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Lab Manual - II

ANSAL INSTITUTE OF TECHNOLOGY

ELECTRICAL SCIENCE LAB

AIM: To Verify Super Position Theorem.

Apparatus: Connecting Wire, Bread Board, Resistor, D.C Power Supply, and Multimeter.

Theory. In any linear resistive network, the voltage across or current through any resistor or some other circuit elements can be calculated by algebraically adding all the current and voltage (sources) through the element due to the sources one at a time

Procedure.

1. First measure the current I through R
2. Now short circuit the voltage source one bye one and individually find the current I' and I'' through R
3. Verify it the sum of I' and I'' is equal to I

Result. The Superposition Theorem has been verified.

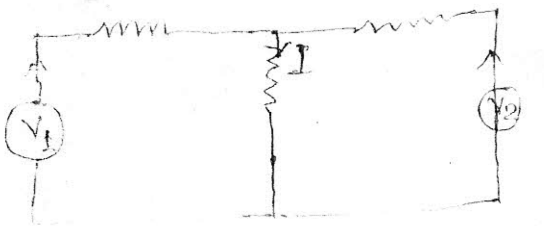
Precautions:

3. Measure the value using Mltimeter properly.
4. Connect the wire properly.

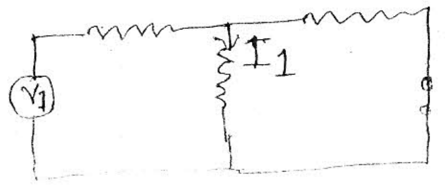
Circuit Diagram:

I = I' + I''

(i)



(ii)



(iii)

ANSAL INSTITUTE OF TECHNOLOGY

ELECTRICAL SCIENCE LAB

AIM: To Verify Maximum Power Transfer Theorem.

Apparatus: Connecting Wire, Bread Board, Resistor, D.C Power Supply, and Multimeter.

Theory: Maximum Power Transfer.

The Power Transferred from a supply source to a load is at its maximum when the resistance of the load is equal to the terminal resistance of the source.

$$P = V_{Th}\, I$$
$$= I^2 R_L$$

$$P = (V_{Th} / R_L + Ri)^2 R_L$$

$$dp/d_{Rl} = 0$$

$$R_i = R_L$$

$$P\,max = V_{Th}^2 / 4\,R_L$$

Procedure:

1. Voltage source was connected to the breadboard and the circuit was completed by connecting the resistor as shown in the circuit Diagram.
2. For the above circuit use the following 3 combinations of R_i and R_L

   i) $R_i = R_L$
   ii) $R_i < R_L$
   iii) $R_i > R_L$

When case i) $R_i = R_L$ Power obtained is maximum.
In case ii) and iii) power obtained is less than power obtained in case i) but in case ii) power obtained is less than power obtained in case iii).

EXPERIMENT

CALIBRATION OF 1PHASE ENERGY METER

THEORY:-

Energy Meters are integrating instruments used to measure the quantity of electrical energy supplied to a circuit in a given time. Single phase energy meter having four parts of the operating mechanism.

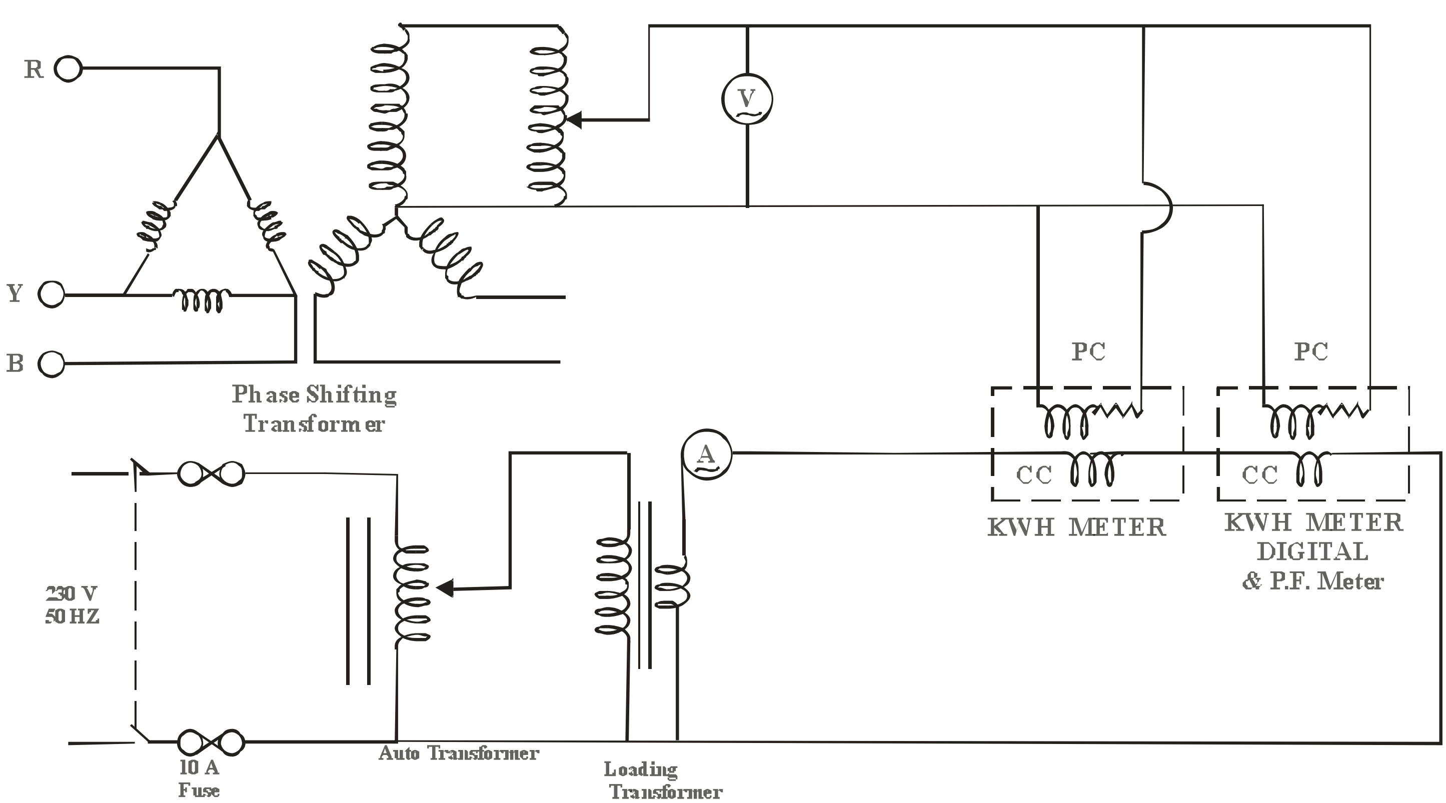
(1) Driving Systems.
(2) Moving Systems.
(3) Braking Systems and
(4) Registering Systems.

APPARATUES REQUIRED:-

1. 1Phase Energy meter 300V, 5-10Amp.
2. Digital Ammeter 0-10Amp.
3. Wattmeter 250Volt, 5Amp.
4. Power Factor meter 250Volt, 5Amp.
5. Energy meter digital.
6. Digital Voltmeter 0-300V.
7. Auto Transformer – 2

Optional:- Phase Shifting Transformer.

ENERGY METER CALIBRATION



PROCEDURE

1. Make the connection as per circuit Diagram.
2. Keep the auto transformer at zero position.
3. Switch ‘ON’ the MCB.
4. Switch ‘ON’ the supply by pressing green switch.
5. Keep the MCB in ‘ON’ position.
6. Now Adjust the auto transformer no -2 on pressure coil circuit the voltmeter reading are adjusted to a rated value 200-220V.
7. Low Load adjustment:- About 10% of the rated current is made to flow through the energy meter by varying the load. The time taken (ti) by the disc to rotate through a known no. of revolutions (5 no.) is found using a stop watch. Also the time taken (t theoretical) that must be taken by the energy meter disc for the same no. of revolution is calculated using the equation.
8. Top Load adjustment:- Here about 90% of the rated current of the energy meter (about 8-9A) is made to flow through the meter & the same procedure as used during low load adjustment is followed here also. The only difference in this case is that if that if the percentage error is greater than 5%, the screw of the brake magnet is adjusted to reduce the error.
9. Adjust the phase shifting transformer to obtain unity power factor condition. This is achieved when the wattmeter reads maximum watts.

