CBCS SCHEME

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BEE304

Third Semester B.E./B.Tech. Degree Examination, June/July 2024

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.	Explain the construction and working principle of single phase transformer with neat sketch.	7	L2	CO1
	b.	Define efficiency. Also, derive an expression for condition for maximum efficiency.	6	L2	CO1
	c.	A 50 KVA single phase transformer has primary winding resistance of 3Ω and reactance of 5Ω. The secondary winding resistance of 0.02 Ω and reactance of 0.03 Ω, it is 2500/250 V, 50 Hz. Find (i) Equivalent resistance, reactance and impedance as referred to primary side. (ii) Equivalent resistance, reactance and impedance as referred to secondary side. (iii) Full load currents on primary side and secondary side. (iv) Total copper losses.	7	L4	CO1
		OR			
Q.2	a.	With a neat circuit, explain the necessity and procedure of Sumpner's test on transformers.	6	L2	CO1
	b.	With a neat phasor diagram, explain the operation of transformer on load for lagging power factor.	7	L2	CO1
	c.	A 200 KVA, 2000/440 V, 50 Hz single phase transformer gave the following test data : OC Test : 2 KV, 1.8 A, 1.75 KW, [HV side] SC Test : 13 V, 300 A, 1 KW [LV side] (i) Find the parameters of equivalent circuit as referred to HV side. (ii) Efficiency at full load at 0.8 p.f. lagging. (iii) Regulation at 0.8 p.f. lagging.	7	L4	CO1
		Module – 2			
Q.3	a.	Describe the constructional features of three-phase transformer, with a neat sketch.	6	L2	CO2
	b.	With a neat circuit diagram, explain the necessity of parallel operation of single phase transformer.	6	L2	CO2
	c.	What is Auto transformer? Show the copper economy in auto transformer with necessary expression.	8	L2	CO2
		OR			
Q.4	a.	Draw a delta/delta connected 3-phase transformer and explain its operation. Also mention its advantages.	7	L3	CO2
	b.	What is the necessity of tap changing? Explain the process of on load tap changing in transformer.	8	L2	CO2
	c.	Determine the core area, the number of turns and the position of the tapping point for a 500 KVA, 50 Hz, single phase, 6600/5000 V auto-transformer. Consider Emf/turn as 8 V and maximum flux density 1.3 Wb/m^2.	5	L4	CO2

		Module – 3			
Q.5	**a.**	With neat sketch, explain the construction and working of synchronous generator.	**8**	**L2**	**CO3**
	b.	Derive an expression for EMF equation of synchronous generator.	**6**	**L3**	**CO3**
	c.	A 24 pole alternator has a star connected armature winding with 144 slots and 10 conductors per slot. It is driven by a speed of 250 rpm. The winding has full pitched coils with a distribution factor of 0.966. The flux per pole is 67 milli-webers. Determine : (i) Frequency of the induced emf (ii) Emf per phase (iii) Line voltage.	**6**	**L4**	**CO3**
		OR			
Q.6	**a.**	Define short circuit ratio. Also draw and explain open circuit and short circuit characteristics in synchronous generator.	**7**	**L2**	**CO3**
	b.	What do you mean by harmonics? Mention its methods of reduction and elimination.	**6**	**L2**	**CO3**
	c.	A 3.5 MVA, star connected alternator ratio at 4160 V at 50 Hz has open circuit characteristic given by the following voltage :	**7**	**L4**	**CO3**

Field current (A)	50	100	150	200	250	300	350	400	450
EMF (volts)	1620	3150	4160	4750	5130	5370	5550	5650	5750

A field current of 200 A is found necessary to circulate full load current on short circuit of the alternator. Neglect resistance, find regulation at 0.8 pf lagging using synchronous impedance method.

		Module – 4			
Q.7	**a.**	Discuss about two reaction theory and voltage regulation.	**6**	**L2**	**CO4**
	b.	Describe the parallel operation of generators and load sharing.	**8**	**L2**	**CO4**
	c.	Write a note on hunting and damper windings.	**6**	**L2**	**CO4**
		OR			
Q.8	**a.**	Draw power angle diagram if synchronous generator, explain.	**7**	**L3**	**CO4**
	b.	Define synchronization. Explain any one method of synchronization in synchronous generator.	**8**	**L2**	**CO4**
	c.	Write a note on voltage regulation by EMF method in synchronous generator.	**5**	**L2**	**CO4**
		Module – 5			
Q.9	**a.**	Explain the basic components of wind energy conversion system with a suitable sketch.	**10**	**L2**	**CO5**
	b.	Describe the principle of solar cell.	**5**	**L2**	**CO5**
	c.	List the advantages and disadvantages of wind energy conversion system.	**5**	**L2**	**CO5**
		OR			
Q.10	**a.**	Explain the basic solar photo voltaic system for power generation with a neat sketch.	**10**	**L2**	**CO5**
	b.	List the advantages and disadvantages of solar photo voltaic system.	**5**	**L2**	**CO5**
	c.	Write short notes on horizontal and vertical axis in WECS.	**5**	**L2**	**CO5**

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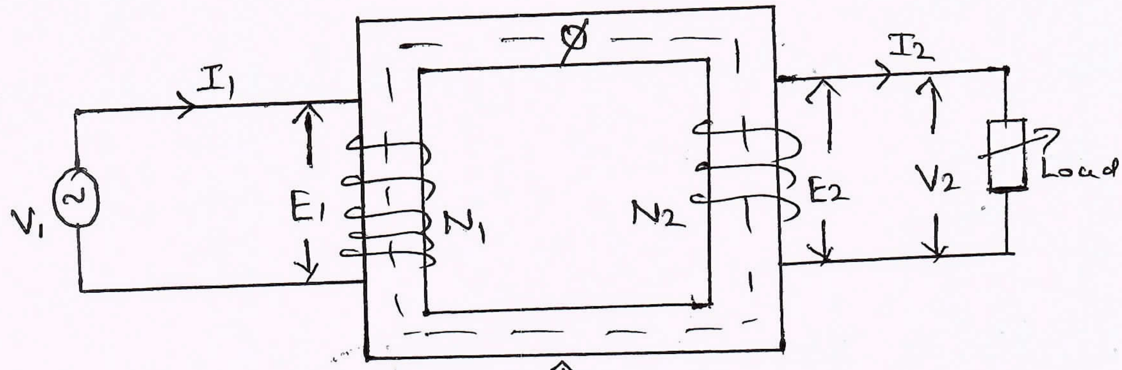
1a) Explain the construction and working of 1ϕ transformer with neat sketch. 7M

Ans:-



The Transformer is a static electrical device, its working principle based on mutual induction. The main parts of transformer is core & winding. Core is made up of iron, different shapes stampings line L, I, E, U used to make core. Stamping forms lamination & its dipped in varnis to insulate the each lamination, which reduces the eddy current loss. Windings are made up from copper, each limb carries half of primary & secondary winding. Between the low & high voltage winding insulation is provided. Based on the voltage requirement number of turns are decided. Core is the media to transfer flux.

V_1 = Supply voltage

V_2 = Voltage at the terminals of load

E_1 = Induced emf on Primary side

E_2 = Induced emf on secondary side

N_1 = Number of primary turns

N_2 = Number of secondary turns.

I_1 = Primary current

I_2 = Secondary current

When V_1 is applied on primary side, I_1 flowing through N_1 it produces flux ϕ. Hence emf induced on primary side.

$$e_1 = -N_1 \frac{d\phi}{dt} \quad \text{(self induced emf)}$$

Same flux links with the secondary side & induce the emf.

$$e_2 = -N_2 \frac{d\phi}{dt}$$

$$\frac{e_2}{e_1} = \frac{N_2}{N_1} = \frac{E_2}{E_1} = K$$

K = Transformation ratio

Transformer transfer the power from one side to another side without changing frequency.

Primary Power = Secondary power

$$E_1 I_1 = E_2 I_2$$

$$\frac{I_1}{I_2} = \frac{E_2}{E_1}$$

$$K = \frac{E_2}{E_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}$$

1b) Define efficiency. Also derive an expression for condition for maximum efficiency. 6M

Ans:- Efficiency is the ratio of output power to the input power.

$$\eta = \frac{\text{Output Power}}{\text{Input Power}} \times 100$$

Input power = $V_1 I_1 \cos\phi_1$

$$\text{Efficiency } (\eta) = \frac{\text{Input power} - \text{Losses}}{\text{Input power}}$$

$$\eta = \frac{V_1 I_1 \cos\phi_1 - W_i - I_1^2 R_{e1}}{V_1 I_1 \cos\phi_1}$$

Condition for maximum efficiency $\frac{d\eta}{dI_1} = 0$

$$\frac{d\eta}{dI_1} = 1 - \frac{W_i}{V_1 I_1 \cos\phi_1} - \frac{I_1^2 R_{e1}}{V_1 I_1 \cos\phi_1}$$

$$= 1 - \frac{W_i}{V_1 I_1 \cos\phi_1} - \frac{I_1 R_{e1}}{V_1 I_1 \cos\phi_1}$$

$$\frac{d\eta}{dI_1} = 0 - \frac{R_{e1}}{V_1 \cos\phi_1} + \frac{W_i}{V_1 I_1^2 \cos\phi_1} = 0$$

$$\frac{R_{e1}}{V_1 \cos\phi_1} = \frac{W_i}{V_1 I_1^2 \cos\phi_1}$$

$$W_i = I_1^2 R_{e1}$$

Iron loss = Copper loss (W_{cu})

Transformer achieves maximum efficiency, when its $W_i = W_{cu}$

1c) A 50 kVA 1Ø transformer has primary winding resistence of 3Ω & reactance of 5Ω. The secondary winding resistence of 0.02Ω & reactence of 0.03Ω, it is 2500/250V, 50Hz. Find

i] Equivalent resistance, reactence & impedance as referred to primary side.

ii] Equivalent resistence, reactance & impedance as referred to secondary side.

iii] Full load current on primary & secondary side.

iv] Total copper losses.

Ans:- $R_1 = 3\Omega$ $X_1 = 5\Omega$ $V_1 = 2500V$ $K = \frac{250}{2500} = 0.1$

$R_2 = 0.02\Omega$ $X_2 = 0.03$ $V_2 = 250V$

i] Equivalent resistence (R_{e1}), Reactance (X_{e1}) & Impedance (Z_{e1}) referred to primary side

$$R_{e1} = R_1 + R_2' = R_1 + \frac{R_2}{K^2} = 3 + \frac{0.02}{(0.1)^2} = 5\Omega$$

$$X_{e1} = X_1 + X_2' = X_1 + \frac{X_2}{K^2} = 5 + \frac{0.03}{0.1^2} = 8\Omega$$

$$Z_{e1} = \sqrt{R_{e1}^2 + X_{e1}^2} = \sqrt{5^2 + 8^2} = 9.43\Omega$$

ii] Equqivalent resistance (R_{e2}), Reactance (X_{e2}) & Impedance (Z_{e2}) referred to secondary side

$$R_{e2} = R_2 + K^2 R_1 = 0.02 + 0.1^2 \times 3 = 0.05\Omega$$

$$X_{e2} = X_2 + K^2 X_1 = 0.03 + 0.1^2 \times 5 = 0.08\Omega$$

$$Z_{e2} = \sqrt{R_{e2}^2 + X_{e2}^2} = \sqrt{(0.05)^2 + (0.08)^2} = 0.0943\Omega$$

iii] Primary Full load current (I_1)

