Jaipur Institute of Technology Group of Institutions

/ Jaipur - Near Mahindra SEZ Kalwara, Ajmer Road

LAB-MANUAL

3rd SEM EE

Machine lab manual

EXPERIMENT NO : EM – II/1

TITLE Different Method of Starting Of Three-Phase Squirrel Cage Induction Motor and Their Comparison. [DOL, Auto-Transformer, Star-Delta]

OBJECTIVE : To study the effect of different methods of starting of three-phase squirrel cage induction motor using

i) DOL starter.

ii) Auto-transformer starter. iii) Star-Delta starter.

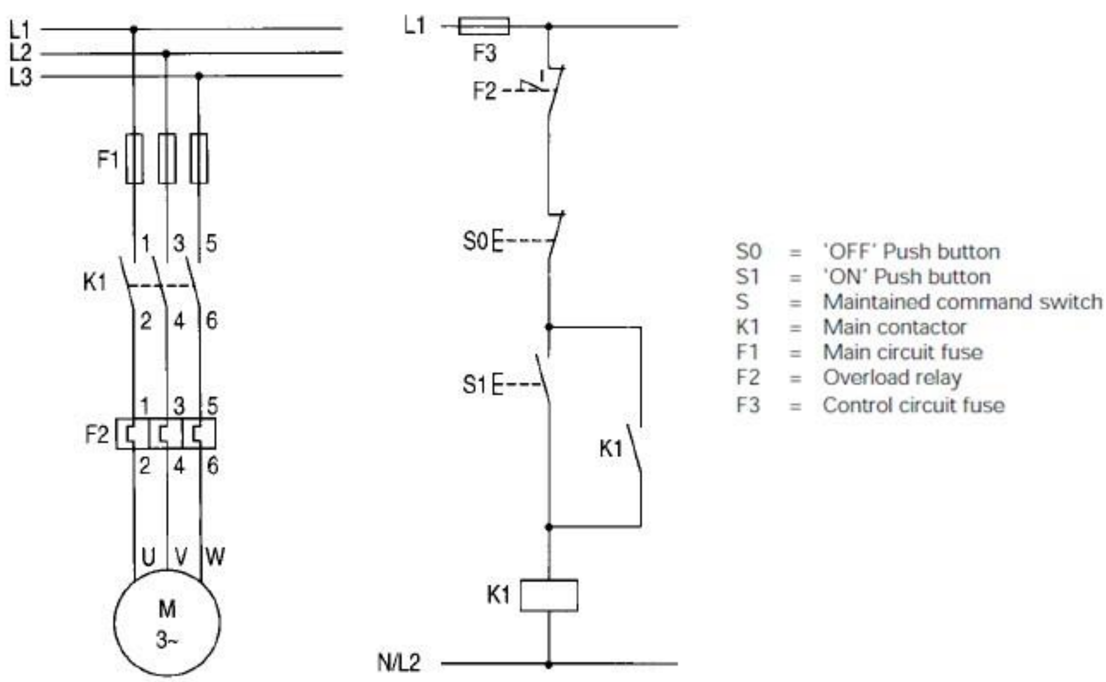
APPRATUS :

Sl No	Apparatus Name	Apparatus Type	Specification/Range	Makers Name	Serial No
1	Induction Motor				
2	Alternator				
3	Voltmeter				
3	DOL Starter				
4	Auto-transformer Starter				
4	Star-Delta Starter				

THEORY :

1. DIRECT ON LINE (D.O.L.) STARTER :

In this case of starting full supply voltage is connected to the motor. This starter doesn't provide any reduction in starting current or starting torque. For small size motor (less than 2 HP) where starting torque is about twice the full-load torque and starting period lasts only a few seconds, this type starter is used. The schematic diagram for DOL starter is shown in Fig.



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I^{sc} s_f —

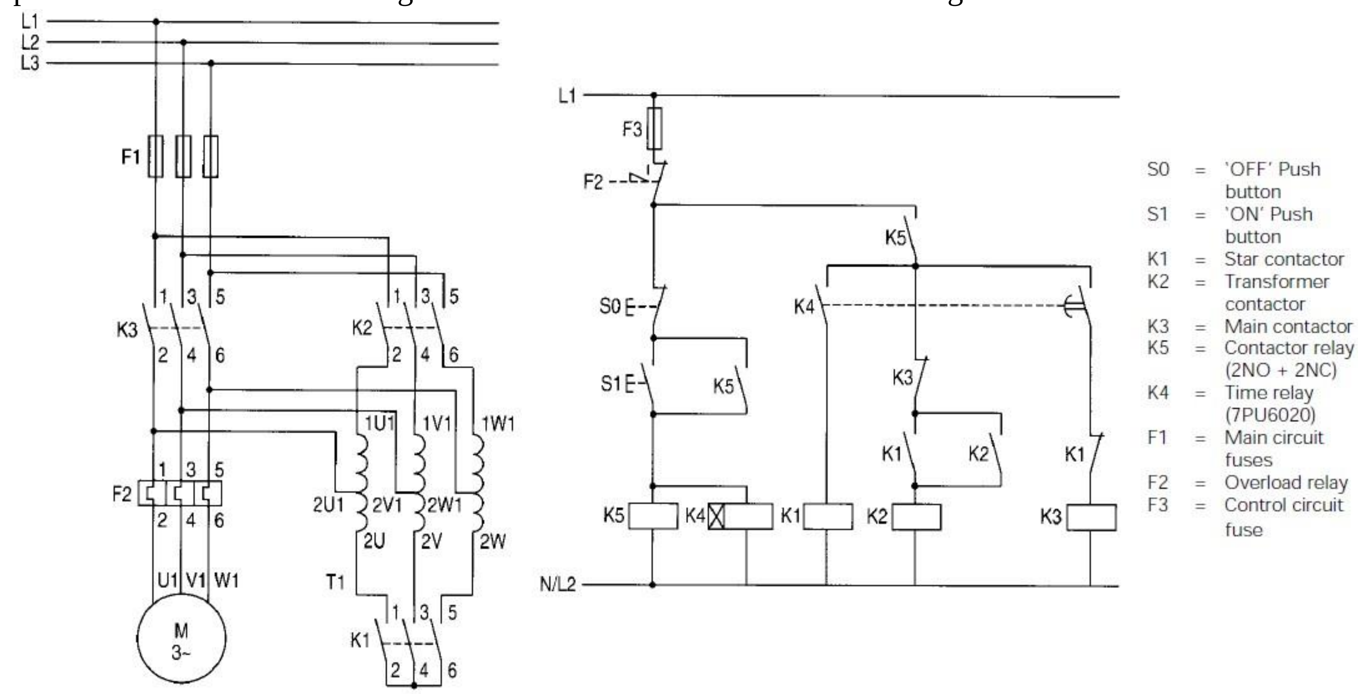
In this case starting torque, T_{st} □T_f □□□ I_f □□□

Where T_f = Full-load torque. I_f = Full-load current.

I_{sc} = Starting current. s_f = Full-load slip.

2. AUTO-TRANSFORMER STARTER :

In this method reduced voltage is obtained by three-phase auto-transformer. Generally 60 to 65% tapping can be used to obtain a safe value of starting current. The full rated voltage is applied to the motor by star connected auto-transformer. When the motor has picked up the speed upto 85 % of its normal speed auto-transformer is taking out from the motor circuit as shown in Fig.



Let the motor be started by an auto-transformer having transformation ratio k. If I_{sc} is the starting current when normal voltage is applied, and applied voltage to stator winding at starting is kV, then motor input current, I_{st} □kI_{sc} and

Supply current = Primary current of auto-transformer

= k x secondary current of auto-transformer

$= k\, I^2{}_{sc}$

2

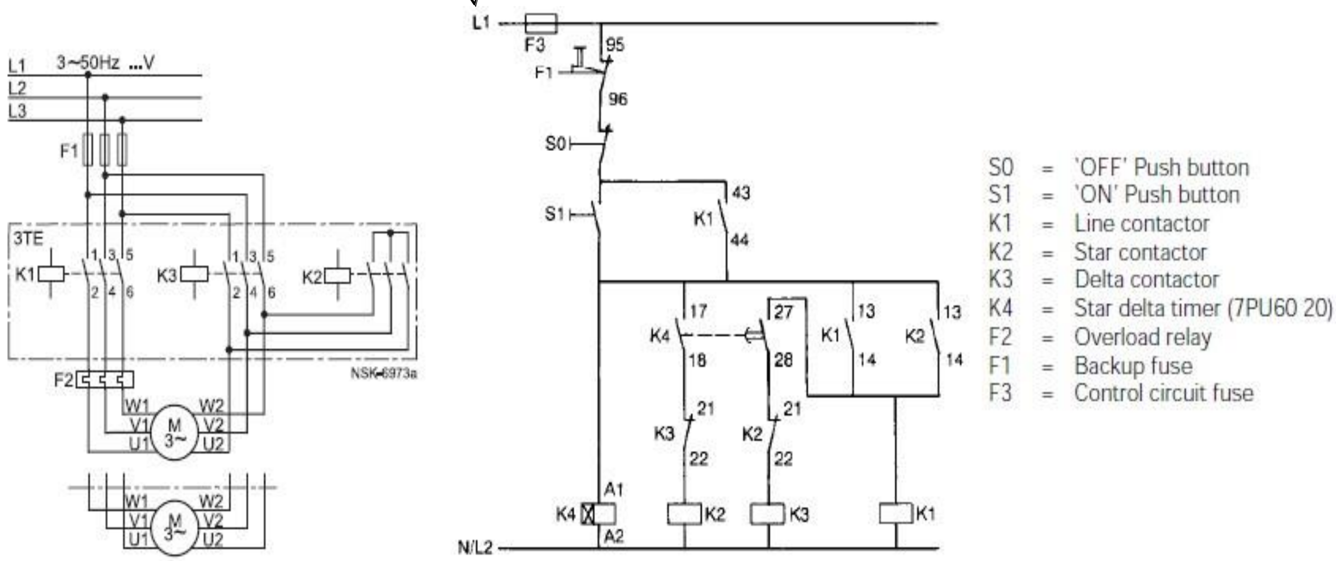
²□ I^{sc} □ s_f Starting

torque, T_{st} □T k_f □□ I_f □□□

□

3. STAR-DELTA STARTER :

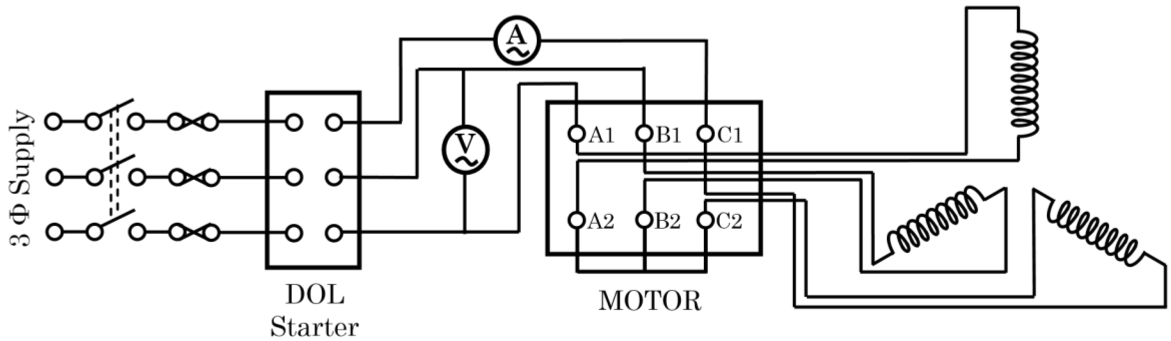
In this method reduced voltage is obtained by star-delta starter. This method of starting is based up to the principle that with 3 windings connected in star, voltage across each winding is $1/\sqrt{3}$ i.e. 57.7 %. Of the line to line voltage whereas the same winding connected in delta will have full line to line voltage across each. The star-delta starter is connected to the stator winding in star across the rated supply voltage at the starting instant. After the motor attain the speed up to 85 % of its normal speed the same stator winding is reconnected in delta through a change over switch across the same supply voltage as shown in Fig.



