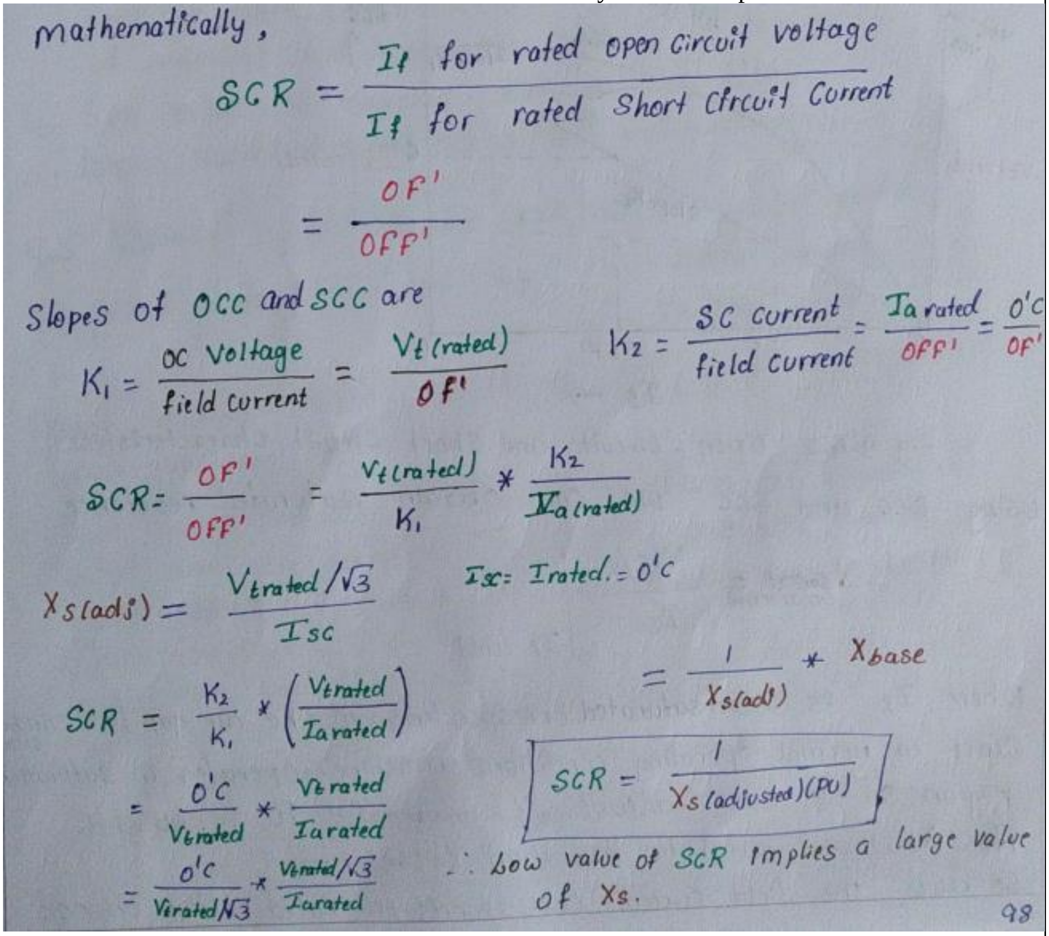
CMR INSTITUTE OF TECHNOLOGY	USN

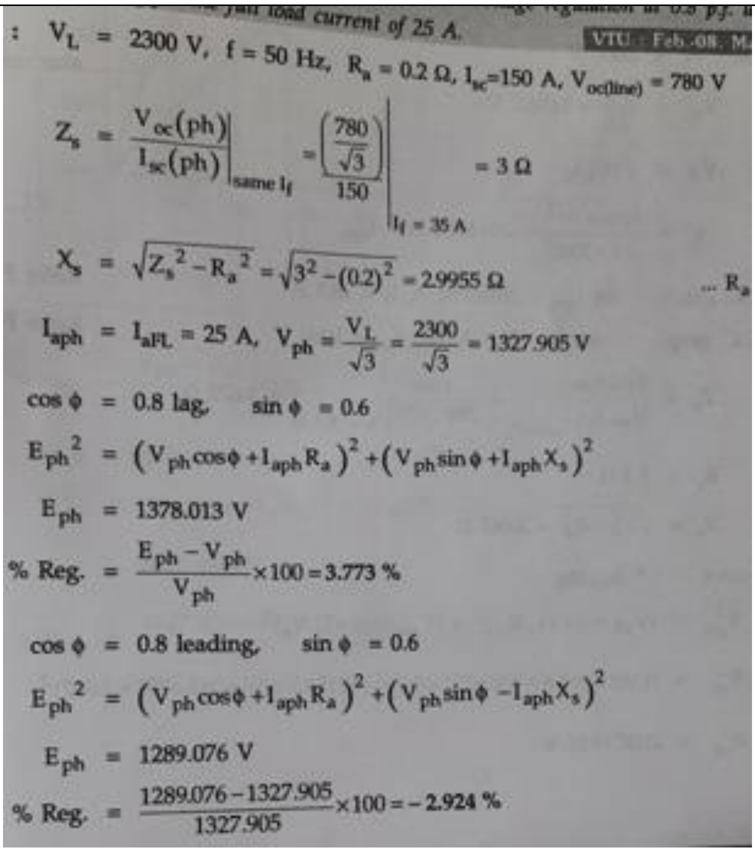
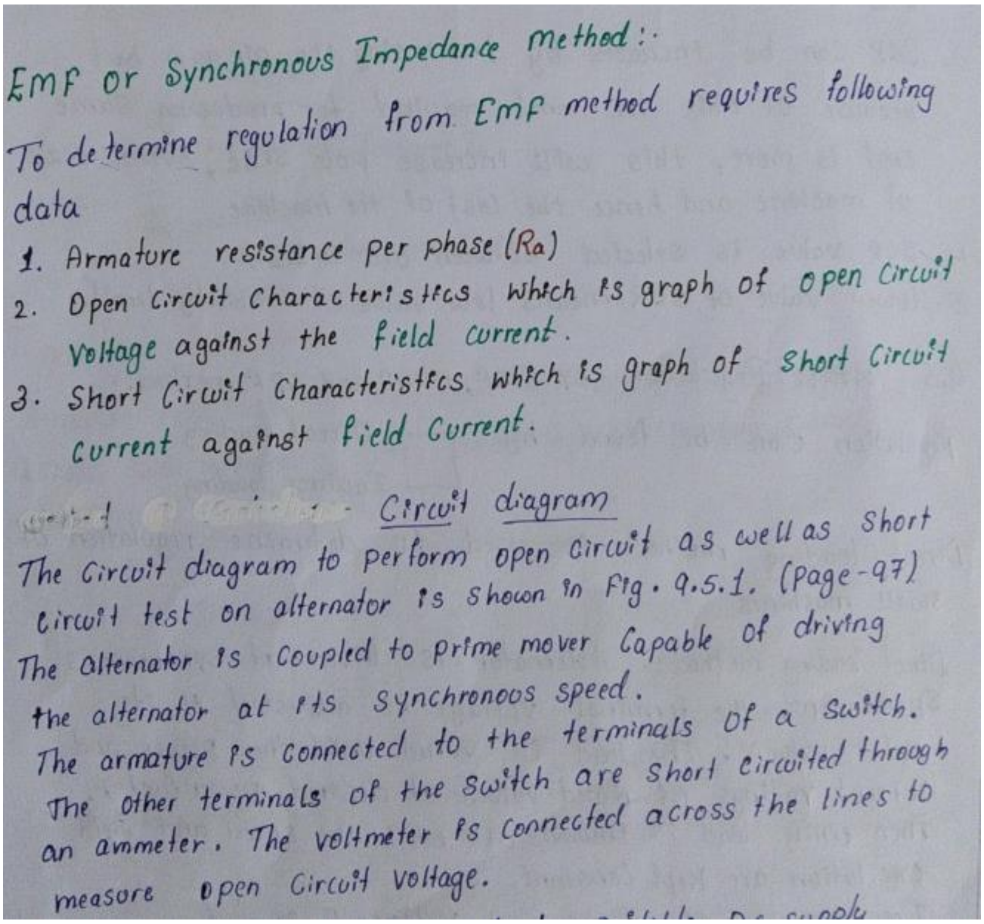
Internal Assesment Test III – December -2022