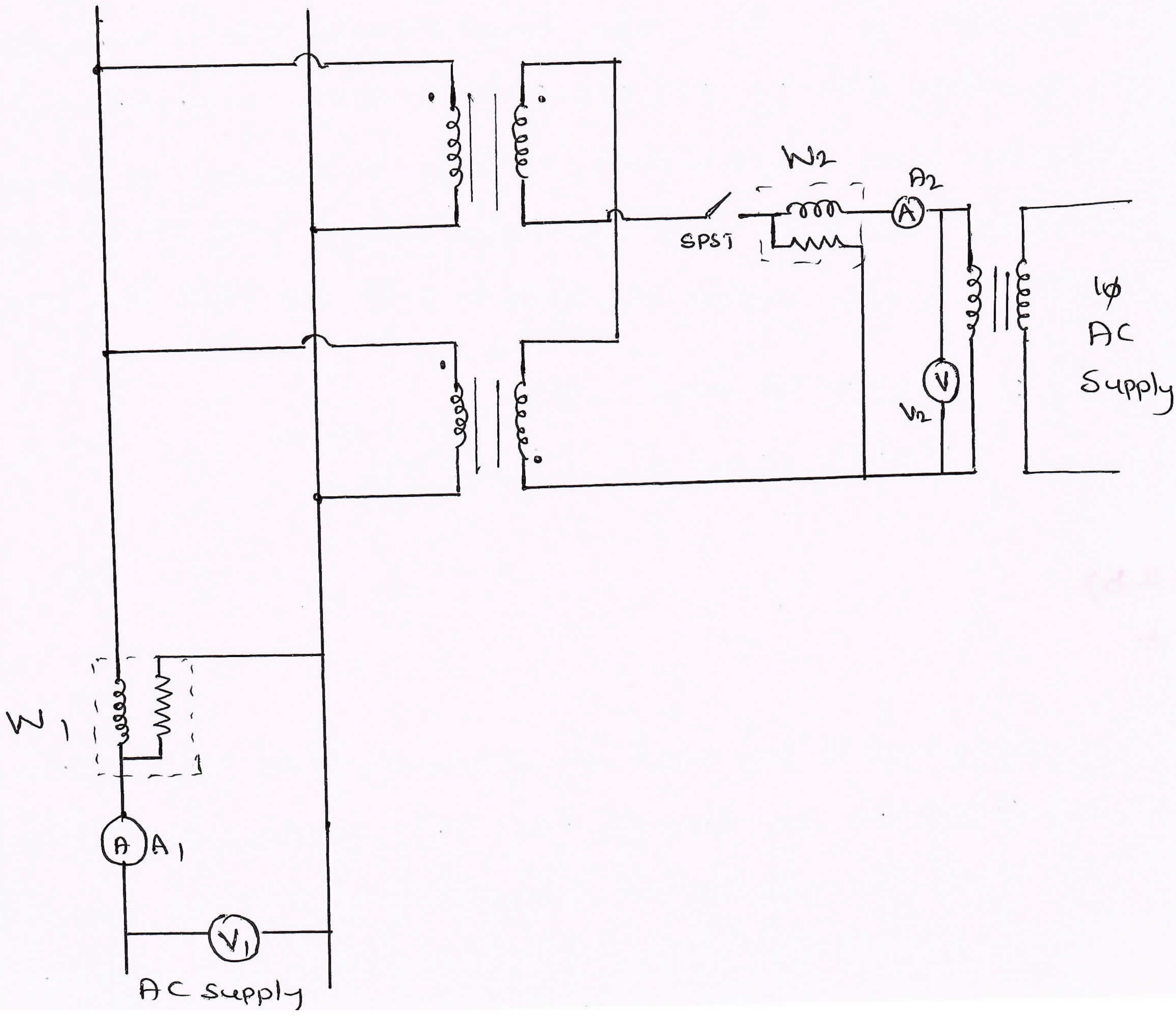
$$I_1 = \frac{KVA}{V_1} = \frac{50\times1000}{2500} = 20A$$

Secondary Full load current (I_2)

$$I_2 = \frac{kVA}{V_2} = \frac{50\times1000}{250} = 200A$$

iv] Total copper loss $= I_1^2 Re_1 = 20^2 \times 5 = 2kW$

Q2 a) With a neat circuit, explain the necessity & procedure of sumpners test on transformers. 6M



Sumpner's test helps to find efficiency, regulation by conducting open & short circuit test. It also gives information about heat rise in transformer. Two identical transformer with same voltage ratio is used to perform sumpner's test. Primary side of the both transformer connected in parallel & secondary connected in series opposition. Primary side voltmeter, ammeter & Watt meter to measure open circuit voltage, current & iron loss of both transformer. OC test is performed on primary side by applying rated voltage.

As secondary side is connected in series opposition, so induced emf in secondary winding of both transformer is oppossing each other & net emf becomes zero. SPST is closed when voltage difference is zero, then short circuit test is performed on secondary side by applying rated current of transformer.

Voltmeter gives short circuit voltage & ammeter SC current, wattmeter W_2 gives full load copper loss of both transformer. This test is also called as back to back or Heat Run Test.

$$\eta = \frac{x \times kVA \times 1000 \times \cos\phi}{x \times kVA \times 1000 \times \cos\phi + \frac{W_i}{2} + x^2 \frac{W_{cu}}{2}} \times 100$$

Q2 b) With a neat phasor diagram, explain the operation of transformer on load for lagging power factor. 7 M

Ans:- When load is connected on secondary side of transformer it circulates the I_2 through N_2. This creates counter flux for main flux. To neutralise the counter flux primary draws additional current I_2', which is antiphase for I_2. When lagging load is connected V_2 lags I_2 ...

$$\vec{I_1} = \vec{I_0} + \vec{I_2'}$$

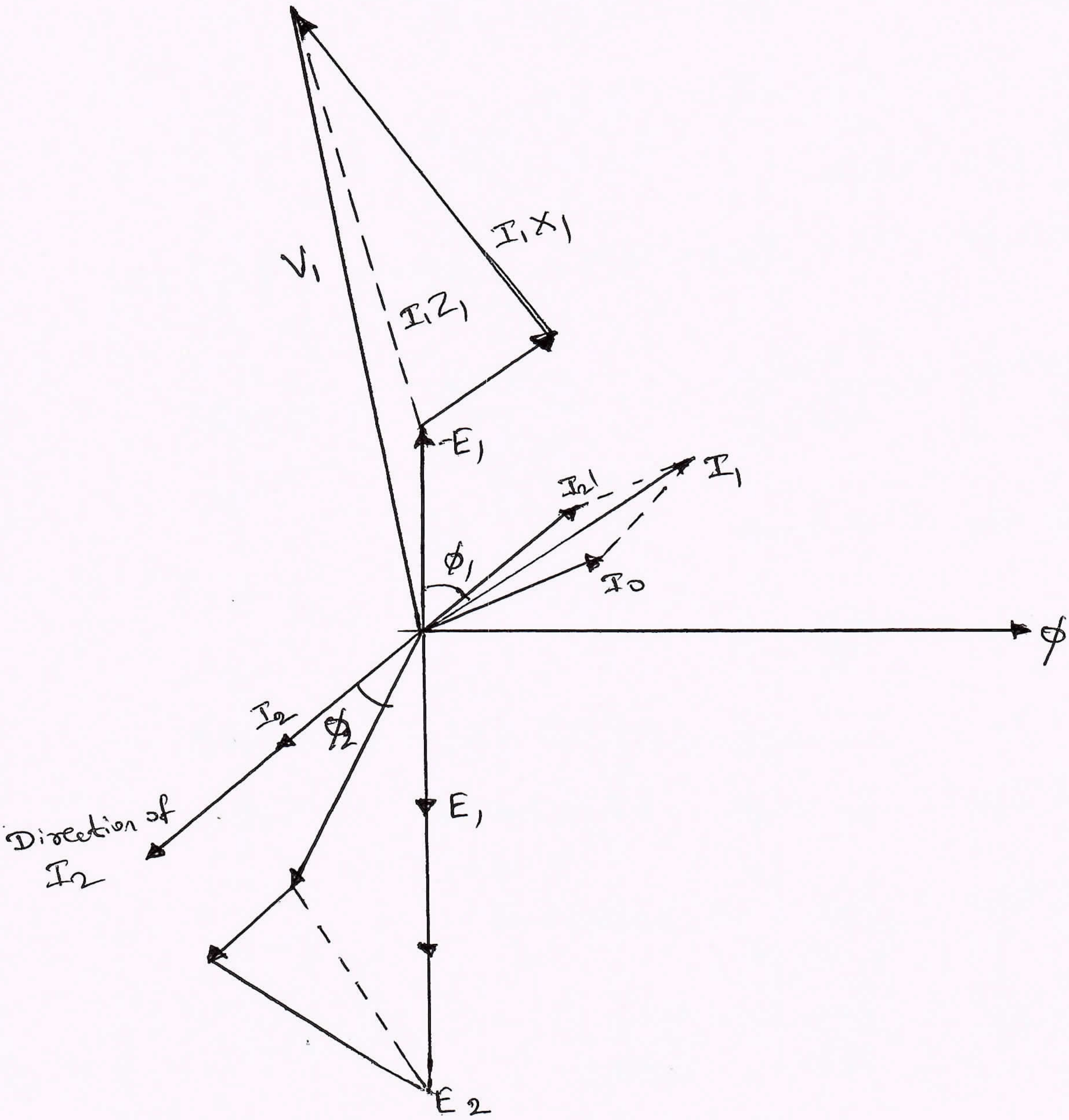
$$\vec{V_1} = -\vec{E_1} + \vec{I_1}\vec{R_1} + j\vec{I_1}\vec{X_1}$$

$$\vec{V_1} = -\vec{E_1} + \vec{I_1}\vec{Z_1}$$

$$\vec{E_2} = \vec{V_2} + \vec{I_2}\vec{R_2} + j\vec{I_2}\vec{X_2}$$

$$\vec{E_2} = \vec{V_2} + \vec{I_2}\vec{Z_2}$$

$$\vec{V_2} = \vec{E_2} - \vec{I_2}\vec{Z_2}$$



c) A 200kVA, 2000/440V, 50 Hz, 1φ transformer gave the following test data:

OC Test : 2kV, 1·8A, 1·75kW (HV side)

SC Test : 13V, 300A, 1kW (LV side)

i] Find the parameters of equivalent circuit as referred to HV side

ii] Efficiency at full load of 0·8 p.f lagging.

iii] Regulation at 0·8 p.f. lagging

7M

Ans:- OC Test

$V_o = 2000V$ $I_o = 1{\cdot}8A$ $W_o = 1{\cdot}75kW$

$$\cos\phi_o = \frac{W_o}{V_o I_o} = \frac{1{\cdot}75k}{2k \times 1{\cdot}8} = 0{\cdot}486$$

$\sin\phi_o = 0{\cdot}874$

$$R_o = \frac{V_o}{I_c}$$

$I_c = I_o \cos\phi_o = 1{\cdot}8 \times 0{\cdot}486 = 0{\cdot}8748 A$

$I_\mu = I_o \sin\phi_o = 1{\cdot}8 \times 0{\cdot}874 = 1{\cdot}573 A$

$$R_o = \frac{2k}{0{\cdot}8748} = 2{\cdot}286k\Omega$$

$$X_o = \frac{V_o}{I_\mu} = \frac{2k}{1{\cdot}573} = 1{\cdot}271k\Omega$$

From SC Test

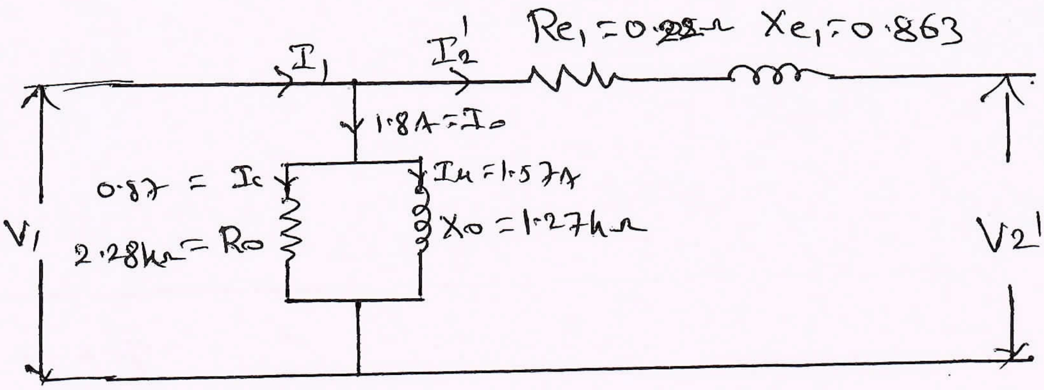
$V_{sc} = 13V$ $I_{sc} = 300A$ $W_{sc} = 1kW$

$$R_{e2} = \frac{W_{sc}}{I_{sc}^2} = \frac{1k}{300^2} = 0.0111\,\Omega$$

$$Z_{e2} = \frac{V_{sc}}{I_{sc}} = \frac{13}{300} = 0.0433\,\Omega$$

$$X_{e2} = \sqrt{Z_{e2}^2 - R_{e2}^2} = \sqrt{0.0433^2 - 0.0111^2} = 0.041879\,\Omega$$