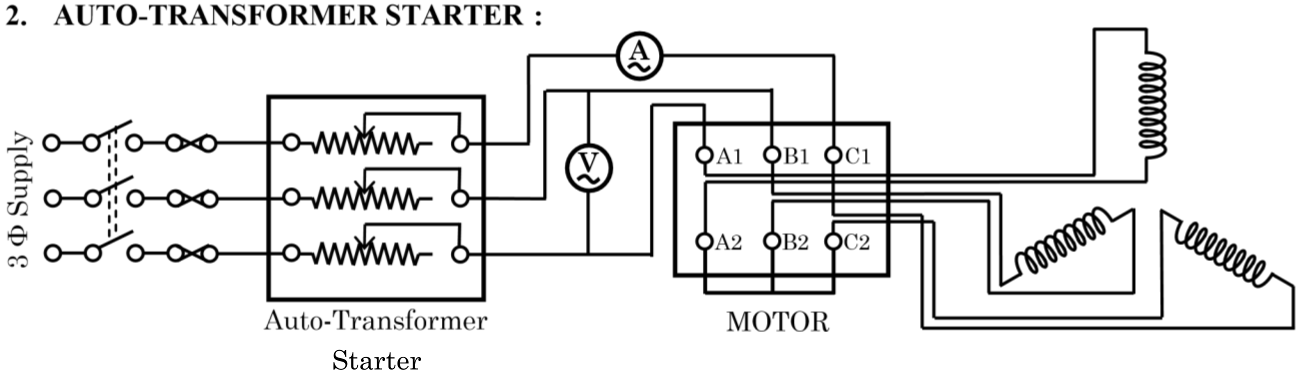
Since at starting instant, the stator winding are connected in star, so voltage across each phase winding is reduced to $1/\sqrt{3}$ of line voltage and therefore starting current per phase become equal to $I_{sc}/3$. So starting torque $T_{st} = T_f \left(\frac{I_{sc}}{3I_f}\right)^2 s_f = \frac{1}{3} T_f \left(\frac{I_{sc}}{I_f}\right)^2 s_f$

CIRCUIT DIAGRAM :

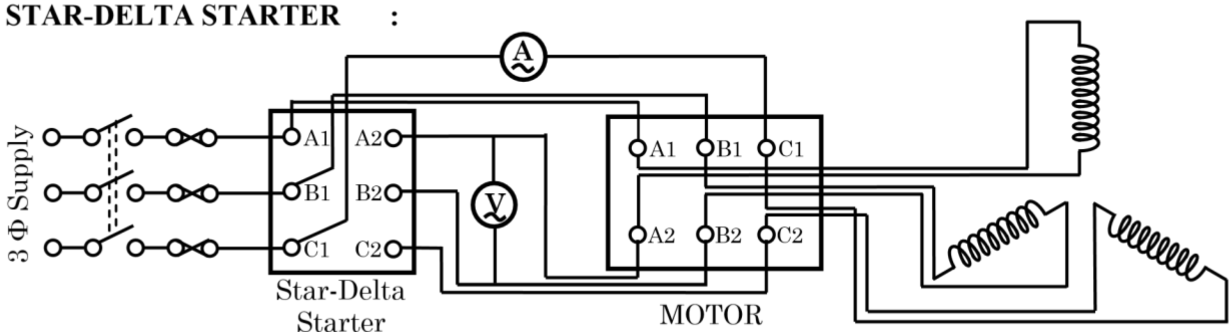
1. DOL STARTER :



2. AUTO-TRANSFORMER STARTER :



3. STAR-DELTA STARTER :



PROCEDURE :

1. **Direct On Line Starting.**
   a) Make the connection as shown in Fig.
   b) Connect the motor in Delta and switch ON the DOL starter and instantly note down the initial current.
   c) When motor attain the rated speed note down the voltage, current and speed of the motor.
   d) Switch OFF the power supply and disconnect the motor.

2. **Auto-transformer starting.**
   a) Make the connection as shown in Fig.
   b) Connect the motor in Delta and switch ON the power supply.
   c) Put the knob of starter on 25 % tap position and instantly note down the initial current.
   d) When motor attain the rated speed note down the voltage, current and speed of the motor.
   e) Follow the same procedure for 50 % tap and 100 % tap.
   f) Switch OFF the power supply and disconnect the motor.

3. Star-Delta starting.

a) Make the connection as shown in Fig.
b) Switch ON the power supply.
c) Put the handle of starter on start position and instantly note down the initial current.
d) When motor attain the speed up to 85 % of its normal speed put the handle of starter on run position and note down the voltage, current and speed of the motor.
e) Switch OFF the power supply and disconnect the motor.

OBSERVATION TABLE :

CONNECTION	CURRENT		VOLTAGE V (volt)	SPEED N (rpm)	SLIP s (%)	TOEQUE RATIO $\frac{T_{st}}{T_f}$
	Initial Max Value I_{sc} (amp)	Steady State Value I_f (amp)				
D.O.L.						
Auto-transformer (25 %)						
Auto-transformer (50 %)						
Auto-transformer (100 %)						
Star-Delta	**Y**	**Δ**				

RESULT **:** Calculate the sleep and ratio of starting torque and full load torque for each step.

DISSCUSSION **:**

1. State the advantage and disadvantage of each starter.
2. Compare the three different method of starting.
3. State the application of each starter.
4. Among the three starters which one has less starting torque? Explain why.

EXPERIMENT NO : EM – II/2

TITLE SPEED CONTROL OF THREE PHASE SQUIRREL CAGE INDUCTION MOTOR BY VOLTAGE CONTROL AND FREQUENCY CONTROL METHOD.

OBJECTIVE : To study the speed control of induction motor by varying supply frequency (V/f control).

THEORY :

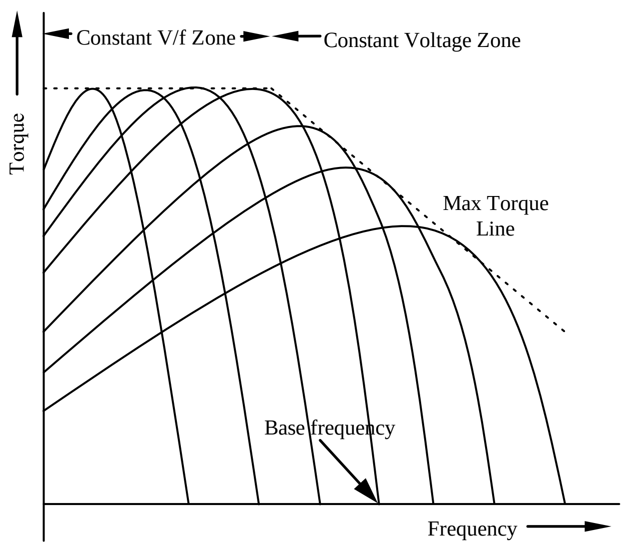
The air-gap induced emf in an ac machine is given by

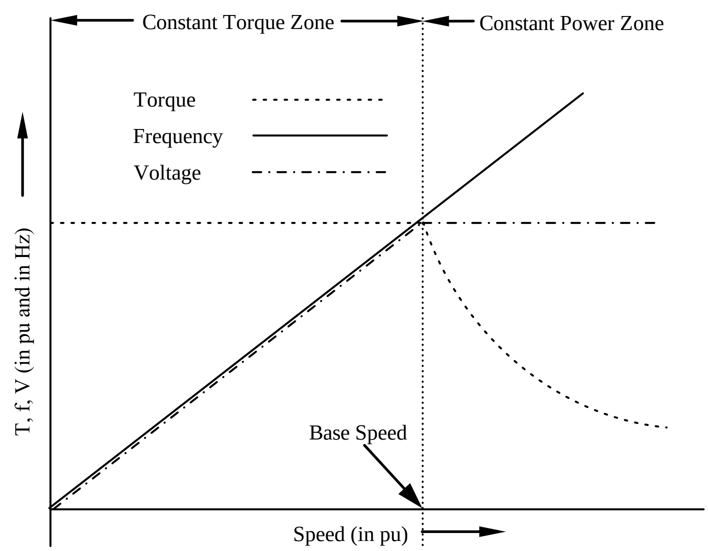
$$E = 4.44 K_w \Phi_m f T$$

Where K_w is stator winding factor, Φ_m maximum air-gap flux, f is supply frequency and T is no of turns per phase in stator. Any reduction in supply frequency, without a change in terminal voltage, causes an increase in air-gap flux. Induction motors are designed to operate at knee point of magnetization characteristic to make full use of magnetic material. Therefore increase in flux will saturate the motor. This will increase magnetizing current, distort line current and voltage, increase core loss and stator copper loss.

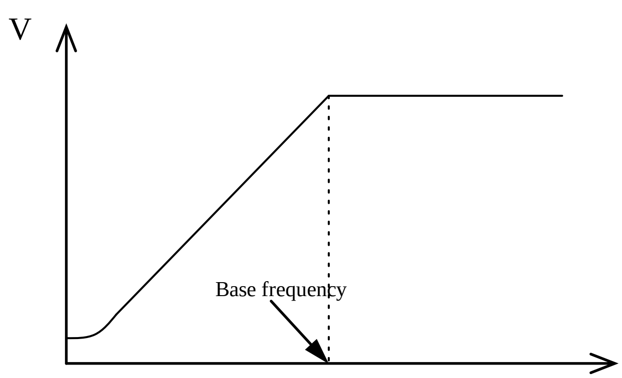
Since voltage induced in stator is proportional to product of supply frequency and air-gap flux, hence the air-gap flux can be maintained constant for optimum flux level in a machine by keeping the ratio of (applied voltage to stator impedance drop) and stator frequency constant. At high voltage level, stator impedance $(R_s + jX_{ls})$ drops is very small, so constant torque operation is maintained by just V/f constant. On the other hand, for low speed operation stator drop increased and thus ratio V/f is to be slightly boosted.

So, with constant torque operation speed can be varied from very low to near synchronous value with both voltage and frequency attaining their rated value at synchronous speed. Any speed above the synchronous speed can be obtained by increasing the above rated value. The applied voltage cannot be increased anymore because this results in weakening the air-gap flux and reduction in torque. The motor now operates in constant power zone. With increase in frequency, air-gap flux also weakens.



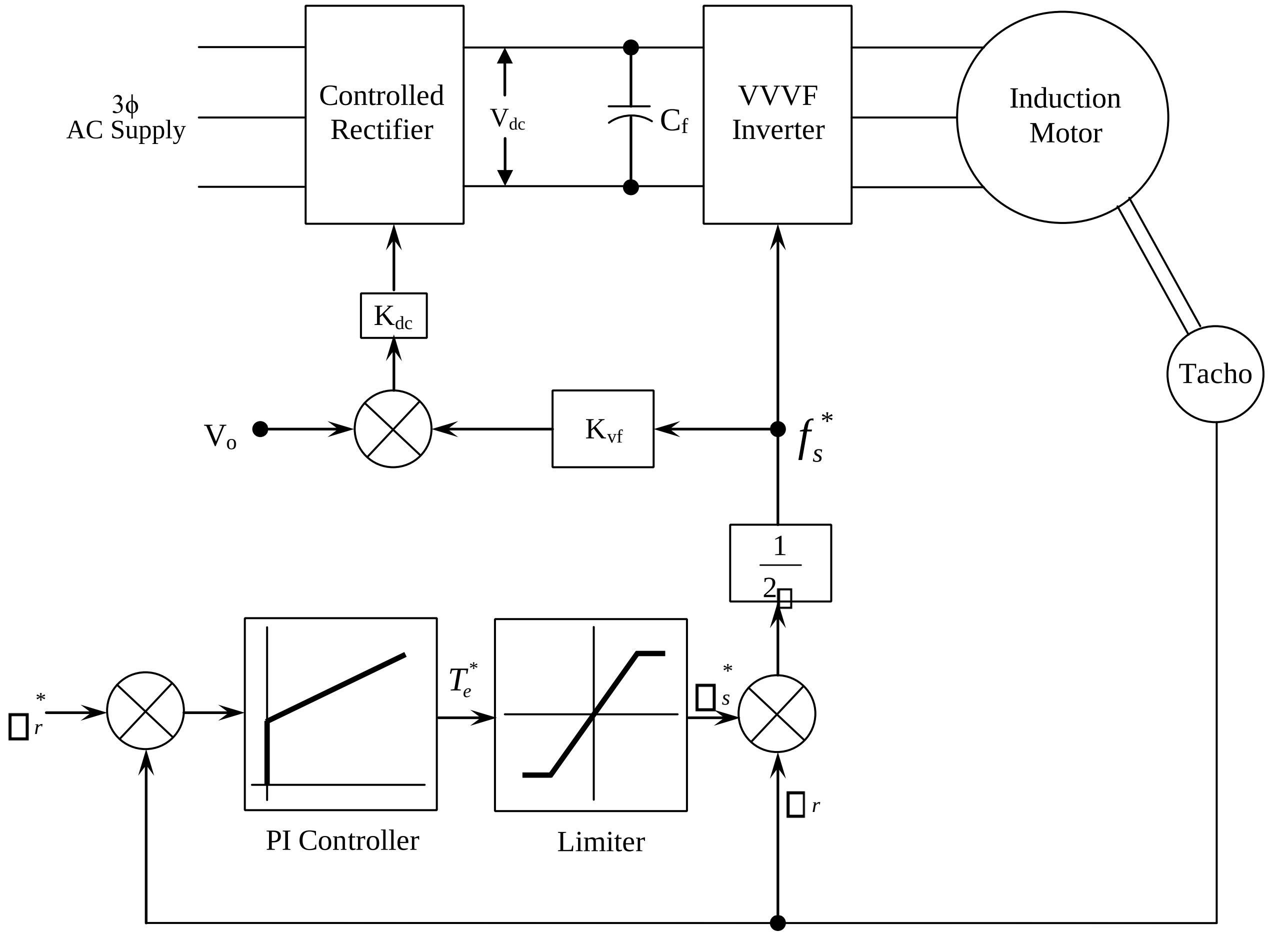


Therefore, whenever stator frequency is changed to obtain speed control, stator input voltage has to be changed accordingly to maintain air-gap flux constant. So, usually a preprogrammed volts-tofrequency relationship is used as shown below.



f

The block diagram of closed-loop induction motor drive with constant volts/Hz control strategy is shown below.



The actual rotor speed is compared with its commanded value, $\square_r^*$and the error is processed through a controller, usually PI controller and a limiter to obtain the slip-speed command, $\square_s^*$. The limiter ensured ensures that the slip-speed command is within the maximum allowable slip speed of the induction motor. The slip-speed command is then added to electrical rotor speed to obtain the stator frequency command. Thereafter, the stator frequency command is processed as in an open-loop drive.

K_{dc} is the proportionality constant between dc load voltage and stator frequency.

PROCEDURE:

1) Switch ON power supply and change the frequency set point from minimum value to maximum value step by step.
2) For each step note down the output voltage, armature current and speed of the motor.