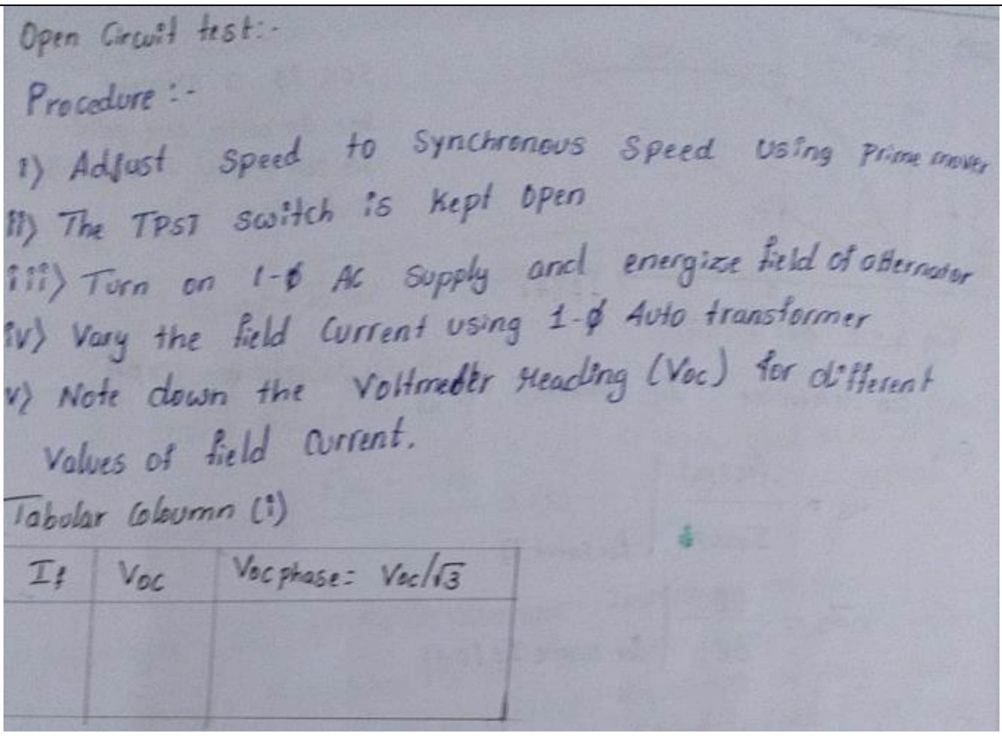
Sub:	Transformers and Generators							Code:	21EE34
Date:	9/2/2022	Duration:	90 Min	Max Marks:	50	Sem:	3	Section:	A & B

Note: Answer any **FIVE FULL** Questions

Sketch Neat Figures Wherever Necessary.

		Marks	OBE	
			CO	RBT
1(a)	**Explain the short circuit ratio of an alternator with derivation.** The Short Circuit Ratio (SCR) is defined as the ratio of field current required to produce rated voltage on open circuit to the field current required to produce rated armature current with armature terminals shorted while machine runs at synchronous speed.  mathematically, $SCR = \frac{I_f \text{ for rated open circuit voltage}}{I_f \text{ for rated Short Circuit Current}}$ $= \frac{OF'}{OFF'}$ Slopes of OCC and SCC are $K_1 = \frac{\text{OC Voltage}}{\text{field current}} = \frac{V_t(\text{rated})}{OF'}$ $K_2 = \frac{\text{SC current}}{\text{field current}} = \frac{I_a \text{ rated}}{OFF'} = \frac{O'C}{OF'}$ $SCR = \frac{OF'}{OFF'} = \frac{V_t(\text{rated})}{K_1} * \frac{K_2}{I_a(\text{rated})}$ $X_s(\text{adj}) = \frac{V_t\text{rated}/\sqrt{3}}{I_{sc}}$ $I_{sc} = I\text{rated} = O'C$ $SCR = \frac{K_2}{K_1} * \left(\frac{V_t\text{rated}}{I_a\text{rated}}\right)$ $= \frac{O'C}{V_t\text{rated}} * \frac{V_t\text{rated}}{I_a\text{rated}}$ $= \frac{o'c}{V_t\text{rated}/\sqrt{3}} * \frac{V_t\text{rated}/\sqrt{3}}{I_a\text{rated}}$ $= \frac{1}{X_s(\text{adj})} * X_{base}$ $\boxed{SCR = \frac{1}{X_s(\text{adjusted})(PU)}}$ ∴ Low value of SCR implies a large value of Xs. 98	[5]	CO5	L2
1(b)	**A 2300V, 50Hz, 3 phase star connected alternator has an effective armature resistance of 0.2Ω. A field current of 35 A produces a current of 150A on short circuit and an open circuit emf of 780V (line). Calculate the voltage regulation at 0.8 p.f. leading for the full load current of 25A.**	[5]	CO5	L3

