	tertiary	
2	Z_{pt}	Primary	tertiary	secondary	
3	Z_{st}	secondary	tertiary	primary	

CALCULATIONS:

Z_{ps} = (Reading of voltmeter in primary side)/ (Reading of ammeter in primary side)

Z_{pt} = (Reading of voltmeter in primary side)/ (Reading of ammeter in primary side)

Z_{st} = (Reading of voltmeter in secondary side)/ (Reading of ammeter in secondary side)

Z_{st} measured is referred to secondary side so convert it to primary side. Then do the following calculation

$$Z_p = (Z_{ps} + Z_{pt} - Z_{st})/2$$

$$Z_s = (Z_{ps} + Z_{st} - Z_{pt})/2$$

$$Z_t = (Z_{pt} + Z_{st} - Z_{ps})/2$$

Where Z_p, Z_s and Z_t are the leakage impedances of the primary, secondary tertiary windings referred to primary circuit.

CONCLUSION:

DISCUSSION:

1. What is leakage reactance?
2. What is the utility of a three phase three winding transformer?
3. What is the use of tertiary winding?

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Experiment-03

POWER FACTOR IMPROVEMENT OF 3 PHASE INDUCTION MOTOR

AIM OF THE EXPERIMENT:

APPARATUS REQUIRED:

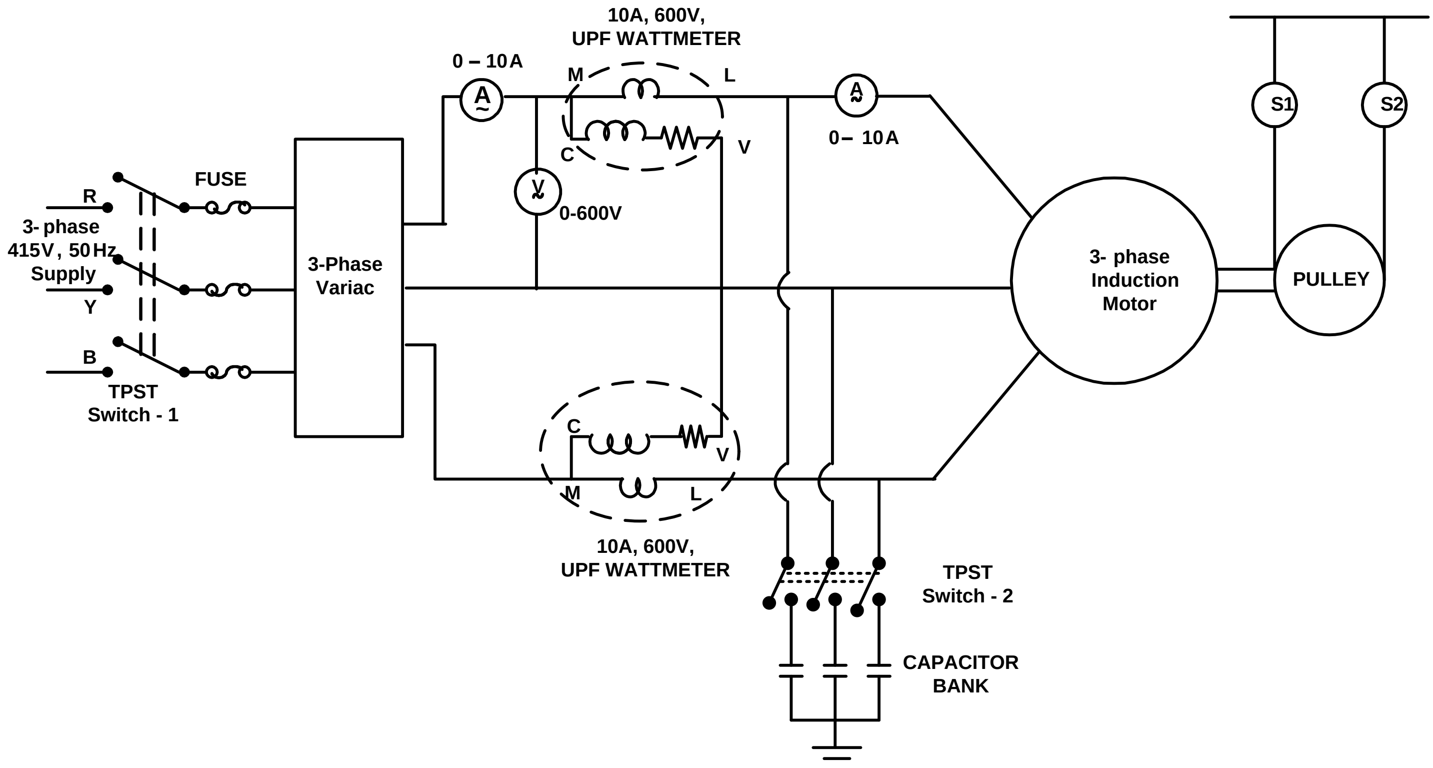
Instruments/Equipments:

Sl.No	Instruments/Equipments	Type	Specification	Quantity
1	3-ϕVariac	Iron core	10 A, 415V	1 No
2	Wattmeter	LPF	5 A, 600 V,0.2 P.F	2 Nos
3	Voltmeter	MI	(0-600) V	1 No
4	Ammeter	MI	(0-10) A	2 Nos.
6	Wattmeter	UPF	10 A, 600V	2 Nos
7	3-Ph.Capacitor Bank		440V,(0-40) Micro-Farad	01 No.
8	Connecting Wires	Cu	1.5 sq. mm	As required

Machines Required:

Sl.No	Machine	Specification	Quantity
1.	3-ΦInduction Motor	3.7 kW / 5 HP , 1430 RPM 415 V, 7.8 A, Delta connection.	1 No

CIRCUIT DIAGRAM:



Circuit diagram for power factor improvement of 3-Ph Induction Motor

THEORY:

In power systems, wasted energy capacity, also known as poor power factor, is often overlooked. It can result in poor reliability, safety problems and higher energy costs. The lower your power factor, the less economically your system operates.

Power factor is the ratio between the real power and the apparent power drawn by an electrical load. Like all ratio measurements it is a unit-less quantity and can be represented mathematically as P.F. = $\frac{\text{True Power (KW)}}{\text{Apparent Power (KVA)}}$.

Where, PF is power factor, kW is the real power that actually does the work, KVA is the apparent power and KVAR (not included in the equation) is the reactive power. In an inductive load, such as a motor, active power performs the work and reactive power creates the electromagnetic field.

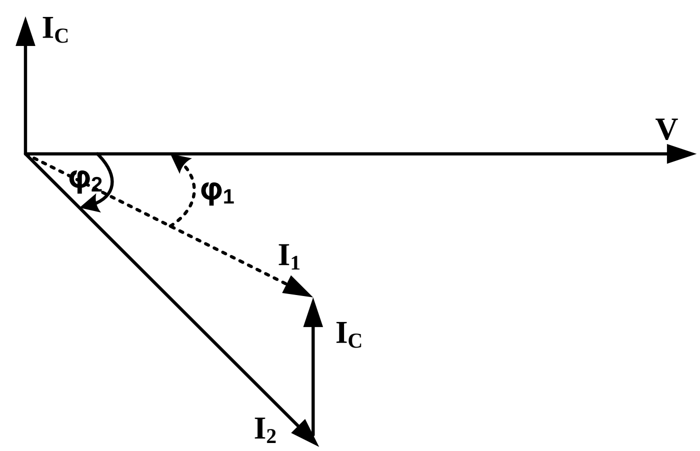
For the purely resistive circuit, the power factor is 1 (Perfect), because the reactive power equals to zero. Here, the power triangle would look like a horizontal line, because the opposite (reactive power) side would have zero length.

For the purely inductive circuit, the power factor is 0, because true power equals zero. Here the power triangle would look like a vertical line, because the adjacent (true power) side would have zero length.

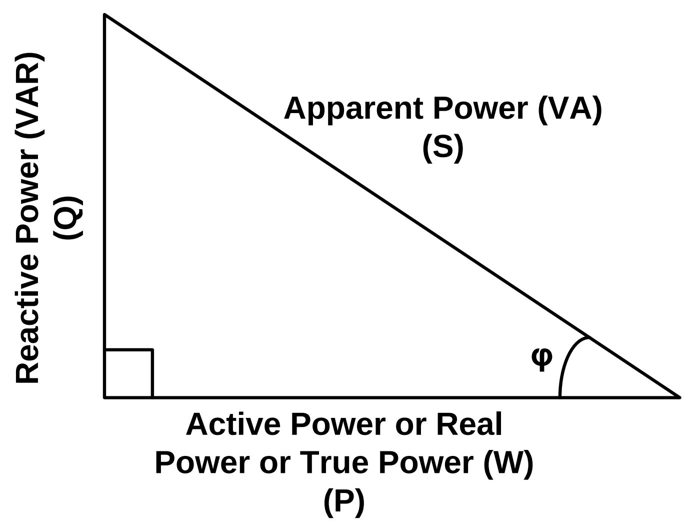
The same could be said for a purely capacitive circuit. If there are no dissipative (resistive) components in the circuit, then the true power must be equal to zero, making any power in the circuit purely reactive. The power triangle for a purely capacitive circuit would again be a vertical line (pointing down instead of up as it was for the purely inductive circuit.)

Power factor can be an important aspect to consider in an AC circuit, because any power factor less than 1 means that the circuit's wiring has to carry more current than what would be necessary with zero reactance in the circuit to deliver the same amount of (true) power to the resistive load. The poor power factor makes for an inefficient power delivery system. Poor power factor can be corrected, paradoxically, by adding another load to the circuit drawing an equal and opposite amount of reactive power, to cancel out the effects of the load's inductive reactance. Inductive reactance can only be canceled by capacitive reactance, so we have to add a capacitor in parallel to our example circuit as the additional load. The effect of these two opposing reactance in parallel is to bring the circuit's total impedance equal to its total resistance (to make the impedance phase angle equal, or at least closer, to zero).

Power factor measures how efficiently the current is being converted into real work with a low power factor, more electrical current is required to provide the same amount of real power. All current causes dissipation in a distribution system. These losses can be modeled as (Loss – I^2*R), where R is the resistance. A power factor of 1 will result in the most efficient loading of the supply' a load with a power factor of 0.5 will result in higher losses in the distribution system.



[Phasor Diagram for Power factor improvement by Capacitor Bank]



[Power Triangle]

PRECAUTION:

1. Connection should be right and tight.
2. Check the circuit connection thoroughly before switching on the supply.
3. Instruments should be connected in proper polarity and range.
4. Do not touch any non-insulated part of any instrument or equipment.
5. Be ensured the zero setting of instrument is on right position. Avoid parallax error.
6. Before switching on the supply set the 3-Φ variac at its minimum position.

PROCEDURE:

1. Make the connection as per the circuit diagram.
2. Keep T.P.S.T.-2 open and T.P.S.T.-1 close to conduct Full-load test without capacitor Bank.
3. Keep both T.P.S.T.-2 and T.P.S.T.-1 close to conduct Full-load test with capacitor Bank.
4. Increase the load up to rated current with rated voltage for both cases.
5. Take the readings of the wattmeter's in watt (**W_1** and **W_2**) ammeter in ampere (**I**) and voltmeter in volt (**V_L**).

OBSERVATION:

For Full-Load Test Without Capacitor Bank							
Sl.No.	V_L	I_1	I_2	W_1	W_2	$P_L=W_1+W_2$	$\cos\varphi_2$

For Full-Load Test With Capacitor Bank							
Sl.No.	V_L	I_1	I_2	W_1	W_2	$P_L=W_1+W_2$	$\cos\varphi_1$

Data Processing and Analysis:

1. Using the data obtained, draw the circle diagram complete in all respect.
2. Compute (a) Max Power (b) Max Torque

   (c) Starting torque and best power factor, utilizing the circle diagram.

CALCULATIONS:

$$\tan\phi_0 = \sqrt{3}\frac{W_{01} - W_{02}}{W_{01} + W_{02}}$$

$$\tan\phi_{sc} = \sqrt{3}\frac{W_{sc1} - W_{sc2}}{W_{sc1} + W_{sc2}}$$

CONCLUSION:

DISCUSSION:

1. Is there any alternative method to improve power factor? Discuss about its advantages and disadvantages oas compared to capacitor method?

2. What are the disadvantages of low power factor?

3. How to improve power factor in case it leads ?

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Experiment No- 4

BACK TO BACK TEST OF TWO 1-Ø TRANSFORMER

AIM OF THE EXPERIMENT:

To determine the equivalent circuit parameters, phasor diagram & efficiency of a given pair of 1-phase Transformers by conducting Back to Back test (Sumpner's test).

EQUIPMENTS REQUIRED:

Instruments/Equipments:

Sl.No	Instruments/Equipments	Type	Specification	Quantity
01	Voltmeter	MI	(0 -150/300)V	02 Nos.
02	Ammeter	MI	0 – 1A	01 No.
03	Wattmeter	LPF	2A, 300V,0.2P.F	01 No.
04	Voltmeter	MI	0 – 150V	01 No.
05	Ammeter	MI	0 – 5A	01 No.
06	Wattmeter	UPF	5A, 150V	01 No.
07	1Φ Variac	Iron core	230 V, 10 A	02 Nos.
08	Connecting wires	Cu	1.5 sq. mm	As Required

Machines Required:

Sl. No.	Machine	Specification	Quantity
1.	Single phase transformer	1kVA Primary:-230V, 4.3A Secondary:-230V,4.3A	02 Nos.

THEORY:

Two very simple tests are used to determine the equivalent circuit parameters and the power losses in the transformer. These consist in measuring the input voltage, current, and power to the primary, first with the secondary short circuited and then with secondary open circuited. The copper losses are determined from the short circuit test. The core losses are determined from the open circuit test.

Stray load loss consists of the losses arising from the non-uniform current distribution in the copper and the additional core losses produced in the iron by distortion of the magnetic flux by the load current. It is difficult to determine such losses accurately by conventional no-load and short circuit load tests.

To obtain exact equivalent circuit and losses, the input and output parameters are directly measured under different loading conditions. This is easy for small rating transformers. However for large transformers, it is difficult and expensive to take direct measurements. *A Back to Back* Test is used in this case.