OBSERVATION TABLE :

Sl. No.	Supply Frequency (Hz)	Applied Voltage (volt)	V/f Ratio	Armature Current (amp)	Speed (rpm)
1	50				
2	45				
3	40				
4	35				

5	30				
6	25				
7	20				
8	18				
9	15				
10	12				
11	10				
12	8				
13	5				
14	3				
15	2				
16	1				

RESULT **:** Draw the applied voltage vs. supply frequency curve.

DISCUSSION **:**

EXPERIMENT NO : EM – II/3

TITLE SPEED CONTROL OF THREE-PHASE SLIP RING INDUCTION MOTOR BY ROTOR RESISTANCE CONTROL.

OBJECTIVE : Speed control of three-phase slip ring induction motor by rotor resistance control.

APPRATUS :

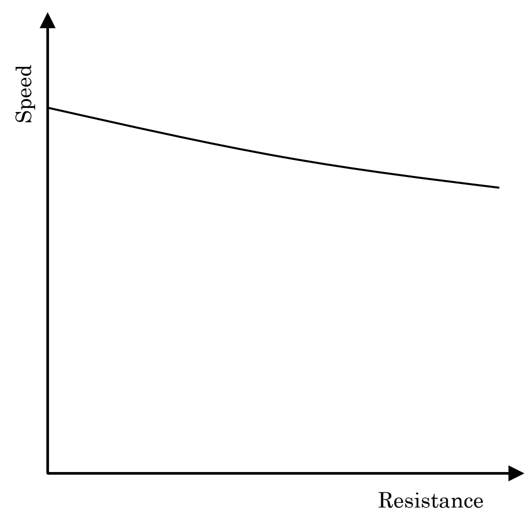
Sl No	Apparatus Name	Apparatus Type	Specification / Range	Makers Name	Serial No
1	Induction Motor				
2	Ammeter				
3	Voltmeter				
4	Resistance				

THEORY **:**

Slip ring induction motors are usually started by connecting starting resistance in the secondary circuit, which are shorted out as the motor speed up. If the ohmic values of these resistances are properly chosen and if the resistors are designed for continuous operation, they can serve dual purpose i.e. starting and speed control. This method of speed control has characteristics similar to those of dc motor speed control by means of resistance in series with armature.

Torque developed by an induction motor is given by $T = \frac{k s E_2^2 R_2}{R_2^2 + s^2 X_2^2}$

When the speed is very near to synchronous speed N_s i.e. when sip is very low the value of the term $s^2 X_2^2$ is very small and can be neglected as compared to R_2^2 and torque developed become proportional to $\frac{s}{R_2}$. So it is obvious that for a given torque, slip s can be increased or speeds can be reduced by increasing the rotor resistance. In this method speed can be control only below the rated speed. If step of external resistance is larger speed control is smoother. In this method efficiency is largely reduced at low speed. The curve of speed vs. resistance is shown in Fig below.



CIRCUIT DIAGRAM :

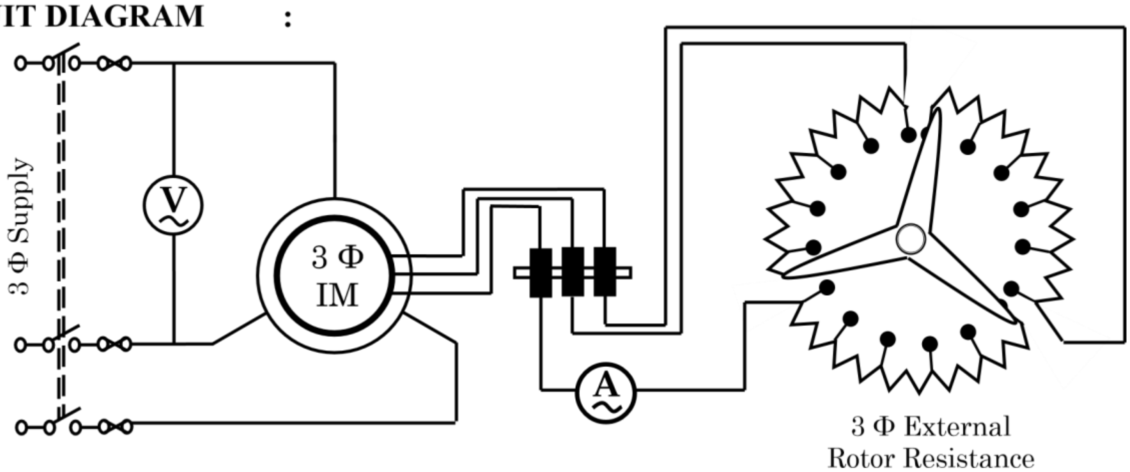


FIG : EXPERIMENTAL SET-UP FOR PERFORMING SPEED CONTROL OF SLIP-RING INDUCTION MOTOR

PROCEDURE :

1) Connect the circuit as shown in Fig.
2) Switch ON the power supply.
3) With the help of external rotor resistance starts the induction motor.
4) Vary the rotor resistance and note down the various speed.
5) Switch OFF the power supply and disconnect the motor.
6) Measure the external rotor resistance in each step by multimeter. 7) Draw the speed vs. rotor resistance curve.

OBSERVATION TABLE :

SL NO	Voltage V (volt)	Rotor Current I (amp)	External Rotor Resistance R_2 (Ω)	Speed N (rpm)
1				
2				
3				
4				
5				

RESULT : Draw the speed vs. rotor resistance curve of slip ring induction motor.

DISCUSSION :

1. State the different method of speed control of squirrel cage induction motor.
2. Compare the different method of speed control of squirrel cage induction motor
3. State any other method of speed control of slip-ring induction motor.

EXPERIMENT NO : EM – II/4 A

TITLE DETERMINATION OF REGULATION OF AN ALTERNATOR BY SYNCHRONOUS IMPEDANCE METHOD.

OBJECTIVE : To determine the voltage regulation of a three phase alternator by synchronous impedance method.

APPRATUS :

Sl No	Apparatus Name	Apparatus Type	Specification / Range	Makers Name	Serial No
1	Motor				
2	Alternator				
3	Voltmeter				
4	Ammeter 1				
5	Ammeter 2				
6	Rheostat				

THEORY :

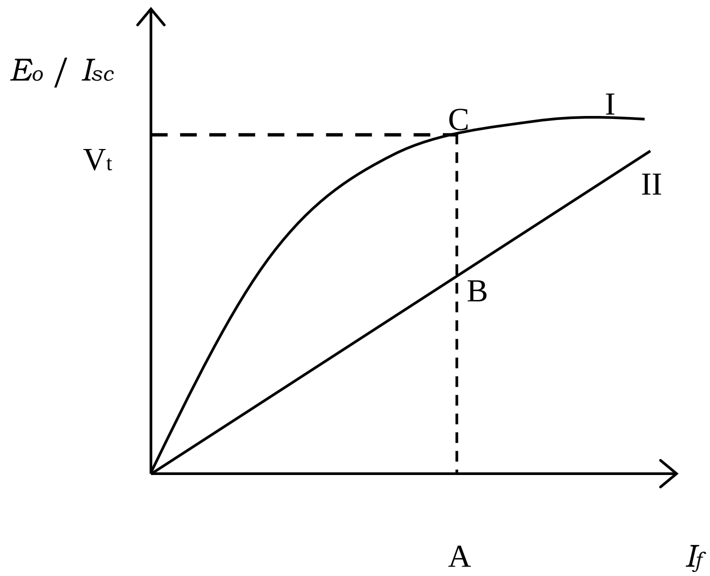
The synchronous impedance of a given three phase alternator can be determined from the following two experiments.

1. **OPEN CIRCUIT TEST :**

In this test, the alternator is run with the prime mover i.e. dc motor. The output terminals of the alternator are kept open i.e. alternator run on no-load. The induce emf per phase corresponding to various values of field current is measured. The curve is drawn between the induced emf per phase and the field current as shown in Fig. This curve is known as open circuit characteristics (O.C.C.).

2. **SHORT CIRCUIT TEST :**

In this test, the output terminals of the alternator are short circuited through low resistance ammeter. The short circuit current is measured corresponding to various values of field current while speed is kept constant with the help of field rheostat. The curve is drawn between short circuit current and field current as shown in Fig. (Curve II). This curve is known as short circuit current (S.C.C.).



From the Fig. let OA represent the field current corresponding to rated terminal voltage. Then AB represents the rated short circuited current and AC represents the induced emf per phase. Under the short circuit condition whole of the emf AC is used to create the short circuit current AB. Now, we can write

$$\text{Synchronous impedance, } Z_s = \frac{AC \text{ in volts}(\ )}{AB \text{ in amperes}(\ )}$$

The value of armature resistance per phase R_a can be determined by an accurate ohmmeter. The effective value of armature resistance can be determined by increasing the measured value by 20 % to account for the skin effect and effect of temperature rise. Then, synchronous reactance X_s can be calculated using the following relation

$$X_s = \sqrt{Z_s^2 - R_a^2}$$

Now no-load induced emf per phase $E_o = \sqrt{(V\cos\phi + IR_a)^2 + (V\sin\phi \pm IX_s)^2}$

And percentage regulation $= \frac{E_o - V}{V} \times 100\%$

N.B. For lagging power factor $\sin\phi$ should be taken as positive and for leading power factor $\sin\phi$ taken as negative.

CIRCUIT DIAGRAM :

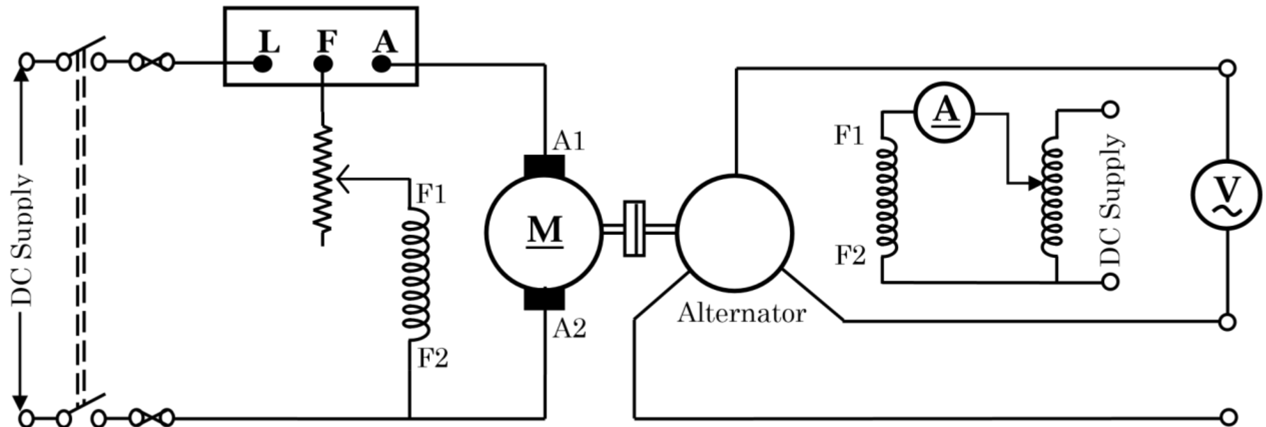


FIG 1 : EXPERIMENTAL SET-UP FOR PERFORMING OPEN CIRCUIT TEST

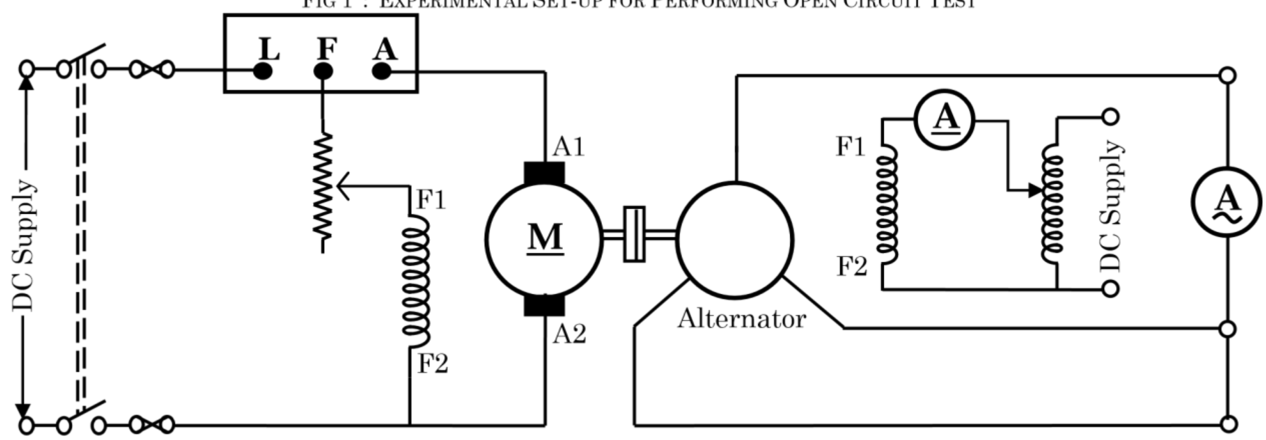


FIG 2 : EXPERIMENTAL SET-UP FOR PERFORMING SHORT CIRCUIT TEST

PROCEDURE :

1) Connect the circuit as shown in Fig. 1.
2) Switch ON the dc power supply and start the motor with the help of three point starter keeping the field rheostat at its minimum value.
3) Now adjust the speed of motor equal to the synchronous speed of alternator with the help of field rheostat. Maintain this synchronous speed throughout the experiment.
4) Increase alternator field current by varying the field voltage gradually. Note down the voltmeter reading connected across the alternator terminals for various values of alternator field current. Go up to 10 % above the rated voltage of alternator.
5) Switch OFF the dc supply.
6) Short the alternator output through ammeter as shown in Fig. 2 and repeat steps 2 and 3 above.
7) Increase alternator field current by varying the field voltage gradually. Note the ammeter readings connected across the alternator terminals for various values of alternator field current.
8) Switch OFF the dc supply and disconnect all connection.
9) Measure per phase armature resistance and field resistance with the help of multi-meter.
10) Plot the O.C.C. and S.C.C. curves.
11) Calculated the value of synchronous reactance and regulation of alternator.