	current of 25 A. VTU : Feb.-08, M : $V_L = 2300$ V, f = 50 Hz, $R_a = 0.2\ \Omega$, I_{sc}=150 A, $V_{oc(line)} = 780$ V $Z_s = \left.\frac{V_{oc}(ph)}{I_{sc}(ph)}\right\|_{same\ I_f} = \left.\frac{\left(\frac{780}{\sqrt{3}}\right)}{150}\right\|_{I_f = 35\ A} = 3\ \Omega$ $X_s = \sqrt{Z_s^2 - R_a^2} = \sqrt{3^2-(0.2)^2} = 2.9955\ \Omega$ ... R_a $I_{aph} = I_{aFL} = 25$ A, $V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{2300}{\sqrt{3}} = 1327.905$ V $\cos\phi = 0.8$ lag, $\sin\phi = 0.6$ $E_{ph}^2 = (V_{ph}\cos\phi + I_{aph}R_a)^2 + (V_{ph}\sin\phi + I_{aph}X_s)^2$ $E_{ph} = 1378.013$ V % Reg. $= \frac{E_{ph}-V_{ph}}{V_{ph}} \times 100 = 3.773$ % $\cos\phi = 0.8$ leading, $\sin\phi = 0.6$ $E_{ph}^2 = (V_{ph}\cos\phi + I_{aph}R_a)^2 + (V_{ph}\sin\phi - I_{aph}X_s)^2$ $E_{ph} = 1289.076$ V % Reg. $= \frac{1289.076-1327.905}{1327.905} \times 100 = -2.924$ %			
2	**Enumerate the various methods available for determining the voltage regulation. Explain in detail the EMF method.** Voltage regulation can be found by Direct loading and Indirect loading methods. Following are the indirect loading methods: A. EMF method or Synchoronous Impedance method B. MMF method or Ampere-turn method C. Zero power factor or Potier method EmF or Synchronous Impedance method :- To determine regulation from EmF method requires following data 1. Armature resistance per phase (R_a) 2. Open circuit characteristics which is graph of open circuit voltage against the field current. 3. Short Circuit Characteristics which is graph of Short Circuit current against field Current. Circuit diagram The circuit diagram to perform open circuit as well as short circuit test on alternator is shown in Fig. 9.5.1. (Page-97) The alternator is coupled to prime mover capable of driving the alternator at its synchronous speed. The armature is connected to the terminals of a switch. The other terminals of the switch are short circuited through an ammeter. The voltmeter is connected across the lines to measure open circuit voltage.	[10]	CO6	L2



Open Circuit test:-

Procedure :-

I) Adjust speed to Synchronous Speed using Prime mover

II) The TPST switch is kept open

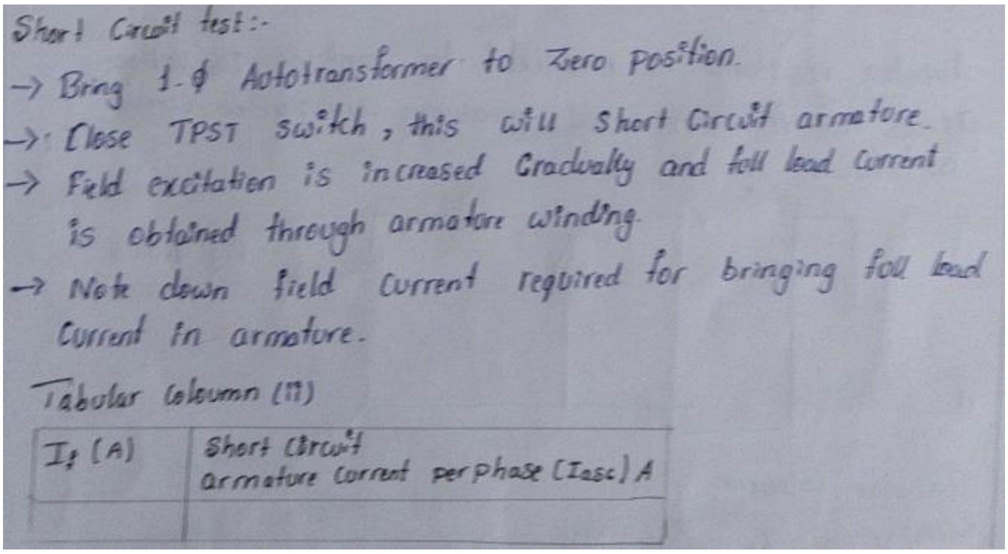
III) Turn on 1-ϕ AC Supply and energize field of alternator

IV) Vary the field Current using 1-ϕ Auto transformer

V) Note down the Voltmeter reading (Voc) for different Values of field current.

Tabular Column (i)

I_f	V_{oc}	V_{oc} phase = $V_{oc}/\sqrt{3}$



Short Circuit test:-

→ Bring 1-ϕ Autotransformer to Zero position.

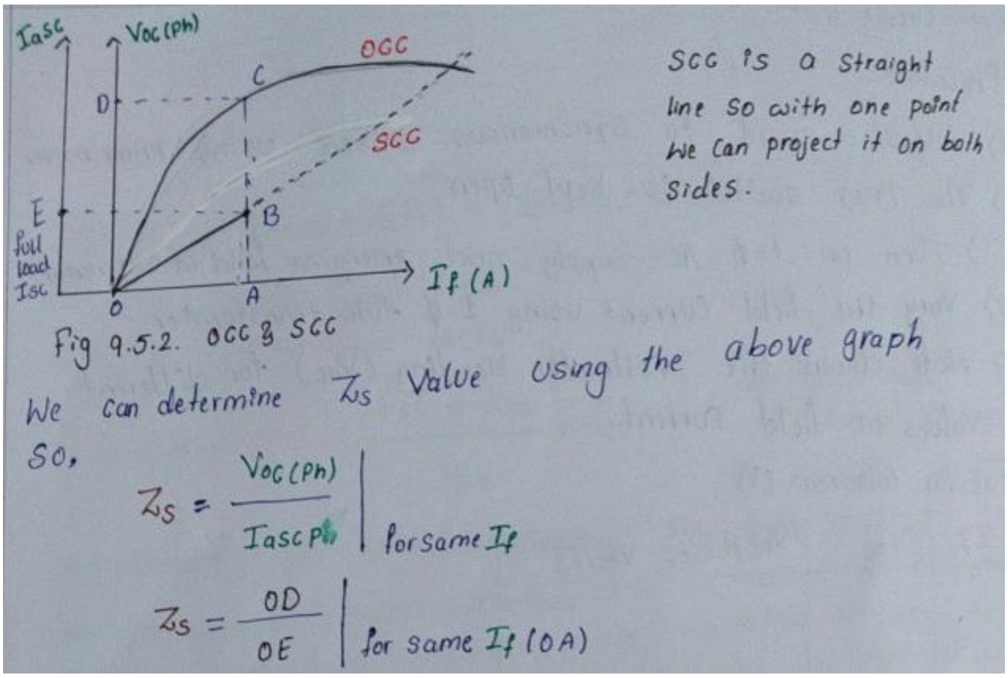
→ Close TPST switch, this will short circuit armature.

→ Field excitation is increased Gradually and full load current is obtained through armature winding.

→ Note down field current required for bringing full load current in armature.

Tabular Column (ii)

I_f (A)	Short Circuit Armature current per phase (I_{asc}) A



SCC is a straight line so with one point we can project it on both sides.