CALCULATION:_

$$Wa = \frac{Kn}{t\ th} \times 3600 \text{ watts}$$

Where Wa = reading of the wattmeter
n = no. of revolutions.
K = Constant of the energy meter obtained from the name plate details
If ti = t th then the energy meter is said to have zero error, if ti = t th (as close as possible upton 5% error)

In above only one set of the reading need be entered which corresponds to reading taken offer the final adjustment is made. Also Wi is calculated using the equation.

$$Wi = \frac{Kn}{Ti} \times 3600 \text{ Watts}$$

TABULAR COLUMN:-

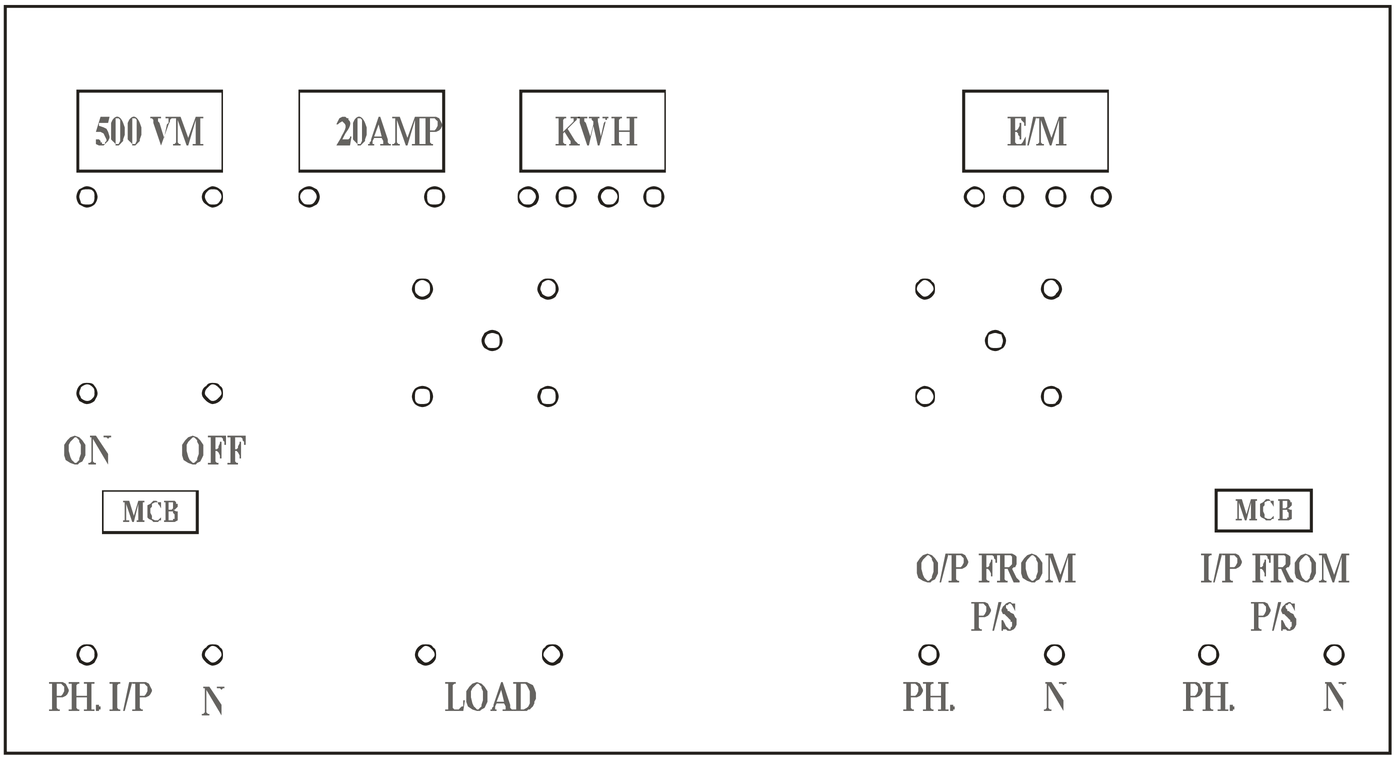
For Low Load adjustment

I Amps	**n rev.**	**Wa Wm reading**	**Ti Sec**	**t th = Kn/Wa X 3600 Sec**	**%error (Wa – Wi/Wa) X 100**

For top Load adjustment

I Amps	**n rev.**	**Wa Wm reading**	**Ti Sec**	**t th = Kn/Wa X 3600 Sec**	**%error (Wa – Wi/Wa) X 100**

PANEL LAYOUT FOR SINGLE PHASE ENERGY METER



2. LOAD TEST ON D.C. SHUNT GENERATOR

1. **AIM :** To perform load test on D.C. Shunt Generator and determine there from the internal and external characteristics of the generator.

2. **NAME PLATE RATINGS :-**

Motor	**Generator**
Power	Power
Voltage	Voltage
Current	Current
Speed	Speed

3. APPARATUS : Prepare a list of apparatus based on name plate and circuit diagram in the following format.

S.No.	Apparatus	Type	Range	Quality
01	Ammeters			
02	Voltmeters			
03	Rheostats			

4. THEORY : When the external circuit is open in a D.C. Shunt Generator, the field winding can be regarded as being in series with the armature. The machine will therefore builds up its own magnetism and will give full voltage on no load, if the field winding resistance is less than critical field resistance. On load, the terminal voltage falls with increase of load. This is due to

i) Armature resistance drop.
ii) Armature reaction and
iii) The drop in terminal voltage due to (i) and (ii) reducing the field current and causing further drop in voltage.

4.1 External Characteristics ; If the terminal voltage on load is plotted against the load current external characteristic is obtained curve (i) in Fig. 1.

4.2 Internal or total characteristics : it is obtained by adding l_a R_a drop (voltage in the armature winding) to the external characteristic.

$la = I_L + l_{sh}$ where I_L is the load current and I_{sh} the shunt field current had there been no armatures reaction effect, the internal characteristic would be a flat curve (iii) in fig
2.1. But due to increasing armature reaction effect, the characteristic drops more and more as load current increases (curve (ii)). Load current is increased by decreasing the external circuit resistance and terminal voltage falls. When the load current reaches a certain value the load resistance shunts the field winding to such an extent that the terminal voltage decreases more rapidly than the load resistance.

Further reduction in load resistance actually causes a decrease in current and the characteristic turns back. The armature may actually get short-circuited and the external or load characteristic cuts the x-axis at ‘C”. When this happens. The internal characteristic will be at B, exhibiting the residual magnetism.

