Electric Machines Laboratory (EE2P001)

EXPERIMENT-6

REGULATION OF 3 Φ ALTERNATOR BY SYNCHRONOUS IMPEDENCE METHOD

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AIM OF THE EXPERIMENT:

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

APPARATUS REQUIRED:

Instruments/Equipment:

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

Machines Required:

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

THEORY:

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

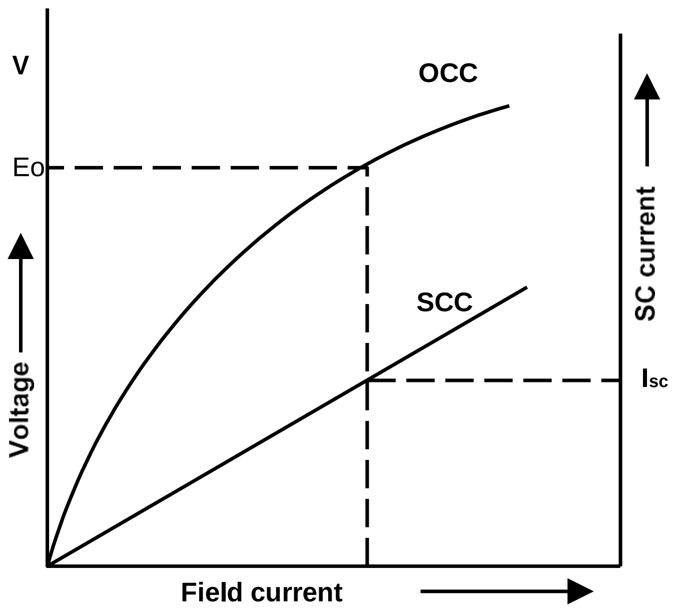
The synchronous impedance method of determining regulation is based on the simple equivalent circuit and phasor diagram given in Fig-1.Inthis method the effect of armature reaction is expressed as a voltage drop, I_aX_{ar} (X_{ar} is commonly called the armature reaction reactance).The leakage reactance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

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

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

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

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



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

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

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

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

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

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

CIRCUIT DIAGRAM:

