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Basrah University
College of Engineering
Department of Electrical Engineering

POWER AND MACHINES LAB.

EXPERIMENTS IN POWER AND MACHINES

Third year Electrical Engineering Department

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CONTENT

EXP. No. 1

Three-Phase Induction Motor Equivalent Circuit and Performance

Aim:- To determine the equivalent circuit parameters of a three phase induction machine and to predict its performance at a specified slip using :
i) Equivalent circuit, ii) Circle diagram.
Also to determine the performance characteristics of the machine by actually loading it.

***Theory*:-** A three phase induction motor and a transformer have certain similarities. The stator and rotor windings of the machine, like the primary and secondary windings of a transformer do not have any electrical interconnection but are only magnetically linked. Therefore, the theory of operation of a transformer with suitable modifications can be extended to cover the operation of an induction motor. It can be shown that an induction motor can be approximately represented by the equivalent circuit as shown in Fig.l. The explanation for the various equivalent circuit parameters shown in this figure are given below :

R_1: A.C. resistance per phase of the stator winding.
X_1: A.C. leakage reactance per phase of the stator winding.
R_2': Effective rotor resistance per phase referred to the stator side.
X_2': Effective rotor leakage reactance per phase referred to the stator side.
R_o: Resistance giving the no-load loss per phase.
X_o: Magnetizing reactance per phase. S: Slip.

These equivalent circuit parameters can be determined by performing the following two tests on the machine:
(i) No-load test (ii) Blocked rotor test.

i) No-load test : In this test, first decouple the machine and run it lightly on no-load by gradually increasing the voltage to the stator through an auto-

transformer. Increase the voltage to the rated value. Record the applied voltage per phase V_o , no-load current I_o and no-load power per phase W_o.
Since at no-load the slip is very small (normally assumed to be zero), the equivalent circuit of Fig.l gets reduced to that shown in Fig.2. From this it can be shown that :
Working component of no-load current $I_w = I_o \cos \emptyset_o$, and magnetising component of no-load current $I_m = I_o \sin \emptyset_o$ where $\cos \emptyset_o = \frac{W_o}{V_o I_o}$

Thus :

$$R_o = \frac{V_o}{I_w} \qquad and \qquad X_o = \frac{V_o}{I_m}$$

ii) Blocked rotor test : In this test the rotor of the machine is held stationary and a reduced voltage V_S per phase is applied to the armature winding. The value of V_S is so adjusted as to allow rated current I_S to flow in the armature winding. Record V_S , I_S, and input power W_S.
It can be shown that at reduced voltage, the magnetizing branch of the equivalent circuit can be neglected. The resulting equivalent circuit is shown in Fig.3. From the circuit it is clear that:

$$\left(R_1 + R_2'\right) = \frac{W_S}{{I_S}^2}$$

And

$$\left(X_1 + X_2'\right) = \sqrt{\left(\frac{V_S}{I_S}\right)^2 - \left(R_1 + R_2'\right)^2}$$

The d.c. value of R_1 can be measured by voltmeter-ammeter method. For this, apply a low d.c. voltage to any terminals of the induction motor stator winding with a variable resistance connected in series. Record the voltage V_{dc} across and the current I_{dc} through the stator winding.
For delta connected stator winding $R_{1dc} = \frac{3}{2}\frac{V_{dc}}{I_{dc}}$

For star connected stator winding $R_{1dc} = \frac{1}{2}\frac{V_{dc}}{I_{dc}}$

The a.c. value of the resistance can be obtained by multiplying the d.c. value of the resistance by a factor of (1.2). The value of $R_2^{\prime}$ can be obtained by subtracting the value of R_1 from the value of ($R_1 + R_2^{\prime}$). The reactances X_1 and $X_2^{\prime}$ cannot be separated easily and it is the usual practice to assume $X_1 = X_2^{\prime}$ (this is almost true for high speed machines).

iii) Load Test: The test motor is coupled to a d.c. generator. Start the motor by applying the voltage gradually through an autotransformer. Increase the voltage to the rated value. Load the motor by loading the d.c. generator. Record the applied voltage V_1, line current I_1, input power W_1, motor torque T, speed N, generator terminal voltage V_{dc} and generator load current I_{dc}.

***Circle diagram*:-** The circle diagram is the current locus diagram of the induction motor. With the help of this diagram it is possible to predict the complete performance of the motor. Follow the procedures given below to draw the circle diagram (See Fig.5):

1) Draw vertical line AB.

2) Choose a suitable current scale.

3) At the bottom end of the line, B, mark an angle equal to the no-load power factor angle ϕ_o along the clockwise direction. Mark off its length BC equal to the no-load current, to the chosen current scale.

4) From point B draw another line BD at an angle ϕ_S in the clockwise direction corresponding to the p.f. angle of the current under blocked load condition.

5) Convert the value of the blocked rotor current I_S corresponding to the rated voltage, according to the relation:

$$I_{BD} = \frac{I_S}{V_S} * rated\ machine\ voltage$$

and mark the length of the line BD equal to current I_{BD} to the chosen current scale.

6) Join CD and draw a perpendicular bisector on it. This perpendicular bisector cuts the horizontal line from point C at F.

7) With F as a centre and CF as a radius draw a semi-circle passing through C and D and let this semi-circle cut the extended 1ine CF at G.

8) From B draw a horizontal line BJ.

9) From D draw a perpendicular DHJ on line BJ.

10) The power scale is now fixed by measuring DJ which is equal to the input power per phase under blocked rotor condition with the rated voltage applied to the stator winding.

11) Divide the length DH at point K, such that

$$\frac{DK}{KH} = \frac{R_2'}{R_1}$$

and join CK.

12) The 1ine CK is then the torque 1ine and the torque per phase is given by the vertical intercept between the semi-circle and the 1ine CK. Thus, for any working point P, the torque per phase in synchronous watts is represented by PR to the power scale. Similarly, the line CD is the power line and for the same point P, the power output is represented by PQ.

13) The slip 1ine : Join GD and produce the 1ine to any convenient point U. From U drop a perpendicular UV on the torque line CK, meeting the line CG at V. With V as zero and U as 100, divide the line UV into 100 equal parts. To find the slip corresponding to the operating point P, join P and G. Let the line PG cut UV at W. The VW will be the slip to the scale UV as 100.

14) The efficiency line : Produce the power line DC backwards to meet base line BJ at B'. Extend the length of CD beyond D to a convenient point D'. Draw $B'C'$ perpendicular to BJ and let a line draw through D' parallel to the line CG meet $B'C'$ at C' . With zero at D' and 100 at C', divide the line $C'D'$ into 100 equal parts. The machine efficiency corresponding to the operating

point P is given by the intercept $D'P'$(with $D'C'$ as 100) where P' is obtained by joining B' to P and producing it to meet $C'D'$at P'.

15) The power factor line : With any convenient radius BX draw a quadrant of a circle XYZ with its centre at B. Divide BX into 100 equal parts with zero at B and 100 at X. To find the power factor corresponding to point P, join BP and produce it further to meet the arc XYZ at Y. From Y draw a horizontal line YY'on BX cutting the later at Y'. The intercept BY' (to scale of BX=100) is the power factor.

***Report*:-**

1. Calculate R_o and X_o from no-load test.
2. Calculate $(R_1 + R_2')$ and $(X_1 + X_2')$from blocked rotor test.
3. Calculate the a.c. values of R_1 and R_2'.
4. Calculate input power, output power, slip, power factor and efficiency for each load and plot the following on the same graph:

- Slip against output power.
- Torque against output power.

and hence derive the torque - slip characteristics. Also plot on the same graph input current, power factor and efficiency against output power.

Give your comments about the shapes of the various curves you have plotted.

5. Draw the circle diagram and from it obtain slip, efficiency, power factor and torque corresponding to the full load condition.
6. From the circle diagram obtain the maximum torque, maximum power, maximum power factor and starting torque of the machine.
7. Choose a few suitable working points on the circle diagram and determine the slip and the corresponding torque. Plot the slip torque characteristic with slip along x-axis.

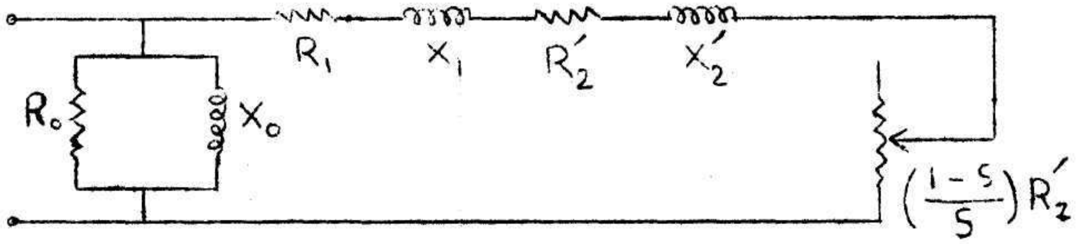


Fig. (1)

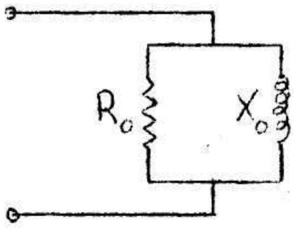


Fig. (2)

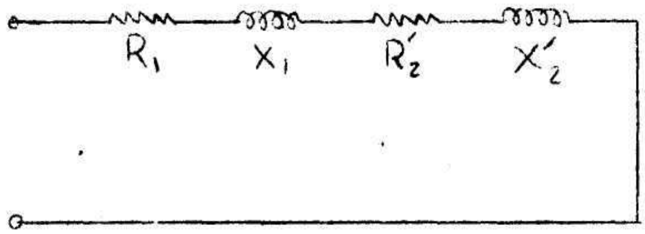


Fig. (3)

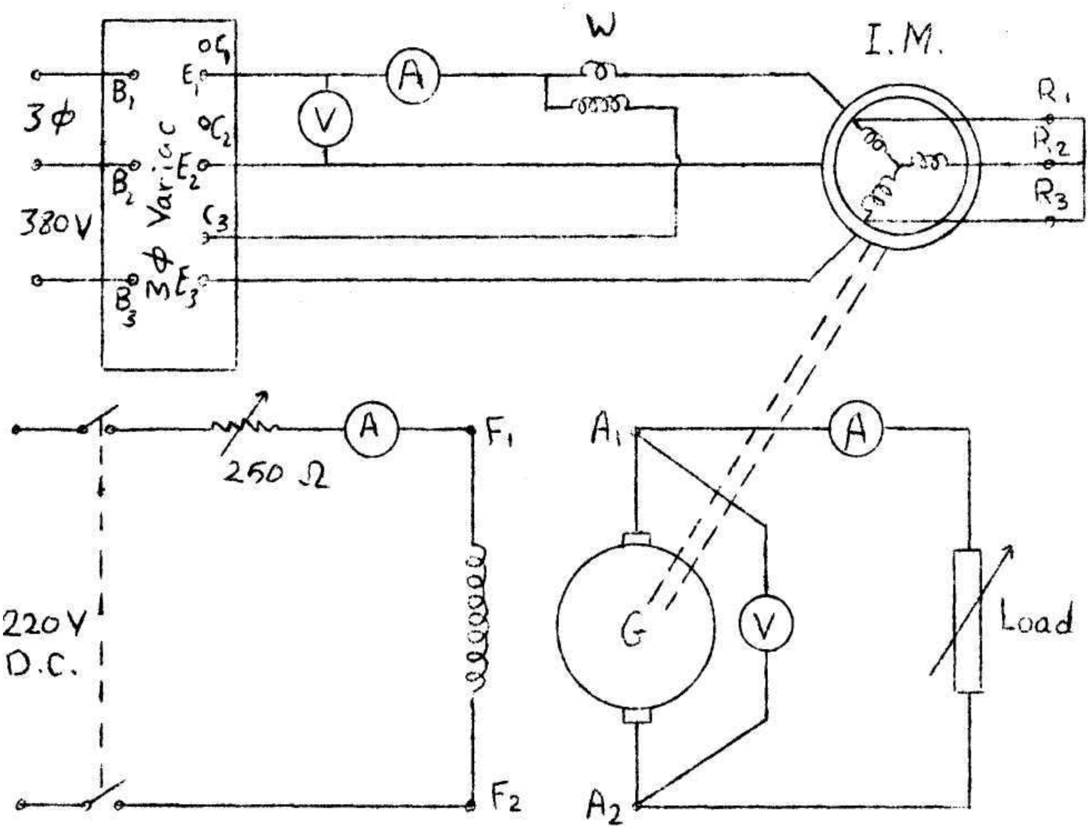


Fig. (4)

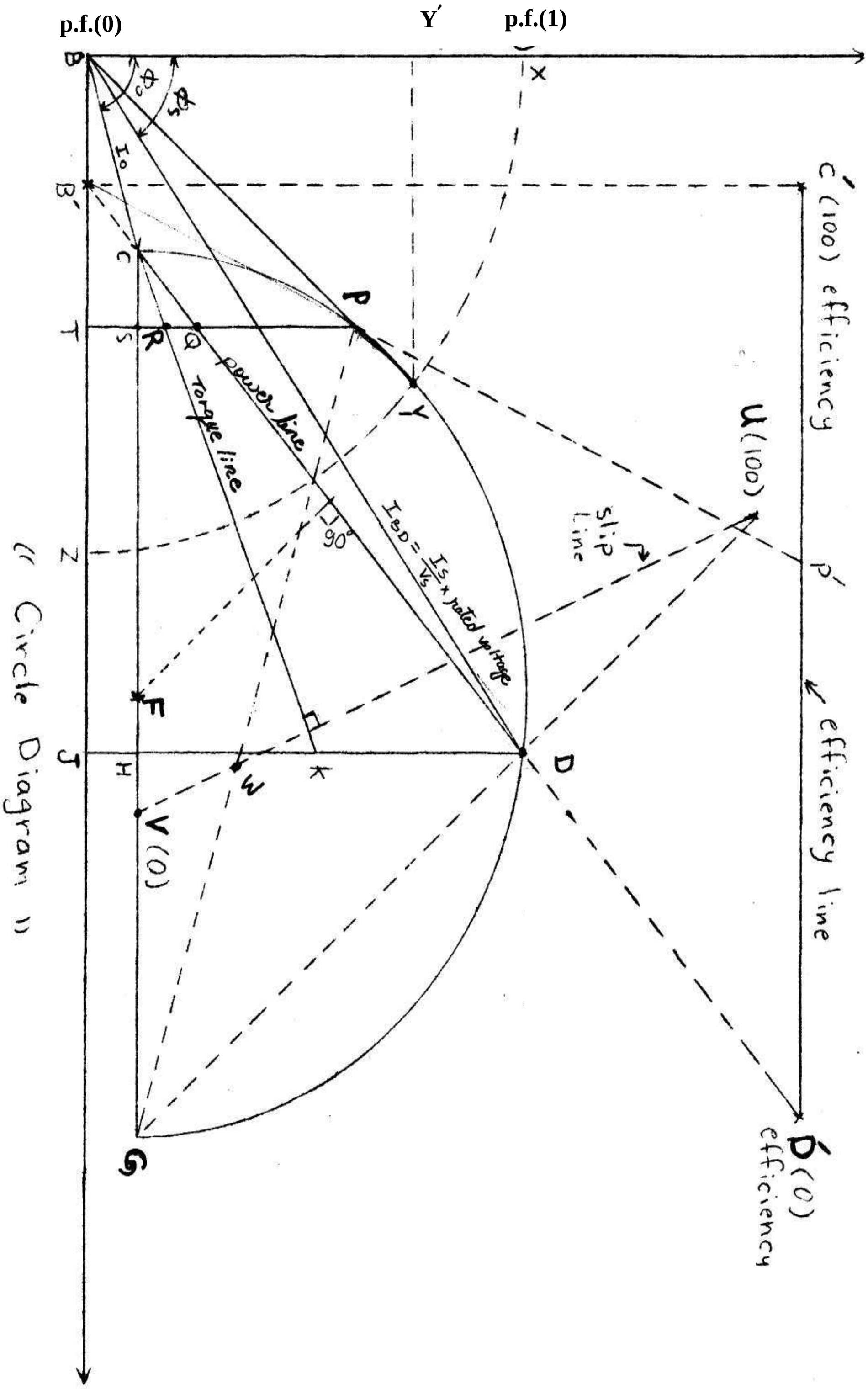

p.f.(0)
Y′
p.f.(1)
C′ (100) efficiency
power line
torque line
slip line
U(100)
$I_{SD} = \frac{I_S}{V_S} \times$ rated voltage
90°
efficiency line
V (0)
D′ (0) efficiency
" Circle Diagram "

Fig. (5)

EXP. No. 2

The Performance Characteristics of 3 - Phase Wound Rotor Induction Motor

Aim:- To study the different methods of starting and the effect of adding resistance in the rotor circuit of a slip-ring induction motor on (i) no-load (ii) load current (iii) speed (iv) starting torque and (v) shape of torque-speed characteristics.

Part I:-

Aim:- To study the different methods of starting an induction motor.

Introduction:- The method of starting an induction motor depends upon its stand still current and hence upon its capacity. Three different methods of starting are discussed here along with their conditions of applicability.

1. Direct-on starting :

The applicability of this method is limited to motors of small rating, since the starting current does not lead to under fall in the supply voltage. This method is applicable irrespective of the connection of the stator phase windings (star or de1ta).

usually for such motors a push-button type of starter is supplied along with the motor by the manufacturer himself. The starter, besides, usually is incorporated with certain protective devices like the low-volt trip coil which will automatically disconnect the motor when there is a sharp fall in the voltage due to extraneous reasons. An overload relay (as in the case of d.c. motor) is provided for isolating the motor from the supply system in case the motor is unduly overload. Provision is usually made for the over load setting by the user.

2. Auto-transformer starting :

This type of starting is the commonly employed one and its applicability is irrespective of the type of connection of the stator phase windings. The basic principle here is to initially apply a reduced voltage and then changing over to normal voltage after the motor has picked up reasonably. The change-over from low voltage to normal voltage is accomplished with the help of a triple-pole double throw switch as shown in the accompanying figure when the switch is thrown towards position 1 a reduced voltage is applied across the stator winding, the magnitude of the voltage depending upon the positions of brushes R_t, S_t, and T_t, of the auto-transformer. After the motor has picked up reasonable speed, the switch is thrown towards position 2. In this position the full supply voltage is available to the stator.

3. Star-delta Starting:

In the "Direct-on" starting and "Auto-transformer" starting it is not necessary that the pairs of terminals, constituting the individual phase windings of the stator should be made available. In the "star-delta" starting the availability of all the six terminals of the stator phase windings is a mandatory requirement. Further, the stator windings for normal running should be of delta connection.

The principle involves connection of the stator windings initially in star and when the motor has picked up reasonable speed the windings are changed over to delta connection.

Thus in the starting position the voltage across each phase winding would be $V/\sqrt{3}$ there by reducing the phase current to $1/\sqrt{3}$ of its nominal value. When once the change over to delta is achieved it will run at the nominal voltage E, taking a no-load current per phase corresponding to it.

The change over from star to delta can be done with a triple-pole double-throw switch by making connections as shown in the accompanying figure.

Procedures:- First throw the switch to the star position, measure voltage, current and speed when the machine is running stably.

Change over the switch to delta position and again when it has stable running measure voltage, current and speed. Determine the voltage and current ratios.

It is desirable to provide a shorting switch across the ammeter to protect it from damage due to probable excessive currents during initial switching to star and subsequent change over to de1ta.

Part II:-

Procedures:- Connect the slip-ring induction motor and d.c. generator set as shown in Fig.4. The d.c. generator is required for loading the motor. With no-load on the motor (With the d.c. generator decoupled) it is switched on with full rotor external resistance. The input voltage is increased from zero to 380V step by step. When full rated voltage is reached the rotor resistance is cut out step by step completely. Under this condition measure speed N, stator current I and the input power W.

Couple the d.c. generator to the motor and apply load. For various loads, with R_e'=0 record speed, stator current, torque developed and input power. Keep the supply voltage constant at 380V. Take readings till the stator current reaches the rated current of the motor.

Introduce a suitable value of the external resistance R_{e1}' in the rotor circuit. Run the motor at no-load (d.c. generator decoupled) and measure speed, stator current and input power.

Now, load the motor with the help of the d.c. generator with external resistance R_{e1}' in the rotor circuit. Take the readings of speed, stator current and input power at various loads.

Keep the supply voltage constant at 380V, repeat the no-load and load test for external resistance R_{e2}' and R_{e3}' such that $R_{e3}' > R_{e2}'$.

The rotor resistance starter has the following resistance (in ohms) per phase.

No. of stud	1	2	3	4	5	6	7	8	9
Resistance	0.00	1.14	2.00	3.38	4.68	6.25	7.25	12.00	15.75

***Results*:-**

1. Plot no-load speed against R_e(x - axis).
2. Plot motor torque against speed for different values of R_e on the same graph sheet.
3. Calculate full load torque from the output speed ratings given on the machine.

$$T = \frac{Output\ in\ watts * 60}{2\pi N}$$

4. For this load torque determine the speeds for different values of R_e from curves draw in (2) above of the results.
5. Plot speed N against external resistance R_e obtained in (4) and (1) above on the same graph sheet.
6. Comment on the effect of R_e on the starting torque with the help of torque-speed characteristics. Can you get the maximum torque at starting ?

***Questions*:-**

1.When do you make use of direct-on starting? What are the usual protective devices in a direct-on starter?

2.What are the advantages of auto-transformer starting ?

3.What are the principles involved in star-delta starting? You are provided with a triple-pole double-throw switch, show with the help of a neat diagram how you would adopt it for star delta starting.

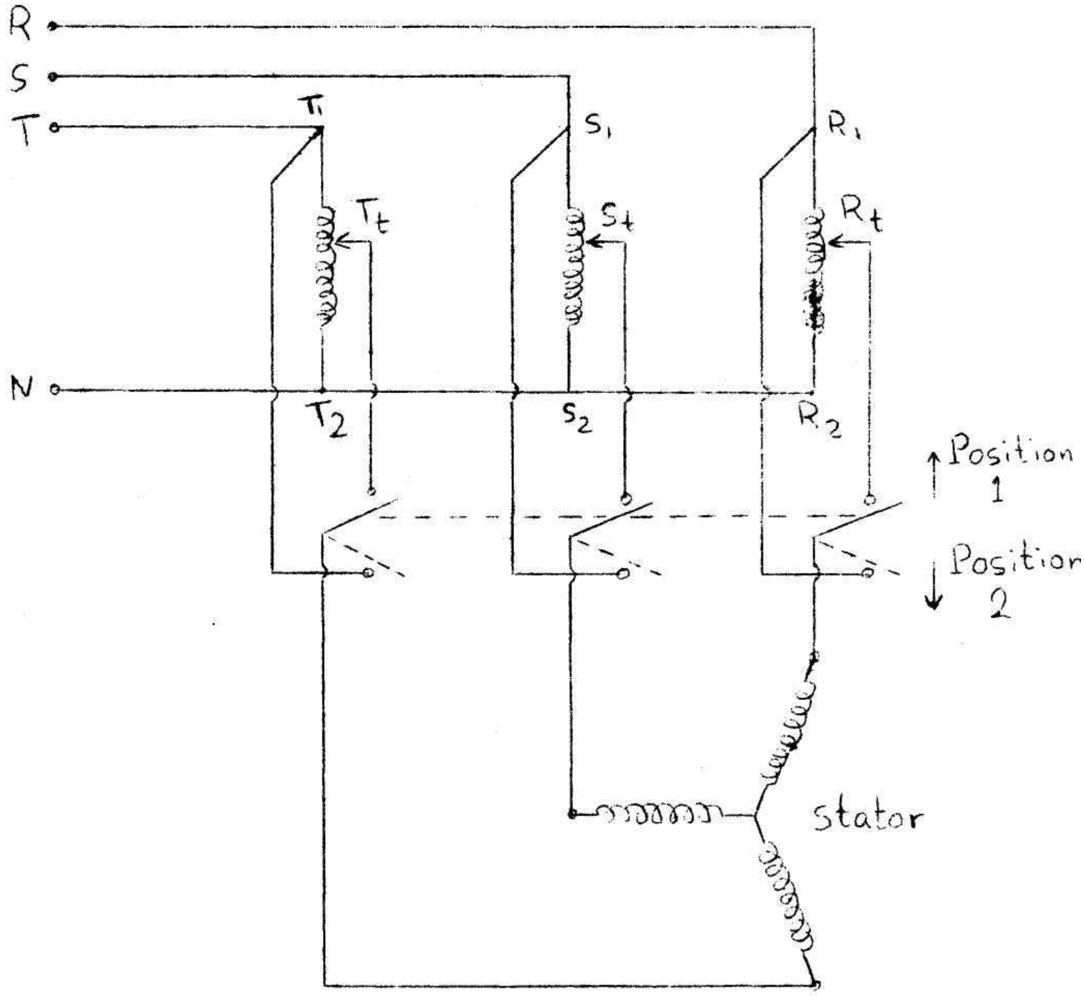


Fig. (1) Auto-Transformer Starting of I.M.

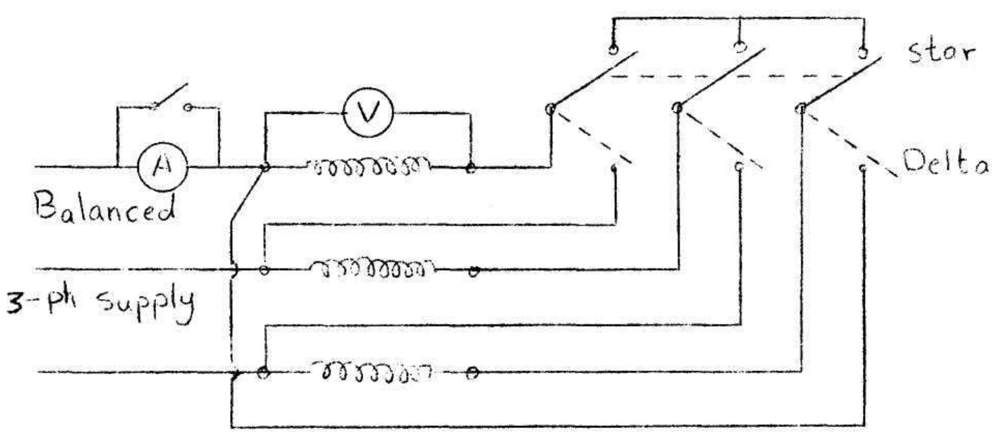


Fig. (2) Star-Delta Starting of I.M.