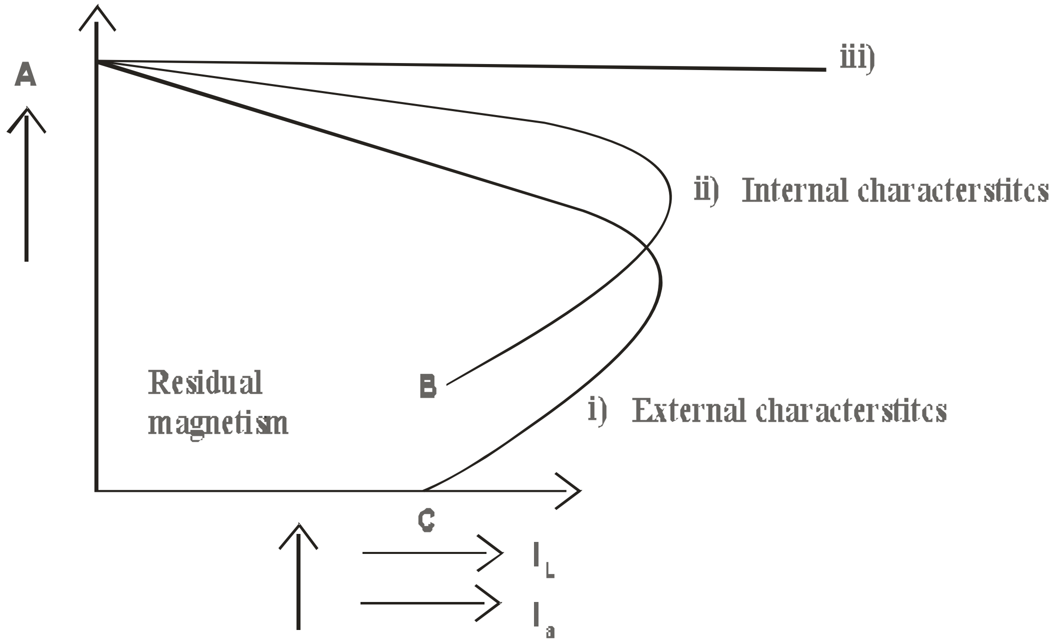


Fig. 2.1 : Characterisitics of the generator

5. CIRCUIT DIAGRAM:

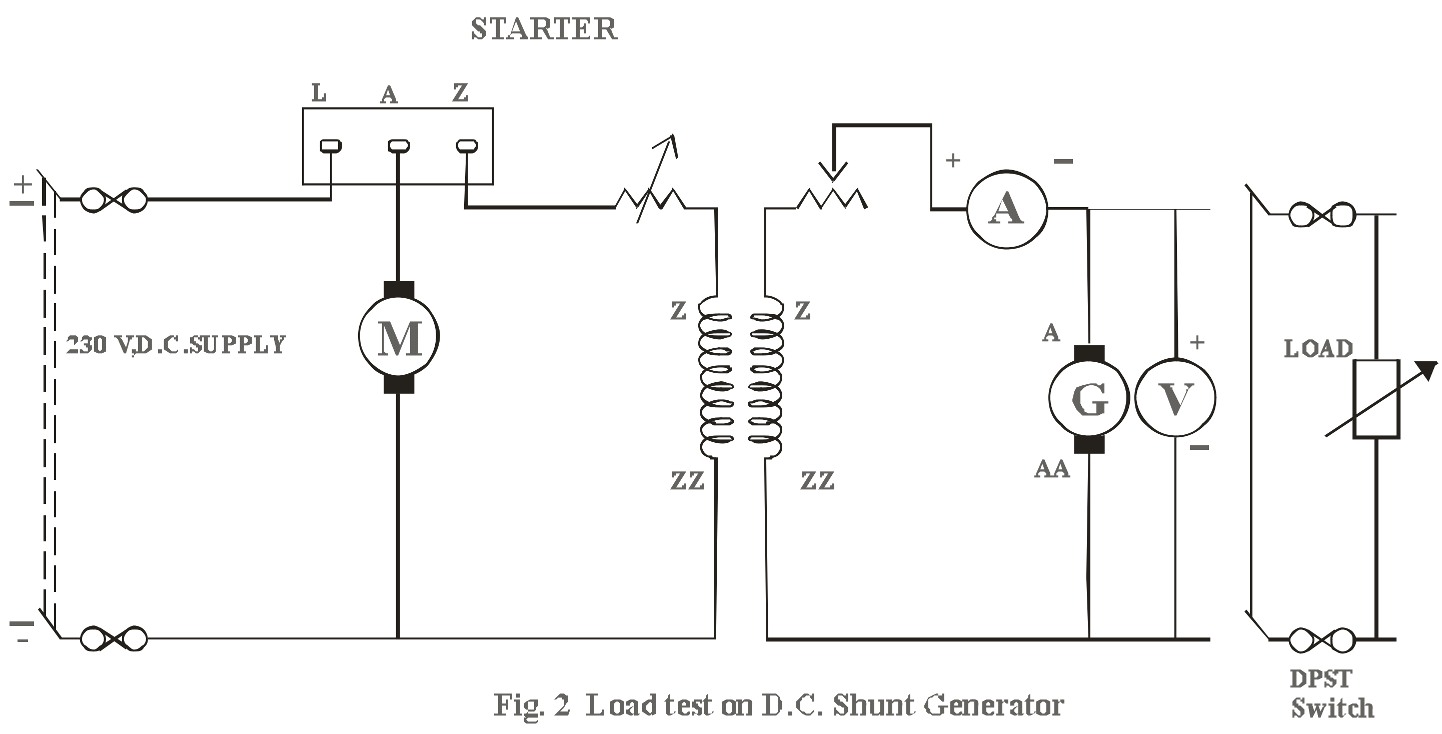


Fig. 2 Load test on D.C. Shunt Generator

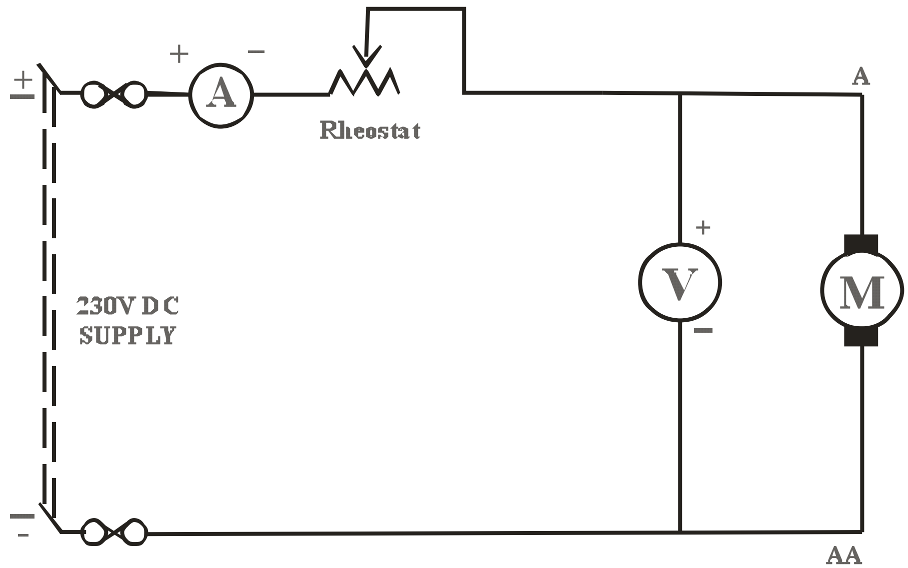


Fig. 2.3 Measurement of armature resistance

6. PROCEDURE :

1) Make the connection as shown in the circuit diagram as shown in the fig 2.1. Start the motor with the help of the starter.
2) Adjust the field regulator of the motor so that the generator runs at its rated speed.
3) Adjust the generator field regulator so that rated voltage is obtained at its terminals.
4) Gradually apply the load in steps and note down the readings of the load as given on the name plate of the generator. Keep the speed constant at its rated value by adjusting motor field regulator throughout experiment.
5) Plot the external load characteristic from the observations.
6) Determine the armature resistance experimentally using the circuit diagram in fig.3.
7) Take at least 6 readings of voltmeter and armature by varying the load resistance and determine the average value of the armature resistance.

7. OBSERVATION TABLE:

Speed ………R.P.M.

S. No.	Load Current I_L	Terminal Voltage V	Field Current I_f

Readings for external characteristic Table No.1

7.1 OBSERVATION FOR ARMATURE RESISTANCE

S.No.	Voltmeter Reading	Armature Reading

8. CALCULATIONS :

Average value of armature resistance Ra = ----------Ω

S.NO.	$l_a = l_L + L_F$	$E = V + L_a R_a$

Table No. 2

9. GRAPHS :

1). Plot the external or load characteristic from the table.1 (l_L V_s V curve)
2) Plot the internal characteristic or total characteristic from Table No.2 (l_a V_s E Curve)

10. RESULTS :

Internal and external characteristics are plotted by conducting load test on the given D.C. Shut generator.

11. PRECAUTIONS :

1) While starting the motor, field regulator (rheostat) must be in minimum position
2) While loading the generator, at every step speed of the generator must be maintained. At rated value by adjusting the motor field regulator.
3). Decrease the speed before removing the load after the experiment is completed at full load.
4) Do not over load the generator.

12. VIVA QUESTIONS :

1) If the shunt generator fails to buildup what could be the reason for it. Explain how this can be over come
2) What is meant by armature reaction ?
3) Why are the characteristics of the shunt generator drooping ?
4) DC Generators are normally designed for max efficiency around ….load
5) What will happen when R-C load is connected across armature?
6) For a properly designed dc generators the over all efficiency could be of the order of -----%
7) Define commercial & electrical efficiencies for dc generators
8) Which losses in a dc generator vary significantly with the load current?
9) Draw the internal and external characteristics for a dc shunt generator.

NO LOAD AND BLOCK ROTOR TEST

AIM : (a) perform no load and block rotor test on 3 phase induction motor.

(b) Using the data obtained above, draw the circle diagram complete in all respect.

(c) Find out, input current, power factor, slip, torque and efficiency, corresponding to full load, using the above circle diagram.

(d) Compute (i) Max power (ii) Max torque (iii) Starting torque and best power factor, utilizing the above circle diagram.

INSTRUMENTS

S. No.	Name	Type	Range	Quantity
1.	Ammeter	MI	0-10/20 A	1
2.	Voltmeter	MI	1-300/600 V	1
3.	Wattmeter	Dynamometer	10/20 A, 200/400 V	2
4.	3 phase variac	Fully variable	15 A, 400/0-400 V	1

THEORY

To draw the circle diagram of a 3 phase induction motor, following data is essential.

(i) No load current, I_0 and its power factor angle, φ_0

(ii) Short circuit current, I_{sc} corresponding to rated voltage and its power factor angle, φ_{sc}

NO LOAD TEST

To obtain no load current and its power factor angle, φ_0, no load test is performed at rated voltage and frequency. Let the readings of ammeter, voltmeter, and two wattmeters connected in the circuit be, I_0, V_0, W_{01} and W_{02} respectively during no load test. Then,

$$\tan \varphi_0 = \sqrt{3} \frac{W_{01} - W_{02}}{W_{01} + W_{02}}$$

Hence, no load power factor angle, φ_0, can be calculated from the readings of two wattmeters. No load current, I_0 has been directly measured by the ammeter.

BLOCK ROTOR TEST

To obtain short circuit current and its power factor angle, block rotor test is performed on the motor. In this test, rotor is not allowed to move (blocked either by tightening the belt, in case provided or by hand) and reduced voltage (25 to 30 percent of the rated voltage) of rated frequency is applied to the stator winding. This test is performed with rated current flowing in the stator winding. Let the readings of ammeter, voltmeter and two wattmeters be, I_{sc}, V_{SC}, W_{SC1} and W_{SC2} respectively under block rotor condition. Then,

$$\tan \varphi_{sc} = \sqrt{3} \frac{W_{sc1} - W_{sc2}}{W_{sc1} + W_{SC2}}$$

Thus, short circuit power factor angle, φ_{sc} can be calculated from the above equation.

Short circuit current, I_{sx} observed during the block-rotor test corresponds to reduced applied voltage, V_{SC}, which should be converted to rated voltage of the motor for plotting the circle diagram. The relation between the short circuit current and the applied voltage is approximately a straight line. Thus, short circuit current, I_{SC}` corresponding to rated voltage, V of the motor is given by,

$$\text{Short circuit current, } I_{sc}` = \frac{V}{V_{SC}} \times I_{sc}$$

It may be remembered, that the power factor of the power factor of the motor is quite low at no load as well as under blocked rotor condition. Thus, one of the wattmeter connected in the circuit will give negative reading in both the test, which may be recorded by reversing the terminals of the pressure coil or the current coil.

Based on the data obtained above, circle diagram can be drawn and the complete performance of the motor can be calculated referring art. 7.9, chapter 7.

CIRCUIT DIAGRAM

Fig. (8.7) shows the circuit diagram, based upon which both the tests can be performed. To obtain more reliable values, range of both the wattmeters should be q0 A, r00 V for conducting no load test, where as it could be 20 A, 200 V for block rotor test. Similarly the range of ammeter and voltmeter during no load test should be 10 A and 600 V respectively, where as it could be 20 A and 300 V for block rotor test.