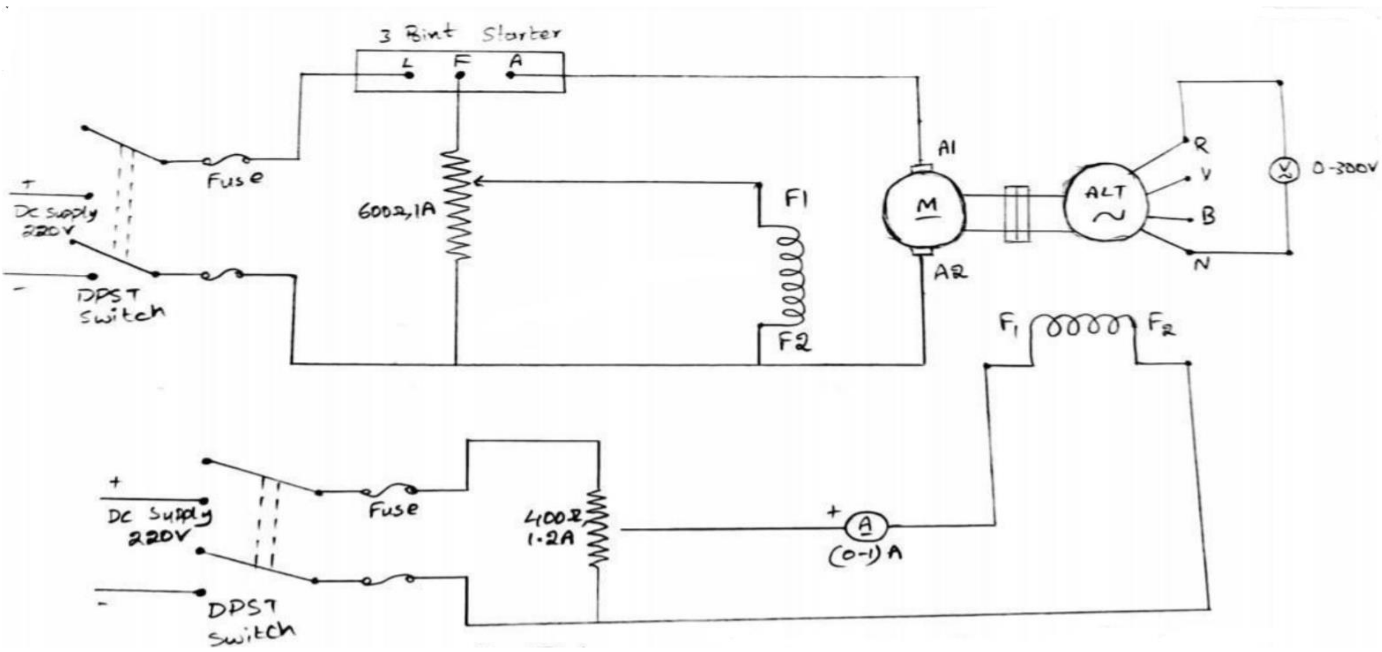


Fig- 1 Circuit Diagram for O.C Test on alternator

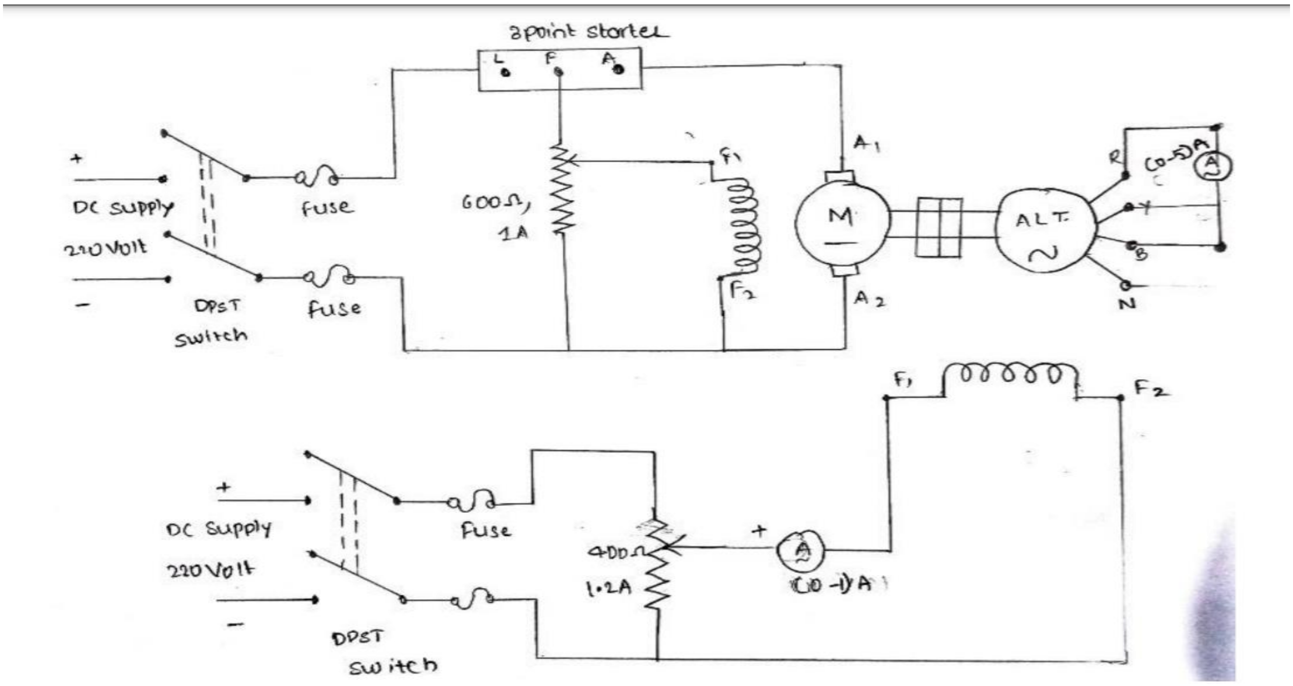


Fig- 2 Circuit Diagram for S.C Test on alternator

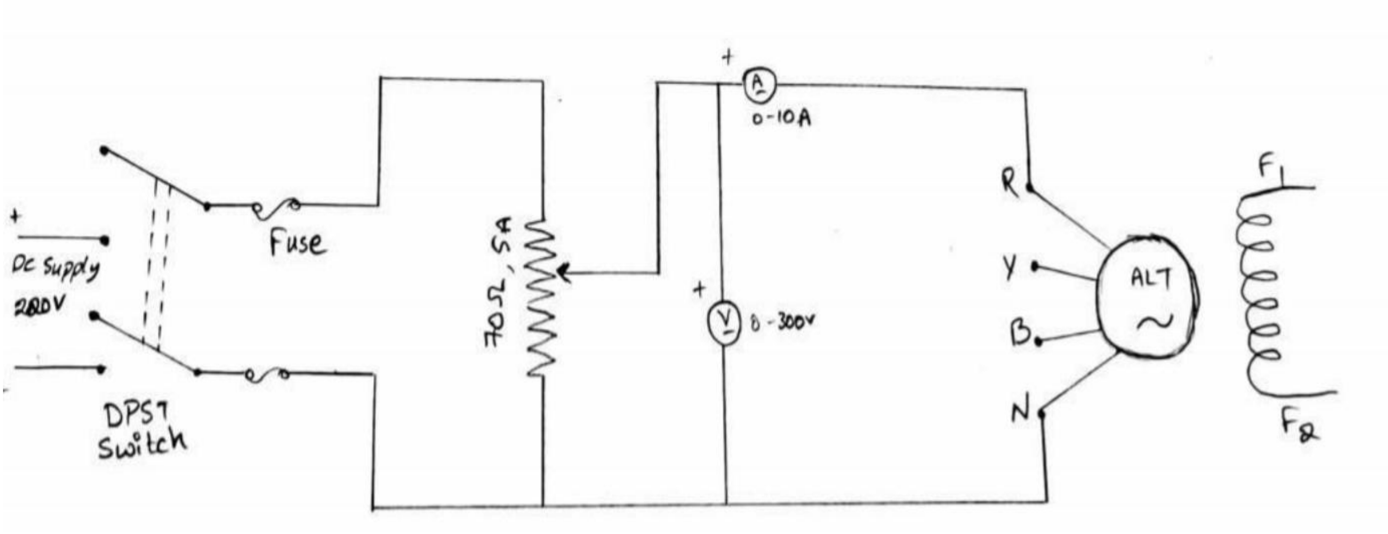


Fig- 3 Circuit Diagram for armature resistance measurement of alternator

PRECAUTION:

1. Connection should be right and tight.
2. Check the circuit connection thoroughly before switching on the supply.
3. Instruments should be connected in proper polarity and range.
4. Do not touch any non-insulated part of any instrument or equipment.
5. Be ensured the zero setting of instrument is on right position. Avoid parallax error.
6. Before starting the dc shunt motor ensure that, the field rheostat of the motor is kept in minimum position.
7. Also, field rheostat of alternator should be at minimum position (i.e. –ve supply end)

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PROCEDURE:

1. Open-Circuit characteristic:

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

2. Short-Circuit characteristic:

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

3. Armature resistance measurement:

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

OBSERVATION:

Sl. No.	Open Circuit Test		Short Circuit Test	
	I_f (A)	V_{oc} (V)	I_f (A)	I_{sc} (A)
1	0.1	78	0.15	0.8
2	0.13	110	0.25	1.21
3	0.18	148	0.30	1.45
4	0.2	160	0.35	1.62
5	0.23	190	0.39	1.88
6	0.29	220	0.43	2.08
7	0.32	230	0.46	2.24
			0.51	2.48
			0.55	2.68
			0.60	2.88
			0.64	3.20
			0.68	3.28
			0.71	3.44
			0.74	3.6

Ra=2.9Ω/phase

Data Processing and Analysis:

- Plot *on the same* graph sheet, the O.C.C (open circuit terminal voltage per phase versus thefield current), and the short-circuit characteristic (short-circuit armature current versus the field current).