Equivalent circuit referred to HV side



$$R_{e1} = \frac{R_{e2}}{K^2} = \frac{0.0111}{0.22^2} = 0.223\,\Omega$$

$$X_{e1} = \frac{X_{e2}}{K^2} = \frac{0.041879}{0.22} = 0.863\,\Omega$$

ii] Efficiency at 0.8 p.f. lagging full load

$$\eta = \frac{x \times kVA \times \cos\phi \times 1000}{x \times kVA \times \cos\phi \times 1000 + W_i + x^2 W_{cu}} \times 100$$

$$\eta = \frac{1 \times 200 \times 1000 \times 0.8}{1 \times 200 \times 1000 \times 0.8 + 1.75k + 1^2 \times 1k} \times 100$$

$$\eta = \frac{160000}{160000 + 1.75k + 1k} \times 100.$$

$$\eta = 98.31\,\%.$$

iii] Voltage regulation at 0.8 p.f. lagging

$$\% VR = \frac{I_{1_{FL}}(R_{e_1} \cos\phi + X_{e_1} \sin\phi)}{V_1}$$

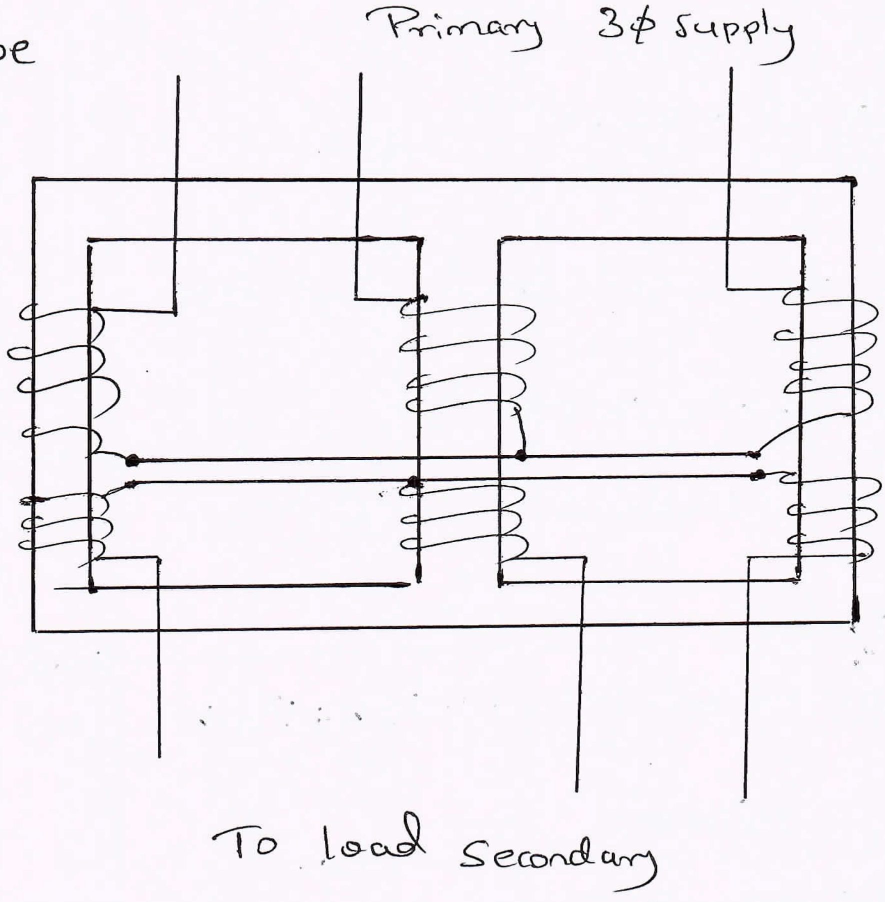
$$I_{1_{FL}} = \frac{200 \times 1000}{2000} = 100A$$

$$\% VR = \frac{100\,(0.223 \times 0.8 + 0.863 \times 0.6)}{2000} \times 100$$

$$\% VR = 3.481\ \%.$$

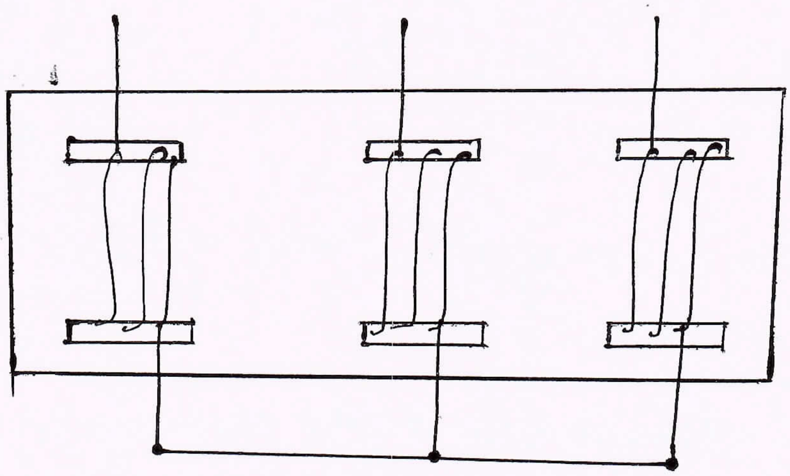
Q3 a) Discribe the constructional features of 3 ϕ transformer, with a neat sketch. 6M

Ans;- Core Type



The core consists of 3 legs with magnetic circuit completed through two yokes, one at the top & the other at the bottom. Each limb has primary & secondary winding arranged concentrically Circular cylindrical coils are used. primary & a secondary winding of one phase are wound on one leg. Flux flows up each leg in turn & down the other two legs in general so that the magnetic circuits of different phases are in series & therefore independent.

Shell type

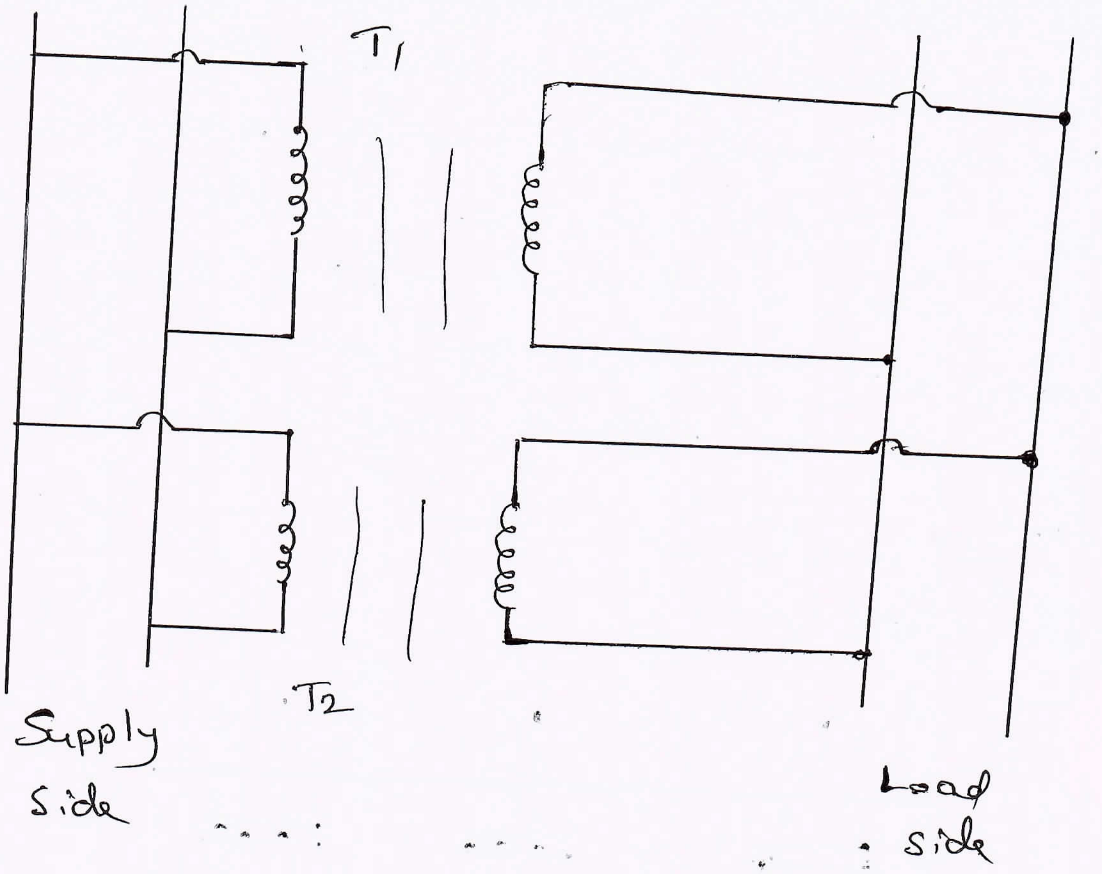


In shell type transformer the 3ϕ are more independent than they are in the core type of 3ϕ transformer. This is because each phase has an individual magnetic circuit which is independent of each other.

Q3 b) With neat diagram, explain the necessity of parallel operation of 1ϕ transformer. 6M

Ans:- Necessity of parallel operation of 1ϕ transformer.

* When the load is higher than the individual transformer parallel operation of smaller units share a high capacity load.



* To make the power system more reliable, the parallel operation is needed.

* According to demand of power, transformers in parallel can be switched ON or OFF.

* When the number of transformer in parallel, cost of stand by unit is much less.

Q.3 c) What is Auto transformer? Show the copper economy in auto transformer with necessary expression. 8M

Ans:- Special type of transformer having only one winding such that the part of the winding is common to the primary & secondary is called Autotransformer.