Fig 9.5.2. OCC & SCC

We can determine Z_s Value using the above graph

So,

$$Z_s = \left.\frac{V_{oc(Ph)}}{I_{asc\,Ph}}\right|_{\text{for same } I_f}$$

$$Z_s = \left.\frac{OD}{OE}\right|_{\text{for same } I_f\,(OA)}$$

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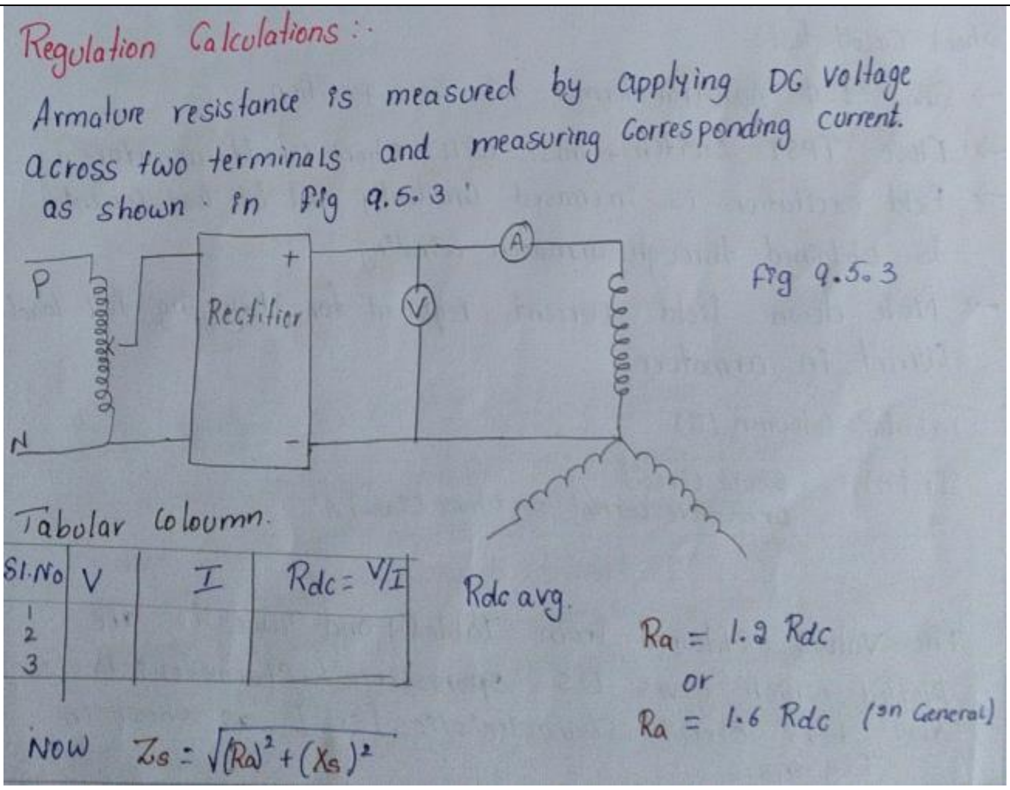


Regulation Calculations :·

Armature resistance is measured by applying DC Voltage across two terminals and measuring Corresponding current. as shown in fig 9.5.3

fig 9.5.3

Tabolar coloumn.

<table>
<tr><th>Sl.No</th><th>V</th><th>I</th><th>$R_{dc} = V/I$</th></tr>
<tr><td>1</td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td></tr>
</table>

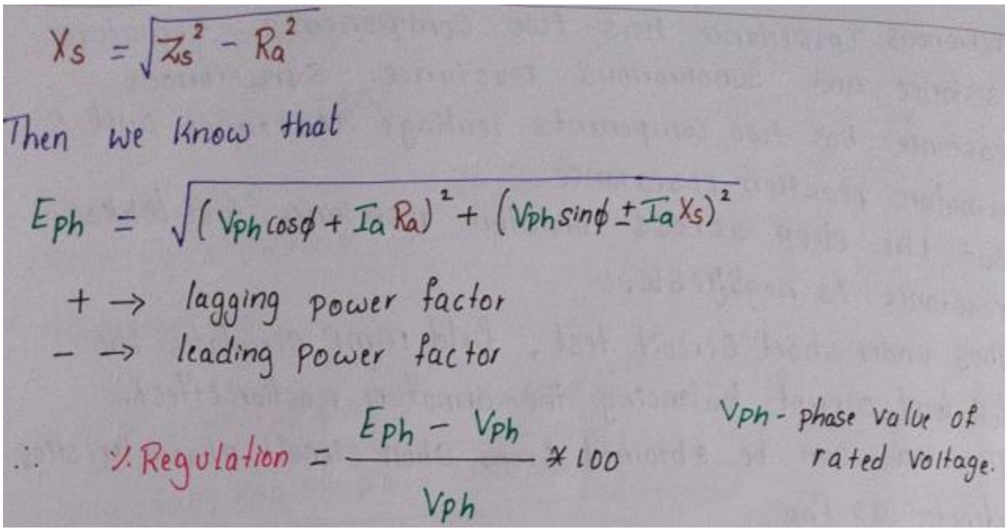
Rdc avg.

$R_a = 1.2\ R_{dc}$

or

$R_a = 1.6\ R_{dc}$ (in General)

Now $Z_s = \sqrt{(R_a)^2 + (X_s)^2}$



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

Then we know that

$$E_{ph} = \sqrt{(V_{ph}\cos\phi + I_a R_a)^2 + (V_{ph}\sin\phi \pm I_a X_s)^2}$$

+ → lagging power factor

− → leading power factor

$$\therefore \ \%\text{ Regulation} = \frac{E_{ph} - V_{ph}}{V_{ph}} * 100$$

V_{ph} - phase value of rated voltage.
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<td>3</td>
<td>Discuss the concept of two-reaction theory in a salient pole synchronous machine with the help of phasor diagrams</td>
<td>[10]</td>
<td>CO6</td>
<td>L2</td>
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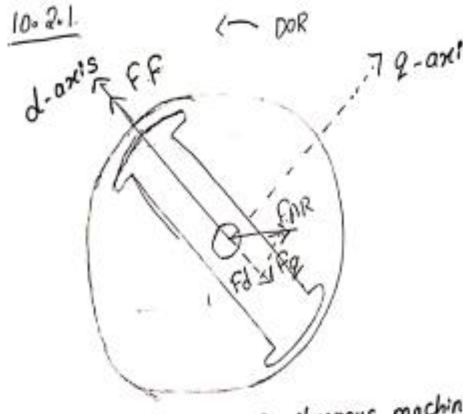
0.2 Two-reaction theory

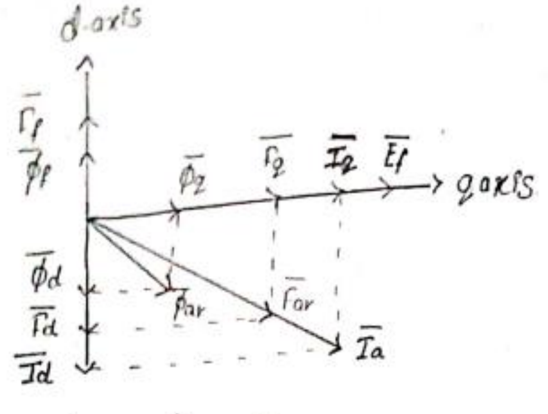
Cylindrical pole alternators have uniform air gap, because of this field flux as well as armature flux vary sinusoidally in air gap, hence reactance remains constant.

But in salient pole alternators the length of air gap varies and reluctance also varies, because of this armature flux and field flux cannot vary sinusoidally so the reluctance on which mmfs act are different in case of salient pole alternators

The cross sectional view of salient pole machine is shown in 10.2.1.