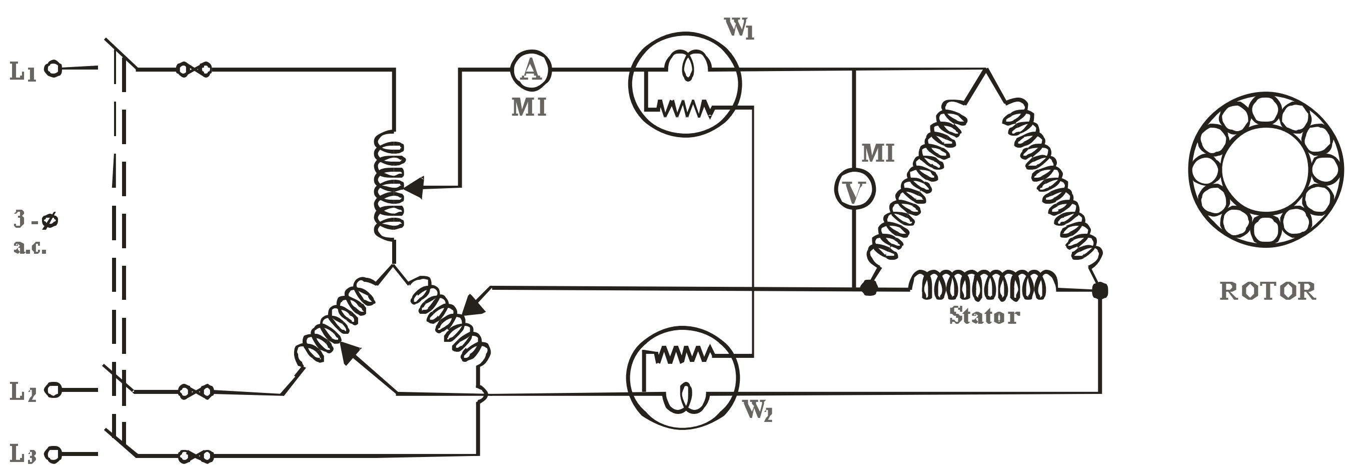


Fig. 8.7 No load block rotor test on 3-phase induction motor

PROCEDURE

No Load Test

1. Connect the circuit as per fig. (8.7).
2. Ensure that the motor is unloaded and the variac is set at zero position.
3. Switch-on the supply and increase the voltage gradually, till the rated voltage of the motor. Thus the motor runs at rated speed under no load.
4. Record the reading of all the meters connected in the circuit.

5. Switch-off the ac supply to stop the motor.

Block Rotor Test

1. Readjust the variac at zero position
2. Change the range of all the instruments for block rotor test as suggest in the discussion on circuit diagram.
3. Block the rotor either by tightening the belt firmly or by hand.
4. Switch-on the ac 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. Record the readings of all the meters, connected in the circuit.]
6. Switch-off the ac supply fed to the motor.
7. Measure the resistance per phase of the stator winding, following ohm;s law concept.

OBSERVATIONS : May be tabulated as follows.

No load test					Block rotor test			
S. No.	V_0	I_0	W_{01}	W_{02}	V_{SX}	I_{SC}	W_{SC1}	W_{SC2}

QUESTIONS

1. Find out various losses occurring under full load condition, using the circle diagram drawn.
2. Mark clearly the stable and unstable region on the circle diagram, drawn on the basis of experimental data.
3. Why the no load power factor is quite small in case of 3-phase induction motor ? Mention its normal range.
4. Discuss the fact that the input power factor of the motor increases with increase in load. Draw an approximate curve to indicate this increase in power factor with load.
5. Why the no load current of an induction motor is so high, as compared to a transformer of identical rating ?
6. Utilizing the information obtained in this experiment, find out the parameters of the equivalent circuit of 3 –phase induction motor.

OPEN-CIRCUIT AND SHORT-CIRCUIT TEST

AIM : (a) To perform open circuit test on single phase transformer

(b) To perform short circuit test on the same transformer

(c) Calculate the complete parameters of the equivalent circuit of this transformer

(d) Calculate the efficiency at 1/4, 1/2, 3/4th, full load and 1.25 times full load and plot the efficiency curve V_S load. Take the operating power factor as 0.85 lagging.

(e) Calculate the regulation at full load and at the following power factor (i) 0.85 lagging (ii) unity (iii) 0.85 leading.

INSTRUMENTS

S. No.	Name	Type	Range	Quantity
1.	Ammeter	MI	0-2A	1
2.	Wattmeter	Dynamometer	2.5A, 200 V	1
3.	Voltmeter	MI	0-300 V	1
4.	Single phase variac		230/0-270 V, 15 A	1
5.	Ammeter	MI	0-15 A	1
6.	Wattmeter	Dynamometer	15 A, 75 V	1
7.	Voltmeter	MI	0-30 V	1

THEORY

Open Circuit Test

In this test low voltage winding (primary) is connected to a supply of normal voltage and frequency (as per the rating of transformer) and the high voltage winding (secondary) is left open as shown in fig (6.3 a). The primary winding draws very low current hardly 3 to 5 percent of full load current (may be upto 10 % for very small rating transformers used for laboratory purposes) under this condition. As such copper losses in the primary winding will be negligible. Thus mainly iron losses occur in the transformer under no load or open circuit condition, which are indicated by the wattmeter connected in the circuit.

Hence, total iron losses = W_0 (Reading of wattmeter)

From the observations of this test, the parameters R_0 and X_m of the parallel branch of the equivalent circuit can also be calculated, following the steps given below :

Power drawn, $W_0 = V_0 I_0 \cos \varphi_0$

Thus, no load power factor, $\cos \varphi_0 = \dfrac{W_0}{V_0 I_0}$

Core loss component of no load current, $I_w = I_0 \cos \varphi_0$

And, magnetizing component of no load current, $I_m = I_0 \sin \varphi_0$

Equivalent resistance representing the core loss, $R_0 = \dfrac{V}{I_W}$

Magnetizing reactance representing the magnetizing current, $X_m = \dfrac{V}{I_m}$

Short circuit test

In this test, low voltage winding is short circuited and a low voltage hardly 5 to 8 percent of the rated voltage of the high voltage winding is applied to the winding. This test is performed at rated current flowing in both the windings. Iron losses occurring in the transformer under this condition is negligible, because of very low applied voltage. Hence the total losses occurring under short circuit are mainly the copper losses of both the winding, which are indicated by the wattmeter connected in the circuit as shown in fig. 6.3 b.

Thus total full load copper losses $= W_{SC}$ (reading of wattmeter)

The equivalent resistance R_{eq}, and reactance X_{eq} referred to a particular winding can also be calculated from the observations of this test, following the step given below.

quivalent resistance referred to H.V. winding $R_{eq} = \dfrac{W_{sc}}{I^2_{sc}}$

Also, equivalent impedance referred to HV. Winding, $Z_{eq} = \dfrac{V_{sc}}{I_{sc}}$

Thus equivalent reactance referred to H.V. winding, $X_{eq} = \sqrt{(Z^2_{eq} - R^2_{eq})}$

Performance calculations

Complete performance of the transformer can be calculated based on the above observations of open-circuit and short-circuit test following the steps given by,

1. Efficiency at different loads :

(a) Efficiency at full load :

Total losses at full load, $= W_0 + W_{sc}$

Let the full load out put power of the transformer in KVA be P_0.

Then percentage efficiency at full load, $\eta_f = \dfrac{P_0 \text{ X } 1000 \text{ X } \cos \varphi}{P_0 \text{ X } 1000 \text{ X } \cos \varphi + W_0 W_{sc}} \text{ X } 100$

(b) Efficiency at half the full load :

Iron losses at half the full load = W_0 (constant)

Total copper losses at half the full load = $\frac{1}{2} W_{sc} = \frac{1}{4} W_{sc}$

Output power at half full load = $\frac{1}{2} P_0$ KVA

Thus, percentage efficiency at half the full load, $\eta_{1/2f} = \frac{1/2\ P_0 \ X\ 1000\ X \cos \varphi}{1/2\ P_0\ X\ 1000\ X \cos \varphi + W_0 + 1/4\ W_{sc}}$ X 100

In a similar manner, efficiency at other loads can be found out and the efficiency V_s output power curve can be plotted.

2. Equivalent circuit :

All the parameters of the approximate equivalent circuit has been calculated above. Thus an approximate equivalent circuit of the transformer can be drawn with these values of parameters marked on it. The equivalent circuit can be solved easily for estimating the performance like terminal voltage across the secondary etc.

3. Regulation :

Regulation of the transformer can now be calculated based on the parameters of the equivalent circuit, using the approximate formula given below.

Percentage Regulation = $\frac{I\ (R_{eq} \cos \varphi \pm X_{eq} \sin \varphi\ )}{V}$ X 100

Where, I – rated current of the winding, referred to which R_{eq} and X_{eq} have been calculated.

V – Voltage of that winding.
cos φ - Power factor at which regulation is to be calculated

CIRCUIT DIAGRAM

Fig (6.3 a) shows the circuit diagram to perform the no load test at rated voltage of the transformer. Ammeter, Voltmeter and wattmeter have been connected in the circuit to measure, no load current, rated voltage applied and the no load power drawn by the transformer respectively.

