CBCS SCHEME

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18EE33

Third Semester B.E. Degree Examination, Jan./Feb. 2021
Transformers and Generators

Time: 3 hrs. Max. Marks: 100

Note: *Answer any FIVE full questions, choosing ONE full question from each module.*

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages.
2. Any revealing of identification, appeal to evaluator and /or equations written eg, 42+8 = 50, will be treated as malpractice.

Module-1

1 a. Explain practical transformer on no-load. **(04 Marks)**

b. With the help of a neat circuit diagram and phasor diagram. Explain the operation of a 3-phase star-Delta transformer. **(06 Marks)**

c. Draw the phasor diagram of a transformer supplying Lagging power factor load. **(04 Marks)**

d. A 230/460V single phase transformer has a primary resistance of 0.2 ohm and a reactance of 0.5ohm and the corresponding values for the secondary are 0.75 ohm and 1.8 ohm respectively. Find the secondary terminal voltage when supplying 10A at 0.8 power factor lagging. **(06 Marks)**

OR

2 a. With neat circuit diagrams, discuss in detail how to perform OC and SC tests on single phase transformer. **(08 Marks)**

b. Explain with circuit diagram and phasor diagram how two transformers connected in open delta can supply the power successfully. **(06 Marks)**

c. Find the all day efficiency of a transformer having maximum efficiency of 98% at 15kVA at unity power factor and loaded an follows :
12Hr 2kW at 0.5 power factor
6 Hr 12kW at 0.8 power factor
6 Hr No load. **(06 Marks)**

Module-2

3 a. With a neat circuit, explain how iron losses can be separated into hysteresis and eddy current losses in a transformer. **(08 Marks)**

b. List the conditions to be satisfied for parallel operation of single phase and Three phase transformers. **(04 Marks)**

c. Two 250kVA transformers supplying a network are connected in parallel on both primary and secondary sides. Their voltage ratios are same. The resistance drops are 1.5% and 0.9% and reactance drops are 3.33% and 4% respectively. Calculate the KVA loading on each transformer and its power factor. When the total load on the transformers is 500KVA at 0.707 lagging power factor. **(08 Marks)**

OR

4 a. Obtain the expression for current shared by two transformers with unequal voltage ratios connected in parallel. The transformers have unequal internal impedance. Also draw the phasor diagram. **(08 Marks)**

b. In a 400V, 50Hz transformer, the total iron loss is 2500W. When the supply voltage and frequency reduced to 200V, 25Hz respectively the corresponding loss is 850W. Calculate the eddy current loss at normal voltage and frequency. **(06 Marks)**

c. An auto transformer supplies a load of 3kW at 115V, unity power factor. If the applied voltage is 230V, calculate the power transferred to the load i) inductively ii) conductively. **(06 Marks)**

Module-3

5 a. What is Cooling of transformer? List different methods of cooling and explain any two of them. **(06 Marks)**

b. An 8 pole wave wound DC generator has 480 armature conductors. The armature current is 200A. Find the armature reaction demagnetizing and cross magnetizing ampere turns per pole, if the brushes are shifted 6° electrical from Geometrical natural axis. **(06 Marks)**

c. Define: i) Distribution factor ii) Pitch factor. Derive the expressions for the factors. **(08 Marks)**

OR

6 a. Define Armature reaction in a DC generator. What are the effects of armature reaction? Explain. **(06 Marks)**

b. With necessary diagrams, explain armature reaction in alternator for lagging, unity and leading power factors. **(06 Marks)**

c. A 3 phase, 8 pole, star connected alternator has the armature coils short chorded by 1 slot. The coil span is 165° electrical. The alternator is driven at the speed of 750rpm. If there are 12 conductors per slot, and flux per pole is 50wmb, calculate the value of the induced emf across the terminals. **(08 Marks)**

Module-4

7 a. Define voltage regulation of the alternator and explain the Ampere turn method of predetermination of regulation. **(08 Marks)**

b. Define Short Circuit Ratio (SCR). Explain its significance. **(04 Marks)**

c. A 3 phase 2000KVA star connected 50Hz, 2300V alternator has a resistance between each pair of terminals as measured by direct current is 0.16ohm. The alternator gave a short circuit current of 600A for a excitation. With same excitation the open circuit voltage is 900V (line). Determine the full load regulation at i) unity power factor ii) 0.8pf lagging. **(08 Marks)**

OR

8 a. Explain the zero power factor method of predetermination of regulation of an alternator. **(08 Marks)**

b. Compare synchronous Impedance method and Ampere turn method of predetermining of regulation. **(04 Marks)**

c. A 3.5MVA, star connected alternator at 4160V at 50Hz has an pen circuit characteristics as given by the following data :

I_f, Amp	50	100	150	200	250	300	350
V_{oc}. Volts (Line)	1629	3150	4160	4750	5130	5370	5550

A field current of 200A is found necessary to circulate full load current on short circuit. Calculate by Ampere turn method full load voltage regulation at 0.8pf lagging. **(08 Marks)**

