

CBCS SCHEME

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BEE304

Third Semester B.E./B.Tech. Degree Examination, Dec.2024/Jan.2025 Transformers and Generators

Time: 3 hrs.

Max. Marks: 100

*Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. M : Marks, L: Bloom's level, C: Course outcomes.*

Module – 1			M	L	C
Q.1	a.	With the help of phasor diagram explain the operation of practical transformer on load.	8	L1	CO1
	b.	A 5 KVA, 500/250 V, 50 Hz, 1- ϕ transformer gave the following readings. OC Test : 500 V, 1 A, 50 W (LV side open) SC Test : 25 V, 10 A, 60 W (LV side shorted) Determine: i) The efficiency on full load 0.8 lagging p.f. ii) Voltage regulation on full load 0.8 leading p.f. iii) The efficiency on 60% of full load 0.8 leading p.f.	12	L2	CO1
OR					
Q.2	a.	With a neat circuit diagram, explain in detail Sumpner's test for determining efficiency of transformer. Mention its advantages and disadvantages.	10	L3	CO1
	b.	In a Sumpner's test on two identical 1- ϕ transformers rated 500 KVA, 11/0.4 KV, 50 Hz the wattmeter reading on HV side is 6000 W and on LV side is 15000 W. Find the efficiency of each transformer on half full load of 0.8 p.f.	10	L4	CO1
Module – 2					
Q.3	a.	With the help of a neat circuit diagram and phasor diagram. Explain the operation of a 3- ϕ star-delta transformer.	6	L1	CO2
	b.	Discuss the necessary condition for the parallel operation of 2-transformers.	6	L1	CO2
	c.	The primary and secondary voltages of an auto transformer are 230 V and 75 V respectively. Calculate the currents in different parts of the winding when the load current is 200 A. Also calculate the saving of copper.	8	L3	CO2
OR					
Q.4	a.	What is an auto transformer? Derive an expression for the saving of copper in an auto transformer as compared to an equivalent 2-winding transformer.	6	L3	CO2
	b.	Explain the working of tap changing transformer.	6	L3	CO2
	c.	Two 1- ϕ transformers share a load of 400 KVA at power factor of 0.8 lag. Their equivalent impedances referred to secondary winding are $(1 + j2.5) \Omega$ and $(1.5 + j3) \Omega$ respectively. Calculate the load shared by each transformer.	8	L3	CO2
1 of 2					

Module – 3

Q.5	a.	Derive an equation for the emf induced in an alternator. Also derive expression for pitch factor and distribution factor.	10	L1	CO3
	b.	A 3- ϕ star connected alternator is rated at 1600 KVA, 13500 volts. The armature resistance and synchronous reactance are 1.5Ω and 30Ω respectively per phase. Calculate the percentage regulation for a load of 1280 KW at a p.f 0.8 lag, upf.	10	L2	CO3

OR

Q.6	a.	Name the various methods of determining the voltage regulation for a 3- ϕ alternator and describe any one method in detail.	10	L4	CO3
	b.	A 2300 V, 50 Hz, 3 - ϕ star connected alternator has an effective armature resistance of 0.2Ω . A field current of 35 A produces a current of 150 A on short circuit and open circuit Emf 780 V (line). Calculate the voltage regulation at 0.8 p.f lagging and 0.8 leading for the full load current of 25 A.	10	L4	CO3

Module – 4

Q.7	a.	Explain the synchronizing of 3 - ϕ alternator by lamps dark method and also mention disadvantages.	6	L2	CO3
	b.	Write a short note on power angle characteristics of an alternator.	4	L2	CO3
	c.	The 1 - ϕ alternators operating in parallel have induced emf's on open circuit of $230 \angle 0^\circ$ and $230 \angle 10^\circ$ volts and respective reactances of $j2 \Omega$ and $j3 \Omega$. Calculate: i) Terminal voltage ii) Current iii) Power delivered by each of the alternators to a load of impedance 6Ω (resistive).	10	L3	CO3

OR

Q.8	a.	Explain the concept of two reaction theory in a salient pole synchronous machine.	10	L3	CO3
	b.	Write a short note on capability curves of synchronous generator.	5	L3	CO3
	c.	What is hunting in synchronous machine? Explain the role of damper winding.	5	L3	CO3

Module – 5

Q.9	a.	Write a brief note on the following: i) Wind energy site selection consideration. ii) The nature of wind.	10	L1	CO4
	b.	Discuss the advantages and disadvantages of PV systems.	10	L2	CO4

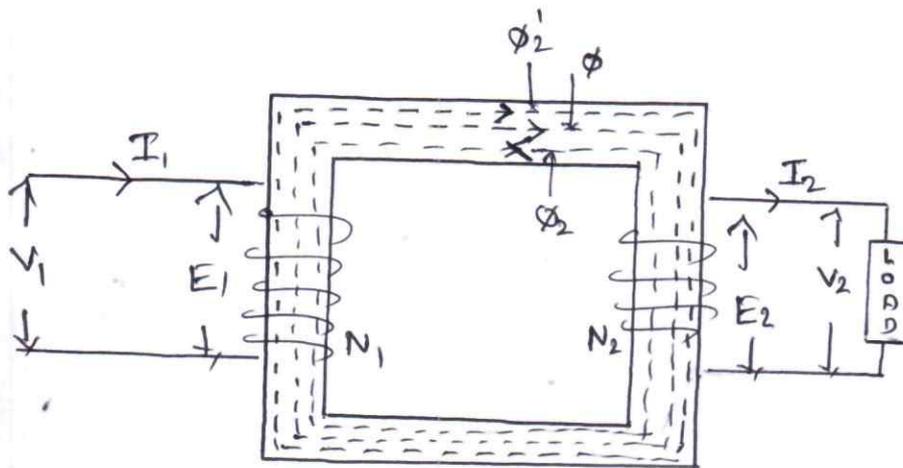
OR

Q.10	a.	With a neat diagram, explain Horizontal and vertical axis wind generators and mention their advantages and disadvantages.	10	L2	CO4
	b.	Write a note on the following: i) Applications of solar cell systems ii) I.V. characteristics of a solar cell.	10	L3	CO4

Module - 1

Q1a) With the help of phasor diagram explain the operation of practical transformer on load 8M

Ans. -



* When load is connected on secondary side, secondary side becomes closed circuit. V_1 is applied on primary side, which circulate I_1 on N_1 , which produces ϕ . This flux ϕ induce the emf on primary side E_1 & secondary side E_2 .

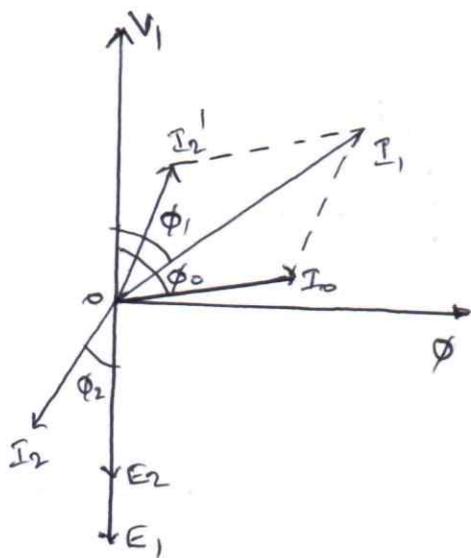
* When load connected on secondary current I_2 flows through N_2 & this $I_2 N_2$ ampere turns produces flux ϕ_2 in core which opposes main flux ϕ . This creates demagnetization, which increases difference between E_1 & V_1 . In order to maintain equal E_1 & V_1 , also to overcome demagnetization effect primary side draws load component of current I_2' , which circulates counter flux for ϕ_2 i.e ϕ_2' which cancels ϕ_2 effect so maintain flux ϕ .

$$N_2 I_2 = N_1 I_2'$$

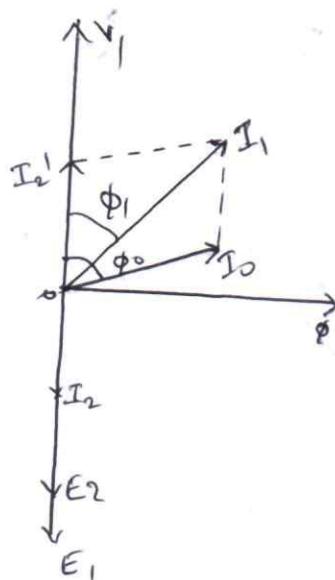
$$I_2' = \frac{N_2}{N_1} I_2 = K I_2$$

Primary current has two parts no load current I_0 & load component of current I_2' .

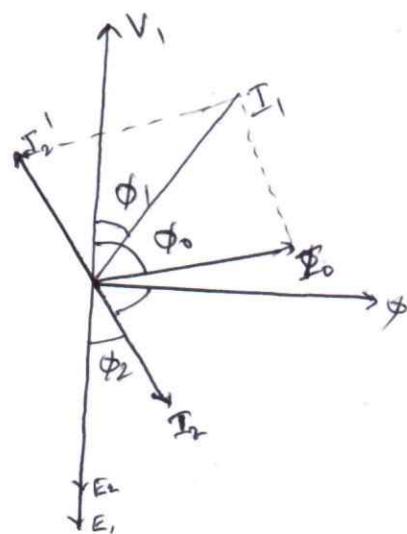
$$\vec{I}_1 = \vec{I}_0 + \vec{I}_2'$$



Inductive load



Resistive load



Capacitive load

1b) A 5kVA, 500/250V, 50Hz, ϕ transformer gave the following readings.

OC Test: 500V, 1A, 50W (LV side open)

SC Test: 25V, 10A, 60W (LV side shorted)

Determine:

- i] The efficiency on full load 0.8 lagging p.f.
- ii] Voltage regulation on full load 0.8 leading p.f.
- iii] The efficiency on 60% of full load 0.8 leading p.f.

