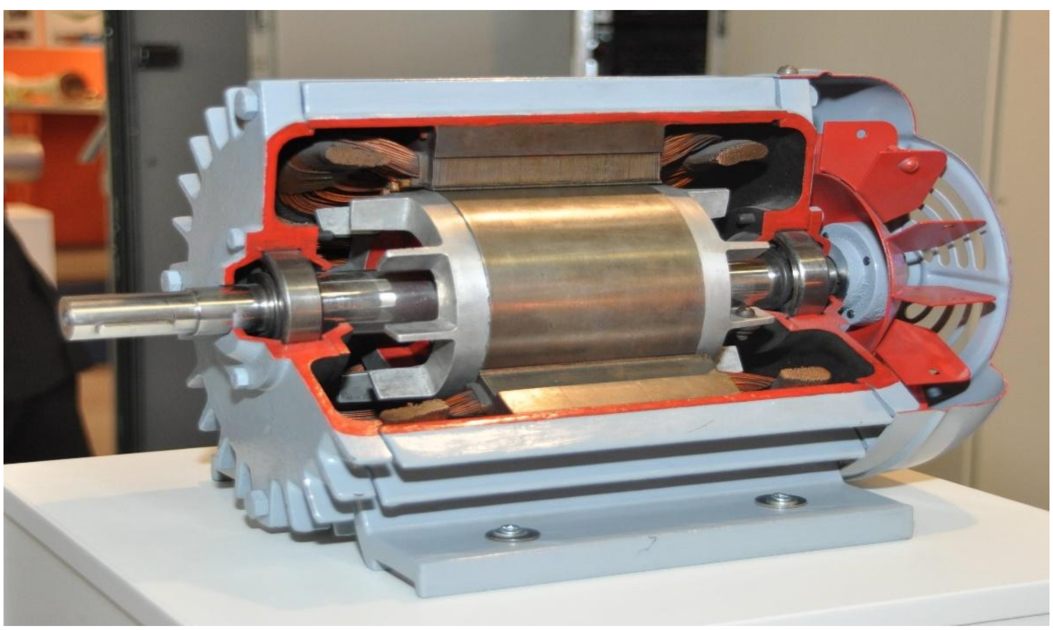
Experiment No: …..1

Running light test and Blocked Rotor Test of Three-Phase Squirrel Cage Induction Motor

Contents



1. Objectives

The aim of thisexperimentisto conduct running light test on a three-phase squirrel cage induction motor and plot input current; power, power factor V/s applied voltage. To conduct blocked rotor test. Measure stator-winding resistance.Find equivalent circuit parameters and compute the performance at rated voltage and a slip of 5%.

2.Expected outcome ofexperiment:

On successful completion of experiment the students will be able to know:

- How to practically conduct light test.
- How to perform block rotor test and its significance.

3. Theory:

Introduction:

The induction motors are widely used in the industries and consume maximum power. To improve its performance characteristics certain tests have been designed like no-load test and block rotor test, etc. A blocked rotor test is normally performed on an induction motor to find out the leakage impedance. Apart from it, other parameters such as torque, motor, short-circuit current at normal voltage, and many more could be found from this test. Blocked rotor test is analogous to the short circuit test of transformer. Here shaft of the motor is clamped i.e. blocked so it cannot move and rotor winding is short circuited. In slip ring motor rotor winding is short circuited through slip rings and in cage motors, rotors bars are permanently short circuited. The testing of the induction motor is a little bit complex as the resultant value of leakage impedance may get affected by rotor position, rotor frequency and by magnetic dispersion of the leakage flux path. These effects could be minimized by conducting a block rotor current test on squirrel-cage rotor.

No Load Test:

The impedance of magnetizing path of induction motor is large enough to obstruct flow of current. Therefore, small current is applied to the machine due to which there is a fall in the stator-impedance value and rated voltage is applied across the magnetizing branch. But the drop-in stator-impedance value and power dissipated due to stator resistance are very small in comparison to applied voltage. Therefore, there values are neglected and it is assumed that total power drawn is converted into core loss. The test is performed at poly-phase voltages and rated frequency applied to the stator terminals. When motor runs for some times and bearings get lubricated fully, at that time readings of applied voltage, input current and input power are taken. To calculate the rotational loss, subtract the stator I^2R losses from the input power.

Blocked Rotor Test

In the blocked rotor test, it should be kept in mind that the applied voltage on the stator terminals should be low otherwise normal voltage could damage the winding of the stator. In block rotor test, the low voltage is applied so that the rotor does not rotate and its speed becomes zero and full load current passes through the stator winding. The slip is unity related to zero speed of rotor hence the load resistance becomes zero. Now, slowly increase the voltage in the stator winding so that current reaches to its rated value. At this point, note down the readings of the voltmeter, wattmeter and ammeter to know the values of voltage, power and current. The test can be repeated at different stator voltages for the accurate value.

4. Equipment required:

S.No.	Name	Range	Remark	Qty.
1	Voltmeter	0-400V	AC	1
2	Ammeter	0-3A 0-2A	AC, AC	1 each
3	Wattmeter	600V,5A,LPF 150V,5A,UPF	---	1
4	Tachometer	2000 RPM	----	1

5. **Methodology for Measurements:**

1. The connections are made as per the circuit diagram.
2. For no load test apply the rated voltage.
3. Take two or three readings by increasing voltage take readings of ammeter, voltmeter and wattmeter.
4. For blocked rotor test apply the rated current and block the rotor by applying load.
5. Take the readings of ammeter, voltmeter and wattmeter.

6. **Measurements**

The figure below shows theconnection diagramfortheexperiment:

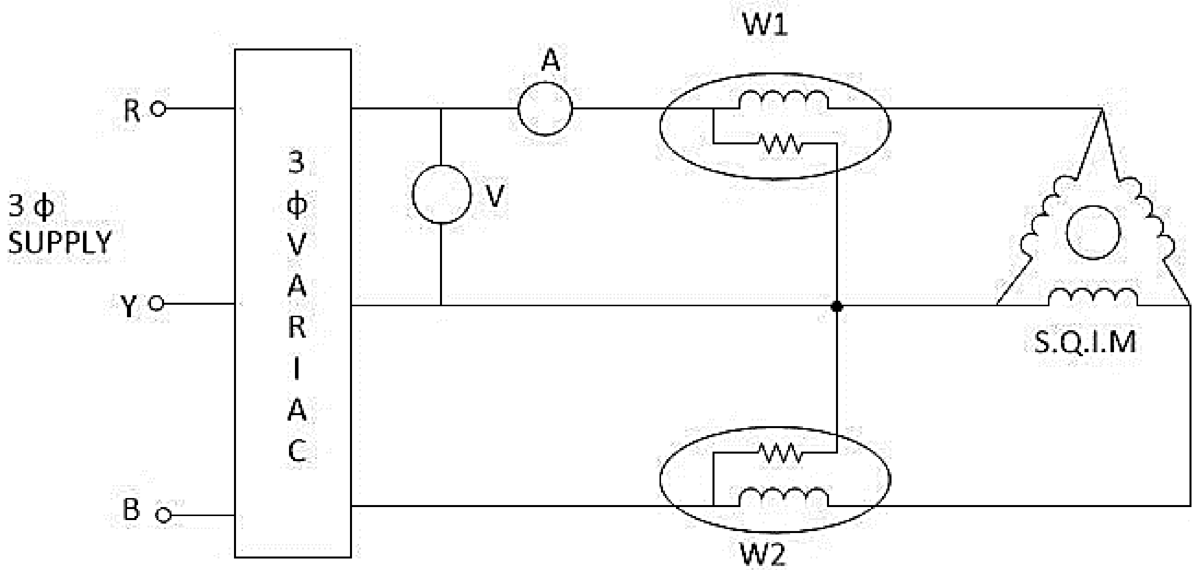


Fig.1: Connection diagram for the experiment

Machinespecifications: -

Name plate details of Induction machine	
Rated Voltage=400V Rated Current= 3.1 A	Power = 3HP Rated Speed=1440rpm

Usingthe above setup notedown yourobservationsinthefollowingTable:

Observation Table: Table to be usedfor recordingthe measurements:

Table No. 1: For no-load or light load condition

S.No.	V	I	W1	W2	W1+W2	P.f

Table No 2: For Blocked rotor test

S. No.	V	I	W1	W2	W1+W2

Precaution:

- Use LPF wattmeter for no load and UPF wattmeter for blocked rotor test.
- Perform no load test at rated voltage.
- Perform blocked rotor test at rated current.
- Perform DC test to measure the resistance of main winding.

7. Results and Discussion

Based on yourmeasurements,letus now discusstheresults thatyou obtained. Please provideresponses to followingpoints:

A. What machine parameters can be obtained from No-Load test?

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B. What is the power factor of the machine? Comment on its value.
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C. Even though there is no-load, why wattmeter reading is not zero?

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…...……………………………………………………………………………………..

D. Comment on the slip of the machine when operated at rated voltage.

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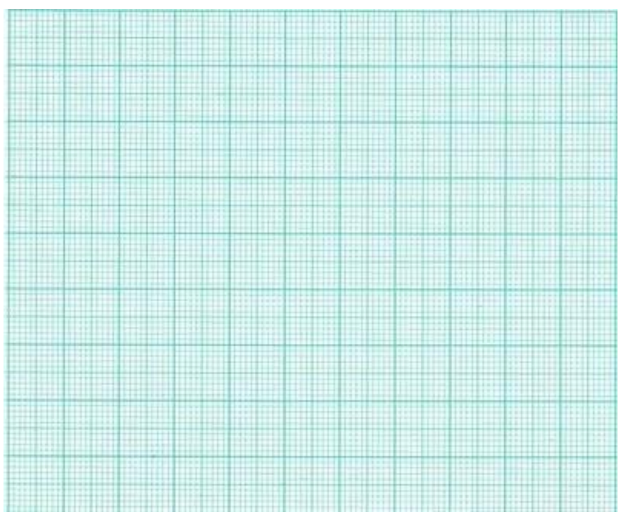
Graph:

Input Power, Current, Power Factor versus Applied Voltage

P, I&p.f



Voltage

8. Conclusions:

Writein yourown wordsthe conclusion ofperformingthis experiment. Write aboutwhatyou learnedfromthisexperiment.

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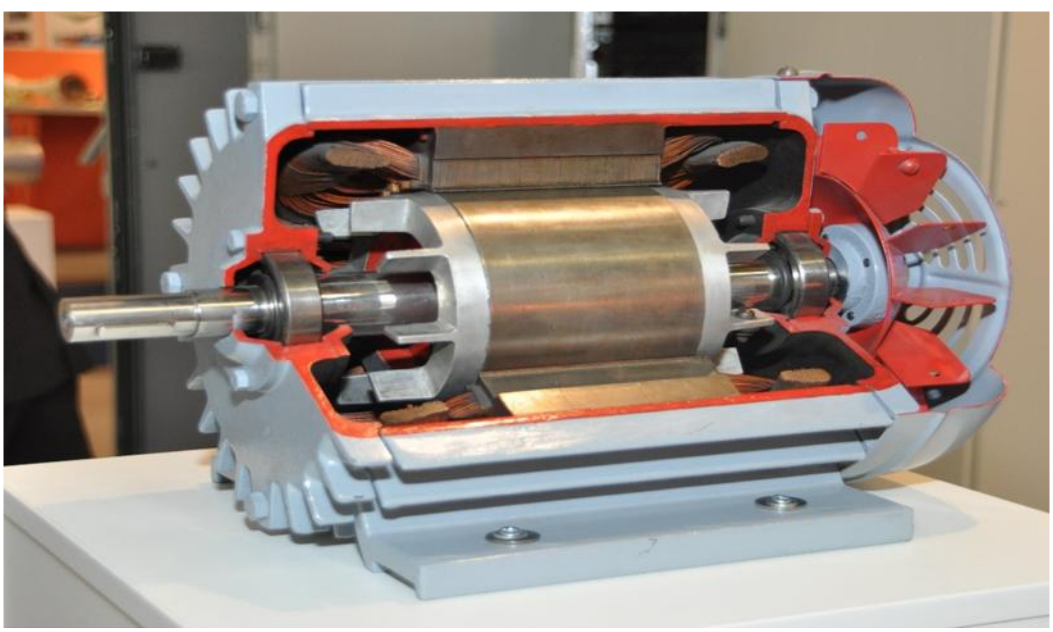
Experiment No: …..2

To conduct direct load test on a three phase squirrel cage induction motor and plot input current, torque, power factor, speed and efficiency V/s output power.