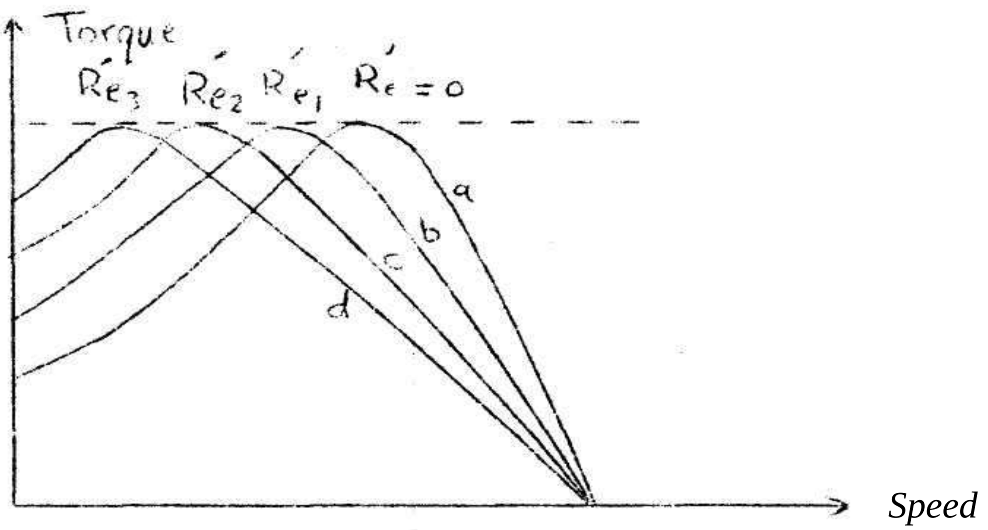

Torque
Re3'
Re2'
Re1'
Re' = 0
a
b
c
d
Speed

Fig. (3)

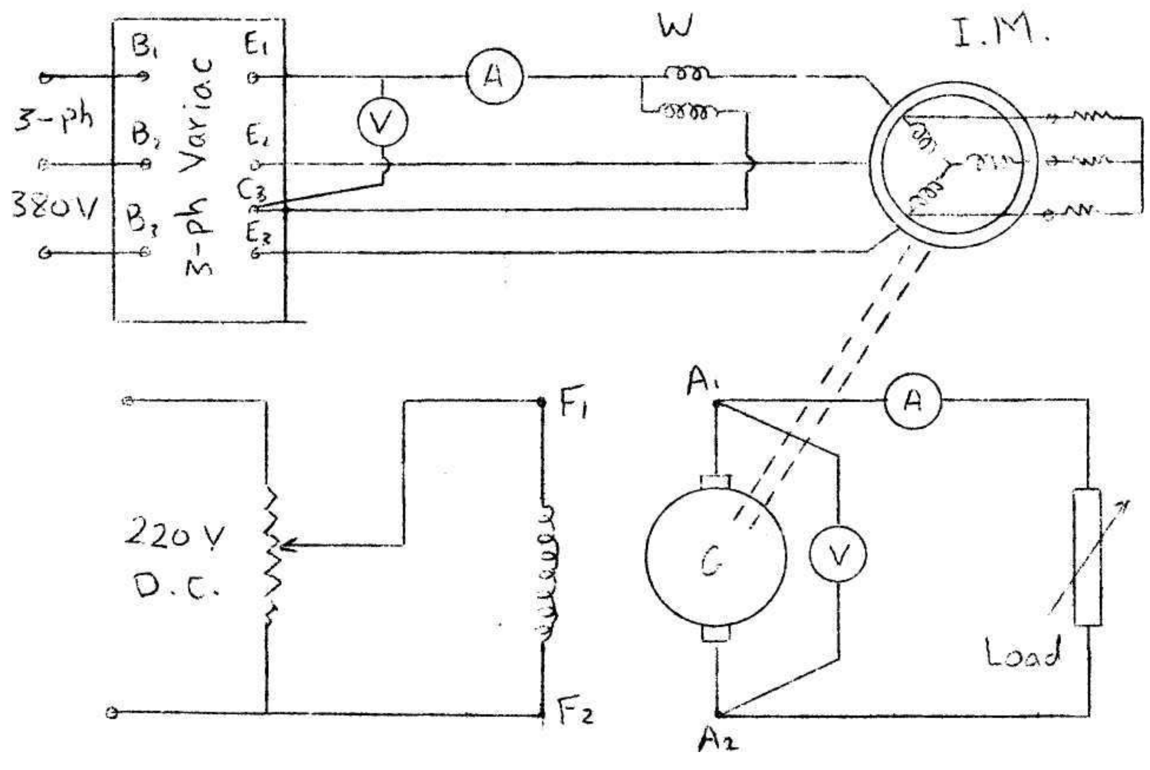

W
I.M.
B1
B2
B3
E1
E2
E3
C3
3-ph
380V
3-ph Variac
A
V
A1
A2
F1
F2
220 V
D.C.
G
Load

Fig. (4)

EXP. No. 3

Single-Phase Induction Motor

Aim:- To determine the equivalent circuit parameters and the performance characteristics of a single-phase induction motor.

Theory:- Refer to Fig.l, in a single phase induction motor, the stator has two windings, a main winding (m) and auxiliary winding (a) which is displaced 90 electrical space with reference to the main winding. The rotor (R) is of the squirrel cage type. When the current in the auxiliary winding is made to have a time phase displacement with reference to the main winding current a rotating field of a varying amplitude is produced resulting in torque production.

Without the auxiliary winding current at starting, no rotating field can be produced, however once the rotor picks up speed, the rotating field is maintained even when the auxiliary winding is switched out.

In the motor under test, auxiliary winding is connected in series with a capacitor (C) in order to obtain a current time phase displace with reference to the main winding current. Once the motor is started the auxiliary winding is cut out by a centrifugal switch.

It can be shown by double revolving field theory that a single-phase induction motor when operating with its main winding only at a speed n r.p.s. can be represented approximately by an equivalent circuit as shown in Fig.2 where:

R_1: Stator resistance.

X_1: Stator leakage reactance.

R_2': Rotor resistance referred to stator.

X_2': Rotor leakage reactance referred to stator.

X_m: Magnetising reactance.

$$S = Slip = \frac{n_S - n}{n_S}$$

n: Speed in r.p.s., n_S: Synchronous speed of field in r.p.s.

E_f: Voltage induced due to forward field

E_b: Voltage induced due to backward field.

Determination of equivalent circuit parameters:-

(a) Blocked rotor test: The approximate equivalent circuit of the motor (with main winding only) under blocked rotor condition (when S =1 and effect of X_m is negligible) is shown in Fig.3. Connections are made as in Fig.4 with only (m) winding is connected. Variac is adjusted to pass a current I_{SC} equal to the rated current. W_{SC} and V_{SC} are noted.

(b) No load test: When the motor is operating on no-load with a low operating value for the slip (s) the approximate equivalent circuit is as shown in Fig.5. Connections are made as in Fig .6. The auxiliary winding is connected for starting purpose only. The variac is adjusted for various values of V_O up to 110% of the rated value and for each adjustment, reading of V_O, I_O and W_O are noted. One adjustment should be for $V_O = V_1$ the rated voltage of the motor.

(c) Stator main resistance: Measure the stator main resistance R_{1dc} by applying small dc voltage. Find $R_1 = R_{1dc}*1.2$.

(d) Direction of rotation: Note the direction of the rotation for the connection you made in Fig.6. Interchange the leads to either the main winding or to the auxiliary winding and note the direction of rotation.

Load Test:-

The motor is connected as shown in Fig.8 with a d.c. generator for loading. The motor is run at its rated voltage V_1 (should be constant for various loadings). Readings of V_1, , I_1, W_1, torque T and speed N r.p.m. are noted.

Results:-

- Blocked rotor test

From the blocked rotor test (test a) find :

$$Z_{SC} = \frac{V_{SC}}{I_{SC}} = \sqrt{\left(R_1 + R_2^{'}\right)^2 + \left(X_1 + X_2^{'}\right)^2}$$

$$\left(R_1 + R_2^{'}\right) = \frac{W_{SC}}{I_{SC}^2} \quad and\ find\ \left(X_1 + X_2^{'}\right)$$

From test (c) find $R_1 = R_{1dc}*1.2$, assume $X_1 = X_2^{'}$. Thus R_1, $R_2^{'}$ and X_1 are determined.

❖ <u>No-load test</u>

1. From test (b), for each value of V_O, we can determine the mechanical and iron losses as below:

$$W = W_O - I_O^2\left(R_1 + \frac{R_2^{'}}{4}\right)$$

W gives the sum of mechanical losses W_m, the stator iron losses W_{is} and the rotor iron losses W_{ir}. Plot W against V_O (refer to Fig.7). Extrapolate the curve to cut the Y-axis to get W_m. The sum of stator iron losses at rated voltage V_1 is determined from the graph as shown in Fig.7.

2. From test (b), we can determine the value of X_m by take the values of I_O and W_O when the voltage is rated value V_1. Then:

$$Z_O = \frac{V_1}{I_O} = \sqrt{\left(R_1 + \frac{R_2^{'}}{4}\right)^2 + \left(X_1 + \frac{X_2^{'}}{2} + \frac{X_m}{2}\right)^2}$$

R_1, $R_2^{'}$, X_1 and $X_2^{'}$ are known from the previous calculations. Hence calculate X_m.

❖ <u>Equivalent circuit</u>

Draw the equivalent circuit as in Fig.2 for slip (s). Insert the values obtained by you in the diagram.

❖ <u>Load Test</u>

For each set of readings calculate:

$P_{out} = \frac{2\pi NT}{60}\ watts,\ Input\ p.f. = \cos\emptyset = \frac{W_1}{V_1 I_1}\ and\ efficiency = \frac{P_{out}}{W_1}$

Plot $\cos\emptyset$, efficiency, and I_1 against P_{out}.

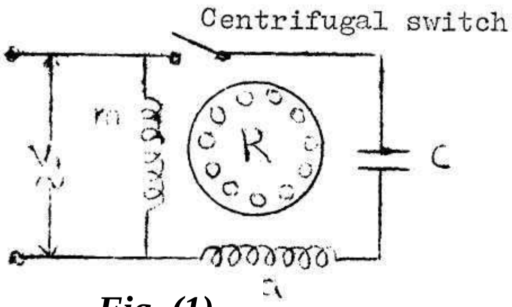


Fig. (1)

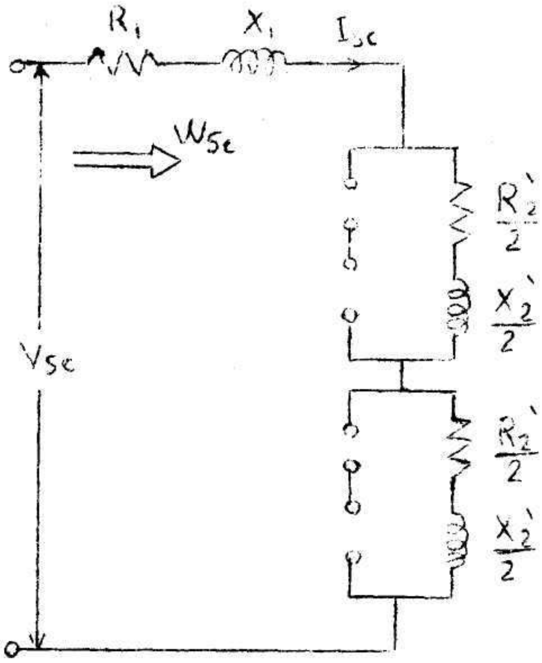


Fig. (3) Equivalent circuit for blocked rotor condition

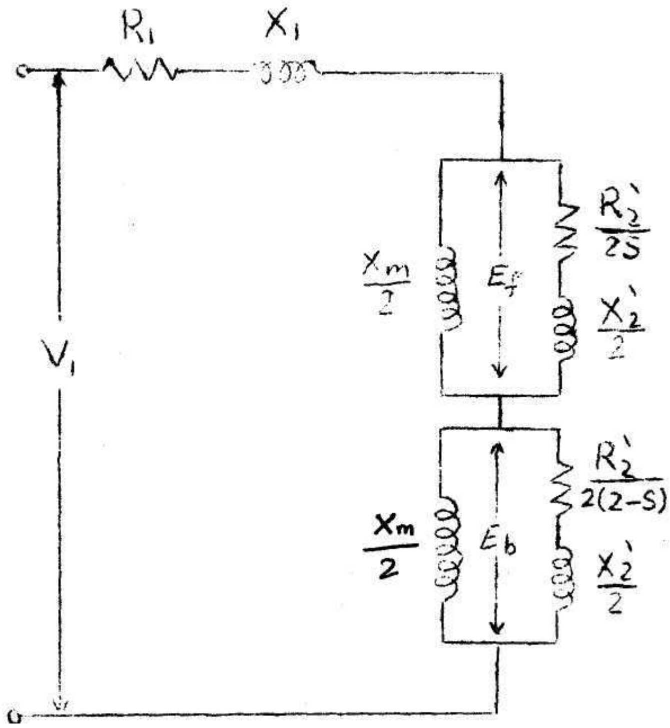


Fig. (2) Equivalent circuit for a slip (S)

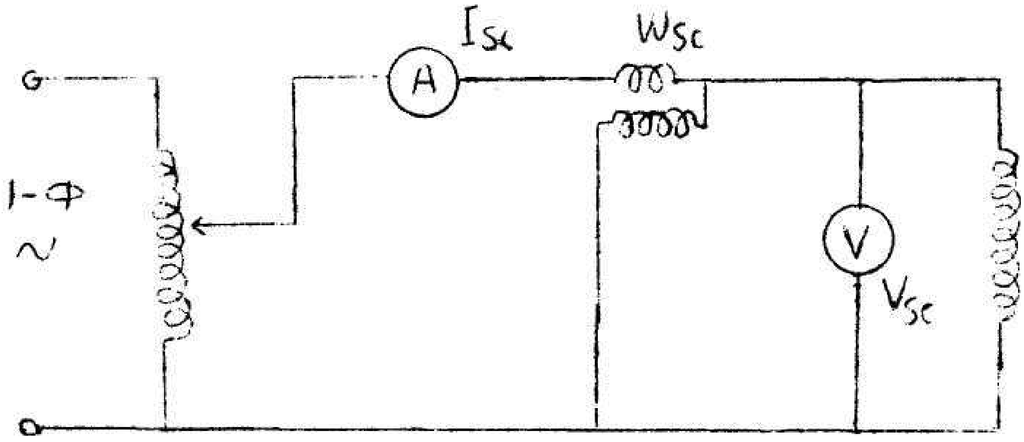


Fig. (4) Blocked rotor test

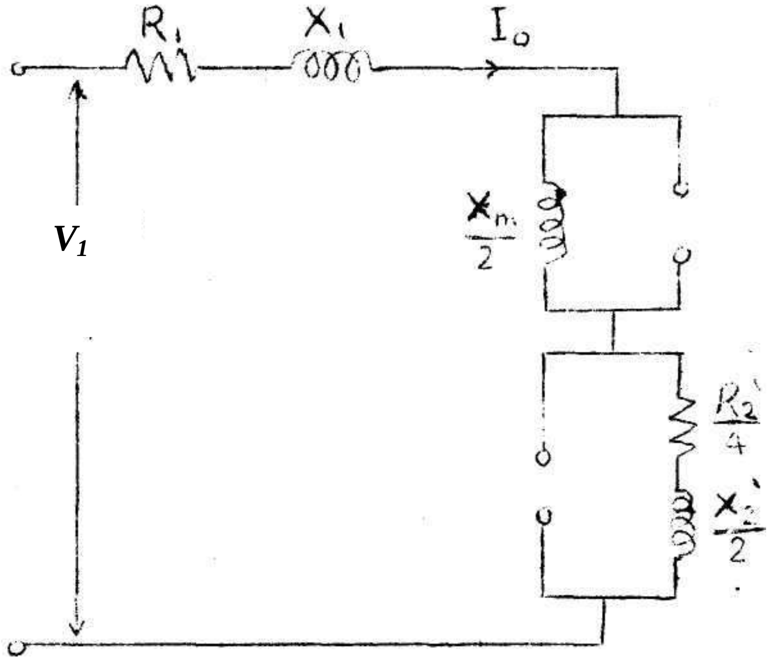


Fig. (5) Equivalent circuit for no-load

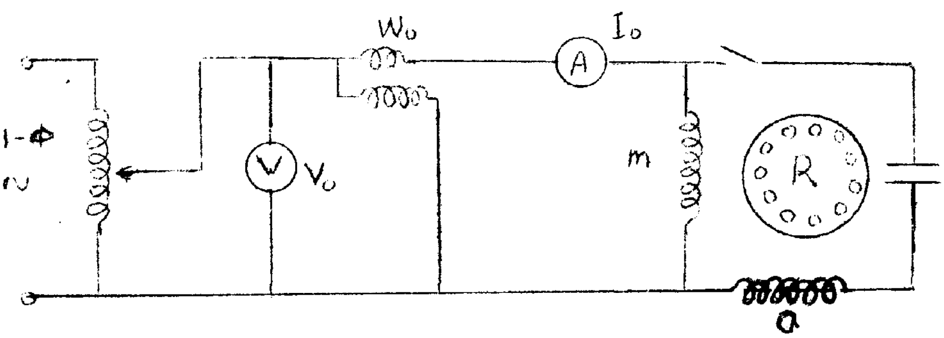


Fig. (6) No-load test

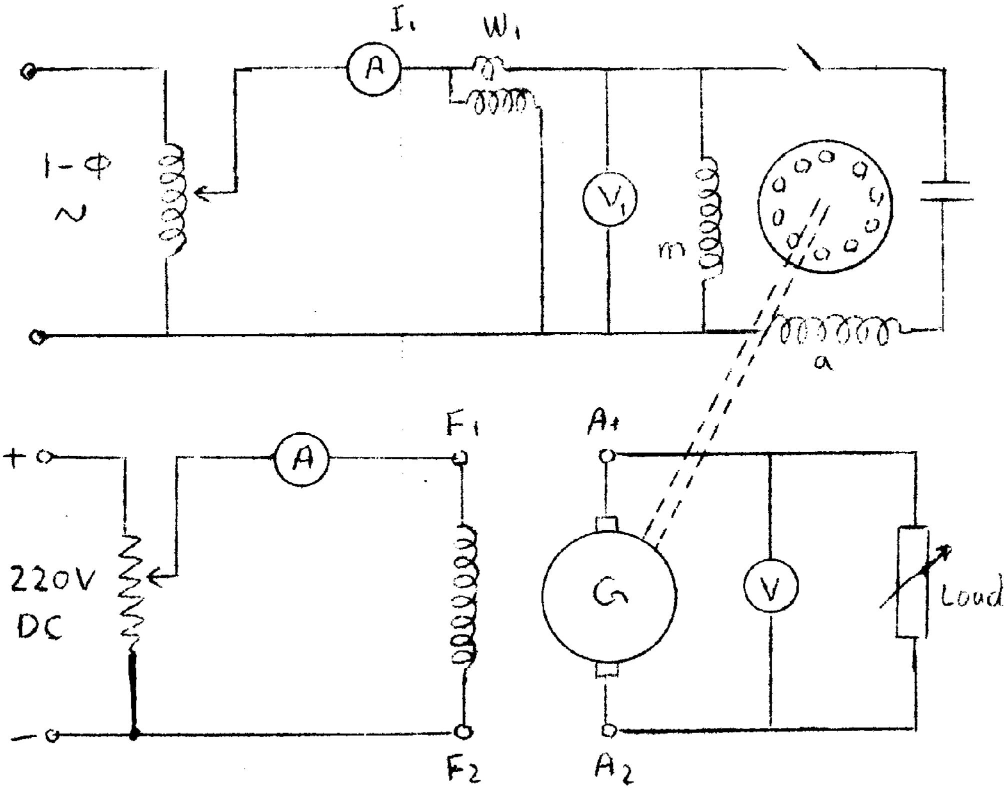


Fig. (8) Load test

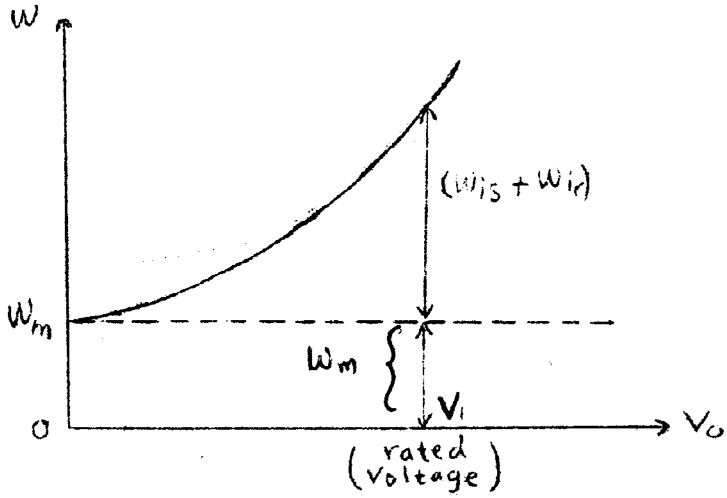


Fig. (7)

EXP. No. 4

Single-Phase Transformer Supplied by Variable Voltage and Frequency

Aim:- 1- To study the effect of varying applied voltage and frequency on a transformer at no load.

2- Separation of iron losses.

Theory:- The operation of a transformer is affected by the changes in the applied voltage, no. of turns and the supply frequency as will be clear from the following discussion:

If the applied voltage V is changed (say increased) keeping the supply frequency and no. of turns unchanged, the effective voltage per turn of the transformer is changed (increased). Since it is known that the voltage per turn, e_t , is given by the expression:

$$e_t = 4.44\emptyset_m f \qquad volts$$

The flux density in the magnetic circuit of the transformer is also automatically changed (increased) as a result. Any increase in the flux density will increase both the iron losses and magnetizing current in the following manner : increase of flux-density increases the hysteresis loss in the ratio of $(B_{new}/B_{old})^{1.6}$ and the eddy current loss is increased by a factor of $(B_{new}/B_{old})^2$.

Reference to the phaser diagram of a transformer will show that the effect of increase of overall iron loss will be reflected in an increase in the loss component of no load current. An increase in the applied voltage will also bring about a proportional increase in the magnetizing component of current (provided that the transformer still operate within the unsaturated region). This qualitative analysis will therefore show that:

(i) In the unsaturated region of operation: An increase in applied voltage will cause an increase in the no load current but the rate of increase of the iron loss component is faster than that of the magnetizing component and so the phaser angle of the no load current will reduce. The no load power factor changes marginally but the losses increases.

(ii) In the saturated region of operation: The rate of increase of the magnetizing component of current is faster than that of the iron loss component of current, thus the phase angle of the no load current will increase making the no load p.f. poorer. The losses increase as before.

If voltage and frequency are varied together keeping V_1 / f_1 = constant, the flux density will be constant, since $(V_1/f_1)\alpha\emptyset_m$. Under these conditions the power input at O.C.T. which is almost entirely iron loss can be written as:

$$W_o = P_{h+e} = K_e f^2 + K_h f = eddy\ current + hesteresis\ loss$$

and

$P_{h+e}/_f = K_e f + K_h$ is an equation of the first order with respect to f.

For a series of frequencies with corresponding changes in input voltage, the measured input power divided by frequency and plotted against frequency will give a straight line as shown in Fig.3. Referring to Fig.3 : 'ao' and 'cd' multiplied by the frequency f_1 are the hysteresis loss and the eddy current loss corresponding to this frequency.

Procedures:-

1. Supply voltage varied :

Connect the transformer through a variac, a low p.f. wattmeter, ammeter and voltmeter of suitable ranges (see Fig.l), and supply from constant frequency source. With the secondary of the transformer kept open circuited, the applied voltage is varied from 75% to 125% of the rated voltage. Record no-load current, applied voltage and no-load power for each voltage setting and estimate the power factor.

2. Frequency varied :The test transformer and the instruments are now supplied by a variable frequency motor - alternator set. The schematic circuit

diagram for the motor - alternator set only is given in Fig.2. Control the frequency of the generated voltage by changing the speed of the d.c. motor (control R_a and/or R_f). The input voltage of the transformer is kept constant (220V) by adjusting the setting of the variac in each case. Change the supply frequency in steps, beginning with a value of 20% below the rated value and go up to 10% above the rated value. Record the input current and no-load power input for each value of supply frequency. Calculate the power factor and record the results.

3. V and f varied, keeping V/f constant :

Connect the test transformer according to the circuit diagram in Test 2 above. Control the speed of the d.c. motor and adjust the variac so that the applied voltage at the rated frequency is equal to the rated voltage of the transformer. Keep the variac at the above setting throughout this test.

Select the terminals corresponding to the rated voltage of the transformer. For different values of V by changing speed of motor (with constant V/f ratios) record the no-load current and power input, also calculate the power factor.

***Report*:-**

Plot the following results from the above calculations :

1. Variation of no-load current I_o , power W_o and power factor $\cos \emptyset_o$ against the applied voltage V (on the same graph).
2. I_o ,W_o and $\cos \emptyset_o$ against the frequency f (on the same graph).
3. I_o , W_o and $\cos \emptyset_o$ against the voltage V (on the same graph).
4. Plot W_o / f against frequency f and determine the value of the eddy current loss and the hysteresis loss at rated frequency.
5. Interpret the above results and draw your conclusions.