Ans:- From OC Test

$$V_o = 500V, \quad I_o = 1A \quad W_o = 50W$$

$$\cos\phi_o = \frac{W_o}{V_o I_o} = \frac{50}{500 \times 1} = 0.1$$

$$I_c = I_o \cos\phi_o = 0.1A$$

$$I_m = I_o \sin\phi_o = 1 \times \sin(\cos^{-1} 0.1) = 0.9949A$$

$$R_o = \frac{V_o}{I_c} = \frac{500}{0.1} = 5k\Omega$$

$$X_o = \frac{V_o}{I_m} = \frac{500}{0.9949} = 502.42\Omega$$

$$W_o = P_i = 50W$$

From SC Test

$$V_{sc} = 25V \quad I_{sc} = 10A \quad W_{sc} = 60W$$

$$R_{ie} = \frac{W_{sc}}{I_{sc}^2} = \frac{60}{10^2} = 0.6\Omega$$

$$Z_{ie} = \frac{V_{sc}}{I_{sc}} = \frac{25}{10} = 2.5\Omega$$

$$X_{ie} = \sqrt{Z_{ie}^2 - R_{ie}^2} = \sqrt{2.5^2 - 0.6^2} = 2.427\Omega$$

$$I_{IFL} = \frac{VA \text{ Rating}}{V_1} = \frac{5k}{500} = 10A$$

$$W_{sc} = (P_{cu})_{FL} = 60W$$

i] η on full load $\cos \phi = 0.8$ lagging

$$\therefore \eta = \frac{\text{VA rating} \times \cos \phi_2}{\text{VA rating} \times \cos \phi_2 + P_i + P_{cu \text{ FL}}} \times 100$$

$$= \frac{5 \times 1000 \times 0.8}{5 \times 1000 \times 0.8 + 50 \times 60} \times 100$$

$$= 97.32 \%$$

ii] Regulation on full load, $\cos \phi = 0.8$ lagging

$$\therefore \text{VR} = \frac{(\mathbf{I}_1)_{\text{FL}} R_{ie} \cos \phi - (\mathbf{I}_1)_{\text{FL}} X_{ie} \sin \phi}{V_1} \times 100$$

$$= \frac{10 \times 0.6 \times 0.8 - 10 \times 2.427 \times 0.6}{500} \times 100$$

$$= -1.95 \%$$

iii] 60% of full load, $\alpha = 0.6$ $\cos \phi_2 = 0.8$ leading

$$\therefore \eta = \frac{\alpha \times \text{VA rating} \times \cos \phi_2}{\alpha \times \text{VA rating} \times \cos \phi_2 + P_i + \alpha^2 P_{cu}} \times 100$$

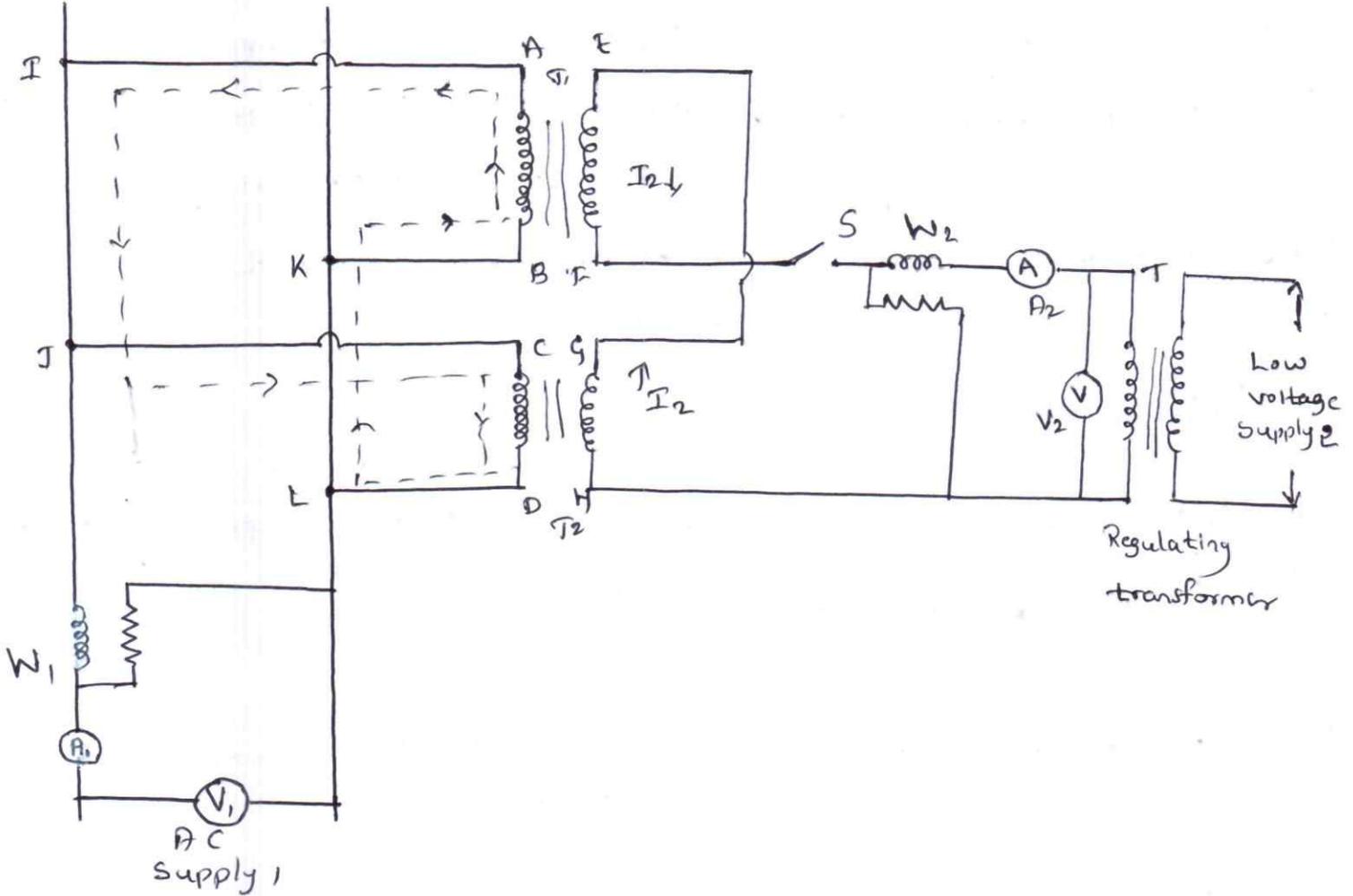
$$= \frac{0.6 \times 5 \times 1000 \times 0.8}{0.6 \times 5 \times 1000 \times 0.8 + 50 + 0.6^2 \times 60} \times 100$$

$$= 97.103 \%$$

Q2 a) With a neat circuit diagram, explain in detail Sumpner's test for determining efficiency of transformer. Mention its advantages & disadvantages.

10M

Ans: -



The Sumpner's test requires two identical transformers. Both the transformers are connected to the supply such that one transformer is loaded on the other. Thus power taken from the supply is that much necessary for supplying the losses of both the transformers & there is very small loss in the control circuit.

While conducting this test, the primaries of the two identical transformers are connected in parallel across the supply V_1 . While the secondaries are connected in series opposition so that induced emf in the two secondaries are connected in series opposition so that induced emfs in the two secondaries oppose each other.

The secondaries are supplied from another low voltage supply and are connected in each circuit to get the readings. The secondaries of T_1 & T_2 are connected in series opposition. Emf induced is equal but the secondaries are connected such that E is connected to G & F is connected to H. Due to such series opposition, two emfs act in opposite direction to each other & cancel each other. Net voltage in the local circuit of secondaries is zero, when primaries are excited by V_1 & frequency.

The input power as measured by wattmeter W_1 , thus ~~reads~~ reads the iron losses of both the transformers.

$$P_i \text{ per transformer} = \frac{W_1}{2}$$

The W_2 reads the total full load copper losses of transformer

$$(P_{cu})_{FL} \text{ per transformer} = \frac{W_2}{2}$$

$$\therefore (\eta)_{FL} \text{ of each transformer} = \frac{\text{Output}}{\text{Output} + \frac{W_i}{2} + \frac{W_{cu}}{2}} \times 100$$

Merits

- * The transformers are tested at full load conditions.
- * Heat run test can be conducted on the two transformers.
- * Equivalent circuit parameters can be obtained.
- * The power required to carry out the test is small.

Demerits

- * Two exactly identical transformers are necessary, which is difficult.
- * Due to requirement of two transformers, the initial cost is high hence not economical.

Q 2 b) In a Sumpners test on two identical 1 ϕ transformers rated 500 kVA, 11/0.4 kV, 50 Hz the wattmeter reading on HV side is 6000 W & on LV side is 15000 W. Find the efficiency of each transformer on half full load of 0.8 p.f. 10M

Ans) - kVA Rating = 500 $W_1 = 6 \text{ kW}$ $W_2 = 15 \text{ kW}$

$$P_i = \frac{W_1}{2} = \frac{6}{2} = 3 \text{ kW for individual transformers}$$

$$(P_{cu})_{FL} = \frac{W_2}{2} = \frac{15}{2} = 7.5 \text{ kW for individual transformers}$$

At half load $\cos \phi_2 = 0.8$ $\alpha = 0.5$

$$\therefore \eta = \frac{\alpha \times \text{kVA rating} \times \cos \phi_2}{\alpha \times \text{kVA rating} \times \cos \phi_2 + P_i + \alpha^2 P_{cu FL}} \times 100$$

$$= \frac{0.5 \times 500 \times 1000 \times 0.8}{0.5 \times 500 \times 1000 \times 0.8 + 3 \text{ k} + 0.5^2 \times 7.5 \text{ k}} \times 100$$

$$= 97.62\%$$

ii] Load current at maximum efficiency is given by

$$I_{2m} = (I_2)_{FL} \sqrt{\frac{P_i}{P_{cu FL}}}$$

$$\therefore \text{kVA at } \eta_{\max} = I_{2m} V_2 = V_2 I_{2FL} \sqrt{\frac{P_i}{P_{cu FL}}}$$

$$= 500 \times \sqrt{\frac{3}{7.5}}$$

$$= 316.55 \text{ kVA}$$

At maximum efficiency, η_{max} , $P_{cu} = P_i$ & assuming c.p.f.