Contents



1. Objectives

To conduct direct load test on a three phase squirrel cage induction motor and plot input current, torque, power factor, speed and efficiency V/s output power.

2. Expected outcome ofexperiment:

On successful completion of experiment the students will be able to know:

- Significance of load test.
- Effects of load test on the performance of induction motor.

3. Theory:

The load test on induction motor is performed to compute its complete performance i.e. torque, slip, efficiency, power factor etc. During this test, the motor is operated at rated voltage and frequency and normally loaded mechanically by brake and pulley arrangement from the observed data, the performance can be calculated, following the steps given below.

SLIP:

The speed of rotor, $N_r$droops slightly as the load on the motor is increased. The synchronous speed, $N_s$of the rotating magnetic field is calculated, based on the number of poles, P and the supply frequency, f i.e.

Synchronous speed: $N_s = \frac{120f}{P}$ rpm

Normally, the range of slip at full load is from 2 to 5 percent.

Torque:

Mechanical loading is the most common type of method employed in laboratories, A brakedrum is coupled to the shaft of the motor and the load is applied by tightening the belt, provided on the brakedrum. The net force exerted at the brake drum in kg is obtained from the readings S_1 and S_2 of the spring balances i.e.

Output = Torque * Speed

Thus as the speed of motor does not vary appreciably with load torque will increase with increasing load.

Net force exerted, W = (S_1 – S_2) kg

Then, load torque, T = W x d/2 kg – m

= W x d/2 x 9.8 N– m

where, d – effective diameter of the brake drum in meters.

Output power, P_0:

The output power in watts developed by the motor is given by,

Output power, P_0=$2\Pi NT/60$watts, where, N is the speed of the motor in r. p. m.

Input power:

Input power is measured by the two wattmeter, properly connected in the circuit i.e.

Input power = (W_1 + W_2) watts

Where, W_1 and W_2 are the readings of the two wattmeter.

Power factor:

Power factor of induction motor on NO-LOAD is very low because of the high valueof magnetizing current. With the increase in load the power factor increases because the power component of the current is increased. Low power factor operation is one of the disadvantages of induction motor. An induction motor draws heavy amount of magnetizing current due to presence of air gap between the stator and rotor. Thus to reduce the magnetizing current in induction motor the air-gap is kept as small is possible.

Efficiency:

Percentage efficiency of the motor,η= $\frac{Poutput}{Pinput}$

Full load efficiency of 3 phase induction motor lies in the range of 72 % (for small motors) to 82 % (for very large motors).

Speed:

When the induction motor is on NO-LOAD speed is slightly below the synchronous speed.

Thecurrent due to induced emf in the rotor winding is responsible for production of torque required at no-load. As the load is increased the rotor speed is slightly reduced. The emf induced in the rotor causes the current increased to produce higher torque, until the torque developed is equal to torque required by load on motor.

4. Equipment required:

S.No.	Name	Range	Remark	Qty.
1	Voltmeter	0-300V 0-300V	AC DC	1 each
2	Ammeter	0-10A 0-10A	AC DC	1 each
3	Rheostat	355Ω/1.6A	--	1
4	Wattmeter	300V/10A/UPF	--	1

5. Methodology for Measurements:

1. The connections are made as per the circuit diagram.
2. Power supply is obtained from 3 variac.
3. The TPST switch is closed.
4. Rated voltage of 3 induction motor is applied by adjusting autotransformer.
5. The initial readings of ammeter, voltmeter and wattmeter are noted.
6. By increasing the load step by step the readings of ammeter, voltmeter and wattmeter are noted.

6. Measurements

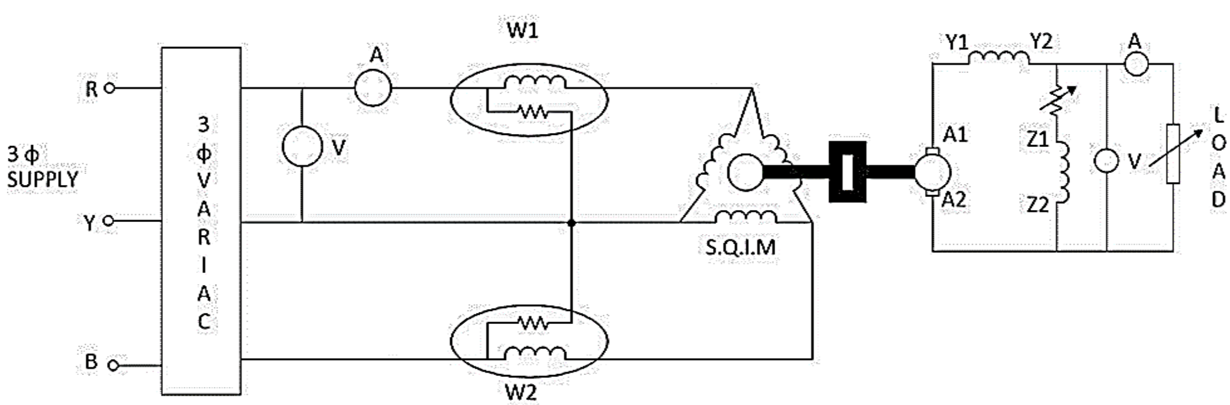


Fig.1: Connection diagram for the experiment

Machinespecifications: -

Name plate details of DC Generator	Name plate details of Induction Motor
Rated Voltage=220V Rated Current=8A Power = 1.75 kW Rated Speed=1421rpm	Rated Voltage=230V Rated Current=56A Power =11Kw Rated Speed=1440rpm

Usingthe above setup notedown yourobservationsinthefollowingTable:

S.No	V	I	W1	W2	I/P power	Speed	V_{dc}	I_{dc}	Output Power	Torq ue	Pf	η

Precaution:

- Use LPF wattmeter at no load.
- Run machine at rated voltage.
- Do not exceed the current beyond rated values for machines.

7. Results and Discussion

Based on yourmeasurements,letus now discusstheresults thatyou obtained. Please provideresponses to followingpoints:

A. What machine parameters can be obtained from direct-Load test?

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B. What is the power factor of the machine? Comment on its value.

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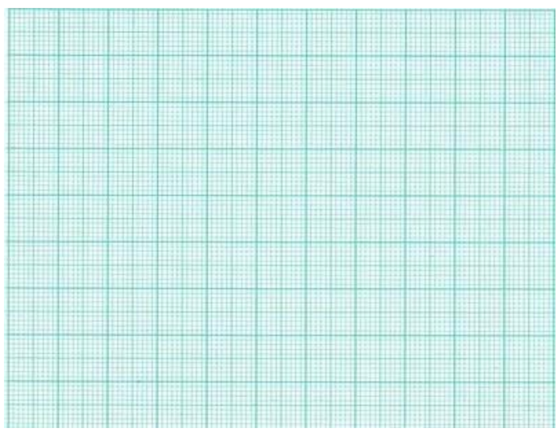
Graph:

Input Current, Power Factor, Torque, Speed and efficiency versus output power



8. Conclusions:

Writein yourown wordsthe conclusion ofperformingthis experiment. Write aboutwhatyou learnedfromthisexperiment.

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Experiment No: …..3

To determine the rotor resistance of a three phase squirrel cage induction motor by performing variable frequency blocked rotor test.

Contents

1. Objectives

To determine the rotor resistance of a three phase squirrel cage induction motor by performing variable frequency blocked rotor test.

2.Expected outcome ofexperiment

On successful completion of experiment the students will be able to know:

- Significance of blocked rotor test.
- Rotor resistance value practically using the test.

3. Theory

The rotor resistance R2 plays an extremely critical role in the operation of an induction motor. Among other things, R1 determines the shape of the torque-speed curve, determining the speed at which the pull out torque occurs. A standard motor test called the blocked-rotor test can be used to determine the total motor circuit resistance. However, this test finds only the total resistance. To find the rotor resistance R1 accurately, it is necessary to know R1 so that it can be subtracted from the total.There is a test for R1 independent of R2, X1 and X2. This test is called the dc resistance test, basically, a dc voltage is applied to the stator windings of an induction motor. Because the current is dc, there is no induced voltage in the rotor circuit and no resulting rotor current. Also, the reactance of the motor is zero at direct current. .

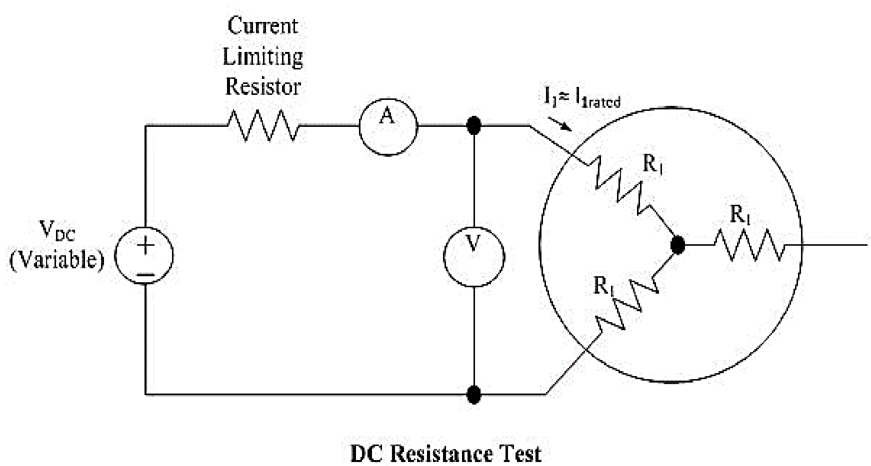

Fig.1: DC Resistance calculation circuit.

Therefore, the only quantity limiting current now in the motor is the stator resistance, and that resistance can be determined. The basic circuit for the dc test is shown in the figure 1. This figure shows a dc power supply connected to two of the three terminals of a V-connected induction motor.

To perform the test, the current in the stator windings is adjusted to the rated value, and the voltage between the terminals is measured. The current in the stator windings is adjusted to the rated value in an attempt to heat the windings to the same temperature they would have during normal operation .The current in flows through two of the windings, so the total resistance in the current path is 2R1. Therefore,

$$R_1 = V_{dc} / 2I_{dc} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

With this value of the stator copper losses at no load may be determined, and the rotational losses may be found as the difference between the input power at no load and the stator copper losses. The value of calculated in this fashion is not completely accurate, since it neglects the skin effect that occurs when an ac voltage is applied to the windings.

Equipment required

S.No.	Name	Range	Remark	Qty.
1	Voltmeter	0-150V	AC	1
2	Ammeter	0-5A	AC	1
3	Rheostat	355Ω/1.6A	-	1
4	Wattmeter	150V,5A,UPF	--	2
5	Tachometer	2000 RPM	--	1

5. Methodology for Measurements:

1. The connections are made as per the circuit diagram.
2. Switch on the power supply and block the rotor with load.
3. Adjust the current through rotor to 4.5 A rated with the help of supply voltage & rheostat.
4. Without disturbing the current vary the speed of motor using rheostat with changes the frequency.
5. In the interval of 10-20 rpm take 4-5 readings of wattmeter, ammeter and voltmeter.