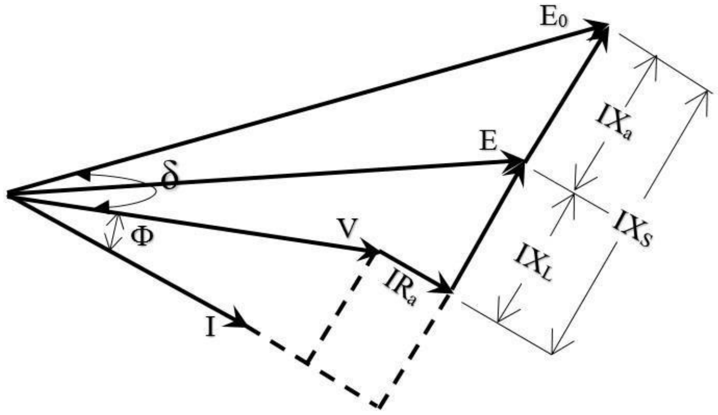
- Calculate the unsaturated value of the synchronous impedance (Z_s), corresponding to rated armature short-circuit current. Calculate the corresponding values of the synchronous reactance (X_s).

  Zs=237/1.67=140.71Ω;Xs=√(Zs^2-Ra^2)=140.68Ω

- Calculate regulation of the alternator under the following conditions:
  a) Full load current at unity power factor.
  b) Full load current at 0.8 power factor lagging.
  c) Full -load current at 0.8 power factor leading.

CALCULATIONS:

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



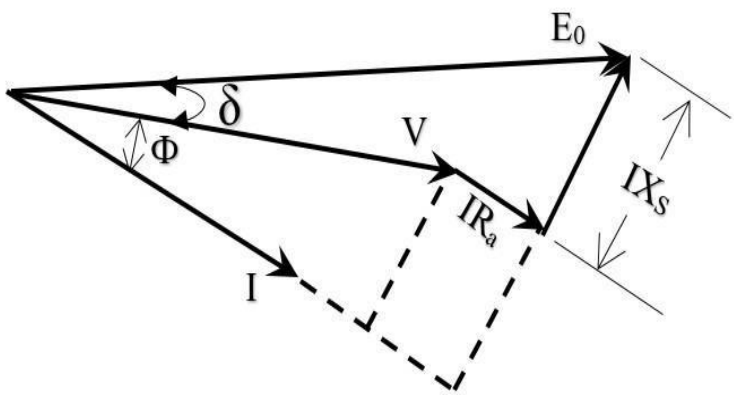
Regulation is found by the following expression.

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

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

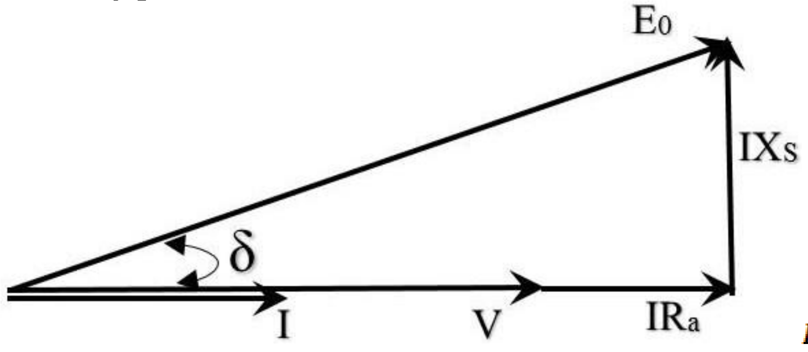
E_0 is estimated by the following methods.

For lagging power factor



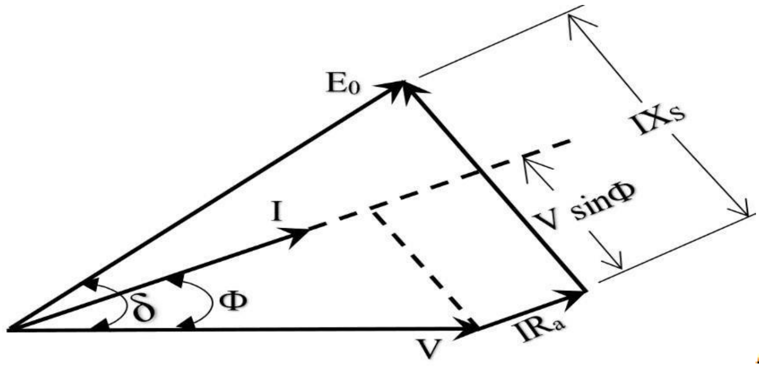
$$E_0 = \sqrt{(V\, cos\Phi + IR_a)^2 + (V\, sin\Phi + IX_S)^2}$$