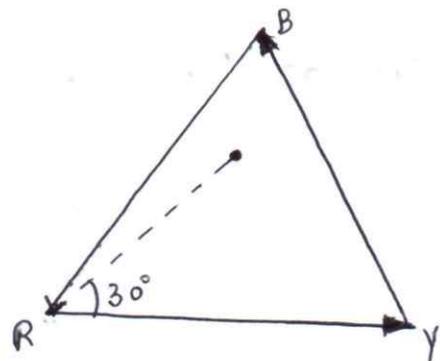
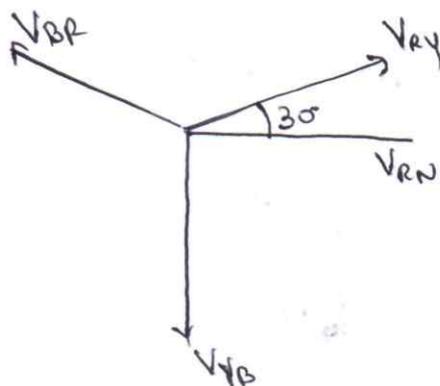
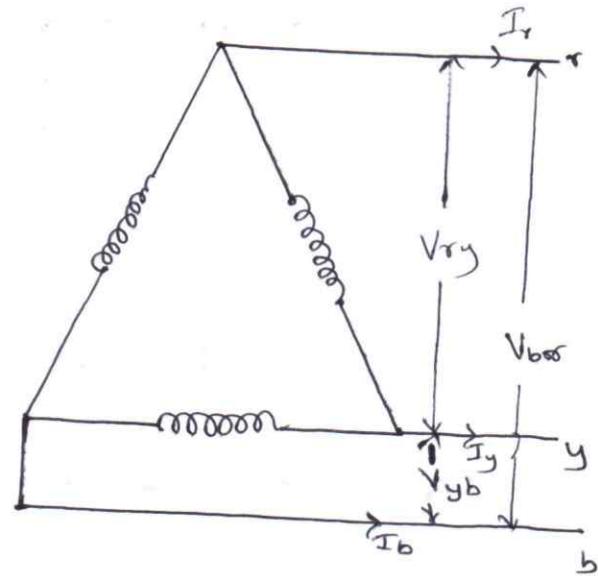
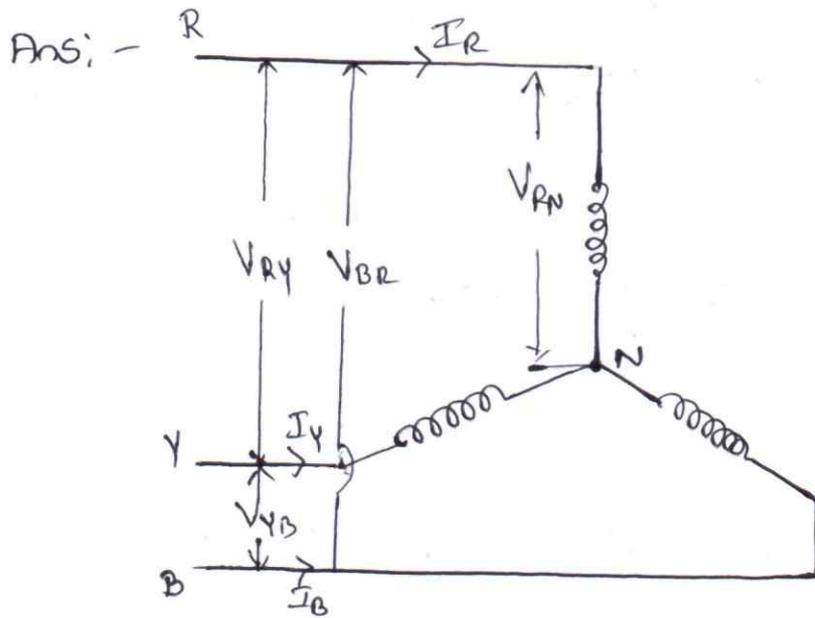
$$\therefore \eta_{max} = \frac{\text{kVA for } \eta_{max} \cos \phi}{\text{kVA for } \eta_{max} \cos \phi + 2P_i}$$

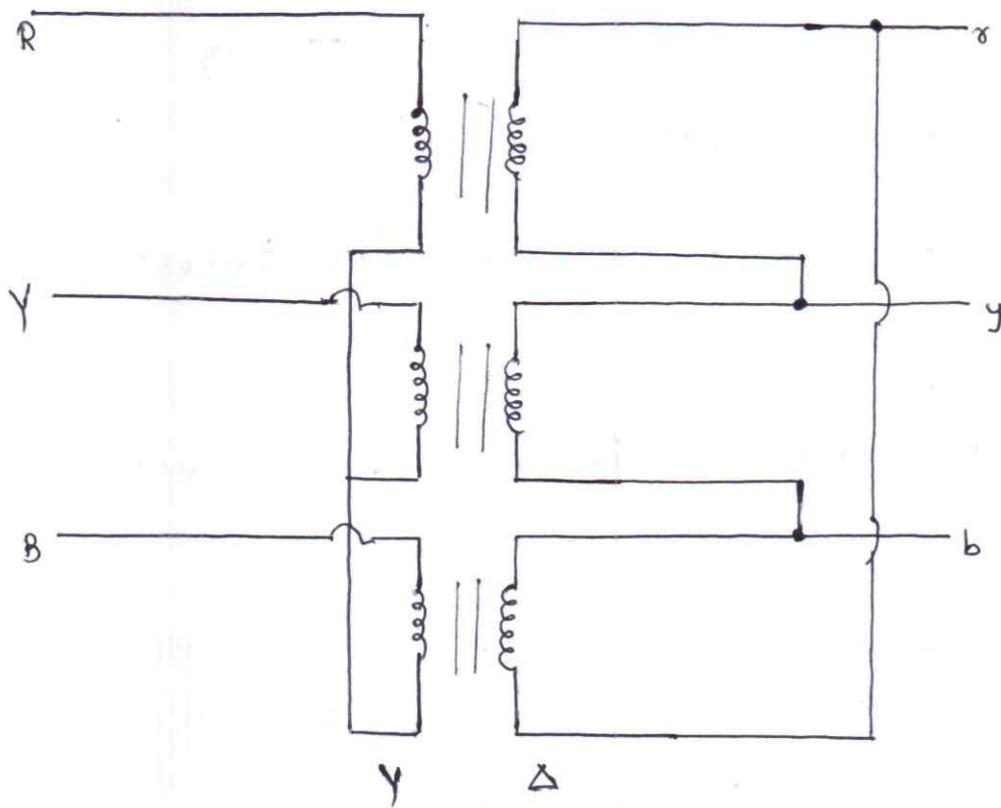
$$= \frac{316.22 \times 1}{316.22 \times 1 + (2 \times 3)} \times 100$$

$$= 98.14\%$$

Module - 2

Q3a) With the help of a neat circuit diagram & phasor diagram explain the operation of a 3 ϕ star-delta transformer. 6M





Normally Y- Δ connection is commonly employed at the substation end of the transmission line. Neutral on primary is grounded. It can be seen that there is phase difference of 30° between primary & secondary line voltages.

$$V_{ph1} = \frac{V_{L1}}{\sqrt{3}}$$

$$\frac{V_{ph2}}{V_{ph1}} = K$$

$$V_{ph2} = K V_{ph1} = K \frac{V_{L1}}{\sqrt{3}}$$

$$V_{ph2} = V_{L2}$$

$$V_{L2} = \frac{K}{\sqrt{3}} V_{L1}$$

Merits

- * The primary side is star connected. Hence fewer number of turns are required. This makes the connection economical for large high voltage step down power transformers.
- * The distortion is avoided by earthing neutral.

Demerit

- * Secondary voltage is not in phase with the primary.

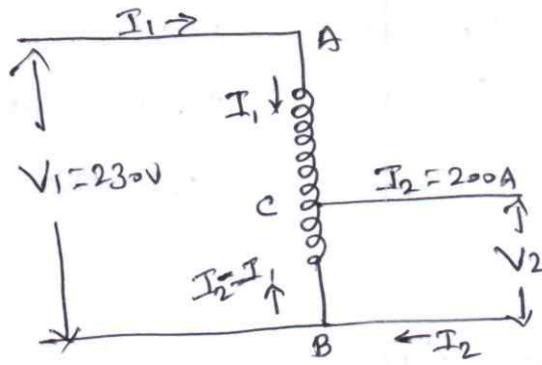
Q3 b) Discuss the necessary condition for the parallel operation of two transformers. 6M

Ans:- Necessary condition for the parallel operation of two transformers.

- 1] The supply system voltage & frequency must suit the primary windings of the transformers.
- 2] The transformers that are connected must have same polarity. In case of 3ϕ transformers, they should have same angular displacement & same phase sequence.
- 3] The voltage ratios of primaries & secondaries of the transformers must be same.
- 4] The percentage impedance should be equal in magnitude & have same X/R ratio in order to avoid circulating currents & operating at different power factors.
- 5] If the transformers have the different kVA ratings, the equivalent impedances should be inversely proportional to individual kVA rating to avoid circulating current.