weight of copper $\propto NI$

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

W_{AT} = Weight of copper in autotransformer

In two winding transformer

weight of copper of primary $\propto N_1 I_1$

weight of copper of secondary $\propto N_2 I_2$

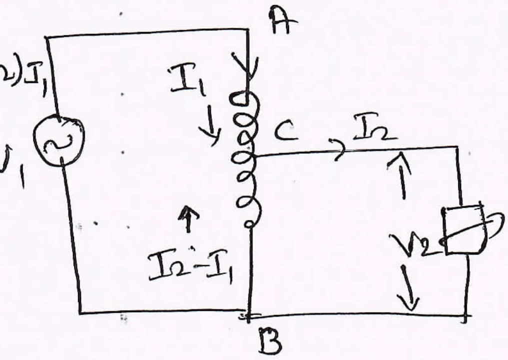
$$W_{TW} \propto N_1 I_1 + N_2 I_2$$

In case of step down autotransformer

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

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

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



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

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

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

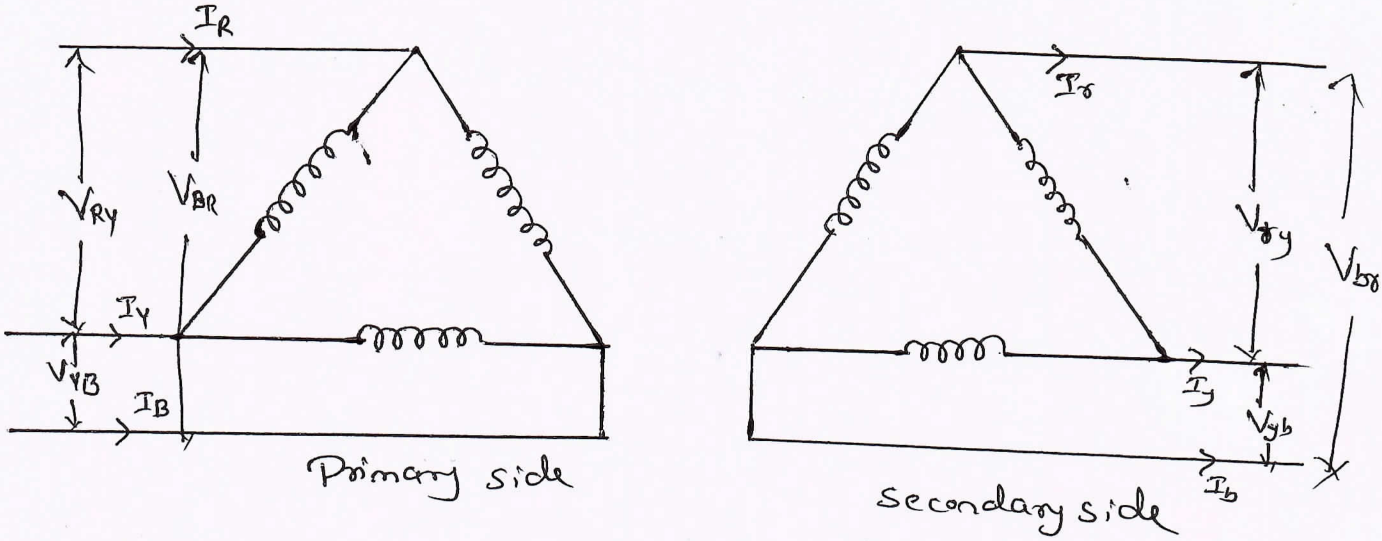
$$\frac{W_{TW}}{W_{AT}} = \frac{N_1 I_1 + K N_1 (I_1/K)}{N_1 I_1 + K N_1 (I_1/K) - 2(K N_1) I_1} = \frac{1}{(1-K)}$$

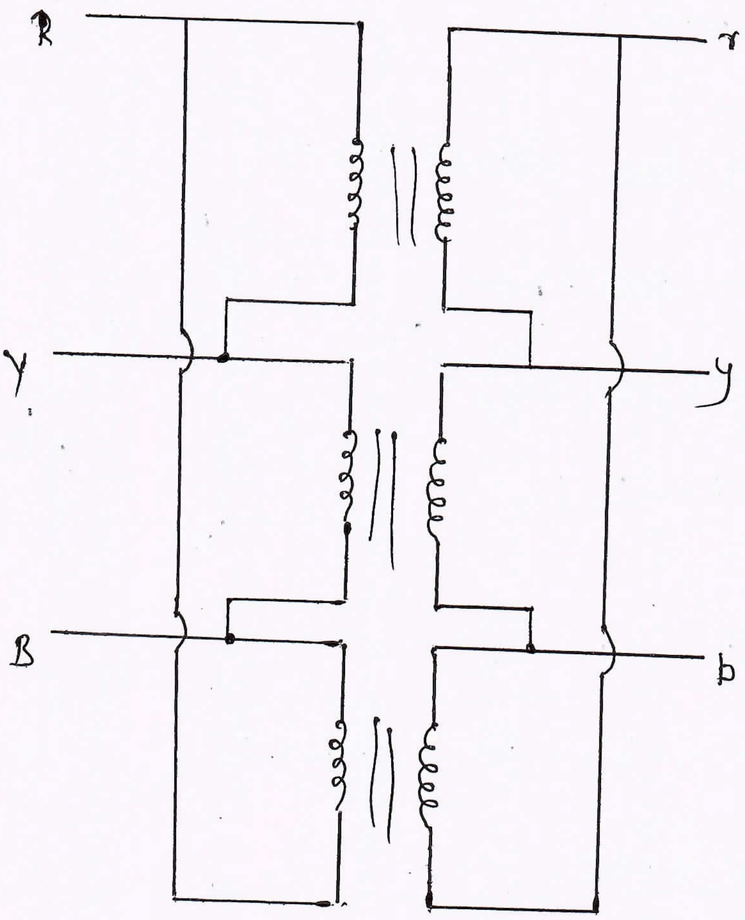
$$W_{AT} = (1-K) W_{TW}$$

Saving of copper $= W_{TW} - W_{AT} = K W_{TW}$

4a) Draw a delta - delta connected 3ϕ transformer & explain its operation. Also mention the advantages.

Ans) -



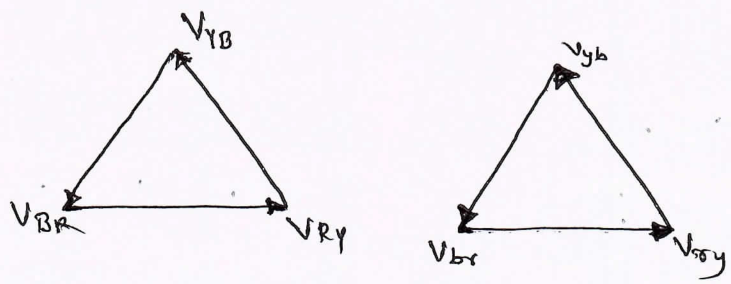


$$V_{L1} = V_{ph1}$$

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

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

$$V_{L2} = V_{ph2} = K\, V_{ph1}$$



Merits

* In order to get secondary voltage as sinusoidal, the magnetizing current of transformer must contain a 3rd harmonic component. The Δ connection provides a closed path for circulation of 3rd harmonic component of current. The flux remains sinusoidal which results in sinusoidal voltages.

* Even if the load is unbalanced the 3 ∅ voltages remains constant.

* There is no distortion in the secondary voltages.

* Open delta connection is possible.

4b) What is the necessity of tap changing? Explain the process of on load tap changing in transformer. 8M

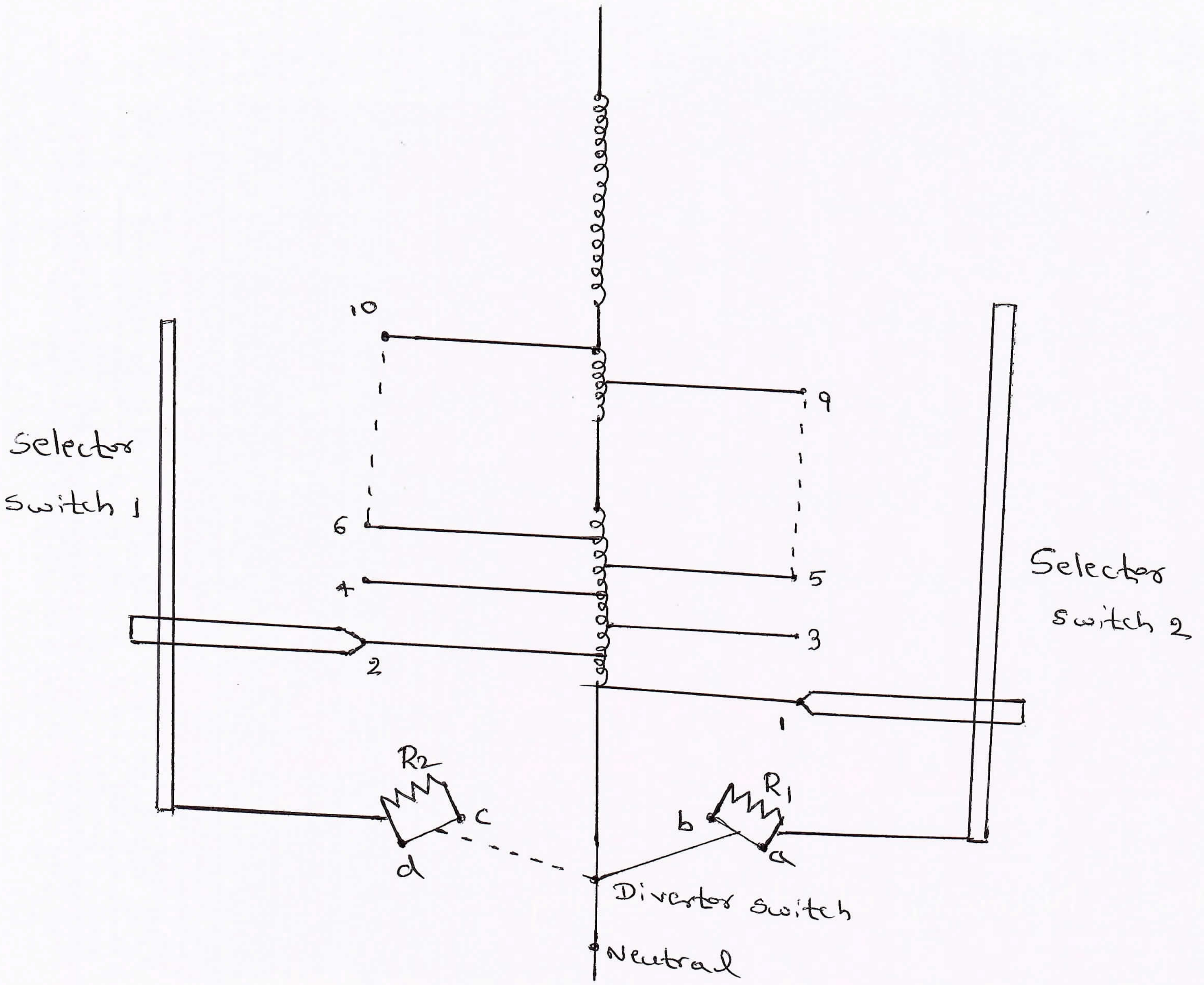
Ans:- Necessity of tap changing

* To inject the voltage in to the power system when the voltage drop is more

* To control active & reactive power. with change in load, the voltage variation is adjusted.

* ON Load Tap Changing Transformer

Under the load condition tappings are changed without interrupting the supply. Normally on load tap changing the tapping are connected at the neutral end of high voltage winding. It is in the form of selector switch, it can be operating using motors.



Resistor or reactors are used to supress the transients while changing the tappings.

To change the selector switch from 1 to 2, initially a b are contacted, current not flows through R_1. Later contact 'a' get opened, current flows through R1. diverter switch moved towards left side & 'b' is contacted with 'c'. Hence R_1 & R_2 are in series. Slowly contact 'b' get open, c & d get shorted, hence current flows through 'cd' not through R_2.

4c) Determine the core area, the number of turns & the position of the tapping point for a 500 kVA, 50 Hz, 1ϕ, 6600/5000V auto transformer. Consider emf/turn as 8V & maximum flux density 1.3 Wb/m^2

Ans:- Core area $a = \frac{E = emf/turn}{4.44 f B_{max}}$

$$a = \frac{8}{4.44 \times 50 \times 1.3} = 270\ cm^2 = 0.027 m^2$$

Number of primary turns (N_1)

$$N_1 = \frac{V_1}{Emf/turn} = \frac{6600}{8} = 825 \text{ turns.}$$

Number of secondary turns (N_2)

$$N_2 = \frac{V_2}{Emf/turn} = \frac{5000}{8} = 625 \text{ turns}$$

Position of tapping

$$N_{tap} = N_1 - N_2$$

$$= 825 - 625$$

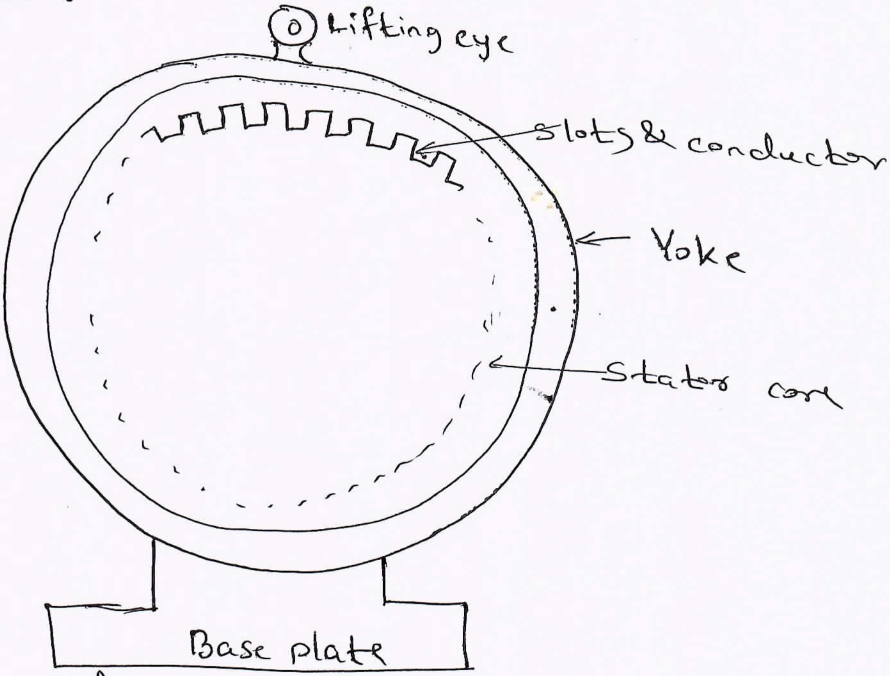
$$= 200 \text{ turns}$$

Tapping point is located 200 turns away from secondary side.