10.2.1 Salient-pole Synchronous machine.



10:2.3 - Phasor diagram

The flux components/pole produced by d-axis & q-axis of armature reaction mmf are

$\phi_d = P_d F_d$

$= P_d K_{ar} I_d \rightarrow ①$

P_d - Permeance along d-axis.

K_{ar} - armature reaction coefficient.

$\phi_q = P_q F_q$

$P_q K_{ar} I_q \rightarrow ②$

P_q - Permeance along q-axis

$P_d > P_q$

Emf induced by ϕ_d & ϕ_q are.

$$\overline{E_d} = K_e \phi_d \angle -90^\circ = -j K_e \phi_d$$

$$\overline{E_q} = K_e \phi_q \angle -90^\circ = -j K_e \phi_q$$

[b/c induced emf lags flux by 90°]

K_e - emf constant of armature winding.

$$\therefore \overline{E_r} = \overline{E_f} - j X_d^{ar} \overline{I_d} - j X_q^{ar} \overline{I_q}$$

$$\boxed{\overline{E_f} = \overline{E_r} + j X_d^{ar} \overline{I_d} + j X_q^{ar} \overline{I_q}} \quad ..$$

For cylindrical-rotor machine

$$X_d^{ar} = X_q^{ar} = X^{ar}$$

$$\boxed{\overline{E_f} = \overline{E_r} + j(I_d + I_q) X^{ar}}$$

The resultant emf $\overline{E_r}$

$$\overline{E_r} = \overline{V_t} + \overline{I_a} R_a + j I_a X_l \qquad \overline{I_a} = \overline{I_q} + \overline{I_d}$$

So,

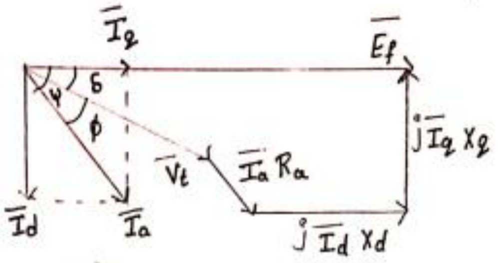
$$\overline{E_f} = \overline{V_t} + \overline{I_a} R_a + j(Y_d^{ar} + X_l)\overline{I_d} + j(X_q^{ar} + X_l)\overline{I_q}$$

$X_d^{ar} + X_l = X_d$ - d-axis sync. reactance $\quad X_d > X_q$

$X_q^{ar} + X_l = X_q$ - q-axis sync. reactance.

$$\boxed{\overline{E_f} = \overline{V_t} + \overline{I_a}R_a + j\,\overline{I_d}X_d + j\,\overline{I_q}X_q} \rightarrow ③$$

The phasor diagram depicting currents & voltages as per eqⁿ ③ is drawn in fig 10.2.4.



10.2.4.

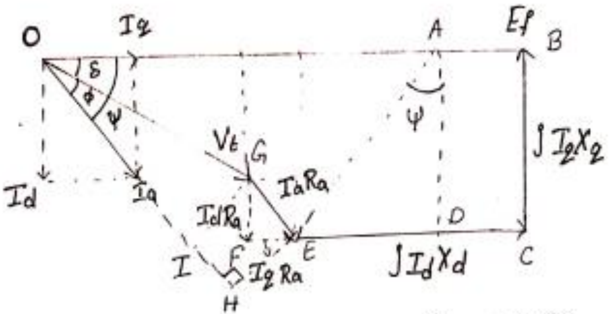
$\overline{I_d} = \overline{I_a}\sin\psi \rightarrow ④$

$\overline{I_q} = \overline{I_a}\cos\psi \rightarrow ⑤$

The drop I_aR_a has two components

$I_dR_d \rightarrow$ drop due to R_a in phase with I_d

$I_qR_a \rightarrow$ drop due to R_a in phase with I_q



$\cos\psi = \frac{DA}{AE} = \frac{I_qX_q}{AE} \rightarrow ⑥$

from eqⁿ ⑤

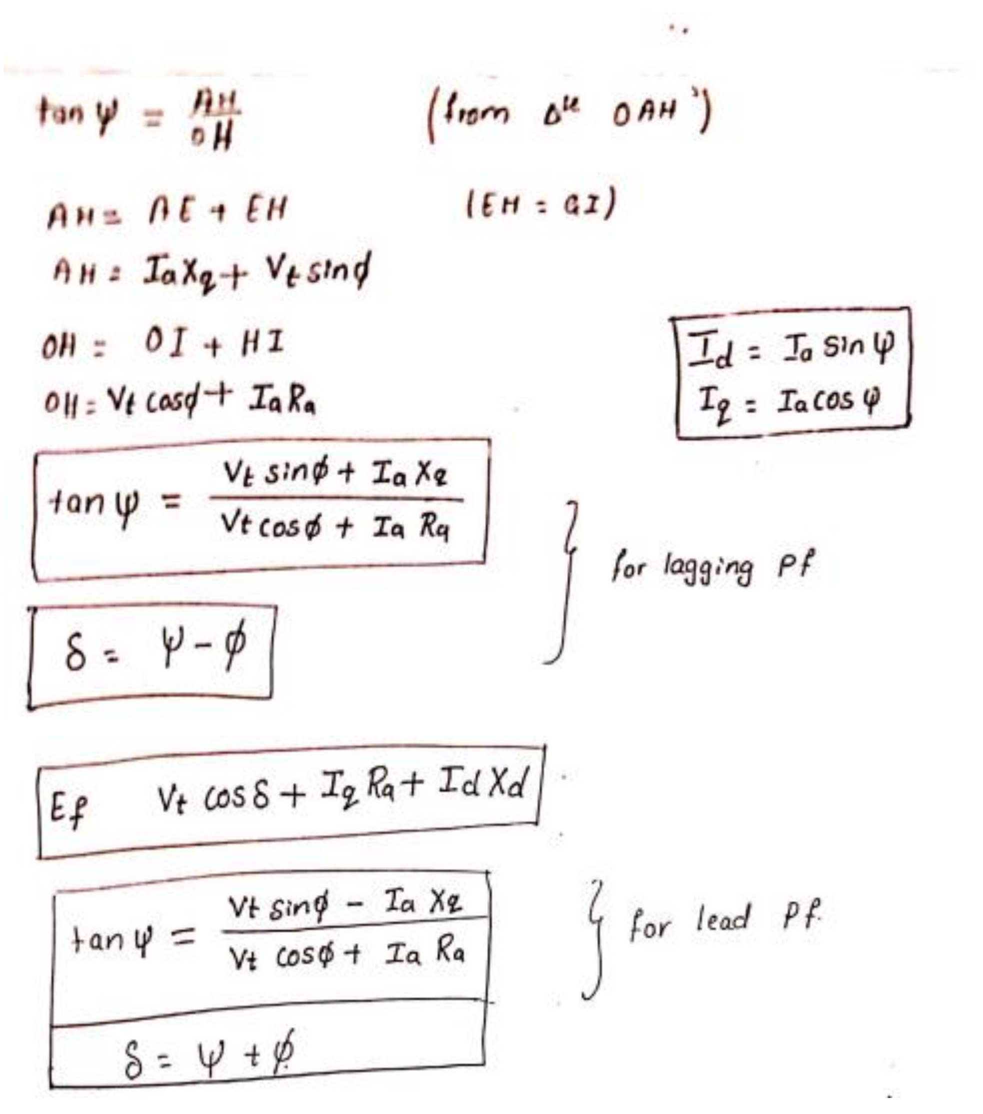
$\cos\psi = \frac{\overline{I_q}}{\overline{I_a}} \rightarrow ⑦$

from ⑥ & ⑦

$$\frac{I_q}{I_a} = \frac{I_q X_q}{AE}$$

$$AE = I_a X_q$$

Scanned by CamSc



$$\tan\psi = \frac{AH}{OH}$$ (from Δ^{le} OAH)