Back-to-Back test is also known as Sumpner's test/Heat run test. This test requires two identical transformers. Primary winding of both the transformer are connected in parallel across same supply and the Wattmeter connected in primaries reads the core losses (Iron losses) of both transformers. These are fed by rated voltage at rated frequency. The secondary winding of both the transformers is connected in phase opposition so that their potentials are in opposite to each other. By connecting so there would be no secondary current flowing around the loop formed by the two secondary. By this test, the equivalent Circuit parameters, efficiency, regulation & heating of both the T/F can be determined

This test facilitates the collection of data for open and short circuit test simultaneously. On secondary side a low voltage just sufficient to flow the full load current is connected.

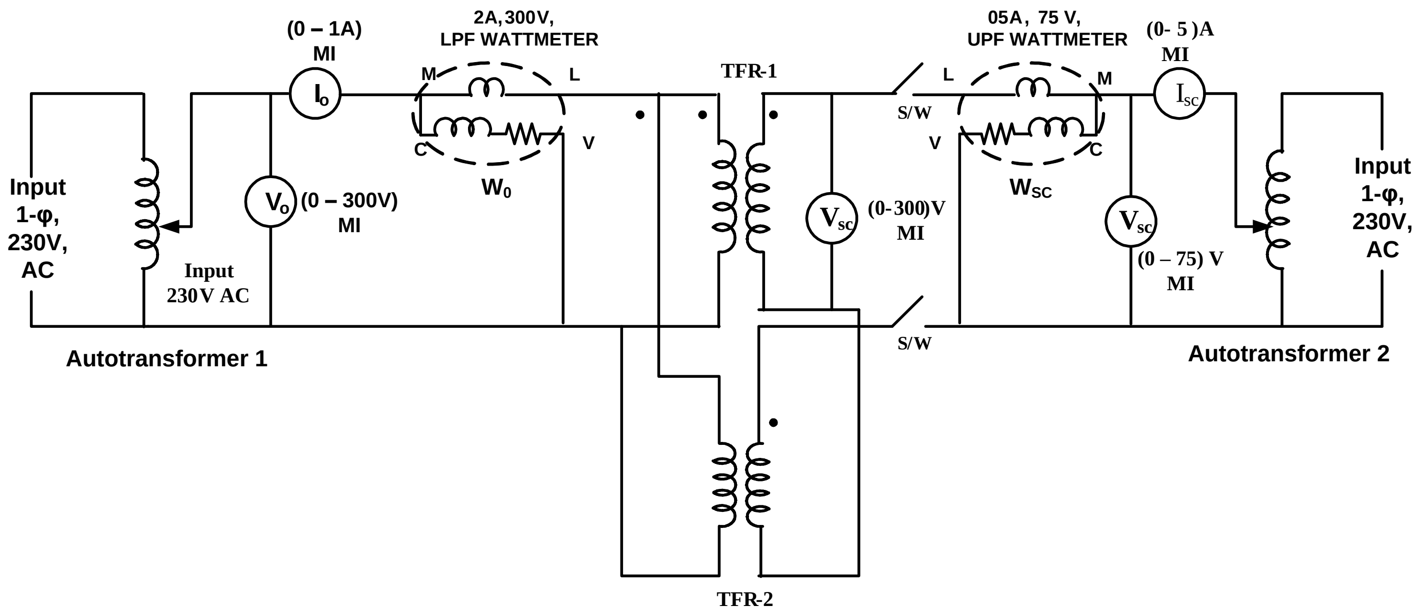
We can justify that the current is just twice the no load current. This means the wattmeter connected on the primary side reads the total iron loses of both the transformers.

The iron loss of one transformer=1/2Wo
The copper loss of one transformer=1/2Wsc
The total losses of one transformer=1/2(W_0+Wsc)

<u>Why Back-to-back test is used in case of large transformers?</u>

- The short circuit test is difficult to be applied, since applying a reduced voltage is very difficult and unpractical.
- This test can simulate the loading conditions on the transformer without using real loads.
- A large transformer supplying large essential loads has usually a second identical transformer installed in the same location for back-up, so using back-to-back transformer in this case is very practical.

CIRCUIT DIAGRAM:



PRECAUTION:

1. Connection should be right and tight.
2. Check the circuit connection thoroughly before switching on the supply.
3. Instruments should be connected in proper polarity and range.
4. Do not touch any non-insulated part of any instrument or equipment.
5. Be ensured the zero setting of instrument is on right position. Avoid parallax error.
6. Before switching on the supply, be sure that variable point of Variac should be at zero.

<u>PROCEDURE</u>:

1. Open Circuit Test:

1) Make connections as per the circuit diagram.
2) Switch-ON the supply keeping the polarity switch open and autotransformer 2 at zero position and apply rated voltage to the primary winding by using the auto transformer 1. Now check the correctness of polarities of the two transformers. If V2 = 0 then polarities of connected transformers are correct i.e. connections are back to back and emf induced in secondaries are in phase opposition but if V2 = 2xKxV1, then secondary emfs are in phase, in that case change the polarities of any one secondary winding.
3) Note the readings of Ammeter (I_o), Voltmeter (V_o) & Wattmeter (W_o)

2. Short Circuit Test:

1) Keeping the primary supply as it, Switch-ON the supply and close the polarity switch.
2) Vary the autotransformer 2 till rated full load current flows through transformers.
3) Note the readings of Ammeter (I_{sc}), Voltmeter (V_{sc}) & Wattmeter (W_{sc}) while doing so, the values V_o, I_o and W_o should not deviate from their earlier readings.

OBSERVATIONS:-

SL No.	Primary voltage (V_o)	Primary current (I_o)	Primary power Iron loss (W_o)	Secondary voltage (V_{sc})	Secondary Current (I_{sc})	Secondary power Cu. Loss(W_{sc})

CALCULATIONS:

$Z_{sc} = \frac{V_{sc}}{I_{sc}}$ $\quad R_{sc} = \frac{w_{sc}}{I_{sc}^2}$ $\quad X_{sc} = \sqrt{Z^2 - R^2}$

$w_0 = V_o I_o Cos\emptyset_o$ $\quad Cos\emptyset_o = \frac{w_0}{I_o V_0}$ $\quad I_\omega = I_o Cos\emptyset_o$ $\quad I_\mu = I_o Sin\emptyset_o$

$X_0 = \frac{V_0}{I_\mu}$ $\quad R_0 = \frac{V_0}{I_\omega}$

Iron loss per transformer $W_i = W_o / 2$
Copper loss per transformer $W_{cu} = W_{sc} / 2$

$$\%efficiency = \frac{\text{Output Power}}{\text{Output Power} + \text{total loss}} * 100$$

$$\%efficiency = \frac{\text{kVA} * \ Cos\emptyset_o}{\text{kVA} * \ Cos\emptyset_o + \text{Iron loss} + \text{Cu loss}} * 100$$

Equivalent Circuit:

Phasor Diagram:

CONCLUSION:

DISCUSSION:

1. Why two transformers, and that too identical are needed in this test ?
2. What are the advantages of the test ?

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Experiment No- 04

PARALLEL OPERATION OF SINGLE-PHASE TRANSFORMERS

AIM OF THE EXPERIMENT:

To perform polarity test and parallel operation of two single-phase transformers.

APPARATUS REQUIRED:

Instruments/Equipment:

Sl.No	Instruments/Equipments	Type	Specification	Quantity
1	1-ϕ variac	Iron Core	15A, 230V	1 No
2	1-ϕ transformer	Iron Core	1KVA, 220V/220V	2 Nos
3	Voltmeter	M.I.	(0-300) V	2 Nos
4	Voltmeter	M.I.	(0-600) V	1 No
5	Ammeter	M.I.	(0-5) A	2 Nos
6	Ammeter	M.I.	(0-10) A	1 No
7	Resistive load		4 kW	1 No
8	SPST switch		230V, 15A	1 No
9	Connecting Wires	Cu	1.5mm^2	As required

THEORY:

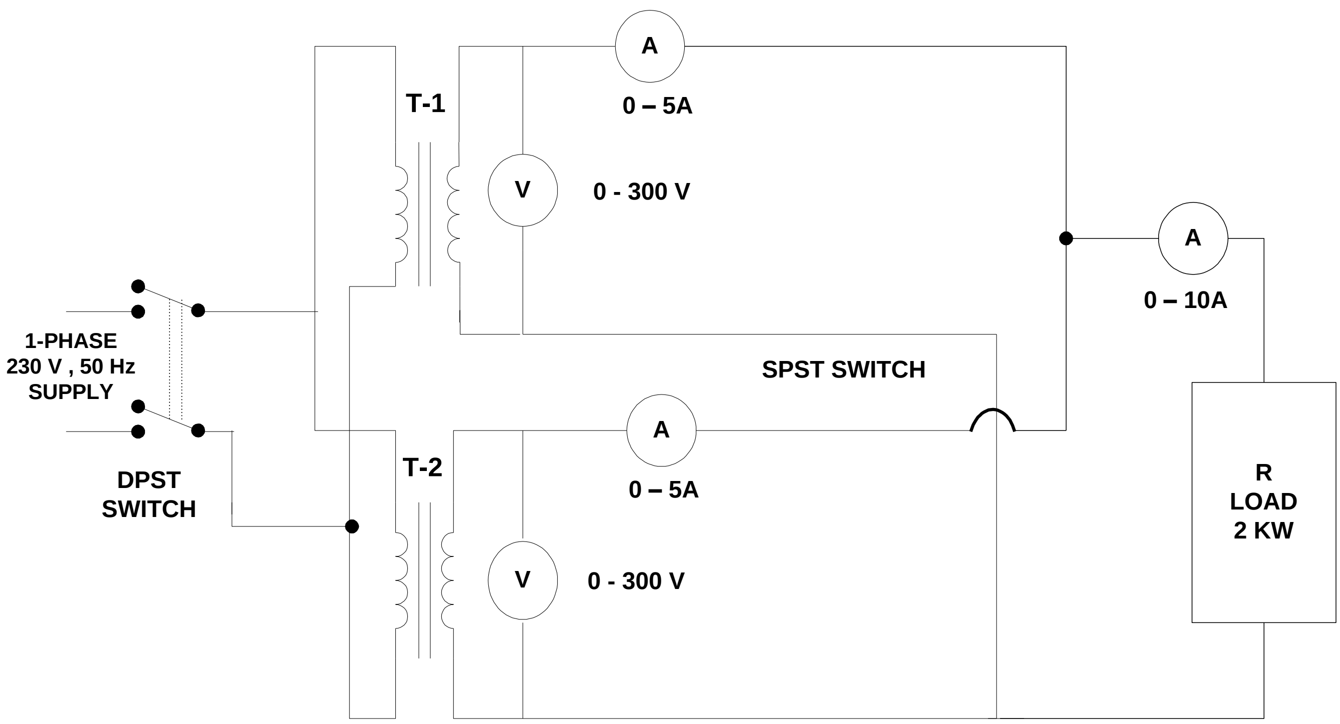
Polarity test is performed to determine the terminals having the same instantaneous polarity. The relative polarities of the primary and secondary terminals at any instant must be known per connecting windings of the same transformer in parallel or series or for interconnecting two or more transformers in parallel or for connecting single-phase transformers for polyphase transformation of voltages. Parallel operation of transformers is frequently necessary in the power system network, which consist of a number of a number of transformers installed at generating stations, substations etc. When operating two or more transformers in parallel, their satisfactory performance requires that the following conditions must be satisfied.

(a) For single phase transformers.
    1. The same polarity.
    2. The same voltage ratio.
(b) For three phase transformers.
    1. The same polarity.
    2. Zero-relative phase displacement.
    3. Same phase sequence.
    4. Same voltage ratio.

In addition to the above essential requirements, the transformers to the operated in parallel should have the following for better load sharing and operating power factor.

1. Equal per unit impedances.
2. Equal ratio of resistance to reactance.

CIRCUIT DIAGRAM:



PRECAUTIONS:

1. Connection should be right and tight.
2. Check the circuit connection thoroughly before switching on the supply.
3. Instruments should be connected in proper polarity and range.
4. Do not touch any non-insulated part of any instrument or equipment.
5. Be ensured the zero setting of instrument is on right position. Avoid parallax error.
6. Ensure that the two secondaries have been connected properly as per the polarity.

PROCEDURE:

1. Two winding of a transformer the two windings are connected in series across a voltmeter while one of the winding is excited from a suitable ac voltage source when the transformer has a subtractive polarity the voltmeter will read the difference of E1 & E2. If the voltmeter reads E1=E2,the polarity marking of one of the windings must be interchanged
2. Connect the circuit as per the circuit diagram.
3. Switch on the power supply and adjust the rated voltage across the circuit.
4. Adjust a particular load on the secondaries and note down the readings of all the meters.
5. Repeat step-3 for more readings.
6. Switch off the supply.

OBSERVATIONS :

Sl.No	V_L	I_L	W_L	I_1	W_1	I_2	W_2

Data Processing and Analysis:

1. Plot graph – (1) I_1 Vs I_L & (2) I_2 Vs I_L

CONCLUSION :

DISCUSSION :

1. If two transformers of the same kVA ratings and transformation ratio but of different equivalent impedances are connected in parallel which transformer will be loaded more?
2. What is meant by circulating current with regard to parallel operation of transformers? How much percentage of circulating connects can be permitted for satisfactory parallel operation? How can it be minimized?

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Experiment-07

REGULATION OF 3 Φ ALTERNATOR BY SYNCHRONOUS IMPEDANCE METHOD

AIM OF THE EXPERIMENT:

a) Perform no-load and short- circuit test on a 3-Φ alternator.
b) Measure the resistance of the stator winding of alternator.
c) Find out regulation of alternator by synchronous impedance method.