For unity power factor

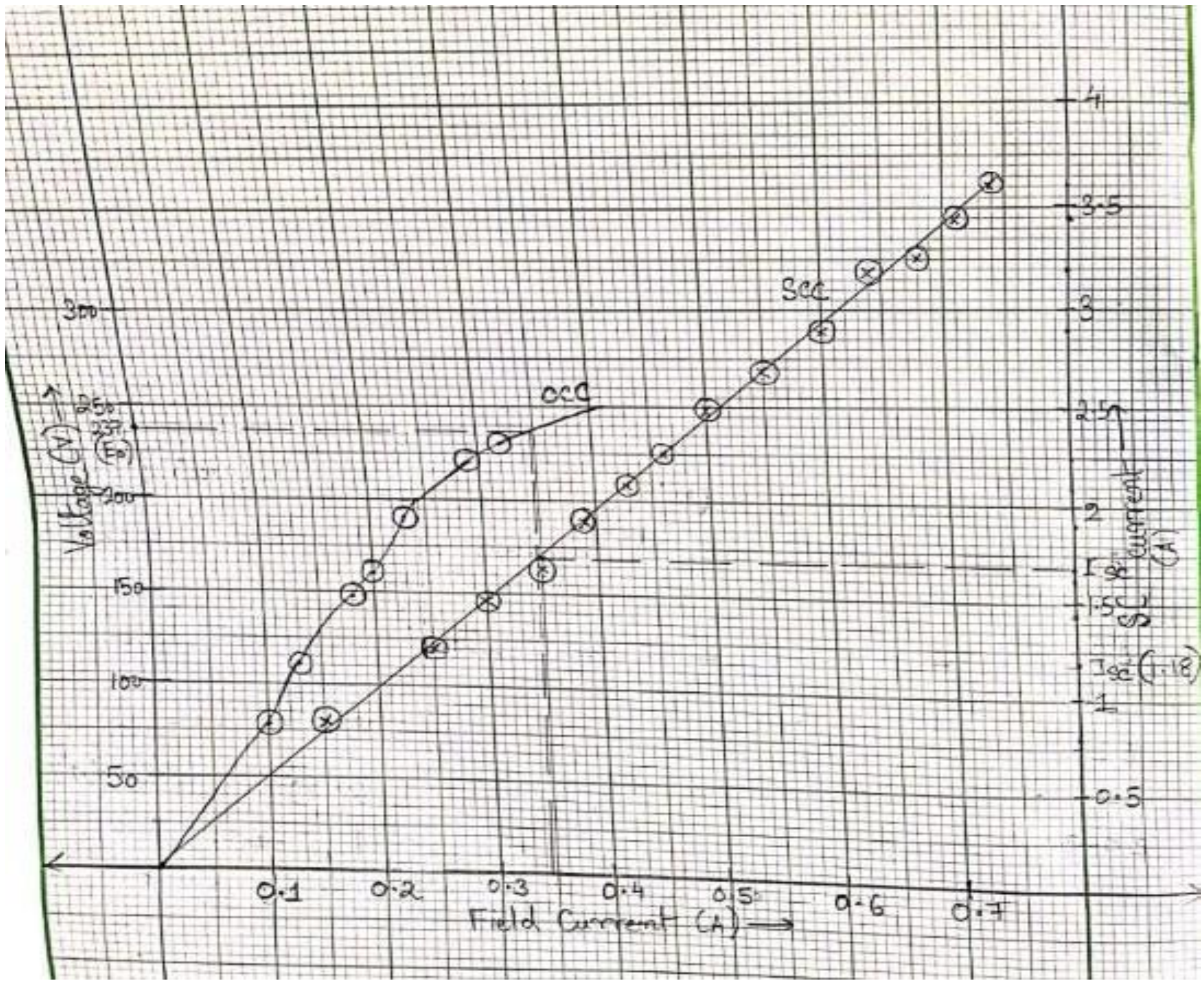


$$E_0 = \sqrt{(V + IR_a)^2 + (IX_S)^2}$$

For leading power factor



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



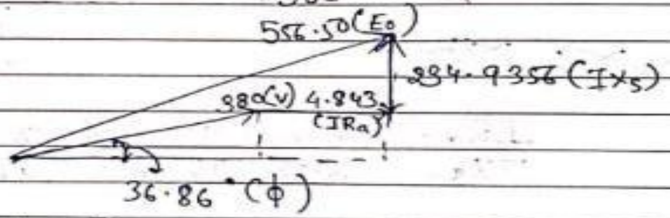
For lagging power factor :-

$\cos\phi = 0.8$
$\sin\phi = 0.6$

Load voltage, $V = 380\,V$, $I = 1.67\,A$

$$\therefore E_0 = \sqrt{(380\times 0.8 + 1.67\times 2.9)^2 + (380\times 0.6 + 1.67\times 140.68)^2}$$
$$= 556.50$$

$$\therefore VR = \frac{556.50 - 380}{380}\times 100 = 46.44\%$$

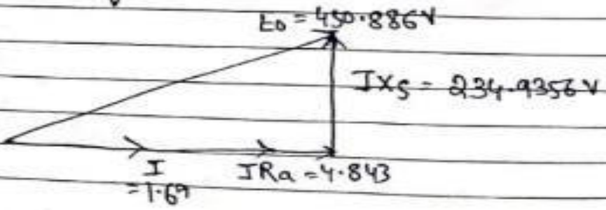


For unity power factor

$$E_0 = \sqrt{(380\times \cancel{00} + 1.67\times 2.9)^2 + (1.67\times 140.68)^2}$$
$$= \cancel{384.843}\ 450.886\ V$$

~~$VR = \frac{384.843 - 380}{380}\times 100 = 1.274$~~

$$VR = \frac{E_0 - V}{V}\times 100 = 18.65\%$$

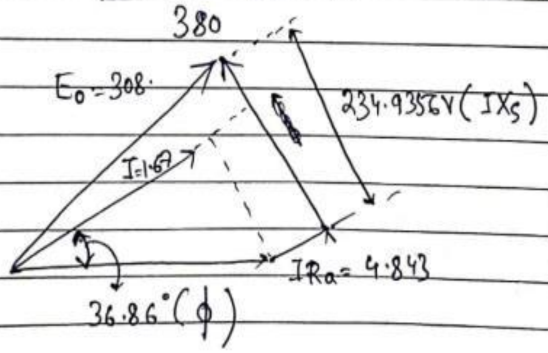


For leading power factor

$$E_0 = \sqrt{(380\times 0.8 + 1.67\times 2.9)^2 + (380\times 0.6 - 1.67\times 140.68)^2}$$

$$E_0 = 308.92$$

$$\therefore VR = \frac{308.92 - 380}{380}\times 100 = -18.7\%$$



CONCLUSIONS

Thus we successfully calculated the synchronous impedance by plotting the graph from the corresponding values we obtained during the open circuit and short circuit test that gave us X_s=140.68Ω. Correspondingly we found the Voltage regulation values for leading, unity and lagging power factors correspondingly as -18.7%,18.65% and 46.44% respectively.

DISCUSSION

1.What are the preconditions necessary for performing the Open Circuit characteristicstest?

Ans: For getting the Open Circuit Characteristics of Synchronous Machine, the alternator is first driven at its rated speed and the open terminal voltage i.e., voltage acrossthe armature terminal is noted by varying the field current. Thus, Open Circuit Characteristic or OCC is basically the plot between the armature terminal voltage.

2.What is the power factor of alternator on Short Circuited condition?

Ans: Under short circuit condition, alternator power factor is near zero (lagging). This is because winding inductive reactance is much larger than winding resistance.

3.Why is the short circuit characteristic of the alternator is a straight line? Up to whatrange of Short Circuit current, the linearity of the characteristic is maintained?