Dr. S.L. Surana

Completed by Dr. Mark

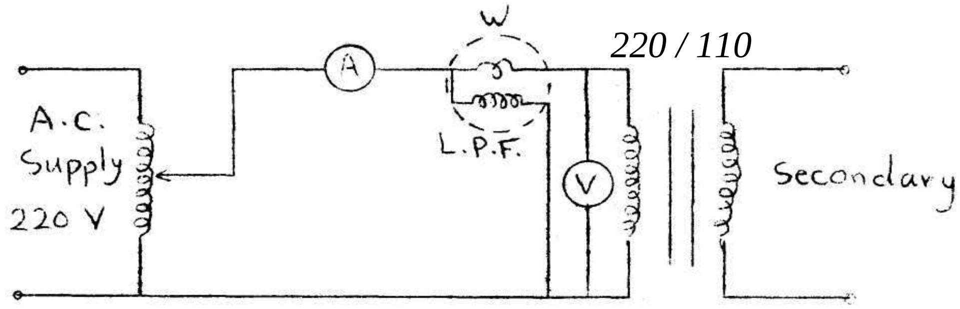


Fig. (1)

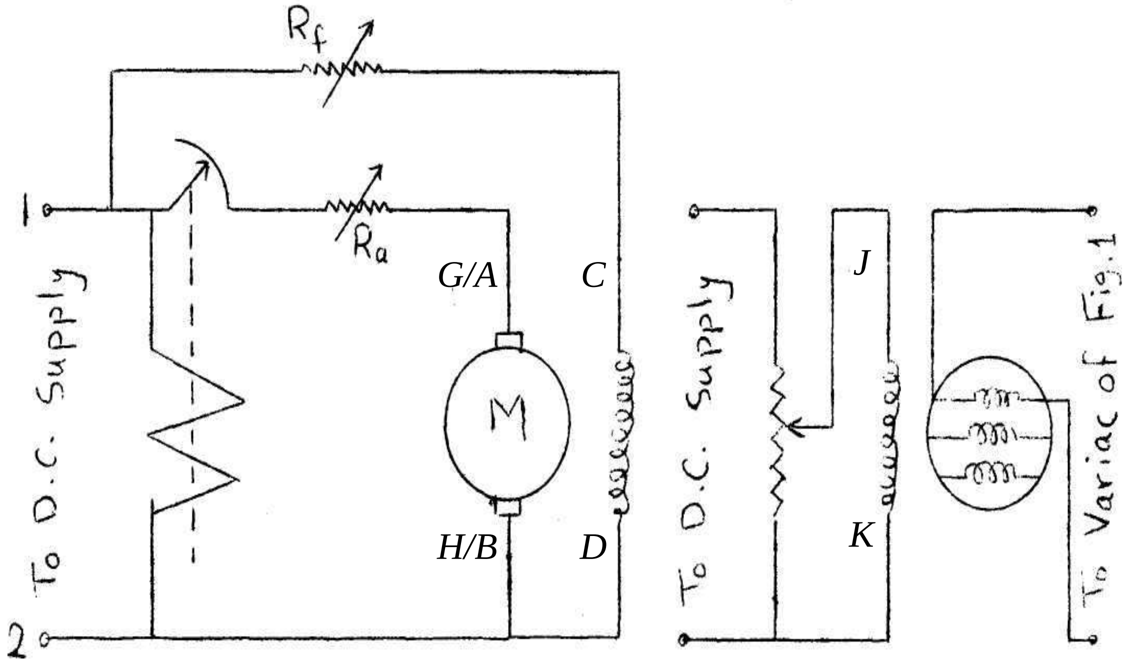


Fig. (2)

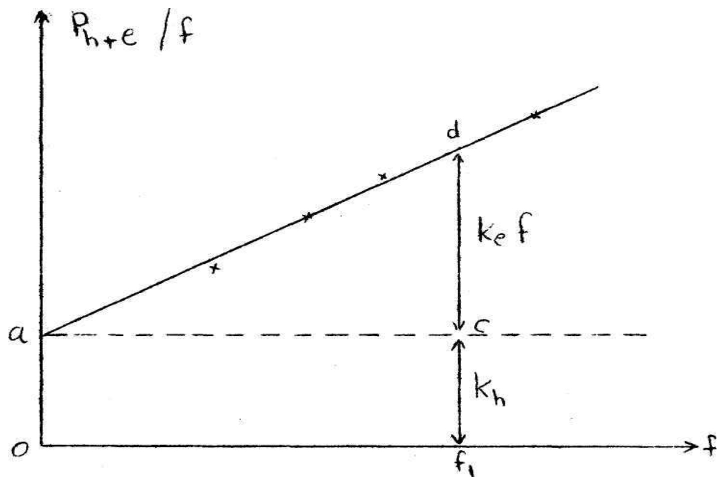


Fig. (3)

EXP. No. 5

Parallel Operation of Three Phase Transformers

Aim:-

1) To connect two three phase transformers in parallel at different groups of connections.
2) To perform load test for the two parallel transformers in order to calculate the circulating current at various load currents.
3) To calculate the circulating current using the equivalent circuit of the two transformers.

Theory:- Before connecting two transformers in parallel, certain essential conditions must be fulfilled and they are:

a) The secondary e.m.f.s should be equal in magnitude and in phase in order to avoid circulating current.
b) The phase sequences for the transformers should be the same, i.e. the phase shift between the secondary e.m.f.s should be zero.

For example, referring to Fig.l which represents only one phase for each transformer, the parallel switch on the secondary side must not be closed until it is certain that the polarity of the incoming transformer is correct, i.e. a must have positive and negative variation of potential at the same instant as b . This can easily be checked by connecting a voltmeter across the switch, which will read zero, presuming $E_A = E_B$, if the polarities are the same. The two e.m.f.s must then be in phase opposition round the local circuit.

The primary winding may be connected directly because, with its secondary circuit open, it can only take the small no-load current. For the case shown, the two transformers have the same input voltage and frequency of the common supply, if instead, each transformer primary was connected to its own supply, the input voltage and frequencies would have to be matched as a separate adjustment. There are other, desirable but not essential, conditions such as:

1. The transformers must have the same circuit connection.
2. The KVA ratings of the transformers must be the same.
3. The ratio X/R of the two transformers must be the same for equal sharing of the load.

From Fig.2, which shows only one phase of the equivalent circuit, referring to the secondary side, of the two transformers connected in parallel (Fig.l).

$$I_A = I\frac{Z_B}{Z_A + Z_B} \quad and \quad I_B = I\frac{Z_A}{Z_A + Z_B}$$

Where:- $I_A=I_{2A}$, $I_B=I_{2B}$, $I=I_L$, Z=Load impedance, $V=V_2$,

$$Z_A = Z_{eq2A} = R_{eq2A} + jX_{eq2A} \;\; and \;\; Z_B = Z_{eq2B} = R_{eq2B} + jX_{eq2B}$$

For equal sharing of load between the two transformers, I_A and I_B must be equal. This can be fulfilled when $Z_A=Z_B$ and this will give:

$$\theta_A(angle\ of\ Z_A) = \theta_B(angle\ of\ Z_B) \rightarrow \tan\theta_A = \tan\theta_B$$

Thus

$$\frac{X_{eq2A}}{R_{eq2A}} = \frac{X_{eq2B}}{R_{eq2B}}$$

And this proves condition number 3.

Fig.3 shows the equivalent circuit per phase referred to the secondary side for the two transformers connected in parallel. From this figure,

$$E_A - I_A Z_A - (I_A + I_B)Z = 0 \quad \ldots\ldots(1)$$

$$E_B - I_B Z_B - (I_A + I_B)Z = 0 \quad \ldots\ldots(2)$$

Substituting for I from (2) in (1) gives:

$$I_A = \frac{E_A}{Z_A + Z + \left({ZZ_A}/{Z_B}\right)} + \frac{E_A - E_B}{Z_A + Z_B + \left({Z_A Z_B}/{Z}\right)} \quad \ldots\ldots(3)$$

Substituting in (2) gives:

$$I_B = \frac{E_B}{Z_B + Z + \left({ZZ_B}/{Z_A} \right)} + \frac{E_B - E_A}{Z_A + Z_B + \left({Z_A Z_B}/{Z} \right)} \quad \ldots \ldots (4)$$

It will be notice from equations (3) and (4) that if the two e.m.f.s are not equal, the second term represents a superimposed circulating current which has components in phase with one of the e.m.f.s, the larger one; the same current, therefore, has anti-phase components with the smaller e.m.f. The circulating current will reduce the load on one transformer and increase it on the other.

From equation (3),

$$I_C = circulating\ current = \frac{E_A - E_B}{Z_A + Z_B + \left({Z_A Z_B}/{Z} \right)} \quad \ldots \ldots (5)$$

And at no load (Z =∞) the circulating current will be :$I_C = \frac{E_A - E_B}{Z_A + Z_B}$

The total load current is:

$$I = I_A + I_B = \frac{E_A Z_B + E_B Z_A}{Z(Z_A + Z_B) + Z_A Z_B} \quad \ldots \ldots (6)$$

And the terminal voltage is :

$$V = IZ = \frac{\left({E_A}/{Z_A} \right) + \left({E_B}/{Z_B} \right)}{\frac{1}{Z_A} + \frac{1}{Z_B} + \frac{1}{Z}} \quad \ldots \ldots (7)$$

The advantage of this solution is that it can be applied to any number of units in parallel simply by addition of terms E_C/Z_C, E_D/Z_D, etc. in the numerator and terms $1/Z_C$, $1/Z_D$, etc. in the denominator. Any current can be calculated; for example,

$$I_A = \frac{E_A - V}{Z_A} \quad \ldots \ldots (8)$$

The phasor diagram for the general case of two transformers connected in parallel (Fig.3) is shown in Fig.4.

Procedures:-

1) Check the polarity of the two transformers.
2) Connect the two transformers as shown in Fig.5.
3) Increase the primary voltages of the two transformers until reaching the rated secondary voltages.
4) Check the phase sequences of the voltages of the two transformers using phase sequence indicator. The phase sequence must be the same. If they are different then the sequence of one of them should be changed.
5) Check the voltmeter across the switch S_1, its reading must be zero before switching on the two transformers in parallel. This can done by changing the variac output.
6) Record the line e.m.f.s of the secondary of the two transformers i.e. E_A, and E_B (the voltages on no load).
7) With switch S_2 open, close S_1. Record the current in the secondary of the two transformers. This is the circulating current on account of unequal voltages of secondary.
8) Close switch S_2. Increase the resistive load current in steps, taking care that the current rating of the transformers is not exceeded. For each step record the terminal voltage, current in the two secondaries (I_A, I_B), power supplied by the two transformers per phase (W_A, W_B), the total power per phase (W) and the load current (I).
9) Open switches S_2 and S_1. To show the effect of unequal voltages of secondaries, change the voltage supplied to transformer A such that the voltmeter across the switch will read value suggested by the supervisor.
10) Repeat steps 6 to 8.
11) Open switches S_2, S_1 and switch off the supply voltages.

12) Change the connections of transformer A to delta/star connections and repeat steps 3 to 6. Now, you must decide is it possible to connect the two transformers in parallel?

Report:-

1) From the data recorded, compute the power factor of the currents in the two transformers for all readings.
2) With the help of phasor diagram, verify the relationship $I_A + I_B = I$ for at least two readings.
3) From the data recorded state if R_{eq2A}/X_{eq2A} equal to R_{eq2B}/X_{eq2B} or not.
4) Using the equivalent circuit of the two transformers, calculate I_A, I_B and I_C for the same load current readings chosen in step 2.
5) Compare the calculated and experimental values of I_A, I_B and I_C.
6) Repeat steps 4 to 6 for the case of unequal secondary voltages.
7) Explain step No.12 of the procedures and prove your explanation analytically. Calculate the circulating current at no-load for this type of connections.
8) What will happen if the transformers secondary terminals are connected with wrong polarity ?
9) Comments on the results.

Dr. Rabee Hashim. Thejel

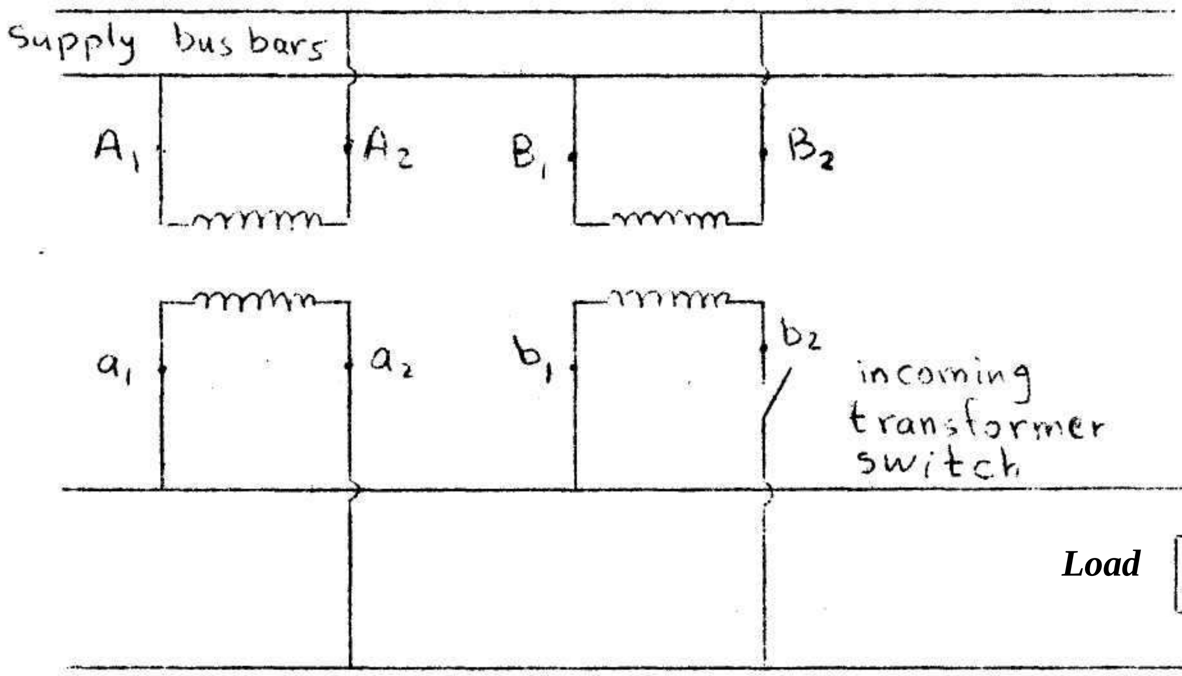


Fig. (1) Actual one-phase circuit of the two parallel 3-phase transformers

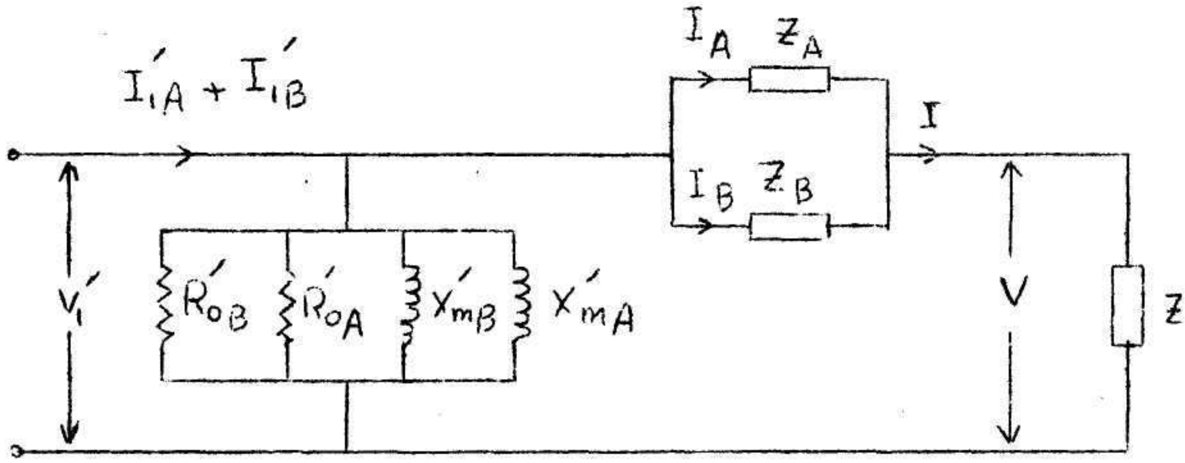


Fig. (2) Equivalent circuit per phase of the two parallel transformers shown in fig. (1)

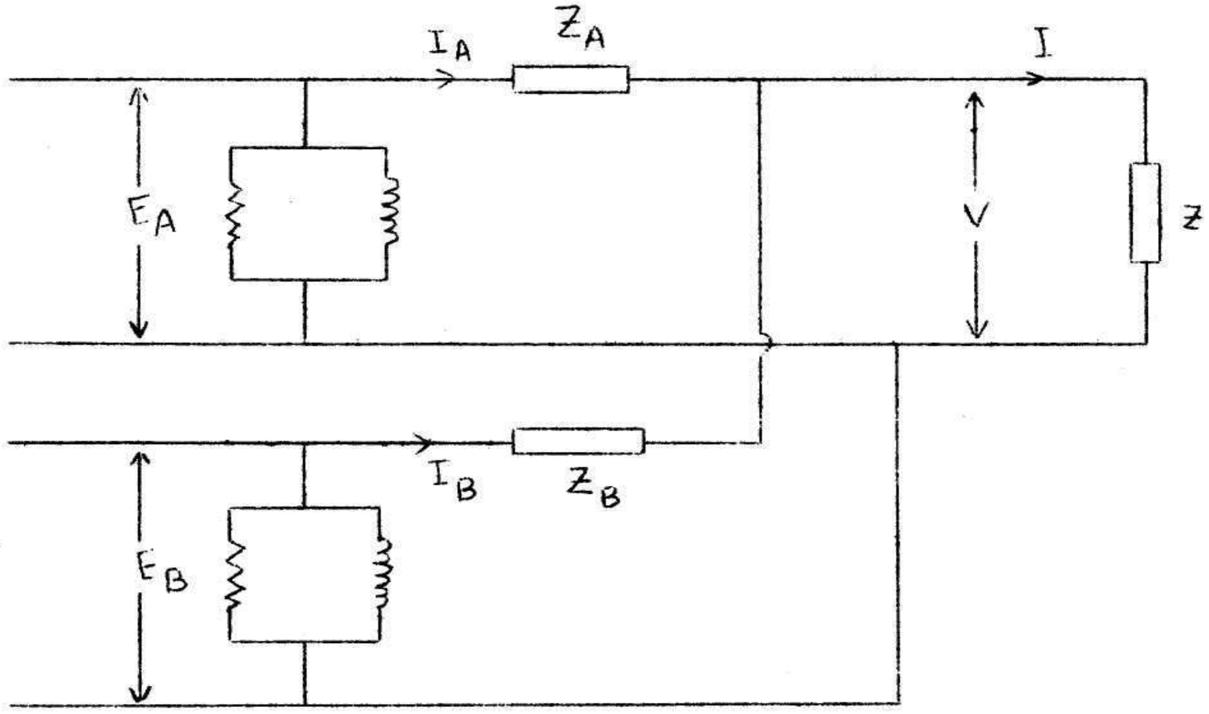


Fig. (3) Equivalent circuit per phase of the two transformers in parallel

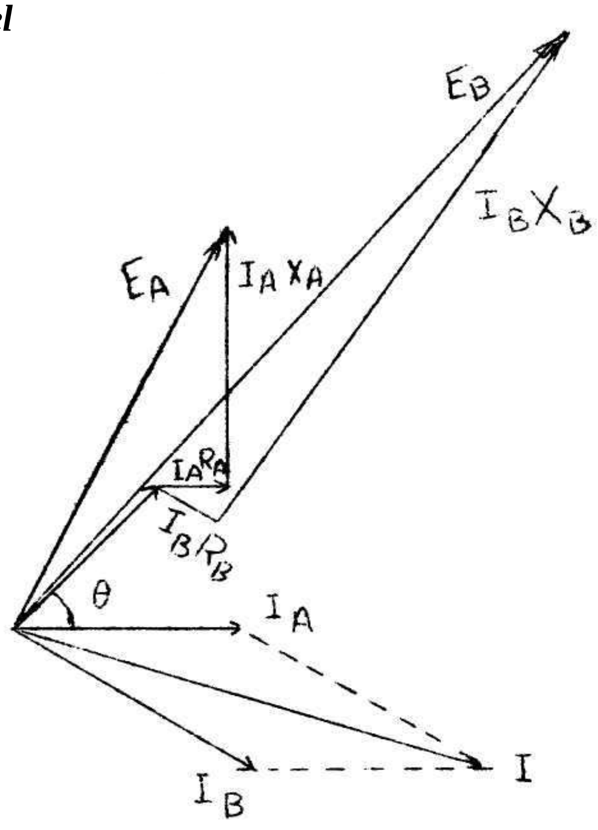


Fig. (4) Phasor diagram for the two parallel transformers shown in fig. (3)

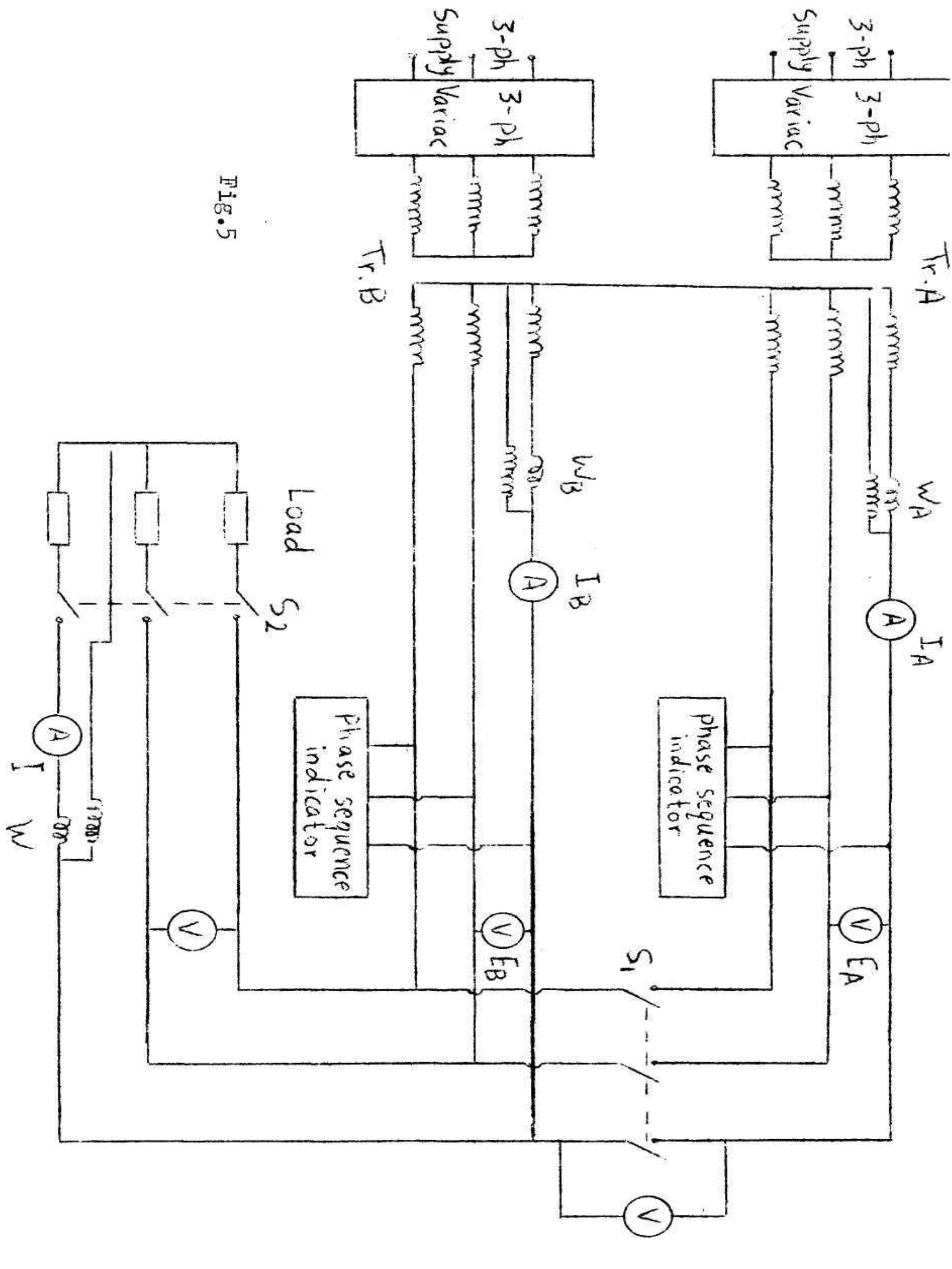

3-ph Supply
3-ph Variac
Tr.A
Tr.B
W_A
W_B
I_A
I_B
phase sequence indicator
E_A
E_B
S_1
S_2
Load
I
W

Fig.5

EXP. No. 6

A.C Armature Winding

Aim:- To study the different number effect of pole on 3-phase induction motor performance.

Introduction:-

The armature of all the rotating machine have certain number of slots depending upon the diameter of the armature. The armature consists of either single turn or multi turn coils. These coils must be suitably arranged in the slot and then connected properly to obtain the required phase grouping. The shape of the end connections, may alter the appearance of the winding but electrically all are identical. A.C winding must be properly arranged so that the e.m.f generated in all the phases are of equal magnitude and frequency. The e.m.fs of all phases must have identical wave form and displacement in time phase by $2\pi/N$, where N is the number of phases.

In this experiment, the machine has double layer winding, 36 slots. Thus there are 36 coils, coil span=7, and terminals of coil are brought outside. These coils can be connected either to from 3-phase, 4-pole and 3-phase, 6-pole with 120o space phase different. Two coil sides are accommodated in each slot in a double layer winding. If one coil side of a coil lies in the top layer of a particular slot then the other coil side of the same coil will lie in the bottom layer of another slot decided by the coil span value.

Connection of the induction machine as 3-phase, 4-pole

The induction machine can be connected as 3-phase, 4-pole. Fig.3-1 shows the developed diagram of a 4-pole, 3-phase, 36 slots and 36 coils double layer winding. The top coil side in the slot is shown by thick line, whereas the bottom coil side is shown by a dotted line, Details:

Total number of stator slot=no. of phase*no. of pole* no. of slots per pole per phase.

No. of slots per pole per phase=36/3*4=3 slots

Pole pitch in terms of stator slots =36/4=9

Coil span=7 in terms of slots

Pole pitch – coil span=9-7=2 slots. Then,

Short pitched coil by two slots.

Thus the coil side in the top layer of slot number 1(coil side number 1) is connected with coil side in the bottom layer of slot 8(coil side number 101).

Slot pitch angle=180o/9=20o electrical degree.

Phase R starts with slot number 1, the phase S will start after 120^o electrical degree, i.e, at slot number 7 and the phase T starts after 240^o electrical degree, i.e, at slot number 13.