APPARATUS REQUIRED:

Instruments/Equipments:

Sl.No	Instrument/Equipment	Type	Specification	Quantity
1	Ammeter	MI	(0-2.5) A	1 No
2	Ammeter	MC	(0-1000)mA	1 No
3	Voltmeter	MC	(0-300)V	1 No
4	Voltmeter	MI	(0-300 / 600)V	1 No
5	Tachometer	Digital	(0-5000)rpm	1
6	Connecting Wires & Patch Chord	Cu	1.5 sq. mm	As required

Machines Required:

Sl.No	Machine	Specification	Quantity
1.	D.C. Motor coupled with 3-Φ Alternator	**D.C. Shunt Motor :-**1.1 Kw , 3000 RPM 220 V , 6.3 A , Excitation- 130 V/0.22 A **3-Φ Alternator :-**1.1 kVA , 220/380 V,50 Hz 2.9/1.67 A ,3000 RPM , Excitation- 110 V/0.4 A	1 Set

THEORY:

The regulation of Alternator is defined as "***the rise in terminal voltage***" when full-load is removed divided by rated terminal voltage with speed and excitation of alternator remaining unchanged.

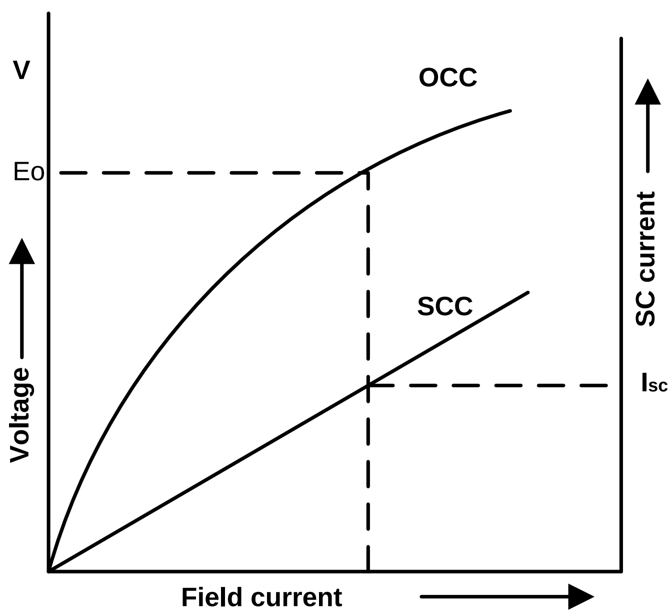
The synchronous impedance method of determining regulation is based on the simple equivalent circuit and phasor diagram given in Fig-1.Inthis method the effect of armature reaction is expressed as a voltage drop, I_aX_{ar} (X_{ar} is commonly called the armature reaction reactance).The leakage reactance and the armature reaction reactance combined together is called the synchronous reactance of the machine, i.e $X_S = X_1 + X_{ar}$

The corresponding per phase impedance Z_s=R_a + jX_s is called the synchronous impedance of the machine where R_e represents the effective resistance per phase. The determination of the synchronous impedance requires the knowledge of open circuit and short circuit characteristics.

If the generator is short circuited the whole of the voltage E is absorbed in the synchronous impedance of the machine, that is, E= Isc*Zs. Thus for a given field current, the ratio of the open circuit armature voltage to the short circuit current gives the synchronous impedance of the machine. From the nature of open-circuit and short-circuit characteristics, it is obvious that the value of synchronous reactance is not constant but decreases as the saturation sets in. Since Zs is varying with excitation, for proper application the value of Zs is chosen corresponding to the rated value of field current. However, for laboratory purposes Zs is chosen corresponding to the field current for the rated value of open circuit voltage.

The experiment involves the determination of the following characteristics and parameters:

1. The open -circuit characteristic (the O.C.C).
2. The short-circuit characteristic (the S.C.C).
3. The effective resistance of the armature winding (Ra).



The open circuit and short circuit characteristics of a 3-Φalternator is plotted on per phase basis. To find out the synchronous impedance from these characteristics, open circuit voltage, (***E0***) and short circuit current (***I***I_{sc},) corresponding to a particular value of field current is obtained. Then, synchronous impedance per phase (***Zs***) is given by-

$$Zs = \frac{Eo}{Isc}$$

At higher values of field current, saturation occurs and the synchronous Impedance of the machine decreases. The value of 'Zs' calculated for the unsaturated region of the O.C.C is called the unsaturated value of the synchronous impedance. If 'Ra' is the effective resistance of the armature per phase, the synchronous reactance 'Xs' is given by-

$$Xs = \sqrt{(Za)^2 - (Ra)^2}$$

If 'V' is the magnitude of the rated voltage of the machine whose regulation is to be calculated for a load current ***'I'*** at a power factor angle (Φ) then the corresponding magnitude of the open circuit voltage 'E_0' is given by-

$E_0 = V + IZs$

$$\%\, of\ Regulation = \frac{(Eo - V) * 100}{V}$$

CIRCUIT DIAGRAM:

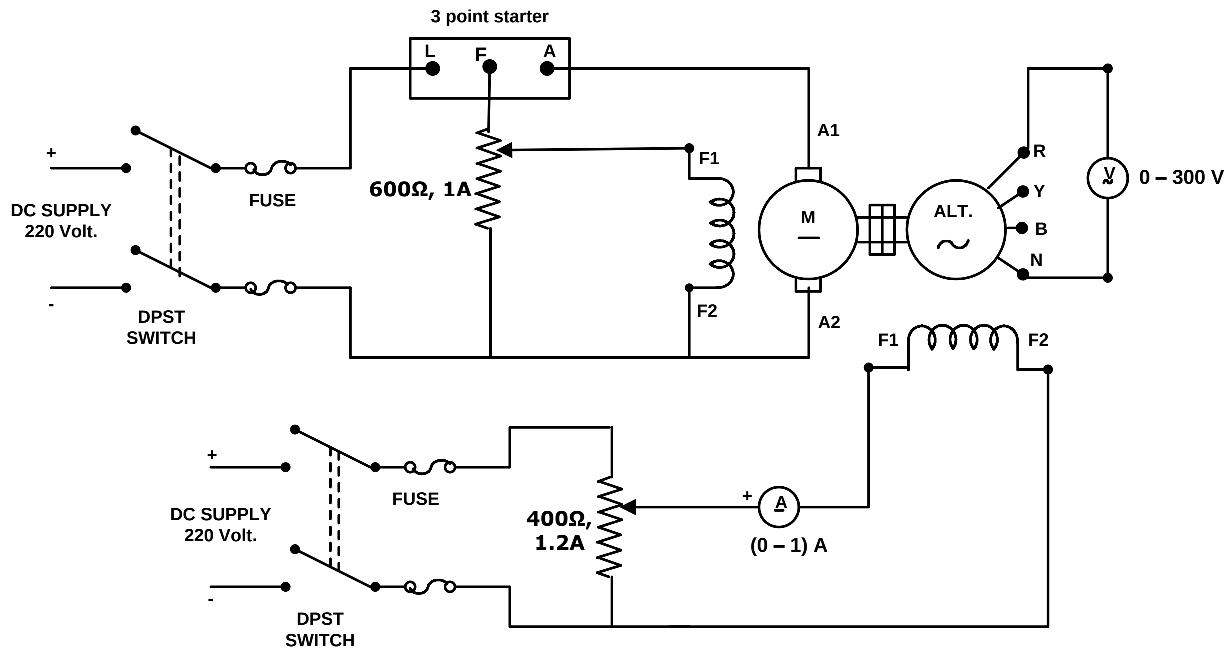


Fig- 1 Circuit Diagram for O.C Test on alternator

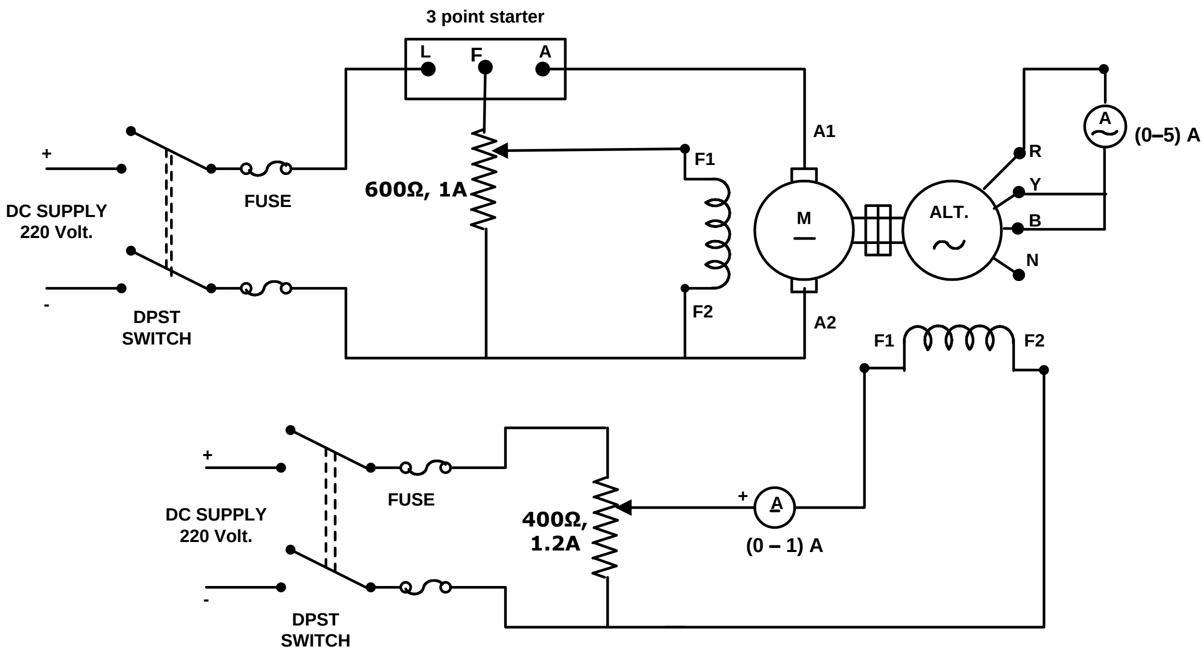


Fig- 2 Circuit Diagram for S.C Test on alternator

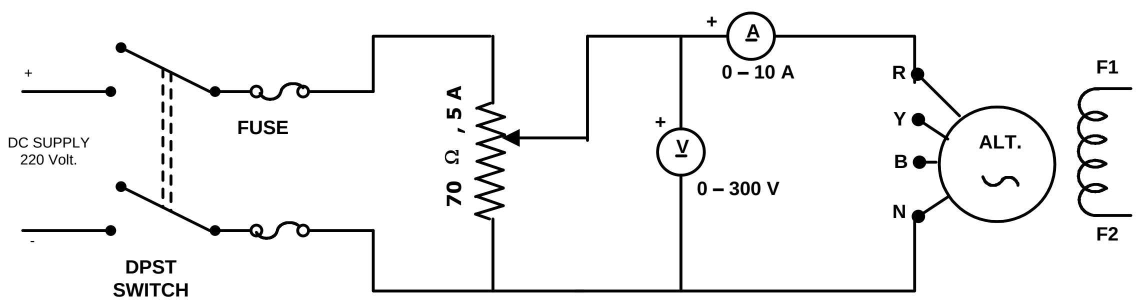


Fig- 3 Circuit Diagram for armature resistance measurement of alternator

PRECAUTION:

1. Connection should be right and tight.

2. Check the circuit connection thoroughly before switching on the supply.

3. Instruments should be connected in proper polarity and range.

4. Do not touch any non-insulated part of any instrument or equipment.

5. Be ensured the zero setting of instrument is on right position. Avoid parallax error.
6. Before starting the dc shunt motor ensure that, the field rheostat of the motor is kept in minimum position.
7. Also field rheostat of alternator should be at minimum position (i.e –ve supply end).

PROCEDURE:

1. Open-Circuit characteristic:

1. Connect the alternator as shown in Fig-1.
2. The prime mover in this experiment is a D.C. shunt motor coupled with alternator. The speed of the alternator is adjusted to rated speed by varying field resistance of DC shunt motor.
3. Adjust the speed of alternator to rated speed with No-load for each setting of the field current of alternator and record the alternator terminal voltage.

4. Record readings [field current (I_f) verses terminal voltage (V_{oc}) of alternator] still open circuit voltage reaches 120% of the rated voltage of the machine in the observation table.

2. Short-Circuit characteristic:

1. Connect circuit diagram as in Fig-2, but short-circuit the armature terminals through an ammeter.
2. The current range of the instrument should be about 25-50 % more than the full load current of the alternator.
3. Starting with zero field current, increase the field current gradually and cautiously till rated current flows in the armature and note down the readings(I_f versus I_{sc}) in observation table
4. The speed of the set in this test also is to be maintained at the rated speed of the alternator.

3. Armature resistance measurement:

1. Connect the circuit as in Fig-3.
2. Switch ON the power supply.
3. Note down the readings ammeter (I) and voltmeter (V) correctly in the observation table for different supply voltages.
4. Switch OFF the power supply.

OBSERVATION:

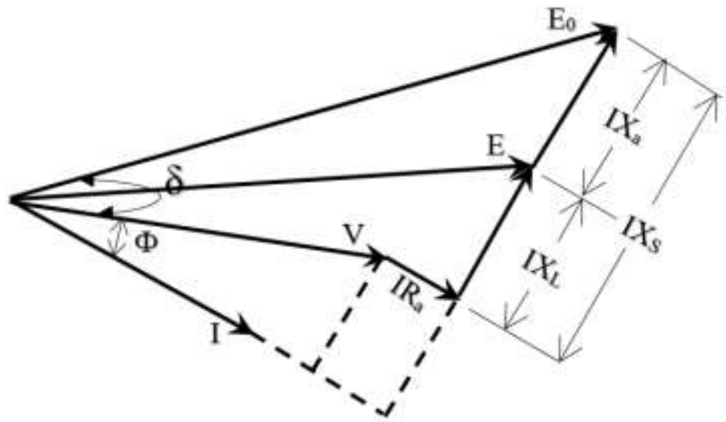
Sl. No.	Open Circuit Test		Short Circuit Test		Armature Resistance				
	I_f	V_{oc}	I_f	I_{sc}	V	I	R_{adc}	Mean R_{adc}	$R_{a}=1.2*R_{adc}$

Data Processing and Analysis:

1. Plot *on the same* graph sheet, the O.C.C (open circuit terminal voltage per phase versus the field current), and the short-circuit characteristic (short-circuit armature current versus the field current).
2. Calculate the unsaturated value of the synchronous impedance (Z_s), corresponding to rated armature short- circuit current. Calculate the corresponding values of the synchronous reactance (X_s).
3. Calculate regulation of the alternator under the following conditions:
   a) Full load current at unity power factor.
   b) Full load current at 0.8 power factor lagging.
   c) Full -load current at 0.8 power factor leading.