$AH = AE + EH$ (EH = GI)

$AH = I_a X_q + V_t \sin\phi$

$OH = OI + HI$

$OH = V_t \cos\phi + I_a R_a$

$$\boxed{\begin{aligned} I_d &= I_a \sin\psi \\ I_q &= I_a \cos\psi \end{aligned}}$$

$$\boxed{\tan\psi = \frac{V_t \sin\phi + I_a X_q}{V_t \cos\phi + I_a R_a}}$$

$$\boxed{\delta = \psi - \phi}$$

} for lagging pf

$$\boxed{E_f \quad V_t \cos\delta + I_q R_a + I_d X_d}$$

$$\boxed{\begin{aligned} \tan\psi &= \frac{V_t \sin\phi - I_a X_q}{V_t \cos\phi + I_a R_a} \\ \delta &= \psi + \phi \end{aligned}}$$

} for lead pf

4

The open circuit and short circuit test is conducted on a 3 phase, star connected, 866V, 100 KVA alternator The O.C. test results are

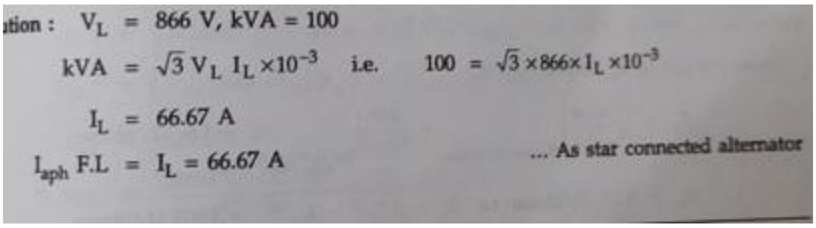
I_f(A)	1	2	3	4	5	6
V_{oc} line(V)	173	310	485	605	728	790

The field current of 1A produces a short circuit current of 25A. The armature resistance per phase is 0.15Ω. Calculate its full load regulation at 0.8 lagging PF condition.

[10]

CO6

L3

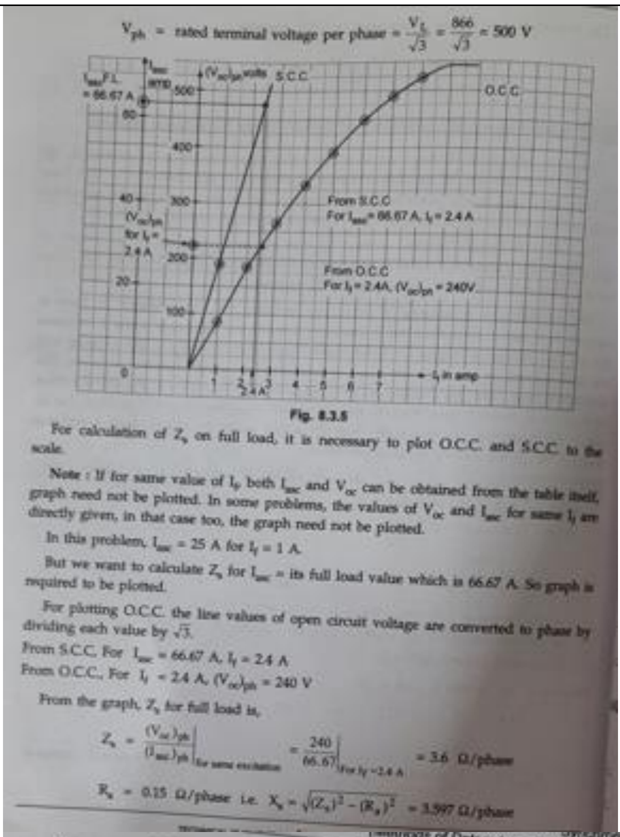
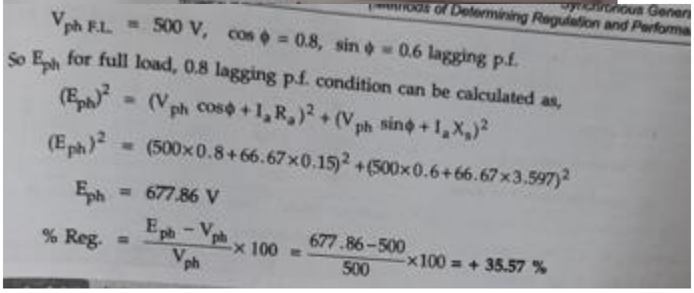


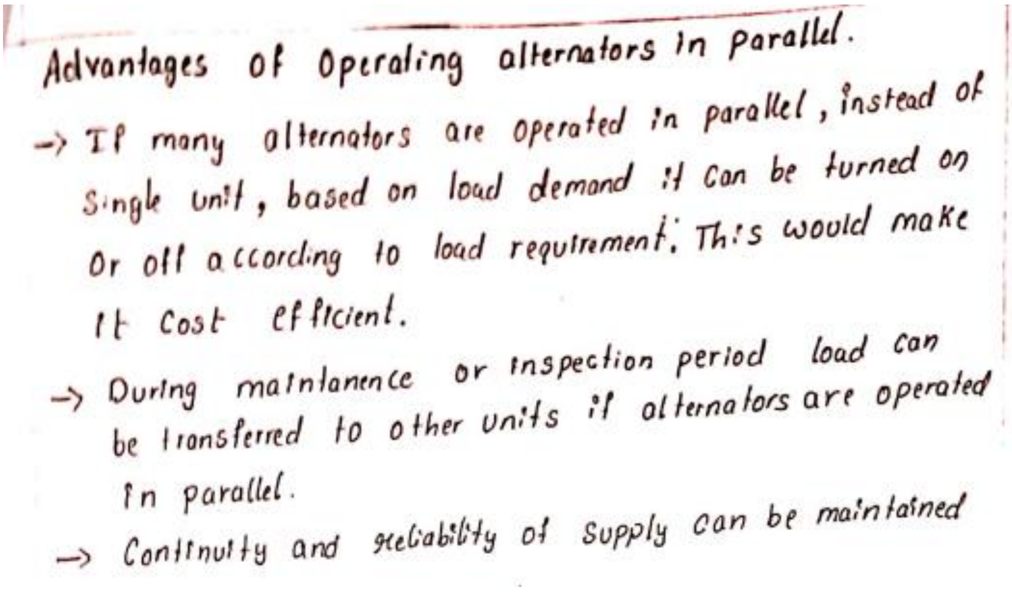
ution : $V_L = 866$ V, kVA = 100

kVA $= \sqrt{3} V_L I_L \times 10^{-3}$ i.e. $100 = \sqrt{3} \times 866 \times I_L \times 10^{-3}$