6. Measurements

The figure below shows theconnection diagramfortheexperiment:

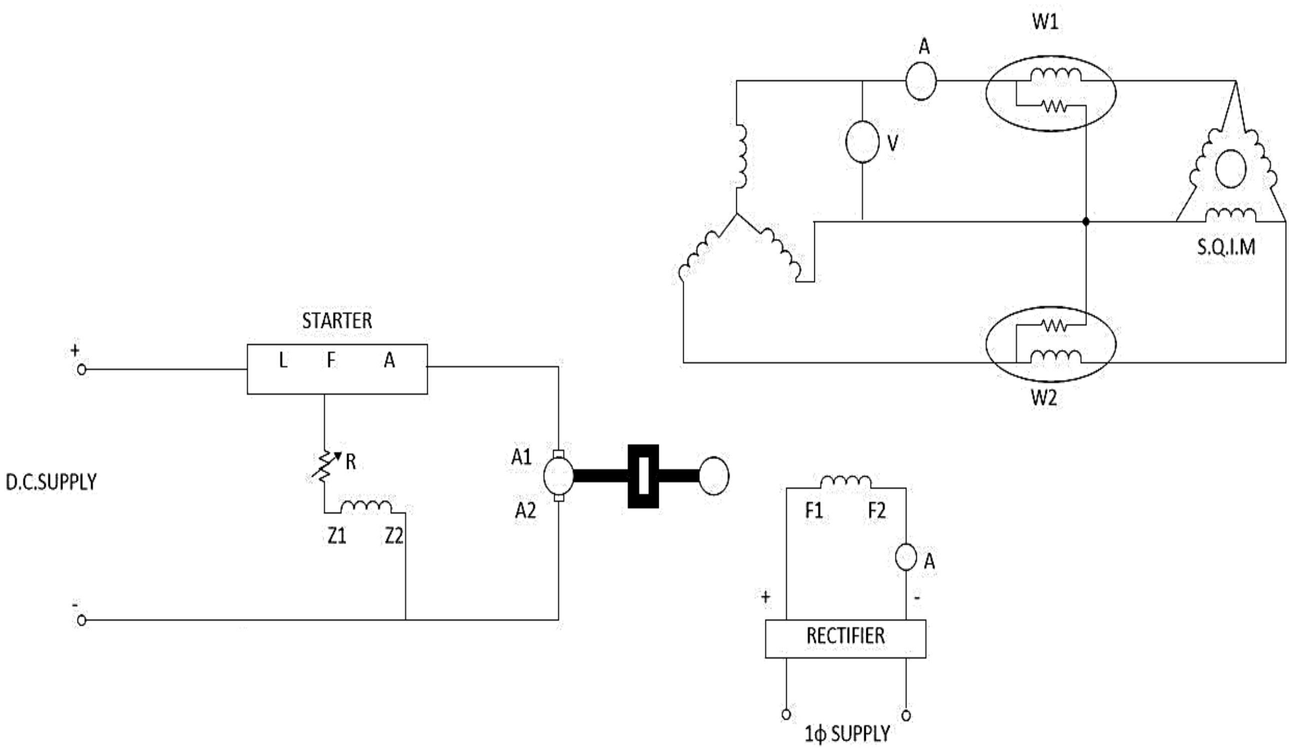

Fig.2: Connection diagram for the experiment

Machinespecifications: -

Name plate details of DC motor	Name plate details of Alternator	Name plate details of Induction motor
Rated Voltage=230V Rated Current=56A Power = 11kW Rated Speed=1500rpm	Rated Voltage=230V Rated Current=56A Power =8 kVA Rated Speed=1500rpm	Rated Voltage= 415V Rated Current= 4.5A Power = 3 HP Rated Speed=1440 rpm

Usingthe above setup notedown yourobservationsinthefollowingTable:

S.No	Speed	V	I	W1	W2	Frequency	Rotor resistance

Precaution:

- Perform the variable frequency blocked rotor test at rated current of the machine.
- Try to perform the test as quickly as possible.

7. Results and Discussion

Based on yourmeasurements,letus now discusstheresults thatyou obtained. Please provideresponses to followingpoints:

A. Why we conduct DC resistance test?

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B. Which one is greater among DC and AC resistance?

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8. **Conclusions**

Writein yourown wordsthe conclusion ofperformingthis experiment. Write aboutwhatyou learnedfromthisexperiment.

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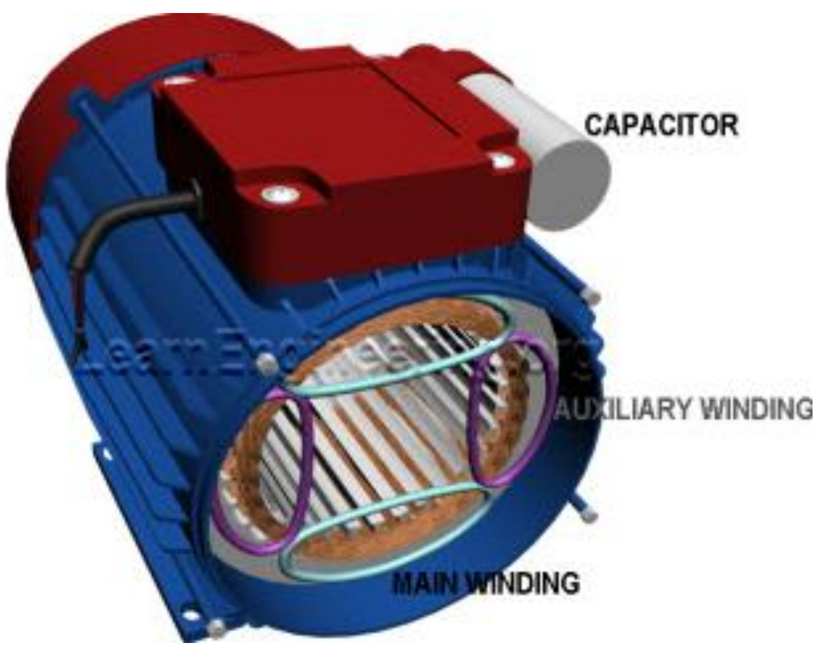
Experiment No: ….4

No-Load and Blocked Rotor Test of Capacitor Start Single-Phase Induction Motor

Contents



1. Objectives

The aim of thisexperiment isto start, run and reverse a single-phase capacitor start induction motor. The next task is to find series and shunt parameters of its equivalent circuit by performing blocked rotor and no-load or light test respectively. Compare its performance at slip of 5%.

2. Expected outcome ofexperiment

On successful completion of experiment the students will be able to know:

- About working of capacitor start single phase induction motors
- Estimation of equivalent circuit parameters of single phase induction motors.

3. Theory

Introduction

The equivalent circuit of a single-phase induction motor can be developed on the bases of two revolving field theory. To develop the equivalent circuit it is first necessary to consider standstill or blocked rotor conditions. The motor with a blocked rotor merely acts like a transformer with its secondary short circuited in the equivalent circuit 'E_m' being emf induced in the stator the motor may now be viewed from the point of view of the two revolving field theory. The two flux components induce in the stator winding respectively E_{mf}&E_{mb}. The phasor sum of E_{mf}&E_{mb} equals the applied voltage V. Since at standstill the two oppositely rotating fields are of the same strength, the magnetizing and rotor impedances are divided into two equal halves connected in series. Thus the equivalent circuit of single phase induction motor at standstill, on the basis of two revolving field theory is shown in figure.

When the rotor is running at speed N with respect to forward field, the slip is s with respect to forward field and (2-s) with respect to the backward rotating field and the equivalent circuit is shown in figure.

At standstill, *s* is unity and the equivalent circuit takes the form shown in equivalent circuit diagram. The parameters of the equivalent circuit can be calculated from the data obtained from the following three tests.

1. **No-load test (Running –light test):**

With the motor running light from a rated voltage, rated frequency source, the input current I and the input power P_0 are recorded. The auxiliary winding must not in circuit while recording the observations.

2. **Blocked-rotor test:**

With rotor blocked and a reduced voltage applied to the main winding, the input current I_{se}, the input powers P_{sc} and the voltage applied V_{se} are recorded. The auxiliary winding should not in circuit during this test as well.

3. **Measurementof DC resistance of main winding**:

This may be measured by the voltmeter-ammeter method, immediately after the blocked rotor test, to get the value at actual winding temperature. Alternatively, the resistance may be measured with the winding at room temperature and hot resistance computed there from. This hot resistance of the main winding is hereafter denoted by R_{14}.

4. Equipment required:

S.No.	Name	Range	Remark	Qty.
1	Voltmeter	0-300V	AC	1
2	Ammeter	0-2A 0-5A	AC	1 each
3	Wattmeter	300V,2.5A,LPF 150V,5A,UPF	---	1 each

5. Methodology for Measurements:

1. The connections are made as per the circuit diagram.
2. To conduct no load test apply rated voltage to motor using 1 variac.
3. Note the readings of ammeter, voltmeter and wattmeter.

4. Now the block the rotor to conduct block rotor test.
5. Apply voltage to the motor slowly using variac such that rated current 3.1A flow in stator.
6. Note down the readings of ammeter, voltmeter and wattmeter.
7. Calculate the motor parameters & draw the equivalent circuit diagram.

6. Measurements

The figure below shows theconnection diagramfortheexperiment:

No-load Test:

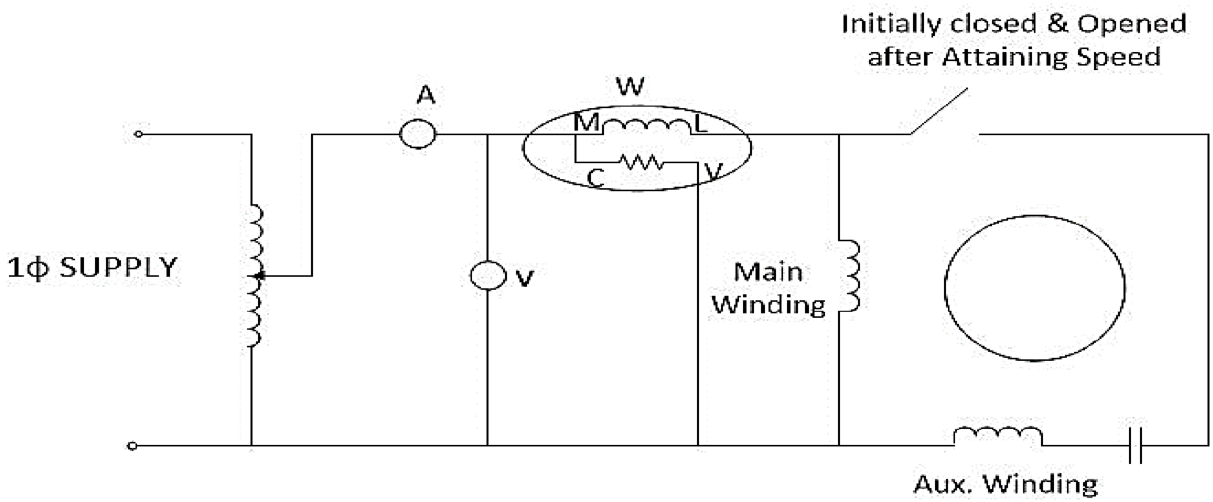


Fig.1: No-Load Test

Blocked rotor test:

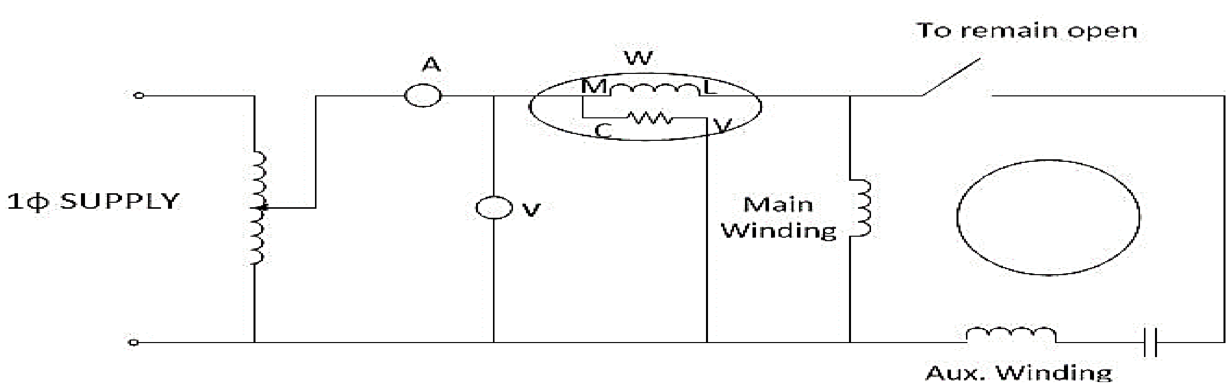


Fig.2: Blocked rotor test

Machinespecifications: -

Name plate details of Induction motor
Rated Voltage= 230V Rated Current= 3.1A Power = 1 HP Rated Speed=1440 rpm

Usingthe above setup notedown yourobservationsinthefollowingTable:

Observation Table: Table to be usedfor recordingthe measurements:

Table No. 1: For running light load or no-load condition

Sl. No.	**Voltage(V)**	**Current(I)**	**Power(W)**

Table No 2: For Blocked Rotor Test

Sl. No.	**Voltage(V)**	**Current(I)**	**Power(W)**

Precaution:

- Use LPF wattmeter for no load and UPF wattmeter for blocked rotor test.
- Perform no load test at rated voltage.
- Perform blocked rotor test at rated current.
- Perform DC test to measure the resistance of main winding.