OBSERVATION TABLE :

SL	Open-circuit Test	Short-circuit Test

NO	Field Current I_f (amp)	Terminal Voltage V_t (volt)	Field Current I_f (amp)	Short-circuit Current I_{sc} (amp)
1				
2				
3				
4				
5				

Armature resistance per phase = Ω
Effective value of armature resistance = Ω

RESULT :

Synchronous reactance per phase = Ω
Voltage regulation at 0.8 power factor lagging = %
Voltage regulation at 0.8 power factor leading = %
Voltage regulation at zero power factor = %

DISCUSSION :

1. What happen if the speed of dc motor is not constant throughout the experiment?
2. Draw the phasor diagram of Induction Motor under lagging, zero and leading power factor load.
3. Why regulation is positive for lagging load and negative for leading load?
4. What are the other methods for regulation calculation?

EXPERIMENT NO : EM – II/4 B

TITLE **DETERMINATION OF REGULATION OF AN ALTERNATOR BY POTIER REACTANCE METHOD.**

OBJECTIVE : To determine the voltage regulation of a three phase alternator by synchronous impedance method.

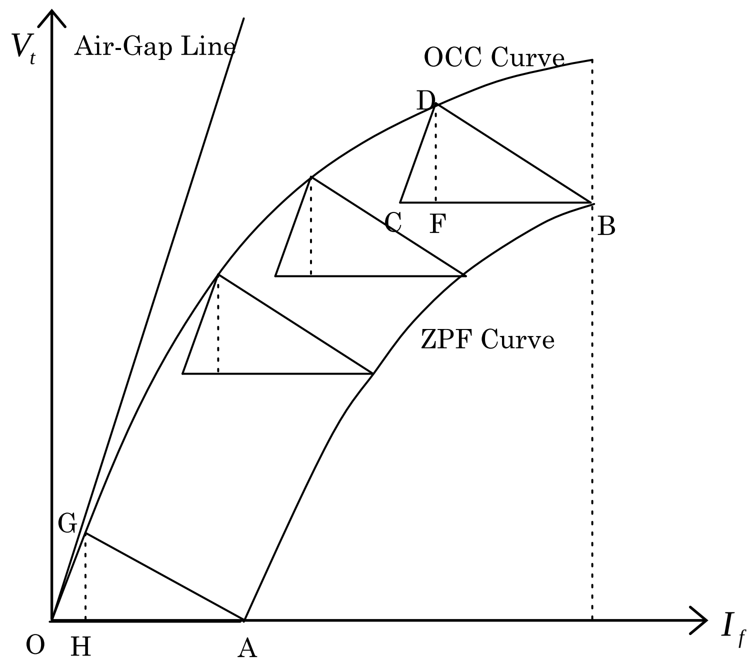
APPRATUS :

Sl No	Apparatus Name	Apparatus Type	Specification / Range	Makers Name	Serial No
1	Motor				
2	Alternator				
3	Voltmeter				
4	Ammeter 1				
5	Ammeter 2				
6	Rheostat				

THEORY :

The regulation obtained by synchronous impedance method is based on total synchronous reactance i.e. sum of armature leakage flux reactance and reactance due to armature reaction. But in Zero Power Factor (ZPF) or Potier reactance method regulation calculation is based on separation of reactance due to leakage flux and that due to armature reaction flux.

To determine the voltage regulation by this method, a curve between terminal voltage and field excitation while machine is being run on synchronous speed and delivering full load at zero power factor (lagging) have to be drawn along with no load characteristic as show in figure. The ZPF characteristic curve is of exactly same shape, as the OCC but it is shifted vertically downward by leakage reactance drop IX_L and horizontally by armature reaction mmf.



The point A is obtained from a short circuit test with full load armature current. Hence OA represents excitation (field current) required to overcome demagnetizing effect of armature reaction and to balance leakage reactance drop at full load. Point B is obtained when full load current flows through the armature. From B, line BC is drawn and parallel to OA. Then a line is drawn through c parallel to initial straight part of OCC (parallel to OG), intersecting the OCC at D. BD is joined and a perpendicular DF is dropped on BC. The triangle BFD is imposed at various points OCC to obtain corresponding points on the ZPF curve. The length BF in □BFD represents armature reactance and the length DF represents leakage reactance drop IX_L . This known as Potier reactance voltage drop and the triangle is known as Potier Triangle. The potier reactance is given as

$$X_p = \frac{\text{voltage drop per phase (DF)}}{\text{zero power factor current per phase}}$$

In case of cylindrical rotor machines, potier reactance is nearly equal to armature leakage reactance. In case of salient pole machine, the magnetizing circuit is more saturated and the armature leakage reactance is smaller than the potier reactance.

POTIER REGULATION DIAGRAM :

OV is drawn horizontally to represent full load terminal voltage, V and OI is drawn to represent full load current at a given power factor. VE is drawn perpendicular to phasor OI and equal to reactance drop (IX_L), neglecting resistance drop. Now phasor OE represents generated emf E. From OCC field excitation I_1 corresponding to generated emf E is determined, OI_1 is drawn perpendicular to phasor OE to represent excitation required to induce emf OE on open circuit. I_1I_2 is drawn parallel to load current phasor OI to represent excitation equivalent to full load armature reaction. OI_2 gives total excitation required. If the load is thrown off, then terminal voltage will be equal to generated emf corresponding to field excitation OI_2. Hence OE_o will lag behind phasor OI_2 by 90°. EE_o represents voltage drop to armature reaction. So, regulation can be obtained from the relation below

$$\text{Percentage regulation} = \frac{E_o - V}{V} \times 100\%$$

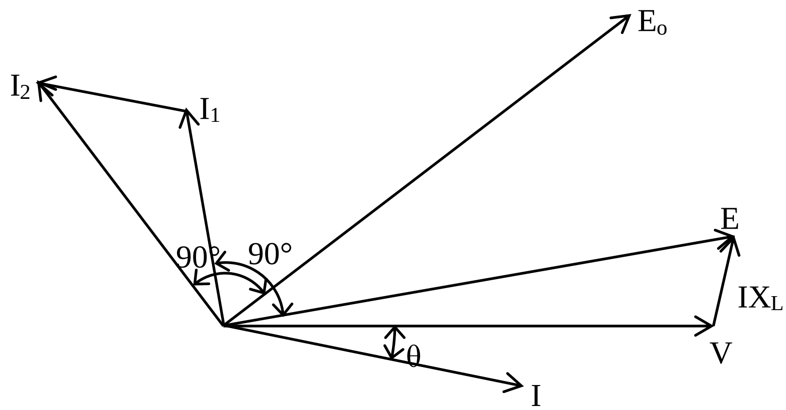


FIG : POTIER REGULATION DIAGRAM

CIRCUIT DIAGRAM :

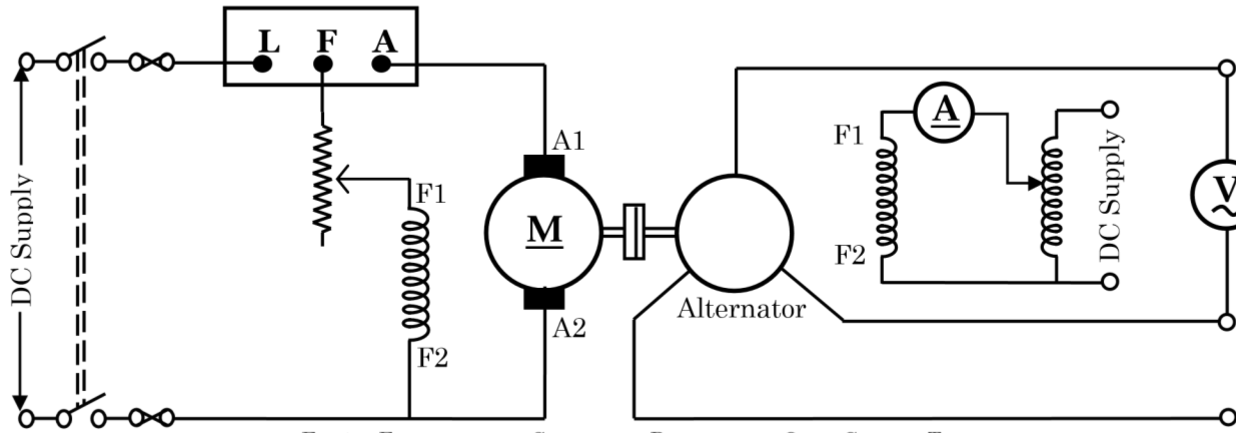


FIG 1 : EXPERIMENTAL SET-UP FOR PERFORMING OPEN CIRCUIT TEST

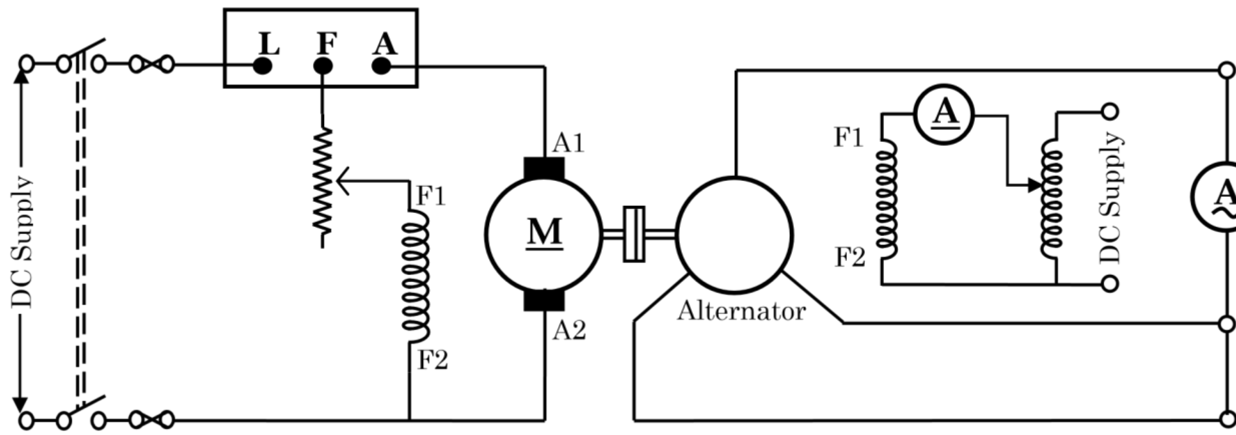


FIG 2 : EXPERIMENTAL SET-UP FOR PERFORMING SHORT CIRCUIT TEST

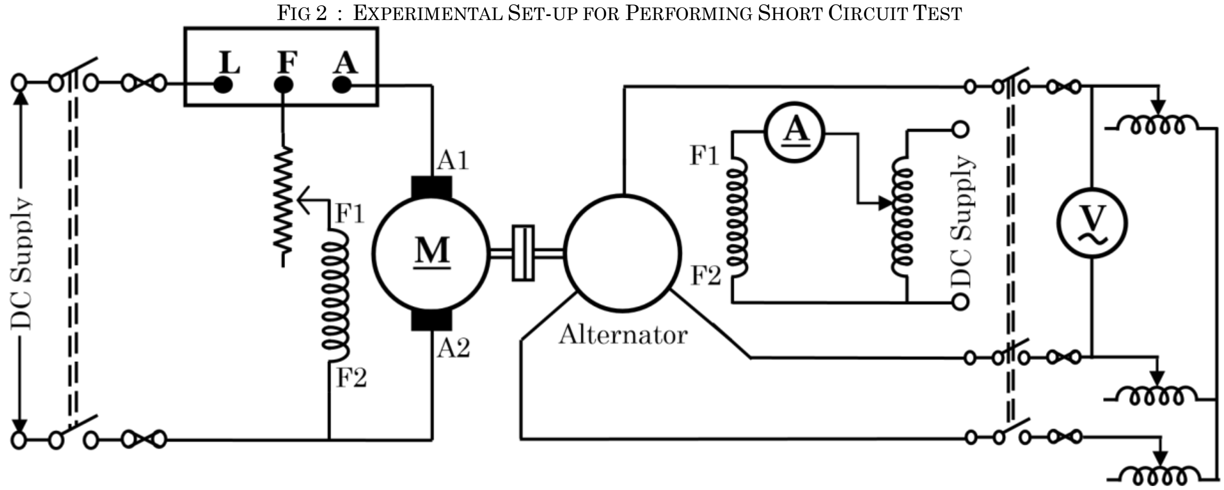


FIG 3 : EXPERIMENTAL SET-UP FOR DRAWING ZPF (LAGGING) CURVE

PROCEDURE :

1) Connect the circuit as shown in Fig. 1.
2) Switch ON the dc power supply and start the motor with the help of three point starter keeping the field rheostat at its minimum value.