The phase are arranged in the slots according to the following tables:

<u>Phase R</u>

	Top layer	Bottom layer	Top layer	Bottom layer
	1 , 2, 3	101, 102, 103	19, 20, 21	119, 120, 121
After 180^0	10, 11, 12	110, 111, 112	28, 29, 30	128, 129, 130

<u>Phase S</u>

	Top layer	Bottom layer	Top layer	Bottom layer
	7 , 8, 9	107, 108, 109	25, 26, 27	125, 126, 127
After 180^0	16, 17, 18	116, 117, 118	34, 35, 36	134, 135, 136

<u>Phase T</u>

	Top layer	Bottom layer	Top layer	Bottom layer
	13 , 14, 15	113, 114, 115	31, 32, 33	131, 132, 133
After 180^0	22, 23, 24	122, 123, 124	4, 5, 6	104, 105, 106

The different coils can be connected to from 3-phase as explained below

First, connect the coils group to form x, u, y, v, z, w phases as shown in Fig.(3-2)

The terminals marked 1,7 and 13 from the x, y and z terminals, while 28, 34 and 4 from u, v and w terminals, the R, S and T phase are now connected in star as given in Fig.(3-3). The complete connection can be shown in Fig.(3-4).

Slowly increase the voltage up to the rated value of 220V line to line.

Note down the no-load current and wattmeter reading. Also measure the slip by stroboscope.

<u>Connection of the induction machine as 3-phase, 6-pole</u>

The induction machine can be connected as 3-phase, 6-pole. Fig.3-5 shows the developed diagram of a 6-pole, 3-phase, 36 slots and 36 coils double layer winding. Details:

Total number of stator slot=no. of phase*no. of pole* no. of slots per pole per phase.

No. of slots per pole per phase=36/3*6=2 slots

Pole pitch in terms of stator slots =36/6=6

Coil span=7 in terms of slots

Pole pitch – coil span=6-7=-1 slots. Then,

long pitched coil by one slot.

Thus the coil side in the top layer of slot number 1(coil side number 1) is connected with coil side in the bottom layer of slot 8(coil side number 101).

Slot pitch angle=$180^o/6=30^o$ electrical degree.

Phase R starts with slot number 1, the phase S will start after 120^o electrical degree, i.e, at slot number 5 and the phase T starts after 240^o electrical degree, i.e, at slot number 9.

The phase are arranged in the slots according to the following tables:

Phase R

	Top layer	Bottom layer	Top layer	Bottom layer	Top layer	Bottom layer
	1, 2	101, 102	13, 14	113, 114	25, 26	125, 126
After 180^0	7, 8	107, 108	19, 20	119, 120	31, 32	131, 132

Phase S

	Top layer	Bottom layer	Top layer	Bottom layer	Top layer	Bottom layer
	5, 6	105, 106	17, 18	117, 118	29, 30	129, 130
After 180^0	11, 12	111, 112	23, 24	123, 124	35, 36	135, 136

Phase T

	Top layer	Bottom layer	Top layer	Bottom layer	Top layer	Bottom layer
	9, 10	109, 110	21, 22	121, 122	33, 34	133, 134
After 180^0	15, 16	115, 116	27, 28	127, 128	3, 4	103, 104

The different coils can be connected to from 3-phase as explained below

First, connect the coils group to form x, u, y, v, z, w phases as shown in Fig.(3-6)

The terminals marked 1,5 and 9 from the x, y and z terminals, while 31, 35 and 3 from u, v and w terminals, the R, S and T phase are now connected in star as given in Fig.(3-7). The complete connection can be shown in Fig.(3-8).

Slowly increase the voltage up to the rated value of 220V line to line.

Note down the no-load current and wattmeter reading. Also measure the slip by stroboscope.

<u>Questions:</u>

1- What are the changes you suggest to connect this 3-phase induction motor as 8-pole?

2- What are the advantages and disadvantages of the double layer winding over the single layer winding?

3- Draw the developed diagram for the stator winding of 3-phase, 4-pole, induction motor. The winding is double layer with full pitch coils. The number of slots are 2 per pole per phase show the direction of current in various phase?

Dr. Basim Talib. Kadhem

Dr. Rabee Hashim. Thejel

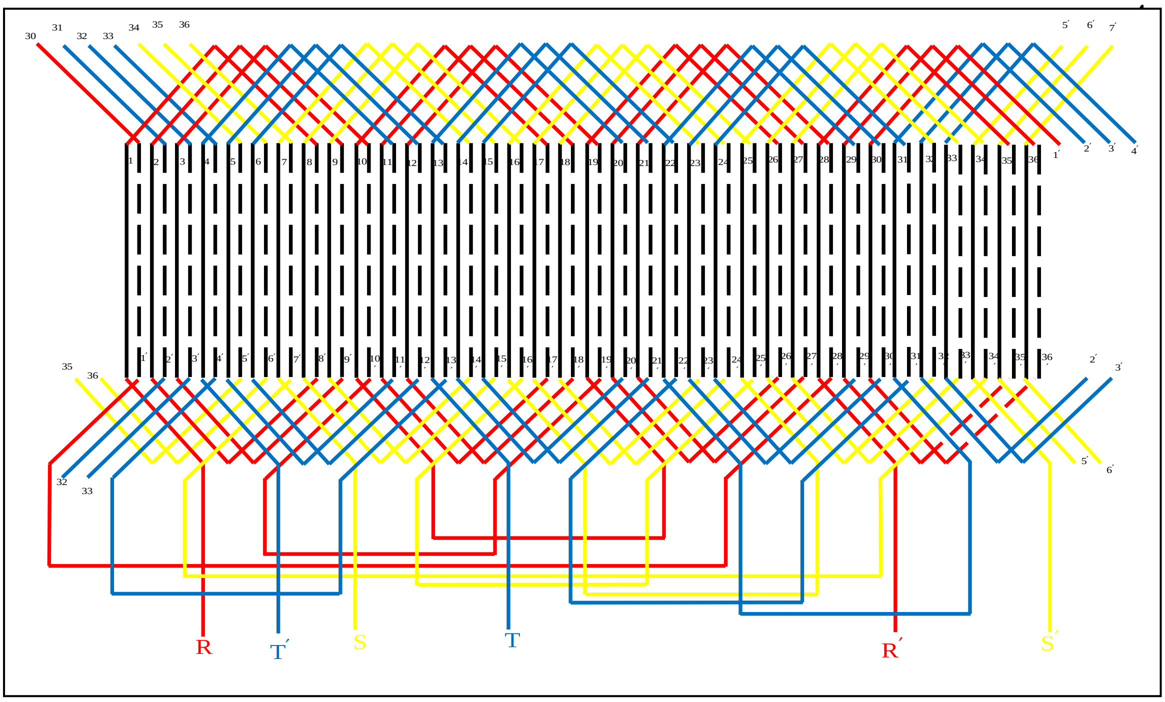


Fig.1. developed diagram of 3-phase, 4-pole

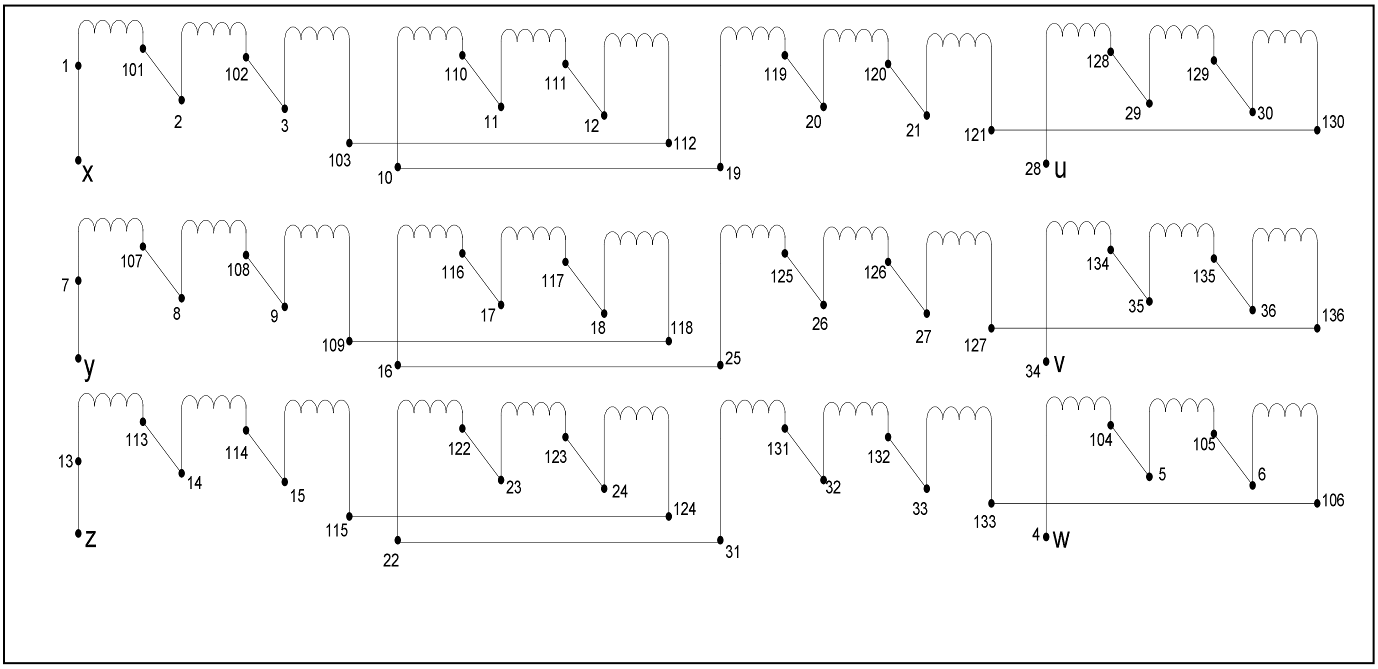


Fig. 2

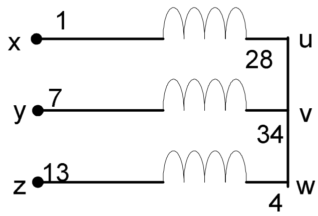


Fig. 3

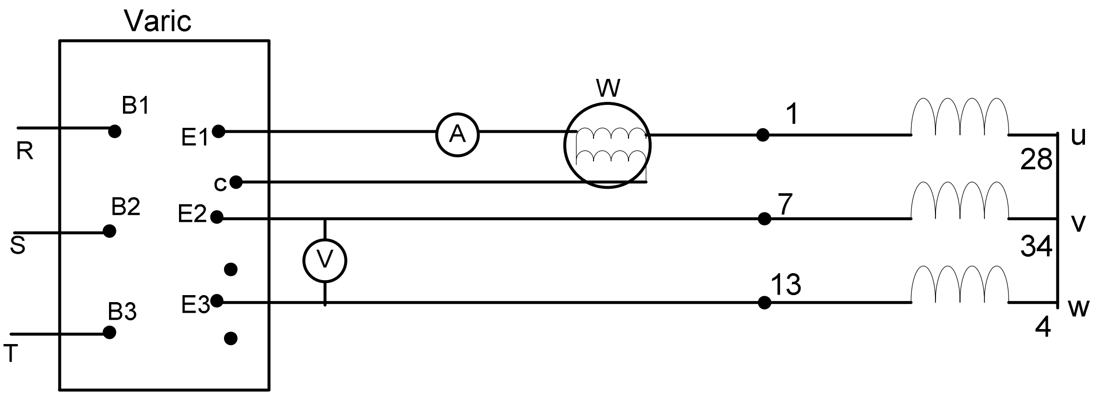


Fig.4

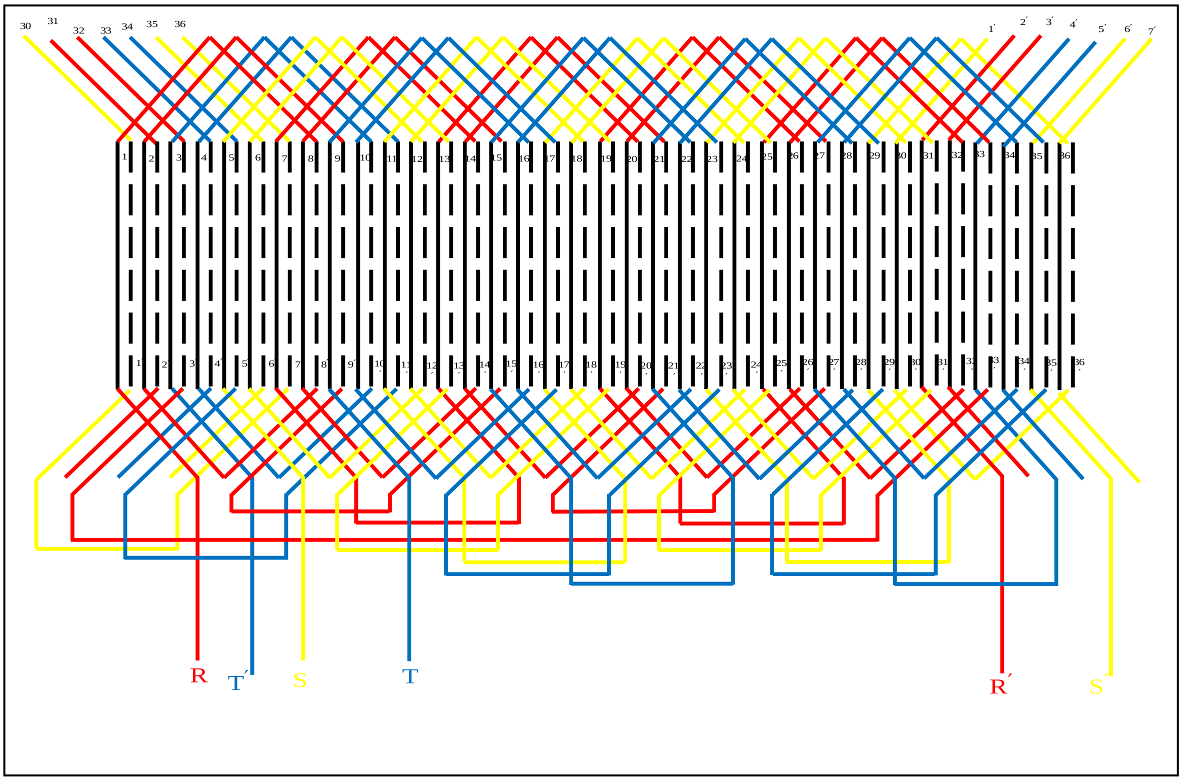


Fig. 5. developed diagram of 3-phase, 6-pole

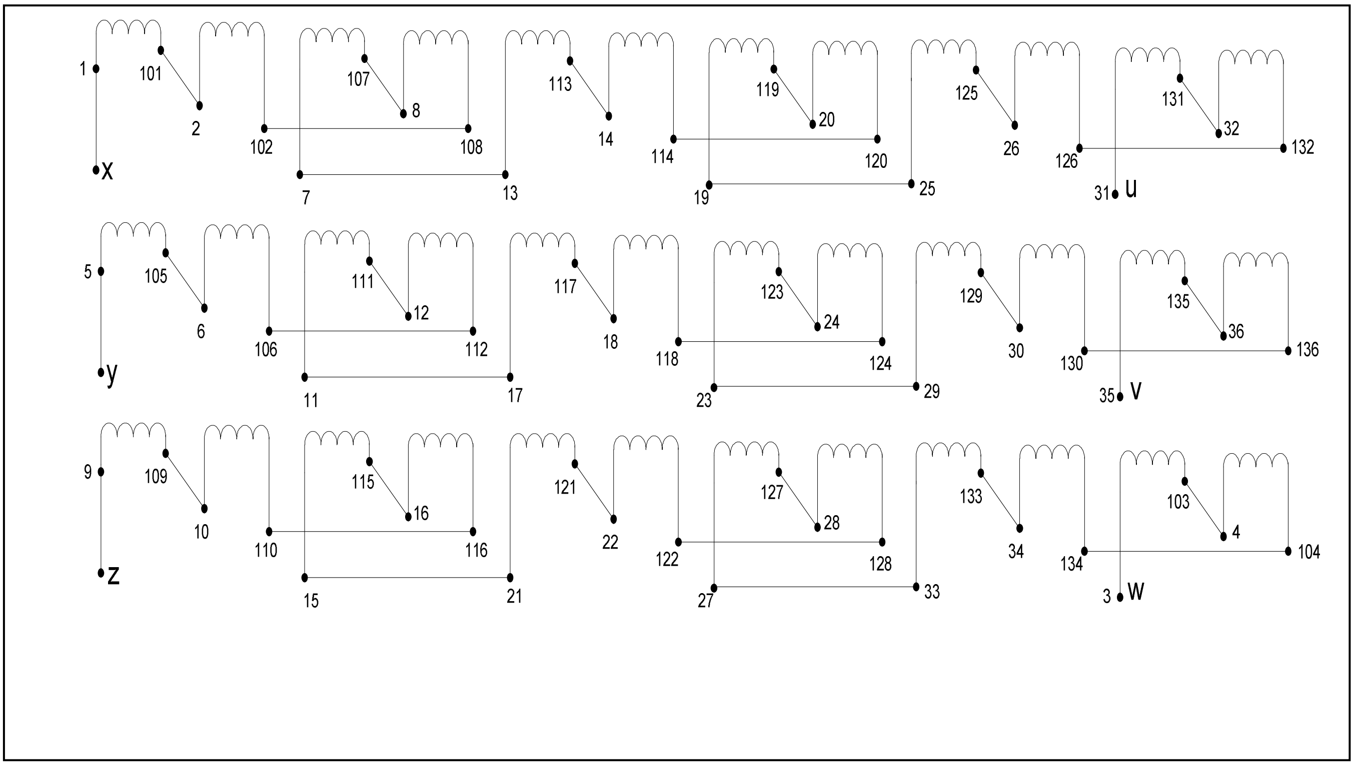


Fig. 6

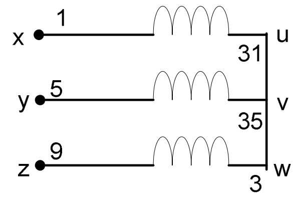


Fig. 7

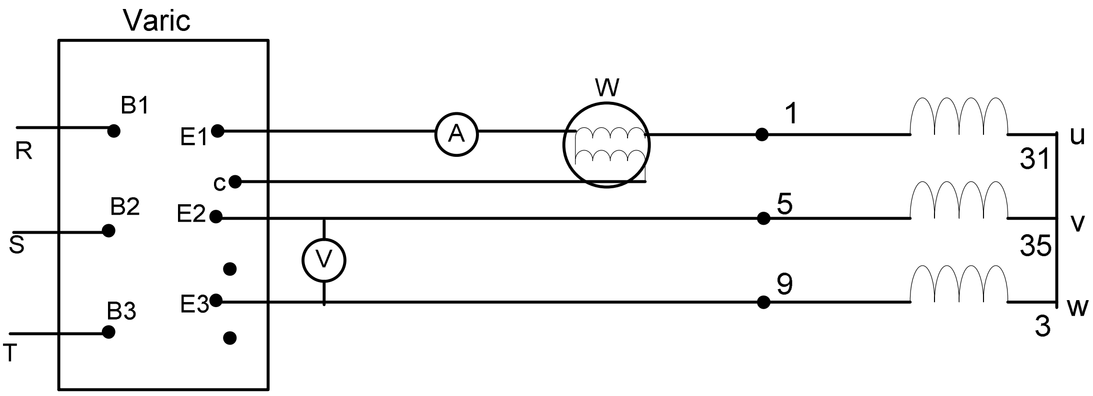


Fig. 8

EXP. No. 7

Induction Generator

***Aim*:-** To determine the performance characteristics of an induction generator and to verify them from circle diagram.

Apparatus required and circuit diagram:

1. The diagram of connection for this experiment is the same as that used for load test of induction motor, on the a.c. side. On the d.c. side, the d.c. machine is connected through suitable meters and motor starter for running as a shunt motor. ***DRAW YOUR OWN CONNECTION DIAGRAM FROM THE ABOVE HINTS***.
2. Record the specifications of the machines.
3. Prepare a list of instruments required and decide on their ranges. Mark the chosen ranges appropriately on the circuit diagram.

Theory:- An induction machine (slip ring or cage type) may be operated as an induction generator if driven at a super-synchronous speed by means of an external drive, while its armature is connected to a 3-phase supply. For proper operation, the induction generator requires a driving source with a rising speed-torque characteristics, and it develops power at constant voltage and constant frequency, which can be fed back into a standard 3-phase supply system. It must be noted that, unlike a normal a.c. generator (alternator), an induction generator receives its excitation and delivers the generated power through a single winding (ITS ARMATURE). The induction generator must be supplied with a lagging current for producing the necessary exciting flux. This aspect of operation of the machine usually requires its working in parallel with other voltage sources. Such a machine deliver only leading power factor currents to the system.

It is also possible to operate an induction machine as an induction generator without connecting its armature to the standard voltage sources, but then it requires balanced three phase banks of capacitors to be connected across its terminals. The armature must, at first, be connected to the standard voltage source. The supply can be disconnected only after the machine starts working in its generation region, and balanced poly phase voltages can be obtained from the motor armature. However, this mode of working is not very practical since the amount of capacitive load must be changed considerably as the output is varied.

Procedure:-

a) Connect the armature of the induction machine to a 3-phase supply system through a 3-phase variac. Short circuit the rotor winding of the machine. The d.c. machine, coupled to the induction machine, should also be connected to a suitable d.c. source for operation as a motor, with a provision for control of speed.
b) Make sure that the direction of rotation of the set when it is run either from the d.c. side or the a.c. side, remains the same.
c) Run up the set from the d.c. side and adjust its speed to a suitable sub-synchronous value (say, a slip of S=0.05 for the induction machine).
d) Apply 3-phase 220 volt (line) through the variac. (PLEASE NOTE THAT THIS IS LESS THAN THE RATED VOLTAGE OF THE A.C. MACHINE). Record the total input power, current, shaft power and speed. Make sure that the wattmeters connections are such that the net power flow into the machine (now working as a motor) is indicated as positive.
e) Increase the speed of the set in steps by controlling from the d.c. side. For each speed setting record the power flow, input current and shaft torque. (THE ARMATURE CURRENT OF THE A.C. MACHINE SHOULD NOT EXCEED 120% OF THE RATED VALUE).
f) Perform no-load test at 220V (lines) and blocked rotor test with rated current in armature. Measure stator resistance.

<u>Report</u>:-

a) From the above observations, determine the following characteristics against slip: i) Input current. ii) Shaft power. iii) Power factor. Also calculate the active and reactive components of armature current and plot against slip.

b) Determine the above characteristics using the circle diagram.

<u>Conclusions</u>:-

a) Compare the pre-determined and experimental results and give your comments.

b) Comment on the generator operation and suggest any practical use.

c) Why are these generators not used commonly for power generation ?

<u>Hints on drawing the circle diagram</u>

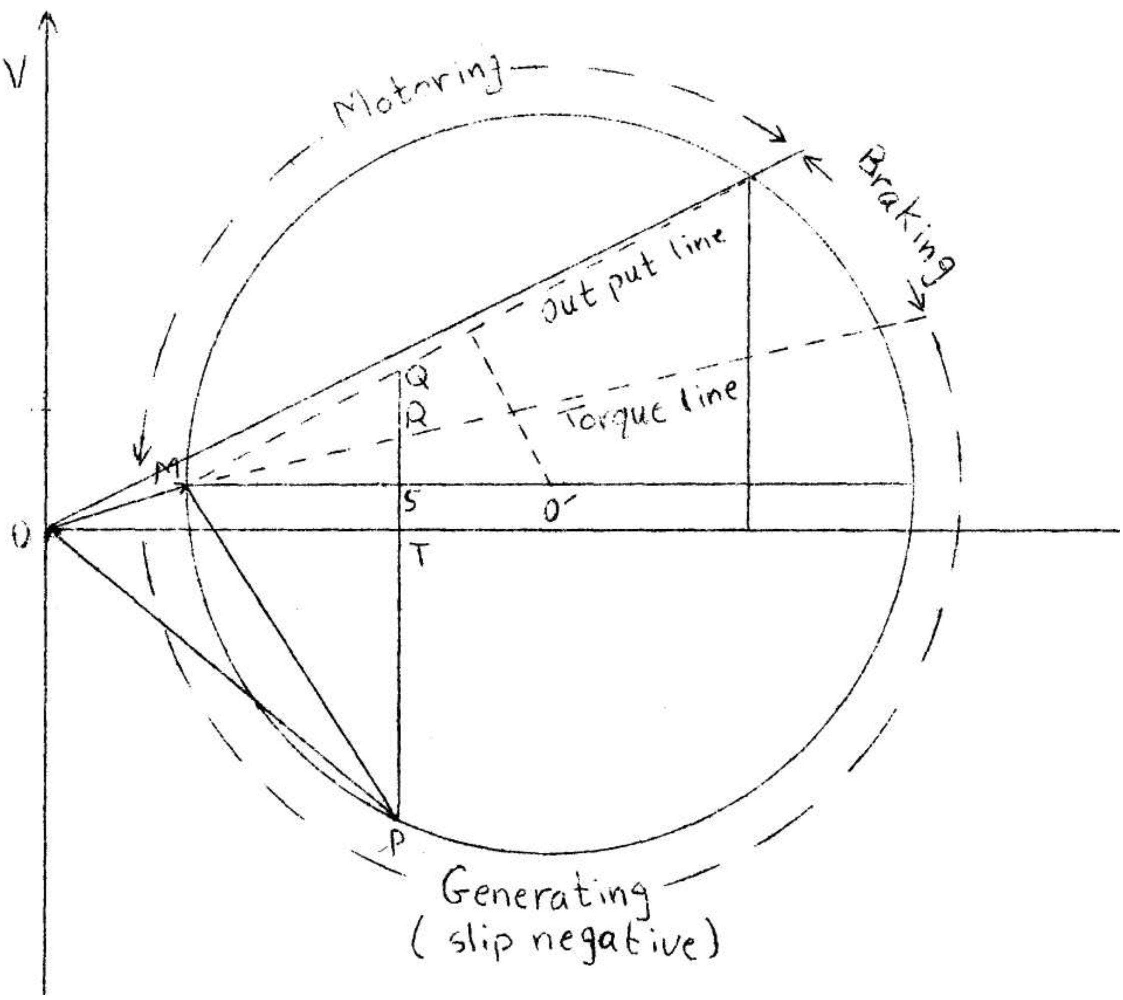
The approximate circle diagram, developed in connection with induction motors, can be applied with fair accuracy for predetermination of both motor and generator characteristics, by completing the circle of the current locus. In this diagram, the upper semi-circle represents MOTOR ACTION while the lower semicircle represents GENERATOR ACTION.