7. Results and Discussion

Based on yourmeasurements,letus now discusstheresults thatyou obtained. Please provideresponses to followingpoints:

A. What machine parameters can be obtained from No-Load test?

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B. What is the power factor of the machine? Comment on its value.
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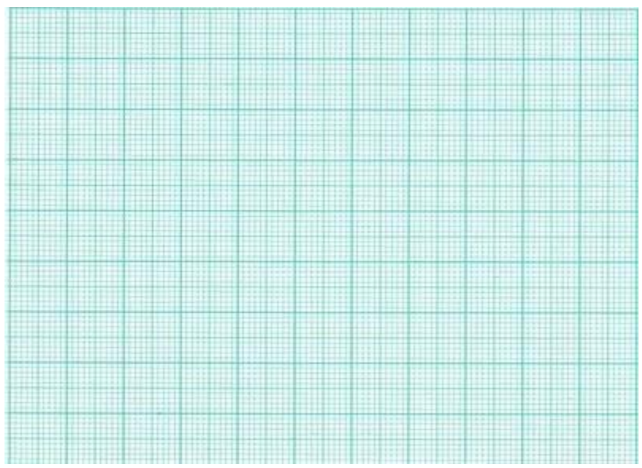
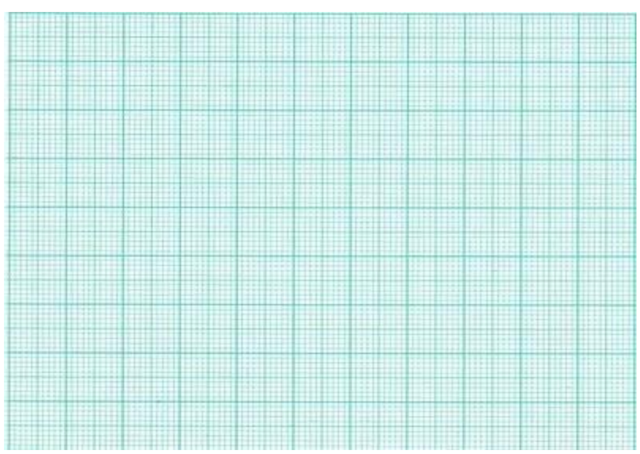
Graph:

Voltage



Current

Power



Voltage

8. **Conclusions**

Writein yourown wordsthe conclusion ofperformingthis experiment. Write aboutwhatyoulearned fromthisexperiment.

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Experiment No.: ….5

QUADRATURE AXIS REACTANCE OF A SYNCHRONOUS MACHINE

Contents

1. Objectives

To conduct the maximum lagging current test on the machine running as a motor and plot the variation of armature current vs field current (reduced to zero, reversed and then increased) and also estimate the value of X_q.

2.Expected outcome ofexperiment:

On successful completion of experiment the students will be able to know:

- How to practically conduct maximum lagging current test.
- Estimation of the value of X_q of the synchronous machine.

3. Theory:

Two reaction theory

Two Reaction Theory was proposed by Andre Blondel. The theory proposes to resolve the given armature MMFs into two mutually perpendicular components, with one located along the axis of the rotor of the salient pole. It is known as the direct axis or d axis component. The other component is located perpendicular to the axis of the rotor salient pole. It is known as the quadrature axis or q axis component.

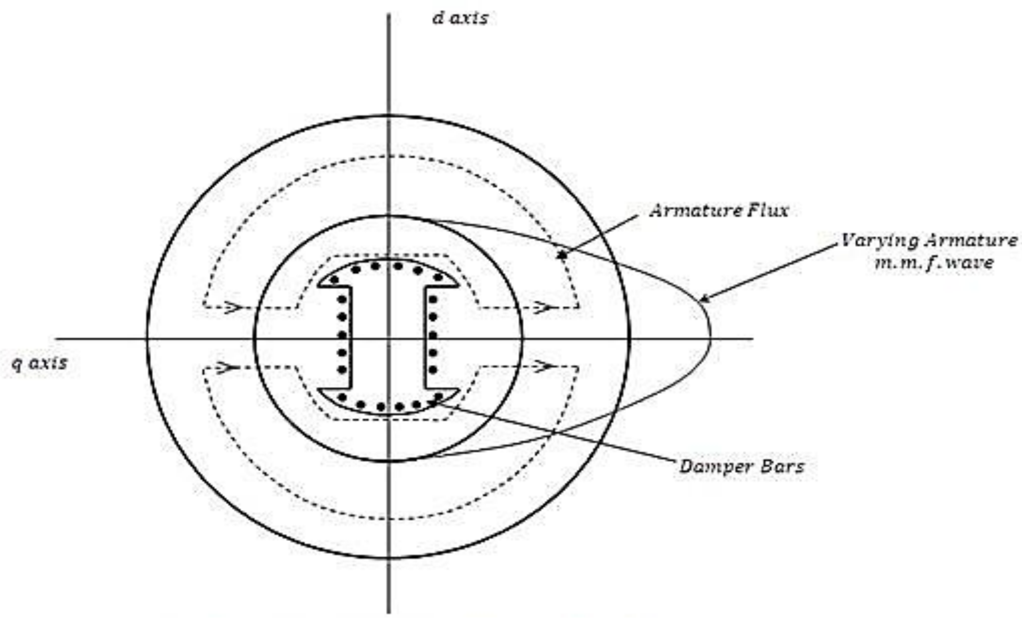

Fig.1: Direct axis and quadrature axis diagram of salient pole synchronous machine

The axis along the axis of the rotor is called the direct or the d axis. The axis perpendicular to d axis is known as the quadrature or q axis. The direct axis flux path involves two small air gaps and is the path of the minimum reluctance. The path shown in the above figure by ϕq has two large air gaps and is the path of the maximum reluctance.

The rotor flux BR is shown vertically upwards as shown in the figure below.

The rotor flux induces a voltage Ef in the stator. The stator armature current Ia will flow through the synchronous motor when a lagging power factor load is connected it. This stator armature current Ia lags behind the generated voltage Ef by an angle Ψ.

The armature current produces stator magneto motive force Fs. This MMF lags behind Ia by angle 90 degrees. The MMF FS produces stator magnetic field BS long the direction of Fs. The stator MMF is resolved into two components, namely the direct axis component Fd and the quadrature axis component Fq.

The total voltage induced in the stator is the sum of EMF induced by the field excitation. The equation is written as follows:-

$$\mathbf{E_f = V + I_a R_a + jX_d I_d + j\,X_q} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

The equation (1) shown above is the final voltage equation for a salient pole synchronous generator.

4. Equipmentrequired:

S.No.	Name	Range	Remark	Qty.
1	Voltmeter	0-600V	AC	1
2	Ammeter	0-5A	DC	1
3	Rheostat	355Ω/1.6A	-	1
4	Ammeter	0-30A	AC	1

5. Methodology for Measurements:

1. Connect the circuit as shown in the figure
2. Run the machine as a motor at rated speed and at the rated voltage.
3. Vary the field current I_f to the maximum value and then gradually decrease in steps until it is zero.
4. Once the I_f becomes zero, now reverse the direction of excitation with the help of TPDT switch and start increasing the excitation current in reverse direction.
5. Note down the values of I_f and I_a for each step.
6. Note down the maximum value of armature current when it shoots up in both directions.

6. Measurements

The figure below shows theconnection diagramfortheexperiment:

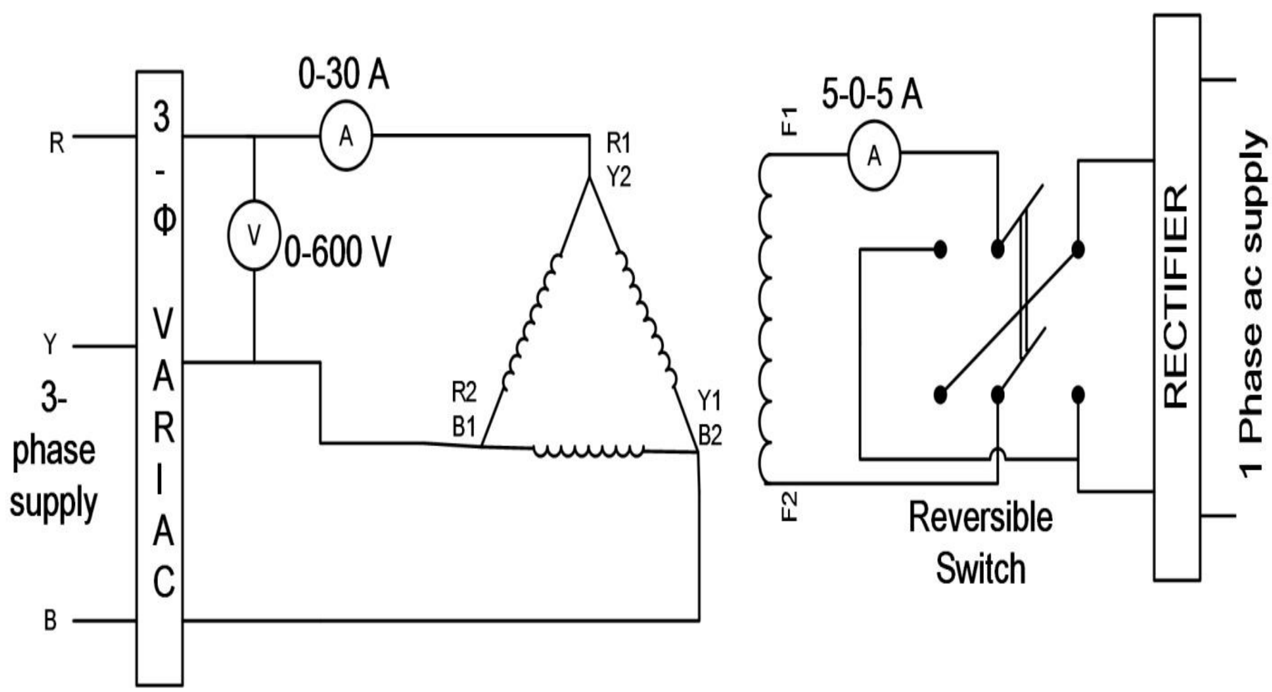

Fig.2: Connection diagram for quadrature axis reactance for synchronous machine

Machinespecifications: -

Name plate details of Synchronous machine	Name plate details of DC Machine
Rated Voltage=400V Rated Current=13.5A Power =7.5 kW Rated Speed=1500rpm	Rated Voltage=230V Rated Current=21.7A Power =5 kW Rated Speed=1500rpm

Usingthe above setup notedown yourobservationsinthefollowingTable:

Table: Table to be usedfor recordingthe measurements:

Forward direction:

S.No.	Field current I_f (A)	Armature current I_a(A)

Reverse direction:

S.No.	Field current I_f (A)	Armature current I_a(A)

Precautions:

1. Circuitconnections shouldnotbe madewhilepowerisON.
2. Ensure variac positionis zero before startingthe experiment.
3. Ensurethe correctconnections ofthetransformer
4. Allconnections should betightandloose connectionsareto beavoided.

7. Results and Discussion

Based on yourmeasurements,letus now discusstheresults thatyou obtained. Please provideresponses to followingpoints:

A. Explain two reaction theory for synchronous machine and tell about the effect of air gape on power factor in synchronous machine?

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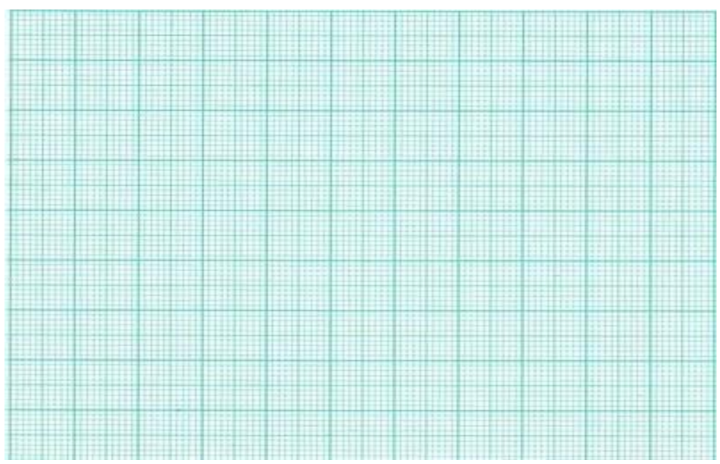
....

B. Plotthe graph betweenfield current and armature current.

Field current



Armature current

8. **Conclusions**

Writein yourown wordsthe conclusion ofperformingthis experiment. Write aboutwhatyoulearned fromthisexperiment, whatyou can tellaboutthe synchronous m/c reactancethatyou didin experiment.