3) Now adjust the speed of motor equal to the synchronous speed of alternator with the help of field rheostat. Maintain this synchronous speed throughout the experiment.
4) Increase alternator field current by varying the field voltage gradually. Note down the voltmeter reading connected across the alternator terminals for various values of alternator field current. Go up to 10 % above the rated voltage of alternator.
5) Switch OFF the dc supply.
6) Short the alternator output through ammeter as shown in Fig. 2 and repeat steps 2 and 3 above.
7) Increase alternator field current by varying the field voltage gradually. Note the ammeter readings connected across the alternator terminals for various values of alternator field current.
8) Switch OFF the dc supply and disconnect all connection.
9) Measure per phase armature resistance and field resistance with the help of multi-meter.
10) Plot the O.C.C. and S.C.C. curves.
11) Calculated the value of synchronous reactance and regulation of alternator.

OBSERVATION TABLE :

SL NO	Open-circuit Test		Short-circuit Test		Zero Power Factor Test	
	Field Current I_f (amp)	Terminal Voltage V_t (volt)	Field Current I_f (amp)	Short-circuit Current V_t (volt)	Field Current I_f (amp)	Terminal Voltage V_t (volt)
1						
2						
3						
4						
5						

Armature resistance per phase = Ω
Effective value of armature resistance = Ω
Field resistance = Ω

RESULT :

Synchronous reactance per phase = Ω
Voltage regulation at 0.8 power factor lagging = %
Voltage regulation at 0.8 power factor leading = %
Voltage regulation at zero power factor = %

DISCUSSION :

5. What happen if the speed of dc motor is not constant throughout the experiment?
6. Draw the phasor diagram of Induction Motor under lagging, zero and leading power factor load.
7. Why regulation is positive for lagging load and negative for leading load?
8. What are the other methods for regulation calculation?

EXPERIMENT NO : EM – II/5

TITLE DETERMINATION OF EQUIVALENT CIRCUIT PARAMETER OF A SINGLE PHASE INDUCTION MOTOR.

OBJECTIVE : Determine the equivalent circuit of a single phase induction motor by No load test and blocked-rotor test.

APPRATUS :

Sl No	Apparatus Name	Apparatus Type	Specification / Range	Makers Name	Serial No
1	Induction Motor				
2	Ammeter				
3	Voltmeter				
4	Wattmeter				
4	Variac				
7	Tachometer				

THEORY :

The equivalent circuit of single phase induction motor is determined by the no-load test and block rotor test. The equivalent circuit of single phase induction motor is shown in Fig. 1. r

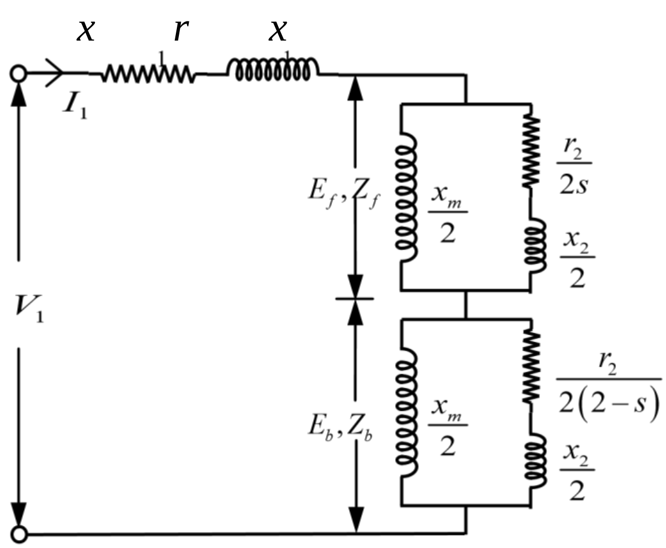


FIG 1 : SINGLE PHASE IM

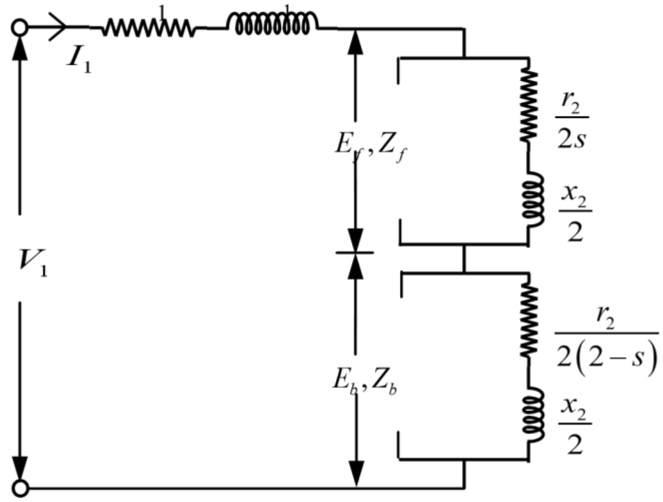


FIG 2 : EQUIVALENT CIRCUIT FOR BLOCK ROTOR TEST

1. BLOCKED-ROTOR TEST :

With the rotor at rest, single-phase voltage, applied to stator main winding, is increased gradually from zero so that rated current flow in main winding. Under these condition i.e. with rotor stationary, the slip $s \approx 1$and the voltage required to circulate full-load current is very low. Therefore, flux is small and the magnetizing current flowing to X_m is also very low. In view of this, magnetizing reactance can be neglected and that gives the equivalent circuit as shown in Fig. 2.

Let consider V_{sc} = Applied short circuit voltage on stator side.

I_{sc} = Short circuit current.

W_{sc} = Total ohmic loss.

Then the total equivalent resistance $R_{sc} = r_1 + r_2 = \frac{W_{sc}}{I_{sc}^2}$

Since resistance of main winding r_1 is already measured, effective rotor resistance $r_2 = R_{sc} - r_1$

The total equivalent per phase impedance $Z_{sc} = \frac{V_{sc}}{I_{sc}}$

Therefore total equivalent per phase reactance $X_{sc} = x_1 + x_2 = \sqrt{Z_{sc}^2 - R_{sc}^2}$

Since the leakage reactance x_1 and x_2 can't be separated out, it is assumed that $x_1 = x_2 = \frac{1}{2} X_{sc}$

2. NO-LOAD TEST :

This test is similar to open circuit test on a transformer. A single-phase auto-transformer is used to supply rated voltage at the rated frequency. The motor is runs at no load. The power input is measured by wattmeter. With the motor running at no load, the slip is very close to zero. It may be therefore be assumed that $s \approx 0$. Under these conditions $\frac{r_2}{2s}$ become infinity and $\frac{r_2}{2(2-s)} \approx \frac{r_2}{4}$ become several times $\frac{x_m}{2}$. In view of these approximation $\frac{r_2}{2s} + j\frac{x_2}{2}$ and $\frac{x_m}{2}$ (across $\frac{r_2}{4} + j\frac{x_2}{2}$) may be neglected smaller than and that gives the equivalent circuit as shown in Fig.

r_1 x_1

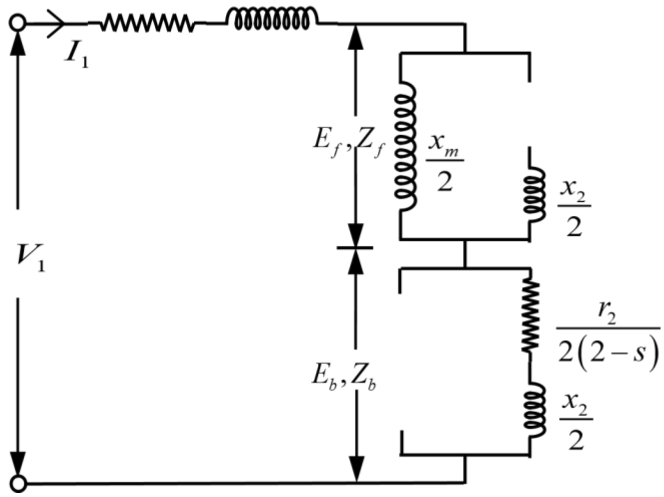


FIG 2 : EQUIVALENT CIRCUIT FOR NO LOAD TEST

Let consider V_o = No-load applied voltage.

I_o = Exciting current or No-load current

W_o = Core loss and Mechanical loss.

Therefore no load power factor $\cos\phi_o = \frac{W_o}{V_o I_o}$

the impedance is $Z_o = \frac{V_o}{I_o}$ and the reactance is $X_o = Z_o \sin\phi_o$ So, the

From the circuit shown in above, we can write that $R_o = r_1 + \frac{r_2}{4}$ and $X_o = x_1 + \frac{1}{2}(x_2 + X_m)$

CIRCUIT DIAGRAM :

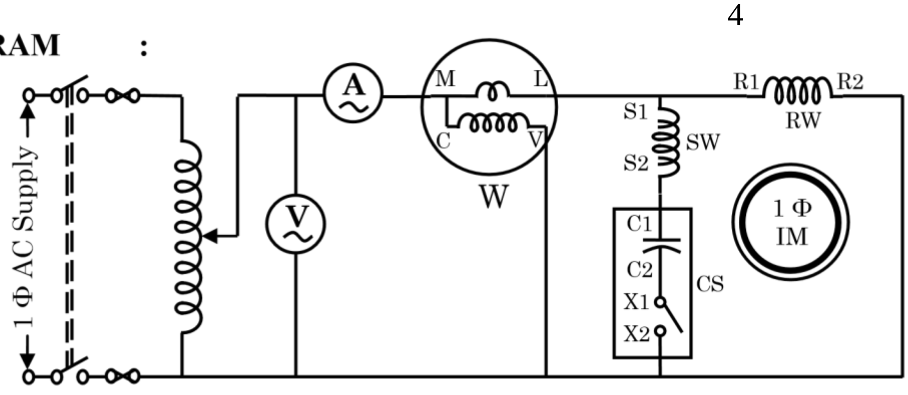


FIG : EXPERIMENTAL SET-UP FOR PERFORMING NO-LOAD AND BLOCK-ROTOR TEST OF SINGLE PHASE INDUCTION MOTOR

PROCEDURE :

1) Connect the circuit as shown in Fig.

2) Switch ON the power supply and apply the rated voltage in stator with the help of single-phase variac.
3) Note down the voltmeter, ammeter and wattmeter reading.
4) Disconnect the power supply and block the rotor with the help of clamp as such a way that it cannot rotate. Rotor can be blocked by disconnecting auxiliary or starting winding (SW) from main or running winding (RW).
5) Apply very low voltage to the main winding only and then gradually increase the voltage until the rated current is flow in stator winding.
6) Note down the voltmeter, ammeter and wattmeter reading.
7) Switch OFF the power supply and disconnect the circuit.
8) Measure the stator resistance or main winding resistance by multi-meter.
9) Calculate the different parameter of single-phase induction motor from the above data.

OBSERVATION TABLE :

No-load Test			Blocked-rotor Test		
Voltage V_o (volt)	Current I_o (Amp)	Power Input W_o (watt)	Voltage V_{sc} (volt)	Current I_{sc} (Amp)	Power Input W_{sc} (watt)

Main winding resistance = Ω

Auxiliary winding resistance = Ω

CALCULATION :

The total series impedance $Z = Z_1 + Z_f + Z_b$

So, the input current $I_m = \frac{V}{Z}$

Now, the core, friction and windage loss $P_r = W_o - I_o^2 R_o$

Therefore, output power $P_{out} = P_{mech} - P_r = I_m^2 (R_f - R_b)(1 - s) - P_r$

And, input power $P_{in} = V I_m \cos\phi$

So, efficiency $\eta = \frac{P_{out}}{P_{in}} \times 100\%$

RESULT :

Rotor resistance = Ω

Magnetizing reactance = Ω

Leakage reactance = Ω

Efficiency of induction motor = %

Draw the equivalent circuit of single phase induction motor.

DISCUSSION :

1. What is the difference between the no-load test on an induction motor and open circuit test on transformer?
2. Why rotor is blocked when auxiliary or starting winding is disconnecting?
3. What is the function of clutch switch (CS)?

EXPERIMENT NO : EM – II/6

TITLE LOAD TEST ON SINGLE PHASE INDUCTION MOTOR TO OBTAIN THE PERFORMANCE CHARACTERISTICS.

OBJECTIVE : To determine the torque, output power, efficiency, input power factor and slip of singlephase Induction motor for various load and plot the following curve.

i. Efficiency vs. output power.
ii. Torque vs. output power. iii. Line current vs. output power.
iv. Power factor vs. output power.
v. Slip vs. output power vi. Torque vs. slip.

APPRATUS :

Sl No	Apparatus Name	Apparatus Type	Specification / Range	Makers Name	Serial No
1	Induction Motor				
2	Ammeter				
3	Voltmeter				
4	Wattmeter				
4	Variac				
7	Tachometer				

THEORY :

The load test on induction motor helps us to compute the complete performance of induction motor means to calculate the various quantities i.e. torque, slip, efficiency, power factor etc at different loading. In this test supply voltage is applied to motor and variable mechanical load is applied to the shaft of motor. Mechanical load can be provided by brake and pulley arrangement. The input current, input voltage, input power and speed of motor are observed from the experiment and various performance quantities are calculated as explain below.

SLIP :

Due to the three-phase supply given to stator of an induction motor, a rotating magnetic field of constant magnitude is set up in the stator of the motor. The speed with which this rotating magnetic field rotates is known as synchronous speed and is given by

$$N_s = \frac{120f}{P}$$

Where f =supply frequency.
P =no of poles on the stator of the rotor.

The actual speed of the rotor N_r is always less than the synchronous speed. So the slip of the motor is given by

$$s = \frac{N_s - N_r}{N_s} \times 100\%$$

This value of slip at full load lies between 2 to 5%.