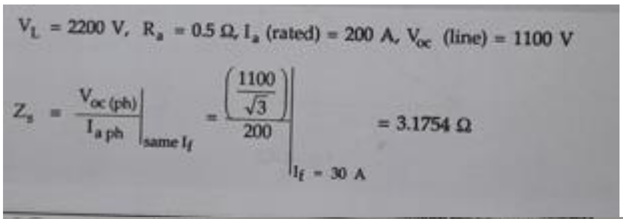
$I_L = 66.67$ A

I_{aph} F.L $= I_L = 66.67$ A ... As star connected alternator

	 V_{ph} = rated terminal voltage per phase = $\frac{V_L}{\sqrt{3}} = \frac{866}{\sqrt{3}} = 500$ V Fig. 8.3.5 For calculation of Z_s on full load, it is necessary to plot O.C.C. and S.C.C. to the scale. **Note :** If for same value of I_f, both I_{asc} and V_{oc} can be obtained from the table itself, graph need not be plotted. In some problems, the values of V_{oc} and I_{asc} for same I_f are directly given, in that case too, the graph need not be plotted. In this problem, I_{asc} = 25 A for I_f = 1 A. But we want to calculate Z_s for I_{asc} = its full load value which is 66.67 A. So graph is required to be plotted. For plotting O.C.C. the line values of open circuit voltage are converted to phase by dividing each value by $\sqrt{3}$. From S.C.C. For I_{asc} = 66.67 A, I_f = 2.4 A From O.C.C., For I_f = 2.4 A, $(V_{oc})_{ph}$ = 240 V From the graph, Z_s for full load is, $Z_s = \left.\frac{(V_{oc})_{ph}}{(I_{asc})_{ph}}\right\|_{\text{for same excitation}} = \left.\frac{240}{66.67}\right\|_{\text{For } I_f = 2.4 \text{ A}} = 3.6\ \Omega/\text{phase}$ $R_a = 0.15\ \Omega/\text{phase}$ i.e. $X_s = \sqrt{(Z_s)^2 - (R_a)^2} = 3.597\ \Omega/\text{phase}$  $V_{ph\ F.L.}$ = 500 V, cos ϕ = 0.8, sin ϕ = 0.6 lagging p.f. So E_{ph} for full load, 0.8 lagging p.f. condition can be calculated as, $(E_{ph})^2 = (V_{ph}\cos\phi + I_a R_a)^2 + (V_{ph}\sin\phi + I_a X_s)^2$ $(E_{ph})^2 = (500\times0.8+66.67\times0.15)^2 + (500\times0.6+66.67\times3.597)^2$ E_{ph} = 677.86 V % Reg. $= \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100 = \frac{677.86-500}{500} \times 100 = +\ 35.57$ %			

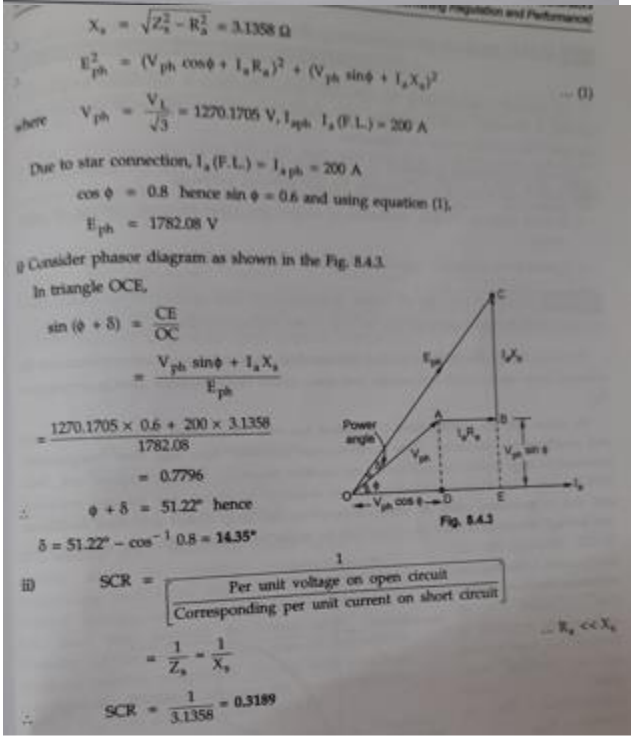
5(a)	**Mention the advantages of operating the alternators in parallel.**  Advantages of Operating alternators in parallel. → If many alternators are operated in parallel, instead of single unit, based on load demand it can be turned on or off according to load requirement. This would make it cost efficient. → During maintanence or inspection period load can be transferred to other units if alternators are operated in parallel. → Continuity and reliability of supply can be maintained	[5]	CO5	L1
5(b)	**A 2200V, 50 Hz, 3 phase, star connected alternator has an effective resistance of 0.5Ω per phase. A field current of 30 A produced the full load current of 200 A on short circuit and a line to line emf of 1100V on open circuit. Determine (i) The power angle of the alternator when it delivers full load at 0.8 pf (lagging). (ii) The SCR of the**	[5]	CO6	L3

alternator.



$V_L = 2200$ V, $R_a = 0.5\ \Omega$, I_a (rated) $= 200$ A, V_{oc} (line) $= 1100$ V

$$Z_s = \left.\frac{V_{oc\,(ph)}}{I_{a\,ph}}\right|_{\text{same } I_f} = \left.\frac{\left(\frac{1100}{\sqrt{3}}\right)}{200}\right|_{I_f = 30\text{ A}} = 3.1754\ \Omega$$



$$X_s = \sqrt{Z_s^2 - R_a^2} = 3.1358\ \Omega$$

$$E_{ph}^2 = (V_{ph}\cos\phi + I_a R_a)^2 + (V_{ph}\sin\phi + I_a X_s)^2 \quad \ldots (1)$$

where $V_{ph} = \frac{V_L}{\sqrt{3}} = 1270.1705$ V, I_{aph} I_a(F.L.) $= 200$ A

Due to star connection, I_a(F.L.) $= I_{a\,ph} = 200$ A

$\cos\phi = 0.8$ hence $\sin\phi = 0.6$ and using equation (1),

$E_{ph} = 1782.08$ V

i) Consider phasor diagram as shown in the Fig. 8.4.3.

