Electric Machines Laboratory (EE2P001)

EXPERIMENT-7

REGULATION OF 3 Φ ALTERNATOR BY ZEROPOWER FACTOR METHOD

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AIM OF THE EXPERIMENT:

a) Perform open circuit and short circuit test on a 3-Φ alternator.
b) Perform load test on 3-Φ alternator with highly lagging load (Approximately zero power factor) when rated voltage and rated current flowing in the starter winding.
c) Find out regulation of alternator by using zero power factor method.

APPARATUS REQUIRED:

Instruments/Equipment:

Sl.No	Instruments/Equipments	Type	Specification	Quantity
1	Ammeter	MC	(0-1000) mA	1 No
2	Voltmeter	MC	(0-150)V	1 No
3	Voltmeter	MI	(0-150/300 / 600)V	1 No
4	Ammeter	MI	(0-5)A	1 No
5	Tachometer	Digital	(0-5000)rpm	1
6	TPST Switch	Knife	16A	1
7	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 Cylindrical Alternator	**D.C. Shunt Motor :-3 kW** , 1500 RPM 220 V , 18 A , Excitation- 120 V/ 0.8 A **3-Φ Alternator :- 2.4** kVA , 220/380 V,50 Hz 6.3/3.6A ,1500 RPM , Excitation- 110 V/0.75 A	1 Set

<u>THEORY:</u>

Zero power factor saturation curve method is most reliable for determining the regulation of alternators because it properly takes into account of the effect of armature leakage reactance drop and the saturation. The following experimental data is needed to determine the regulation by this method.

1. Open circuit characteristic at rated speed of the alternator.
2. Field current corresponding to full load short circuit current.
3. Field current corresponding to full load, rated voltage, zero power factor.
4. AC resistance of the stator winding per phase of the alternator.

To plot zero power factor characteristic from the experimental data and to determine the regulation of the Alternator proceed as follows:

Plotting of zero power factor characteristic

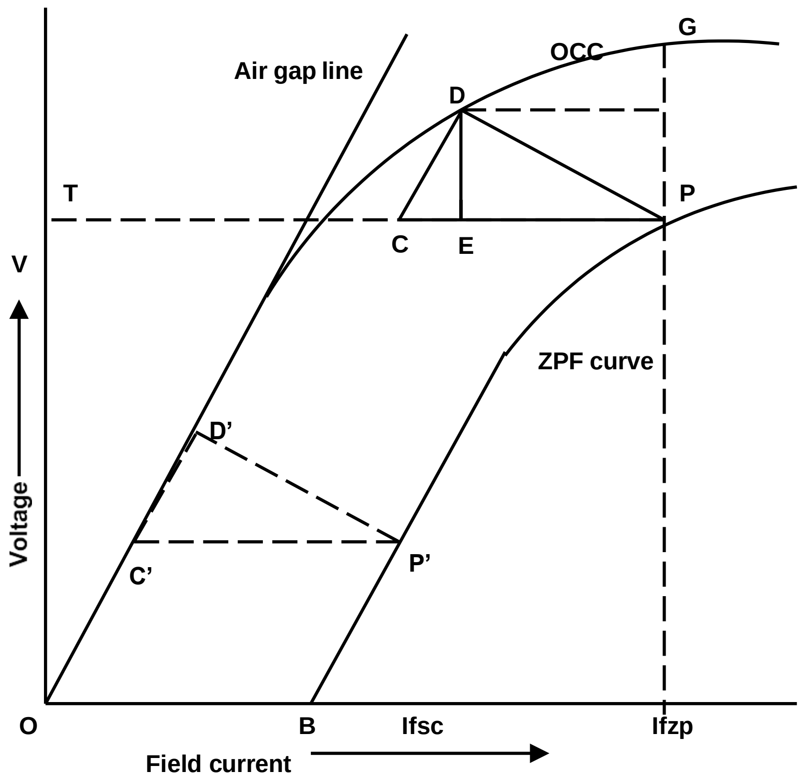


Fig-1 Zero power factor characteristic of alternator

- Draw the open circuit characteristic to proper scale and draw the air gap line as shown in Fig-1.
- Draw the field current, I_{fsc} corresponding to full load short circuit current (line ***OB***).