Fig (6.3 b) shows the circuit diagram to perform the short circuit test at a reduced voltage, such that the current flowing in the windings is of rated full load value. As such a single phase variac has been included in the circuit. Ammeter, wattmeter and voltmeter connected in the circuit measure, full

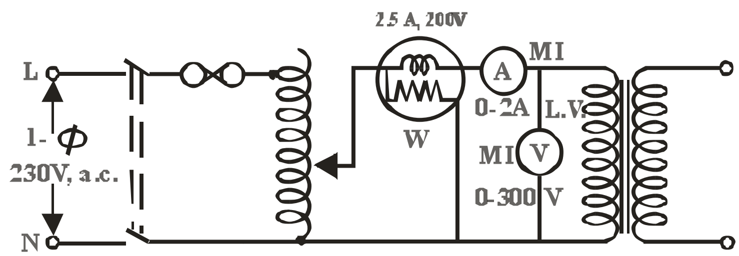


Fig. 6.3 a Open circuit test on transformer

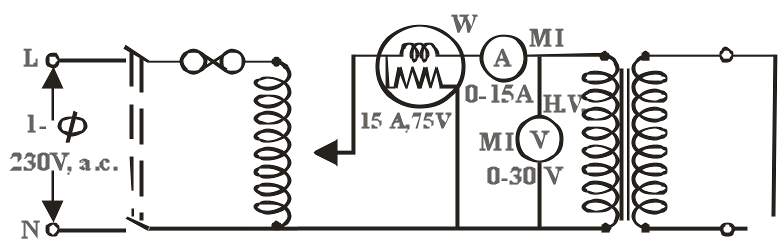


Fig. 6.3 b Short-circuit test on transformer

load short circuit, power drawn under this condition and the reduced voltage applied to the winding of the transformer respectively.

PROCEDURE

(a) Open Circuit Test

1. Connect the circuit as per fig (6.3 a)
2. Ensure that the setting of the variac is at low output voltage.
3. Switch on the supply and adjust rated voltage across the transformer circuit.
4. Record no load current, voltage applied and no load power, corresponding to the rated voltage of the transformer winding.
5. Switch off the ac supply.

(b) Short Circuit Test

1. Connect the circuit as per fig (6.3 b) for conducting short circuit test.
2. Adjust the setting of the variac, so that the output voltage is zero.
3. Switch on the ac supply to the circuit.

4. Increase the voltage applied slowly, till the current in the windings of the transformer is full load rated value.
5. Record, short circuit current, corresponding applied voltage and power with full load current flowing under short circuit conditions.

OBSERVATION : May be tabulated as follow :

S. No.	No Load Test			Short Circuit Test		
	V_0	I_0	W_0	V_{sc}	I_{sc}	W_{sc}

CALCULATIONS : May be tabulated as follows,

S. No.	Cos φ_0	I_w	I_m	R_0	X_m	R_{eq}	X_{eq}	Load	η	Regulation

QUESTIONS

1. Why indirect testing of large size transformer in a must ?
2. Justify that the power drawn by the transformer under no load is equal to the iron losses and under short circuit the full load copper losses.
3. What will happen to the transformer, if a sufficient voltage is applied during the short circuit test ?
4. Discuss the components of iron losses along with their variation occurring in a transformer and mention the parts, in which these occur.
5. A transformer designed for 50 Hz is operated in the laboratory at 40 Hz. The voltage applied is of rated value. Discuss the relative magnitude of iron losses and copper losses at 40 Hz compared to that at 50 Hz operation.

POLARITY, VOLTAGE RATIO AND LOAD TEST

AIM : (a) To find the polarity of primary and secondary windings

(b) To measure voltage ratio of primary and secondary windings

(c) To perform load test on 1 - φ transformer and to determine the following.

(i) Efficiency at different loads and to plot efficiency V_3 load curve.

(ii) Regulation of the transformer and to plot regulation V_3 load curve.

INSTRUMENTS

S. No.	Name	Type	Range	Quantity
1.	Voltmeter	MI	0-300 V	1
2.	Ammeter	MI	0-15 A	1
3.	Wattmeter	dynamometer	15A, 200 V	1
4.	Lamp bank load	resistive	250 V, 5 kw	1

THEORY

Polarity

Each of the terminal of primary as well as secondary winding of a transformer is alternately positive and negative with respect to each other. It is essential to know the relative polarities at any instant of the primary and secondary terminals for making correct connections under the following type of operation of the transformer.

(i) When two single phase transformers are to connected in parallel to share the total load on the system.

(ii) For connecting three single phase transformers to form a 3 phase bank with proper connections of primary and secondary windings.

Referring fig (6.2a), if at any instant, the included emf E_1 in the primary winding acts from the terminals marked A_2 to A_1, the induced emf E_2 in the secondary winding will act form a_2 to a_1 i.e. if at any instant A_1 is positive and A_2 negative with respect to the applied voltage V_1 across the primary winding then the terminal voltage V_2 across the secondary winding will be positive at a_1 and negative at a_2.

If the two windings are connected by joining A_1 to a_1 as shown in (fig 6.2a), and an alternating voltage V_1 applied across the primary, then the marking are correct if the voltage V_3 is less than V_1. Such a polarity is generally termed as subtractive. The standard practice is to have subtractive polarity for transformer connections, because it reduces the voltage stress between the adjacent leads. In case V_3 is greater than V_1, the emfs induced in the primary and secondary windings have an additive relation and the transformer is said to have additive polarity.

VOLTAGE RATIO :

The induced emf per phase in the primary and secondary windings of a transformer is given by,

Induced emf in primary, $E_1 = 4.44\, f\, \varphi\, T_1$

Induced emf in secondary, $E_2 = 4.44\, f\, \varphi\, T_2$

However, $E_1 \approx V_1$ and $E_2 \approx V_2$

Hence, the voltage ratio, $\frac{V_2}{V_1} \qquad \frac{T_2}{T_2}$

LOAD TEST :

Performance of the transformer can be determined as follows from the observations of load test.

Power input to the transformer = W_1 (reading of wattmeter)

Power output of transformer = VI watts (cos φ being unity for lamp bank load)

Thus, efficiency at a particular load, $\eta = \frac{V1}{W1}$ X 100 percent

No load voltage across secondary = E_2 Terminal voltage across secondary at a particular load = V_2

Then, regulation of the transformer at that load = $\frac{E_2 - V_2}{E_2}$ X 100 percent

CIRCUIT DIAGRAM

Fig (6.2 a, b, c) shows respectively the circuit diagram for polarity test, voltage ration test and load test on a single phase transformer, which are self explanatory.

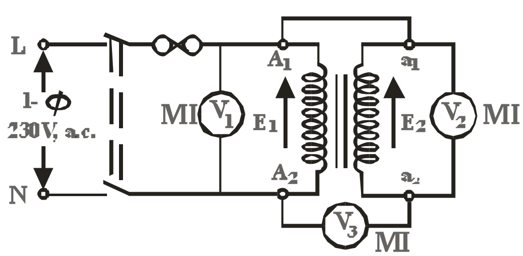


Fig. 6.2 a Polarity test

PROCEDURE

(a) Polarity test ;

1. Connect the circuit as per fig (6.2 a)
2. Switch-on single phase ac supply.

3. Record the voltage V_1, V_2, and V_3. It is advisable to use a single voltmeter with probes to measure these three voltage. In case $V_3 < V_1$, the polarity is subtractive.
4. Repeat step 3, after connecting the terminals A_1 and a_2. The transformer should be disconnected before making

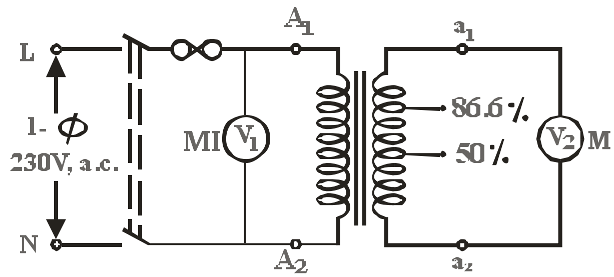


Fig. 6.2 b Voltage ratio test

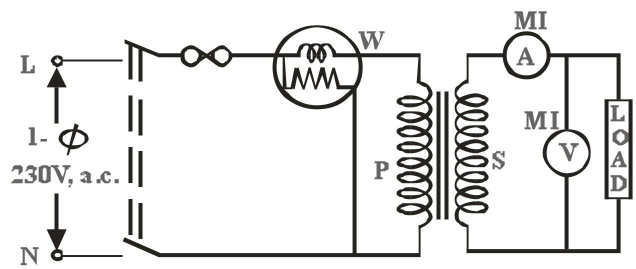


Fig. 6.2 c Load test on transformer

This change. In this case $V_3 > V_1$, which indicates additive polarity.

5. Switch off the dc supply.

(b) Voltage Ratio test :

1. Connect the circuit as per fig (6.2 b).
2. Switch on ac supply.
3. Record the voltage V_1 across various tapping of the secondary. It will be preferred, if all the voltages are measured by the same voltmeter.
4. Switch off the supply.