In triangle OCE,

$$\sin(\phi + \delta) = \frac{CE}{OC}$$

$$= \frac{V_{ph}\sin\phi + I_a X_s}{E_{ph}}$$

$$= \frac{1270.1705 \times 0.6 + 200 \times 3.1358}{1782.08}$$

$$= 0.7796$$

$\therefore \quad \phi + \delta = 51.22°$ hence

$\delta = 51.22° - \cos^{-1} 0.8 = \mathbf{14.35°}$

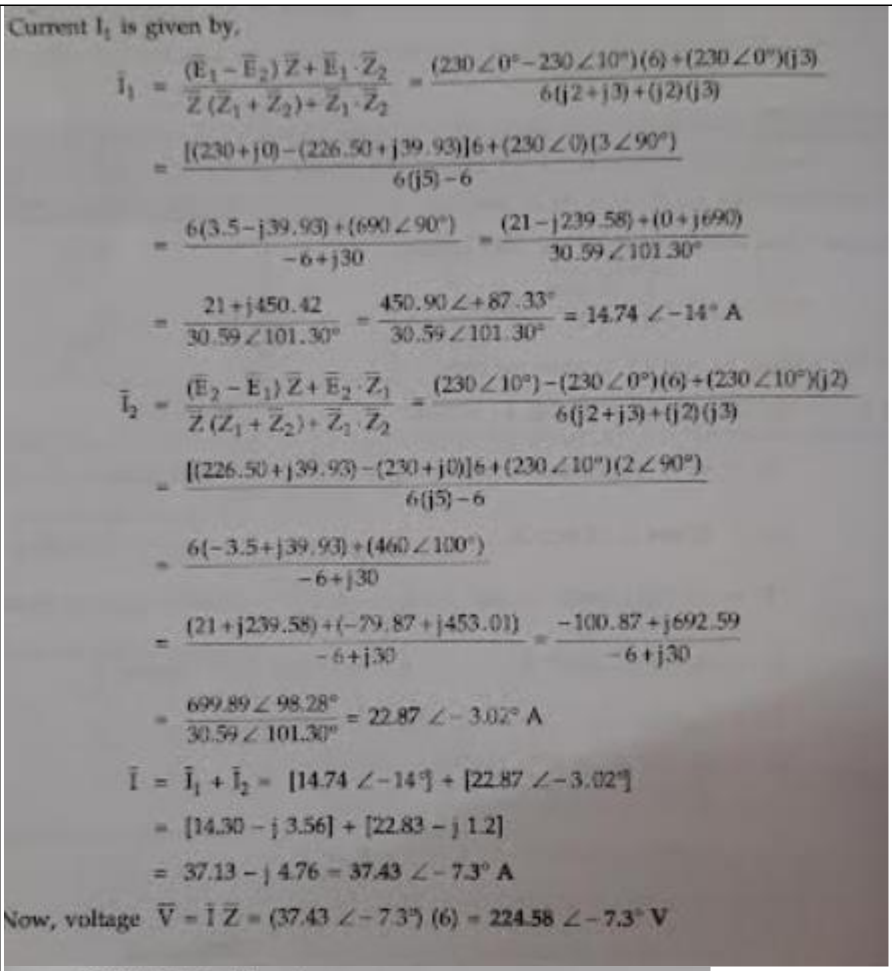
Fig. 8.4.3

ii) $$SCR = \frac{1}{\left[\frac{\text{Per unit voltage on open circuit}}{\text{Corresponding per unit current on short circuit}}\right]}$$

$$= \frac{1}{Z_s} = \frac{1}{X_s} \quad \ldots R_a << X_s$$

$$\therefore \quad SCR = \frac{1}{3.1358} = \mathbf{0.3189}$$

6	**The single phase alternators operating in parallel have induced e.m.fs on open circuit of 230<0º and 230<10º volts and respective reactances of j2 Ω and j3 Ω. Calculate: (i) Terminal voltage; (ii) Current; (iii) Power delivered by each of the alternators to a load of impedance 6Ω (resistive).**	[10]	CO6	L3



Current I_1 is given by,

$$\bar{I}_1 = \frac{(\bar{E}_1 - \bar{E}_2)\bar{Z} + \bar{E}_1 \cdot \bar{Z}_2}{\bar{Z}(\bar{Z}_1 + \bar{Z}_2) + \bar{Z}_1 \cdot \bar{Z}_2} = \frac{(230\angle 0^\circ - 230\angle 10^\circ)(6) + (230\angle 0^\circ)(j3)}{6(j2 + j3) + (j2)(j3)}$$

$$= \frac{[(230 + j0) - (226.50 + j39.93)]6 + (230\angle 0)(3\angle 90^\circ)}{6(j5) - 6}$$

$$= \frac{6(3.5 - j39.93) + (690\angle 90^\circ)}{-6 + j30} = \frac{(21 - j239.58) + (0 + j690)}{30.59\angle 101.30^\circ}$$

$$= \frac{21 + j450.42}{30.59\angle 101.30^\circ} = \frac{450.90\angle +87.33^\circ}{30.59\angle 101.30^\circ} = \mathbf{14.74\angle -14^\circ\ A}$$

$$\bar{I}_2 = \frac{(\bar{E}_2 - \bar{E}_1)\bar{Z} + \bar{E}_2 \cdot \bar{Z}_1}{\bar{Z}(\bar{Z}_1 + \bar{Z}_2) + \bar{Z}_1 \cdot \bar{Z}_2} = \frac{(230\angle 10^\circ) - (230\angle 0^\circ)(6) + (230\angle 10^\circ)(j2)}{6(j2 + j3) + (j2)(j3)}$$

$$= \frac{[(226.50 + j39.93) - (230 + j0)]6 + (230\angle 10^\circ)(2\angle 90^\circ)}{6(j5) - 6}$$

$$= \frac{6(-3.5 + j39.93) + (460\angle 100^\circ)}{-6 + j30}$$

$$= \frac{(21 + j239.58) + (-79.87 + j453.01)}{-6 + j30} = \frac{-100.87 + j692.59}{-6 + j30}$$

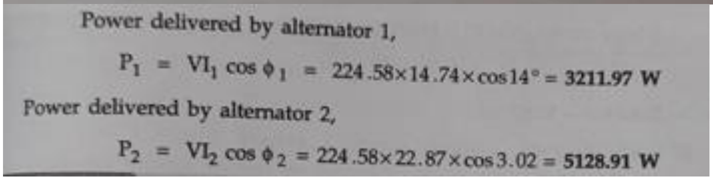
$$= \frac{699.89\angle 98.28^\circ}{30.59\angle 101.30^\circ} = 22.87\angle -3.02^\circ\ A$$

$$\bar{I} = \bar{I}_1 + \bar{I}_2 = [14.74\angle -14^\circ] + [22.87\angle -3.02^\circ]$$

$$= [14.30 - j\,3.56] + [22.83 - j\,1.2]$$

$$= 37.13 - j\,4.76 = \mathbf{37.43\angle -7.3^\circ\ A}$$

Now, voltage $\bar{V} = \bar{I}\,\bar{Z} = (37.43\angle -7.3^\circ)(6) = \mathbf{224.58\angle -7.3^\circ\ V}$



Power delivered by alternator 1,

$$P_1 = VI_1 \cos\phi_1 = 224.58 \times 14.74 \times \cos 14^\circ = \mathbf{3211.97\ W}$$

Power delivered by alternator 2,

$$P_2 = VI_2 \cos\phi_2 = 224.58 \times 22.87 \times \cos 3.02 = \mathbf{5128.91\ W}$$

******** ALL THE BEST ********

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