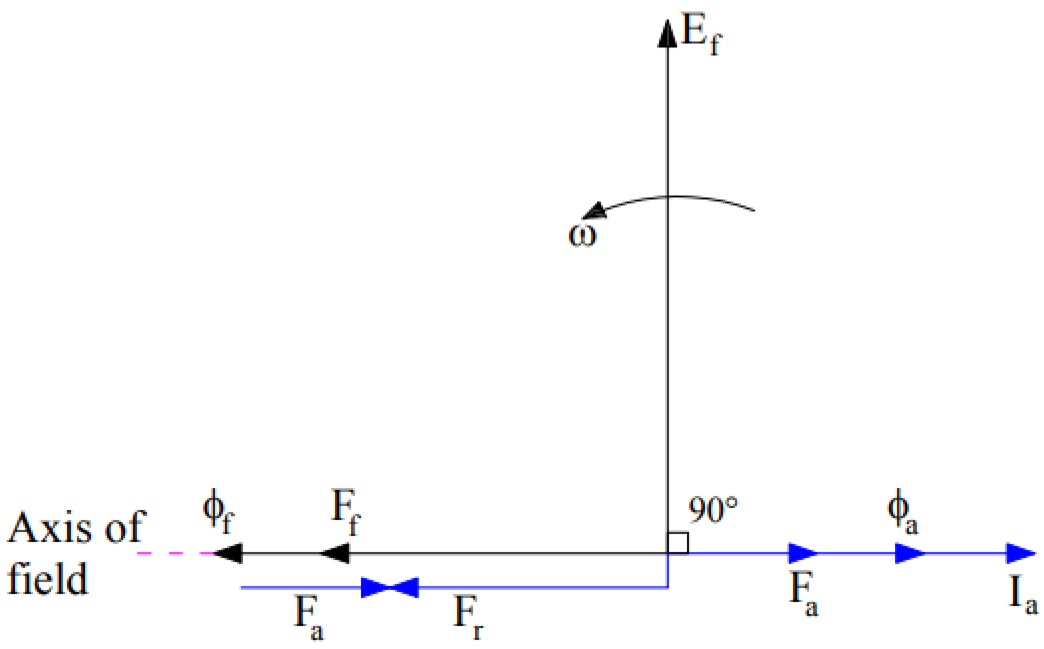
Ans: The short circuit characteristic is linear. The flux density in the machine is very low since the terminal voltage is zero. The air-gap flux is sufficient to produce a voltageto overcome the leakage reactance drop. From these two curves, the synchronous reactance can be found.
In SCC, the effect of armature reaction is purely demagnetization i.e., the armature current (or short circuit current in this case) will be opposite to main field flux 180 degrees out of phase. As the effect is demagnetizing, the machine works at low flux density condition and hence the chance of occurrence of saturation here is very less (or no). Thus, the graph of short circuit current vs. Field current is linear. But the graph is linear up to the point of saturation. When a machine drives into saturation it demands very high magnetizing current and machine windings may damage. Then there will be no direct proportionality between the armature shot-circuit current and the field current.

4. What is the effect of power factor on armature reaction?

Ans: The effect of armature reaction mmf is purely demagnetizing in zero pflagging load

condition. This can be explained in 2 methods.

1. In Zero power factor lagging load, the load current is lagging behind theexcitation voltage by 90 degree as shown in figure below.