Q3 c) The primary & secondary voltages of an auto transformer are 230V & 75V respectively. Calculate the currents in different parts of the winding when the load current is 200A. Also calculate the saving of copper. 8M

Ans:-



$$K = \frac{V_2}{V_1} = \frac{75}{230} = 0.326$$

$$\frac{I_1}{I_2} = K$$

$$I_1 = K I_2 = 0.326 \times 200 = 65.217A$$

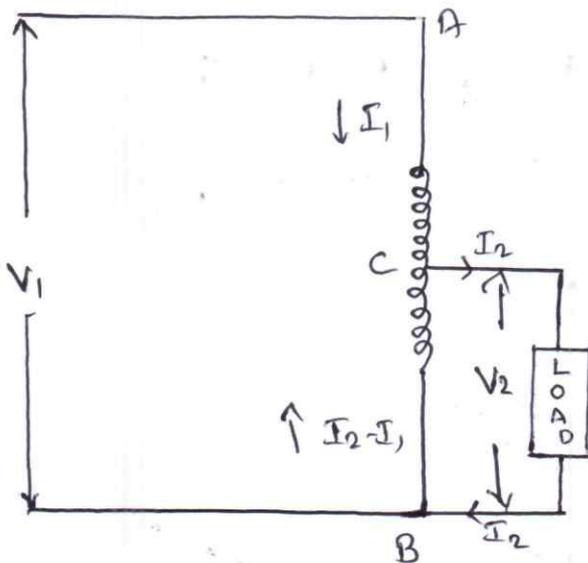
$$I_2 - I_1 = 134.783A$$

$$\text{Copper saving} = K W_{TW} = 0.326 W_{TW}$$

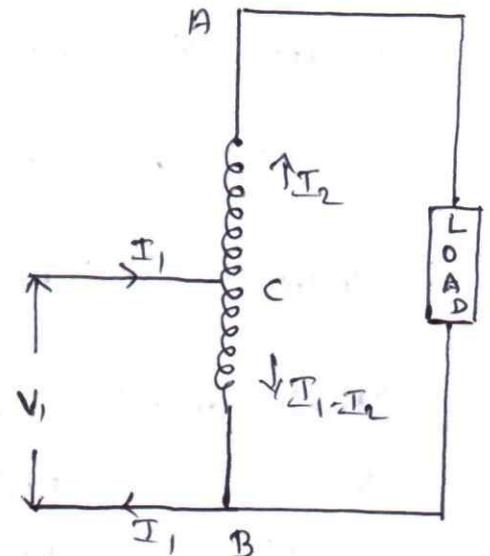
$$\therefore \text{Copper saving} = 32.6\%$$

4a) What is an auto transformer? Derive an expression for the saving of copper in an auto transformer as compared to an equivalent 2-winding transformer. 6M

Ans:-



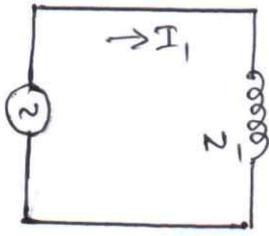
step down



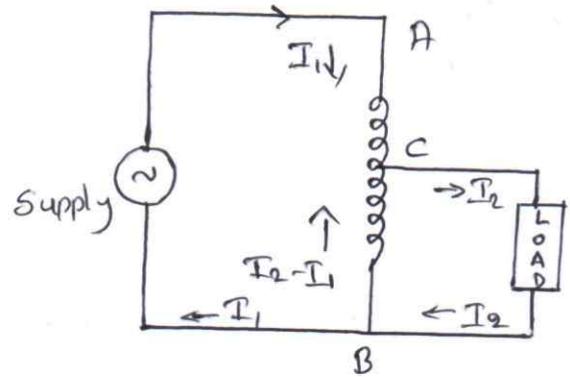
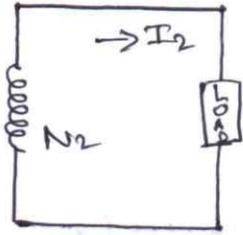
step up

A special type of transformer having only one winding such that part of the winding is common to the primary & secondary is called autotransformer. Power is transferred through conductive & inductive.

Copper Saving in Autotransformer



Two winding transformer



step down autotransformer

W_{TW} = Total weight of copper in two winding transformer

W_{AT} = weight of copper in autotransformer

weight of copper of primary $\propto N_1 I_1$

weight of copper of secondary $\propto N_2 I_2$

$$W_{TW} \propto N_1 I_1 + N_2 I_2$$

In case of step down autotransformer

weight of copper of section AC $\propto (N_1 - N_2) I_1$

weight of copper of section BC $\propto (I_2 - I_1) N_2$

$$W_{AT} \propto (N_1 - N_2) I_1 + N_2 (I_2 - I_1)$$

Taking ratio of the two weights

$$\frac{W_{TW}}{W_{AT}} = \frac{N_1 I_1 + N_2 I_2}{(N_1 - N_2) I_1 + N_2 (I_2 - I_1)}$$

$$\frac{W_{TW}}{W_{AT}} = \frac{N_1 I_1 + N_2 I_2}{N_1 I_1 + N_2 I_2 - 2 N_2 I_1}$$

$$K = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$

$$\frac{W_{TW}}{W_{AT}} = \frac{N_1 I_1 + K N_1 (I_1/K)}{N_1 I_1 + K N_1 (I_1/K) - 2 (K N_1) I_1}$$

$$\frac{W_{TW}}{W_{AT}} = \frac{1}{1-K}$$

$$W_{AT} = (1-K) W_{TW}$$

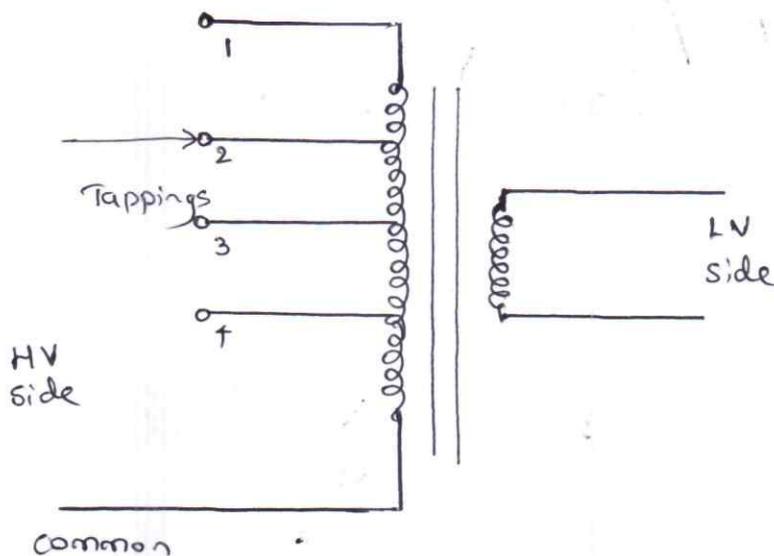
$$\text{Saving of copper} = W_{TW} - W_{AT} = W_{TW} - (1-K) W_{TW}$$

$$\text{Saving of copper} = K W_{TW} \quad \text{step down}$$

$$\text{Saving of copper} = \frac{1}{K} W_{TW} \quad \text{step up}$$

Q 4b) Explain the working of tap changing transformer. 6M

Ans: - The voltage supplied by transformers can be varied by changing its transformation ratio. This can be achieved by tappings which are provided on transformers. The tappings are the leads which are connected to various points on a transformer winding.



The tapings are placed either on high voltage or low voltages or sometimes on both high & low voltage windings. The tapping are brought out at a terminal connection box located on the transformer. The line lead connection made to the desired tap. When it is desired to change the voltage as per the requirement the reconnection of line leads to other tap is to be done which is the most inexpensive method which is applicable where line voltage is stable & the change in the tapings are not required to be done periodically.

The principle winding in case of a distribution transformer with voltage rating 11kV/400V is a tapping on high voltage winding which when connected to rated voltage of 11kV gives rated voltage of 400V on low voltage side. Depending on constructional availability, the location of tapings are made. They can be provided either at phase end, at the neutral point or in the middle of the winding.

Q4C) Two ϕ transformers share a load of 400kVA at power factor of 0.8 lag. Their equivalent impedances referred to secondary winding are $(1+j2.5)\Omega$ & $(1.5+j3)\Omega$ respectively. Calculate the load shared by each transformer.

Ans: $Z_A = (1+j2.5)\Omega$ $Z_B = (1.5+j3)\Omega$

$S = 400\text{kVA}$ $\cos\phi = 0.8$

$Q = 400 \angle -36.86^\circ \text{ kVA}$

$Z_A + Z_B = (2.5 + j5.5) = 6.0415 \angle 65.55^\circ \Omega$

$$Q_A = Q \left(\frac{Z_B}{Z_A + Z_B} \right) = \frac{400 \angle -36.86^\circ \times 3.354 \angle 63.434^\circ}{6.0415 \angle 65.55^\circ}$$

$$= 222.064 \angle -38.97^\circ \text{ kVA}$$

$$Q_B = Q \left(\frac{Z_A}{Z_A + Z_B} \right) = \frac{400 \angle -36.86^\circ \times 2.692 \angle 68.198^\circ}{6.0415 \angle 65.55^\circ}$$

$$= 178.233 \angle -34.212^\circ \text{ kVA}$$

Load shared by transformer 1 = 222.064 kVA at 0.77 lag

Load shared by transformer 2 = 178.233 kVA at 0.827 lag

Module 3

Q5a) Derive an equation for the emf induced in an alternator. Also derive expression for pitch factor & distribution factor. 10M

Ans:- ϕ = Flux per pole in Wb

N_s = Synchronous speed in rpm

f = Supply frequency in Hz

Z = Total stator conductor

P = Number of poles.

The average

Total flux cut in one revolution = $P\phi = d\phi$

Time taken for one revolution = $\frac{60}{N_s} = dt$

The average emf induced in one conductor = $\frac{d\phi}{dt} = \frac{P\phi N_s}{60}$ volts

where $f = \frac{PN_s}{120}$

$E_{avg} = \frac{1}{\phi} \times \frac{120}{f} \times \frac{p}{2} \times 2$

$E_{avg} = \phi f Z$

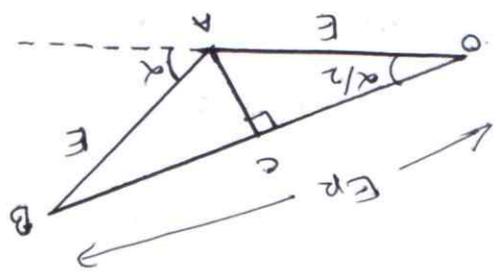
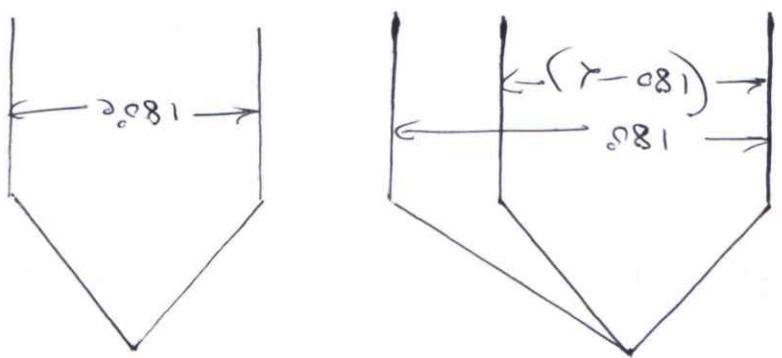
rms value of emf induced $E_{ph} = \frac{1}{\sqrt{2}} E_{avg}$