When all quantities ape represented in their phase values, the circle diagram gives :

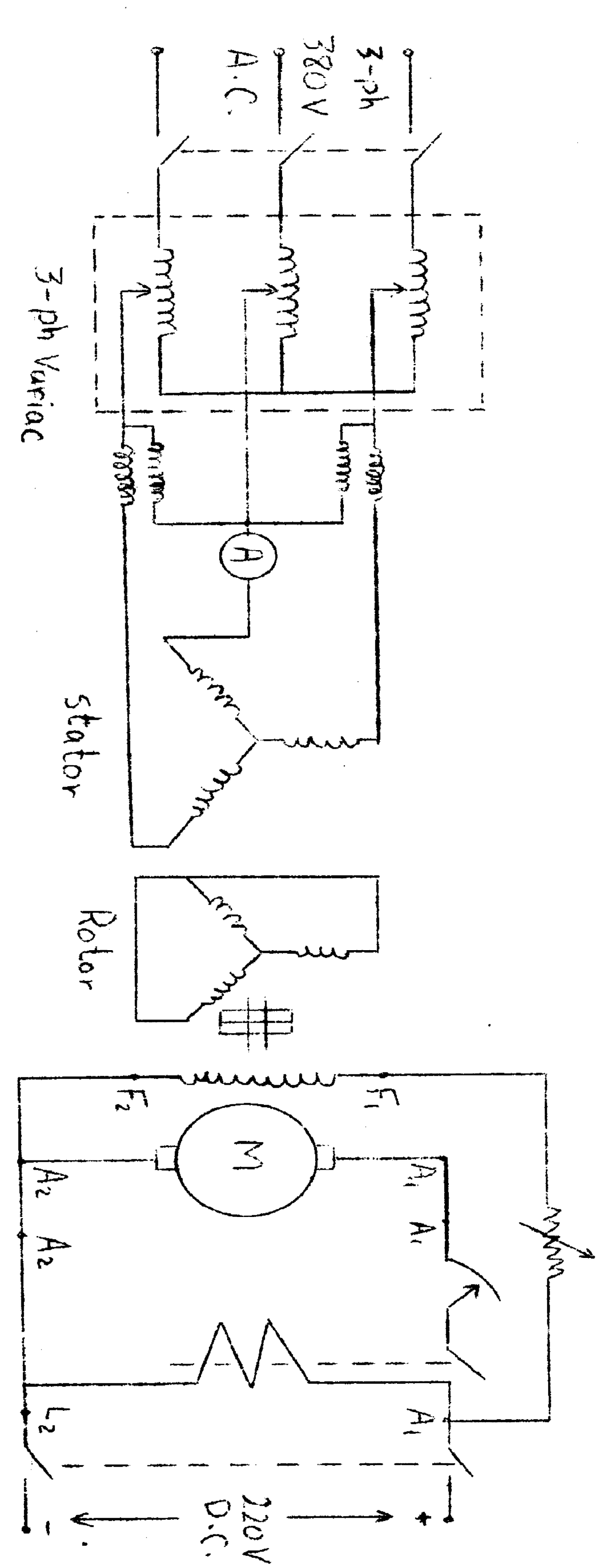
- OM - No load current in amps.
- OP - Stator current in amps.
- MP - Rotor current in stator terms.
- QP - Input in watts per phase (power scale).
- ST - Constant losses of the machine per phase (power scale).
- RS - Stator copper loss per phase (power scale).
- TP - Output power in watts per phase (power scale).
- QR - Rotor copper loss per phase (power scale).
- Cos θ - Machine power factor (lead).

- TP/QP - Efficiency.
- QR/RP - Slip.

Use the test results of (f) to draw the circle diagram for motor and generator action. Determine the machine characteristics with the help of the above information.



The complete circle diagram



Induction Generator

EXP. No. 8

Induction Regulator

Aim:- To use a wound rotor induction motor as an induction regulator and to study the effect of rotor position on the output voltage at no load. To study its behavior under load condition and to verify the results from the theoretical considerations.

Apparatus required and circuit diagram

- The connection diagram for load condition is given in Fig.l.
- Record the specifications of the machines.
- List the instruments required with ranges and show the values on your circuit diagram.

Theory:- A wound-rotor induction machine can be operated as an Induction Regulator to produce a constant-frequency variable-voltage supply system. The schematic connection diagram of a 3-phase induction regulator is shown in Fig.2. Note that one of the members (with three terminals) is connected to the supply in the normal fashion. One end of each of the three phases of the other member (which has six terminals) is also connected to the supply. CARE MUST BE TAKEN TO ENSURE THAT ‘ A ‘OF THE FIRST MEMBER AND a’ (ONE END OF THE CORRESPONDING PHASE) OF THE SECOND MEMBER ARE CONNECTED TO THE SAME SUPPLY PHASE, AND SIMILARLY, B and b’ and C and c’. The three free terminals a”, b’’ and c’’ give the 3-phase variable voltage. The induction machine will, now, function as a poly-phase phase-shifting transformer, with the difference that the e.m.f. induced in the second member is a result of cutting the rotating magnetic field produced in the first member. The magnitude of the induced voltage is, therefore, independent of the rotor position, although the relative phasor position of the induced voltage with respect to its primary counterpart (applied to the first member) is determined by the rotor position.

The phasor diagrams shown in Fig.3, indicate the relative position of the applied and induced voltages phasors in the first and second members for all the three phases. Using these phasors it is possible to estimate the relative phasor position of the voltages across the output terminals a’’- b’’- c’’. It is clear from Fig.3I that the output voltage per phase would vary over a range of:

$V_O = V_p \pm V_s = V_P \pm K\ V_p$ Where :

K= the transformation ratio between the first and the second member.

V_p = the applied voltage per phase to the first winding.

V_s = the induced e.m.f. per phase in the second member.

If K = 1 , (condition of unity transformation ratio),

$0 \leq V_O \leq 2V_P$

A notable feature of the induction regulator is that the control of the output voltage is associated with a phase-shift.

Procedures:-

III. Determination of transformation ratio

a) Connect the stator winding of the induction machine in star.
b) Connect a voltmeter V_r across any two rotor terminals. DO NOT SHORT CIRCUIT THE ROTOR TERMINALS, LEAVE THEM OPEN-CIRCUITED.
c) Apply a suitable voltage, V_{S1} (line) to the stator winding and record V_r (line). If the machine shows any sign of rotation, block it with hand.
d) Remove the supply connection from the stator terminals. Leave the voltmeter V_S connected to the stator as before. The stator is now open-circuited. Using a variac, apply V_r (line) as measured in (c) above across the rotor terminals. Record the new voltmeter reading V_{S2} (line) across the stator terminals.

The transformation ratio of the induction machine, ROTOR : STATOR, is given by:

$$\frac{2V_r}{(V_{S1} + V_{S2})}$$

II. Output voltage as a function of rotor position

a) Connect the machine as in Fig.l. Leave the output terminals of the induction regulator open-circuited.

b) Apply 120 V (line) across the rotor terminals using a 3-phase variac.

c) Move the rotor (with hand) slowly and adjust rotor position to yield maximum output voltage. Note the corresponding angular position of the rotor on the ‘ Angle Dial ‘ and assume this position to be zero.

d) Now move the rotor by hand for every 10 mechanical displacement on either sides of this zero position and record (i) the output voltage, (ii) the primary line voltage (iii) the secondary induced phase voltage and (iv) the secondary output voltage per phase for each rotor position. (NOTE: FOR THIS EXPERIMENT, THE ROTOR IS THE PRIMARY AND THE STATOR ACTS AS THE SECONDARY).

e) From above data plot the voltage diagrams (similar to Fig.3) and compare the actual and the estimated results.

III. Load test

a) Connect the machine as in Fig.l and apply 120 V (line) across the rotor terminals through a 3-phase variac.

b) Adjust the rotor position for maximum output voltage.

c) Block the rotor at this position using suitable blocking mechanism.

d) Load the machine in steps up to an output current of 2.5A. DO NOT EXCEED THIS VALUE AS OTHERWISE HEATING WOULD BE EXCESSIVE.

e) Using the data, determine the efficiency, power factor, output voltage and input current variations against output power.

Report:-

a) Plot all experimental results listed in (e) above.

b) Plot the output voltage-rotor angle curve of the machine at no-1oad.

c) Draw the phasor diagram and determine the effective phase shift of the output to input voltages. Plot the phase shift rotor angle characteristics.

Conclusions:-

a) List your conclusions from the above characteristics.

b) In determining the transformation ratio why is V_{S1} not equal to V_{S2}?

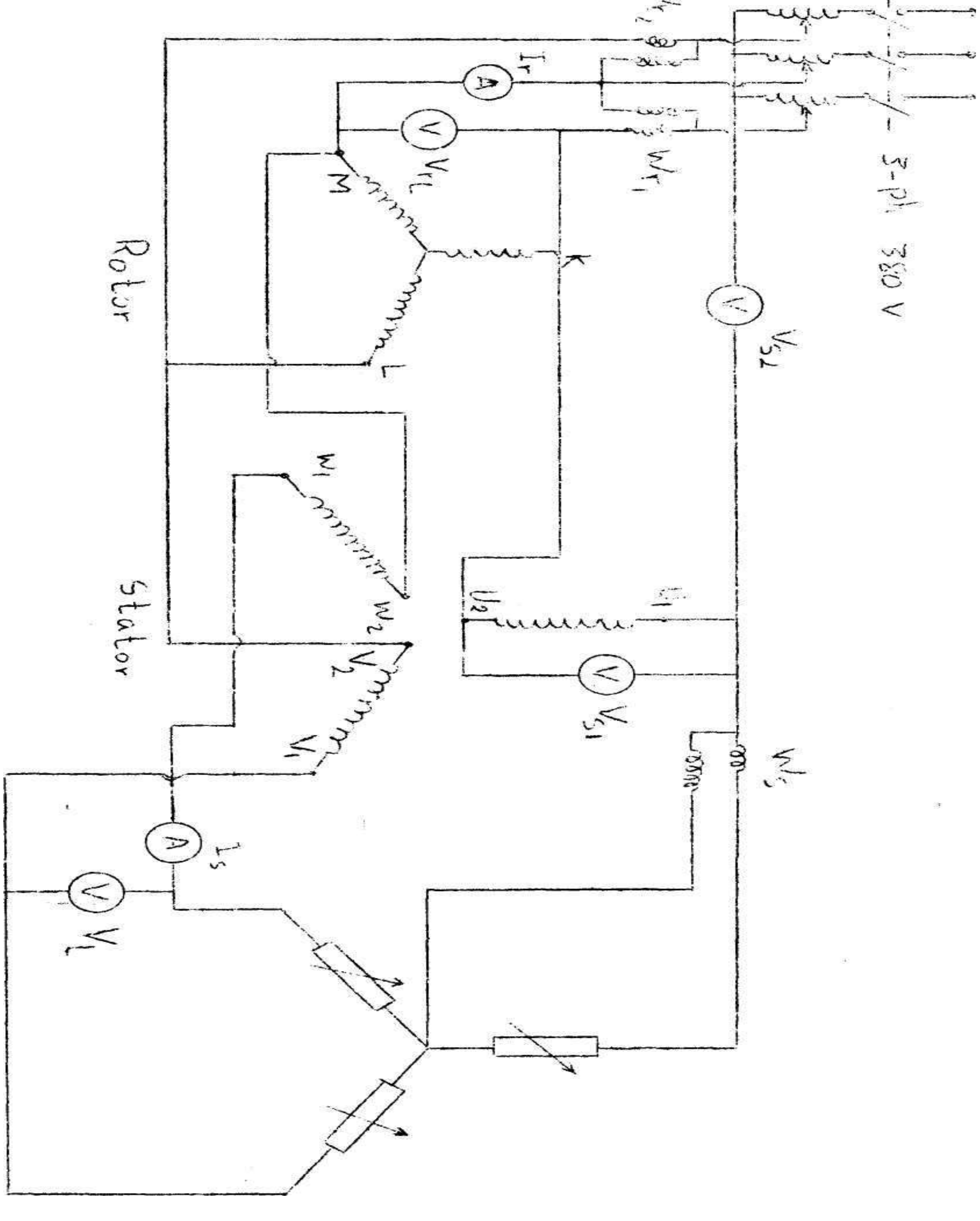


Fig. (1)

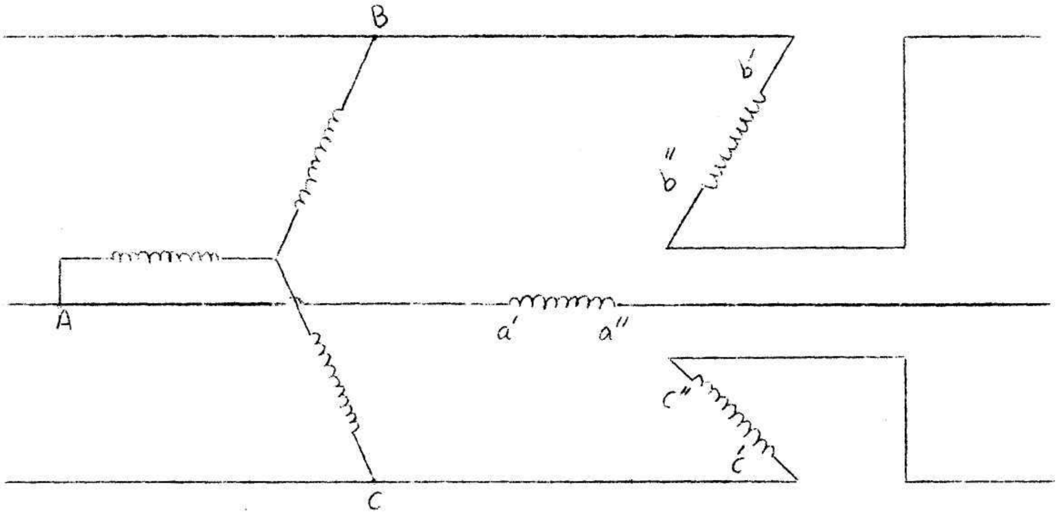


Fig. (2) Schematic diagram for an induction regulator

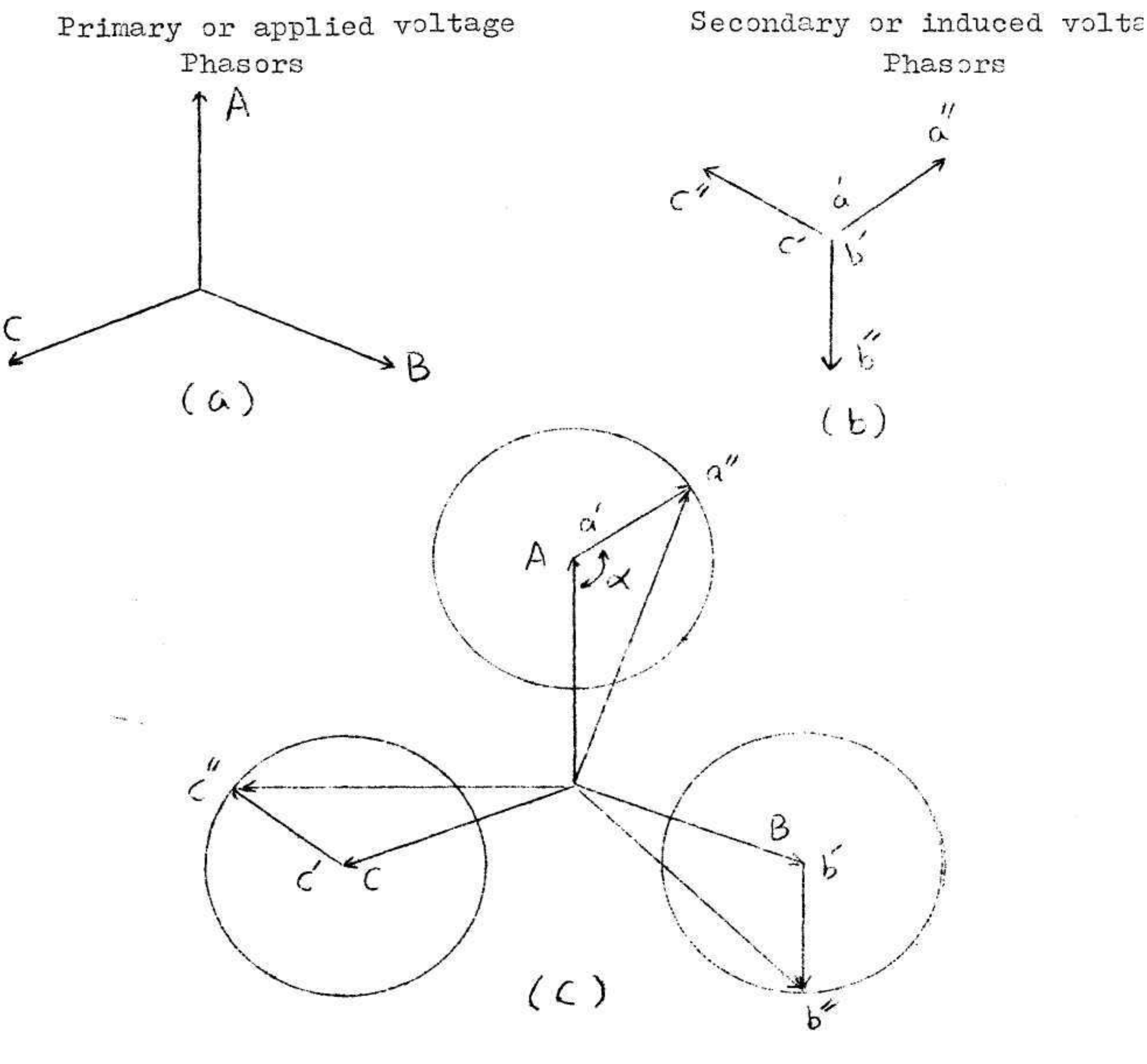


Fig. (3) Output voltage phasors

EXP. No. 9

Long Transmission Line

Aim:-

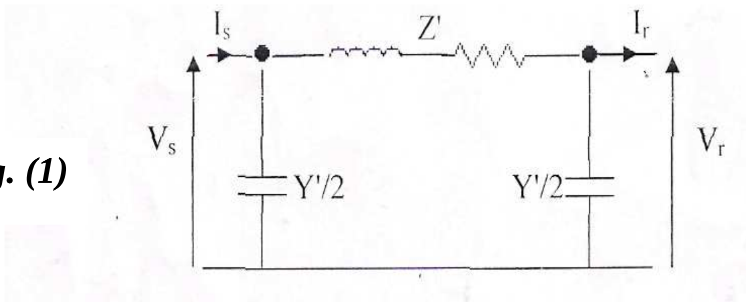
1) To determine the ABCD constants, line characteristic impedance and propagation constant.
2) To determine the shunt reactance to counteract the voltage rise on no load.
3) To determine the voltage profile along the line with and without shunt compensation.
4) To determine the reactive power required for zero regulation at different loads.

Introduction:-

Long lines give rise to special problems in power systems. The voltage at the receiving end may rise on no load or light load, beyond permissible limits, but on load, the voltage may go below normal. The phase shift may become exceedingly large and lead to instability problems. The no load current, may be large, if no compensated and interrupting, such currents present problems. This experiment will help in understanding some of the problems associated with long lines.

The long transmission line can be represented as the equivalent circuit shown in Fig.1:

Fig. (1)



The equations for long transmission by using general constants of two ports network shown in Fig.2 can be written as follows:

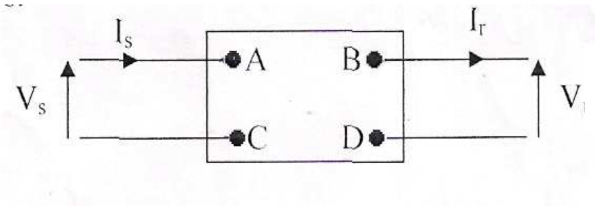


Fig. (2)

$V_s = AV_r + BI_r \dots\dots (1)$ $\qquad I_s = CV_r + DI_r \dots\dots (2)$

And the equations for long transmission are:

$$V_s = V_r \cosh \gamma_L + Z_c I_r \sinh \gamma_L \dots\dots (3)$$

$$I_s = \left({V_r}/{Z_c} \right) \sinh \gamma_L + I_r \cosh\gamma_L \dots\dots (4)$$

By comparing the equations (1) & (2) with (3) & (4) yield:

$$A = D = \cosh\gamma_L , B = Z_c \sinh \gamma_L , C = \left({1}/{Z_c} \right) \sinh \gamma_L , AD - BC = 1$$

Impedance of transmission line at sending end when receiving end open circuit = $Z_{so} = {V_s}/{I_s} = {A}/{C}$.

Impedance of transmission line at sending end when receiving end short circuit = $Z_{ss} = {V_s}/{I_s} = {B}/{D}$.

Line characteristics impedance = $Z_c = \sqrt{Z_{so} Z_{ss}}$

Propagation constant = $\gamma_L = \sqrt{ZY} = \alpha_L + \beta_L$

α_L= Attenuation constant,

β_L= Phase constant in radians per unit length.

Procedure:-

Part I

1) Connect the transmission lines as shown in Fig.3 to represent single phase long transmission line.
2) Measure Zso by apply 110V in sending end and receiving end open circuit.
3) For measuring Zss, pass a current of 5A or less in receiving end when it short circuit by apply low voltage in sending end.
4) Calculate Zso and Zss (as phasor) and ABCD constants (as phasor) and specify the unit of each constant.
5) Determine Zc and γ_L as phasor.
6) Calculate the total phase shift β_L.
7) Comment on magnitude and angle of A, angle of Zso and the total phase shift.

Part II

1) Connect the transmission lines as shown in Fig.4 to represent single phase long transmission tine.
2) When the switch OFF adjust the sending end to 110V and note the receiving end voltage.
3) When the switch ON adjust the shunt reactance till the receiving end voltage reaches 110V (Vs=Vr).
4) Note the current taken by the reactor and determine its VAR rating and its ohmic value.

Part III

1) With adjustment as in part II above.
2) When the switch OFF. Measure the voltage at the sending end, one third, two thirds of the length and at the end of the line.
3) When the switch ON. Measure the voltage at the sending end, one third, two thirds of the length and at the end of the line.

4) Plot the voltage profiles with and without the shunt reactor and compare the results in the cases.

Part IV

1) Connect the transmission lines as shown in Fig.5 to represent single phase long transmission line.
2) Adjust the loading resistance to take a power between 0 and 400 watts in steps of about 50 watts.
3) For each value of power, adjust L or C of the loading units to make Vr = l 10V.
4) For each value of power determine ±Q, the reactive power to obtain the condition (Vr=Vs=l 10V).
5) Plot the result in the P-Q plane.
6) What is the approximate shape of the current?
7) Comment on results.

Answer: What are the used of shunt reactors, capacitors and synchronous motors in power system?

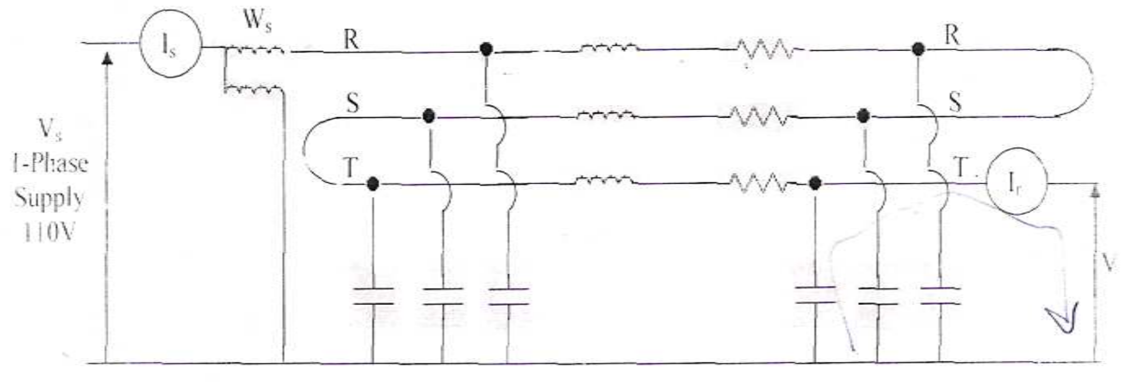


Fig.3

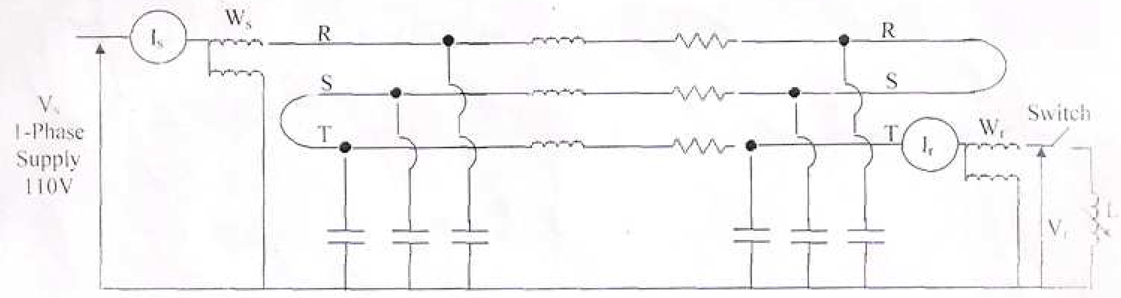


Fig.4

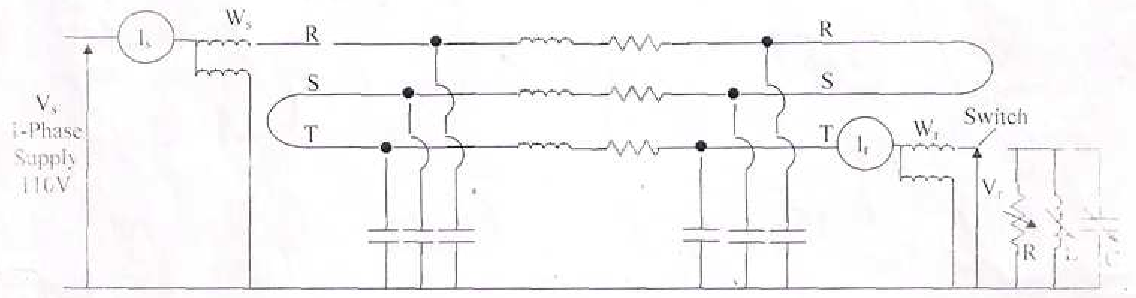


Fig.5

EXP. No. 10

Neutral Grounding

***Aim*:-** To study the effect of system neutral grounding on single line to ground faults.

***Introduction*:-**

Neutral grounding has been in practice in many systems all over the world; but there are some systems which still operate with ungrounded neutral. Ungrounded system is one in which there is no intentional system, there always exists a capacitive coupling between the system conductors and ground. When the neutral of a system is not grounded it is possible for high voltages to appear from line to ground during normal switching of a circuit having a line to ground fault.