Module-5

9 a. What is synchronization? Explain with the help of a neat sketch. The three lamps dark method of synchronization. **(08 Marks)**

b. Derive an expression for the power angle characteristics of cylindrical rotor alternator. Sketch the power angle curve. **(06 Marks)**

c. An alternator has a direct axis synchronous reactance of 0.7pu and a quadrature axis synchronous reactance of 0.4pu. It is used to supply full load at rated voltage at 0.8pf. Find the induced emf on open circuit. **(06 Marks)**

OR

10 a. With the help of a circuit diagram, explain the measurement of direct axis and quadrature axis reactances by slip test. **(08 Marks)**

b. Draw and explain the capability curve of synchronous generator. **(06 Marks)**

c. What is hunting in synchronous machines? How do you eliminate hunting? **(06 Marks)**

TRANSFORMERS AND GENERATORS

18EE33

3rd SEM

SOLUTION FOR VTU QUESTION PAPER

JAN-FEB 2021

Prof: S. M. INAMADAR

Module-1

1 a Explain Practical Transformer on no load. [4 marks]

Soln: Practical Transformer on No load means secondary is not having any load.

Primary current under no load condition has to supply iron losses [hysteresis and eddy current loss and primary copper loss.

I_o = No load current = [3 to 5% of Full load current]

I_m = Magnetising component of No load current
= Purely reactive and wattless component

I_c = Power component of No load current I_o
= Active component and wattfull component
= Core loss component of No load current I_o

$\hat{I_o} = \hat{I_m} + \hat{I_c}$

I_o lags V_1 by angle ϕ_o

So $\cos\phi_o$ = no load power factor

W_o = Total power input on no load = $V_1 \cos\phi_o I_o$

$W_o = V_1 I_c \quad \because I_c = I_o \cos\phi_o$

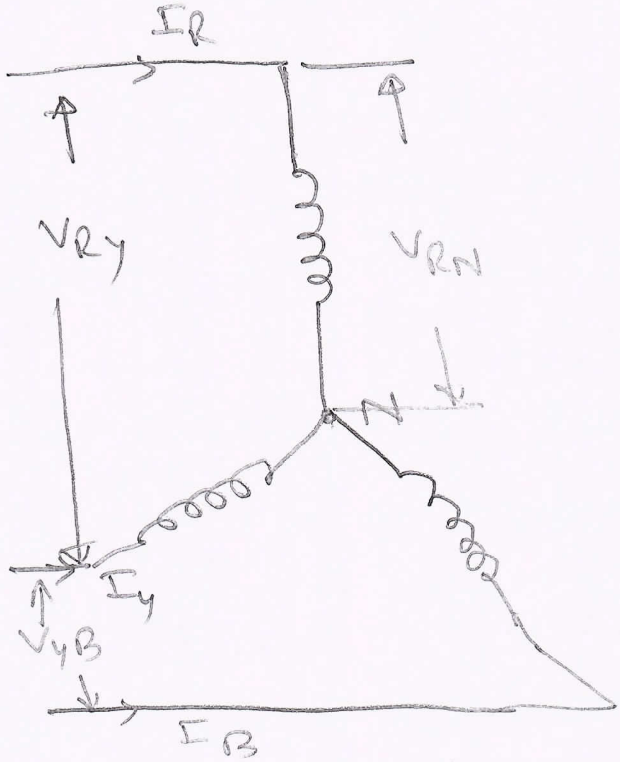
$W_o = V_1 \cos\phi_o I_o \approx P_i$ = Iron loss

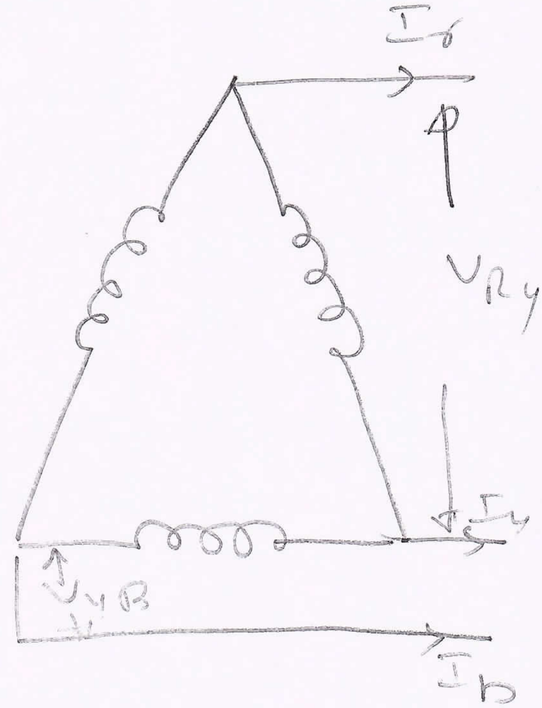
To minimize losses

High grade silicon steel is used

Laminated core are used to reduce eddy current loss. $\eta = \frac{P_{out}}{P_{out} + P_i + P_{cu}}$