$E_{ph} = \frac{1}{\sqrt{2}} \phi f Z$

$E_{ph} = 4.44 \phi f T_{ph}$

$T_{ph} = \frac{2}{p}$

Pitch factor



$E_R = E + E = 2E$

AC is the drawn on OB bisecting OB

$\angle COB = \angle CAB = \frac{\alpha}{2}$

$\angle BOA = \alpha$

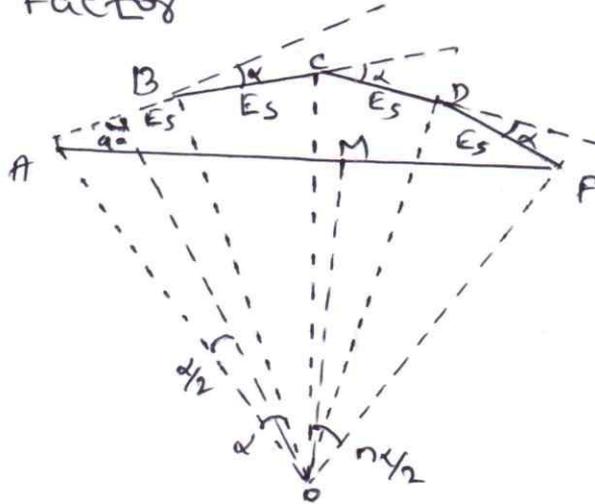
$\cos \frac{\alpha}{2} = \frac{OC}{OA} = \frac{2E}{E_R}$

$E_R = 2E \cos(\frac{\alpha}{2})$

$$K_c = \frac{E_r \text{ when coil is short pitched}}{E_r \text{ when coil is full pitched}} = \frac{2 E \cos(\alpha/2)}{2 E}$$

$$K_c = \cos(\alpha/2)$$

Distribution Factor



Let e_1 be the middle point of AB

$$\sin \frac{\alpha}{2} = \frac{AQ}{OA} = \frac{AQ}{r} \quad \therefore AQ = r \sin \frac{\alpha}{2}$$

$$E_s = AB = 2AQ = 2r \sin \frac{\alpha}{2}$$

OM is drawn perpendicular to AF

$$\sin \frac{n\alpha}{2} = \frac{MF}{OF} = \frac{MF}{r} \quad MF = r \sin \frac{n\alpha}{2}$$

The vector sum of all the emfs induced is equal to AF

$$AF = 2MF = 2r \sin \frac{n\alpha}{2}$$

Distribution factor (K_d)

$$K_d = \frac{AF}{nE_s} = \frac{2r \sin \frac{n\alpha}{2}}{n \left(2r \sin \frac{\alpha}{2} \right)} = \frac{\sin \frac{n\alpha}{2}}{n \sin \frac{\alpha}{2}}$$

n = no. of slots/pole/phase

α = slot angle = $\frac{180}{n}$

Q5b) A 3 ϕ star connected alternator is rated at 1600kVA, 13500 V. The armature resistance & synchronous reactance are 1.5 Ω & 30 Ω respectively per phase. Calculate the percentage regulation for a load of 1280kW at a p.f. 0.8 lag, upf.

Ans:- $V_L = 13.5 \text{ kV}$ $R_a = 1.5 \Omega$ $X_s = 30 \Omega$

$$V_{ph} = \frac{13.5 \text{ k}}{\sqrt{3}} = 7794.22 \text{ V}$$

when $\cos \phi = 0.8$ lag, $\sin \phi = 0.6$

$$I_L = \frac{P_{out}}{\sqrt{3} V_L \cos \phi} = \frac{1280 \text{ k}}{\sqrt{3} \times 13.5 \text{ k} \times 0.8} = 68.42 \text{ A}$$

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

$$= \sqrt{(7.79 \text{ k} \times 0.8 + 68.42 \times 1.5)^2 + (7.79 \text{ k} \times 0.6 + 68.42 \times 30)^2}$$

$$E_{ph} = 9244.17 \text{ V}$$

$$\therefore \text{Regulation} = \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100 = \frac{9244.17 - 7794.2}{7794.2} \times 100$$

$$= 18.6\%$$

when $\cos \phi = 1$

$$I_L = \frac{P_{out}}{\sqrt{3} V_L \cos \phi} = \frac{1280 \text{ k}}{\sqrt{3} \times 13.5 \text{ k} \times 1} = 54.74 \text{ A}$$

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

$$E_{ph} = \sqrt{(7794.2 + 54.74 \times 1.5)^2 + (54.74 \times 30)^2}$$

$$E_{ph} = 8045.72 \text{ V}$$

$$\begin{aligned} \therefore \text{Regulation} &= \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100 \\ &= \frac{8045.72 - 7794.2}{7794.2} \times 100 \\ &= 3.22 \% \end{aligned}$$

Q6a) Name the various methods of determining the voltage regulation for a 3 ϕ alternator & describe any one method in detail
10M

Ans. - To find the regulation of alternator three methods are used.

1] EMF Method / Synchronous Impedance Method

2] Ampere turn method

3] ZPF method

EMF Method

To find the regulation of alternator using EMF method, these are the following data's essential.

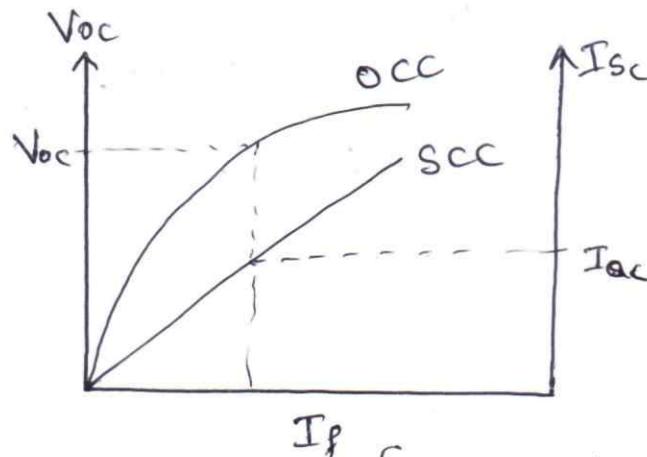
* The armature resistance per phase (R_a)

* OCC graph

* SCC graph

* OCC test is performed by keeping stator open circuit. Slowly voltage is build till it generates rated voltage. In each step open circuit voltage (V_{oc}) and field current (I_f) is noted down. V_{oc} v/s I_f OCC graph is plotted.

* Stator winding is shorted & rated current circulated (I_{sc}) & short circuit voltage (V_{sc}) noted down. I_{sc} v/s I_f is plotted in SCC.



$$\text{Synchronous impedance } (Z_s) = \frac{(V_{oc})_{ph}}{(I_{ac})_{ph}} \quad \text{for same } I_f$$

$$Z_s = \sqrt{R_a^2 + X_s^2} \quad \Omega/ph$$

$$X_s = \sqrt{Z_s^2 - R_a^2} \quad \Omega/ph$$

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

$$\therefore \text{Voltage regulation} = \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100$$

Q6b) A 2300V, 50Hz, 3 ϕ star connected alternator has an effective armature resistance of 0.2 Ω . A field current of 35A produces a current of 150A on short circuit & open circuit Emf 780V (line). Calculate the voltage regulation at 0.8 p.f. lagging & 0.8 leading for the full load current of 25A.

10M

Ans: $V_L = 2300V$ $f = 50Hz$ $R_a = 0.2\Omega$ $I_{sc} = 150A$ $V_{oc(line)} = 780V$

$$Z_s = \frac{V_{oc(ph)}}{I_{sc(ph)}} \quad \left\{ \text{for same } I_f \right.$$

$$Z_s = \frac{(780/\sqrt{3})}{150} \quad \left| \quad I_f = 35A \right.$$

$$Z_s = 3\Omega$$

$$X_s = \sqrt{Z_s^2 - R_a^2} = \sqrt{3^2 - 0.2^2} = 2.99\Omega$$

$$I_{aph} = I_{afl} = 25A, \quad V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{2300}{\sqrt{3}} = 1327.9V$$

i] $\cos\phi = 0.8 \text{ lag}$ $\sin\phi = 0.6$

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

$$= \sqrt{\left(\frac{2300}{\sqrt{3}} \times 0.8 + 25 \times 0.2\right)^2 + \left(\frac{2300}{\sqrt{3}} \times 0.6 + 25 \times 2.99\right)^2}$$

$$= 1378.013V$$

$$\begin{aligned} \therefore \text{Voltage regulation} &= \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100 \\ &= \frac{1378.013 - 1327.905}{1327.905} \times 100 \\ &= 3.773\% \end{aligned}$$

ii] $\cos\phi = 0.8$ leading $\sin\phi = 0.6$

$$E_{ph} = \sqrt{(V_{ph} \cos\phi + I_{aph} R_a)^2 + (V_{ph} \sin\phi - I_{aph} X_s)^2}$$

$$E_{ph} = \sqrt{\left(\frac{2300}{\sqrt{3}} \times 0.8 + 25 \times 0.2\right)^2 + \left(\frac{2300}{\sqrt{3}} \times 0.6 - 25 \times 2.99\right)^2}$$