These voltages may cause failure of insulation at other locations on the system and results in damage to equipment. A ground fault on one phase cases full line to line voltage to appear between ground and the two unfaulted phases. Line to ground fault on ungrounded neutral systems causes very little ground fault current to flow and it may not be enough to actuate protective relays. The neutral of the system may be grounded through resistance, reactance, or directly. Generally the neutral of source transformers or generators with star connected windings is grounded. Grounding the neutral reduce the magnitude of transient voltage, improve protection against lightning, protection of line to ground faults become reliable, improve reliability and safety. Also the potential of the neutral gets fixed, where as in the grounded system, the neutral will be floating .

The value of reactance used to ground the neutral will be chosen to either neutralize the capacitive current or to limit the line to ground fault current to that of a three phase fault current. The value of the resistance is chosen to limit the line to ground fault current to that of a three phase fault current.

Procedure:-

Part I:-

Ungrounded Neutral:-

Connect as in Fig. 1. Keep S1, and S2 open, thus isolating the neutral of the transformer from the ground. It is now equivalent to a line to ground fault on phase T.

Vary the line to line voltage V_S (line to line voltage at sending end), starting at zero, and in steps of 20V. For each value of V_S, note V_O, I_T, I_F, Is and V_R. Make sure that the current in the line and the transformer is within the rated value.

Part II:-

Neutral Grounded Through a Reactor:-

Close S2 connecting the reactor X_O between the neutral and ground. Keep S1 open as before. Keep the line to line voltage V_S constant at 110V. Vary X_O from a large value to a minimum possible, keeping I_T within the rated current of the line. For each value of X_O, note V_O, I_F, I_C, I_T, I_{XO}, and V_R. Note that I_F reaches minimum.

Neutral Grounded Through a Resistor:-

Open S2 and Close S1. The neutral of transformer is now connected to the ground through the resistor R_O. Keep V_S constant at 110V. Vary R_O from a large value to a minimum possible, keeping I_T within rated value. For each step of R_O note V_O, I_F, I_C, I_T, I_{RO}, and V_R. Note that I_F passes through a minimum.

Report:-

1) From the readings of part I, plot each variable verse V_S.
2) From the readings of part II (a) and (b), plot each variable verse I_{XO} and I_{RO} respectively.
3) Calculate the value of X_O and there from L_O for minimum value of I_F. Also calculate the value of L_O from($L_O = \left({}^{1}\!/_{3\omega^2 C} \right)$), where C is the

line to ground capacitance. Compare the two values of L_O and comment.

4) Calculate the value of R_O for minimum value of I_F.

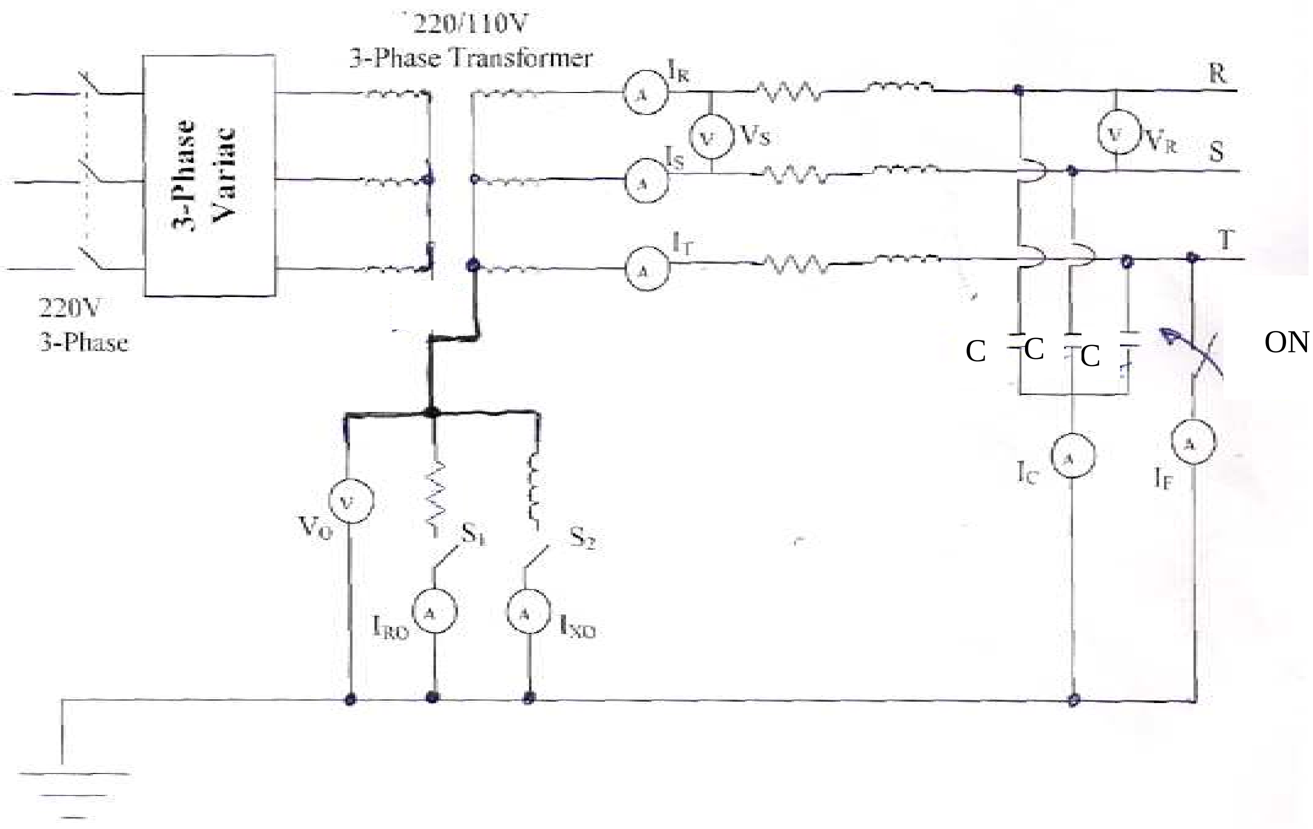


Fig. (1)

EXP. No. 11

Potential Distribution Along Suspension Insulator String

Aim:- 1) To study factors affecting the potential distribution.

2) To acquaint students methods of the string efficiency improvement.

Theory:- A string of suspension insulators consists of a number of porcelain or glass discs connected in series through metallic links. The insulation part of each disc is inserted between two metal links. Therefore each disc forms a capacitor (C) and this is known as mutual capacitance or self capacitance. The typical value of this capacitance is about 30 pF. If there were mutual capacitance alone, then charging current would have been the same through all discs and consequently voltage across each unit would have been the same (see Fig. 1a). However, in actual practice capacitance also exists between metal fitting of each disc and tower or earth. This called shunt capacitance (C_O). Due to shunt capacitance charging current is not the same through all discs of string. Therefore, voltage across each disc seems to be different (see Fig. 1b). Obviously, the disc nearest to the line conductor has much higher voltage than the other disc. This unequal potential distribution is undesirable and is usually expressed in terms of string efficiency which is defined as the ratio of voltage across the whole string to the product of number ***n*** of discs and the voltage across the disc nearest to the conductor i.e.

$$String\ Efficiency = \frac{Voltage\ across\ the\ string}{n * Voltage\ across\ disc\ nearest\ to\ conductor}$$

The greater the string efficiency, the more uniform is the voltage distribution. Thus 100% string efficiency is an ideal case for which the voltage across each disc will be exactly the same.

Fig.1b shows the equivalent circuit for a 5-unit string. Let us assume that shunt capacitance C_O is some fraction K of self capacitance i.e. Co=KC. Starting from the tower, the voltage across each unit is V_1, V_2, V_3, V_4, and V_5

respectively as shown. Applying Kirchhoff's current law to nod points A, B, C, and D, we get:

$$I_2 = I_1 + i_1 \quad or \quad V_2(2\pi fC) = V_1(2\pi fC) + V_1(2\pi fKC)$$

$$and\ V_2 = V_1(1 + K)$$

$$I_3 = I_2 + i_2 \ \ or \ \ V_3(2\pi fC) = V_2(2\pi fC) + (V_1 + V_2)(2\pi fKC)$$

$$and\ V_3 = V_1(1 + 3K + K^2)$$

$$I_4 = I_3 + i_3 \ \ or \ \ V_4(2\pi fC) = V_3(2\pi fC) + (V_1 + V_2 + V_3)(2\pi fKC)$$

$$and\ V_4 = V_1(1 + 6K + 5K^2 + K^3)$$

$$I_5 = I_4 + i_\$ \ \ or \ \ V_5(2\pi fC) = V_4(2\pi fC) + (V_1 + V_2 + V_3 + V_4)(2\pi fKC)$$

$$and\ V_4 = V_1(1 + 10K + 15K^2 + 7K^3 + K^4)$$

If the total number of units in a string is **N** the voltage between the unit number **n** (where 0 < n < N) and the earthed tower can be calculated using generalized solution as

$$V_n = V\frac{\sinh(\sqrt{K}n)}{\sinh(\sqrt{K}N)}$$

The following points may be noted from the above mathematical analysis:

1. The disc nearest to the conductor has the maximum voltage across it.
2. The greater the value of K (= C_O/C), the more non-uniform is the potential across the disc and lesser is the string efficiency.
3. The inequality in voltage distribution increases with the increase of number of discs in the string. Therefore, shorter string has more efficiency than the longer one.

If the insulation of the highest stressed insulator breaks down, the breakdown of other units will take place in succession. This necessitates to equalize the potential across the various units of the string i.e. to improve the string efficiency. The various methods for this purpose are:

1) <u>By using longer cross arms</u>

The value of string efficiency depends upon K i.e. ratio of shunt capacitance to self capacitance. The value of K can be decreased by reducing the shunt capacitance. In order to reduce shunt capacitance, the distance of conductor from tower must be increased i.e. longer cross arms should be used. However, limitation of cost and strength of tower do not allow the use of very long cross arms. In practice K=0.1 is the limit which can be achieved by this method.

2) By grading insulators

In this method insulators of different self capacitance are used. The insulators are capacitance graded i.e. they are assembled in the string in such a way that the top unit has the minimum capacitance increasing progressively as the bottom unit (i.e. the nearest to conductor) is reached. Since the voltage is inversely proportional to capacitance this method tends to equalize the potential distribution. The advantage of this method is a large number of different size insulators which are required to assemble the string.

3) By using guard ring

The Potential across each unit in a string can be equalize by using a guard ring which is a metal ring electrically connected to the conductor and surrounding the bottom insulator as is shown in Fig.2. The guard ring introduces capacitance between metal fittings and the line conductor. The ring is contoured in such a way that shunt capacitance currents i_1, i_2 etc are equal to metal fitting line capacitance currents i_1', i_2' etc. The result is that the same charging current I flows through each unit of string. Consequently, there will be uniform potential distribution across the units.

Procedure and Report:-

Part I

1) Calculate the voltage distribution for 5-unit string of insulators and its efficiency for the following values of K: 0.22, 0.1, and 0.069.

2) Connect the circuit of the insulator string model neglecting the line to pin capacitance (Fig.3) and measure using a high input impedance voltmeter the voltage distribution along string model for K equal to 0.22, 0.1, and 0.069. Find the string efficiency of each connection.
3) Compare the measurement results with the calculations obtained above and plot the voltage across each unit (expressed as a percentage of the average value) against the number of the insulator.

Part II

1) It is required to improve the voltage distribution of a string having 5 suspension insulators Fig.3. Determine the line to pin capacitances (C_1, C_2, C_3 and C_4) that would give the same voltage across each insulator of the string if the pin earth capacitance are equal to KC (C=1μF).
2) Make the connection as the string model shown in Fig.3 using box capacitors as the line to pin capacitances, set the capacitors for the above calculated values K is equal to 0.22, 0.1, and 0.069 in turn, and record the potential distribution for each setting.

Answer the Following Problems:-

1) Describe with neat sketch the various types of insulators used as the overhead line insulators.
2) Explain how electrical breakdown can occur in insulators.
3) Explain why such big value of self capacitance (1 μF) applied in the model makes the voltage distribution measurements more accurate.

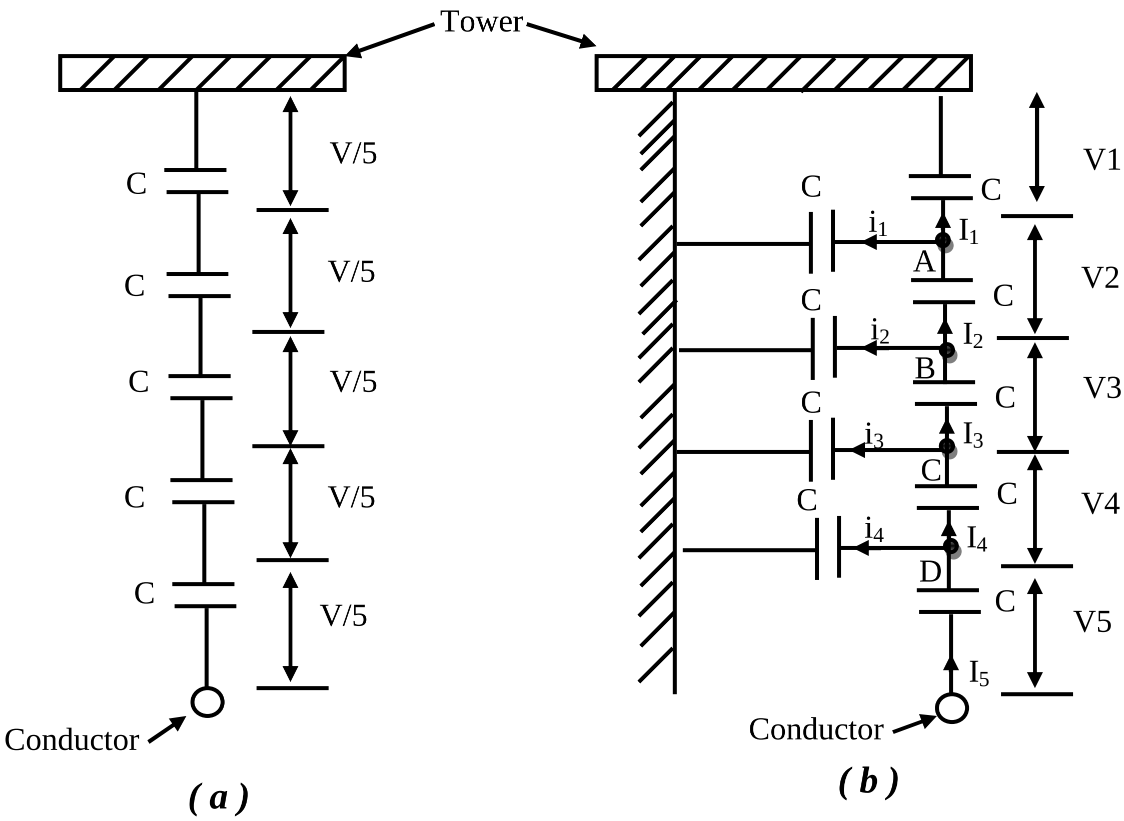

Tower
C
C
C
C
C
V/5
V/5
V/5
V/5
V/5
Conductor
(a)
C
C
C
C
C
C
C
C
C
i1
i2
i3
i4
I1
I2
I3
I4
I5
A
B
C
D
V1
V2
V3
V4
V5
Conductor
(b)

Fig. (1)

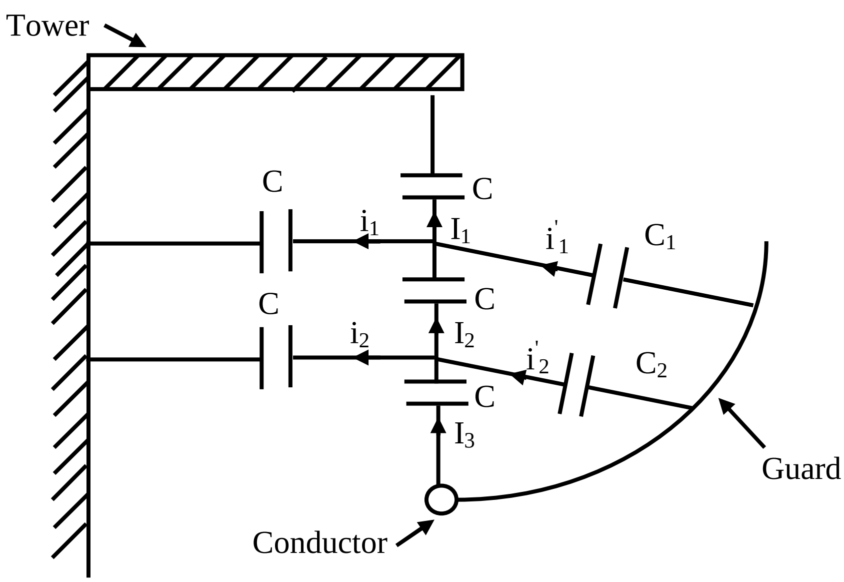

Tower
C
C
C
C
C
i1
i2
I1
I2
I3
i'1
i'2
C1
C2
Guard
Conductor

Fig. (2)

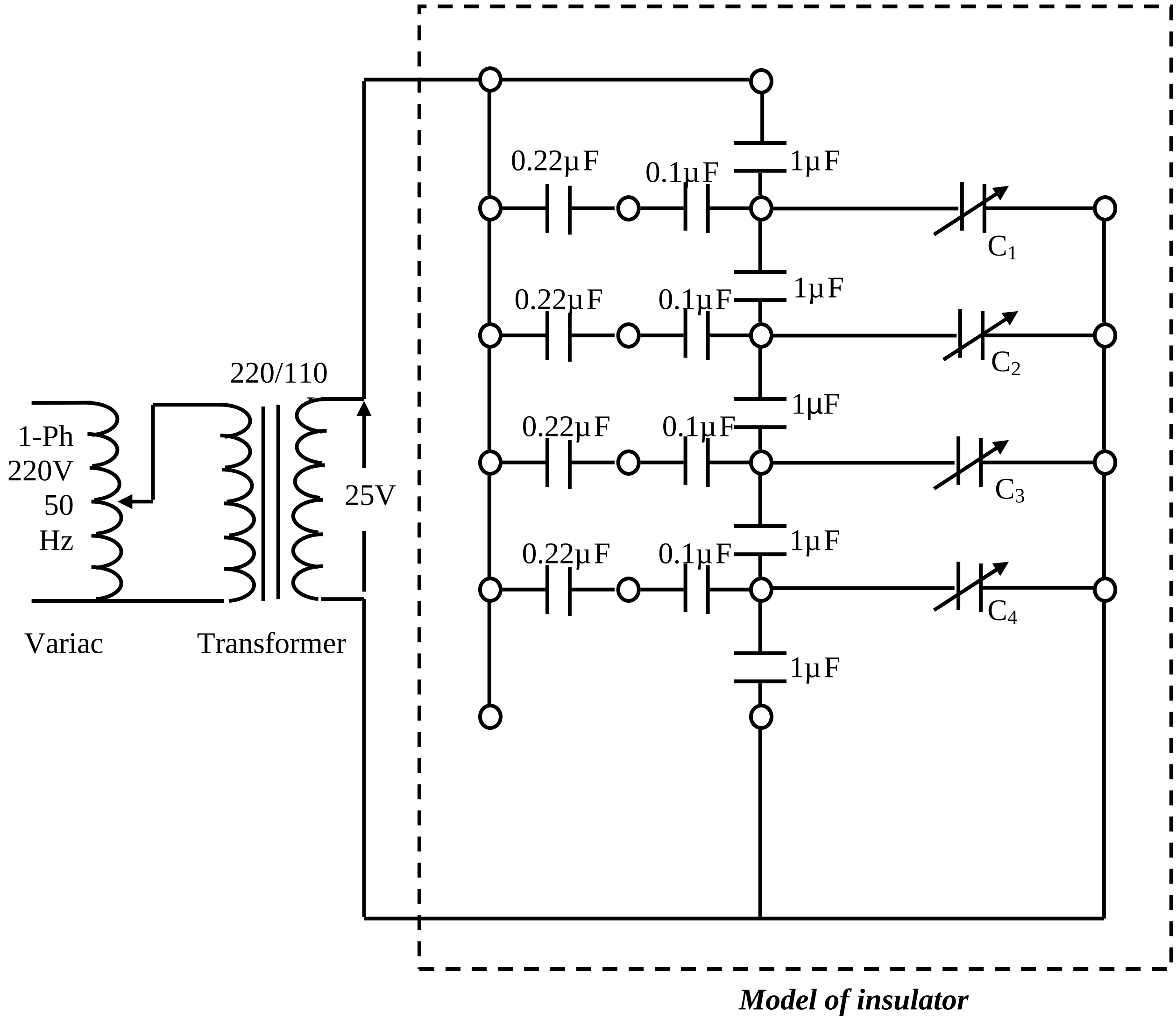

0.22μF
0.1μF
1μF
C1
C2
C3
C4
220/110
1-Ph
220V
50
Hz
25V
Variac
Transformer
Model of insulator

Fig. (3)

EXP. 12

Voltage Regulation of 3-Phase Alternator

Aim:- To perform no-load and short circuit tests on a given three-phase alternator and to predetermine its regulation by synchronous impedance method. Also to perform the load test on the alternator and hence to determine its regulation.

Theory:- The no-load terminal voltage of an alternator depends upon the following two factors (i) the speed of the magnetic field relative to the armature (this fixes the value of the frequency of the generated voltage). (ii) The value of the field excitation (this governs the magnitude of flux per pole).

When an alternator is loaded, the terminal voltage is found to change even if the speed of the magnetic field and the field excitation are maintained constant. This change in terminal voltage under load conditions is due to: a) voltage drop in the armature winding caused by winding resistance and internal reactance, b) Armature reaction.

The difference in the terminal voltage between no load condition and load condition is called the voltage regulation. It is normal practice to express it as a percentage of the terminal voltage at the specified load.

Definition:- Voltage regulation of an alternator is defined as the change in its terminal voltage when the machine which is originally supplying a specified load at a specified power factor is suddenly relieved of its load, this being expressed as a percentage of the load voltage. The other conditions, namely the speed of the machine and the field excitation are kept unchanged during this process.

$$Percentage\ regulation = \frac{V_O - V}{V} * 100\%$$

Where, V= terminal voltage per phase on load.

V_O= terminal voltage per phase when load is removed.

In the synchronous impedance method or EMF method the effect of armature reaction is considered by introducing an equivalent fictitious reactance, called synchronous reactance.

When the resistance of the armature is also considered the effective impedance of the armature is called the synchronous impedance. If the load condition on the machine is specified and the terminal voltage on load is known, it is possible to predict the corresponding terminal voltage at no load from the knowledge of the synchronous impedance of the machine. Referring to the phasor diagram of an alternator as shown in Fig.l, where,

I=load current per phase, ϕ=load impedance angle, Z_S= synchronous impedance per phase, X_S=synchronous reactance per phase, R_a=armature resistance per phase. The no load terminal voltage is given by :

$$V_O = ((V\cos\emptyset + IR_a)^2 + (V\sin\emptyset + IX_S)^2)^{1/2}$$

In the above expression positive sign is used for lagging power factor and negative sign is used for leading power factor.

Procedures:-

Determination of R_a and Z_S

The d.c. value of armature resistance can be measured by applying a low voltage across one of the armature phase windings and measuring the current. The ratio of voltage to current gives the d.c. value of armature resistance per phase. The a.c. resistance R_a can be obtained by multiplying the d.c. resistance by a factor of 1.2 to take into consideration the skin effect.

The synchronous impedance Z_S can be determined experimentally by performing the no-load test and short-circuit test on the machine. It can be shown that the synchronous impedance per phase is given by :

$$Z_S = \frac{No - load\ terminal\ voltage\ per\ phase\ at\ a\ particular\ excitation}{Short\ circuit\ current\ per\ phase\ at\ the\ same\ excitation}$$

when the machine is driven at the synchronous speed of the machine. Thus,

$$X_S = \sqrt{(Z_S^2 - R_a^2)}$$

No-load test

Connect the machine as shown in part (a) of Fig.3. Run the machine at its synchronous speed with the help of a d.c. motor coupled to it. Supply the field winding of the alternator with excitation . Vary the excitation current in the increasing order (or in the decreasing order, but not both at the same time). Record no-load voltage V_O and excitation current I_f. Take readings till you reach no-load voltage value equal to 120 percent of the rated voltage. This is necessary to take the saturation effect into account.

Short circuit test

The alternator connections are now modified as shown in part (b) of Fig.3. The machine is run up from the d.c. side and the speed is adjusted to the synchronous speed. The excitation is reduced to zero and the switch S is closed. The excitation current I_f is slowly varied and the corresponding short circuit current I_{SC} is recorded. Take readings till you reach short circuit current equal to 120 percent of the full load current.

Load test

The alternator connections are again modified as shown in part (c) of Fig.3. The machine is run and the speed is adjusted to synchronous speed.

i. The resistive load and the excitation are adjusted so that the alternator delivers a load current of 6.5 amps at rated voltage. Record excitation current I_f, load current I_a, terminal voltage V and wattmeters readings W_1 and W_2. Keeping this excitation unchanged, switch off the load and record the no-load terminal voltage V_O.
ii. The parallel combination of resistive and inductive loads and the field excitation are simultaneously adjusted so that the alternator delivers at rated voltage a load current of 6.5 amps at power factor of 0.5 lagging. Under this condition one of the wattmeters will read zero power.

Record again I_f, I_a, V, W_1 and W_2. Keeping this excitation unchanged, switch off the load and record V_O.