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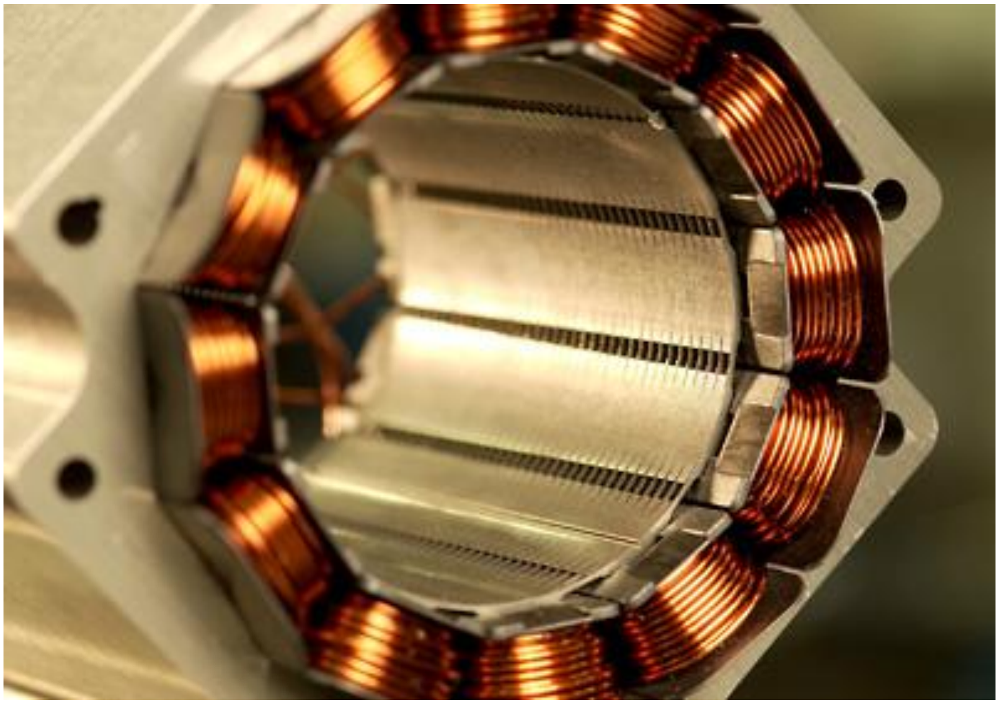
Experiment No.: ……6

SYNCHRONOUS IMPEDANCE OF A SYNCHRONOUS MACHINE

Contents



1. Objectives

1. Obtain OCC and SCC at rated, speed.
2. Determine the variation of synchronous impedance with field current and determine the value of SCR.
3. Estimate the full load regulation at 0.8 pf. (lagging and leading) by mmf and emf methods and compare the results.

2. Expected outcome ofexperiment

On successful completion of experiment the students will be able to know:

- Practically observe the OCC and SCC characteristics.
- About the synchronous impedance and short circuit ratio.
- Load regulation estimation using mmf and emf methods.

3. Theory

Introduction

Synchronous Impedance Z_S is a fictitious impedance employed to account for the voltage effects in the armature circuit produced by the actual armature resistance, the actual armature leakage reactance and the change in the air gap flux produced by the armature reaction.
The actual generated voltage consists of the summation of the two component voltages. One of these component voltages that would be generated if there were no armature reaction. It is the voltage that would be generated because of only the field excitation. This component of the generated voltage is called the **Excitation Voltage** (E_{exc}).

The other component of the generated voltage is known as the **Armature ReactionVoltage** (E_{AR}). Thus, the two voltages that are the armature reaction voltage and the excitation voltage are added to keep a check on the effect of armature reaction upon the generated voltage. The equation is shown below.

$$E_a = E_{exc} + E_{AR} \quad \text{...}(1)$$

The voltage in a circuit caused by the change in the flux by the current is a result of armature reaction. The nature of this effect is inductive reactance. Therefore, E_{AR} is equivalent to a voltage of inductive reactance and is given by the equation shown below.

$$E_{AR} = -jX_{AR}I_a \quad \text{..}(2)$$

The Inductive Reactance X_{AR} is a fictitious reactance. As a result a voltage is generated in the armature circuit. Therefore, armature reaction voltage can be modeled as an inductor in series with the internally generated voltage.

In addition to the effects of armature reaction, the stator winding also has a self-inductance and resistance.

Let,

X_a is the self-inductive reactance of stator winding

R_a is the armature stator resistance.

The terminal voltage V is given by the equation shown below.

$$V = E_a - j\,X_{AR}I_a - jX_aI_a - R_aI_a \quad \text{..............................}(3)$$

Where,

R_aI_a is the armature resistance drop

X_aI_a is the armature leakage reactance drop

$X_{AR}I_a$ is the armature reaction voltage

The armature reaction effects and the leakage flux effects on the machine are both represented by inductive reactance. Therefore, all these combine to form a single reactance called **Synchronous Reactance** of the machine X_S.

$$X_S = X_a + X_{AR} \quad \text{..}(4)$$

Therefore,from (3)

$$Z_s = X_a + X_{AR} \quad \text{..}(5)$$

The impedance Z_S in the above equation (5) is the **Synchronous Impedance**, and X_S is the **Synchronous Reactance.**

4. Equipmentrequired:

S.No.	Name	Range	Remark	Qty.
1	Voltmeter	0-300V	AC	1
2	Ammeter	0-15A 0-5A	AC,DC	1 each
3	Rheostat	355Ω/1.6A	-	1

5. Methodology for Measurements:

Open circuit characteristics:

1. Connect the circuit as shown in fig.1
2. Start the prime mover, i.e., dc motor and bring it to the rated speed.
3. Note down the voltage across armature if any.
4. Switch in the excitation and adjust it so that about 10% of rated voltage is obtained across the armature terminals. Note that voltage.
5. Increase field current and note down the corresponding armature voltage.
6. Take several readings by changing current till 110% of the rated voltage is obtained.

Short circuit characteristics:

1. Connect the circuit as shown in fig.2
2. Start the prime mover, i.e., dc motor and bring it to the rated speed.
3. Increase the excitation current in steps and note down the armature current till the rated current flows in the armature. However the readings may be taken up to 110% of the rated current value.

Armature resistance measurement:

Use Multimeter to measure the armature resistance of the synchronous machine.

6. Measurements

The figure below shows theconnection diagramfortheexperiment:

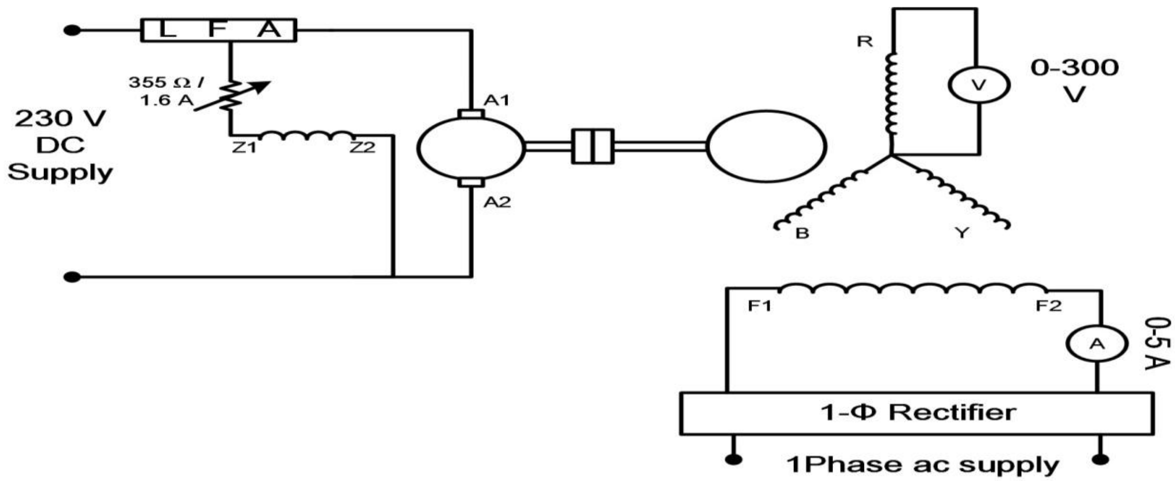


Fig.1: ConnectionDiagram for open circuit characteristics

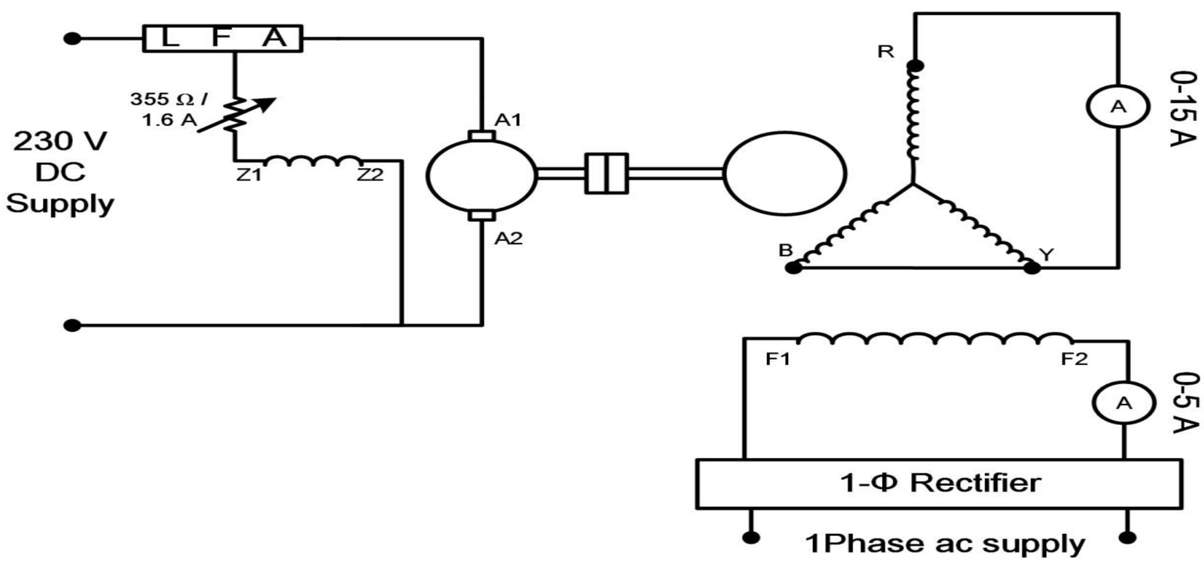


Fig.2: ConnectionDiagram for short circuit characteristics

Machinespecifications: -

Name plate details of Synchronous Machine	Name plate details of 1-ϕ DC Machine
Rated Voltage=400V Rated Current=56A Power =8 kVA Rated Speed=1500rpm	Rated Voltage=230V Rated Current=56A Power =11Kw Rated Speed=1500rpm

Usingthe above setup notedown yourobservationsinthefollowingTable:

Table: Table to be usedfor recordingthe measurements:

1. **OCC characteristics**

S.No.	Field current (Amp)	OC Voltage (Volts)

2. **SCC characteristics**

S.No.	Field current (Amps)	Armature Current (Amps)

<u>Precautions</u>:

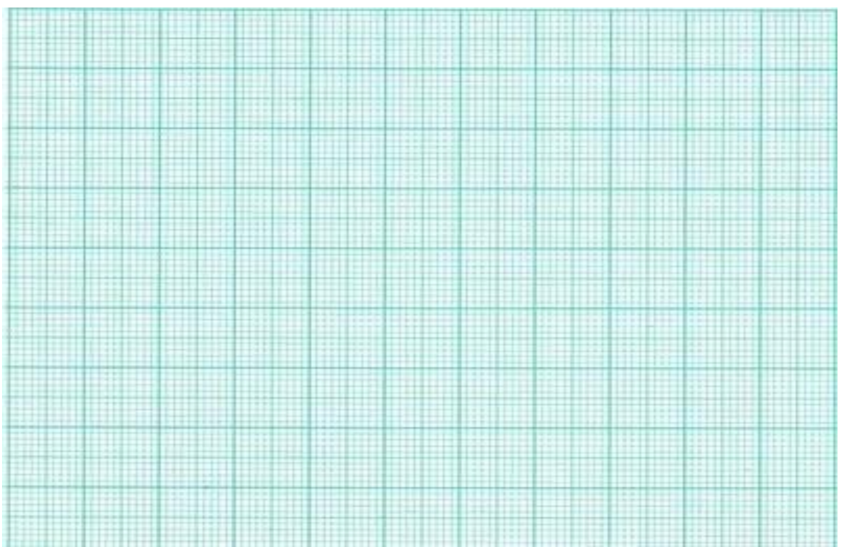
1. Circuitconnections shouldnotbe madewhilepowerisON.
2. Ensure variac positionis zero before startingthe experiment.