Module 3

5 a) With neat sketch, explain the construction and working of synchronous generator 8M

Ans :- Stator

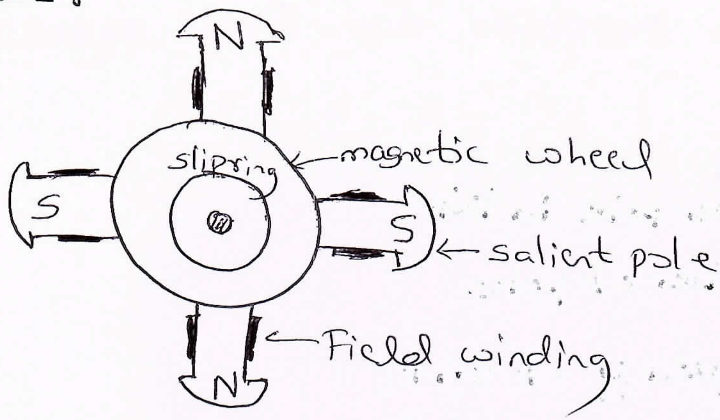


Stator is in cylindrical shape, circular laminations are jointed togather to make stator core. It consists of slots to hold the conductor, which is distributed in 360° Stator core is made up from steel or mild steel. Base-plate & lifting eye attached to stator. It acts as armature in generator.

Rotor

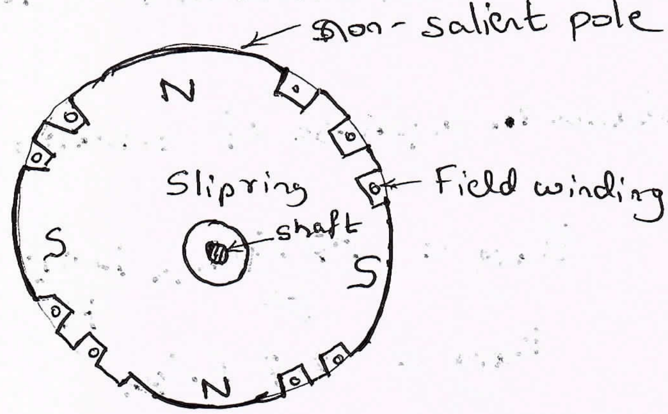
Rotor acts as field system in generator. There is 4mm to 0.4mm gap between rotor & stator. Based on rotor construction alternator broadly classified as salient & non salient pole rotor.

Salient Pole Rotor



Normally its used for 300 to 600rpm medium speed application. It consists of large magnetic wheel drum, number of poles are attached with the help of nuts & bolts. Field windings are placed on each pole to produce flux. It has short axial length & large diameter.

Non Salient Pole Rotor



Smooth cylindrical pole rotor is used for high speed application (1500rpm -3000rpm). Central polar area is unsloted & flux density is maximum in that area, so its considered as pole. It has small diameter & large axial length.

5b) Derive an expression for EMF equation of synchronous generator. 6M

Ans:- ϕ = Flux per pole in Wb

P = Number of poles

f = frequency of emf

Z_{ph} = Stator conductors/phase

$N = N_s$ = Rotor speed in rpm

T_{ph} = Turns per phase of stator

Total flux produced $= P\phi = d\phi$

Time taken to complete one revolution $= \frac{60}{N}$ sec $= dt$

Average emf induced in a conductor $= 1 \times \frac{P\phi}{60/N} = \frac{P\phi N}{60}$

Average emf induced in a phase of stator $= \frac{P\phi N}{60} \times Z_{ph}$

$$E_{avg} = \frac{P\phi Z_{ph}}{60} \times \frac{120f}{P}$$

$$E_{avg} = 2\phi f Z_{ph}$$

RMS value of emf induced/phase $E_{ph} = 1.11\, E_{avg}$

$$E_{ph} = 1.11 \times 2 \times \phi \times f \times Z_{ph} = 2.22\, \phi f Z_{ph} \text{ Volts}$$

$$E_{ph} = 2.22\, \phi f Z_{ph} K_p K_d \text{ Volts}$$

$$E_{ph} = 4.44\, \phi f T_{ph} K_p K_d \text{ Volts}$$

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

K_p = Pitch factor

K_d = Distribution factor

5c) A 24 pole alternator has a star connected armature winding with 144 slots & 10 conductors/slot. It is driven by a speed of 250 rpm. The winding has full pitched coils with a distribution factor of 0.966. The flux per pole is 67m Wb. Determine : i] Frequency of the induced emf ii] Emf per phase iii] Line voltage.

Ans:- $P = 24$

Number of slots = 144

conductors/slot = 10

Speed $N = 250\,rpm$

Flux per pole $\phi = 67\,mWb$

Distribution factors $K_d = 0.966$

Pitch factor $K_c = 1$ (Full pitched coil)

i] Frequency of the induced emf (f)

$$f = \frac{PN}{120} = \frac{24 \times 250}{120} = 50\,Hz$$

Stator conductors per phase Z_{ph}

$$Z_{ph} = \frac{144 \times 10}{3} = 480$$

ii] Emf per phase (E_{ph})

$$E_{ph} = 2.22\,\phi f Z_{ph} K_p K_d$$

$$E_{ph} = 2.22 \times 67m \times 50 \times 480 \times 1 \times 0.966$$

$$E_{ph} = 3448\,V = 3.448\,kV$$

iii] Line voltage (E_L)

$$E_L = \sqrt{3}\,E_{ph} = 5966\,V = 5.96\,kV$$

Q 6a] Define short Circuit Ratio. Also draw & explain open circuit & short circuit characteristics in synchronous generator. 7M

Ans:- Short Circuit Ratio (SCR)

It is the ratio of the excitation required to produce open circuit voltage equal to the rated voltage to the excitation required to produce rated full load current under short circuit.

$$SCR = \frac{I_f \text{ for rated open circuit Voltage}}{I_f \text{ for rated short circuit current}}$$

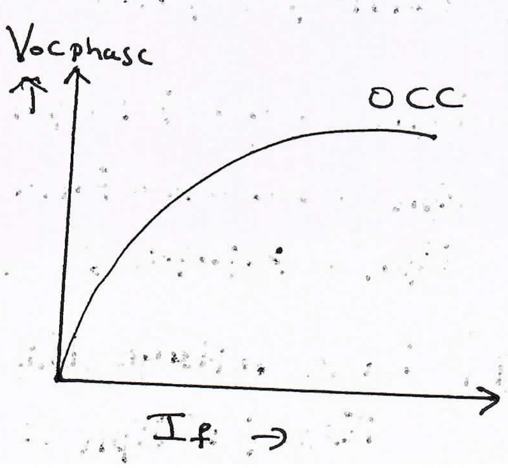
Open Circuit Characteristics (OCC)

* Stator of alternator is kept open. Field excitation (I_f) is regulated through rheostat. Prime mover speed is regulated through rheostat.

* By varing the rheostat connected to prime mover bring the speed of alternator to rated speed. By keeping stator terminal open, gradually increase field excitation & note down open circuit line voltage in each step.

* Build the voltage till alternator rated voltage reach.
* Plot the open circuit voltage per phase V/s field current (I_f)

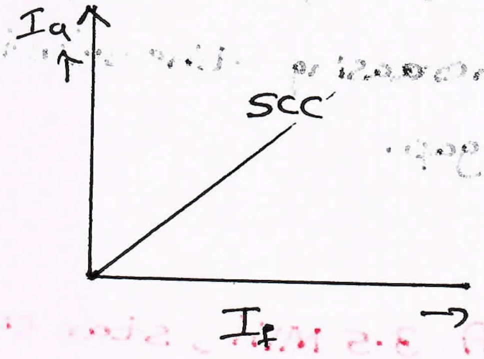
Voc line	I_f	Voc phase



Short Circuit Characteristics (SCC)

* Stator of the alternators are shorted through ammeter. bring the speed of the rotor of alternator to its rated value by varying prime mover rheostat.
* Gradually increase the field excitation till rated current flows on stator. Note down the field current & armature current.

I_f	I_a



6b) What do you mean by harmonics? Mention its methods of reduction & elemination.

Ans:- Multiplication of fundamental frequency of sinusoidal waveform of complex wave is called as harmonics. The fundamental wave is defined as that component which is having same frequency as that of complex wave.

$$e = E_{1m}\sin(\omega t + \phi_1) + E_{2m}\sin(\omega t + \phi_2) + \dots + E_{nm}\sin(n\omega t + \phi_n)$$

Methods of harmonics reduction & elemination

i] Distribution of armature windings.

Distribution of winding in each slot reduces the harmonics.

ii] Chording

chording of slots reduces the emf generated, but improves wave shape by eleminating the harmonics.

iii] Fractional slot windings

It reduces the harmonics in the wave form.

iv] Skewing

skewing the pole face will help in eleminating the slot harmonics.

v] Large length of air gap

Increasing the reluctance by increasing airgap reduces air gap.