Calculations:-

From the graphs of V_O / I_f and I_{SC} / I_f calculate the regulation by synchronous impedance method and compare it with the results obtained by the load test.

Report:-:

1. Plot no load terminal voltage V_O and short circuit current I_{SC} against excitation current I_f (x-axis).
2. Determine Z_S and X_S corresponding to the excitation needed to develop rated voltage on open circuit.
3. Also determine Z_S for a number of field excitations from open circuit and short circuit tests. Plot Z_S (y-axis) against field excitation (x-axis).
4. Calculate regulation of the alternator corresponding to a load current of 6.5 amps unity power factor and 0.5 power factor lagging by EMF method using the value of X_S obtained in step 2 above.
5. Also calculate regulation of the alternator under conditions specified in step 3 from the load test.
6. Compare the results and give your comments.

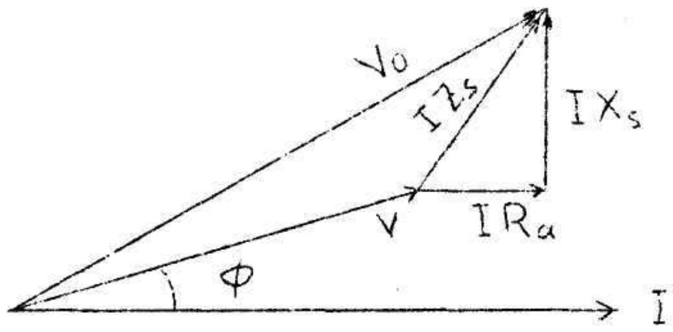

Vo
IZs
IXs
V
IRa
Φ
I

Fig.(1)

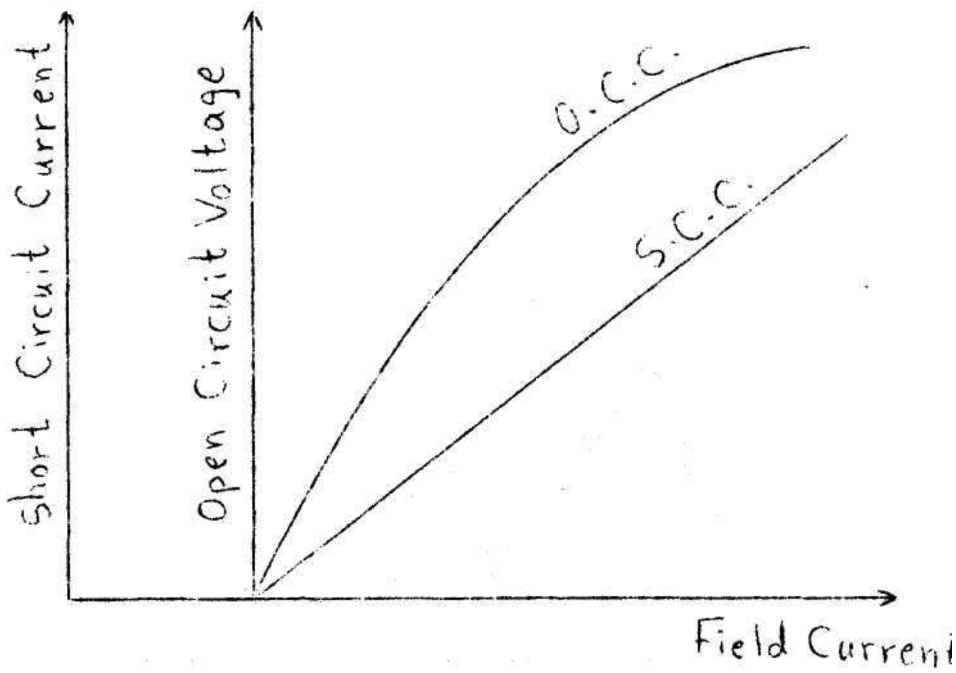

Short Circuit Current
Open Circuit Voltage
O.C.C.
S.C.C.
Field Current

Fig.(2)

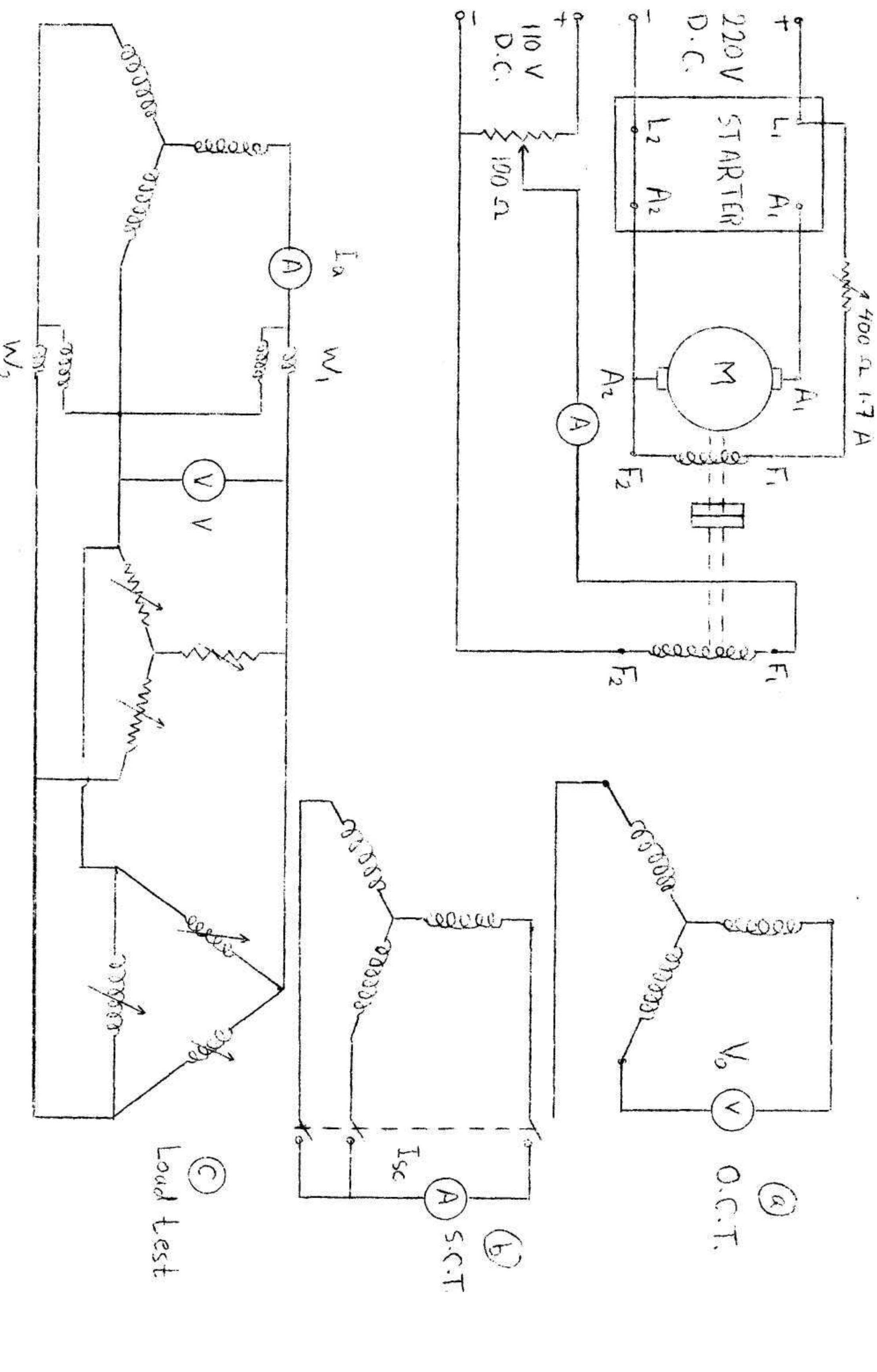


Fig.3

EXP. No. 13

Testing of a Three Phase Synchronous Generator

Aim:- To determine the basic steady state operating characteristic as well as open and short circuit characteristics.

Theory:-

Open circuit characteristic (O.C.C.) of a S.G.: It is the relation between the e.m.f. E induced in the armature winding and the field current at constant speed ***($E = f (I_f)$ at $\omega = \omega_S$ = constant and $I_a = 0$)***. The value of the e.m.f. at zero field current (I =0) differs from zero. This residual voltage V_{res} is caused by the residual magnetization of the generator (Fig.l.a). The basic features of the magnetic circuit of the S.G. can be determined with the help of the O.C.C. These are:

- the value of the residual voltage V_{res}.
- the value of the magnetic hysteresis according to the width of the O.C.C. measured at increasing and decreasing of the field current.
- saturation factor K_S, on the basis of the mean value of the O.C.C. (No.2 Fig.l.a).

The saturation factor is defined as the ratio of the total m.m.f. to the m.m.f. of the air gap at the e.m.f. E= rated voltage, thus from Fig.l.b:

$$K_S = \frac{F_t}{F_g} = \frac{\overline{AC}}{\overline{AB}}$$

Another characteristic quantity which can be determined from O.C.C. is the value of the filed current I_{fn} at which E = V_n . Where V is the rated voltage.

External characteristic : It is the relation between the terminal voltage V and the armature current I_a at the constant value of the rotor speed, constant filed current and constant value of the power factor (Fig.2). The test is usually carried out at $I_f = I_{fn}$. The change in the terminal voltage under load conditions is due to :

- Armature reaction effect (magnetizing or demagnetizing).
- Voltage drop in the armature winding caused by the winding resistance and internal reactance.

The numerical difference in terminal voltage between no load condition E_O and full load condition V_n is called voltage regulation. It is normal practice to express it as a percentage of the terminal voltage at the specified load:

$$V.R.\% = \frac{E_O - V_n}{V_n} * 100$$

__Load characteristic__: It is the relation between the terminal voltage V and the field current I_f at constant armature current, constant power factor and the constant speed ω_S (Fig.3). The most important, from the practical point of view, is the load characteristic at pure inductive load (Cosϕ = 0 lag.). It is situated below the O.C.C. which is also a particular case of a load characteristic (at I_a =0).

__Compound (regulation) characteristic__: It is the relation between the field current If and the armature current Ia at constant (rated) terminal voltage, constant speed ωS and constant value of the power factor (Fig.4). The shape of this characteristic is determined by the appropriate external characteristic. This means that the compound characteristic shows how the field current of a S.G. should be changed in order to maintain constant value of terminal voltage when the load current is varied.

__Short circuit characteristic (S.C.C.)__: It is the relation between the armature short circuit current ISC and the field current If at the constant speed ωS and zero terminal voltage (Fig.5.a). At zero value of the field current, the S.C.C. passes through $I_{ares} = V_{res}/ X_S$.

This is the current caused by the residual magnetization of the S.G. An important value which can be determined from S.C.C. is I_f' which is the value of the field current at which the short circuit armature current $I_{SC} = I_{ar}$ (rated value).

The short circuit ratio (S.C.R.) is the quantity which determines the stability of a 3-phase S.G. working with the power system. The value of the S.C.R. can be determined on the basis of the O.C.C. and S.C.C. as follows:

$$S.C.R. = \frac{I_{fn}}{I_f'} (p.u.)$$

It can be proved that S.C.R.= 1 / X_S if the machine is unsaturated and X_S is in p.u.; where X_S= synchronous reactance, R_a= armature resistance.

In most of the S.G.: $X_S >> Ra$, hence the change of the generator's speed (frequency) at short circuit test (at I_f = constant) does not influence the value of the armature short circuit current I_{SC} , in a very wide range of speed (frequency) (Fig.5.b).

Procedures:-

Resistance: Resistances of the armature and field windings should be measured, each for three different values of current.

No-load(open circuit)characteristic: ***(E=f (I_f) at $\omega=\omega_S$=constant and I_a=0)***
Connect the machine as shown in Fig.6.a. The machine is run at its synchronous speed with a d.c. motor coupled to it. With the field winding of the S.G. not excited record the value of the terminal voltage. Switch on the excitation current and vary it. Record the no load voltage and the excitation current I_f. Take readings till you reach no load voltage value equal to 120% of the rated value. This is required to take the saturation effect into account. In order to determine the influence of the magnetic hysteresis loop on the O.C.C. take from 6 to 10 readings while increasing the current I_f to its maximum value and then take 6 to 10 readings while decreasing the current

I_f in steps to zero. If the generator's speed n_x is different from the nominal value n , then the proper value of the e.m.f. can be calculated:

$$E = E_X \frac{n_n}{n_x}$$

<u>*External characteristic*</u>*:* ***(V=f (I_a) at $\omega=\omega_S$=constant, I_f= I_{fn} and cosϕ=constant)***

Connect the machine as shown in Fig.6.c. The machine is run at its synchronous speed and the field current I_f = I_{fn} is adjusted to give the rated terminal voltage at no load. To the generator's terminals connect:

a) 3-ph variable resistor (Cosϕ =1).
b) 3-ph variable inductor (Cosϕ = 0 lag.).
c) 3-ph variable capacitor (Cosϕ = 0 lead.).

In each case (a, b, c) adjust the load so that the armature current is varied from zero to the rated value (except point c). Record the excitation current I_f, load current I_a, terminal voltage V , wattmeter's readings W_1 and W_2.

<u>*Load characteristic*</u>*:* ***(V=f (I_f) at I_a=constant, $\omega=\omega_S$=constant and cosϕ=constant)***

Connect the machine as shown in Fig.6.c and run it at the synchronous speed. The armature current I_a should remain constant while changing the impedance of the load. Among the measured characteristics, the most important one is that taken at power factor =0 lagging and the rated armature current. Record the terminal voltage V, field current I_f, armature current I_a which is constant and wattmeter's readings W_1 and W_2.

<u>*Compound (regulation) characteristics*</u>*:* ***(I_f =f (I_a) at V=V_n, $\omega=\omega_S$=constant and cosϕ=constant)***

Connect the circuit as shown in Fig.6.c. At no load, adjust the field current so that the terminal voltage is equal to its rated value. Connect the load and while changing its value (at Cosϕ = constant) vary the value of the field current in order to maintain the terminal voltage at its rated value. Take 5 readings at different values of the armature current. Repeat the test for 3 different types of load :

a) resistive (Cosϕ = 1).
b) inductive (Cosϕ = 0. lagg.)
c) capacitive (Cosϕ = 0. lead)

<u>*Short circuit characteristic*</u>*:*

a)(I_{SC} =f (I_f) at V=0 and $\omega=\omega_S$=constant (Fig.5.a))

Connect the circuit as shown in Fig.6.b and short circuit the armature through 3 ammeters. The speed of the machine is adjusted to the synchronous speed and the excitation is reduced to zero. The excitation current I_f is gradually increased and the corresponding short circuit armature current I_{SC} is recorded. Take at least 5 readings till you reach short circuit current to about 120% of the full load current.

b)(I_{SC} =f (ω) at V=0 and I_f =constant (Fig.5.b))

The machine is connected as shown in Fig.6.b and is run with the synchronous speed. The field current I_f' is adjusted to give the rated armature current at short circuit. Reduce gradually the speed of the machine to zero by increasing the field current of the d.c. motor and by increasing the resistance in the armature circuit of the d.c. motor. Take 6 to 8 readings and at least half of them should be taken at very low speeds.

<u>Note</u>:- If necessary, introduce the additional resistor into the d.c. motor's armature circuit in order to obtain very low angular speed of the motor - generator set.

<u>Report</u>:

1) Plot the O.C.C.
2) Determine the value of the saturation factor at E = V_n.

3) Plot the external characteristics at three different values of the power factor.
4) Plot the load characteristic for pure inductive load.
5) Plot the compound (regulation) characteristics.
6) Plot the S.C.C. a) at $\omega_S = \omega$ = constant : $I_{SC} = f(I_f)$

   b) at I_f = constant : $I_{SC} = f(\omega)$
7) Determine the value of the S.C.R.
8) Prove and discuss the shapes of the characteristics, particularly part 6.b.

Dr. Mark Chomiakow

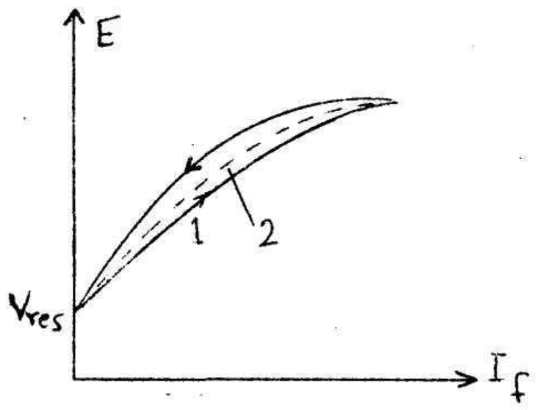


Fig. (1-a)

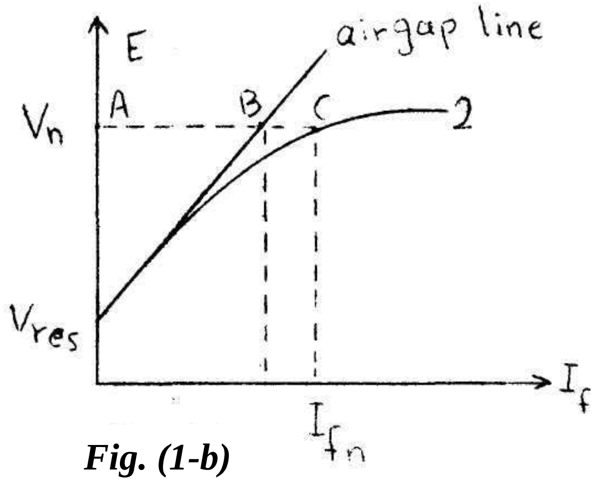


Fig. (1-b)

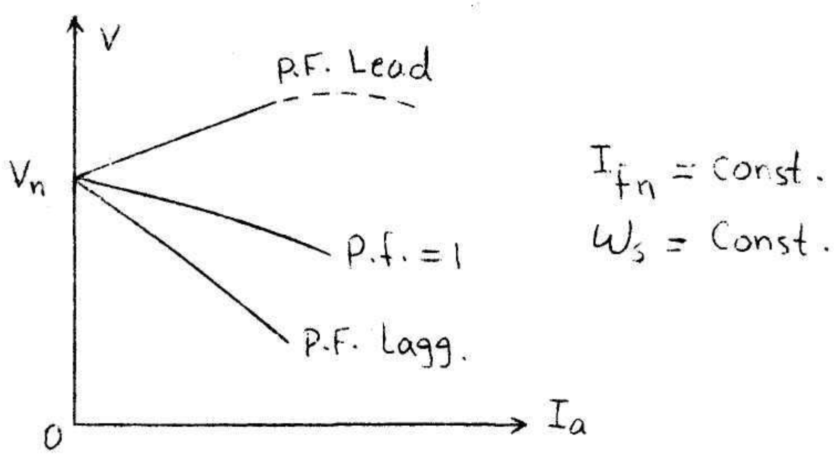
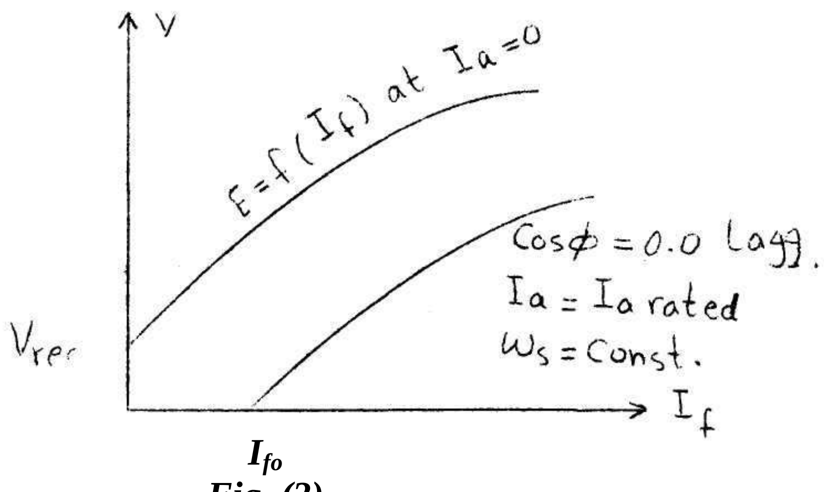


Fig. (2)



I_{fo}
Fig. (3)

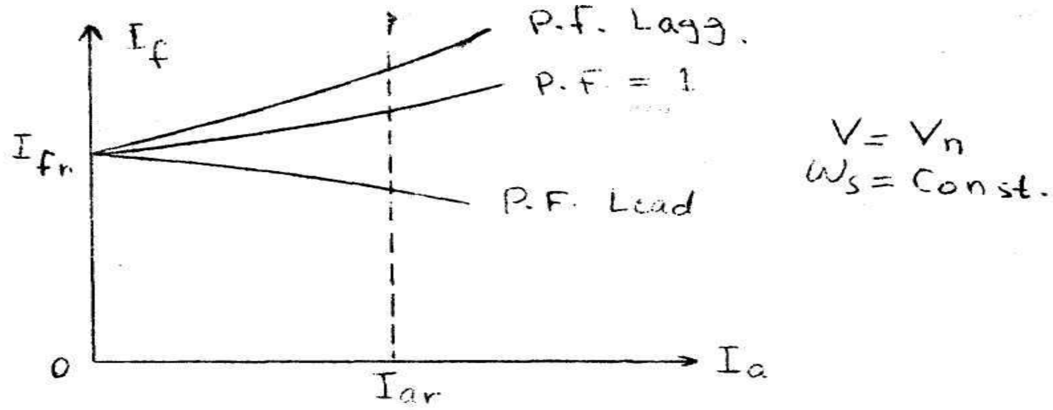


Fig. (4)

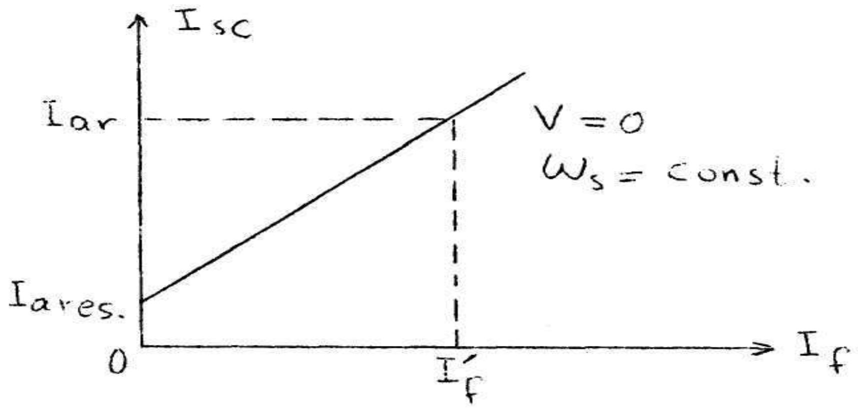


Fig. (5-a)

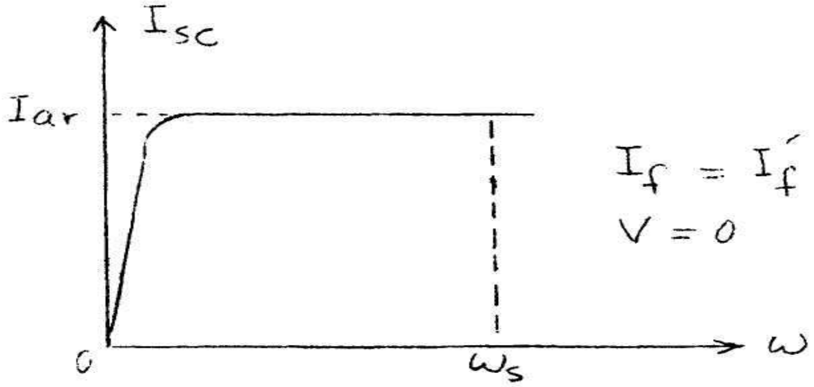


Fig. (5-b)

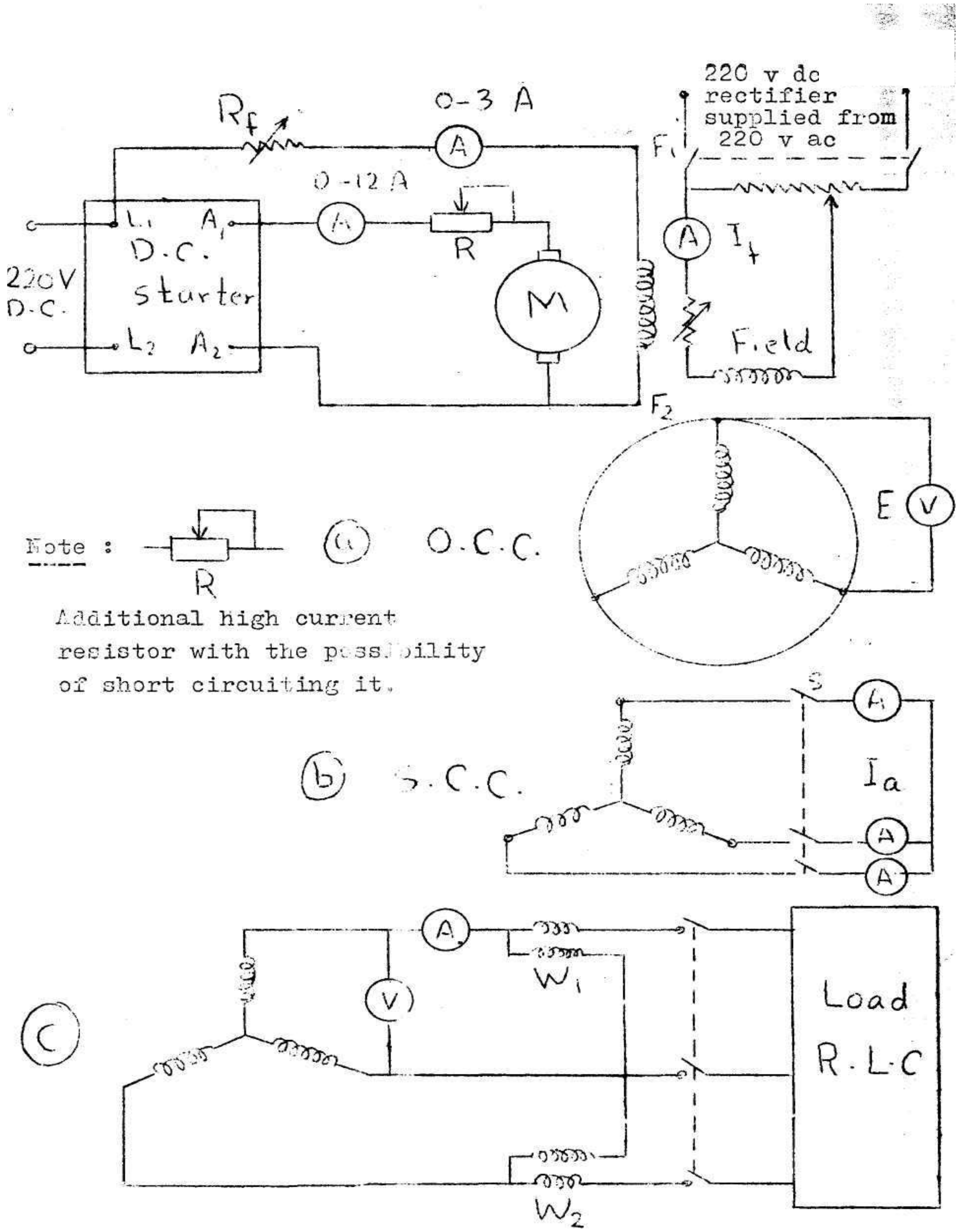


Fig. (6)

EXP. No. 14

Synchronization of a Three-Phase Alternator With Infinite Bus-Bar and Operation With Constant Power Output

Aim:- A synchronizing panel is used to synchronize the given 3-phase synchronous generator with the bus bars and the characteristics of the generator are determined for constant power output conditions.