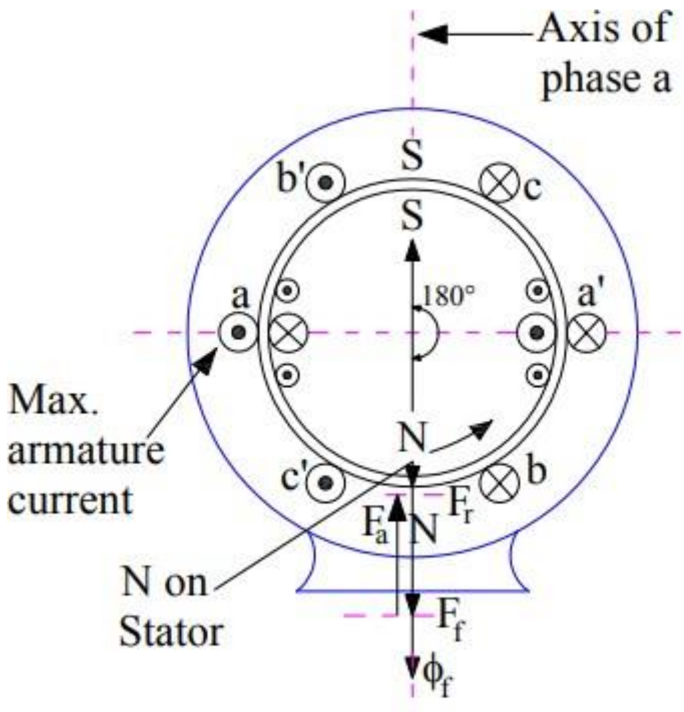


The above phasor diagram has been drawn considering the following facts:

- The excitation emf lags the field mmf by 90 degree.
- As saturation is neglected, the field flux will be along the field mmf.
- Armature reaction mmf is along the armature current.

From the above phasor diagram, we can deduce that armature reaction mmf F(a) is in opposition of field mmf Ø(f). This means that the resultant air-gap mmf will be equal to F(f) -F (a). Hence the effect of armature reaction mmf is purely demagnetizing.

2. Due to zero power factor lagging load, the current in phase "a" of armature winding will become maximum when the field poles have advanced by 90 degree in assumed counter-clockwise direction. This isshown in figure below.



It can be seen that, in this case the direction of armature reaction mmf F (a) will be along the phase "a" axis and that of and field mmf Ø(f). will be vertically downward. This direction canbe found by using right hand screw rule. Thus, we see that, both the armature reaction and filed mmf are opposing each other. Hence, the effect of armature reaction mmf is purely demagnetizing.

5. Why the synchronous reactance of Alternator is different at different values of fieldcurrent?

   Ans: As alternator core iron gets saturated, rate of rise of open circuit voltage with fieldcurrent decreases. On the other hand, short circuit current keeps rising linearly with field current. Therefore, synchronous reactance (Xs) decreases as core gets saturated.

6. Why it is necessary to separate the effect of armature reaction and leakage reactanceof the Alternator?

   Ans: The mutual flux in the air gap will not entirely link with the armature windings hence a portion of that flux will be lost or "leak" which is referred as the leakage flux represented by its self reactance in series with its armature resistance.
   When the load is connected to the alternator, the armature winding of the alternator carries a current. Every current carrying conductor produces its own flux so armature ofthe alternator also produces its own flux, when carrying a current. So, there are two fluxespresent in the air gap, one due to armature current while second is produced by the filedwinding called main flux. The flux produced by the armature is called armature flux.

7. What do you understand by effective resistance of Alternator and how can itmeasured in laboratory?

   Ans: Generally, the armature resistance is measured by applying the known d.c. voltageand measuring the d.c. current through it. The ratio of applied voltage and measured current is the armature resistance. But due to the skin effect, the effective resistance under a.c. conditions is more than the d.c. resistance. Generally, the effective armature resistance under a.c. conditions is taken 1.25 to 1.75 times the d.c. resistance.

   The windings resistance can be directly measured with an ohmmeter. Another method is to calculate the resistance by measuring the current trough every winding, using an ammeter A, when a voltage is applied and measured with a voltmeter V.

8. Why does the terminal voltage of an alternator change with load current? How doesthe load power factor effect this voltage change?

   Ans: The voltage is also a function of speed, but when the load is increased the increased magnetic field associated with the increased current flow in the armature (stator) will causethe terminal voltage to decrease.
   Generally, alternators work while being synchronized to the grid and if that is the case, it'sterminal voltage will not change, no matter what because the grid had a huge electrical inertia.
   But, if we talk about its induced voltage, E.g., we find that it gets affected with change of power factor. When load pf changes from lagging to leading, the induced emf vector decreases gradually on a straight-line locus, parallel to terminal voltage. At lagging pf, themachine is in overexcited condition. As pf tend towards leading, it changes to normally excited and then finally, under excited. This is in consideration to the assumption that mechanical input through the Prime Mover is kept constant.