$$E_{ph} = 1289.076 \text{ V}$$

∴ voltage regulation = $\frac{E_{ph} - V_{ph}}{V_{ph}} \times 100$

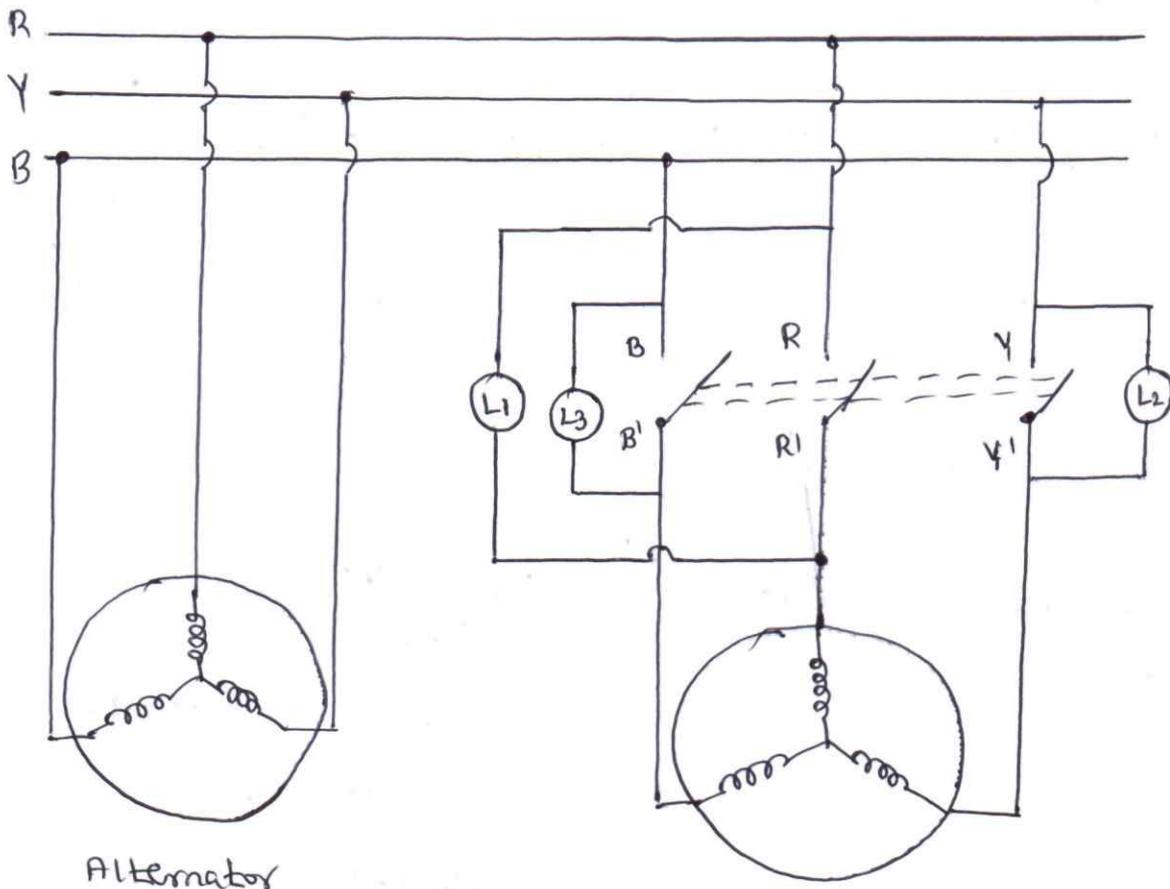
$$= \frac{1289.076 - 1327.905}{1327.905} \times 100$$

$$= -2.924 \%$$

Module 4

Q7a) Explain the synchronizing of 3 ϕ alternator by lamps dark method and also mention disadvantages. GM

Ans: -



- * Alternator which is to be synchronize with bus bar is called as incoming alternator. The bus bar sequence is RYB, Incoming alternator sequence is R'Y'B'.
- * Through TPST incoming alternator is connected to bus bar. L₁, L₂, L₃ connected across TPST. TPST is turned on when condition required for synchronization is met.
- * When frequency is mismatched all three lamps flickers simultaneously. By adjusting speed frequency can be matched.
- * If the flickering of lamps is not simultaneous, flickers one after the another it indicates sequence. By interchanging phases we can match sequence.
- * By varying field excitation each phase voltage can be matched, once all these 3 conditions are met 3 lamps become complete dark. Hence bus bar & incoming alternator synchronized.

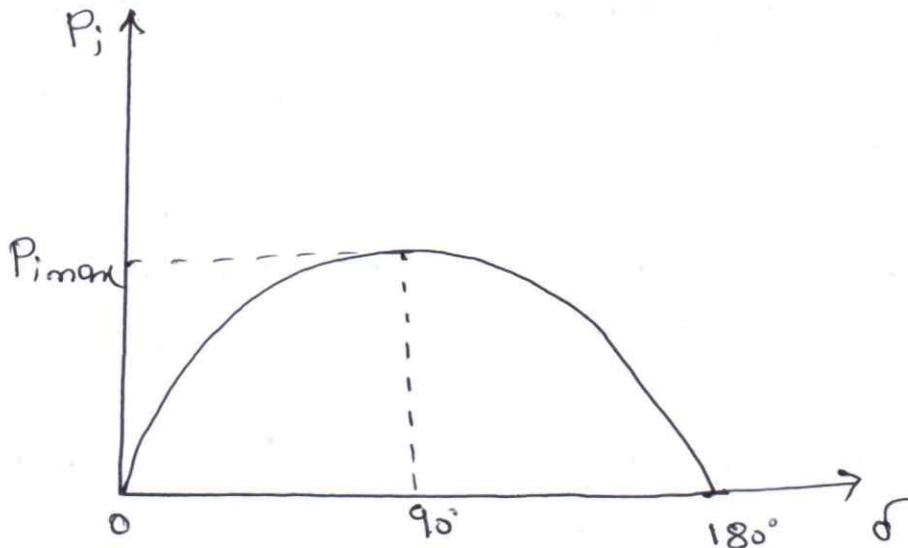
Disadvantages

- * This method do not give idea about how much the machine is slow or fast.
- * Due to large voltage lamp may burn, extra step down transformer is required.
- * When there is a large difference between the two voltages, the lamps become dark as voltage across them is about half of their rated voltage. Hence faulty synchronization may be done in the dark period which may damage the machine.

Q7b) Write a short note on power angle characteristics of an alternator

4M

Ans: -



$$P_i = \frac{EV \sin \delta}{X_s}$$

The maximum power occurs at $\delta = 90^\circ$. Beyond this point machine loses synchronism step by step.

$$\triangle CBD, \angle CBD = \phi$$

$$\angle DEF = \phi$$

$$EF = I_a X_s \cos \phi$$

$$DF = I_a X_s \sin \phi = Cq$$

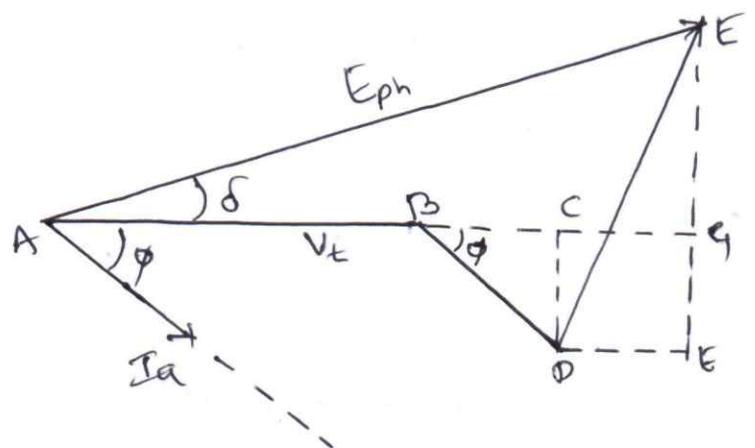
$$BC = I_a R_a \cos \phi$$

$$CD = qf = I_a R_a \sin \phi$$

$$\triangle AqE$$

$$\tan \delta = \frac{Eq}{Aq}$$

$$\tan \delta = \frac{I_a [X_s \cos \phi - R_a \sin \phi]}{V_t + I_a [X_s \sin \phi + R_a \cos \phi]}$$



Q7c) The 1 ϕ alternator operating in parallel have induced emfs on open circuit of $230 \angle 0^\circ$ & $230 \angle 10^\circ$ volts & respective reactances of $j2 \Omega$ & $j3 \Omega$. calculate

i] Terminal voltage ii] Current

iii] Power delivered by each of the alternators to a load of impedance 6Ω (resistive). 10M

Ans: - $\vec{Z}_1 = j2 \Omega$ $\vec{Z}_2 = j3 \Omega$, $\vec{E}_1 = 230 \angle 0^\circ \text{ V}$, $\vec{E}_2 = 230 \angle 10^\circ \text{ V}$

Load impedance $\vec{Z} = 6 \Omega$

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

$$= \frac{6(3.5 - j39.93) + (690 \angle 90^\circ)}{-6 + j30}$$

$$= \frac{(21 - j239.58) + (0 + j690)}{30.59 \angle 101.30^\circ}$$

$$\vec{I}_1 = \frac{450.90 \angle 87.33^\circ}{30.59 \angle 101.30^\circ} = 14.74 \angle -14^\circ \text{ A}$$

$$\vec{I}_2 = \frac{(\vec{E}_2 - \vec{E}_1) \vec{Z} + \vec{E}_2 \vec{Z}_1}{\vec{Z}(\vec{Z}_1 + \vec{Z}_2) + \vec{Z}_1 \vec{Z}_2}$$

$$= \frac{(230 \angle 10^\circ - 230 \angle 0^\circ)(6) + (230 \angle 10^\circ)(j2)}{6(j2 + j3) + (j2)(j3)}$$

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

$$\vec{I}_2 = \frac{-100.87 + j692.59}{-6 + j30}$$

$$\vec{I}_2 = \frac{699.89 \angle 98.28^\circ}{30.59 \angle 101.30^\circ} = 22.87 \angle -3.02^\circ \text{ A}$$

$$\vec{I} = \vec{I}_1 + \vec{I}_2$$

$$= (14.30 - j3.56) + (22.83 - j1.2)$$

$$= 37.13 - j4.76$$

$$= 37.43 \angle -7.3^\circ \text{ A}$$

$$\vec{V} = \vec{I} \vec{Z} = (37.43 \angle -7.3^\circ)(6) = 224.58 \angle -7.3^\circ \text{ V}$$

Power delivered by alternator 1

$$P_1 = VI_1 \cos \phi_1 = 224.58 \times 14.74 \times \cos 14^\circ = 3.21 \text{ kW}$$

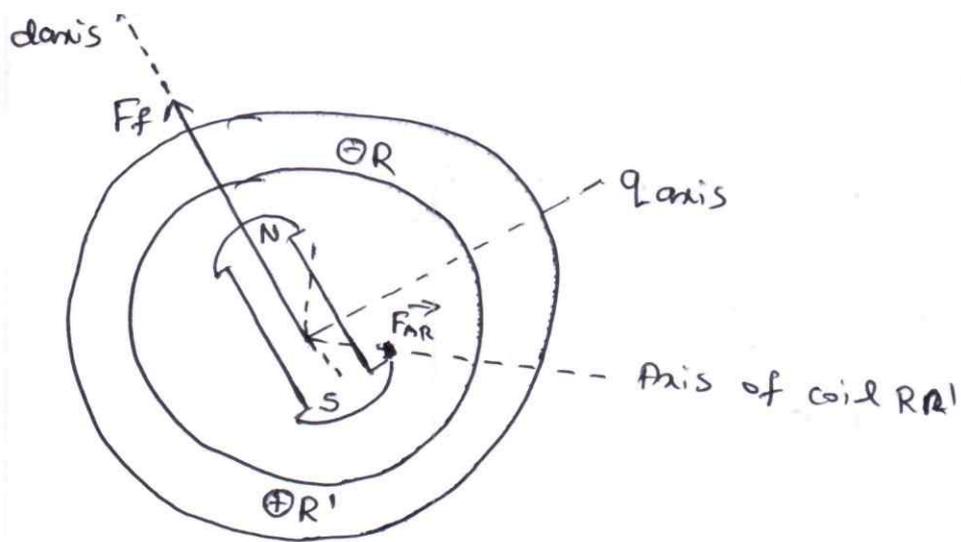
Power delivered by alternator 2.

$$P_2 = VI_2 \cos \phi_2 = 224.58 \times 22.87 \times \cos 3.02^\circ = 5.72 \text{ kW}$$

Module

Q8a) Explain the concept of two reaction theory in a salient pole synchronous machine. 10M

Ans: - In salient pole machine the problem associated with variable reluctance due to variable air gap can be resolved using two-reaction theory.