6c) A 3.5 MVA, star connected alternator ratio of 4160V at 50 Hz has open circuit characteristics given by the following voltage:

Field current (Amps)	50	100	150	200	250	300	350	400	450
EMF (Volts)	1620	3150	4160	4750	5130	5370	5550	5650	5750

A field current of 200A is found necessary to circulate full load current on short circuit of the alternator. Neglect resistance, find regulation at 0.8 p.f. lagging using synchronous impedance method. 7M

Ans:- $I_f = 200A$

$$I_L = \frac{3.5\times10^6}{\sqrt{3}\times4160} = 485.7514\ A = I_{aph}$$

$V_{oc(line)} = 4750V$ for $I_f = 200A$

$$Z_s = \frac{V_{oc\,ph}}{I_{asc\,ph}}\Bigg|_{I_f = 200A}$$

$$Z_s = \frac{4750/\sqrt{3}}{485.75}\Bigg|_{I_f = 200\,A} = 5.64\,\Omega$$

$$R_a = 0\,\Omega$$

$$X_s = Z_s = 5.64\,\Omega$$

$$V_{ph} = \frac{4160}{\sqrt{3}} = 2401.7\,V$$

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

$$E_{ph} = \sqrt{(2401.7 \times 0.8 + 0)^2 + (2401.7 \times 0.6 + 485.75 \times 5.64)^2}$$

$$E_{ph} = 4603.618\,V$$

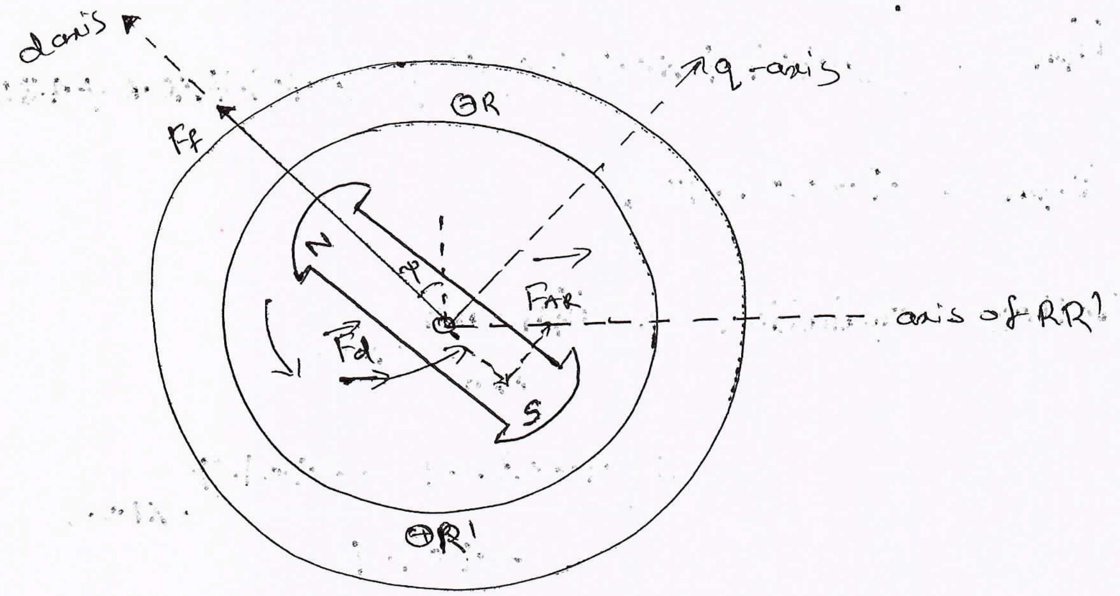
$$\%\ \text{Voltage regulation} = \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100$$

$$= \frac{4603.61 - 2401.7}{2401.7} \times 100$$

$$= 91.675\ \%$$

Q7a) Discuss about two reaction theory & Voltage regulation. 6M

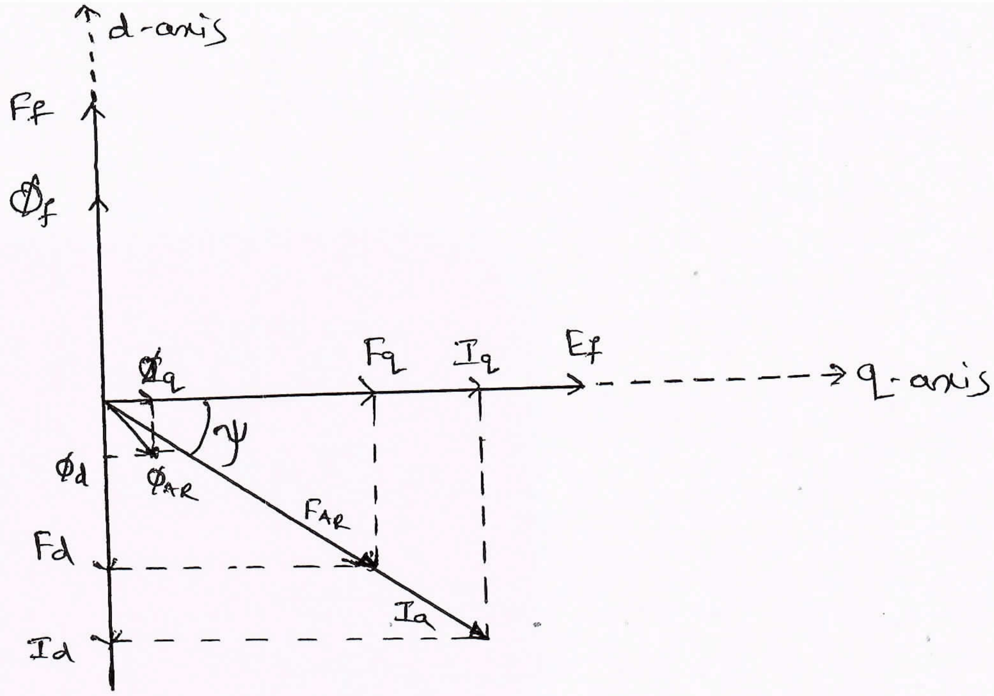
Ans:- The theory which gives the method of analysis of the disturbing effects caused by salient pole construction is called Two Reaction Theory. As per this theory armature mmf can be divided in to two components. i.e direct axis & quadrature axis. The component acting along 'd' axis can be magnetising or demagnetising. The component acting along 'q' axis is cross magnetising.



Reluctance offered in d axis is less. In q axis reluctance offered is more. Ff is the mmf wave produced by field winding. This mmf is produce an excitation emf Ef which lags Ff by 90°. Armature produces mmf of FAR & it consists two component Fd & Fq. Armature current Ia has two components Id & Iq.

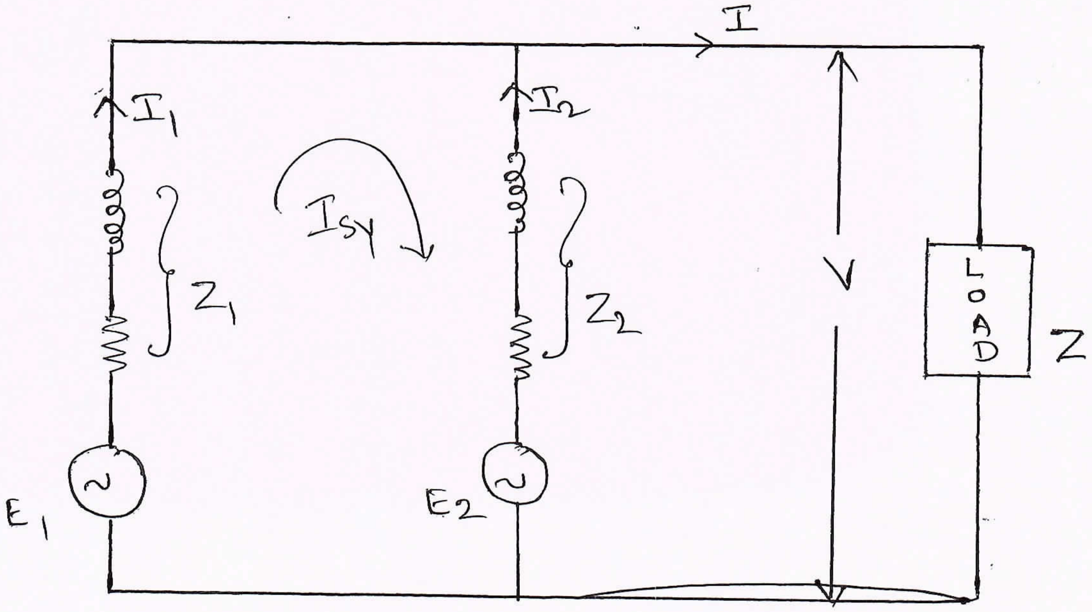
Changing of voltage from no load to full load, by keeping excitation constant is called as voltage regulation.

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



7b) Describe the parallel operation of generators & load sharing 8M

Ans:- To meet the load demand generators are connected in parallel. Generators are connected parallel with bus bar or its synchronized. Different capacity generators can be connected in parallel, but its phase sequance, voltage & frequency should be same. It shares the load as per its ~~the~~ capacity. Parallel operation is economical & it enhance the reliabily of power system.



$$V = E_1 - I_1 Z_1 = \vec{E_2} - \vec{I_2}\vec{Z_2}$$

$$\vec{V} = \vec{I} \cdot \vec{Z}$$

$$\vec{I} = \vec{I_1} + \vec{I_2}$$

$$\vec{E_1} = \vec{I}\vec{Z} + \vec{I_1}\vec{Z_1} = \vec{I_1}(\vec{Z} + \vec{Z_1}) + \vec{I_2}\vec{Z}$$

$$\vec{E_2} = \vec{I}\vec{Z} + \vec{I_2}\vec{Z_2} = \vec{I_2}(\vec{Z_2} + \vec{Z}) + \vec{I_1}\vec{Z}$$

$$\vec{I_1} = \frac{(\vec{E_1} - \vec{E_2})\vec{Z} + \vec{E_1}\vec{Z_2}}{\vec{Z}(\vec{Z_1} + \vec{Z_2}) + \vec{Z_1}\vec{Z_2}}$$

$$\vec{I_2} = \frac{(\vec{E_2} - \vec{E_1})\vec{Z} + \vec{E_2}\vec{Z_1}}{\vec{Z}(\vec{Z_1} + \vec{Z_2}) + \vec{Z_1}\vec{Z_2}}$$

$$\vec{I} = \vec{I_1} + \vec{I_2} = \frac{\vec{E_1}\vec{Z_2} + \vec{E_2}\vec{Z_1}}{\vec{Z}\left[(\vec{Z_1} + \vec{Z_2}) + \frac{\vec{Z_1}\vec{Z_2}}{\vec{Z}}\right]}$$

$$\vec{V} = \vec{I}\vec{Z}$$

$$= \frac{\vec{E_1}\vec{Z_2} + \vec{E_2}\vec{Z_1}}{(\vec{Z_1} + \vec{Z_2}) + \frac{\vec{Z_1}\vec{Z_2}}{\vec{Z}}}$$

$$\vec{I_{sy}} = \frac{\vec{E_1} - \vec{E_2}}{Z_1 + Z_2}$$

7c) Write a note on hunting & damper windings. 6M

Ans:- Hunting is a mechanical phenomenon which produces pulsations in the voltage, current & power due to variations of varitions of angular velocity due to oscillations of rotating part of the machine. If such hunting is not controlled, the machine becomes unstable & may fall out of synchronism.

Causes for hunting

* Sudden change in load.
* Sudden change in field current.
* A fault in the supply system.
* Change in supply frequency.
* A load consists of harmonic torques.

Effect of hunting

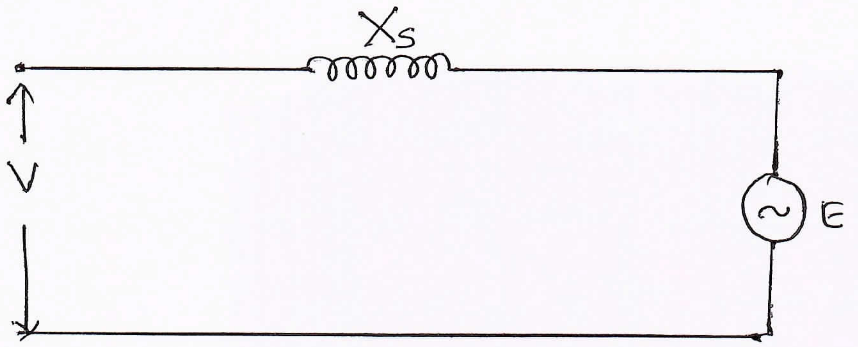
* Large surges in current & power.
* Produces more losses in the machine.
* Increases temperature rise of the machine.
* The machine may become unstable & fall out of step.

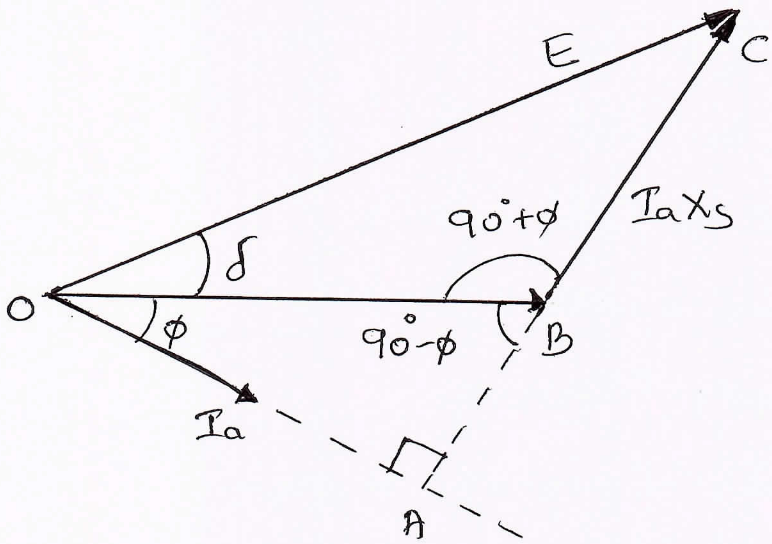
Damper Windings

The damper windings are short circuited copper or — aluminium bars. These are placed in the faces of the field poles of salient pole machines. When there are oscillations in the rotor, there is relative motion between magnetic field & damper winding. This induces emf in the damper winding to set up eddy currents. This damps the rotor oscillation.