- Draw the field current, I_{fzp} at rated voltage which corresponding to full load zero power factor, thus obtaining a point ***P*** on the zero power factor, full load characteristic (line ***TP***).
- From the point ***P*** draw a horizontal line ***PC*** representing the field current corresponding to full load short circuit current i.e. ***PC***=***OB***.
- From the point ***C*** draw a line ***CD*** parallel to air gap line.
- Join ***D*** and ***P***. Now ***PCD*** is a triangle, which normally called as ***Potier triangle***.

Determination of leakage reactance

- Drop a perpendicular from the point ***D***, meeting the line ***PC*** at the point ***E***. then line ***ED*** represents the leakage reactance drop, which is also called as ***Potier reactance drop*** (E_x).

Determination of Regulation

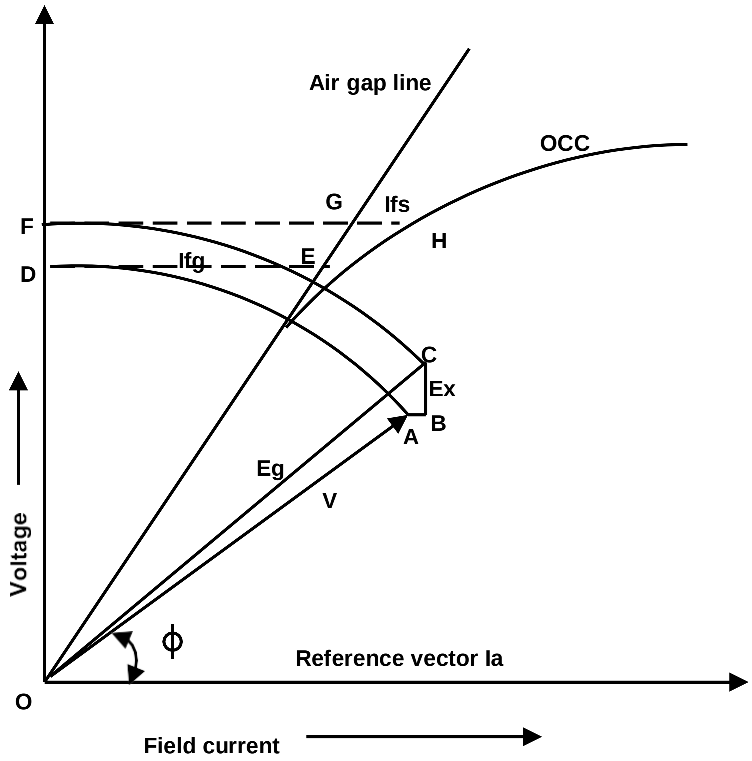


Fig-2 Determination of saturation effect

- Draw the current phasor, $\boldsymbol{I_a}$ as shown in Fig-2 horizontally, which is a reference phasor. Terminal voltage phasor, ***V*** is drawn at power factor angle Φ with respect to current (line ***OA***). ☐ Add armature resistance drop I_aR_a (line ***AB***) to the terminal voltage phasor V.

- Potier reactance drop, E_x is added in quadrature to the current phasor (line ***BC***).
- Join ***O*** and ***C***, line ***OC*** represents the internally generated emf, ***Eg***.
- Phasors ***OA*** and ***OC*** are projected by arc to vertical line.
- Intercept ***DE*** shown by dotted horizontal line in Fig-2 represents the field current, ***Ifg*** corresponding to rated no load voltage.
- The portion ***GH*** of the intercept ***FH*** represents the field current, ***Ifs*** which takes into account the effect of saturation.