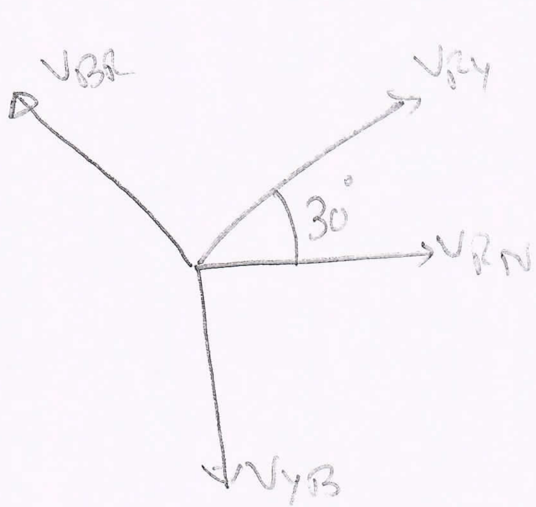
1 (b) With help of neat Circuit Diagram, Explain the operation of 3phase Star-Delta Transformer [06 marks]

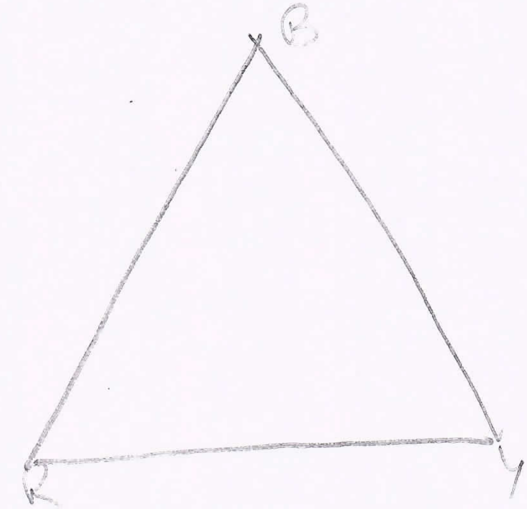


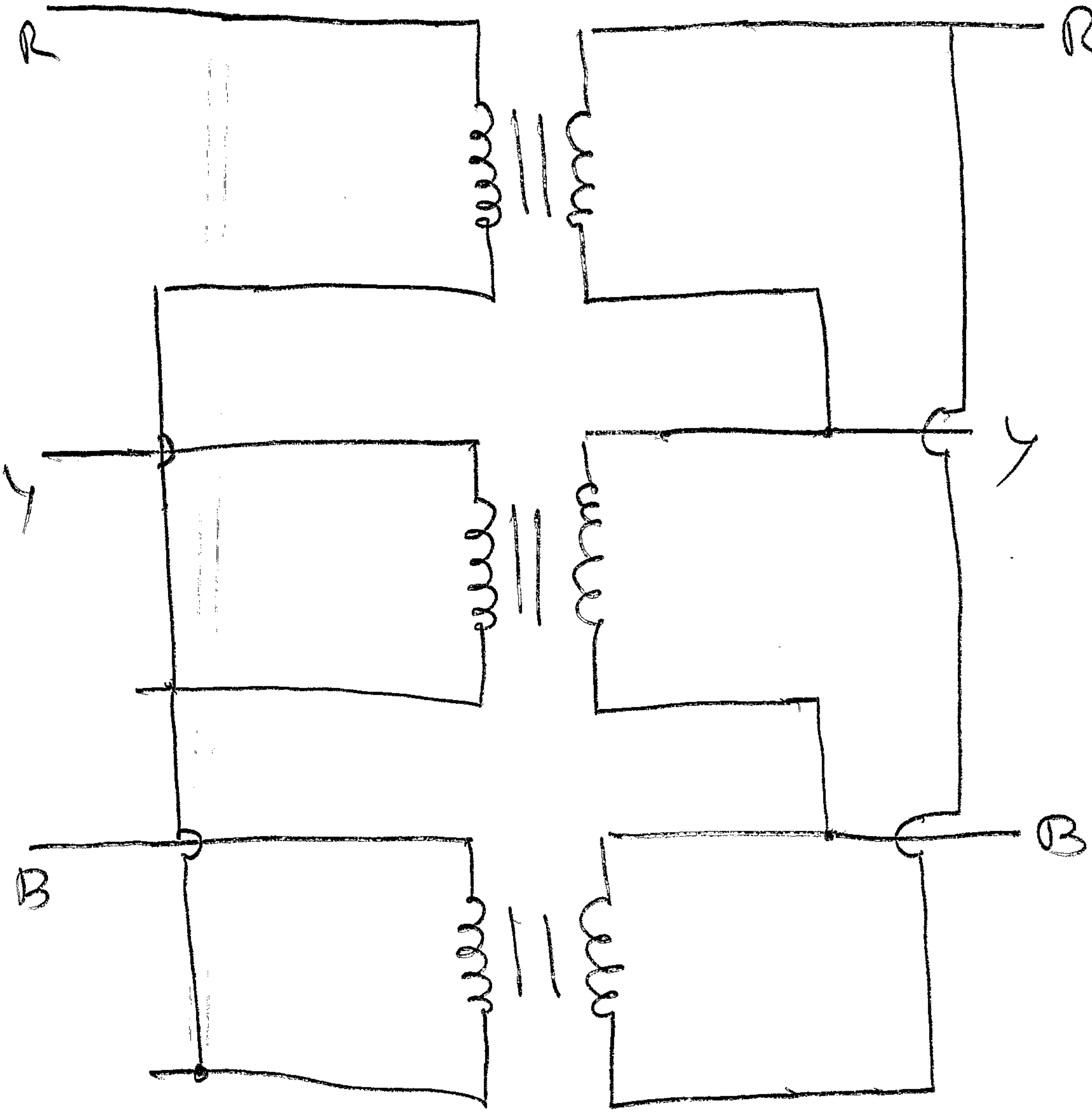


Primary Side

Vector Diagram







Equations for star

$V_{ph} = V_L/\sqrt{3}$ ⇒ Less No of Turns, stress on Insulation is less

$I_{ph} = I_{Line}$ ⇒ windings can bear heavy load and short circuits.

Equation for Delta

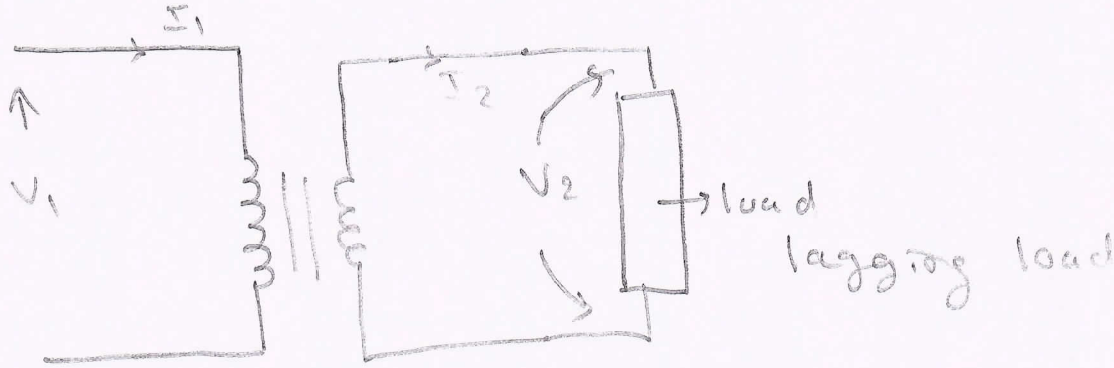
$V_L = V_{ph}$

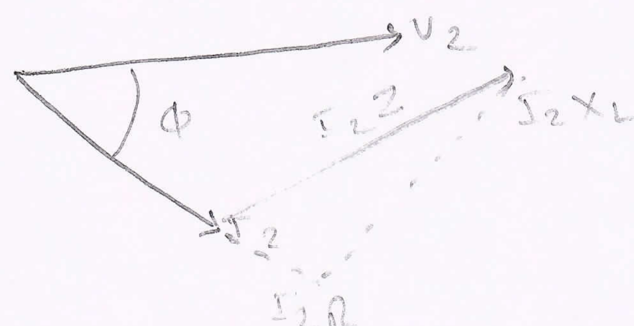
$I_{ph} = I_L/\sqrt{3}$ ⇒ Used for step down of voltage

Star to Delta Connection involves phase difference of 30° between 30° from primary and secondary line voltages.

1 c Draw the Phasor Diagram of Transformer supplying lagging power factor load. [04 marks]

Soln:

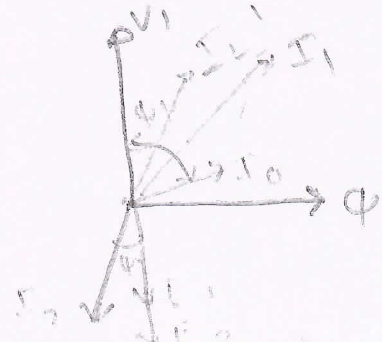




$\cos\phi$ = Power factor = $\frac{R}{Z} = \frac{KW}{KVA}$

Load Z = $R + jX_L$ ∴ lagging load

Circuit diagram and vector diagram are drawn for lagging load. V_2 is output of Transformer



4

1 d A 230/460V, Single phase Transformer has a primary resistance of 0.2 Ω and reactance of 0.5 Ω, and corresponding values for secondary are 0.75 Ω and 1.8 Ω respectively. Find the secondary Terminal voltage when supplying 10A at 0.8 p.f lagging.