8 a) Draw power angle diagram of synchronous generator explain. 7M

Ans:-





Power delivered to infinite bus $P_i = V I_a \cos\phi$

$$\angle OBA = 90-\phi$$

$$\angle OBC = 180-(90-\phi) = 90+\phi$$

From ΔOBC

$$\frac{BC}{\sin \angle BOC} = \frac{OC}{\sin \angle OBC}$$

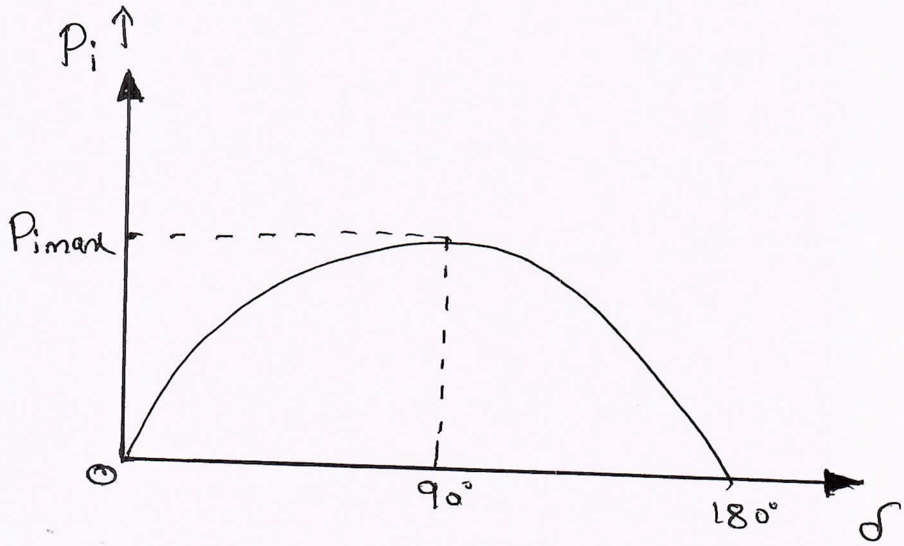
$$\frac{I_a X_s}{\sin\delta} = \frac{E}{\sin(90+\phi)}$$

$$I_a X_s \sin(90+\phi) = E\sin\delta$$

$$I_a X_s \cos\phi = E\sin\delta$$

$$I_a \cos\phi = \frac{E \sin\delta}{X_s}$$

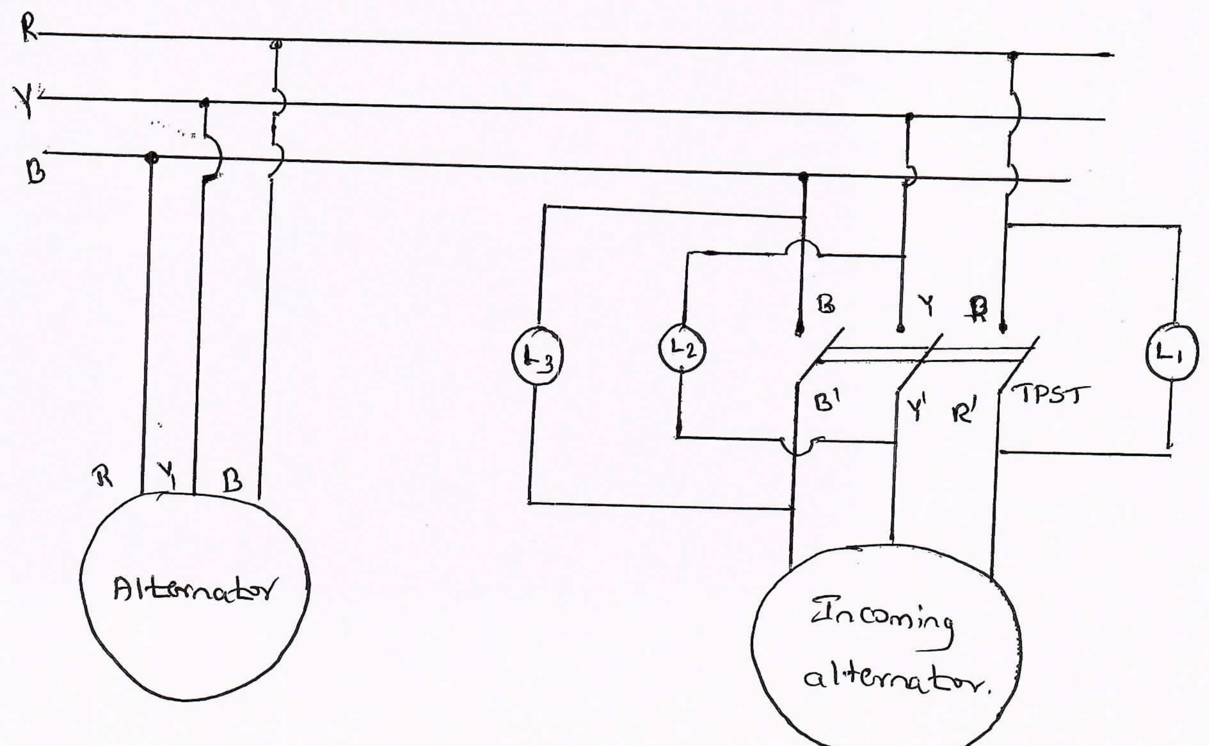
$$P_i = \frac{EV}{X_s} \sin\delta$$



The relationship between P_i & δ is known as power angle characteristics of the machine. The machine is normally operated at δ much less than 90°.

8b) Define Synchronization. Explain any one method of Synchronization in synchronous generator. 8M

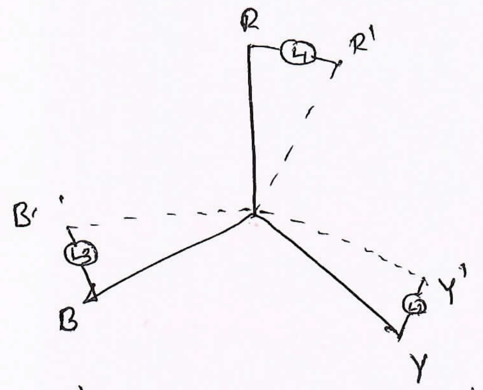
Ans:-



Connecting alternators in parallel to increase the capacity of the power generation is called as synchronization. Frequency, phase sequance & voltage plays vital role in synchronization.

Three dark Lamp method

In this method TPST switch is connected between incoming alternator & bus. ~~Iaco~~ Bus sequance is RYB & incoming alternator is R'Y'B'. 3 lamps are connected across TPST. Lamp is connected between RR', YY' & BB'. When there is frequency mismatch between busbar & incoming generator lamps flickers ~~one~~ simultenibusly, because angle ~~di~~ between RR', YY' & BB' are not same.



when RR', YY' & BB' get in phase with each other frequency of busbar & incoming become equal. If phase sequance is not same lamps flickers one after the other. Interchanging of two phase give solution for that. When the voltage difference between bus-bar & incoming generator is more, lamp brightness also more. all 3 lamp become dark, once voltage get matched. Once all 3 parameters are satisfied generators are get synchroni-zed.

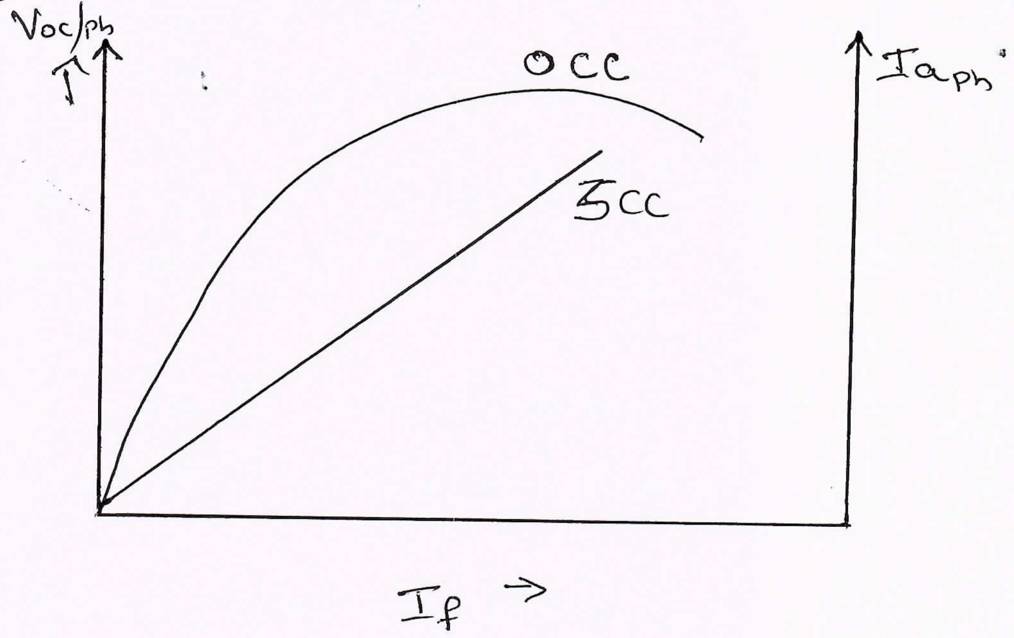
8c) Write a note on voltage regulation by EMF method in synchronous generator. 5M

Ans:- To find the voltage regulation by emf method of synchronous generator requires following data:

* The armature resistance/phase (Ra)

* Open circuit characteristic which is the graph of open circuit voltage against the field current. This is possible by conducting open circuit test on the alternator.

* Short circuit characteristics which is the graph of short circuit current against field current. This is possible by conducting short circuit test on the alternator.