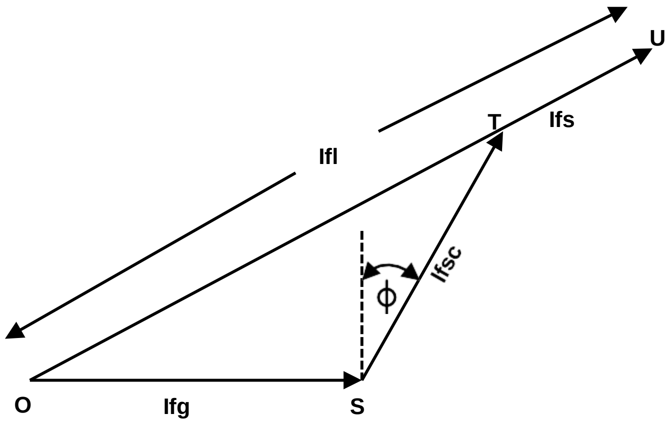


Fig-3 Phasor diagram for ZPF method

- Draw the field current ***Ifg*** horizontally (line ***OS***) as shown in Fig-3.
- Add the field current ***Ifsc*** (line ***ST***) at power factor angle Φ with the vertical as shown in Fig-3.☐Join ***OT*** and add the field current ***Ifs*** (line ***TU***), thus giving a total field current ***Ifl.***
- No load emf, E_o corresponding to field current ***Ifl*** is found out from the open circuit characteristic. Then

☐

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

CIRCUIT DIAGRAM:

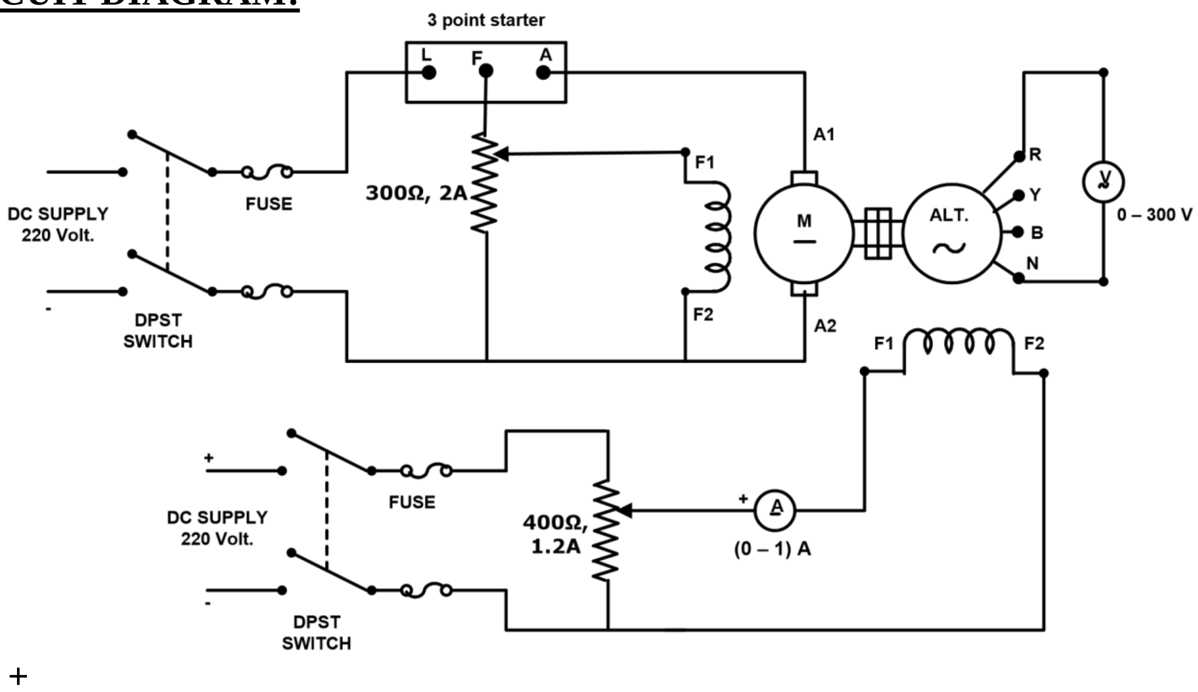


Fig- 4 Circuit Diagram for O.C Test on alternator

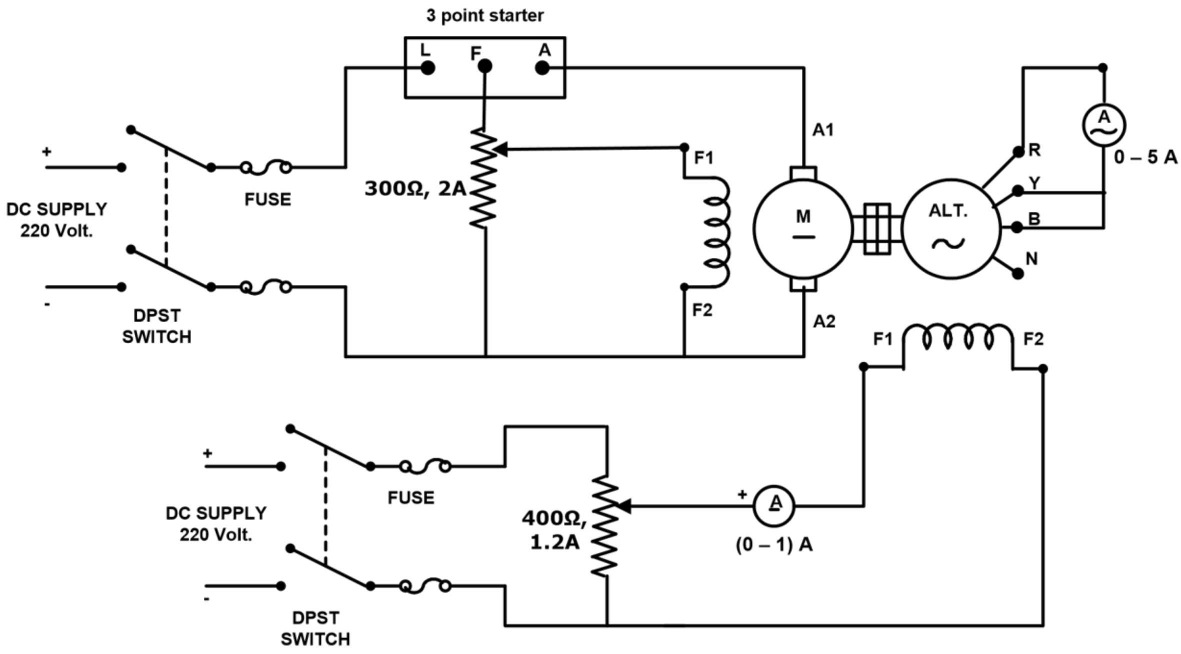


Fig- 5 Circuit Diagram for S.C Test on alternator

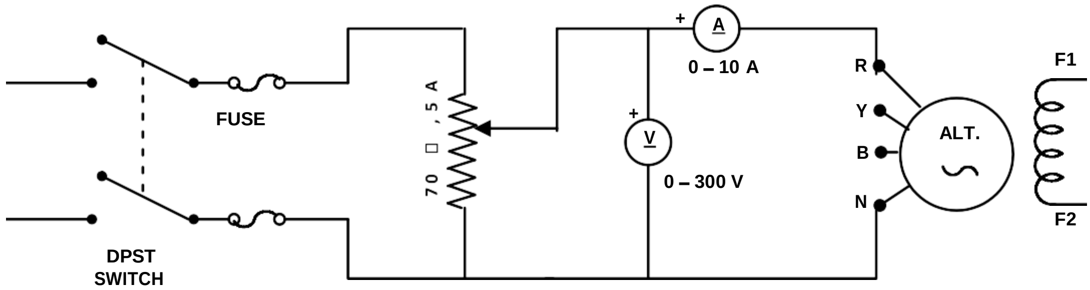


Fig- 6 Circuit Diagram for armature resistance measurement of alternator

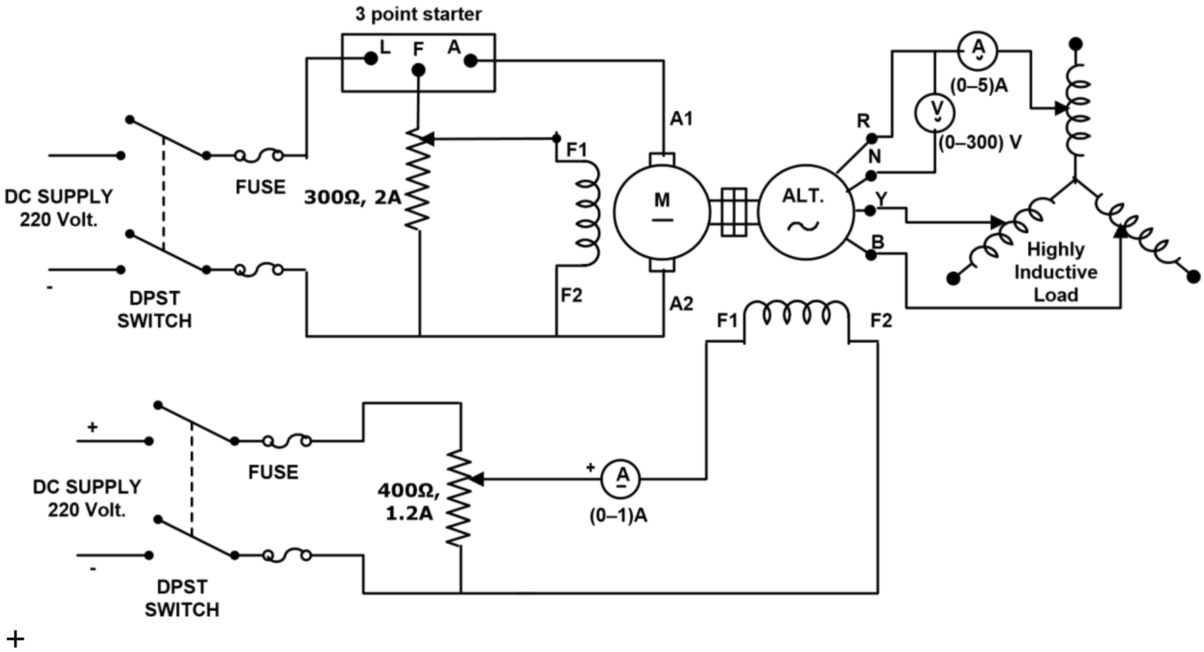


Fig-7 Zero power factor, full load test on alternator

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).

PROCEDURE:

1. Open-Circuit characteristic:

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

2. Short-Circuit characteristic:

5. Connect circuit diagram as in Fig-5, but short-circuit the armature terminals through an ammeter.
6. The current range of the instrument should be about 25-50 % more than the full load current of the alternator.
7. Starting with zero field current, increase the field current gradually and cautiously till rated current flows in the armature and note down the readings(I_f versus I_{sc}) in observation table-1
8. 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 a DMM and find out the resistance of the stator winding of the alternator .

4. For zero power factor test:

1. Connect the circuit as in Fig-7.
2. Set the field Regulator rheostat of alternator, so that the field current of alternator is minimum.
3. Switch on the DC Supply and set the field voltage of DC Shunt Motor at it's rated value.
4. Start the DC Shunt Motor with the help of starter and run it at rated speed of alternator.

5. Increase the field regulator rheostat of the alternator to obtain rated voltage.
6. Close the TPST Switch. Load the alternator gradually in steps and keep load current constant (may be at 50%,75%,100% of full load value) for each step variation.
7. Note down the terminal voltage across the load for each step variation.
8. Maintain the speed of the alternator at rated value throughout the experiment.
9. Decrease the load on the alternator gradually and side by side, reduce the field current of the alternator.
10. Switch off the dc supply to the field of the alternator and dc motor.