7. Results and Discussion

Based on yourmeasurements,letus now discusstheresults thatyou obtained. Please provideresponses to followingpoints:

A. Draw two graphs OCC characteristics ($E_f$vs I_f) and SCCcharacteristics ($I_a$vsI_f).

E_f/ I_a



I_f

8. Conclusions

Writein yourown wordsthe conclusion ofperformingthis experiment. Write aboutwhatyoulearned fromthisexperiment, whatyou can tellaboutthe OCC and SCC characteristics of synchronous machine thatyou didin experiment.

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Experiment No.: ….7

Zero power factor characteristics of Synchronous Machine

Contents

1. Objectives

1. To obtain full load zpf lagging characteristics of a synchronous machine.
2. Obtain OCC and field excitation to circulate the rated current during short circuit test.
3. Draw the Potier triangle and estimate the full load regulation using potier method at 0.8 pf (lagging and leading).

2. Expected outcome ofexperiment

On successful completion of experiment the students will be able to know:

- Concept of potier triangle practically.
- About the full load regulation under different power factor.

3. Theory

Introduction

This method is also called potier method. In the operation of any alternator, the armature resistance drop and armature leakage reactance drop $I*X_L$ are actually e.m.f. quantities while the armature reaction is basically m.m.f. quantity. In the synchronous impedance all the quantities are treated as e.m.f. quantities as against this in M.M.F. method all are treated as m.m.f. quantities. Hence in both the methods, we are away from reality.

This method is based on the separation of armature leakage reactance and armature reaction effects. The armature leakage reactance X_L is called Potier reactance in this method, hence method is also called potier reactance method.

To determine armature leakage reactance and armature reaction m.m.f. separately, two tests are performed on the given alternator. The two tests are,

Open Circuit Test:

A graph of If and (Voc) i.e. field current and open circuit voltage per phase is plotted to some scale. This is open circuit characteristics.

Zero Power Factor Test:

In this test, there is no need to obtain number of points to obtain the curve. Only two points are enough to construct a curve called zero power factor saturation curve.This is the graph of terminal voltage against excitation when delivering full load zero power factor current.

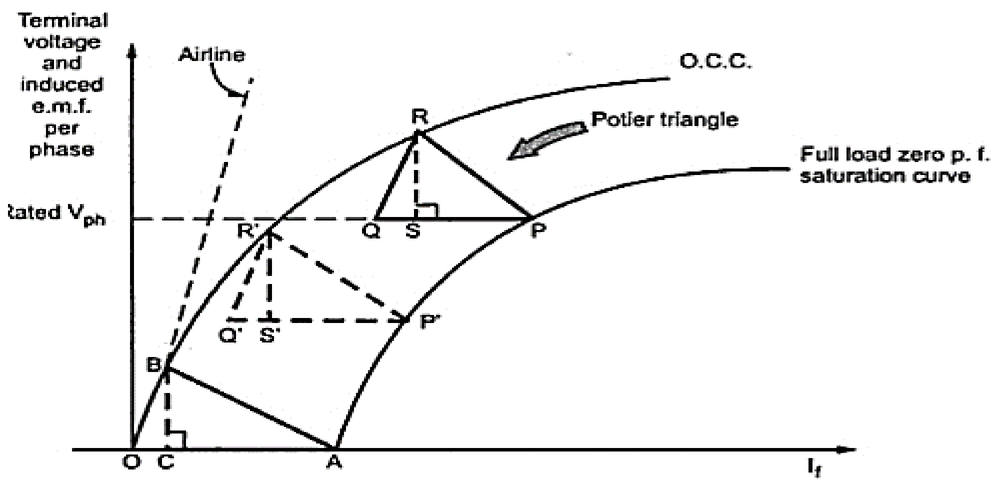


Fig.1: O.C.C and full load ZPF curve characteristics showing Potier Triangle

4. Equipmentrequired

S.No.	Name	Range	Remark	Qty.
1	Voltmeter	0-300V	AC	1
2	Ammeter	0-15A 0-5A	AC, DC	1 each
3	Rheostat	355Ω/1.6A	-	1
4	Variable Inductor	1.5A , 300 ohm, 0-300 V	-	1

5. Methodology for Measurements

Open circuit characteristics:

1. Connect the circuit as shown in fig.1
2. Start the prime mover, i.e., dc motor and bring it to the rated speed.
3. Note down the voltage across armature if any.
4. Switch in the excitation and adjust it so that about 10% of rated voltage is obtained across the armature terminals. Note that voltage.
5. Increase field current and note down the corresponding armature voltage.
6. Take several readings by changing current till 110% of the rated voltage is obtained.

Short circuit characteristics:

1. Connect the circuit as shown in fig.2
2. Start the prime mover, i.e., dc motor and bring it to the rated speed.
3. Increase the excitation current in steps and note down the armature current till the rated current flows in the armature. However the readings may be taken up to 110% of the rated current value.

ZPF Characteristics:

1. Run the prime mover at the rated speed with pure inductive load across the synchronous machine.
2. Adjust the field current such that full load current Ia is flowing in the armature windings.
3. Now, vary the external load and the field current in simultaneously such that full load current is flowing in the armature.
4. Repeat step 3 to note down several observations.

Armature resistance measurement:

Use Multimeter to measure the armature resistance of the synchronous machine.

6. Measurements

The figure below shows theconnection diagramfortheexperiment:

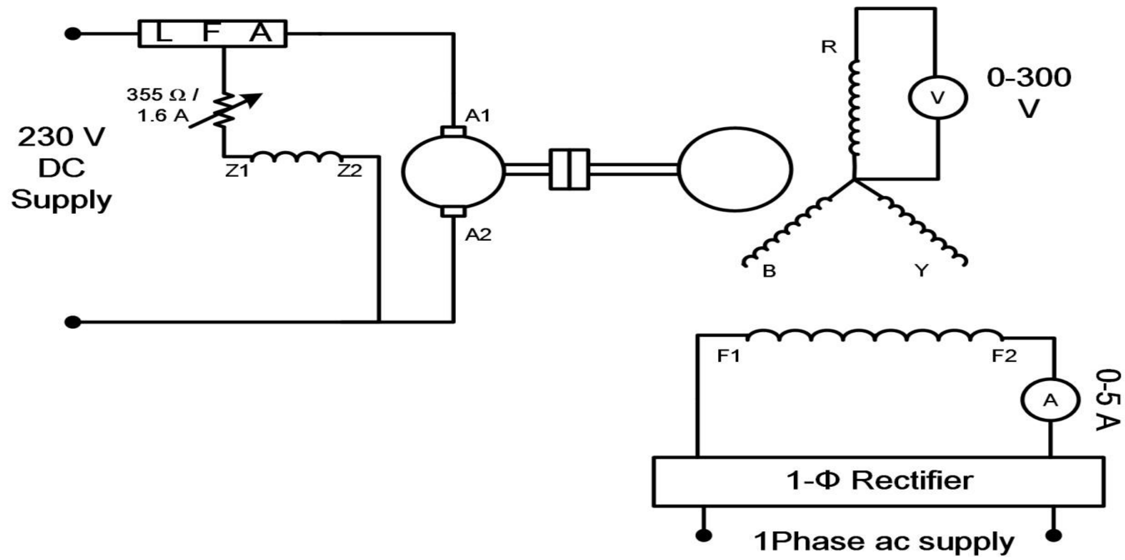


Fig.2: ConnectionDiagramfor OCC

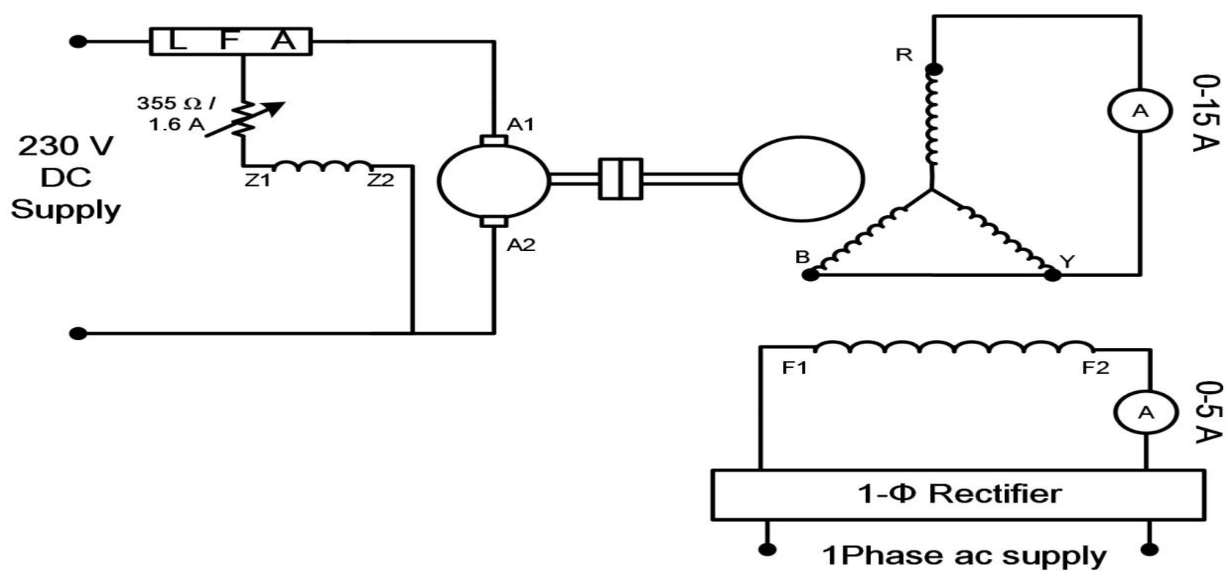


Fig.3: ConnectionDiagramfor SCC

Machinespecifications: -

Name plate details of Synchronous Machine	Name plate details of 1-ϕ DC Machine
Rated Voltage=400V Rated Current= 11.5 A Power = 8kVA Rated Speed=1500rpm	Rated Voltage=230V Rated Current= 56A Power = 11 kW Rated Speed=1500rpm

Usingthe above setup notedown yourobservationsinthefollowingTable:

Table: Table to be usedfor recordingthe measurements:

1. **OCC characteristics**

S.No.	Field current (Amp)	OC Voltage (Volts)

2. **SCC characteristics:**

S.No.	Field current (Amps)	Armature Current (Amps)

3. **ZPF characteristics:**

S.No.	Field current (Amp)	OC Voltage (Volts)

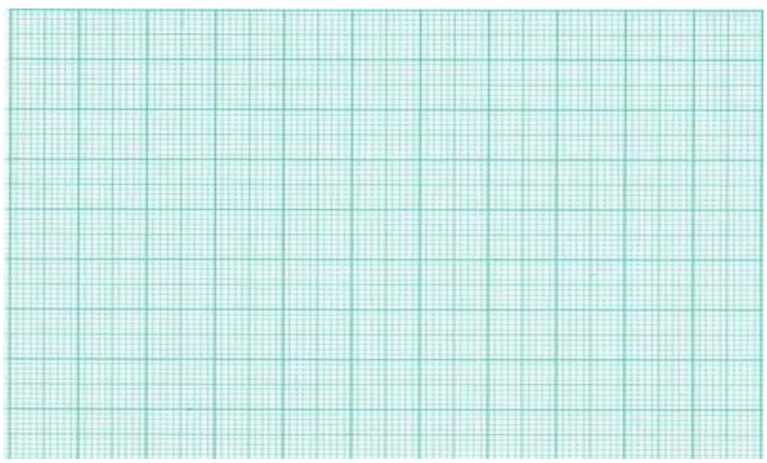
Precautions:

1. Circuitconnections shouldnotbe madewhilepowerisON.
2. Ensure variac positionis zero before startingthe experiment.
3. Ensurethe correctconnections ofthetransformer
4. Allconnections should betightandloose connectionsareto beavoided.

7. Results and Discussion

Based on yourmeasurements,letus now discusstheresults thatyou obtained. Please provideresponses to followingpoints:

A. Draw OCC and ZPF for potier triangle?



8. Conclusions

Writein yourown wordsthe conclusion ofperformingthis experiment. Write aboutwhat youlearned fromthisexperiment, whatyou can tellaboutthe ZPF characteristics of synchronous machinethatyou didin experiment.