CALCULATIONS:

Phasor diagram of an alternator at lagging power factor is as follows:

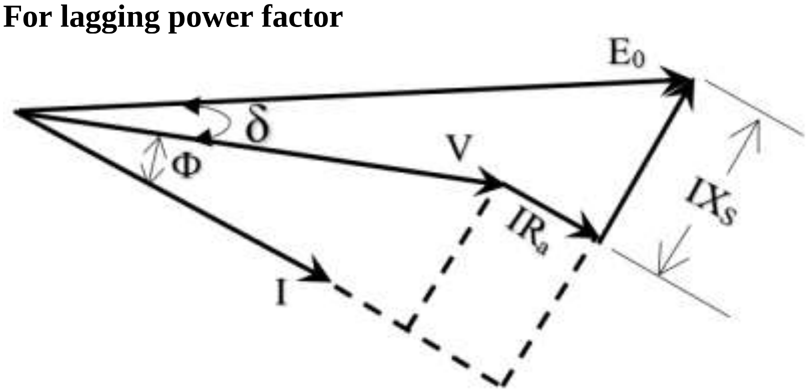


Regulation is found by the following expression.

$$\% \, Regulation = \frac{E_0 - V}{V} \times 100$$

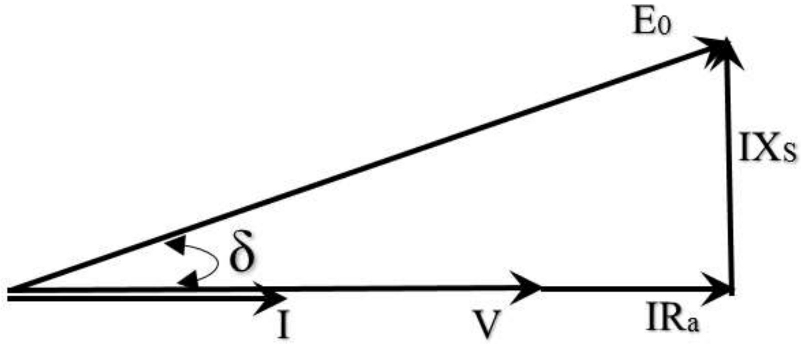
where V is the terminal voltage and E_0 is the induced voltage.For any load current I and phase angle Φ $E_0$is the vector sum of V, IR_a and IX_S.
E_0 is estimated by the following methods.

For lagging power factor



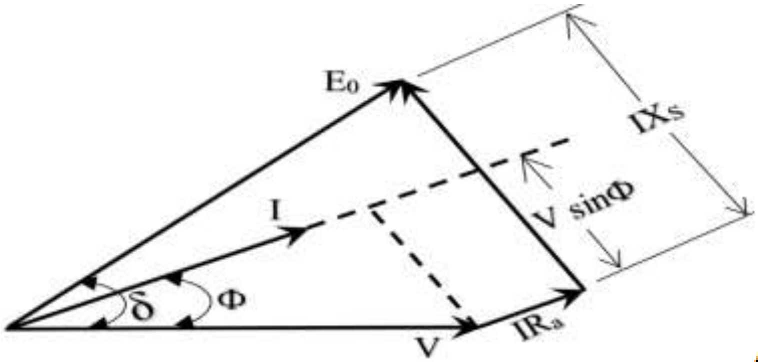
$$\boldsymbol{E_0 = \sqrt{(V\,cos\Phi + IR_a)^2 + (V\,sin\Phi + IX_S)^2}}$$

For unity power factor



$$\boldsymbol{E_0 = \sqrt{(V + IR_a)^2 + (IX_S)^2}}$$

For leading power factor



$$E_0 = \sqrt{(V\, cos\Phi + \mathrm{I}R_a)^2 + (V\, sin\Phi - \mathrm{I}X_S)^2}$$

CONCLUSION:

DISCUSSION:

1. What are the preconditions necessary for performing the Open Circuit characteristics test?
2. What is the power factor of alternator on Short Circuited condition?
3. Why is the short circuit characteristic of the alternator is a straight line? Up to what range of Short Circuit current, the linearity of the characteristic is maintained?
4. What is the effect of power factor on armature reaction?
5. Why the synchronous reactance of Alternator is different at different values of field current?
6. Why it is necessary to separate the effect of armature reaction and leakage reactance of the Alternator?
7. What do you understand by effective resistance of Alternator and how can it measured in laboratory?
8. Why does the terminal voltage of an alternator change with load current? How does the load power factor effect this voltage change?

Experiment No- 8

DIRECT AND QUADRATURE AXIS SYNCHRONOUS REACTANCE OF ALTERNATOR

AIM OF THE EXPERIMENT:

Determination of the direct and quadrature axis synchronous reactance by slip test of synchronous machine.

EQUIPMENTS REQUIRED:

Instruments/Equipments:

Sl.No	Instruments/Equipments	Type	Specification	Quantity
1	Voltmeter	MI	0-100V	1
2	Ammeter	MI	0-10A	1
3	Rheostat	Tubular	500Ω, 3A	1
4	3-ϕVariac	Iron core	415 V, 10 A	1 No
5	Tachometer	Digital	0-2000rpm	1
6	Connecting wires	Cu	1.5 sq. mm	As required

Machines Required:

Sl. No.	Machine	Specification	Quantity
1.	D.C. Motor coupled with 3-Φ Alternator	**D.C. Shunt Motor :-6** HP , 1500 RPM 220 V , 24 A , Excitation- 220 V/ 2 A **3-Φ Salient Pole Type Alternator :-** 5 kVA, 415V,50Hz, Star, 7A,1500 RPM, 0.8 pf Excitation- 220 V/2 A	1 Set

THEORY:

From slip test the value of direct and quadrature axis synchronous reactance can be determined. The synchronous machine is driven by a separate prime-mover (in this case dc motor) at a speed slightly different from synchronous speed. The field winding is left open and positive sequence balanced voltage of reduced magnitude (around 25% of rated value) and rated frequency is impressed across the armature terminals. Under these conditions the relative velocity between the field poles and the rotating armature mmf wave is equal to the difference between synchronous speed and the rotor speed, i.e. the slip speed. A small ac voltage across the open field winding indicates that the field poles and rotating mmf wave are revolving in the same direction and this is required in slip test. If field poles revolve in a direction opposite to the rotating mmf wave negative sequence reactance would be measured.

At one instant when the peak of armature mm wave is in line with field pole or direct axis, the reluctance offered by the small air gap is minimum. At this instant the impressed terminal voltage per phase divided by the corresponding armature current per phase gives d-axis synchronous reactance X_d.

After one quarter of slip cycle the peak of armature mmf wave acts on the inter polar or q-axis of the magnetic circuit, and the reluctance offered by long air gap is maximum. At this instant the ratio of armature terminal voltage per phase to the corresponding armature current per phase gives q-axis synchronous reactance X_q.

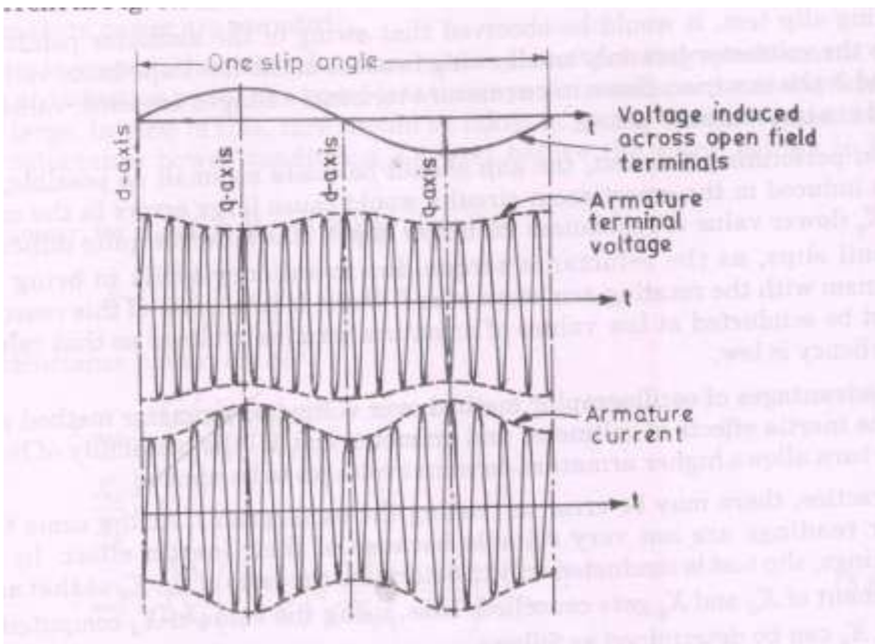


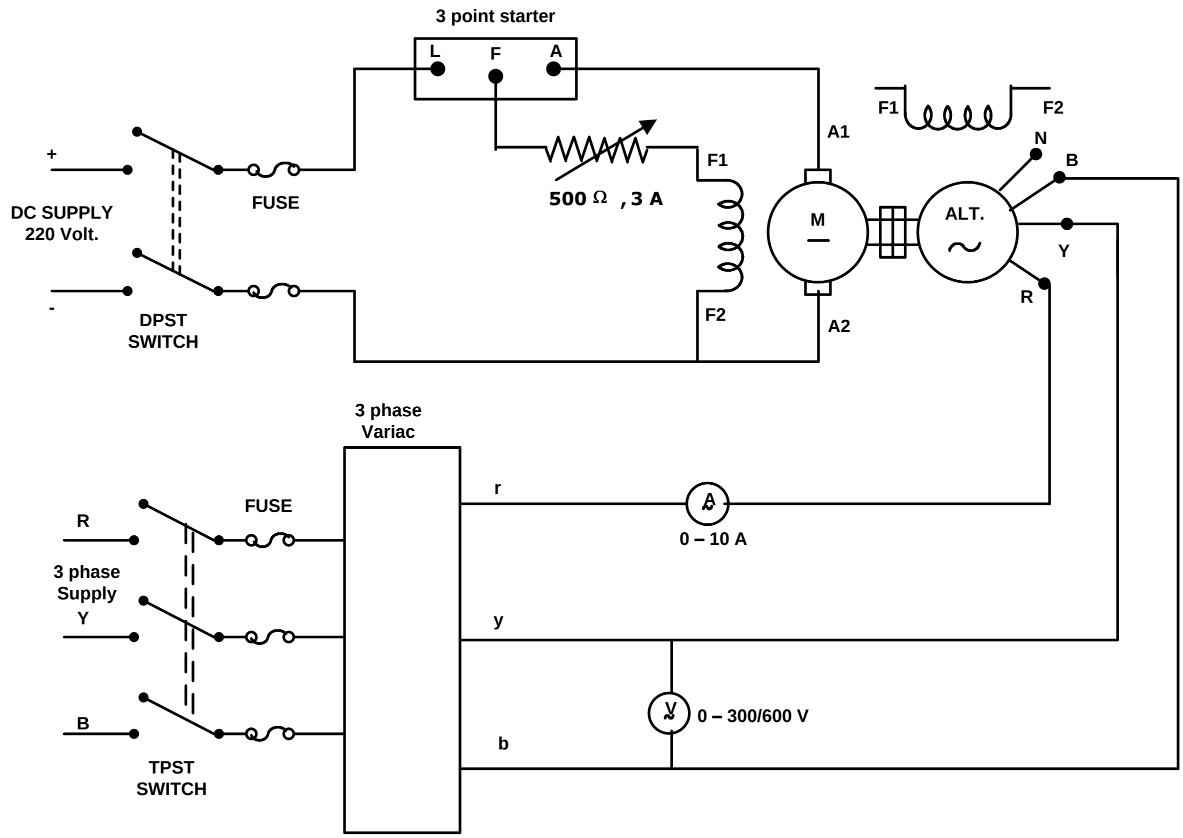
Fig. 5.93. Typical oscillograms in slip test.

FORMULAE USED:

$$\textbf{Direct axis unsaturated reactance} = \frac{\textbf{Maximum armature terminal voltage per phase}}{\textbf{Minimum armature current per phase}}$$

$$\textbf{Quadrature axis unsaturated reactance} = \frac{\textbf{Minimum armature terminal voltage per phase}}{\textbf{Maximum armature current per phase}}$$

CIRCUIT DIAGRAM:



PRECAUTION:

1. Connection should be right and tight.
2. Check the circuit connection thoroughly before switching on the supply.
3. Instruments should be connected in proper polarity and range.
4. Do not touch any non-insulated part of any instrument or equipment.
5. Be ensured the zero setting of instrument is on right position. Avoid parallax error.
6. Before switching on the supply, be sure that variable point of Variac should be at zero.

PROCEDURE:

1. Make the field circuit open.
2. Set the speed of the alternator slightly less than the synchronous speed (1480 to 1490 rpm) by dc motor.
3. Apply reduced voltage (around 25% of rated value) to the armature terminals by the 3-phase autotransformer.
4. Note down the maximum and minimum readings of the ammeter and voltmeter deflections.

OBSERVATIONS:-

Sl. No.	V_{ph} maximum/minimum	I maximum/minimun	X_d	X_q

CONCLUSION:

DISCUSSION:

1. Will you get X_d and X_q in case of cylindrical rotor type alternator? If not why? Discuss.
2. What is the difference between synchronous reactance, leakage reactance and armature reactance? Do they have any relation among themselves?
3. What is the salience factor of an alternator?

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Experiment No- 09

REGULATION OF 3 Φ ALTERNATOR BY ZERO POWER FACTOR METHOD

AIM OF THE EXPERIMENT:

a) Perform open circuit and short circuit test on a 3-Φ alternator.
b) Perform load test on 3-Φ alternator with highly lagging load (Approximately zero power factor) when rated voltage and rated current flowing in the starter winding.
c) Find out regulation of alternator by using zero power factor method.