[06 marks]

Soln

230V/460V

$R_p = 0.2\,\Omega$ $X_p = 0.5\,\Omega$

$R_s = 0.75\,\Omega$ $X_s = 1.8\,\Omega$

$V_s = ?$ $I_L = 10A$ $\cos\phi = 0.8$ lagging

$\frac{V_2}{V_1} = \frac{460}{230} = K = 2 = \frac{I_1}{I_2}$

$I_{FL} = 10A$

$R_{equivalent} = R_p + R_s' = R_p + \frac{R_s}{K^2}$

$= 0.2 + \frac{0.75}{4} = 0.3875\,\Omega$

$X_{equivalent} = 0.2 + 1.8/4 = 0.65\,\Omega$

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

$\% R = \frac{I_1 [R_{equi} \cos\phi - X_{equivalent} \times \sin\phi)}{V_1}$

$= \frac{10 [0.3875 \times 0.8 - 0.65 \times 0.6)}{230} \times 100$

$= 0.043 [0.31 - 0.585) \times 100 = -1.18\%$

$$\% \text{ Regulation} = \frac{E_2 - V_2}{E_2} \times 100$$

$$-1.18 = \left(\frac{460 - V_2}{460}\right) \times 100$$

$$-1.18 \times 460 = 460 - V_2$$

$$460 - V_2 = -1.18 \times 460$$

$$460 + 1.18 \times 460 = V_2$$

$$460 + 542.8 = V_2$$

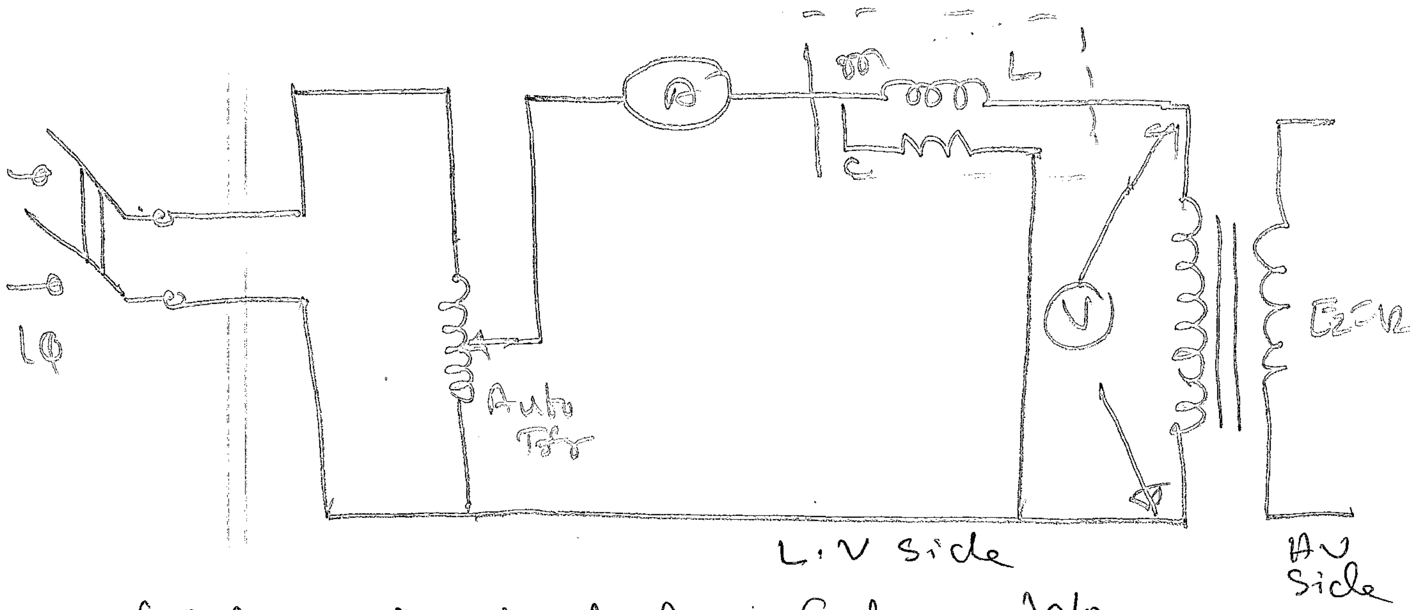
$$\boxed{V_2 = 542.8 \text{ V}}$$

2 (a) With neat Circuit Diagrams, discuss in detail how to perform OC and SC Tests on Single phase Transformer. [08 marks]

Sol: Open Circuit Test is Indirect loading method Secondary is kept open of Single phase Transformer.
Primary side voltage of Transformer is varied from zero volts to upto rated voltage by Auto Transformer connected in Primary. Wattmeter and Ammeter connected gives the no load power and no load current of single phase Transformer.