Synchronizing Panel:- The detailed inside connection are shown in Fig.2. This consists of a synchroscope, double voltmeter, double frequency meter and a zero voltmeter. "The basic principles of the synchroscope may be studied from your last year Measurement Course work". The double voltmeter and double frequency meter indicate the voltages and frequencies on the bus and the generator sides respectively. The zero voltmeter shows the geometric difference between the voltages to be compared. For the purpose of synchronization, in addition to the synchronizing panel two phase-sequence indicators are also needed as shown in Fig.l.

Connection:- The connections are made as in the Fig.l. A load on the d.c. mains is provided to absorb the d.c. power in the event of synchronous machine operating as a motor. The wattmeter should be so connected as to measure the power 'output' of the synchronous machine. The d.c. starter unit contains the starting resistance R_a.

Procedure:- With the 3 phase mains switch (S_2) and the synchronizing switch (S_3) kept in "off" position, the d.c. switch (S_1) is put "on" and the speed is brought to 1500 rpm using R_{f2} if necessary. The 3-phase mains switch is put "on" and the voltage V_b is adjusted to the rated value (380V).

The phase sequence on the bus side and the generator side are noted. They should be the same. If they are different then the sequence of one of them should be changed, taking care to switch "off" both the a.c. mains and the d.c. excitation to the synchronous generator.

The excitation of the generator is then adjusted so that the voltage of the generator and the a.c. mains on the synchronizing switch are exactly the same making use of the double voltmeter on the panel. Then the speed of the generator is adjusted so that the frequencies of the generator and the bus are the same on the double frequency meter on the panel. The synchroscope on the panel is of the rotating type. The speed of rotation of the pointer will be high if the difference in frequencies is high. This speed decreases as the frequency difference is reduced. The correct moment of synchronization is when the pointer comes to the middle position pointing downwards. At this instant the "zero voltmeter" read zero. The synchronizing switch (S_3) is then closed, there by synchronizing the generator with the bus bar.

Constant Output Power Operation:-

1. The prime mover field is adjusted so that the synchronous machine just "floats" on the bus bar, that is, it neither absorbs nor delivers power (that is, W=0). For this condition, I_f the excitation of the synchronous generator is changed, taking care that the machine does not exceed the rated current. The readings of I_a, I_f,, and V are noted. (V is kept constant at its rated value).
2. The above test is repeated for two more values of output power fed into the bus bars. This is done by reducing the prime mover excitation. The readings of I_a, I_f and V are noted as before.

Results:-

1. Calculate the power factor in each case, using V, I_a and P.
2. Calculate Q, the reactive volt amp=$\sqrt{3} V I_a \sin \emptyset$.
3. Plot Q, I_a, and p.f. against I_f on x-axis. Indicate in the diagram the regions of lagging and leading P.Fs.
4. Explain with phasor diagram how the operating p.f. of the generator changes when the excitation is varied.

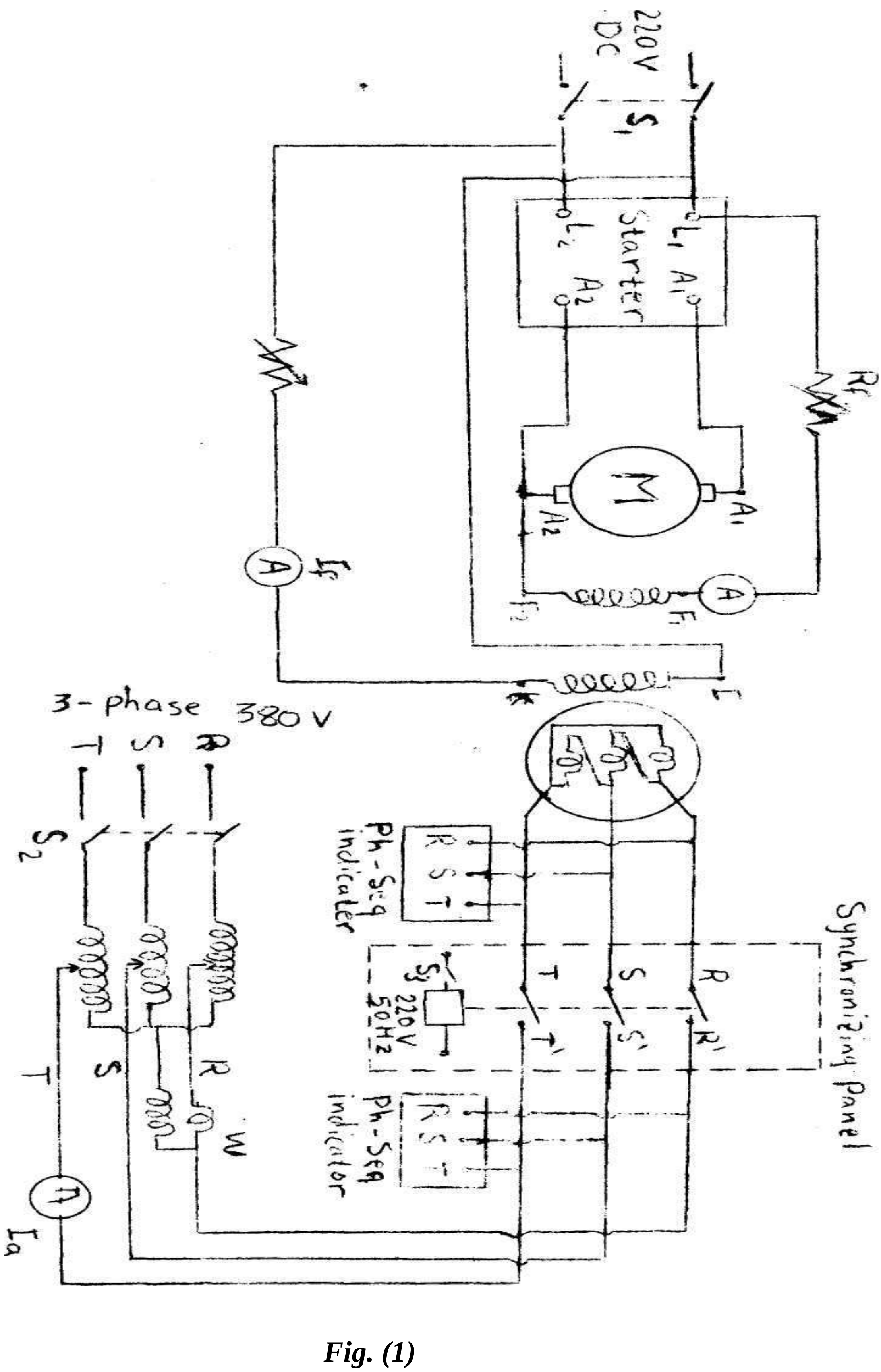

220V DC
Starter
M
3-phase 380V
Synchronizing Panel
220V 50Hz

Fig. (1)

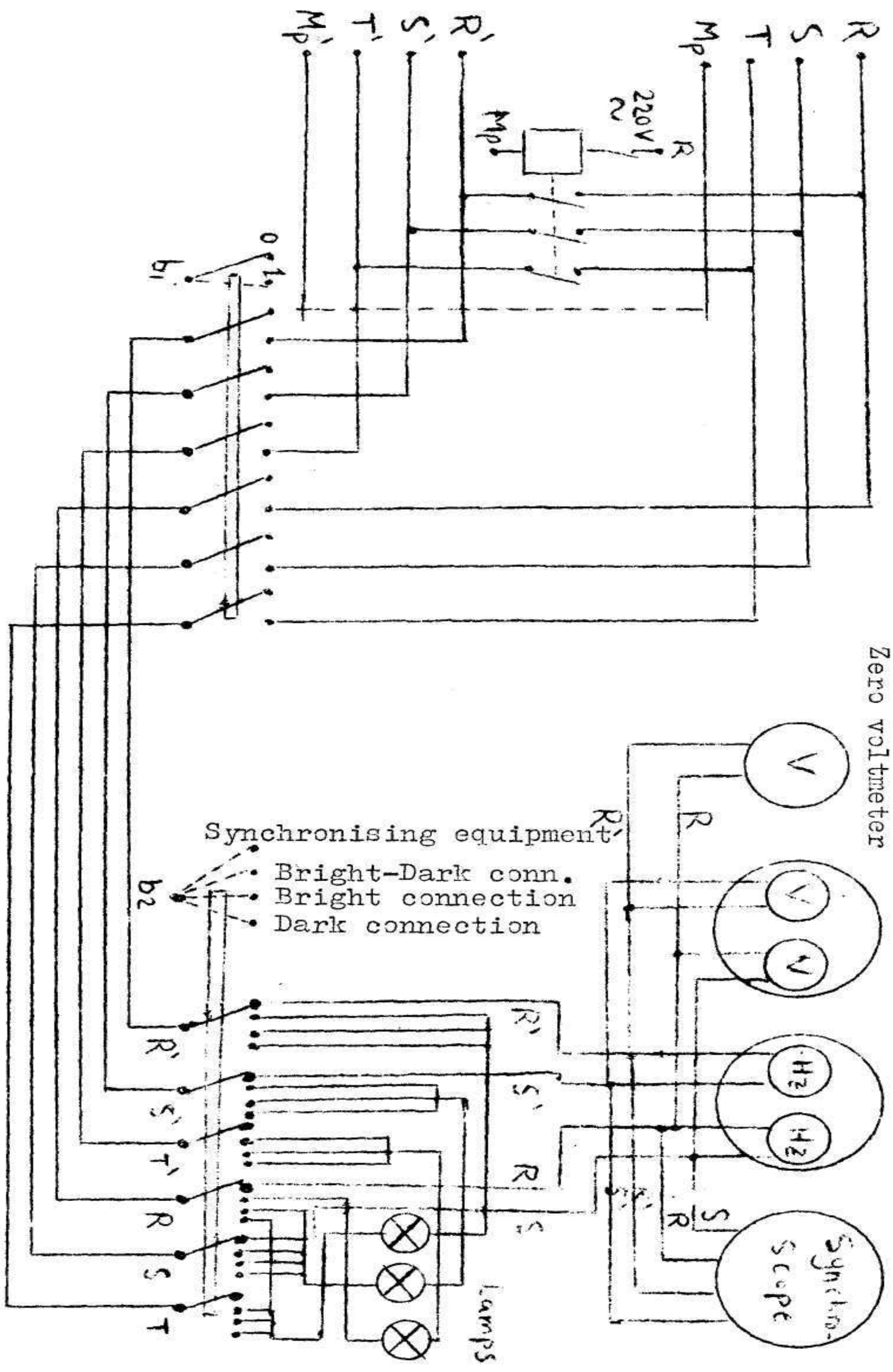


Fig. (2) Synchronizing Panel

EXP. No. 15

Predetermination of Regulation of 3-Phase Alternator by Potier Triangle and ASA Methods

Aim:- To obtain the zero power factor characteristic of an alternator and to determine regulation by Potier triangle and ASA method using the no-load and short circuit characteristics obtained previously.

Theory:- The ASA method is a modified form of the emf and mmf methods. The method involves the determination of the leakage reactance voltage drop in the armature and the armature reaction mmf at a specified load. These two quantities can be estimated by drawing the Potier triangle. The Potier triangle is right angle triangle drawn such that the vertical side represents the leakage drop to the scale of voltage and the horizontal side indicates the armature reaction mmf to the scale of the excitation current in the field.

The Potier triangle can be plotted experimentally from the no-load and short circuit characteristics and zero p.f. lagging characteristic of the machine corresponding to the specified 1oad.

1. Draw the no-load magnetization curve as shown in Fig.l (use the readings you got in the o.c.c. test).
2. From the short circuit test, determine the field excitation required to circulate the load current according to the specified load. Mark off this excitation along the x-axis as shown by OQ in Fig.l (use the readings you got in the s.c. test).
3. From the zero pf test, determine the field excitation and the terminal voltage across the zero pf load for a load current corresponding to the specified loading. Let this point be P.
4. From P draw a horizontal line PO' and mark $PO' = OQ$.
5. From O' draw $O'T'$ parallel to OT, cutting the no-load magnetisation curve at R.

6. Join PR and drop a perpendicular on $O'P$ from R.
7. Draw QR' parallel to PR. The vertical line $R'S'$, to the scale of voltage, gives the leakage reactance drop per phase and $S'Q$ to the scale of the field excitation, denotes the armature reaction mmf. The triangle PRS (or $QR'S'$) is known as the potier triangle.

<u>Determination of V_O using Potier triangle method</u>:- The magnitude of V_O can be obtained using Potier triangle method as below :

1. The magnetisation curve and Potier triangle are drawn as described above and shown in Fig.l. From the Potier triangle, the following points can be invoked:
   a) The value of IX_L drop in volts/ph (RS in Fig.l to voltage scale of the curve).
   b) Armature reaction mmf M_a per phase in equivalent field amps ($S'Q$ in Fig.l to the field excitation scale of the curve).
2. The rated terminal voltage per phase OV is drawn to a suitable voltage scale and taken as a reference (see Fig.2).
3. The current phasor OI is drawn, taking into consideration the power factor of the load.
4. To phasor OV, the armature resistance drop VA is added in phase with OI and leakage reactance drop AV'(equal to IX_L drop RS in 1 (i) above) perpendicular to OI as shown and find the induced emf on load OV'.
5. From the magnetisation curve in Fig.l determine the value of M_r, the corresponding mmf required for OV', to the field excitation scale by referring to Fig.2 and draw OB at right angle to OV' making $OB=M_r$ to a suitable field current scale.

6. Draw BC parallel to OI and make BC equal to the armature mmf (obtained from $S'Q$ in 1 (ii) above) to the same scale of field currents in 5. Find out the magnitude of the resultant OC.
7. V_O is obtained by reading of the voltage generated for the resultant mmf of 6 above from the no-load magnetisation curve in Fig.l.

***ASA Method*:-** The following construction is carried out for determination of regulation by ASA method. Refer to Fig.3:

1. The magnetisation curve obtained previously is plotted as in Fig.3.
2. On the same diagram, the rated terminal voltage per phase OV is drawn at an angle ϕ above the horizontal (for lagging p.f. only), where ϕ is p.f. angle.
3. To OV is added geometrically the per phase values of IR_a (R_a is the a.c. resistance per phase) and IX_L (X_L is the leakage reactance), the IX_L being obtained from the Potier triangle, thus giving the magnitude of E.
4. The magnitude of E is transferred to the voltage axis by striking an arc EE' with O as the origin.
5. From E' draw a horizontal 1ine $E'FF'$ intersecting the tangent to the magnetisation curve (called air gap line) and no-load characteristic at F and F' respectively. The intercept FF', to the scale of field excitation, is the additional field excitation required to compensate for the partial saturation of the machine.
6. The mmf diagram is now drawn. For this purpose, mark off OM at right angle to OE and equal to $E'F'$. From M draw MN parallel to OX and equal to $S'Q$ as obtained from the Potier triangle in Fig.l (to the scale of field excitation) to represent the armature reaction mmf. Join ON and produce it further to point N (to the scale of field excitation) such that NN=FF.

7. Mark off ON' along OX by striking the arc $N''N'$ with O as the origin and draw a vertical line from N' to cut the no-load magnetisation curve at N''. The vertical intercept $N'N''$ is the corresponding no-load voltage V_o to the scale of the voltage.

Procedures:-

Zero p.f. Test:- Connect the alternator as shown in the circuit diagram in Fig.4. Start the machine from the d.c. side and run it up to its synchronous speed value. Keeping the speed constant at this value, adjust the field excitation and the load so that the current in the alternator is 6.5 A. Record the excitation and phase voltage. Adjust the load and the field excitation again so that the current in the alternator is 6.5 A. Record the excitation current and phase voltage. Adjust the load and the field excitation simultaneously so that the load current remains constant at 6.5 A and obtain a number of points to plot the zero p.f. characteristic corresponding to a load current of 6.5 A.

Report:-

1. Plot the zero p.f. characteristic of the machine at a load current of 6.5 A.
2. Construct the Potier triangle from the no-load and short circuit characteristics (using readings obtained previously) and zero p.f. test and determine (i) the IX_L, drop per phase (ii) armature reaction mmf corresponding to a load current of 6.5 A.
3. Calculate the % regulation at 6.5 A , 0.5 p.f. lag and unity by using Potier method and ASA method.

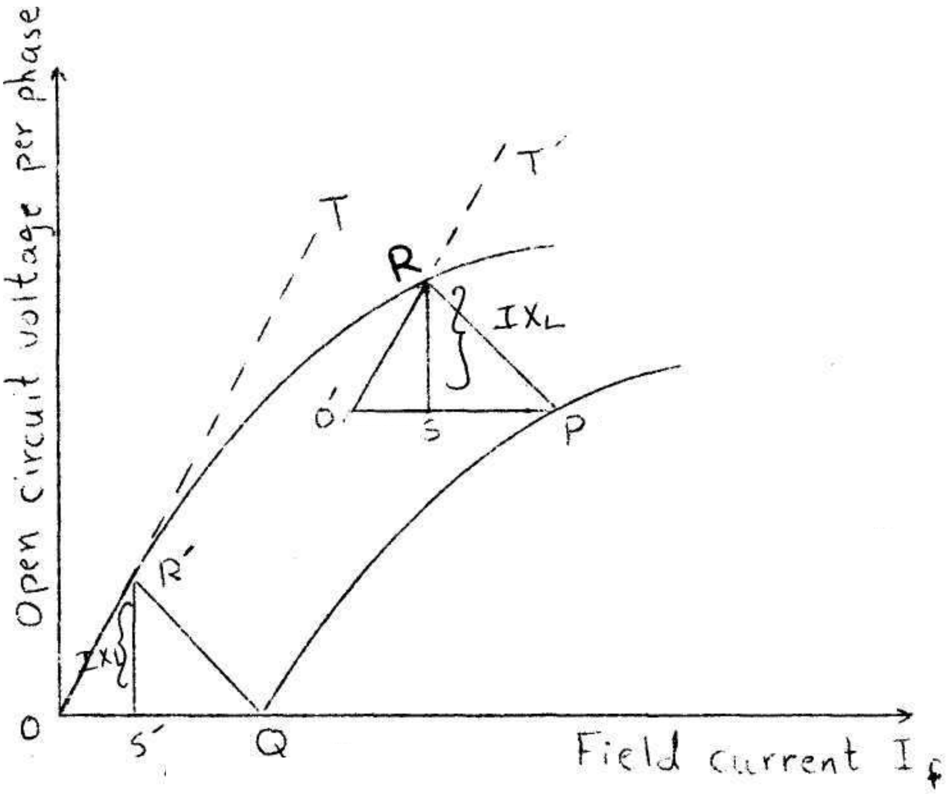

Open circuit voltage per phase
T
T′
R
IXL
O′
S
P
R′
IXL
O
S′
Q
Field current If

Fig. (1)

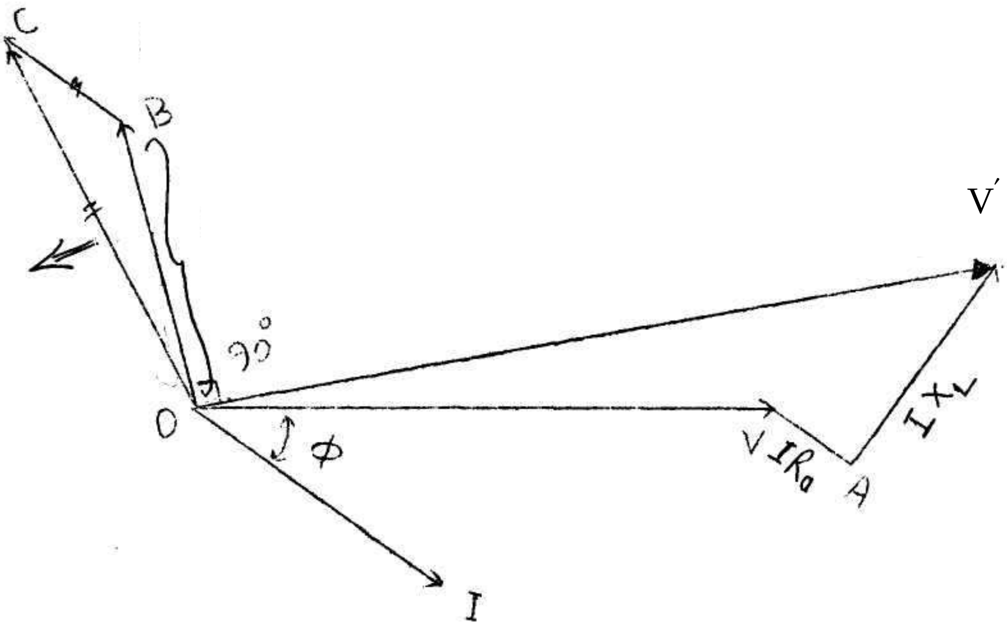

C
B
V′
90°
O
φ
V
IRa
A
IXL
I

Fig. (2)

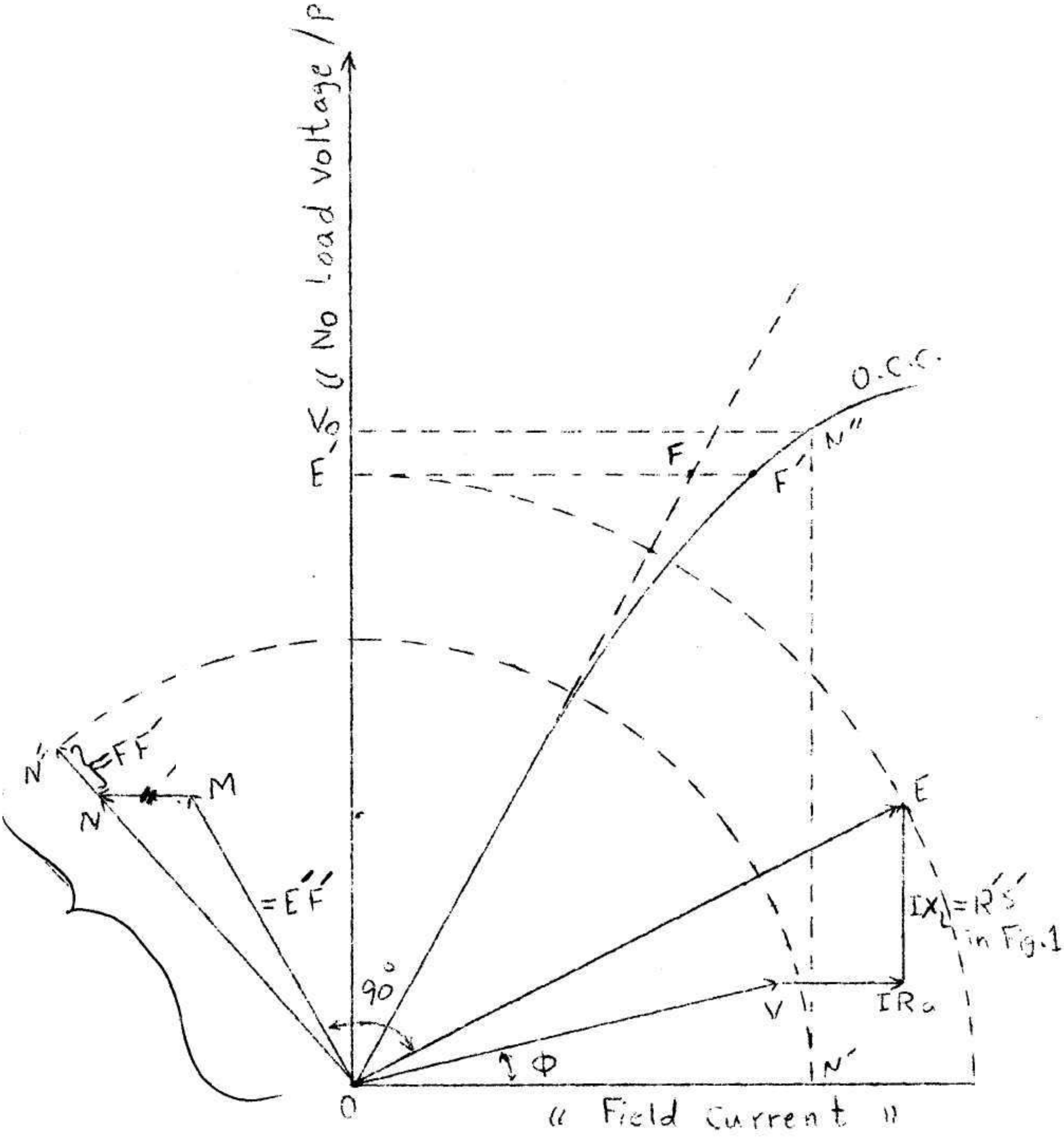

E, V₀ ((No Load voltage / P
O.C.C.
F
F′
N″
E
IX$_L$ = R′S′ in Fig.1
IRa
V
N′
Φ
90°
O
((Field Current))
M
N
=FF′
=EF″

Fig. (3)

Fig. (4)