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Experiment No.: ….8

V – Curves for Synchronous Machines

Contents

1. Objectives

To draw V- curves for synchronous machine. Run the machine as motor and plot the variation of armature current Vs excitation at different loads.

2. **Expected outcome ofexperiment**

On successful completion of experiment the students will be able to know:

- About variation of armature current Vs excitation at different loads.
- About performance of machine at leading and lagging pf.

3. Theory

V-curve of a synchronous machine shows its performance in terms of variation of armature current with field current when the load and input voltage to the machine is constant. When a synchronous machine is connected to an infinite bus, the current input to the stator depends upon the shaft-load and excitation (field current). At a constant load, if excitation is changed the power factor of the machine changes, i.e. when the field current is small (machine is under-excited) the P.F. is low and as the excitation is increased the P.F. improves so that for a certain field current the P.F. will be unity and machine draws minimum armature current. This is known as normal excitation. If the excitation is further increased the machine will become over-excited and it will draw more line current and P.F. becomes leading and decreases.

Therefore, if the field current is changed keeping load and input voltage constant, the armature current changes to make $VI\cos\varphi$ constant. Because of their shape (Fig. 6.1), graphs of variation of armature current with excitation are called ‘V’ curves. If the ‘V’ curves at different load conditions are plotted and points on different curves having same P.F. are connected the resulting curve is known as “compounding curves”.

The power factor of the synchronous motor can be controlled by varying the field current I_f. As we know that the armature current I_a changes with the change in the field current I_f. Let us assume that the motor is running at NO load. If the field current is increased from this small value, the armature current Ia decreases until the armature current becomes minimum. At this minimum point, the motor is operating at unity power factor. The motor operates at lagging power factor until it reaches up to this point of operation.

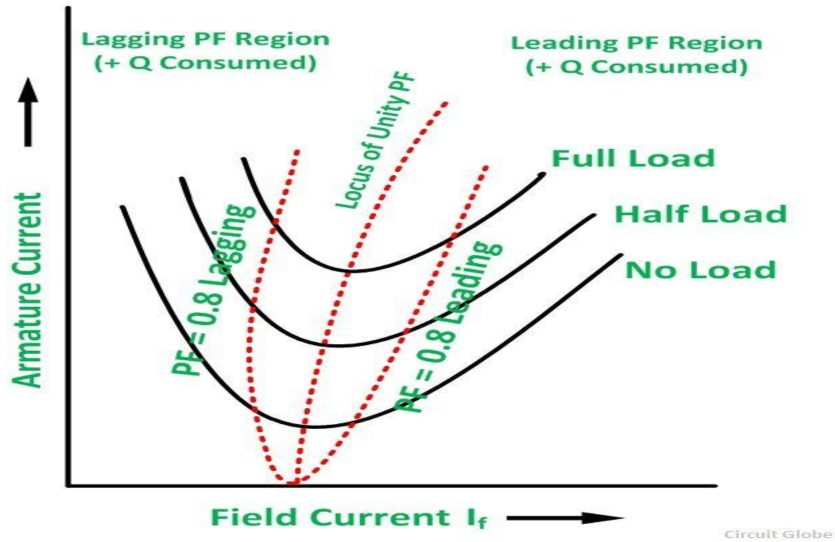

Fig.1: V curves representation at different load and power factor region

4. Equipmentrequired

S.No.	Name	Range	Remark	Qty.
1	Voltmeter	0-600V 0-300V	AC DC	1 each
2	Ammeter	0-15A 0-5A 0-20A	AC, DC DC	1 each
3	Rheostat	355Ω/1.6A	-	1
4	Load	Resistive	-	-

5. Methodology for Measurements

1. Connect the circuit as shown in the figure.
2. Start the synchronous machine as induction motor. When its speed becomes near to the rated speed, excite the field winding to run it as synchronous motor.
3. Under no load operating conditions (i.e., the generator coupled is under no load), keep the field current value minimum.
4. Now gradually increase the field current in steps and note down the armature current at each step, till the rated current at leading power factor is drawn by the armature. Note down the armature current and field current for each step.
5. Bring the excitation to its normal value.
6. Repeat the steps 4 & 5 for 50%, 75% and 100% of rated outputs of the motor.

6. Measurements

The figure below shows theconnection diagramfortheexperiment:

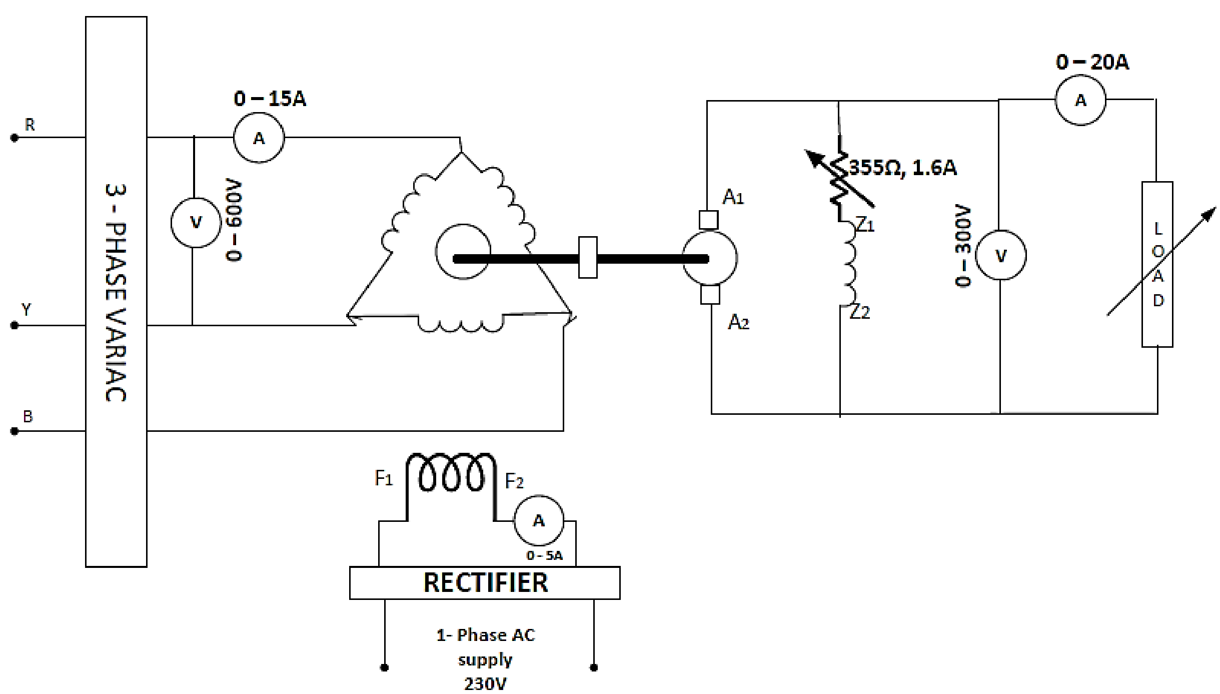

Fig.2: ConnectionDiagramfor obtaining V curves

Machinespecifications: -

Name plate details of Synchronous Machine	Name plate details of 1-ϕ DC Machine
Rated Voltage=400V Rated Current= 13.5 A Power = 7.5 kW Rated Speed=1500rpm	Rated Voltage=230V Rated Current=21.7A Power =5 kW Rated Speed=1500rpm

Usingthe above setup notedown yourobservationsinthefollowingTable:

Table: Table to be usedfor recordingthe measurements:

		At no load	**At 25% load**	**At 50% load**
S.No.	**Field current (Amps)**	**Armature current (Amps)**	**Armature current (Amps)**	**Armature current (Amps)**

Precautions:

1. Circuitconnections shouldnotbe madewhilepowerisON.
2. Ensurevariac positionis zero before startingthe experiment.
3. Ensurethe correctconnections ofthetransformer
4. Allconnections should betightandloose connectionsareto beavoided.

7. Results and Discussion

Based on yourmeasurements,letus now discusstheresults thatyou obtained. Please provideresponses to followingpoints:

A. Discuss the variation of current at different power factors.

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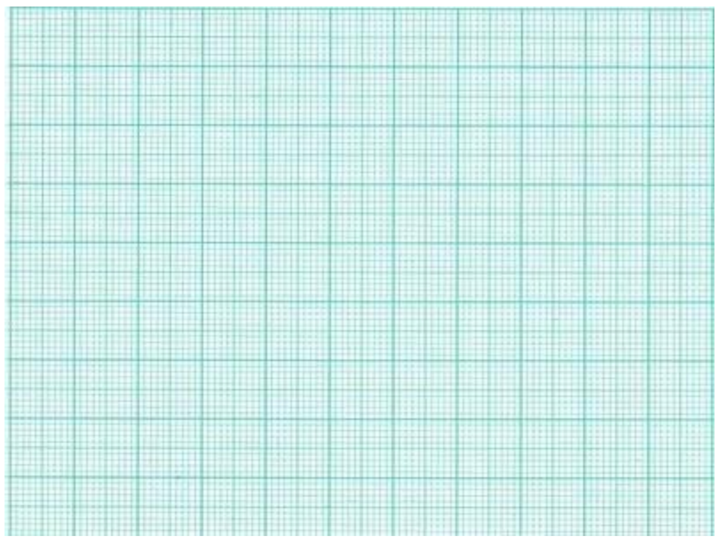
B. Plots the variation of armature current Vs excitation at different loads.

Armature current



Field current

8. Conclusions:

Writein yourown wordsthe conclusion ofperformingthis experiment. Write aboutwhatyoulearned fromthisexperiment, whatyou can tellaboutthe v curve thatyou studiedin the experiment.

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Experiment No….9

SLIP-TEST on Salient-Pole Machine

Contents

1. Objectives

To perform slip test on a salient pole synchronous machine at different values of slip not exceeding 5% and plot the variation of d-axis &q-axis reactance Vs. slip. And also estimate the values of Xd and Xq.

2. **Expected outcome ofexperiment**

On successful completion of experiment the students will be able to know:

- Estimation of direct axis and quadrature axis reactance.
- Variation of both with respect to slip.

3. Theory

Introduction

The method used to determine Xq and Xd, the direct and quadrature axis reactance is called slip test. In the slip test, a three phase supply is applied to the armature, having voltage must less than the rated voltage while the field winding circuit is kept open. The circuit diagram is shown in the The alternator is run at a speed close to synchronous but little less than synchronous value.The three phase currents drawn by the armature from a three phase supply produce a rotating flux. Thus the armature m.m.f. wave is rotating at synchronous speed as shown in the Fig. 1.

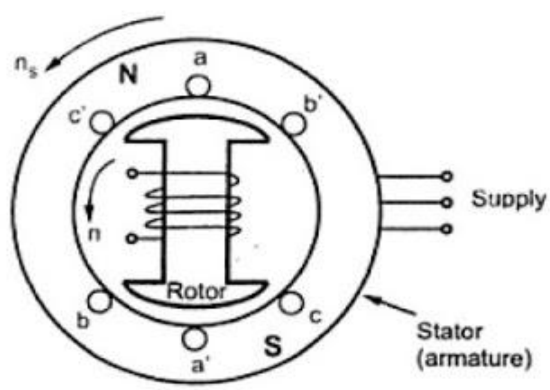

Fig.1: Rotating armature mmf

Note that the armature is stationary, but the flux and hence m.m.f. wave produced by three phase armature currents is rotating. This is similar to the rotating magnetic field existing in an induction motor.The rotor is made to rotate at a speed little less than the synchronous speed. Thus armature m.m.f. having synchronous speed, moves slowly past the filed poles at a slip speed (ns -n) where n is actual speed of rotor. This causes an e.m.f. to be induced in the field circuit. When the stator m.m.f. is aligned with the d-axis of field poles then flux Φd per poles is set up and the effective reactance offered by the alternator is Xd.When the stator m.m.f. is aligned with the q-axis of field poles then flux Φq per pole is set up and the effective reactance offered by the alternator is Xq.

The r.m.s. current is minimum when machine reactance is Xd and it is maximum when machine reactance is Xq.