(b) Load Test :

1. Connect the circuit as per the circuit diagram shown in fig (6.2 c).
2. Ensure that there is no load on the secondary winding of the transformer.
3. Switch on the ac supply and record the no load voltage across the secondary winding.
4. Adjust approximately 10 percent of full load current in the secondary by switching on certain lamps in the lamp bank load. Record the readings of all the meters.
5. Repeat step A for various load current, till the full load value.
6. Reduce the load on the transformer by switching off the bulbs in the lamp bank load.
7. Switch off the ac supply.

OBSERVATIONS : May be tabulated as follows.

(a) Polarity test (b) Voltage Ratio test

S. No.	V_1	V_2	V_3	S. NO.	V_1	V_2	V_2/V_1

(c) Load test

S. No.	W_1	V_2	I_2	V_2I_2	% η	%Requlation

QUESTIONS :

1. Why the terminal voltage across the load decreases with increase in load on the transformer ?
2. What is normally the range of efficiency of large rating power transformer ?
3. Why the efficiency of a transformer is much higher compared to a rotating machine of similar rating ?
4. Can this method be applied to determine the efficiency of large rating transformer, discuss with reasoning ?
5. Define regulation of the transformer and comment upon its usual values for medium and large rating transformers.

POWER MEASUREMENT (by 3 ammeter method)

AIM : (a) To measure the power drawn by a single phase ac circuit, using three ammeters.
(b) Draw the phasor diagram of this circuit using experimental data, hence find out the power factor of the circuit.
(c) Calculate the power factor of the circuit from the readings of three ammeters and verify the result with that obtained in (b).

INSTRUMENTS

S. No.	Name	Type	Range	Quantity
1.	Ammeter	MI	0-5 A	2
2.	Ammeter	MI	0-10 A	1
3.	Voltmeter	MI	0-300 V	1
4.	Single phase variac	-	230/0-270 V, 8A	1
5.	Choke coil	inductive	-	1
6.	Rheostat	single tube	45 Ω, 5 A	1

THEORY

Fig. (2.11) shows the circuit diagram for the measurement of power in an inductive circuit using three ammeters. The choke coil in which power is to be measured is connected in parallel with a non inductive resistor R of known value. The ammeters connected in the circuit measure the following currents.

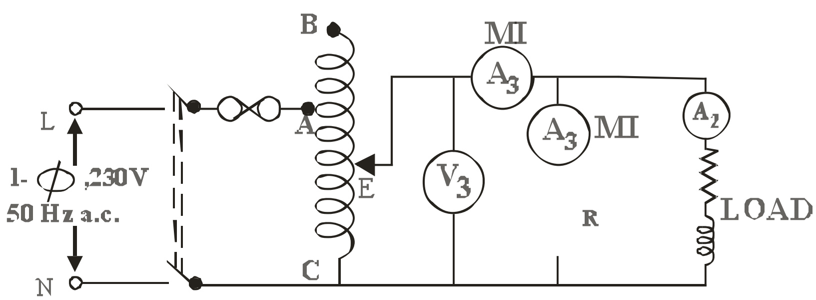


Fig. 2.9. Three voltmeter method

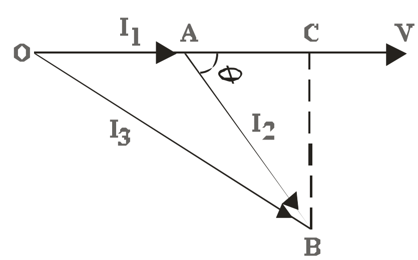


Fig. 2.12. Phasor Diagram

Ammeter, A_1 – current drawn by non – inductive resistor R, I_1

Ammeter, A_2 – current drawn by the choke coil, I_2 lagging the supply voltage by an angle φ.

Ammeter, A_3 – total current drawn from the supply, I_3.

Power consumed, by the choke coil, $P = V I_2 \cos\varphi$

Moreover, supply voltage, $V = I_1 R$

Thus, power consumed, $P = I_1 I_2 R \cos\varphi$ …..(i)

Fig. (2.12) shows the phasor diagram of the circuit with supply voltage as the reference phasor. Draw a perpendicular BC on the reference phasor, then in triangle OBC.

$$OB^2 = OC^2 + CB^2$$

Or $$I_3^2 = (I_1 + I_2 \cos\varphi)^2 + (I_2 \sin s\varphi)^2$$

$$= I^2 + I^2 + 2 I_1 I_2 \cos\varphi \qquad \ldots\ldots(ii)$$

Substituting for $I_1 + I_2 \cos\varphi$ from equ. (ii) into eqn. (i),

Power consumed, $$P = \frac{R}{2}(I^2 - I^2 - I^2)$$

Power factor, $$\cos\varphi = \frac{I_3^2 - I_1^2 - I_2^2}{2 I_1 I_2}$$

Hence the power consumed by the inductive load can be measured by recording the readings of three ammeters and the known value of R.

CIRCUIT DAIGRAM

Fig. (2.11) shows the circuit diagram, in which various instruments serve the function indicated against each.

1. Choke coil – inductive load, in which power has to be measured.
2. Resistor R – of known value, connected in parallel with the load, so that supply voltage to the circuit can be expressed in terms of current I_1 i.e. $V = I_1 R$
3. Variac – to very the applied voltage to the circuit for more observations.
4. Ammeter – to measure currents in the two branches and the total current.
5. Voltameter – to record the voltage applied to the circuit.

PROCEDURE

1. Connect the circuit as per fig. (2.11)
2. Adjust the variac, so that voltage applied to the circuit is zero or low.
3. Switch-on the supply to the circuit.
4. Adjust the voltage applied to the circuit to approximately 100 V and note down the readings of all the meters connected in the circuit.
5. Repeat step 4 for various voltage applied to the circuit.
6. Reduce the voltage applied to the circuit to a low value.
7. Switch-off the supply.

OBSERVATIONS : May be tabulated as follows :

S. No.	V	I_1	I_2	I_3	P	cosφ

QUESTIONS

1. Compare this method with 3 voltmeter method of power measurement.
2. Can this method be used for measurement of power in capacitive load ?
3. What is the nature of power factor of the two branches and that of the whole circuit ?
4. Suggest an alternative way of taking more observations without including the variac in the circuit.
5. Derive an expression for the input power factor of the circuit.

POWER MEASUREMENT (by three voltmeter method)

AIM : (a) To measurement the power drawn by a single phase ac circuit, using three voltmeters.

(b) Draw the phasor diagram of the circuit using experimental data, hence find out the power factor of the circuit.

(c) Calculate the power factor of the circuit from the readings of three voltmeters and verify the result with that obtained in (b).

INSRUMENTS

S. No.	Name	Type	Range	Quantity
1.	Voltmeter	MI	0-300 V	3
2.	Ammeter	MI	0-5 A	1
3.	Single phase variac		230/0-270 V, 8A	1
4.	Resistor/Rheostat	Single tube	45 Ω, 5 A	1
5.	Choke coil	inductive	rated current 5 A	1

THEORY

Fig. (2.9) shows the circuit diagram for the measurement of power in an inductive load by three voltmeters, which are connected to measure the following voltages.

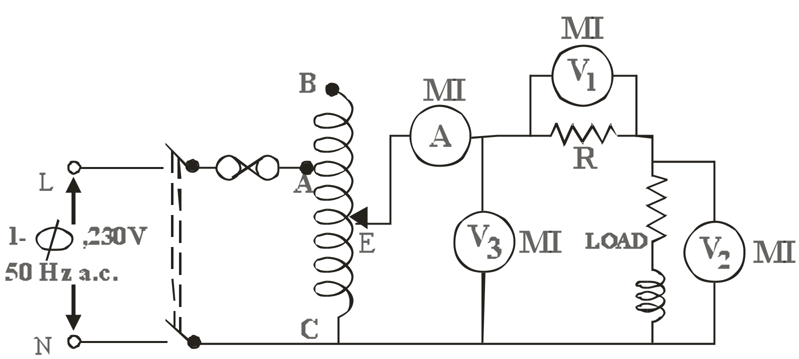


Fig. 2.9. Three voltmeter method

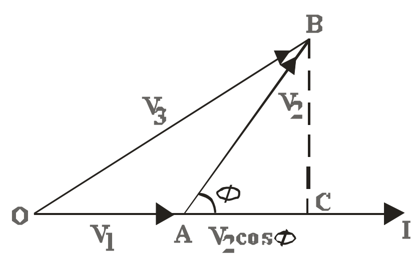


Fig. 2.10. Phasor Diagram

(i) Voltmeter, V_1 - records the voltage across the non inductive resistor R of known value. It may be a rheostat of 45 Ω, 5A.

(ii) Voltmeter, V_2 - measures the voltage across inductive load, which leads the current by an angle φ

(iii) Voltmeter, V_3 - reads the voltage applied to the circuit.

Power consumed by the inductive load, $P = V_2 I \cos \varphi$

More over, voltage, $V_1 = IR$

Thus, power consumed by load, $P = \dfrac{V_1 V_2}{R} \cos \varphi$ ……(i)

The phasor diagram of the above circuit has been drawn in fig. 2.10, with current, I as the reference phasor. Draw BC perpendicular to the current phasor, then in triangle OBC,

$$OB^2 = OC^2 + CB^2$$

or $V_3^2 = (V_1 + V_2 \cos \varphi)^2 + (V_2 \sin \varphi)^2$

or $V_3^2 = V_1^2 + V_2^2 \cos^2 \varphi + 2V_1 V_2 \cos \varphi + V_2^2 \sin^2 \varphi$

$= V_1^2 + V_2^2 + 2V_1 V_2 \cos \varphi$

Thus, $V_1 V_2 \cos \varphi = \dfrac{V_3^2 - V_1^2 - V_2^2}{2}$ ……(ii)

Combining equations (i) and (ii).