V_0 = Rated Voltage W_0 = Input Power

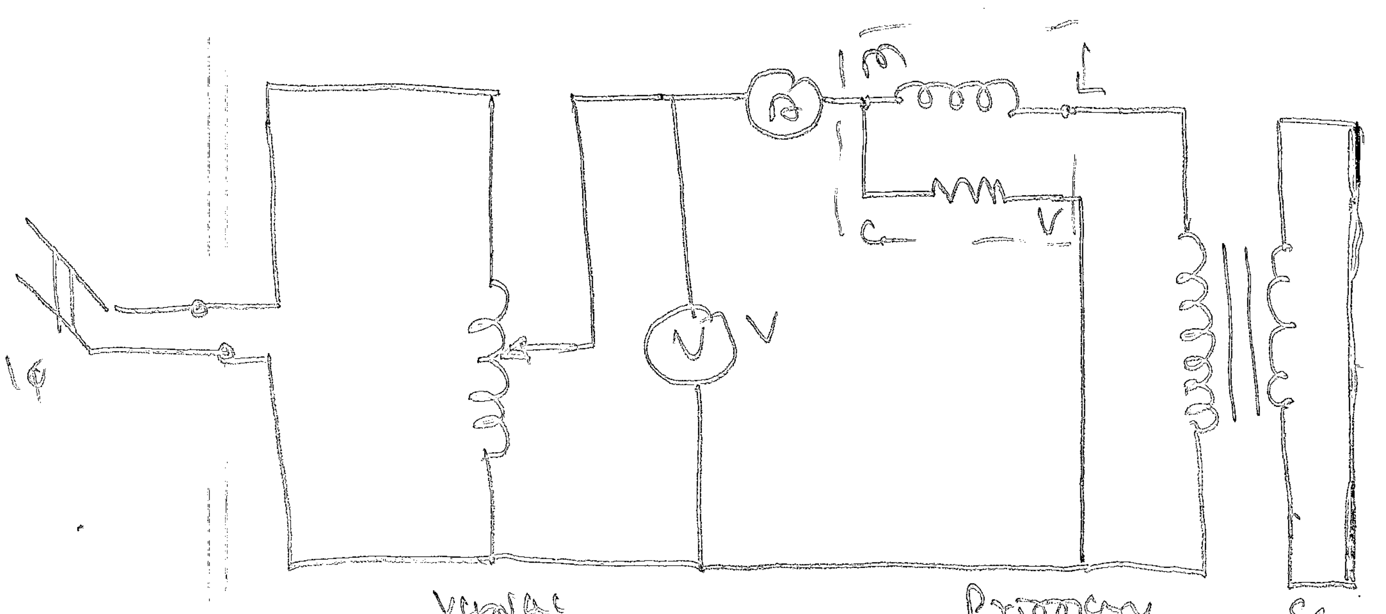
I_0 = No load current



$\cos\phi_0$ = No load power factor = $\frac{W_0}{V_0 I_0}$

O.C Test gives info about iron losses which is constant for all loads.

Short Circuit Test



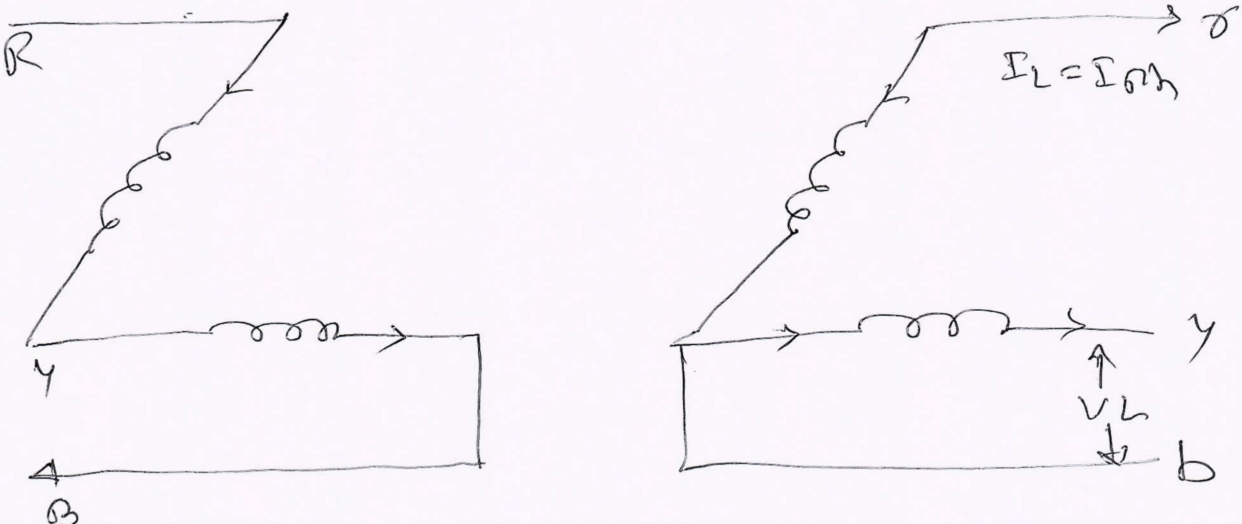
Single phase transformer secondary is shorted with thick wire of copper. Low voltage is applied at primary till rated current at primary is obtained.