From the above graph synchronous impedance is calculated (Zs)

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

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

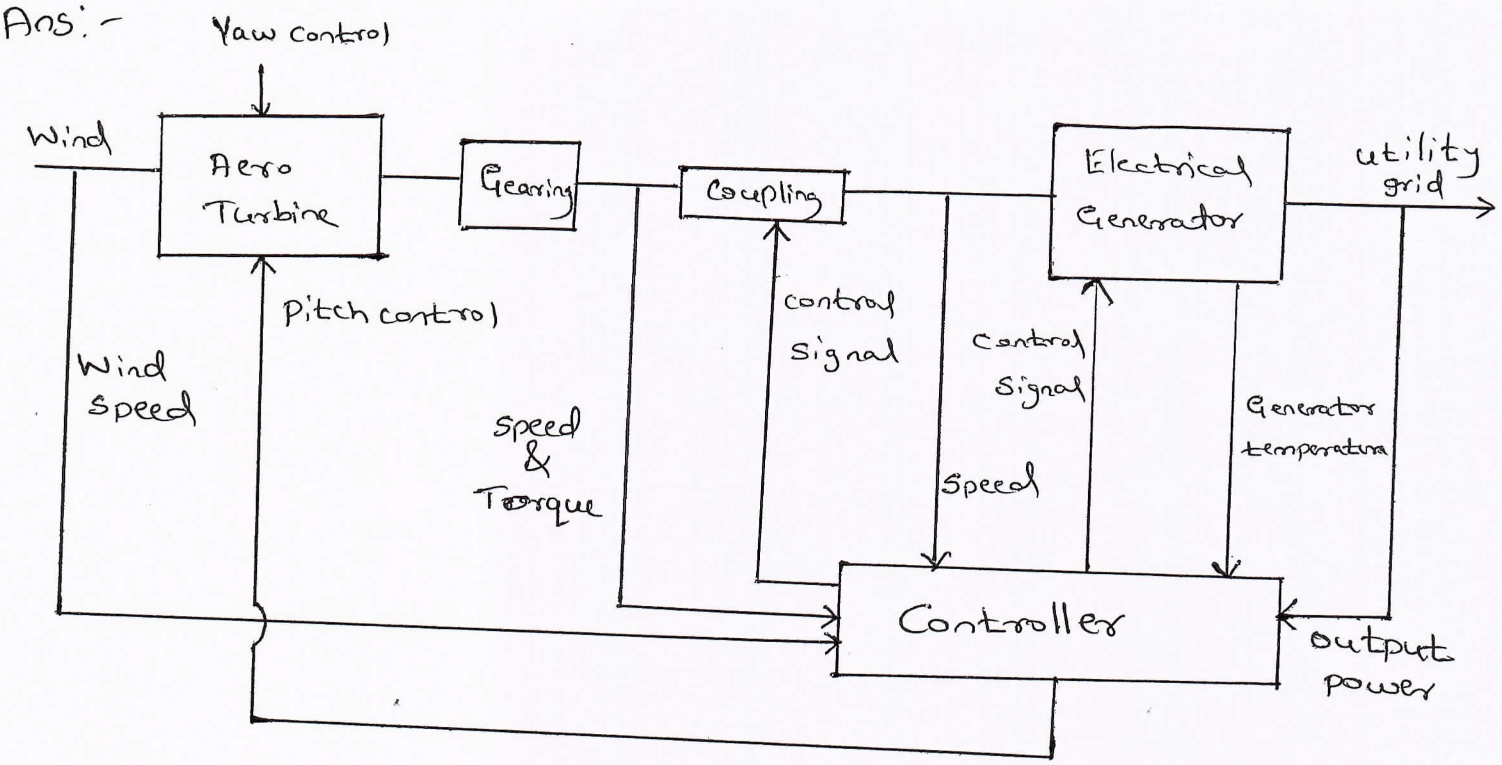
$$X_s = \sqrt{Z_s^2 - R_a^2}$$

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

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

Q 9 a) Explain the basic components of wind energy conversion system with a suitabe sketch. 10M

Ans:-



Aero Turbine -> It converts energy in moving air to rotary mechanical energy. They require pitch & yaw control for proper operation.

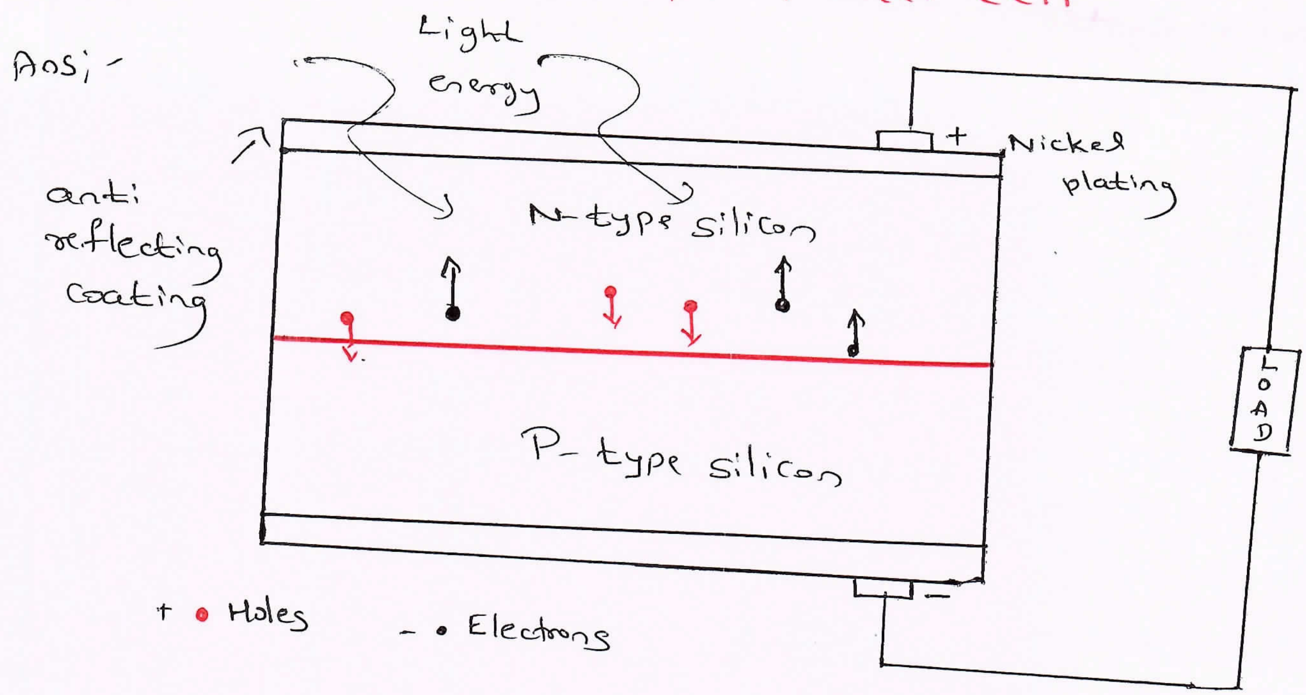
Yaw control -> To fix the orientation of rotor with swept area perpendicular to the predominant wind direction.

Controller -> It sense the wind speed, wind direction, shaft speed & torques at one or more points, output power, generator temperature as necessary & appropriate control signals for matching the electrical output to the wind energy input & protect the system from extreme condition.

Generator -> It converts mechanical energy to electrical energy. It consists stator & rotor.

9b) Describe the principle of solar cell 5M

Ans;-



* It is a electrical device that converts light energy in to electrical energy through photovoltaic effect.

* Basically it consists p-n junction diode, when light falls over it, generates electricity. n-layer is bit thicker than p-layer.

* When light falls over cell, photons reaches p-n junction through p-type layer, they supply enough energy to create multiple electron-hole pairs. The incident light breaks the thermal equilibrium condition of junction. free electrons is depletion region quickley move towards n-type junction.

* Holes travels towards p type; due to the potential barries electrons from n-side unable to cross the band.

* Seperation of holes & electrons generates the voltage, & when load is connected current start to circulate.

9c) List the advantages & disadvantages of wind energy conversion system. 5M

Ans: Advantages of WECS

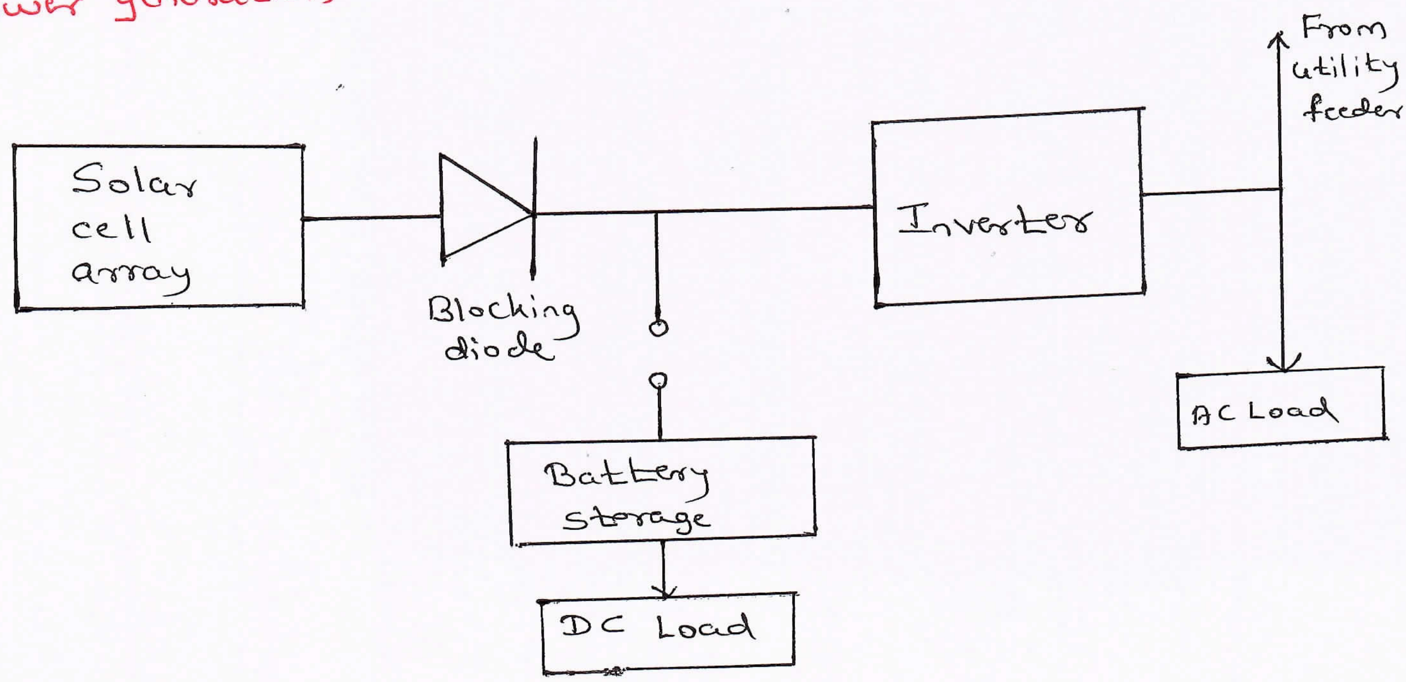
* It is lowest cost renewable energy technology.
* It is clean source of energy, doesn't pollute air.
* It can also be built on farms or ranches.
* It is available as a domestic source of energy in many countries.

Disadvantages of WECS

* Wind is intermittent & not continuosly available.
* Higher initial investment
* Maintenance charge are more.
* Large area is needed.
* Over noise generation.

10 a) Explain the basic solar photo voltaic system for power generation with a neat sketch. 10M

Ans:-



Solar Cell Array → Solar cell converts light energy in to electrical energy. Number of cells are arranged in rows & coloumns is called as array. set of array called as panel.

Blocking diode → It avoids bi-directional power flow. During the night time current may flows from battery to solar panel, it damages the cell. To avoid this blocking diode used.

Battery → It stores the dc charges. Its capacity is interms of Ampere-hours (Ah). Batteries are avilable in different voltages like 6V, 9V, 12 V, 24V, 48V. dry or lead acid batteries are normally used. Greater the Ah longer the duration of use.

Inverter → It converts DC supply to AC supply. It recreates the frequency using fast switching devices like MOSFET, BJT, IGBT, SCR. Inverted supply is applied to ac load or connected to grid.

10b) List the advantages & disadvantages of solar photo voltaic system.

5M

Ans;- Merits of Solar PV system

* No moving parts in this mechanism, so mechanicall lose is zero.
* Cleanest form of energy generation system
* Highly reliable
* High power to weight ratio
* Longer life

Demerits of solar PV system.

* High initial cost
* Low efficiency.
* Bulk storage is costly.

c) Write short notes on horizontal & vertical axis in WECS. 5M

Ans:- Horizontal Axis WECS

* It is widely used for higher volume of production which requires huge space & investment. The rotational axis of horizontal axis wind turbine is parallel towards the direction of wind in order to generate electricity.

* Mainly it consists Tower, Blades, Nacelle, Hub, Drive & main shaft, gear box, Generators.

* Its efficiency is quite high & able to convert strong wind to electricity.

Vertical Axis WECS

* It is widely used for residential purpose. It consists rotor shaft & two or three blades. where the rotor shaft moves vertically.

* It consists Central shaft, Rotor blades, Gear box, Generator, Brake & control unit.

* It doesnt need yaw mechanism, able to operate in any direction. It produces less noise.

* Its efficiency is less & power generating capacity also less.

S M Hegde

HoD

Dean Academics