Power consumed by inductive load, $P = \dfrac{V_3^2 - V_1^2 - V_2^2}{2R}$

Power consumed by inductive load, $P = \dfrac{V_3^2 - V_1^2 - V_2^2}{2R}$

CIRCUIT DIAGRAM

Circuit diagram shown in fig. (2.9) consists of a choke coil, a known resistance R and an ammeter connected in series. The circuit is fed through a single phase variac, so that different voltages can be applied to vary the current in the series circuit. It is advisable to use only one voltmeter for measuring all the three voltage, V_1 V_2 and V_3, in order to avoid error in the measurement.

PROCEDURE

1. Connect the circuit as per fig. 2.9.
2. Ensure that the output voltage of the variac is set at zero.
3. Switch on the ac supply.
4. Apply a certain voltage to the circuit through the variac.

5. Record various voltage V_1, $V_{2,}$ V_3, and the current I. Use the same voltmeter with probe to measure V_1, V_2, $V_{3.}$
6. Repeat step 4 and 5 for more observations.
7. Switch-off the ac supply.

OBSERVATION : May be tabulated as follows :

S. No.	I	V_1	V_2	V_3	Power	power factor

QUESTIONS

1. What is the nature of power factor of this circuit ?
2. What are the other methods of power measurement in single phase ac circuit ?
3. Compare these methods of power measurement with 3 voltmeter method.
4. Why the use of one voltmeter only has been suggested in this method ?
5. Derive an expression for the power factor of the choke coil in terms of $V_{1,}$ V_2, V_3, and R.

SPEED CONTROL OF DC MOTOR

AIM : (a) To study the speed control of dc motor below the normal range by armature resistance control and to plot speed Vs armature voltage, characteristic.

(b) To study speed control of dc motor above the normal range by field control and to plot speed Vs field current, characteristic.

S. No.	Name	Type	Range	Quantity
1.	Voltmeter	MC	0-300 V	1
2.	Ammeter	MC	0-2 A and 0-5 A	1 each
3.	Rheostat	Single tube	45 Ω, 5 A	1
4.	Rheostat	Single tube	272 Ω, 1.7 A	1
5.	Techometer	Digital	0-2000 rpm	1

THEORY

The back emf for a dc motor is given by,

$$\text{Back emf, } E_b = \frac{P\varphi NZ}{60\ A}$$

The number of poles, P the armature conductors, Z and the number of parallel paths, A are constant for a particular machine. Thus the speed of dc motor is given by,

$$\text{Speed of the motor, } N = K\frac{E_b}{\Phi} = K\frac{V - I_a R_a}{\varphi}$$

The equation for the speed of the motor clearly indicated the following,

(i) Speed of the dc motor can be controlled below the normal range of speed by varying the resistance in the armature circuit included in the form of a rheostat as a variable resistance (armature control).

(ii) Speed of the dc motor can be controlled above the normal range of speed by decreasing the flux φ i.e. by decreasing the current in the field circuit by including an external resistance in the form of a rheostat as variable resistance (field control).

Armature Control

Let the external resistance in the armature circuit of shunt motor be R ohms, then the speed equation modifies to,

$$N = K\frac{V - I_a (R_a + R)}{\Phi}\ \text{rpm}$$

Hence the speed of the motor decreases with an increase in the value of external resistance R. Thus reduced speeds lower than the no load speed can be obtained by this method. However, there is an excessive wastage of power in the additional resistance, which lowers the efficiency of the motor considerably.

Field Control

The speed of the dc motor can be increased beyond the no load speed by inserting an external resistance in the shunt field circuit. The current in the external resistance is very low, hence the losses occurring in the additional resistance is quite small.

CIRCUIT DIAGRAM

Fig. (4.5) shows the circuit diagram for speed control of dc motor. Instruments used in the circuit serve the function mentioned against each.

Rheostat (45 Ω, 5 A) - to vary the voltage applied to the armature winding of dc motor.

Voltmeter - to measure the applied voltage across the armature winding.

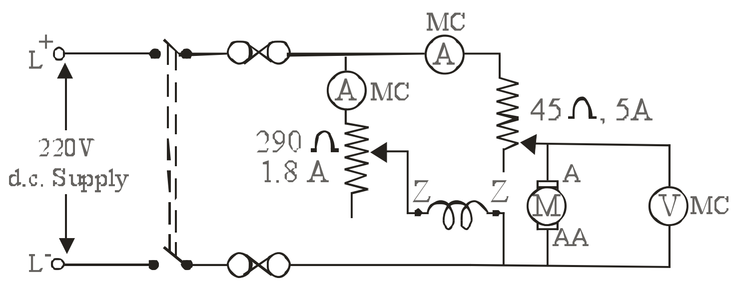


Fig. 4.5. Speed control of dc motor

Rheostat (290 Ω, 1.8 A) - to vary the field current of dc motor.

Ammeter - to measure the field current.

PROCEDURE

1. Connect the dc motor as per the circuit diagram shown in fig. (4.5).
2. Ensure that the external resistance in the armature circuit is maximum.
3. Ensure that the external resistance in the field circuit is minimum.
4. After ensuring step 2 and 3, switch on the dc supply, as a result motor will start running at a low speed.
5. Cut out the external resistance in the armature circuit and adjust the field current, so that the speed of the motor becomes rated speed.

6. The field current is kept constant to the above value. Vary the voltage applied to the armature by varying the external resistance in the armature circuit. Record the applied voltage and the corresponding speed.
7. Repeat step 6 for various values of applied voltage to the armature, till the rated voltage of the motor.
8. Keep the applied voltage to the armature constant at its rated value. Vary the speed of the motor by inserting external resistance in the field circuit. Record the field current and the corresponding speed of the motor.
9. Repeat step 8 for various values of field current, till the speed of the motor is about 1.4 times the rated speed of the motor. It is not advisable to increase the speed beyond 1.4 times the rated speed, otherwise mechanical stresses will be high, which may damage the motor. Hence, the field current should not be decreased to a very low value.
10. Switch off the main supply to stop the motor.

OBSERVATION : May be tabulated as follows.

Armature control			**Field control**		
S. No.	**Applied voltage**	**Speed**	**S. No.**	**Field Current**	**Speed**

QUESTIONS

1. It is possible to obtain the speed higher than the rated speed by armature control, discuss ?
2. Why speed control is essential from industrial point of view ?
3. What is approximately the back emf developed by the motor, when it is running at the rated speed and connected across a dc supply of 220 volts ?
4. Discuss with suitable diagram, any other method of speed control giving wide range of speed control.
5. It is possible to obtain speeds lower than the rated value by using field control ?

SPEED CONTROL OF DC MOTOR

AIM : (a) To study the speed control of dc motor below the normal range by armature resistance control and to plot speed Vs armature voltage, characteristic.

(b) To study speed control of dc motor above the normal range by field control and to plot speed Vs field current, characteristic.

S. No.	Name	Type	Range	Quantity
1.	Voltmeter	MC	0-300 V	1
2.	Ammeter	MC	0-2 A and 0-5 A	1 each
3.	Rheostat	Single tube	45 Ω, 5 A	1
4.	Rheostat	Single tube	272 Ω, 1.7 A	1
5.	Techometer	Digital	0-2000 rpm	1

THEORY

The back emf for a dc motor is given by,

$$\text{Back emf, } E_b = \frac{P\varphi NZ}{60\ A}$$

The number of poles, P the armature conductors, Z and the number of parallel paths, A are constant for a particular machine. Thus the speed of dc motor is given by,

$$\text{Speed of the motor, } N = K\frac{E_b}{\Phi} = K\frac{V - I_a R_a}{\varphi}$$

The equation for the speed of the motor clearly indicated the following,

(i) Speed of the dc motor can be controlled below the normal range of speed by varying the resistance in the armature circuit included in the form of a rheostat as a variable resistance (armature control).

(ii) Speed of the dc motor can be controlled above the normal range of speed by decreasing the flux φ i.e. by decreasing the current in the field circuit by including an external resistance in the form of a rheostat as variable resistance (field control).

Armature Control

Let the external resistance in the armature circuit of shunt motor be R ohms, then the speed equation modifies to,

$$N = K\frac{V - I_a (R_a + R)}{\Phi}\ \text{rpm}$$

Hence the speed of the motor decreases with an increase in the value of external resistance R. Thus reduced speeds lower than the no load speed can be obtained by this method. However, there is an excessive wastage of power in the additional resistance, which lowers the efficiency of the motor considerably.

Field Control

The speed of the dc motor can be increased beyond the no load speed by inserting an external resistance in the shunt field circuit. The current in the external resistance is very low, hence the losses occurring in the additional resistance is quite small.

CIRCUIT DIAGRAM

Fig. (4.5) shows the circuit diagram for speed control of dc motor. Instruments used in the circuit serve the function mentioned against each.

Rheostat (45 Ω, 5 A) - to vary the voltage applied to the armature winding of dc motor.

Voltmeter - to measure the applied voltage across the armature winding.