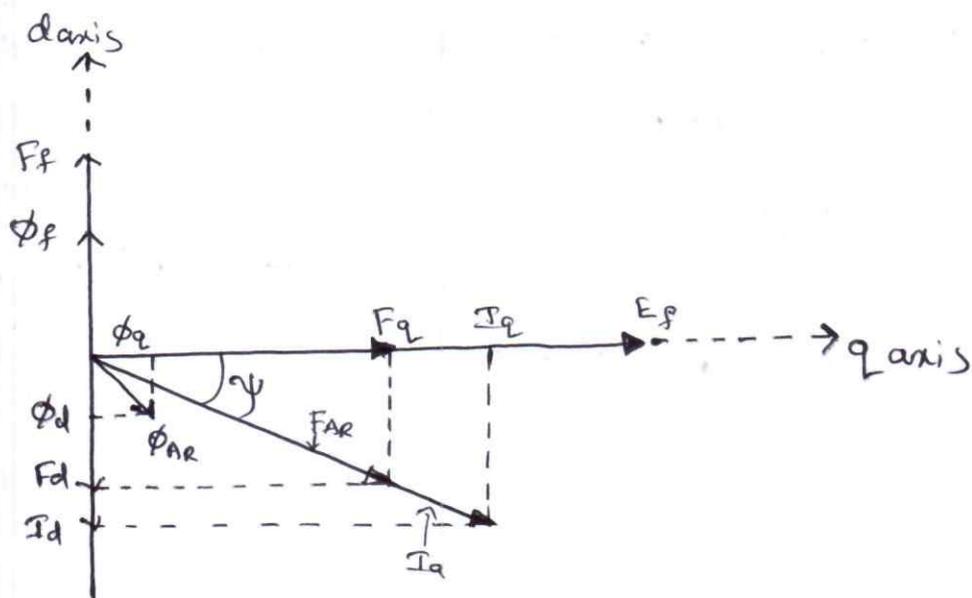


F_d = component along d axis

F_q = component along q axis

I_d = component along d axis

I_q = component along q axis



$$\phi_d = F_d P_d$$

$$F_d = m m f = K_{ar} I_d$$

$$\phi_d = K_{ar} I_d P_d$$

$$\phi_q = K_{ar} I_q P_q$$

$$P_d > P_q$$

$$\vec{E}_f = \vec{V}_t + \vec{I}_a \vec{R}_a + \vec{I}_a \vec{X}_L$$

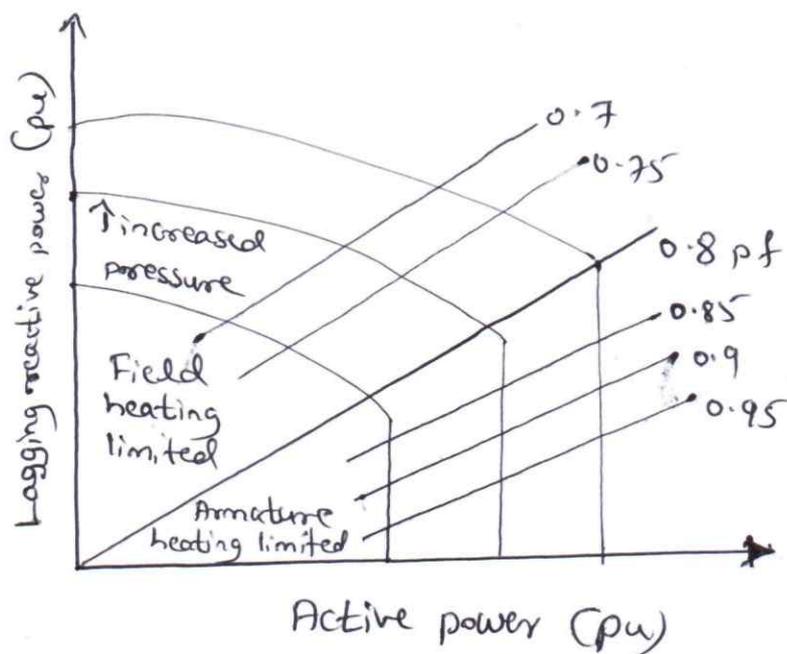
$$\vec{E}_f = \vec{V}_t + \vec{I}_a R_a + j \vec{X}_d \vec{I}_d + j \vec{X}_q \vec{I}_q$$

$$\vec{E}_f = V_t \cos \delta + I_q R_a + I_d X_d$$

where $\delta = \theta - \phi$

Q8b) Write a short note on capability curves of synchronous generator.

Ans: - The capability curve for synchronous generator specifies the bounds within which it can operate safely. The loading on generator should not exceed the generator rating as it may lead to heating of stator. The turbine rating is limiting factor for MW loading. The operation of generator should be always away from steady state stability limit. The field current should not exceed its limiting value as it may caused rotor heating. To enhance cooling effect hydrogen pressure is increased



$$\text{Apparent power} = \sqrt{P^2 + Q^2} = V_t I_a$$

$$P^2 + Q^2 = (V_t I_a)^2$$

$$\vec{E} = \vec{V}_t + \vec{I}_a (R_a + jX_s)$$

$$\vec{E} = \vec{V}_t + jI_a X_s \quad (R_a = 0)$$

$$P - jQ = \vec{V}_t \vec{I}_a$$

$$P^2 + \left(Q + \frac{V_t^2}{X_s}\right)^2 = \left(\frac{E V_t}{X_s}\right)^2$$

Q8c) What is hunting in synchronous machine? Explain the role of damper winding. 5M

Ans: - Hunting is mechanical phenomenon which produces pulsation in the voltage, current & power due to variation of angular velocity due to oscillation of rotating part of the machine. If hunting is not controlled, the machine becomes unstable & may fallout of synchronism.

Damper Windings

- * The effective practical way of reducing hunting is the use of damper windings. The damper windings are short circuited copper or aluminium bars.
- * When there are oscillations in the rotor, there is relative motion between magnetic field & damper winding. This induces emf in the damper winding. This induces emf in the damper winding to set up eddy currents.

* The direction of these currents is so as to oppose the cause producing them, as per Lenz's law, hence hunting reduced in synchronous machine.

Module 5

Q9a) Write a brief note on the following

i] Wind energy site selection consideration.

ii] The nature of wind.

Ans: - i] Wind energy site selection considerations

1] Wind resource assessment

* Wind speed: - Ideal sites have an average wind speed of at least 5-6 m/s at turbine hub height.

* Wind consistency: - Steady & strong winds throughout the year are preferred.

* Wind direction: - Consistent direction helps in optimal turbine alignment.

2] Topography & Terrain

* Flat or gently sloping terrain is ideal; hills or ridges can enhance wind speed if oriented properly.

* Obstructions: - Trees, buildings & other structures can cause turbulence & reduce efficiency.

3] Land availability & use

* Adequate space for turbine placement & access roads.

* Land use compatibility: - Prefer areas with minimal conflicts.

4] Accessibility

- * Road access:- For transporting turbines, equipment & maintenance.
- * Grid proximity:- Close to substations or transmission lines to reduce grid connection costs.

5] Environmental Impact

- * Minimize harm to wildlife, especially birds & bats
- * Consider noise & visual impact on surrounding areas

6] Energy demand & Grid integration

- * Close to areas of high electricity demand
- * Stability & reliability of the local grid.

ii] The nature of wind

- * Wind is the natural movement of air caused by the uneven heating of earth surface.
- * Its clean, renewable source of energy.
- * Wind speed vary with geography, altitude & time of day.
- * Consistent & unidirectional wind is ideal for efficient turbine operation.
- * Wind power increases with the cube of wind speed, making high-speed areas more efficient.
- * Wind speed increases with height, so turbines are mounted on tall towers.
- * Turbulence due to obstacles like buildings or hills can reduce wind energy efficiency.

Q9b) Discuss the advantage & disadvantages of PV systems.