4. Equipmentrequired

S.No.	Name	Range	Remark	Qty.
1	Voltmeter	0-300V	AC	1
2	Ammeter	0-2A	AC	1
3	Rheostat	355Ω/1.6A, 9Ω/9A	-	2

5. Methodology for Measurements

1. Connect the circuit as shown in the figure
2. Testing the direction of rotation
    a. Start the DC motor and note the direction of the rotation
    b. Then turn off the DC motor and start the synchronous machine and note the direction of rotation.
    c. Directions as observed in ‘a’ & ‘b’ should be same. Otherwise corrective action is required.

3. Run the motor at less than slip 5% with field circuit left open & reduced voltage across the armature terminals, which results into oscillations in current and voltage.
4. Note down the readings of V_{max}, V_{min} and I_{max} and I_{min} and speed.
5. Take 5-6 different readings at different values of slips, but not exceeding the value of slip more than 5%.
6. Calculate the value of X_d, X_q and plot the graph between X_d, X_q Vs Slip.

6. Measurements

The figure below shows theconnection diagramfortheexperiment:

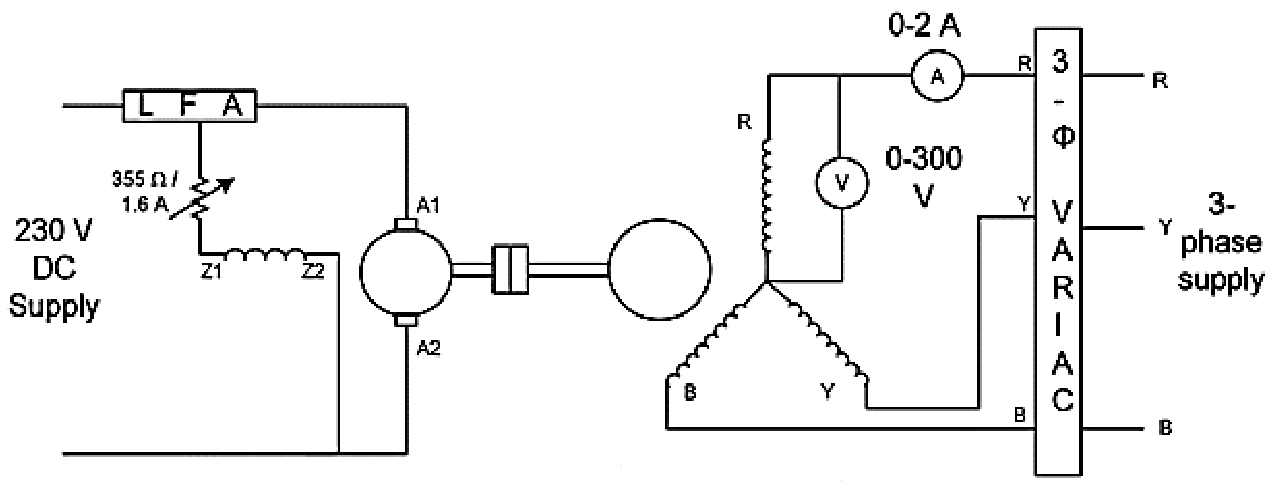

Fig.2: ConnectionDiagramfor slip test.

Machinespecifications: -

Name plate details of Synchronous Machine	Name plate details of 1-ϕ DC Machine
Rated Voltage=400V Rated Current= 19 A Power = 10 kW Rated Speed=1500rpm	Rated Voltage=230V Rated Current=32.6A Power = 7.5 kW Rated Speed=1500rpm

Usingthe above setup notedown yourobservationsinthefollowingTable:

Table: Table to be usedfor recordingthe measurements

S.No.	Speed	Vmax (Volts)	Vmin (Volts)	Imax (Amps)	Imin (Amps)	Slip	Xd = Vmax/Imin	Xq = Vmin/Imax

<u>Precautions</u>:

1. Circuitconnections shouldnotbe madewhilepowerisON.
2. Ensure variac positionis zero before startingthe experiment.

7. Results and Discussion

Based on yourmeasurements,letus now discusstheresults thatyou obtained. Please provideresponses to followingpoints:

A. Which axis reactance has more air gap?

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B. Why we perform slip test?

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8. Conclusions

Writein yourown wordsthe conclusion ofperformingthis experiment. Write aboutwhatyou learned fromthisexperiment, whatyou can tellaboutslip test thatyou didin experiment.

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Experiment No: ….10

To run the induction machine as a self-excited induction generator and plot the variation of terminal voltage and frequency vs speed for different excitation capacitances.

Contents

1. Objectives

The aim of thisexperimentisto run the induction machine as a self-excited induction generator and plot the variation of terminal voltage and frequency V/S speed for different excitation capacitances.

2. Expected outcome ofexperiment:

On successful completion of experiment, the students will be able to know:

- About the excitation of induction generator.
- To run as an induction generator, speed should be above synchronous speed.

3. Theory:

Principle of operation:

Induction machine operates as a motor when its speed (ωm) lies between 0 and synchronous speed (ωs), i.e. 0 <ωm<ωs. If the machine speed crosses ωs then the machine operates with negative slip. This means that the rotor field is rotating "ahead of" the stator field. The torque produced is negative and hence the machine is generating power. The complete torque speed characteristics can be seen in the Fig.1

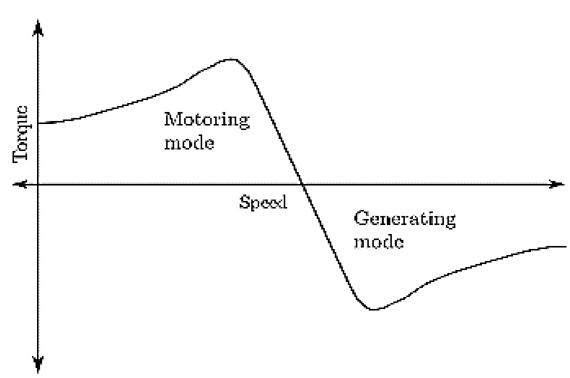

Fig.1: Torque-Speed Characteristics of Induction Machine

The rotor currents in the induction machine are due to the induced emf in the rotor. There is no separate excitation supplied to the rotor. The motor can enter generating mode only of receives reactive power in the form of field supply. Two such cases have been considered here based on the source of reactive power.

Standalone Induction Generator:

The standalone induction generator can operate at any speed. Start the induction machine by using a prime mover. The reactive power needed for generator operation is provided using capacitor banks. Switch in capacitor banks across the machine terminals that will excite the induction machine and 1will enter generating mode. The value of capacitor bank needed for self-excitation depends on the parameters of the induction machine.

Excitation:

An induction machine requires externally supplied armature current. Because the rotor field always lags behind the stator field, the induction machine always "consumes" reactive power, regardless of whether it is operating as a generator or a motor. A source of excitation current for magnetizing flux (reactive power) for the stator is still required, to induce rotor current. This can be supplied from the electrical grid or, once it starts producing power, from the generator itself. An induction machine can be started by charging the capacitors, with a DC source, while the generator is turning typically at or above generating speeds. Once the DC source is removed the capacitors will provide the magnetization current required to begin producing voltage. An induction machine that has recently been operating may also spontaneously produce voltage and current due to residual magnetism left in the core.

Limitations:

An induction generator connected to a capacitor system can generate sufficient reactive power to operate on its own. When the load current exceeds the capability of the generator to supply both magnetization reactive power and load power the generator will immediately cease to produce power. The load must be removed and the induction generator restarted with either a DC source, or if present, residual magnetism in the core.

4. Equipmentrequired

S.No.	Name	Range	Remark	Qty.
1	Voltmeter	0-300V	AC	1
2	Frequency Meter	50 Hz	AC	1
3	Rheostat	355Ω/1.6A, 9Ω/9A	Field, Armature	2
4	Tachometer	2000RPM	----	1

5. Methodology for Measurements

1. The connections are made as per the circuit diagram.
2. Rotor speed can be increased above synchronous speed by prime mover, which is run by DC motor.The DC supply of DC motor can be changed by using rheostat
3. Switch on the capacitor banks one by one. Change the supply voltage using rheostat.
4. Then note down the value of speed of rotor using tachometer.Take more than 6 readings on 10V difference. Then plot terminal voltage V/s speed.

6. Measurements

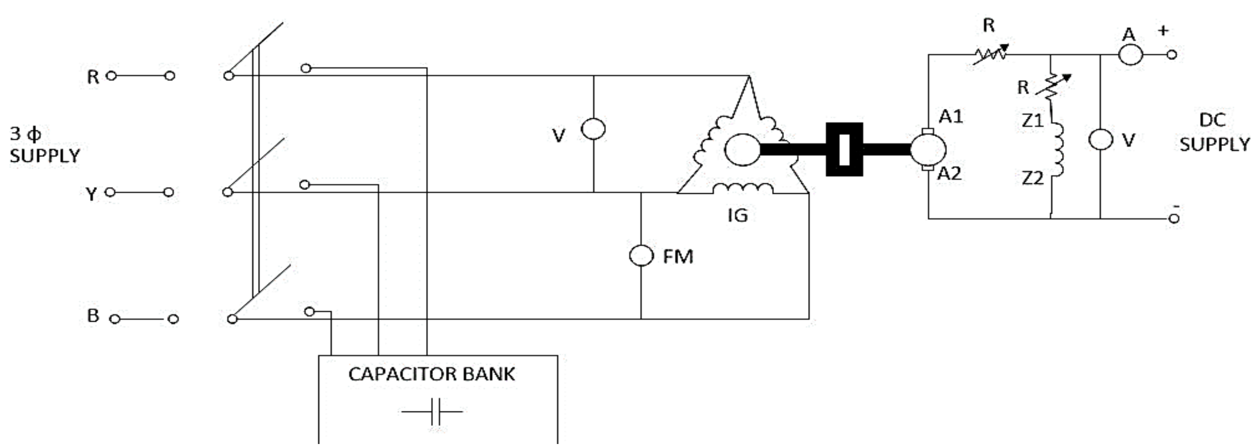

Fig.2: ConnectionDiagramto run self-excited induction generator

Machine Specifications:

Name plate details of DC generator	**Name plate details of Induction Motor**
Rated Voltage=220V Rated Current= 8A Power = 1.75 kW Rated Speed=1421rpm	Rated Voltage=230V Rated Current= 8.6A Power = 2.2 kW Rated Speed=1440rpm

Usingthe above setup notedown yourobservationsinthefollowingTable:

Table: Table to be usedfor recordingthe measurements:

S. No.	**Speed**	**V**	**I**	**W1**	**W2**	**Frequency**	**Rotor Resistance**
1.							
2.							
3.							
4.							

<u>Precautions</u>:

1. Be ensurethatproper connection is done before giving supply.
2. Use capacitor bank for excitation of induction generator
3. Tachometer should be proper
4. Perform the variable frequency blocked rotor test at rated current of the machine.
5. Try to perform the test as quickly as possible.
6. Perform DC test to measure the values of stator resistance.

7. Results and Discussion

Based on yourmeasurements,letus now discusstheresults thatyou obtained. Please provideresponses to followingpoints:

A. Whyshouldspeed of induction machine kept more than synchronous speedduringthis experiment?

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B. Is induction generator self-excited?

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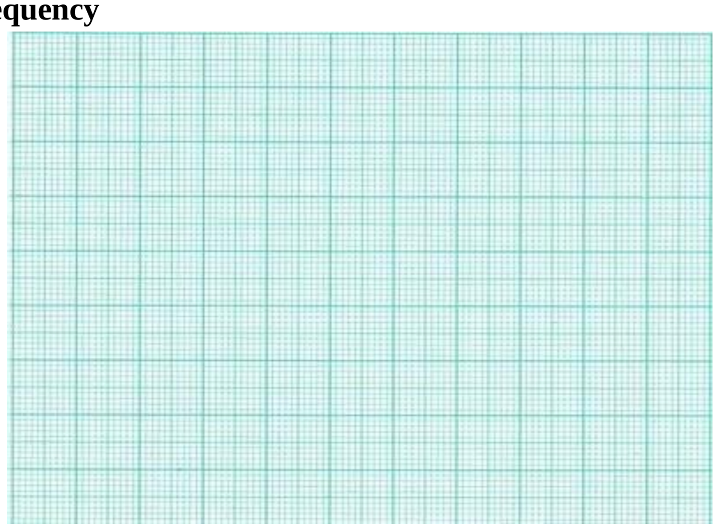
C. Plotthe graph betweenVoltage and Frequency versus Speed

Voltage & Frequency



Speed (rpm)

8. Conclusions

Writein yourown wordsthe conclusion ofperformingthis experiment. Write aboutwhatyoulearned fromthisexperiment.

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