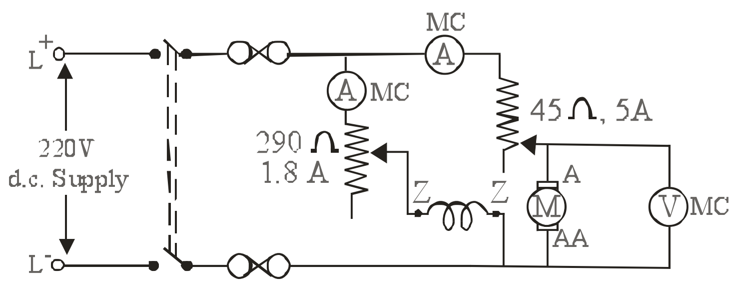


Fig. 4.5. Speed control of dc motor

Rheostat (290 Ω, 1.8 A) - to vary the field current of dc motor.

Ammeter - to measure the field current.

PROCEDURE

1. Connect the dc motor as per the circuit diagram shown in fig. (4.5).
2. Ensure that the external resistance in the armature circuit is maximum.
3. Ensure that the external resistance in the field circuit is minimum.
4. After ensuring step 2 and 3, switch on the dc supply, as a result motor will start running at a low speed.
5. Cut out the external resistance in the armature circuit and adjust the field current, so that the speed of the motor becomes rated speed.

6. The field current is kept constant to the above value. Vary the voltage applied to the armature by varying the external resistance in the armature circuit. Record the applied voltage and the corresponding speed.
7. Repeat step 6 for various values of applied voltage to the armature, till the rated voltage of the motor.
8. Keep the applied voltage to the armature constant at its rated value. Vary the speed of the motor by inserting external resistance in the field circuit. Record the field current and the corresponding speed of the motor.
9. Repeat step 8 for various values of field current, till the speed of the motor is about 1.4 times the rated speed of the motor. It is not advisable to increase the speed beyond 1.4 times the rated speed, otherwise mechanical stresses will be high, which may damage the motor. Hence, the field current should not be decreased to a very low value.
10. Switch off the main supply to stop the motor.

OBSERVATION : May be tabulated as follows.

Armature control			**Field control**		
S. No.	**Applied voltage**	**Speed**	**S. No.**	**Field Current**	**Speed**

QUESTIONS

1. It is possible to obtain the speed higher than the rated speed by armature control, discuss ?
2. Why speed control is essential from industrial point of view ?
3. What is approximately the back emf developed by the motor, when it is running at the rated speed and connected across a dc supply of 220 volts ?
4. Discuss with suitable diagram, any other method of speed control giving wide range of speed control.
5. It is possible to obtain speeds lower than the rated value by using field control ?

MEASUREMENT OF POWER IN THREE PHASE CIRCUITS

AIM : (a) To measure power drawn by a 3 phase inductive load using two wattmeters.

(b) To calculate the power factor of the load from the readings of two wattmeters.

INSTRUMENTS

S. No.	Name	Type	Range	Quantity
1.	Wattmeters	dynamometer	5/10 A, 200/400 V	2
2.	Ammeter	MI	0-10 A	1
3.	Voltmeter	MI	0-600 V	1
4.	3-phase variac	-	400/0-400 V, 15 A	1
5.	3-phase inductive load	inductive		1

THEORY

Power consumed by a 3 phase balanced or unbalanced load (star or data connected) can be measured by using two wattmeters properly connected in the load circuit. The current coils of the wattmeters are connected in series with the load in any two lines, whereas to the two pressure coil are connected between these lines and the third line as shown in fig. (2.13).

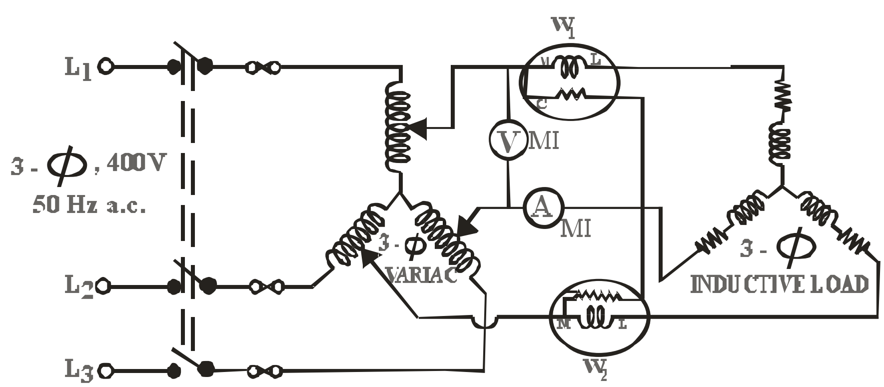


Fig. 2.13. Two wattmeter method

The phasor diagram of this circuit, assuming balanced lagging load has been shown in fig. (2.14). As such, rms values of currents, I_R, I_Y and I_B are taken equal in magnitude and lagging by an angle φ with respect to its own phase voltage, similarly, rms values of phase voltages are also equal in magnitude but displaced by 120^0. The phase sequence has been assumed as R Y B. Based on the phasor diagram, power consumed and the power factor of load can be calculated from the readings of two wattmeters W_1 and W_2 as explained below.

(i) Power consumed by the load :

Current through the current coil of wattmeter, $W_1 = I_R$

Voltage across the pressure coil of wattmeter, $W_1 = V_{RB}$

Phase difference between I_R and V_{RB} (ref phasor diagram) $= 30 - \varphi$

Hence, reading of wattmeter, $W_1 = I_R V_{RB} \cos(30 - \varphi)$ …..(i)

Similarly, reading of wattmeter, $W_2 = I_Y V_{YB} \cos(30 + \varphi)$ ….(ii)

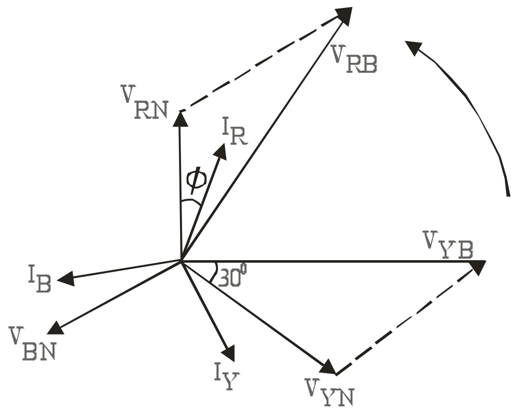


Fig. 2.14. Phasor Diagram

More over, $I_R = I_Y = I_B = I_L$ (line current) ….(iii)

Also, $V_{RY} = V_{YB} = V_{BR} = V_L$ (line voltage) ….(iv)

Substituting equs (iii) and (iv) into eqns. (i) and (ii) and then adding these,

$W_1 + W_2 = \sqrt{3}\ V_L I_L \cos\varphi$ = power drawn by 3 phase load ….(v)

Hence, the sum of two wattmeter readings is equal to the total power drawn by a 3 phase balanced load.

(ii) Power factor of the load :

Subtracting equ. (ii) from equ. (i),

$W_1 - W_2 = V_L I_L \cos(30 - \varphi) - V_L I_L \cos(30 + \varphi)$

$= V_L I_L \sin\varphi$

Dividing equ (vi) by equ. (v),

$$\tan\varphi = \sqrt{3}\ \frac{W_1 - W_2}{W_1 + W_2}$$

Thus, power factor of the load, $= \dfrac{1}{\sqrt{1 + 3\,(W_1 - W_2/W_1 + W_2}}$

Hence, the power factor of the load can also be calculated from the observed readings of the two wattmeters.

Conclusion : following important conclusions can be drawn from the above derivations, regarding the balanced inductive load.

(i) When the power factor of the load is low (less than 0.5), the reading of wattmeter W_2 will be negative.

(ii) When the power factor of the load is 0.5 lagging, reading of wattmeter W_2 will be zero

(iii) When the power factor of the load is greater than 0.5, both the wattmeters will record positive readings.

(iv) When the power factor of the load is unity, the readings of both the wattmeters will be the same.

CIRCUIT DIAGRAM

The circuit diagram to perform the experiment has been shown in fig. (2.13). The various details of the same have already been explained above.

PROCEDURE

1. Connect the circuit as per fig. (2.13).
2. Ensure that the output voltage of 3 phase variac is at zero or low.
3. Switch on the 3 phase ac supply.
4. Apply a certain voltage to the circuit and note down the readings of all the meters connected in the circuit.
5. Repeat step 4 for various values of applied voltage till the rated supply voltage.
6. Reduce the voltage applied to 3 phase load and then switch off the supply.
7. Reduce the voltage applied to 3 phase load and then switch off the supply.

Experiment could also be conducted by varying the 3 phase inductive load.

OBSERVATION : May be tabulated as follows :

S. No.	V	I	W_1	W_2	$W_1 + W_2$	$W_1 – W_2$	Cos φ

QUESTIONS

1. Draw a circuit diagram for measuring the power in 3 phase inductive balanced load, star connected with neutral available, using one wattmeter only.
2. How the circuit diagram is modified if neutral is not available and still power is to be measured by using one wattmeter only ?
3. Prove that the power consumed by a 3 phase load is equal to $\sqrt{3}\ V_L\ I_L \cos \varphi$, starting from the basic fundamentals.
4. What will be the power factor of the load, when the two wattmeters readings are 1500 watts and 500 watt. The later reading has been recorded by reversing the connections of pressure coil ? What is the total power in the above case ?
5. Find the readings of the two wattmeters, when the total power consumed by 3 phase load is 10 kw and its power factor is 0.82 lagging.

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