TORQUE :

Mechanical loading is applied on induction motor by means of brake and pulley arrangement. The belt can be tightened or loosened by means of threaded rods with handles fixed on frame. Two spring balances are provided at the end of belt. The net force exerted at the brake drum can be obtained from the readings of the two spring balance i.e. F_1 and F_2

Net force exerted on drum, $F = (F_1 - F_2)$ Kgf d

And Torque $T = \frac{d}{2} \times F \times 9.81$ Nw-m

Where d = effective diameter of brake drum in meter.

OUTPUT POWER :

The output power of induction motor can be calculated as $P_o = \frac{2\pi N_r T_r}{60}$

Where N_r = speed of induction motor in rpm.

INPUT POWER :

The input power can be calculated from the readings of wattmeter connected in the circuit

$$P_{in} = W$$

POWER FACTOR :

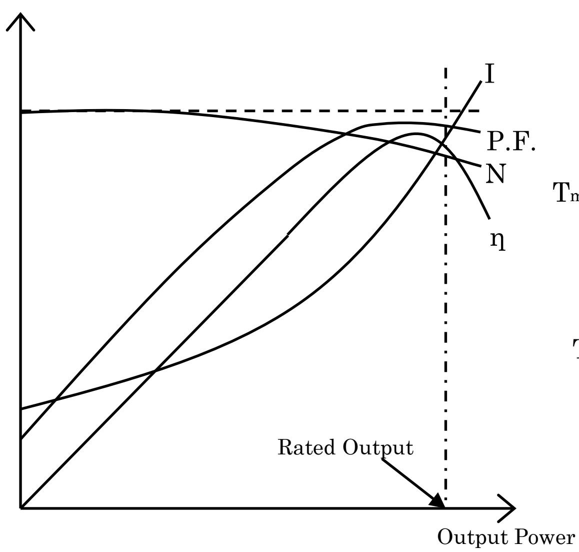
The power factor can be calculated from the following relation

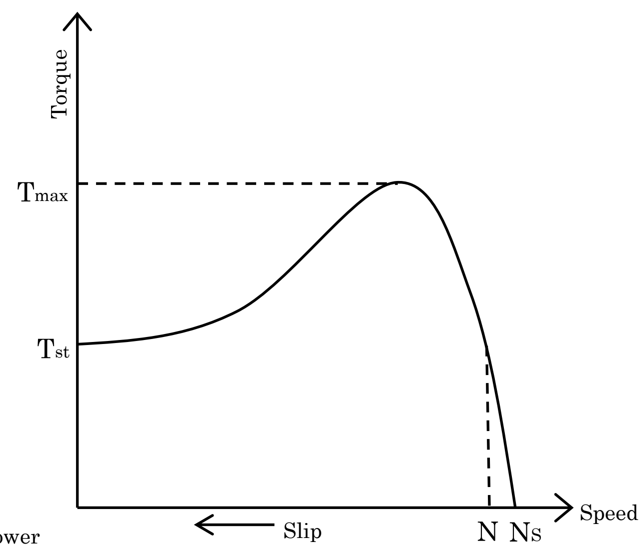
$$\cos\phi = \frac{P_{in}}{VI}$$

EFFICIENCY :

The efficiency of induction motor can be calculated using the relation output

$$\eta = \frac{\text{output power}}{\text{input power}} \times 100\%$$





CIRCUIT DIAGRAM :

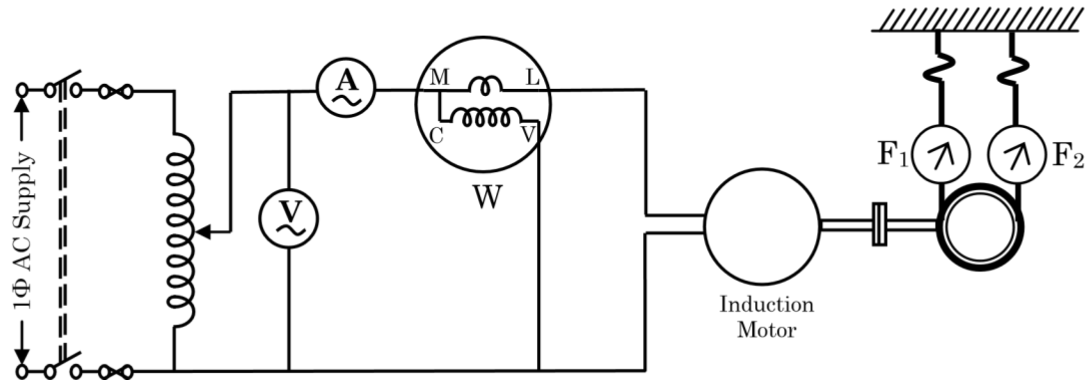


FIG : EXPERIMENTAL SET-UP FOR PERFORMING NO-LOAD AND BLOCK-ROTOR TEST OF SINGLE PHASE INDUCTION MOTOR

PROCEDURE :

1) Connect the circuit as shown in Fig.
2) Set the single-phase variac at minimum voltage and brake pulley arrangement at no load.
3) Switch ON the power supply and start the induction motor.
4) Now gradually increase the applied voltage by varying the variac very slowly up to the rated voltage.
5) Increase the mechanical load on motor step by step and note down the various reading for load.
6) Switch OFF the supply and disconnect the motor.
7) Calculate the various quantities and draw the various curves as stated above.

OBSERVATION TABLE :

SL NO	Input Voltage V (volt)	Input Current I (amp)	Input Power W (watt)	Force (Kgf)			Speed N_r (rpm)
				F_1	F_2	$F = F_1 - F_2$	
1							
2							
3							
4							
5							

Diameter of pulley, d = m.

CALCULATION :

SL NO	Input Power P_{in} (watt)	Total Force F (Kgf)	Output Torque T (Nw-m)	Output Power P_o (watt)	Slip (%)	Power Factor	Efficiency (%)
1							
2							
3							
4							
5							

RESULT **:** Draw the following curve of single-phase slip ring induction motor

i. Efficiency vs. output power.
ii. Torque vs. output power. iii.
Line current vs. output power.
iv. Power factor vs. output power.
v. Slip vs. output power vi.
Torque vs. slip.

DISCUSSION :

1. Explain the nature of above curve mathematically.

EXPERIMENT NO : EM – II/7

TITLE **DETERMINE THE DIRECT-AXIS REACTANCE (X_D) AND QUADRATURE-AXIS REACTANCE (X_Q) OF A THREE PHASE SYNCHRONOUS MACHINES BY SLIP TEST.**

OBJECTIVE : To determine the direct-axis synchronous reactance (X_d) and quadrature-axis synchronous reactance (X_q) of a three phase synchronous machines by slip test.

APPRATUS :

Sl No	Apparatus Name	Apparatus Type	Specification / Range	Makers Name	Serial No
1	Synchronous Machine				
2	Ammeter				
3	Voltmeter				
4	Variac				
7	Tachometer				

THEORY :

When a three phase synchronous alternator operates under normal condition, the resultant armature mmf is stationary with respect to the field mmf. As such the effect of armature mmf cannot be studied unless it is resolved into two components, one is along the axis of pole known as direct axis and another is along the axis quadrature to this known as quadrature axis. The component of armature mmf acting along direct axis has overcome lesser reluctance as compared the component of armature mmf acting along quadrature axis, and can therefore, establish more flux. On the other hand, quadrature axis path has higher reluctance and therefore, quadrature axis mmf will establish lesser flux. So, under the steady stat operation condition of the synchronous machine we define two reactance as follows

Direct axis reactance = X_d

Quadrature axis reactance = X_q

The value of X_d and X_q are determined by applying a balanced reduced external voltage to an unexcited synchronous machine at a speed of little less than the synchronous speed. Due to applied voltage to the stator terminals a current will flow causing a stator mmf. This stator mmf moves slowly relative to the poles and induced an emf in the field circuit in a similar fashion to that of rotor in an induction motor at slip frequency. The effect will be that the stator mmf. will move slowly relative to the poles. The physical poles and the armature-reaction mmf are alternately in phase and out, the change occurring at slip frequency.

When axis of the pole and axis of armature reaction mmf wave coincide, the armature mmf acts through the field circuit. Therefore, the corresponding reactance is direct axis reactance and is given by maximum value of armature voltage (phase value)

X_d □ ____

minimum value of armature current (phase value)

When armature reaction mmf is in quadrature with the field poles, the applied voltage is equal to the leakage reactance drop plus the equivalent voltage drop of the cross-magnetizing field component. Therefore, the corresponding reactance is quadrature axis reactance and is given by minimum value of armature voltage (phase value)

X_q □ ____

maximum value of armature current (phase value)

CIRCUIT DIAGRAM:

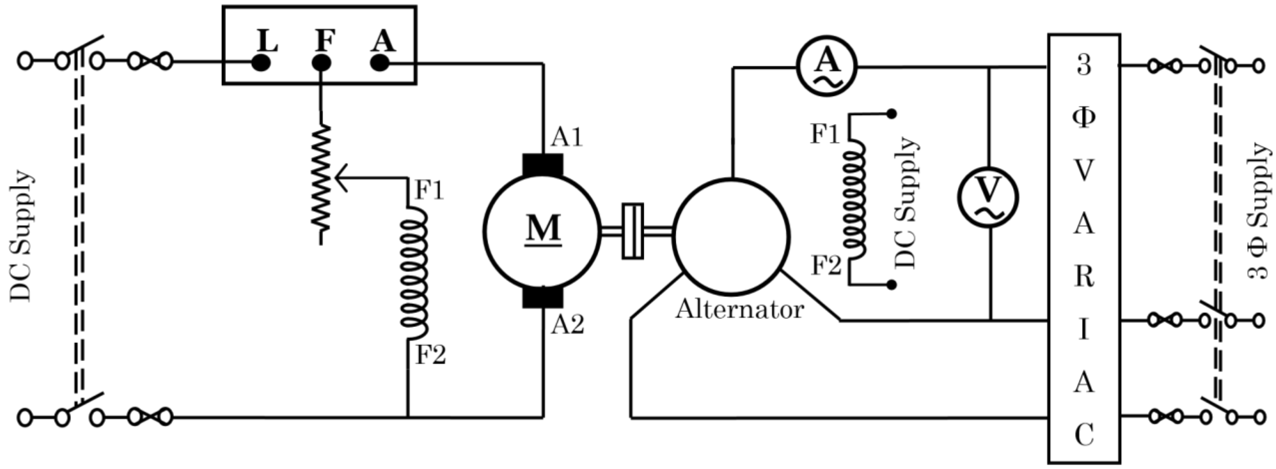


FIG : EXPERIMENTAL SET-UP FOR PERFORMING SLIP TEST OF SYNCHRONOUS MACHINE

PROCEDURE :

1) Connect the circuit as shown in Fig.
2) Bring the field circuit rheostat of D.C. motor to its minimum value and switch ON the supply.
3) Start the D.C. motor with the help of three point stater.
4) Check the direction of rotation of the synchronous machine. The direction of rotation of synchronous machine when run by D.C. motor should be the direction of rotation when run as induction motor. If it is not same, change either the direction of rotation of D.C. motor or the phase sequence of synchronous machine.
5) Increase the speed of D.C. motor by increasing the field rheostat so that the speed reaches a little less than the synchronous speed of machine. Maintain the slip to be less than 5 %.
6) Check that the three phase variac is set to zero position. Switch ON the ac supplies with opening field circuit and apply it to the stator of synchronous machine.
7) Increase the supply voltage using three phase variac so that the machine draw the rated current.
8) It will be observe that induced voltage, applied voltage to the stator winding and current in stator winding will fluctuate from their minimum values to maximum values.
9) Note down the reading.
10) Repeat the step 5, 7 and 8 for some other suitable speeds.
11) Reduce the applied voltage to stator winding of synchronous machine by means of three phase variac to zero and switch OFF the ac supply.
12) Reduce the speed of dc motor by decreasing its field resistance and switch OFF the dc supply.

OBSERVATION TABLE :

SL			Armatures Voltage	Armature current			

NO	Speed N (rpm)	Slip S (%)	Maximum (V)	Minimum (V)	Maximum (A)	Minimum (A)	X_d (Ω)	X_q (Ω)	$\frac{X_q}{X_d}$
1									
2									
3									
4									
5									

RESULT :

The average direct axis reactance X_d = Ω

The average quadrature axis reactance X_q = Ω

DISCUSSION :

1. What should be the value $\frac{X_q}{X_d}$?
2. What should be the permissible value of slip for this experiment?
3. Why the reading of Voltmeter and Ammeter are fluctuating?

EXPERIMENT NO : EM – II/8

TITLE **LOAD TEST ON WOUND ROTOR INDUCTION MOTOR TO OBTAIN THE PERFORMANCE CHARACTERISTICS.**

OBJECTIVE **:** To determine the torque, output power, efficiency, input power factor and slip of three-phase wound rotor induction motor for various load and plot the following curve. i. Efficiency vs. output power.

ii. Torque vs. output power.
iii. Line current vs. output power.
iv. Power factor vs. output power.
v. Slip vs. output power vi. Torque vs. slip.

APPRATUS :

Sl No	Apparatus Name	Apparatus Type	Range	Makers Name	Serial No
1	Induction Motor				
2	Ammeter				
3	Voltmeter				
4	Wattmeter				
5	Variac				
7	Tachometer				

THEORY :

The load test on induction motor helps us to compute the complete performance of induction motor means to calculate the various quantities i.e. torque, slip, efficiency, power factor etc at different loading. In this test supply voltage is applied to motor and variable mechanical load is applied to the shaft of motor. Mechanical load can be provided by brake and pulley arrangement. The input current, input voltage, input power and speed of motor are observed from the experiment and various performance quantities are calculated as explain below.