APPARATUS REQUIRED:

Instruments/Equipment:

Sl.No	Instruments/Equipments	Type	Specification	Quantity
1	Ammeter	MC	(0-1000) mA	1 No
2	Voltmeter	MC	(0-150)V	1 No
3	Voltmeter	MI	(0-150/300 / 600)V	1 No
4	Ammeter	MI	(0-5)A	1 No
5	Tachometer	Digital	(0-5000)rpm	1
6	TPST Switch	Knife	16A	1
7	Connecting Wires & Patch Chord	Cu	1.5 sq. mm	As required

Machines Required:

Sl.No	Machine	Specification	Quantity
1.	D.C. Motor coupled with 3-Φ Cylindrical Alternator	**D.C. Shunt Motor :-3 kW** , 1500 RPM 220 V , 18 A , Excitation- 120 V/ 0.8 A **3-Φ Alternator :- 2.4** kVA , 220/380 V,50 Hz 6.3/3.6A ,1500 RPM , Excitation- 110 V/0.75 A	1 Set

THEORY:

Zero power factor saturation curve method is most reliable for determining the regulation of alternators because it properly takes into account of the effect of armature leakage reactance drop and the saturation. The following experimental data is needed to determine the regulation by this method.

1. Open circuit characteristic at rated speed of the alternator.
2. Field current corresponding to full load short circuit current.
3. Field current corresponding to full load, rated voltage, zero power factor.
4. AC resistance of the stator winding per phase of the alternator.

To plot zero power factor characteristic from the experimental data and to determine the regulation of the Alternator proceed as follows:

Plotting of zero power factor characteristic

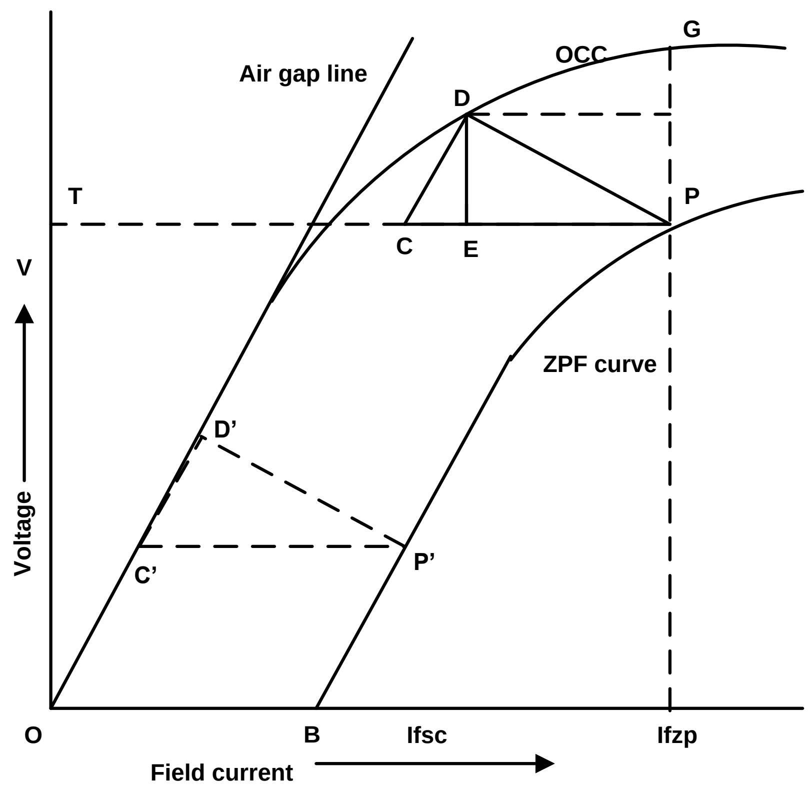

Fig-1 Zero power factor characteristic of alternator

- Draw the open circuit characteristic to proper scale and draw the air gap line as shown in Fig-1.
- Draw the field current, I_{fsc} corresponding to full load short circuit current (line ***OB***).
- Draw the field current, I_{fzp} at rated voltage which corresponding to full load zero power factor, thus obtaining a point ***P*** on the zero power factor, full load characteristic (line ***TP***).
- From the point ***P*** draw a horizontal line ***PC*** representing the field current corresponding to full load short circuit current i.e. ***PC***=***OB***.
- From the point ***C*** draw a line ***CD*** parallel to air gap line.
- Join ***D*** and ***P***. Now ***PCD*** is a triangle, which normally called as ***Potier triangle***.

Determination of leakage reactance

- Drop a perpendicular from the point ***D***, meeting the line ***PC*** at the point ***E***. then line ***ED*** represents the leakage reactance drop, which is also called as ***Potier reactance drop (*** E_x ***).***

Determination of Regulation

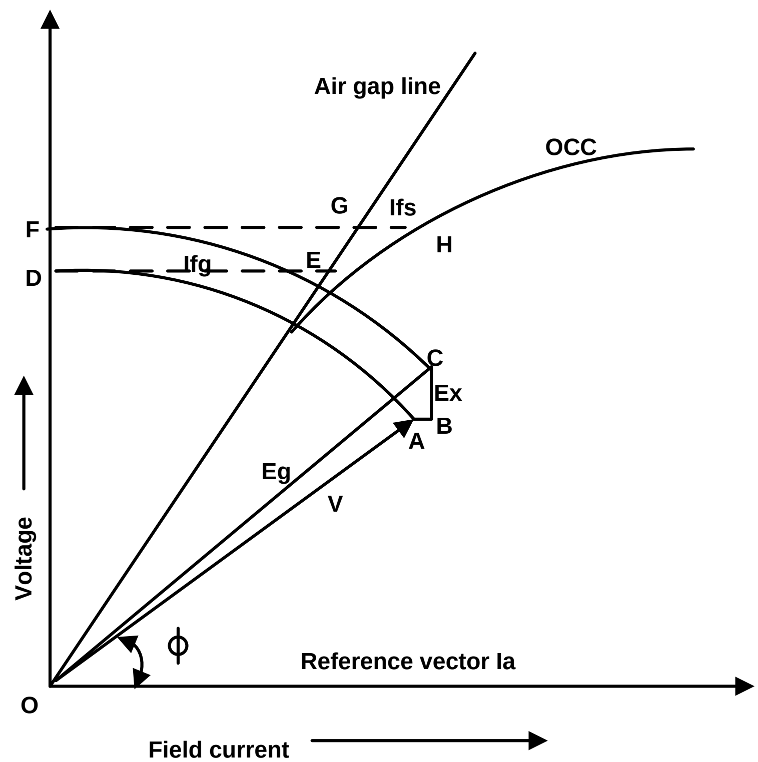

Fig-2 Determination of saturation effect

- Draw the current phasor, I_a as shown in Fig-2 horizontally, which is a reference phasor.
- Terminal voltage phasor, ***V*** is drawn at power factor angle Φ with respect to current (line ***OA***).
- Add armature resistance drop I_aR_a (line ***AB***) to the terminal voltage phasor V.
- Potier reactance drop, E_x is added in quadrature to the current phasor (line ***BC***).
- Join ***O*** and ***C***, line ***OC*** represents the internally generated emf, ***Eg***.
- Phasors ***OA*** and ***OC*** are projected by arc to vertical line.
- Intercept ***DE*** shown by dotted horizontal line in Fig-2 represents the field current, ***Ifg*** corresponding to rated no load voltage.
- The portion ***GH*** of the intercept ***FH*** represents the field current, ***Ifs*** which takes into account the effect of saturation.

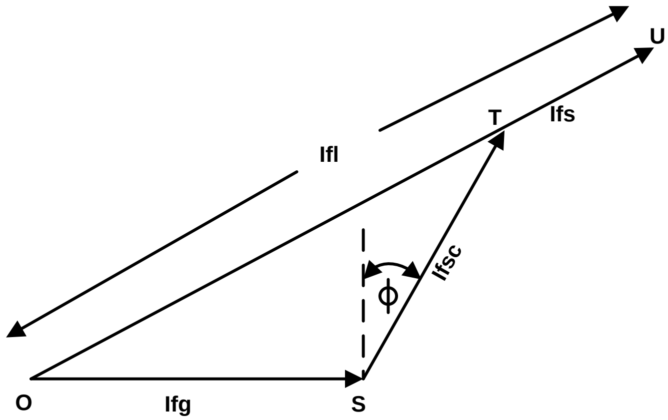

Fig-3 Phasor diagram for ZPF method

- Draw the field current ***Ifg*** horizontally (line ***OS***) as shown in Fig-3.
- Add the field current ***Ifsc*** (line ***ST***) at power factor angle Φ with the vertical as shown in Fig-3.
- Join ***OT*** and add the field current ***Ifs*** (line ***TU***), thus giving a total field current ***Ifl.***
- No load emf, E_o corresponding to field current ***Ifl*** is found out from the open circuit characteristic. Then
-

$$\% \; of \; Regulation = \frac{(Eo - V) * 100}{V}$$

CIRCUIT DIAGRAM:

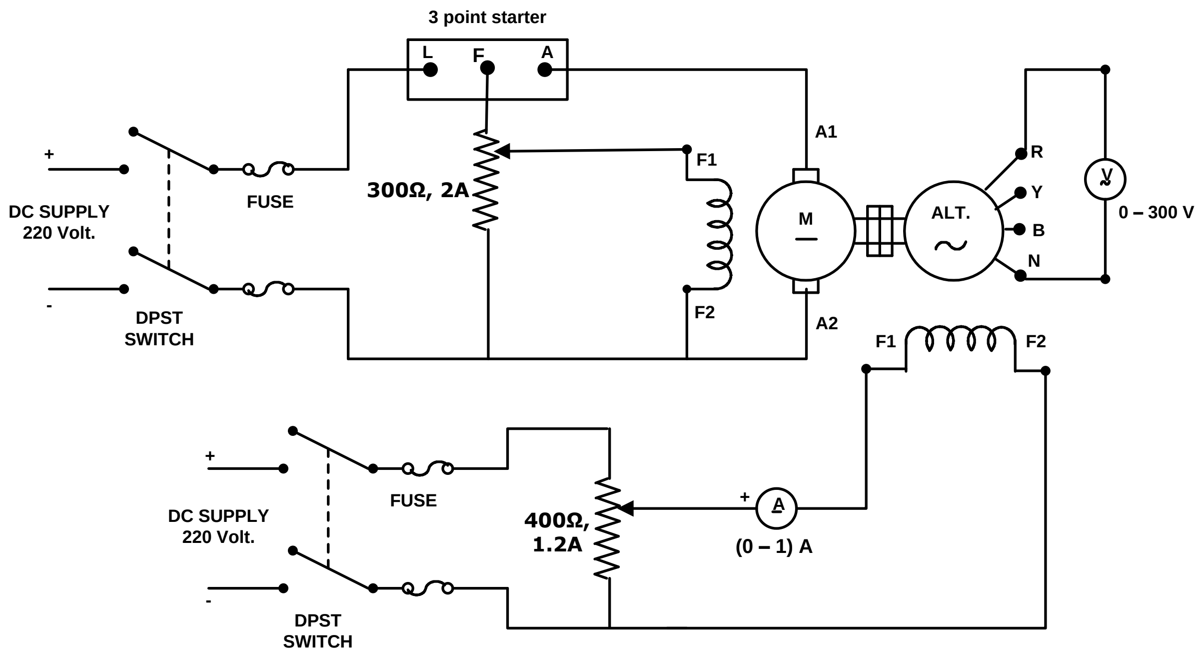

Fig- 4 Circuit Diagram for O.C Test on alternator

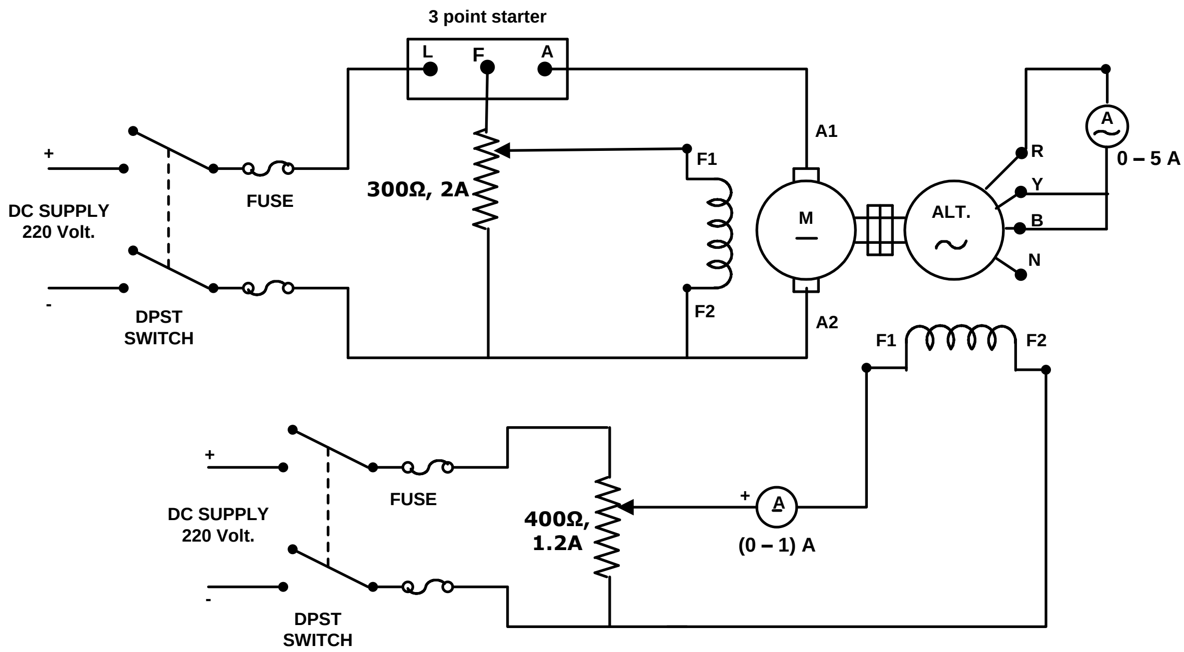

Fig- 5 Circuit Diagram for S.C Test on alternator

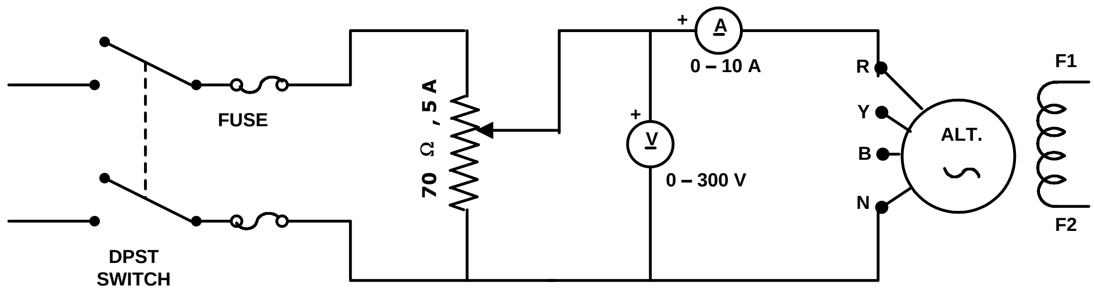

Fig- 6 Circuit Diagram for armature resistance measurement of alternator

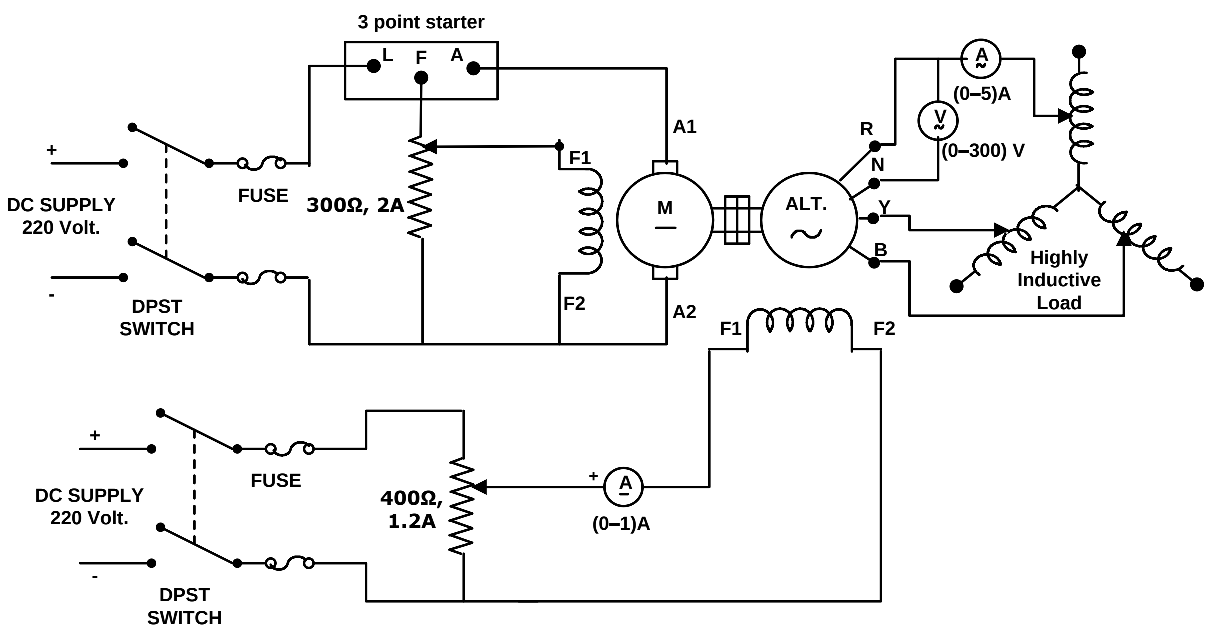

Fig-7 Zero power factor, full load test on alternator

PRECAUTION:

1. Connection should be right and tight.

2. Check the circuit connection thoroughly before switching on the supply.

3. Instruments should be connected in proper polarity and range.

4. Do not touch any non-insulated part of any instrument or equipment.

5. Be ensured the zero setting of instrument is on right position. Avoid parallax error.

6. Before starting the dc shunt motor ensure that, the field rheostat of the motor is kept in minimum position.

7. Also field rheostat of alternator should be at minimum position (i.e –ve supply end).

PROCEDURE:

1. Open-Circuit characteristic:

5. Connect the alternator as shown in Fig-4.
6. The prime mover in this experiment is a D.C. shunt motor coupled with alternator. The speed of the alternator is adjusted to rated speed by varying field resistance of DC shunt motor.
7. Adjust the speed of alternator to rated speed with No-load for each setting of the field current of alternator and record the alternator terminal voltage.
8. Record readings [field current (I_f) verses terminal voltage (V_{oc}) of alternator] still open circuit voltage reaches 120% of the rated voltage of the machine in the observation table-1.

2. Short-Circuit characteristic:

5. Connect circuit diagram as in Fig-5, but short-circuit the armature terminals through an ammeter.
6. The current range of the instrument should be about 25-50 % more than the full load current of the alternator.
7. Starting with zero field current, increase the field current gradually and cautiously till rated current flows in the armature and note down the readings(I_f versus I_{sc}) in observation table-1
8. The speed of the set in this test also is to be maintained at the rated speed of the alternator.

3. Armature resistance measurement:

1. Connect a DMM and find out the resistance of the stator winding of the alternator .

4. For zero power factor test:

1. Connect the circuit as in Fig-7.
2. Set the field Regulator rheostat of alternator, so that the field current of alternator is minimum.
3. Switch on the DC Supply and set the field voltage of DC Shunt Motor at it’s rated value.
4. Start the DC Shunt Motor with the help of starter and run it at rated speed of alternator.
5. Increase the field regulator rheostat of the alternator to obtain rated voltage.
6. Close the TPST Switch. Load the alternator gradually in steps and keep load current constant (may be at 50%,75%,100% of full load value) for each step variation.
7. Note down the terminal voltage across the load for each step variation.
8. Maintain the speed of the alternator at rated value throughout the experiment.
9. Decrease the load on the alternator gradually and side by side, reduce the field current of the alternator.
10. Switch off the dc supply to the field of the alternator and dc motor.

OBSERVATION:

Table – 1 (OC & SC Test and Ra Measurement)

Sl. No.	Open Circuit Test		Short Circuit Test		Armature Resistance				
	I_f	V_{oc}	I_f	I_{sc}	V	I	R_{adc}	Mean R_{adc}	$R_a = 1.2*R_{adc}$

Table – 1 (ZPF Test)

Sl. No.	Stator Current	Terminal voltage	Field current

Data Processing and Analysis:

1. Plot *on the same* graph sheet, the O.C.C (open circuit terminal voltage per phase versus the field current), and the short-circuit characteristic (short-circuit armature current versus the field current).
2. Calculate the unsaturated value of the synchronous impedance, and the value corresponding to rated current at short circuit. Also calculate the corresponding values of the synchronous reactance.
3. Calculate regulation of the alternator under the following conditions:
   d) Full load current at unity power factor.
   e) Full load current at 0.8 power factor lagging.
   f) Full -load current at 0.8 power factor leading.

CALCULATIONS:

CONCLUSION:

DISCUSSION:

1. What are the preconditions necessary for performing the Open Circuit characteristics test?
2. What is the power factor of alternator on Short Circuited condition?
3. Why is the Short Circuit characteristic a straight line? Up to what range of Short Circuit current the linearity is maintained?
4. Why do you think ZPF method is more accurate method as compared to synchronous impedance method?
5. By which other methods can you load the alternator for watt less current?
6. Discuss how it enables to separate the armature reaction drop from the leakage reactance drop.
7. Write in brief construction of the Potier triangle.

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Experiment-10

SEQUENCE IMPEDANCE OF 3 Φ ALTERNATOR

AIM OF THE EXPERIMENT:

a. To determine negative sequence impedance Z_2 of a 3-Φ alternator.
b. To determine zero sequence impedance Z_0 of a 3-Φ alternator.

APPARATUS REQUIRED:

Instruments/Equipments:

Sl. No	Instruments/Equipments	Type	Specification	Quantity
1	Ammeter	MI	(0–5/10)A	2 No
2	Voltmeter	MI	(0–15/30/75) V	1 No
3	Voltmeter	MI	(0–150/300/600) V	1 No
4	Rheostat	Tubular	500Ω, 3A	1 No
			70Ω, 3A	1 No
5	1-ϕVariac	Iron core	230 V, 10 A	1 No
6	3-ϕVariac	Iron core	415 V, 10 A	1 No
7	Tachometer	Digital	(0-2000)rpm	1
8	Phase Sequence Indicator	Analog		1
9	Connecting Wires	Cu	1.5 sq. mm	As required

Machines Required:

Sl. No	Machine	Specification	Quantity
1.	D.C. Motor coupled with 3-Φ Alternator	**D.C. Shunt Motor :-**6 HP, 1500 RPM 220 V, 24 A, Excitation- 220V/ 2 A **3-Φ Alternator :-** 5 kVA, 415V,50 Hz 7A, 1500RPM, 0.8 pf, Star connected Excitation- 220 V/4 A	1 Set

THEORY:

Symmetrical components are mainly used for the resolution of unsymmetrical Phase currents or voltages in to a set of components that possess certain symmetry features. The positive sequence components possess –three phase symmetry having the phase sequences R1Y1B1 or A1B1C1; the negative sequences components possess three phase symmetry having the phase sequences R2Y2B2 or A2C2B2; and the Zero sequences components (R0Y0B0 or A0B0C0) have equal magnitudes and phases. The Impedance offered to these sequences components are called Positive, Negative and Zero-sequence Impedances.

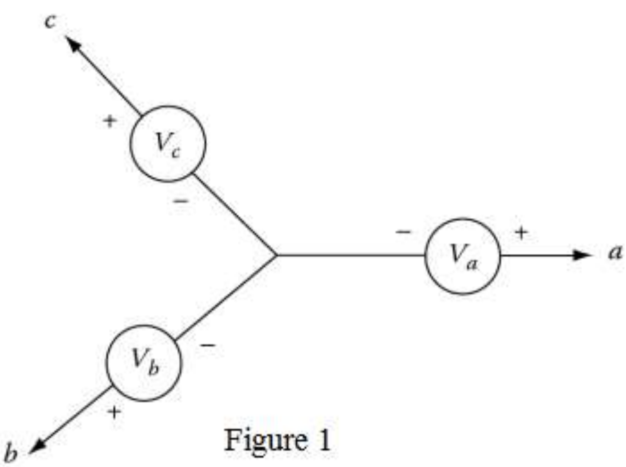


Figure 1

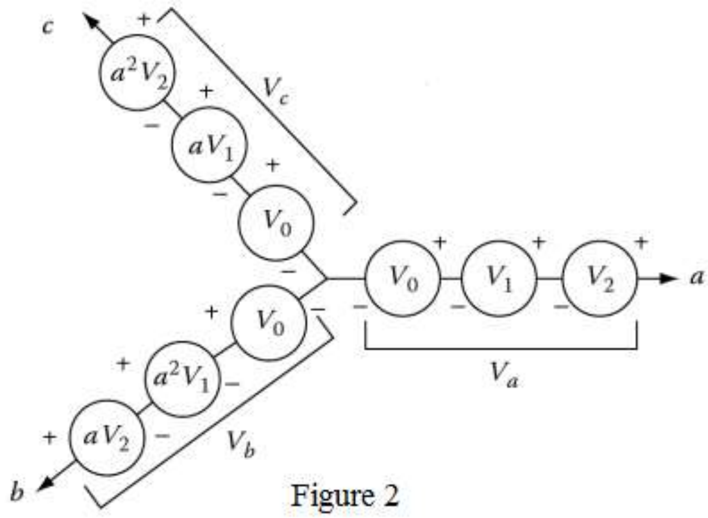


Figure 2

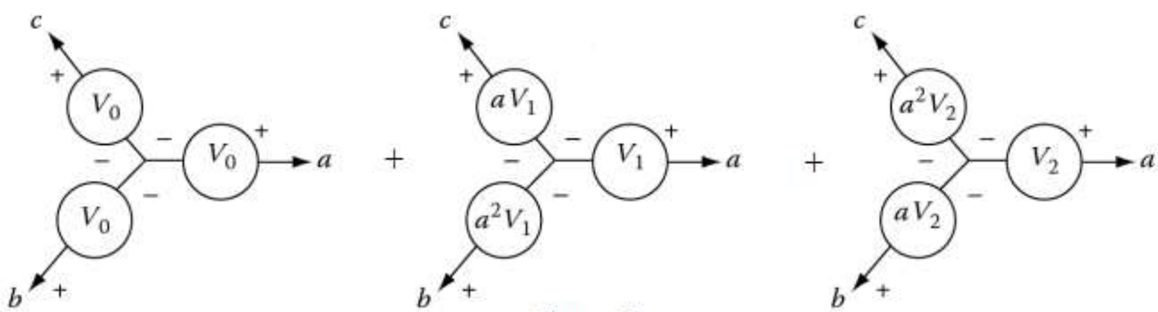


Figure 3

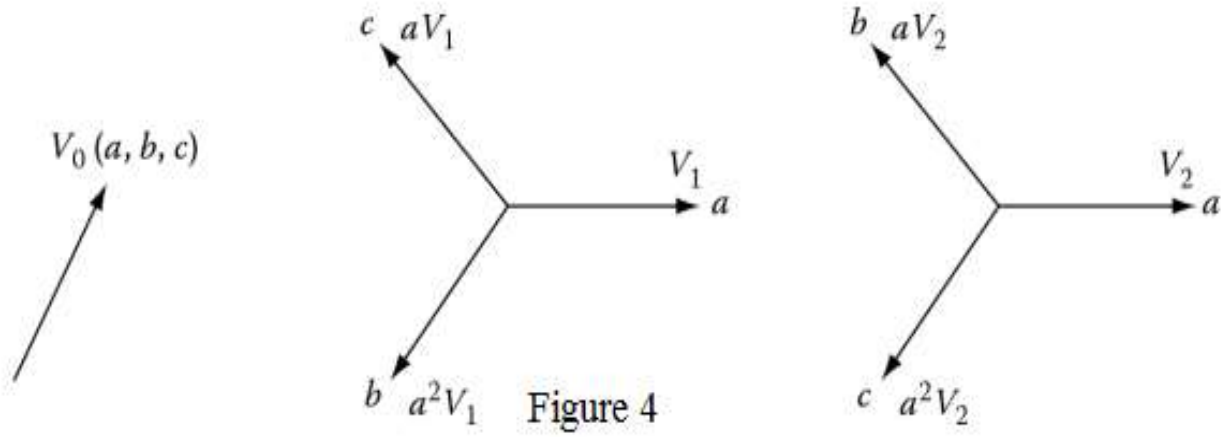
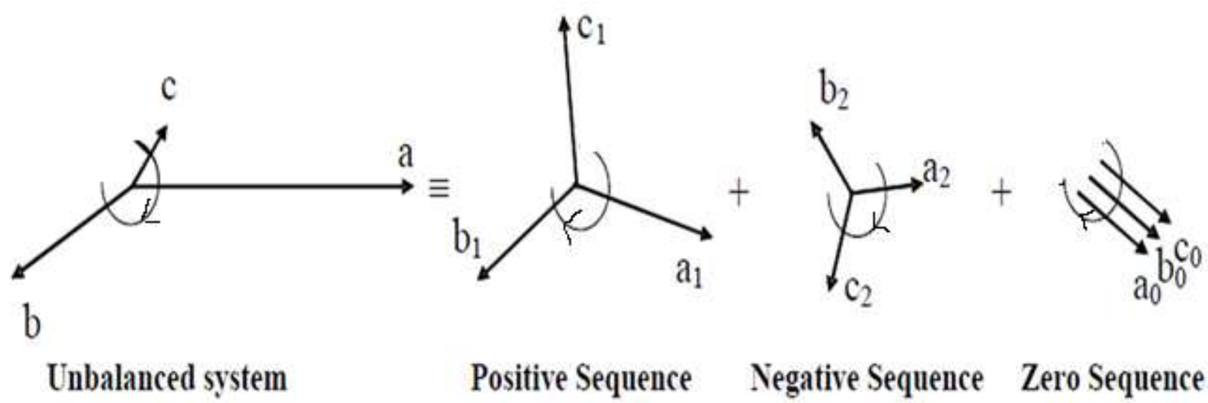


Figure 4



POSITIVE SEQUENCE COMPONENT

These are the components having equal in magnitude and having 1200 phase displacement. Its phase sequence is same as that of the original phase sequence of network.