OBSERVATION:

Table – 1 (OC & SC Test and Ra Measurement)

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
8			0.51	2.48
9			0.55	2.68
10			0.60	2.88
11			0.64	3.20
12			0.68	3.28
13			0.71	3.44
14			0.74	3.6

Ra=2.9Ω/phase

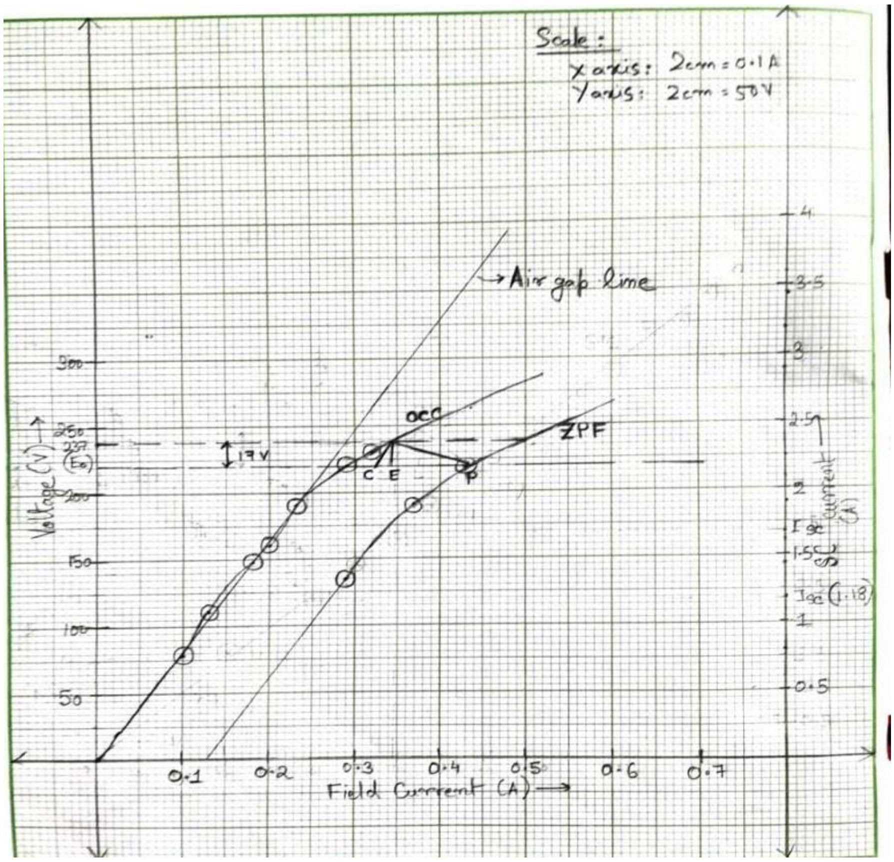
Table – 1 (ZPF Test)

Sl. No.	Stator Current (A)	Terminal voltage (V)	Field current (A)
1.	1.2	136	0.29
2.	1.2	192	0.37
3.	1.2	220	0.43

Data Processing and Analysis:

1. Plot *on the same* graph sheet, the O.C.C (open circuit terminal voltage per phase versus the field current), and the short-circuit characteristic (short-circuit armature current versus the field current).
2. Calculate the unsaturated value of the synchronous impedance, and the value corresponding to rated current at short circuit. Also calculate the corresponding values of the synchronous reactance.
3. Calculate regulation of the alternator under the following conditions:
   d) Full load current at unity power factor.
   e) Full load current at 0.8 power factor lagging.
   f) Full -load current at 0.8 power factor leading.