SLIP :

Due to the three-phase supply given to stator of an induction motor, a rotating magnetic field of constant magnitude is set up in the stator of the motor. The speed with which this rotating magnetic field rotates is known as synchronous speed and is given by

$$N_s = \frac{120f}{P}$$

Where f =supply frequency.
P =no of poles on the stator of the rotor.

The actual speed of the rotor N_r is always less than the synchronous speed. So the slip of the motor is given by following equation. This value of slip at full load lies between 2 to 5%.

$$s = \frac{N_s - N_r}{N_s} \times 100\%$$

TORQUE :

Mechanical loading is applied on induction motor by means of brake and pulley arrangement. The belt can be tightened or loosened by means of threaded rods with handles fixed on frame. Two spring balances are provided at the end of belt. The net force exerted at the brake drum can be obtained from the readings of the two spring balance i.e. F_1 and F_2

Net force exerted on drum, $F = (F_1 - F_2)$ Kgf and Torque $T = F \times \frac{d}{2} \times 9.81$ Nw-m

Where d = effective diameter of brake drum in meter.

OUTPUT POWER :

The output power of induction motor can be calculated as $P_o = \frac{2\pi N T_r}{60}$

Where N_r = speed of induction motor in rpm.

INPUT POWER :

The input power can be calculated from the readings of two wattmeter connected in the circuit

$$P_{in} = W_1 + W_2$$

At low power i.e. under no load condition one of the wattmeter may read negative. In that case the connection of one wattmeter coil either pressure coil or current coil should be reversed however such reading should be recorded as negative reading.

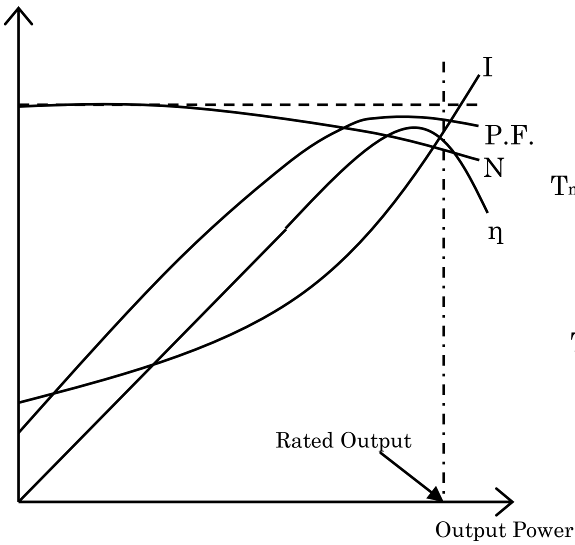
POWER FACTOR :

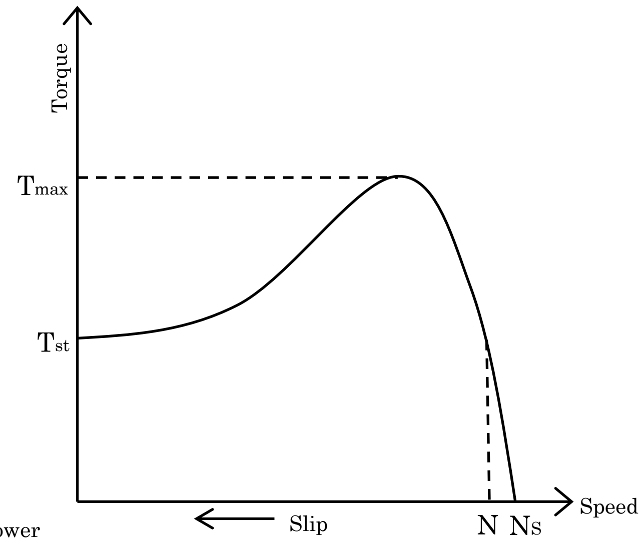
The power factor can be calculated from the two wattmeter reading using following relation

$$\cos\phi = \cos\tan^{-1}\left(\frac{\sqrt{3}\,(W_1 - W_2)}{W_1 + W_2}\right)$$

EFFICIENCY :

The efficiency of induction motor can be calculated using the relation, $\eta = \frac{\text{output power}}{\text{input power}} \times 100\%$





CIRCUIT DIAGRAM :

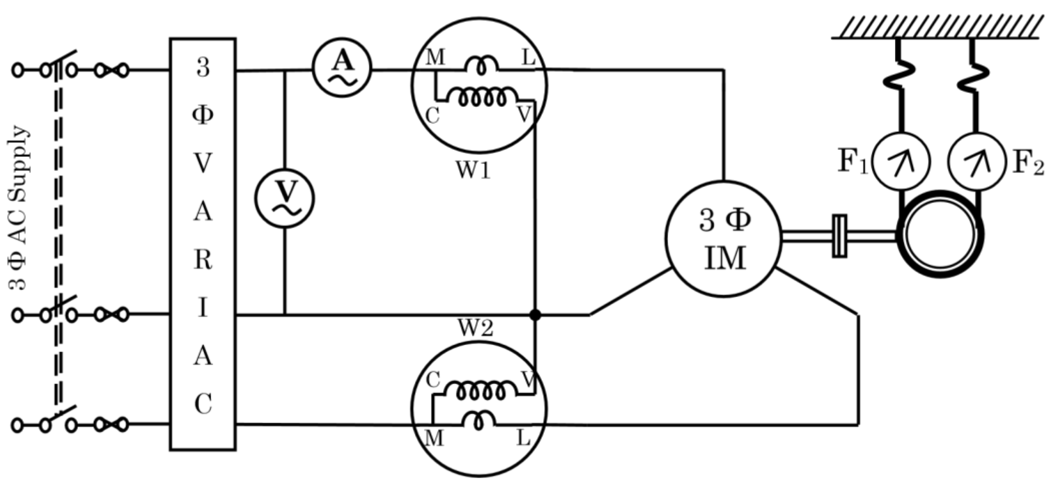


FIG : EXPERIMENTAL SET-UP FOR PERFORMING LOAD TEST OF WOUND ROTOR INDUCTION MOTOR

PROCEDURE :

1) Connect the circuit as shown in Fig.
2) Set three-phase variac for minimum voltage and brake pulley arrangement is set for no load.
3) Switch ON the power supply and start the induction motor.
4) Now gradually increase applied voltage by varying the variac very slowly up to the rated voltage.
5) Increase the mechanical load on motor step by step and note down the various reading for load.
6) Switch OFF the supply and disconnect the motor.

OBSERVATION TABLE :

SL	Input	Input	Input Power	Force (Kgf)	Speed

NO	Voltage V (volt)	Current I (amp)	W_1 (watt)	W_2 (watt)	F_1	F_2	$F = F_1 - F_2$	N_r (rpm)
1								
2								
3								
4								
5								

Diameter of pulley, d = m.

CALCULATION :

SL NO	Input Power P_{in} (watt)	Total Force F (Kgf)	Output Torque T (Nw-m)	Output Power P_o (watt)	Slip (%)	Power Factor	Efficiency (%)
1							
2							
3							
4							
5							

**RESULT : ** Draw the following curve of three-phase slip ring induction motor

i. Efficiency vs. output power.
ii. Torque vs. output power. iii. Line current vs. output power.
iv. Power factor vs. output power.
v. Slip vs. output power vi. Torque vs. slip.

DISCUSSION :

1. Explain the nature of above curve mathematically.

EXPERIMENT NO : EM – II/8

TITLE **LOAD TEST ON WOUND ROTOR INDUCTION MOTOR TO OBTAIN THE PERFORMANCE CHARACTERISTICS.**

OBJECTIVE **:** To determine the torque, output power, efficiency, input power factor and slip of three-phase wound rotor induction motor for various load and plot the following curve. i. Efficiency vs. output power.

ii. Torque vs. output power.
iii. Line current vs. output power.
iv. Power factor vs. output power.
v. Slip vs. output power

APPRATUS :

Sl No	Apparatus Name	Apparatus Type	Specification / Range	Makers Name	Serial No
1	Induction Motor				
2	DC Machine				
3	Ammeter 1				
4	Ammeter 2				
5	Voltmeter 1				
6	Voltmeter 2				
7	Wattmeter 1				
8	Wattmeter 2				
9	Load Box				
10	Rheostat				
11	Tachometer				

THEORY :

The load test on induction motor helps us to compute the complete performance of induction motor means to calculate the various quantities i.e. torque, slip, efficiency, power factor etc at different loading. For load test, load put on the induction motor (using coupled dc machine and loading it) is increased and corresponding readings for input current, power, power factor, output power and speed are noted. As soon as the supply voltage is applied to induction motor, motor will starts and rotor of dc machine act as a mechanical load which is applied to the shaft of induction motor by mechanical coupler. When electrical load will change speed of rotor will also change and consequently mechanical load of induction motor will also changed.

When induction motor is running on no-load, slip is small and a very little amount of no-load current flows. As the mechanical load on motor is increased, the speed drops due to its retarding effect, and consequently rotor current and rotor power output will increased. Thus, motor adjust itself to the new load conditions of increased output, and correspondingly stator current (input current) also increases and speed drops slightly. As active power i.e. stator input power increases and active component of current also increases accordingly and meanwhile reactive current component remains fairly constant, the power factor at light load is poor and lagging but under load it is improved.

The input current, input voltage, input power and speed of motor are observed from the experiment and various performance quantities are calculated as explain below.

INPUT POWER :

The input power can be calculated from the readings of two wattmeter connected in the circuit

$$P_{in} = W_1 + W_2$$

At low power i.e. under no load condition one of the wattmeter may read negative. In that case the connection of one wattmeter coil either pressure coil or current coil should be reversed however such reading should be recorded as negative reading.

POWER FACTOR :

The power factor can be calculated from the two wattmeter reading using following relation

$$\cos\phi = \cos\left[\tan^{-1}\left\{\sqrt{3}\,\frac{W_1 - W_2}{W_1 + W_2}\right\}\right]$$

OUTPUT POWER :

The output power of dc machine $P_{in} = V_{dc} I_{dc}$

No-load loss of dc machine $P_i = \frac{1}{2}$ (power to induction motor at no-load)

Copper loss of dc machine $P_{cu} = I_{dc}^2 R_a$

Total loss of dc machine $P_{loss} = P_i + P_{cu}$

So, input power of dc machine $= P_{in} + P_{loss}$

Hence, output of induction motor = input of dc machine.

EFFICIENCY :

The efficiency of induction motor can be calculated using the relation,

$$\eta = \frac{\text{output power}}{\text{input power}} \times 100\%$$

SLIP :

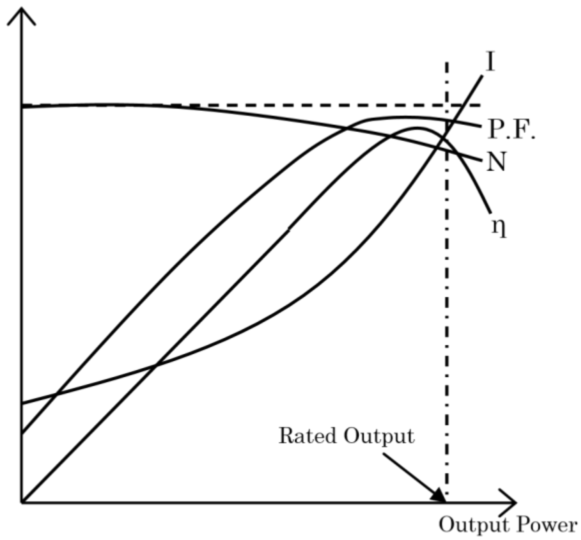
Due to the three-phase supply given to stator of an induction motor, a rotating magnetic field of constant magnitude is set up in the stator of the motor. The speed with which this rotating magnetic field rotates is known as synchronous speed and is given by

$$N_s = \frac{120 f}{P}$$

Where f = supply frequency and P = no of poles on the stator of the rotor.