- Direction of rotation of rotor of synchronous generator is the reference in order to decide the sequence of power system network.
- The sequence at which the system is working before fault is called as original sequence of network.

NEGATIVE SEQUENCE COMPONENT

These are the components having equal in magnitude and having 1200 phase displacement. Its phase sequence is opposite to that of the original phase sequence of network.

ZERO SEQUENCE COMPONENTS

These are the components having equal in magnitude and having no phase displacement. There is no need to compare phase sequence.

Negative Sequence Impedance (Z2):

The negative sequence impedance of the alternator is the impedance offered by the alternator to flow of negative sequence current. A set of negative sequence currents in the armature creates in the air gap a magnetic field that rotates at synchronous speed in a direction opposite to the normal direction of rotation (i.e. normal direction of rotation is identical to the direction of rotation of field created by positive sequence currents). Thus the negative sequence magnetic field rotates with twice the normal speed with respect to the rotor.

Test for Determining Z2:

The synchronous machine is driven at synchronous speed with help of prime mover. The machine is unexcited and connected to a voltage source which is gradually increased till full load current flows. The terminals are so connected that the direction of rotating field produced by the armature current is opposite to the direction of rotation of the pole structure. It is important to keep the field winding short-circuited during the test. The negative sequence impedance Z2 = V_2 / I_2.

Zero sequence impedance (Z_2):

If zero-sequence currents are applied to the armature, there is no space fundamental m.m.f. Hence the reactance is small and is hardly affected by the motion of the rotor. The zero sequence currents produces leakage fluxes (slot-leakage, end-winding-leakage and differential leakage). Although very little flux is set up, and the zero-sequence reactance is the lowest of the synchronous machine reactances.

Test for Determination of Z0:

The machine is driven at rated speed with field winding short-circuited. All phases are connected in series and a single phase voltage applied across them. It may be sometimes more convenient to connect the phases in parallel. The series connection is, however, preferred as the currents of the same magnitude and phase is flowing through all the three phases, a condition which must be positively fulfilled while determining X0. For series connection

Z0= V0 / (3*I0)

Where, V0 = applied voltage across three phase winding in series

I0 = current flowing in three phase windings in series.

For parallel connection of armature winding Z0=V0/ (I0/3)

Where, V0 = applied voltage across three phase winding connected in parallel

I0 = current flowing in three phase windings connected in parallel. The zero sequence impedance is the impedance offered to the flow of zero sequence current i.e. the voltage drop across any one phase (star connected) divided by the current in each of the phase.

CIRCUIT DIAGRAM:

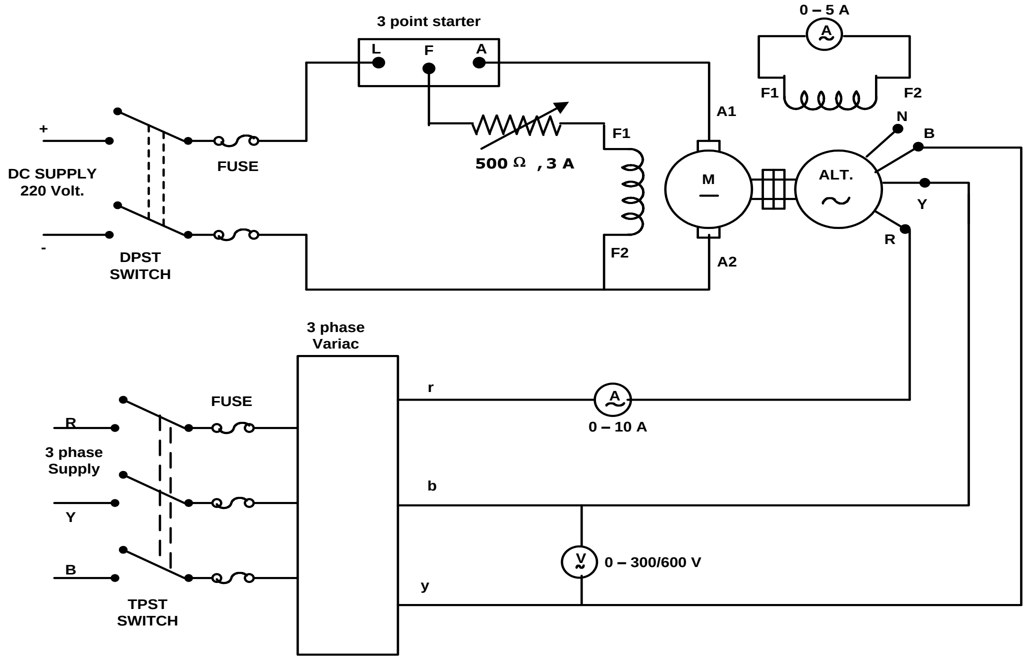


Fig1 Circuit Diagram for Negative sequence Impedance (Z_2)

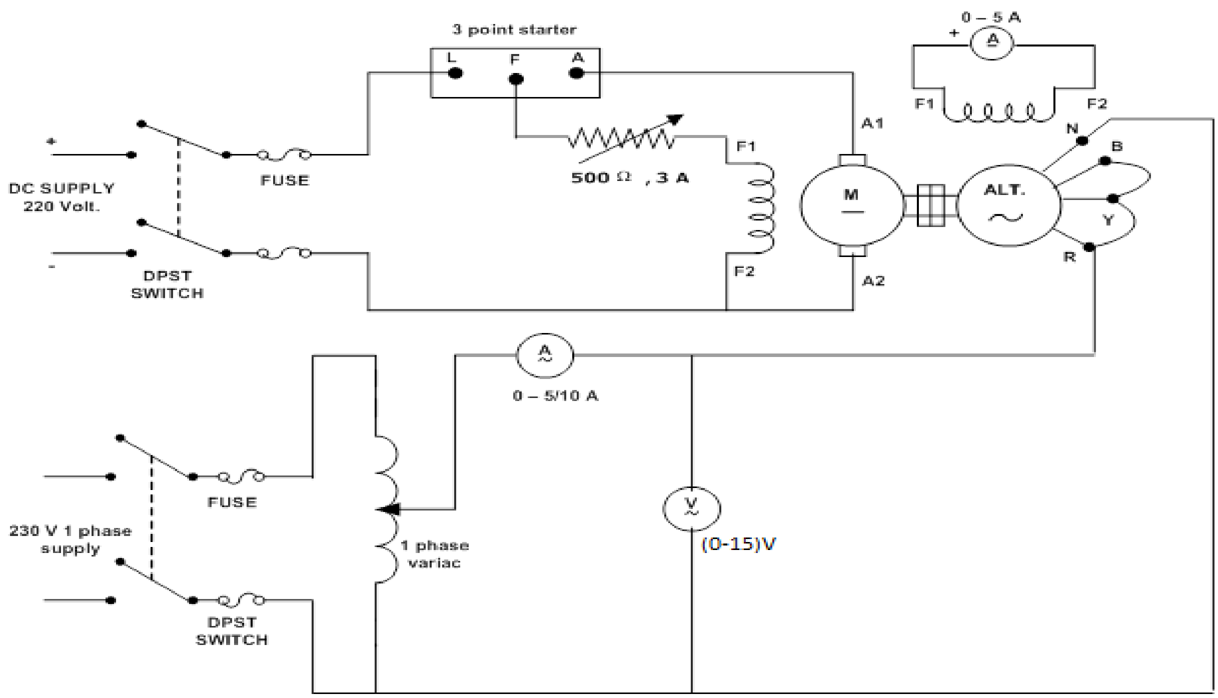


Fig- 2 Circuit Diagram for zero sequence Impedance (Z_0).

PRECAUTION:

1. Connection should be right and tight.
2. Check the circuit connection thoroughly before switching on the supply.
3. Instruments should be connected in proper polarity and range.
4. Do not touch any non-insulated part of any instrument or equipment.
5. Be ensured the zero setting of instrument is on right position. Avoid parallax error.
6. While applying voltage the armature current should not exceed 7 A.
7. The short circuit current should be kept low in order to avoid undue heating of the field winding.

PROCEDURE:

1. For Negative Sequence Synchronous Impedance (Z_2)

1. Connect the circuit as shown in Fig-1.
2. Rotate the rotor at synchronous speed with field winding unexcited & short circuited.
3. Apply the balanced 3-ϕ voltage.
4. Note down the instrument readings in observation table-1.
5. Switch off the 3-ϕ supply & stop the machine.

2. For Zero Sequence Synchronous Impedance (Z_0)

1. Connect the circuit as shown in Fig-2.
2. Rotate the rotor at synchronous speed with field winding unexcited & short circuited.
3. Apply the 1-ϕ voltage.
4. Note down the instrument readings in observation table-2.
5. Switch off the1-ϕ supply & stop the machine.

OBSERVATION:

Table-1 for Z_2

Sl. No	**V**	**I**	**I_f**	**Z_2**

Table-2 for Z_0

Sl. No	**V**	**I**	**I_f**	**Z_0**

CALCULATIONS:

$$\mathbf{Z_2} = \frac{V}{\sqrt{3}I}$$

$$\mathbf{Z_0} = \frac{3V}{I}$$

CONCLUSION:

DISCUSSION:

1. Define positive, negative and zero sequence components for unbalanced power system.
2. Can zero sequence currents produce rotating field? Justify your answer.
3. Explain how double frequency current are produced in the rotor field when negative sequence currents are impressed on armature.
4. Explain why X_1& X_2 are different in synchronous machine whereas they are equal in Transformer.
5. Explain how X_2 is arithmetic sum of "X_d" and "X_q".

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Experiment No- 11

PERFORMANCE CURVE OF 3 PHASE INDUCTION MOTOR

AIM OF THE EXPERIMENT:

a. Perform no load and block rotor test on 3-Φ induction motor.
b. Using the data obtained above, draw the circle diagram complete in all respect.
c. Compute max power, max torque, starting torque and best power factor using the circle diagram.

APPARATUS REQUIRED:

Instruments/Equipments:

Sl.No	Instruments/Equipments	Type	Specification	Quantity
1	Ammeter	MI	(0-5/10) A	1 No
2	Voltmeter	MI	(0-600) V	1 No
			(0-150) V	1 No
3	3-ϕVariac	Iron core	10 A, 415V	1 No
4	Wattmeter	LPF	5 A, 600 V,0.2PF	2 Nos
		UPF	10 A, 125V	2 Nos
5	Connecting Wires	Cu	1.5 sq. mm	As required

Machines Required:

Sl.No	Machine	Specification	Quantity
1.	3-ΦInduction Motor	3.7 kW / 5 HP , 1430 RPM 415 V, 7.8 A, Delta connection.	1 No

THEORY:

The**circle diagram** is the graphical representation of the performance of the electrical machines (such as Induction Motor, Alternator etc). The circle diagram is drawn using the data obtained from No-Load Test and short circuit Tests or, in case of Induction motor, Block rotor tests. To find out the Induction motor parameters which affect the performance of the Motor, we do both No-load Test and Block rotor test.

No-Load Test:

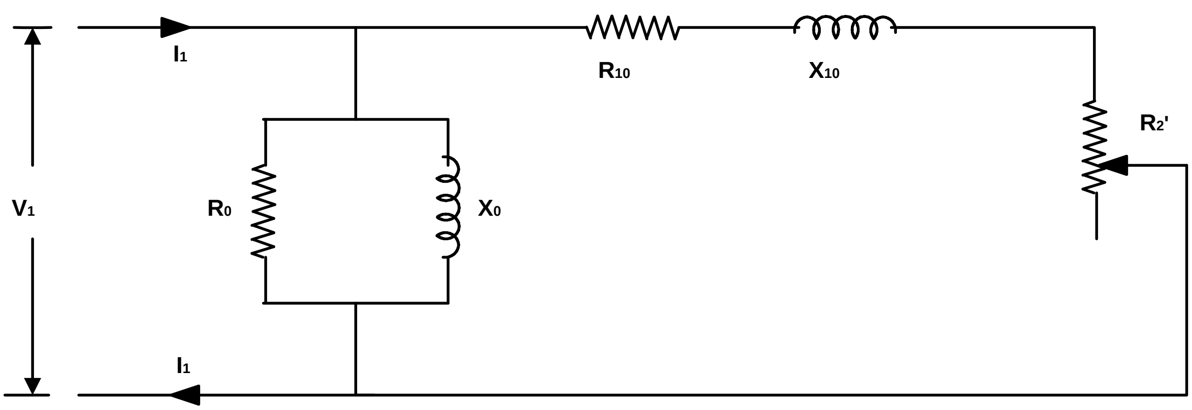
The no-load test of Induction machine, like the open circuit test on a transformer, gives information about exciting current and rotational losses. The test is performed by applying balanced rated voltage at rated frequency on the stator windings. The small power provided to the machine is due to core losses, friction and winding loses. The machine will rotate at almost synchronous speed, which makes slip nearly zero.