GRAPH:



CALCULATIONS:

Calculations

From graph:- $\frac{I_a}{3} X_L = 17V$

$\therefore X_L = \frac{17\times3}{3.6} = \frac{85}{6} = 14.17\Omega$

(where I_a is rated $I = 3.6A$)

$R_a = 1.25\times2.9$ (AC value is 2.5 times DC value)

$= 3.625\Omega$

$V_{full\ load} = 220V$, I_a rated $= 3.6A$

$VR = \frac{E_0 - V_{full\ load}}{V_{full\ load}} \times 100\%$

~~Lagging power factor:~~

I_{f_2} = EP intercept from graph $= 0.43 - 0.34$

$= 0.09$

Lagging power factor

$\cos\phi = 0.8$, $\sin\phi = 0.6$, $\phi = \cos^{-1}0.8 = 36.87$

$E_g = \sqrt{(V_{ft}\cos\phi + I_aR_a)^2 + (V_{ft}\sin\phi + I_aX_L)^2}$

$= 263.12\ V$

Corresponding I_{f_1} (from OCC curve) $= 0.435A$

Date: / /

$I_f = \sqrt{I_{f_1}^2 + I_{f_2}^2 + 2I_{f_1}I_{f_2}\cos(180-(90+\phi))}$

$= \sqrt{0.435^2 + 0.09^2 + 2\times0.435\times0.09\cos(90-36.87°)}$

$= 0.494$

$\therefore E_0 = 275V$ (from corresponding OCC curve)

% Voltage regulation $= \frac{275-220}{220}\times100 = 25\%$

Unity power factor

$E_g = \sqrt{(V_{ft} + I_aR_a)^2 + (I_aX_L)^2}$

$= 238.58\ V$

$I_{f_1} = 0.345A$

$I_f = \sqrt{0.345^2 + 0.09^2 + 2\times0.345\times0.09\cos(90-36.87)}$

$= 0.40\ A$

$E_0 = 255V$

$\therefore \%VR = \frac{255-220}{220} = 15.90\%$

0.8 Leading power factor

$E_g = 205.66\ V$

I_{f_1} from graph $= 0.255A$

$I_f = \sqrt{0.255^2 + 0.09^2 + 2\times0.255\times0.09\cos(90-36.87)}$

$= 0.3172A$

$\therefore E_0 = 155V$

$VR = \frac{155-220}{220}\times100 = -29.54\%$

CONCLUSION:

So we successfully constructed the potier triangle and conducted the ZPF test to find out more accurate VR values..ie positive VR values for unity and lagging power factor,and negative VR for leading power factor.

DISCUSSION:

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

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 across the 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 thanwinding resistance.

3. Why is the Short Circuit characteristic a straight line? Up to what rangeof Short Circuit current the linearity 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 voltage to 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 occurance 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 upto 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. Why do you think ZPF method is more accurate method as compared tosynchronous impedance method?

Ans: In Potier Triangle or ZPF method, voltage quantities are calculated onemf basis and mmf quantities are calculated on mmf basis. Synchronous impedance method gives result which is higher than the original value. That's why it's called the 'pessimistic method'.Therefore ZPF method is more accurate than synchronous impedance method.

5. By which other methods can you load the alternator for watt less current?

Ans: Wattless current would mean there IS a current ($I \neq 0$) and $P=0$ In that case, the only solution to $P=VI$ is $V=0$ is possible in two ways:

1. If no external voltage is applied to the conductor and no internalvoltages are present in the material. In this case, there would notbe any current as well. Hence, it can be considered a trivial solution.

2. Considering Ohm's law, V=RIV=RI, if I≠0I≠0 we could have V=0V=0 ONLY if R=0R=0. Even with the most advancedsuperconductor technologies conceivable, we would never reacha point of absolute zero resistance. There will always be some resistance. It may by really, really close to zero, evennegligible… But not actually zero. So, if by "wattless current" you mean a negligible (but not zero) power beingdissipated, yes, it can be achieved depending on the properties of the material and your definition of "wattless" (like if P < [some -non zero- value], it can beconsidered "wattless"). But if you mean absolute zero, I would say no even in the most ideal conditions.