Ans:- Advantages of PV system

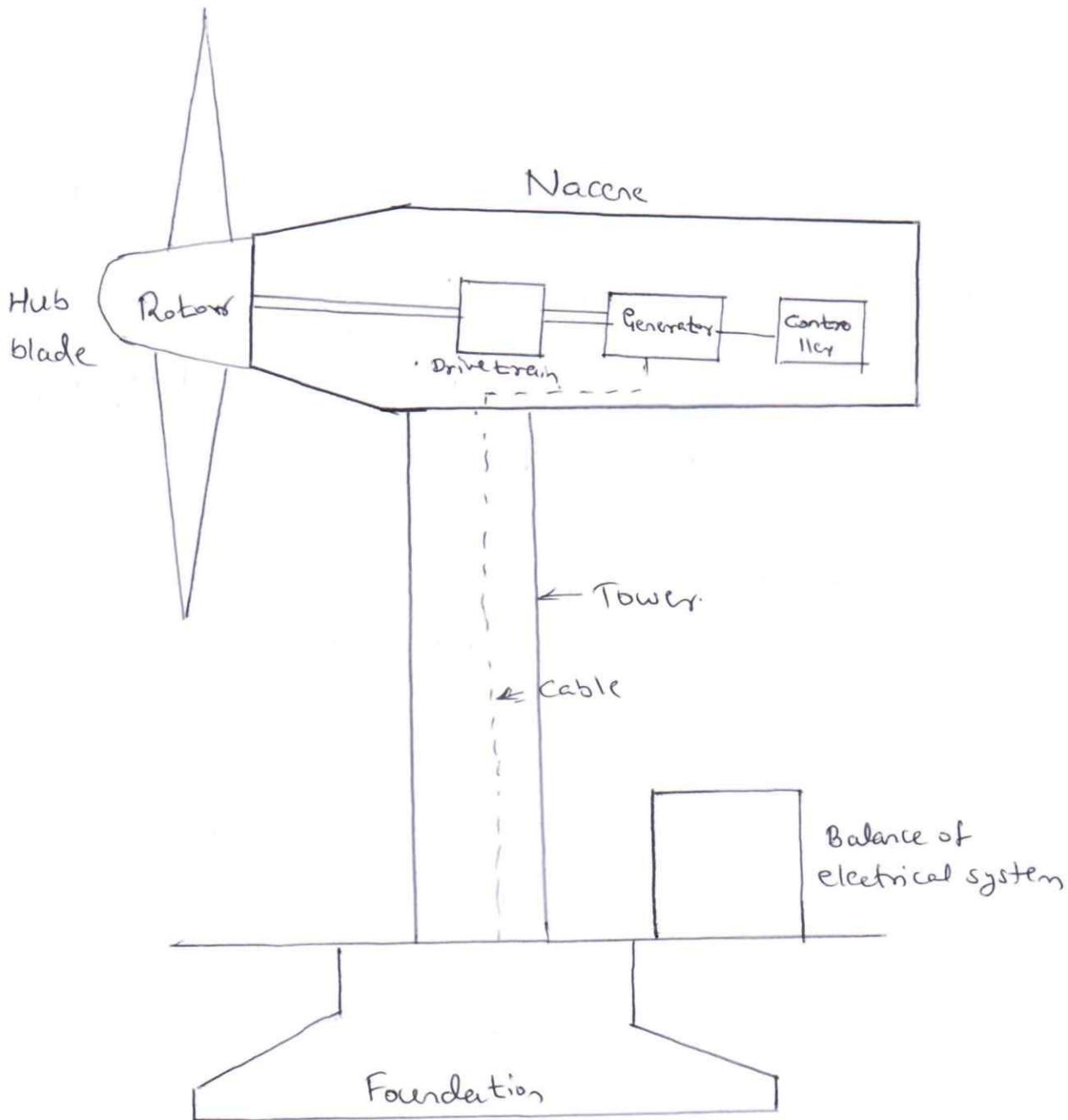
- * PV system harness renewable energy, no environmental pollution.
- * Low operating cost
- * Silent in operation, no vibrations or sound.
- * Systems can be scaled up or down based on energy needs.
- * Long life span (25 to 30 years)
- * Useful for remote areas where grid connection is difficult.
- * Reduce the reliance on fossil fuel.

Disadvantages of PV system

- * High initial cost to install panel, inverter etc...
- * Power generation is depending on weather conditions.
- * Batteries are needed to store energy, battery maintenance become adds more cost.
- * Large space requirement to install panels.
- * Maintenance in dusty areas.
- * Grid integration is challenges.

Q10 a) With a neat diagram, explain Horizontal & Vertical axis wind generators & mention their advantages & disadvantages 10M

Ans: Horizontal Axis Wind Generators



To harness more amount of wind energy to generate electricity horizontal axis wind generators are used. It consists blades to swept the air to generate the mechanical energy. These blades are fixed to rotor hub. rotor is coupled to drive trains then generator. Normally doubly fed induction generators are employed in horizontal axis wind turbines.

Controller is the brain part of this mechanism. It ~~control~~ controls the all the action happens in HAWT. Normally its efficiency is about 35% to 40%.

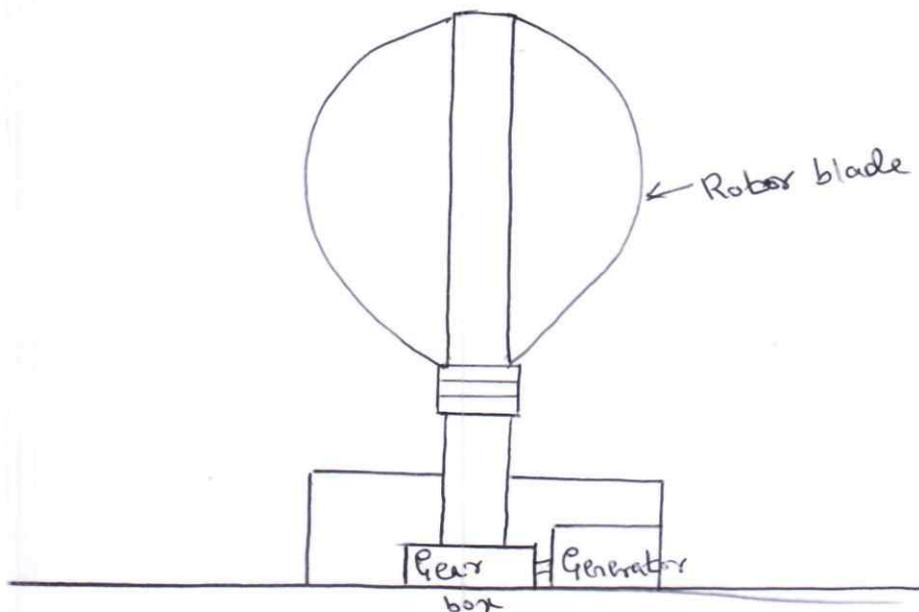
Merits

- * High efficiency
- * Better performance
- * Self starting
- * Tall towers can access stronger, more consistent winds at higher altitudes.
- * Low operating cost

Demerits

- * High initial cost
- * Noise pollution
- * Large land requirement
- * Bird & bat hazard
- * Difficult maintenance

Vertical axis wind generator



This type of wind turbine where the main rotor shaft is set transverse to the wind while the main components are located at the base of the turbine. The generator & gearbox to be located close to the ground, facilitating service & repair. Savonius & Darrieus are the types of vertical axis turbines. Normally its used for domestic application.

Merits

- * Works in all wind directions
- * Suitable for urban areas
- * Low installation height
- * Simple in construction.
- * Quieter operation
- * Lower start up wind speed.

Demerits

- * Lower efficiency
- * Less power output
- * Unstable at high wind speeds
- * Shorter life span
- * Less commercial availability

Q10 b) Write a note on the following

i] Applications of solar cell systems.

10M

ii] I V characteristics of a solar cell

Ans:- i] Applications of solar cell systems.

* Residential Power supply \Rightarrow Roof top solar panels.

* Commercial & Industrial use.

* Offgrid application.

* Solar street light

* Solar powered water pumps

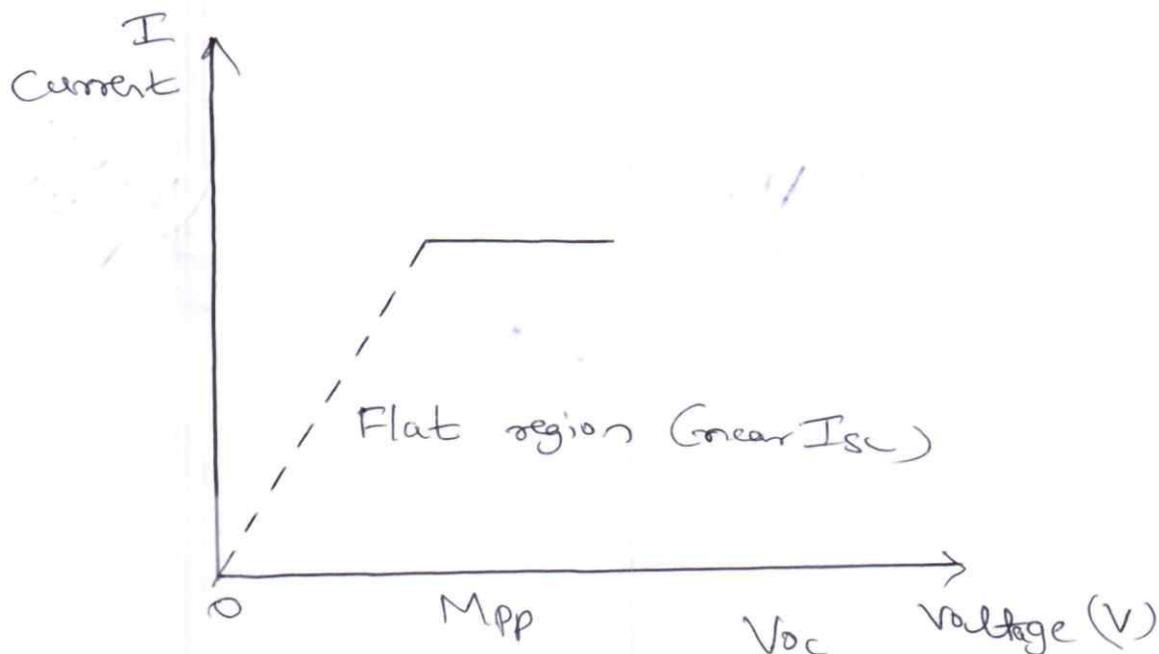
* Solar chargers & power banks

* Spacecraft & satellites

* Traffic signals & road safety

* Solar powered vehicles

ii] I V characteristics of a solar cell



The V-I characteristics of a solar cell show the relationship between the out voltage & current under constant sunlight. When the terminals are shorted, the current is maximum and this is called the short circuit current (I_{sc}). When the circuit is open, the voltage is maximum, known as open circuit voltage (V_{oc}). The curve starts with high current & low voltage, as voltage increases the current gradually decreases. At a certain point on the curve, the power output ($V \times I$) is maximum, which is called Maximum Power Point (MPP). The area under the curve determines the power output of the cell. The shape of the curve is influenced by light intensity & temperature.



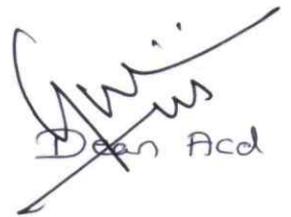
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