The actual speed of the rotor N_r is always less than the synchronous speed. So the slip of the motor is given by following equation. This value of slip at full load lies between 2 to 5%.

$$s = \frac{N_s - N_r}{N_s} \times 100\%$$



CIRCUIT DIAGRAM :

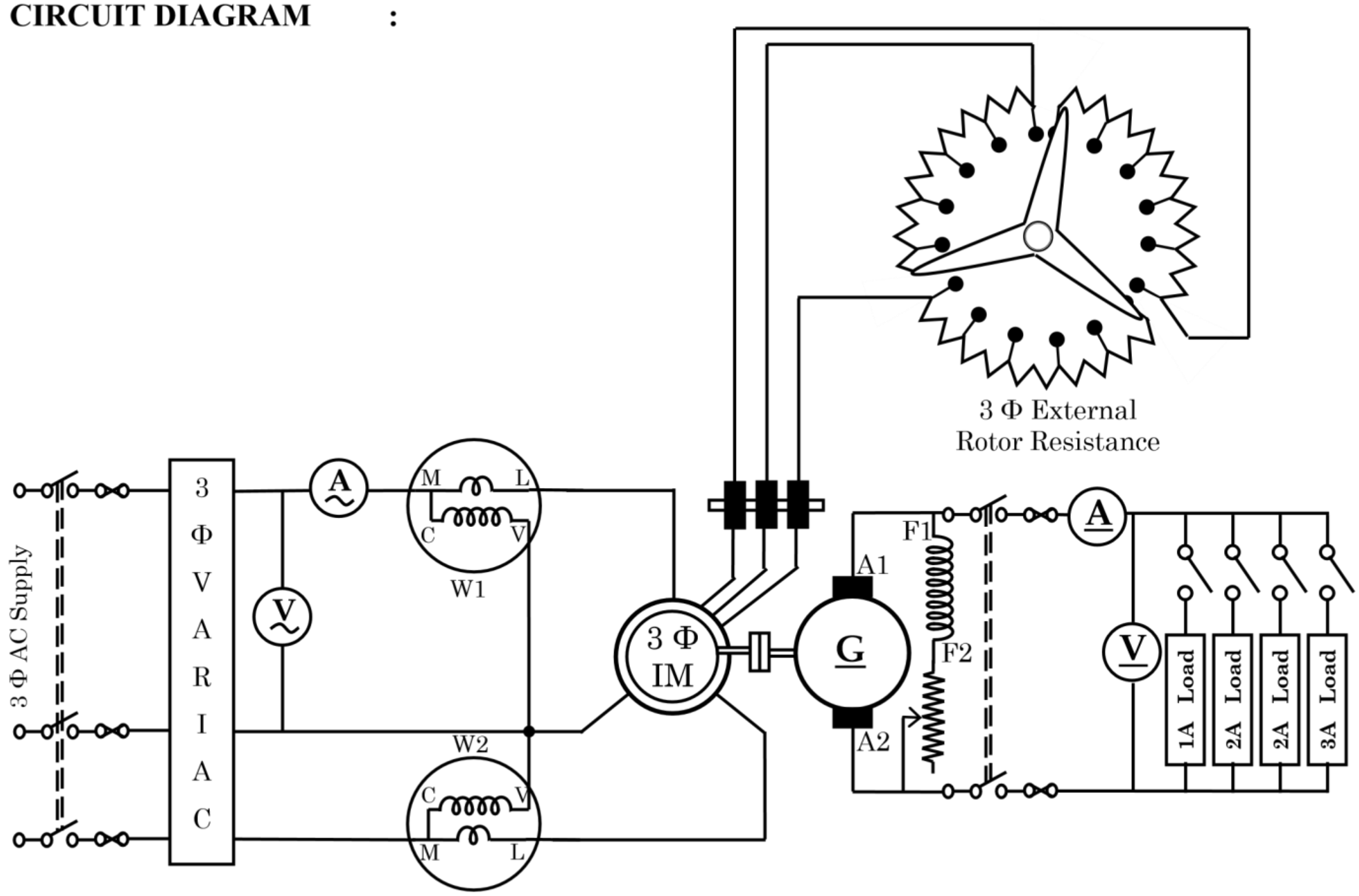


FIG : EXPERIMENTAL SET-UP FOR PERFORMING LOAD TEST OF WOUND ROTOR INDUCTION MOTOR

PROCEDURE :

1) Connect the circuit as shown in Fig.

2) Put the all load switches off. Start the three phase induction motor with the help of threephase external resistance and run it to its normal rated speed.
3) Excite the dc machine as dc shunt generator to its rated voltage. Note down the input no-load power and speed.
4) Put the generator load on and bring the dc generator voltage to its rated voltage by varying field resistance. Increase the generator load step by step and note down the various reading for different load.
5) Switch OFF the power supply and disconnects all loads and motors.

OBSERVATION TABLE :

SL NO	Load	Induction Motor				DC Generator		Speed N_r (rpm)
		Input Voltage V_{in} (volt)	Input Current I_{in} (amp)	Input Power		Output Voltage V_{out} (volt)	Output Current I_{out} (amp)	
				W_1 (watt)	W_2 (watt)			
1	0A							
2	1A							
3	2A							
4	3A							
5	4A							
6	5A							

Armature resistance of DC machine, R_a = Ω.

CALCULATION :

No-load loss of dc machine = watt

SL NO	Induction Motor		DC Generator				Induction Motor Efficiency (%)
	Power Input P_{in} (watt)	Power Factor cos□	Output Power P_{out} (watt)	Copper Loss P_{cu} (watt)	Total Loss P_{loss} (watt)	Input Power P_{in} (watt)	
1							
2							
3							
4							
5							

**RESULT : ** Draw the following curve of three-phase slip ring induction motor

i. Efficiency vs. output power.
ii. Torque vs. output power. iii.
Line current vs. output power.
iv. Power factor vs. output power.
v. Slip vs. output power

DISCUSSION :

1. Explain the nature of above curve mathematically.

EXPERIMENT NO : EM – II/12

TITLE V CURVE OF SYNCHRONOUS MOTOR

OBJECTIVE : To draw V curve and inverted V curve of synchronous motor.

APPRATUS :

Sl No	Apparatus Name	Apparatus Type	Range	Makers Name	Serial No
1	Synchronous Motor				
2	Ammeter				
3	Ammeter				
4	3 Φ AC Variac				
5	DC Variac				
7	Tachometer				

THEORY :

In a.c. electromagnetic device (or in a.c. motor) magnetizing current or lagging reactive VA, drawn from a.c. source is to set up the flux in the magnetic circuit of the device. A synchronous motor is a doubly-excited machine; its armature winding is energized from three phase a.c. source and its field winding from a d.c. source. When synchronous motor is working at constant applied voltage, the resultant air gap flux as demanded by constant supply voltage, remains sub-stantially constant by following equation

$$\phi_{air\ gape} \approx \frac{V_t}{\sqrt{2}\pi f k T_{wph}}$$

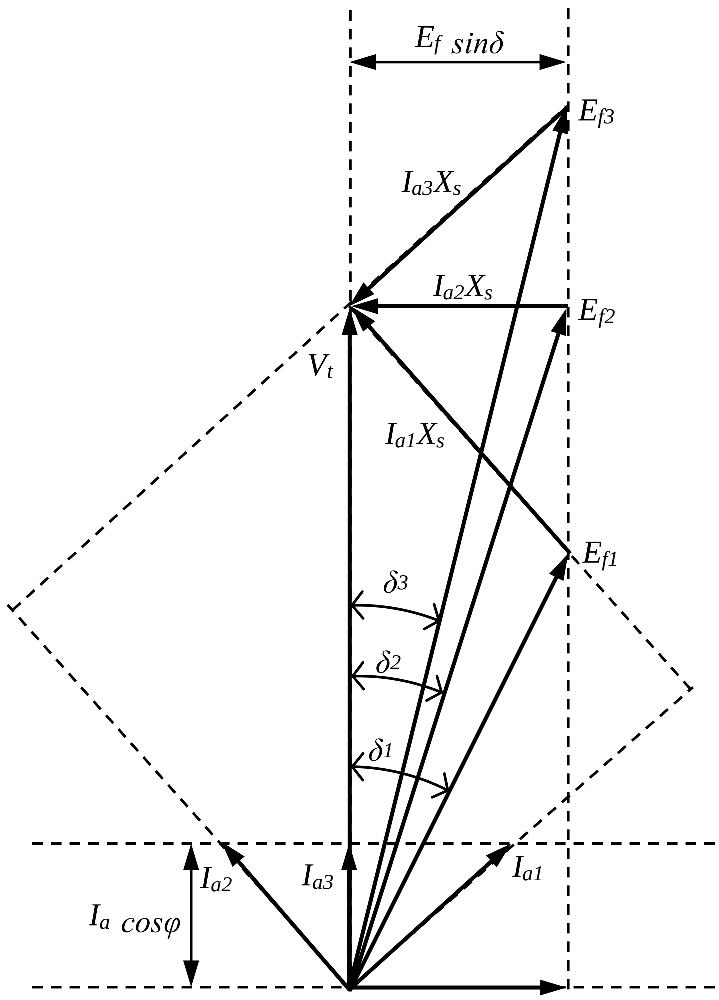
This resultant air gape flux is established by the co-operation of both a.c. in armature winding and d.c. in field winding. If the field current is sufficient enough to set up the air gap flux, as demanded by constant V_t then magnetizing current or lagging reactive VA required from the a.c. source is zero and therefore the motor operate at unity power factor. This field current is known as normal excitation or normal field current.

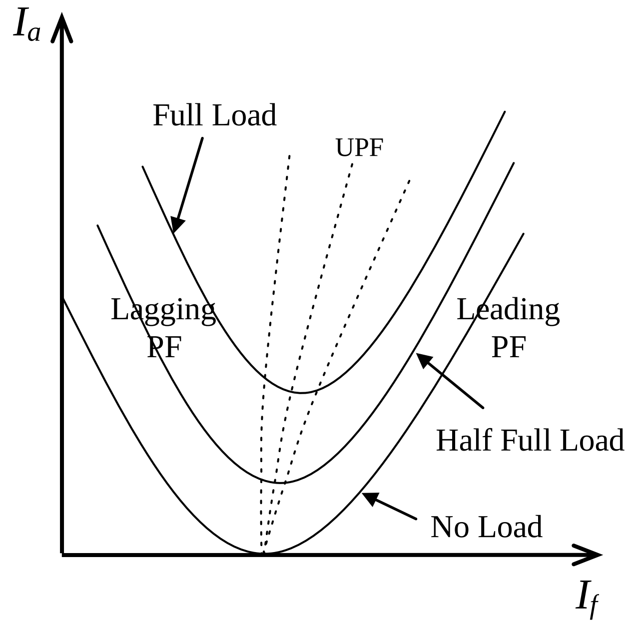
If the field current is made less than the normal excitation, i.e. the motor is under-excite, then the deficiency in flux (difference between constant air gape flux and flux set up by d.c. in field winding) must be made up by the armature winding m.m.f. In order to do the needful, the armature draws a magnetizing current or lagging reactive VA from the a.c. source and as a result of it, the motor operates at lagging power factor.

If the field current is made more than the normal excitation, i.e. the motor is over-excite, then the excess flux (difference between flux set up by d.c. in field winding and constant air gape flux) must be neutralized by the armature winding m.m.f. The armature can do so only if it draws a demagnetizing current from the a.c. source. Since in motor, magnetizing current lags the applied voltage by about 90°, demagnetizing current must be leads the applied voltage by about 90°. In view of this, the excess flux can be counterbalanced only if armature draws a demagnetizing current or leading reactive VA fron a.c. source and as a result of it, the motor operates at leading power factor.

Therefore, a synchronous motor with under excitation condition operates at lagging power factor and with over excitation condition operates at leading power factor. The effect of field current on synchronous motor power factor can also be explained with the help of its phasor diagram. For simplicity, armature resistance r_a is neglected and synchronous reactance X_s and terminal voltage V_t are assumed to remain constant. The per phase power is

$$P = \frac{E_f V_t}{X_s} \sin\delta = V_t I_a \cos\varphi$$





CIRCUIT DIAGRAM :

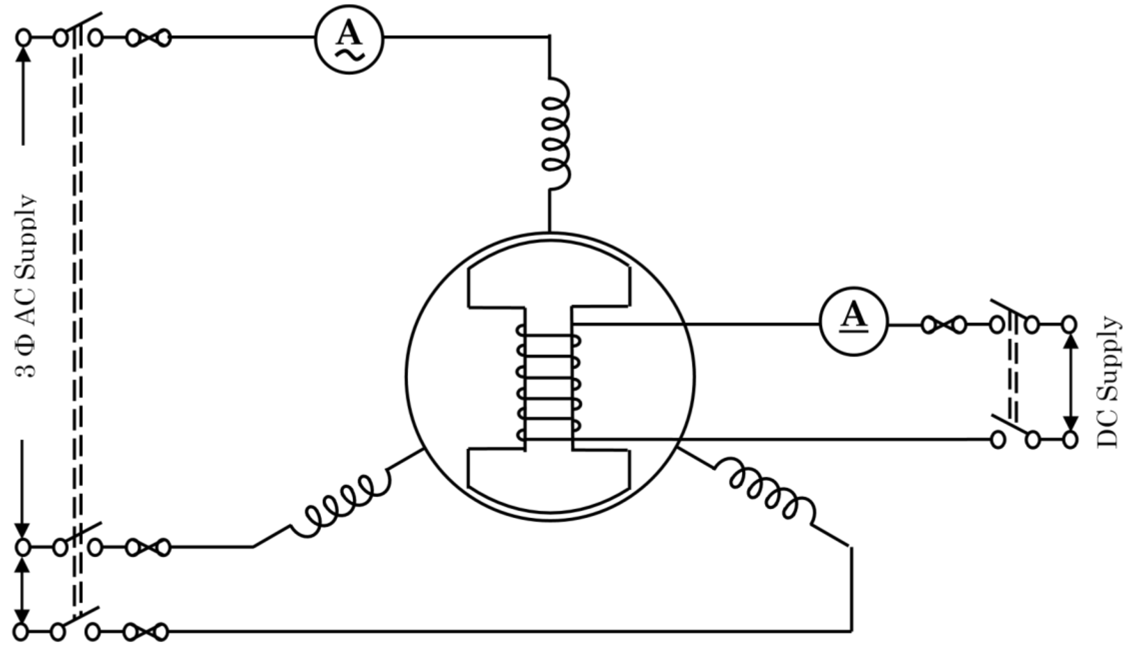


FIG : EXPERIMENTAL SET-UP FOR PERFORMING V CURVE TEST OF SYNCHRONOUS MOTOR

PROCEDURE :

1) Connect the circuit as shown in Fig.
2) Switch on the power 3 Φ a.c. supply and fed to stator of synchronous motor with the help of 3 Φ variac gradually and slowly.
3) When the motor run at synchronous speed, energized the field winding by d.c. supply.
4) Vary the field current step by step and note down the armature current at no load. 5) Switch OFF the power supply and disconnects all loads and motors.

OBSERVATION TABLE :

SL NO	Field Current I_f (amp)	Armature Current I_a (amp)
1		
2		
3		
4		
5		
6		
7		
8		
9		

10		

RESULT **:** Draw the ‘V’ curve of synchronous motor between field current and armature current.