   Moreover With a purely inductive of capacitive circuit, we would havea reactive current flowing in. Reactive power is measured in Volts-Amperes, soit would "technically" be wattless (even though Watts and Volts-Amperes are dimensionally equivalent, it is just a convention to distinguish active from reactive power more easily and directly).

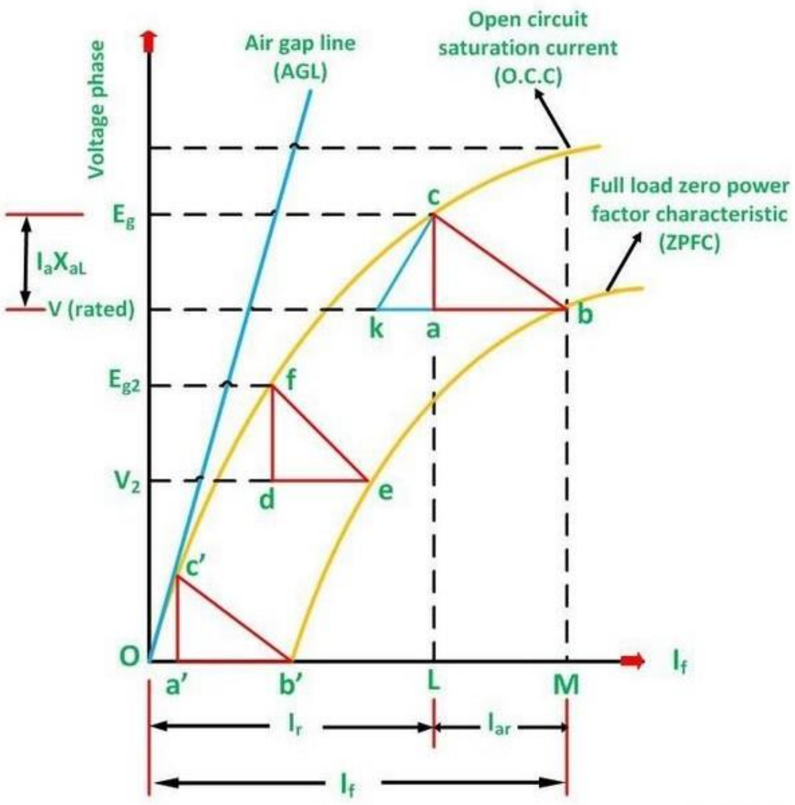
6. Discuss how it enables to separate the armature reaction drop from theleakage reactance drop.

Ans: In order to obtain voltage regulation using potier's method. The armature leakage reactance X_L (emf quantity) and armature reaction effect (mmf quantity) are determined separately by performing two testson the alternator.

- Open circuit test
- Zero power factor test:XL is determined according to the formulae:(Voltage drop/phase)/(Full load armature current)

7. Write in brief construction of the Potier triangle.

   Ans:



- Take a point b on the ZPFC preferably well upon the knee of thecurve.
- Draw bk equal to b'O. (b' is the point for zero voltage, full loadcurrent). Ob' is the short circuit excitation Fsc.
- Through k draw, kc parallel to Oc' to meet O.C.C in c.
- Drop the perpendicular ca on to bk.
- Then, to scale ca is the leakage reactance drop I_aX_{aL} and ab is the armature reaction MMF F_{aR} or the field current IfaR equivalent toarmature reaction MMF at rated current.

The effect of field leakage flux in combination with the armature leakage fluxgives rise to an equivalent leakage reactance Xp, known as the Potier Reactance. It is greater than the armature leakage reactance.

$$\text{Potier Reactance Xp} = \frac{\text{Voltage drop per phase which is equal to (ac)}}{\text{(ZPF rzted armature current per phase Ia)}}$$

For cylindrical rotor machines, the Potier reactance X_p is approximately equal tothe leakage reactance X_{aL}. in salient pole machine, X_p may be as large as 3 times X_{aL}.