The No-load power factor ($\cos\phi_0$) = $P_0/(\sqrt{3} * V_0 * I_0)$

Where, P_0 - Power consumed by the Induction motor at no load

I_0 – No-load current drawn by the Induction motor

V_0 – Line voltage supplied to Induction motor



Equivalent Circuit diagram of Induction Motor

Block rotor Test:

The locked rotor test of Induction machine, like short circuit test on a transformer, provides the information about leakage impedances and rotor resistance. Low voltage is applied to stator windings to circulate rated current in stator winding of the motor by keeping rotor at standstill using brake drum arrangement. Measure the voltage and power per phase. Since there is no rotation slip, ***s=1.***

The short circuit power factor ($\cos\phi_{sc}$) =$P_{sc}/(\sqrt{3} * V_{sc} * I_{sc})$

CIRCUIT DIAGRAM:

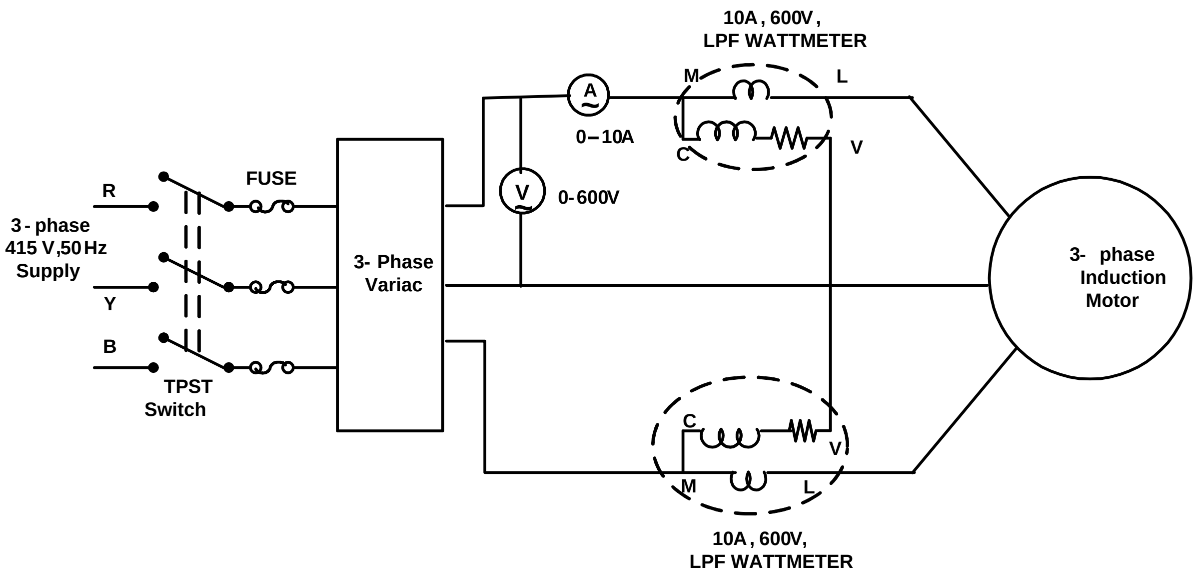


Fig-1 Circuit diagram for No load test

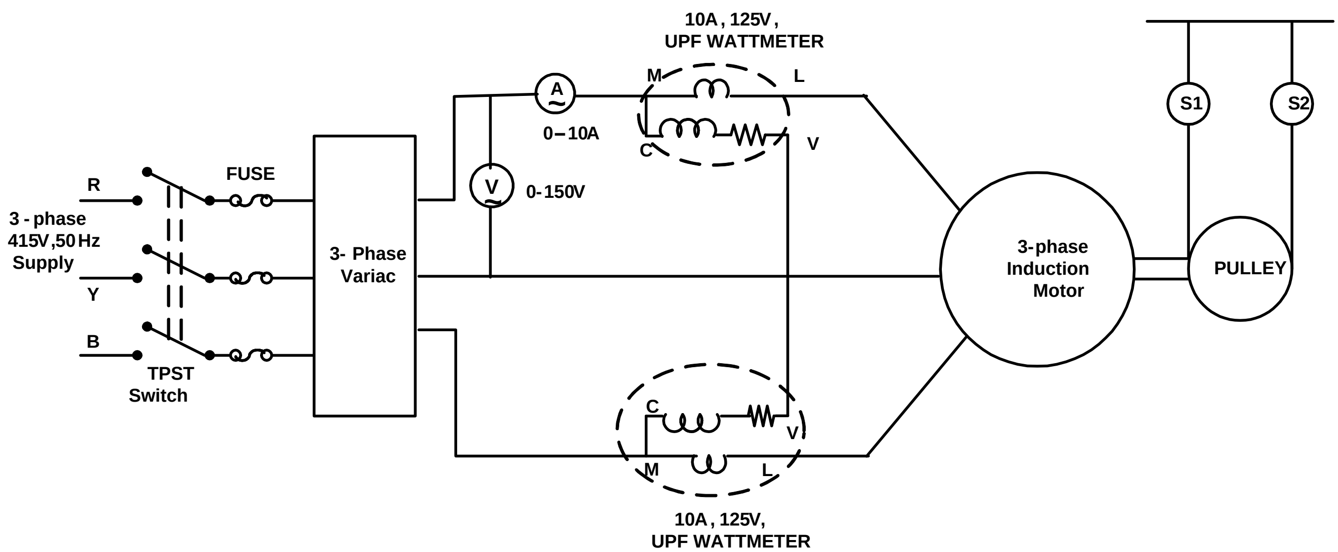


Fig-1 Circuit diagram for block rotor test

PRECAUTION:

1. Connection should be right and tight.
2. Check the circuit connection thoroughly before switching on the supply.
3. Instruments should be connected in proper polarity and range.
4. Do not touch any non-insulated part of any instrument or equipment.
5. Be ensured the zero setting of instrument is on right position. Avoid parallax error.
6. Before switching on the supply, be sure that variable point of Variac should be at zero.

PROCEDURE:

1. No-load Test:

1. Connect the circuit as shown in Fig-1.
2. Ensure that the motor is unloaded and the 3-ϕ Variac is set at zero position.
3. Switch on the supply and increase the voltage gradually till the rated voltage of the motor.
4. Note down the readings of all the meters in observation table.
5. Switch off the a.c. supply to stop the motor.

2. Block Rotor Test:

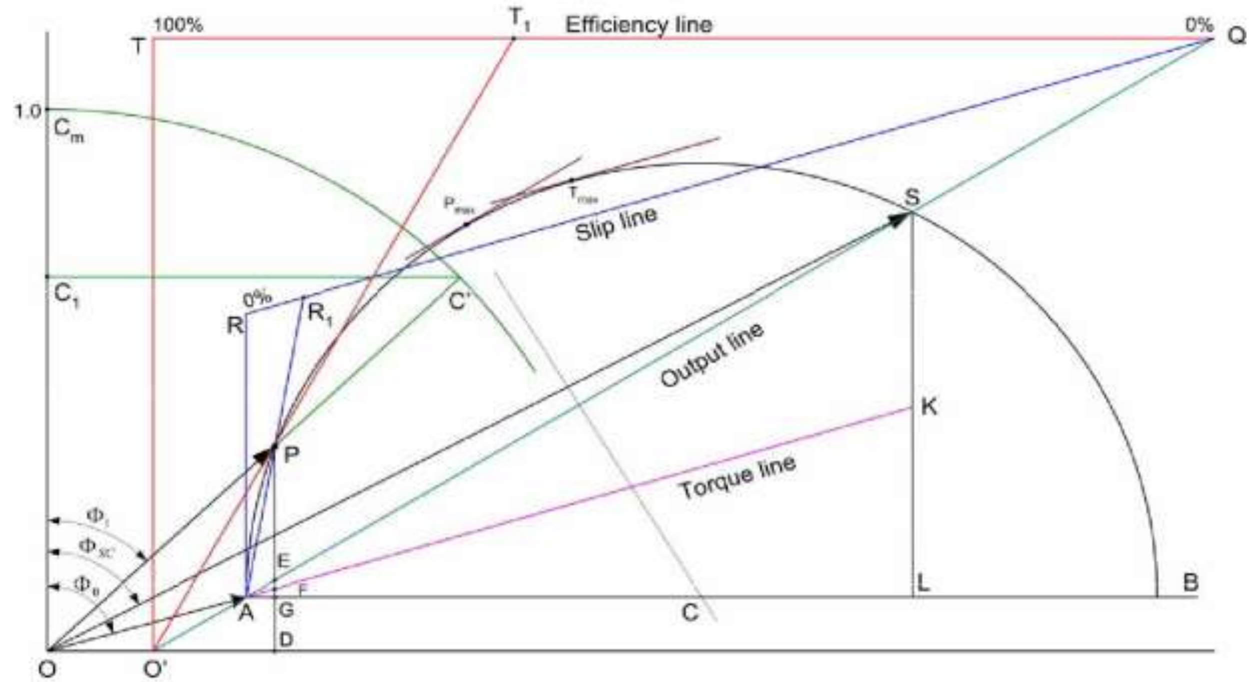
1. Connect the circuit as shown in Fig-2.
2. Readjust the 3-ϕ Variac at zero position.
3. Block the rotor by tightening the belt.
4. Switch on the a.c. supply and apply reduced voltage, so that the input current drawn by the motor under blocked rotor condition is equal to the full load current of the motor.
5. Note down the readings of all the meters in observation table.
6. Switch off the a.c. supply.
7. Measure the resistance per phase of the stator winding.

3. Construction of Circle Diagram

Conduct No load test and blocked rotor test on the induction motor and find out the per phase values of no load current I_0, short circuit current I_{SC} and the corresponding phase angles Φ_0 and Φ_{SC}. Also find short circuit current I_{SN} corresponding to normal supply voltage. With this data, the circle diagram can be drawn as follows.

1. With suitable scale, raw vector ***OA*** with length corresponding to I_0 at an angle Φ_0 from the vertical axis. Draw a horizontal line ***AB***.
2. Draw ***OS*** equal to I_{SN} at an angle Φ_{SC} and join ***AS***.
3. Draw the perpendicular bisector to ***AS*** to meet the horizontal line ***AB*** at ***C***.
4. With ***C*** as centre, draw a portion of circle passing through ***A*** and ***S***. This forms the circle diagram which is the locus of the input current.
5. From point ***S***, draw a vertical line ***SL*** to meet the line ***AB***.
6. Divide ***SL*** at point ***K*** so that ***SK*** : ***KL*** = rotor resistance : stator resistance.
7. For a given operating point ***P***, draw a vertical line ***PEFGD*** as shown.

   then ***PE*** = output power, ***EF*** = rotor copper loss, ***FG*** = stator copper loss, ***GD*** = constant loss (iron loss + mechanical loss)
8. To find the operating points corresponding to maximum power and maximum torque, draw tangents to the circle diagram parallel to the output line and torque line respectively. The points at which these tangents touch the circle are respectively the maximum power point and maximum torque point.



Efficiency line:

1. The output line ***AS*** is extended backwards to meet the X-axis at ***O′***.
2. From any convenient point on the extended output line, draw a horizontal line ***QT*** so as to meet the vertical from ***O′***. Divide the line ***QT*** into 100 equal parts.
3. To find the efficiency corresponding to any operating point ***P***, draw a line from ***O′*** to the efficiency line through ***P*** to meet the efficiency line at T_1. Now QT_1 is the efficiency.

Slip Line:

1. Draw line ***QR*** parallel to the torque line, meeting the vertical through ***A*** at ***R***. Divide ***RQ*** into 100 equal parts.
2. To find the slip corresponding to any operating point ***P***, draw a line from ***A*** to the slip line through ***P*** to meet the slip line at R_1. Now RR_1 is the slip

Power Factor Curve:

1. Draw a quadrant of a circle with ***O*** as centre and any convenient radius. Divide OC_m into 100 equal parts.
2. To find power factor corresponding to ***P***, extend the line ***OP*** to meet the power factor curve at ***C′***. Draw a horizontal line $C'C_1$ to meet the vertical axis at C_1. Now OC_1 represents power factor.

OBSERVATION:

No-load test				Block rotor test			
V_0	I_0	W_{01}	W_{02}	Vsc	Isc	W_{sc1}	W_{sc2}

Data Processing and Analysis:

1. Using the data obtained, draw the circle diagram complete in all respect.
2. Compute (a) Max Power (b) Max Torque

   (c) Starting torque and best power factor, utilizing the circle diagram.

CALCULATIONS:

$\tan\phi_0 = \sqrt{3}\dfrac{W_{01} - W_{02}}{W_{01} + W_{02}}$ $\tan\phi_{sc} = \sqrt{3}\dfrac{W_{sc1} - W_{sc2}}{W_{sc1} + W_{sc2}}$

CONCLUSION:

DISCUSSION:

1. Why should there be a difference between D.C and A.C resistance?
2. Are the core losses and mechanical losses constant for all operating conditions? Comments your view.
3. How does core losses vary with voltage and why?
4. Did the blocked rotor loss vary exactly proportional to square of the current? Explain the deviations if any.
5. What are the possible errors due to the approximate equivalent circuit?
6. What will happen if one line of the supply is cut off (a) When the motor is supplying full load (b) When the motor is at stand still.
7. Does the no-load current steadily decrease as the supply voltage is reduced? If not, explain why?
8. Why one wattmeter gives negative reading for No-load Test and Block rotor Test but, positive reading for rated load condition?
9. Find out various losses occurring under full load condition, using the circle diagram.
10. Mark clearly the stable and unstable region on the circle diagram.
11. Why the no load power factor is quite small in case of 3-ϕ induction motor.
12. Discuss the fact that the input power factor of the motor increases with increase in load.