W_{sc} = Full load copper loss = $V_{sc} I_{sc} \cos\phi_{sc}$

$\cos\phi_{sc}$ = Short circuit power factor

2b Explain with Circuit Diagram and phasor diagram how two Transformers connected in Open Delta can supply power successfully [06 Marks]

Soln:



Open Delta System helps to connect load in emergency if one transformer is under repair condition.

$$V-V \text{ Capacity} = \sqrt{3} V_L I_L$$

$$= \sqrt{3} V_L I_{ph}$$

Comparing with $\Delta - \Delta$

$$\Delta-\Delta \text{ Capacity} = 3 V_L I_{ph}$$

$$\frac{V-V}{\Delta-\Delta} \text{ Capacity} = \frac{\sqrt{3} V_L I_{ph}}{3 V_L I_{ph}} = \frac{1}{\sqrt{3}} = 58\%$$

We connect only 58% of load under V-V connection.

$$\text{Utility Factor} = \frac{\text{Operating Capacity in V-V}}{\text{Available Capacity in V-V}}$$

$$= 0.866$$

2c Find the All Day Efficiency of a Transformer having Maximum Efficiency of 98% at 15 KVA at unity Power factor and loaded as follows.

1) 12 Hrs 2 Kw at 0.5 power factor

2) 6 Hrs 12 Kw at 0.8 power factor

3) 6 Hrs No load.

[06 marks]

Soln Given Data

$\eta = 98\%$ KVA = 15 KVA at u.p.f

$\cos\phi = 1$

$$\%\eta = \frac{[VA] \cos\phi}{(VA)\cos\phi + 2P_i} \times 100$$

$$0.98 = \frac{15 \times 1000 \times 1}{15 \times 1000 + 2P_i}$$ $P_i = 153.061\,W$

$P_{cu} = P_i = 153.61\,W$

Energy output = 2 Kw × 12 + 12 Kw × 6

= 24 + 72 = 96 kwh

Energy spent due to iron loss = $P_i \times 24$ Hrs

= 3.673 kwh

$\cos\phi = \frac{kw}{kVA}$

$kVA = \frac{2}{0.5} = 4\,kVA$ From load 1

$kVA = \frac{12}{0.8} = 15\,kVA$ from load 2 load 1 $P_{cu} = P_{cu}$ at 15 kVA $\left(\frac{4}{15}\right)^2$

$= 153.061 \times 0.07111$

$= 10.8843$ W

Energy spent = load 1 P_{cu} × Hours

$= 10.8843 \times 12$

$= 130.6116$ Wh

$= 0.130$ kWh

load 2 P_{cu} = P_{cu} at 15 kVA

$= 153.061$ W

∴ Energy spent = $153.061 \text{ W} \times 6$

$= 918.366$

$= 0.9183$ kWh

∴ Total Energy spent = $0.130 + 0.9183 + 3.6734$

$= 4.72236$ kWh

$$\text{All Day Efficiency} = \frac{\text{Total Energy Output in 24 Hrs}}{\text{Total Energy o/p in 24 Hrs} + \text{Energy Spent in 24 Hrs}}$$

$$= \left[\frac{96}{96 + 4.7236}\right] \times 100$$

$= 95.311\%$

All Day efficiency is 95.31%

Module - 2

3 (a) With a neat Circuit, Explain how iron losses can be seperated into hysteresis and Eddy Current losses in transformer. [08 Marks]

Soln:

Core losses = hysteresis losses + Eddy losses

$= P_h + P_e$

$= K_h B_m^{1.67} f V + K_e B_m^2 f^2$

$P_i = P_h + P_e$

$= A B_m^{1.67} f + B B_m^2 f^2$

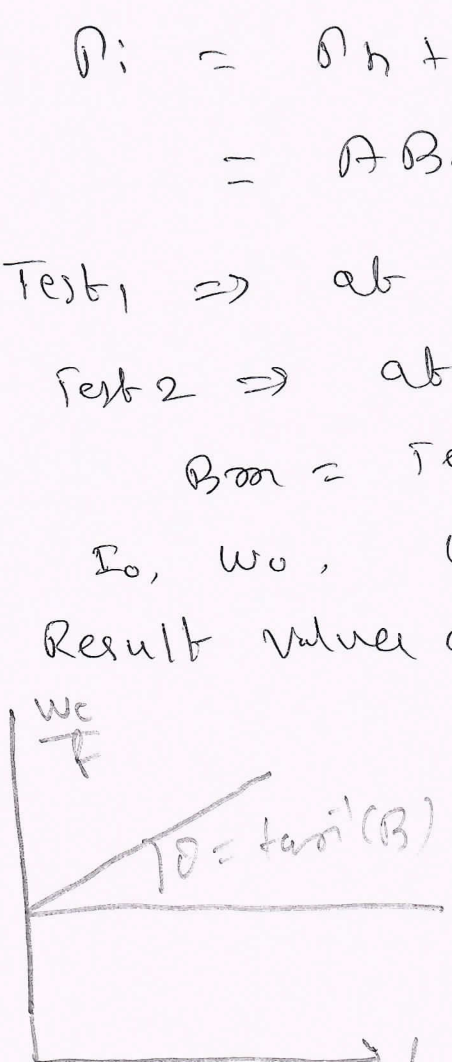
Test 1 ⇒ at f_1 freqency

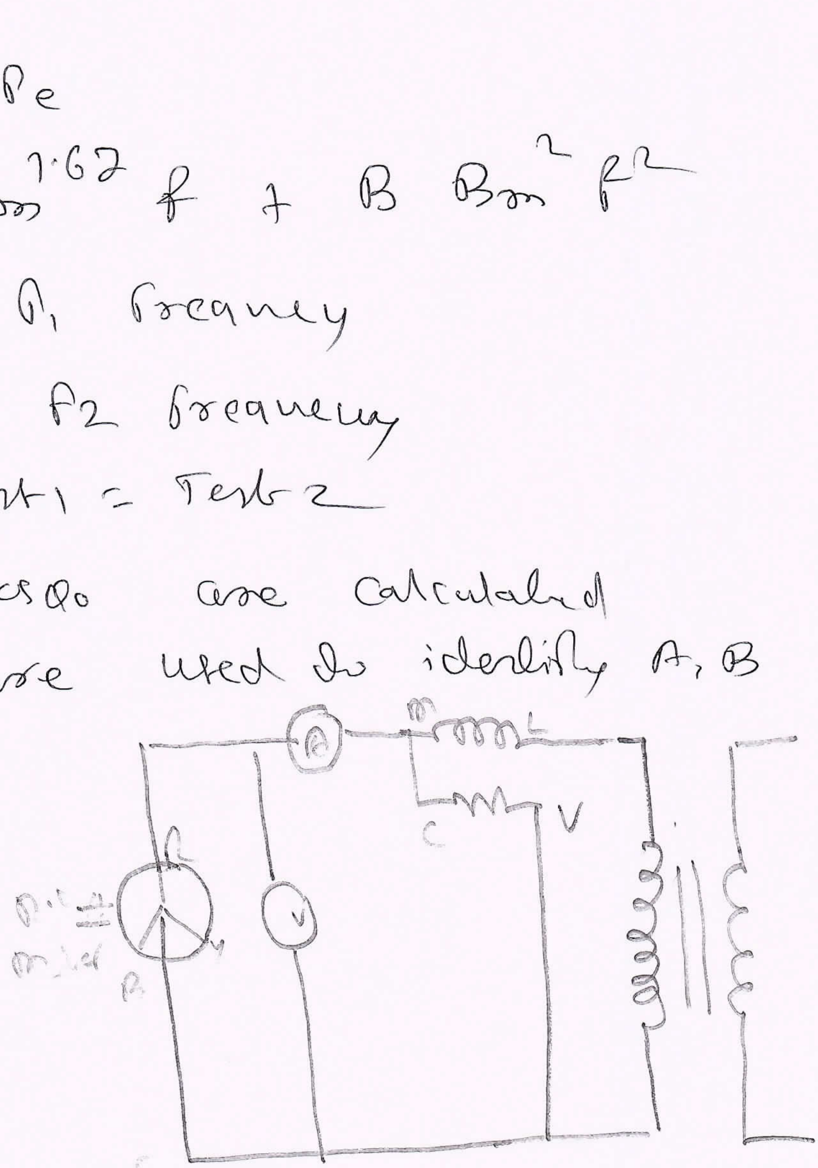
Test 2 ⇒ at f_2 freqency

B_m = Test 1 = Test 2

I_o, W_o, $\cos\phi_o$ are calculated

Result values are used to identify A, B





3 b List the Conditions to be satisfied for Parallel operation of single phase and 3 phase Transformers. [04 Marks]

Soln: Conditions for Single Phase Parallel Operation

1) Transformers Connected have same polarity
2) Voltage ratios of primary and secondary of Transformer must be same.
3) Percentage impedance should be equal in magnitude, to avoid Circulating Currents.
4) If Transformers have different KVA rating, then Equivalent impedance should be inversely proportional to individual KVA ratings

Condition for Three phase Parallel operation

1) Angular Displacements and phase rotation between two units to be made parallel, must be same.
2) Standard lead marks are used for connecting in parallel.
3) Ratio of (R/X) must be same for both transformers.
4) Voltage ratios must be same.
5) Ratio of Equivalent XL to Equivalent R should be same.

3 c

Two 250 KVA Transformer supplying a network are connected in parallel on both primary and secondary side. Voltage ratios are same. Resistance drops are 1.5% and 0.9% and reactance drops are 3.33% and 4%. Calculate KVA loading on each Transformer and it's power factor. When the total load on Transformer is 500 KVA at 0.707 lagging power factor.

[08 mark]

Soln: (S_1) Transformer 1 $\Rightarrow$ $Z_1 = R_1 + jX_1 = 1.5 + j3.33$

$\Rightarrow Z_1 = 1.5 + j3.33 = 3.65\angle 65.751$

(S_2) Transformer 2 $\Rightarrow$ $Z_2 = R_2 + jX_2$

$= 0.9 + j4 = 4.1\angle 77.32°$

$S = 500$ KVA $\cos\phi = 0.707$ $\phi = 45.008$

$Z_1 + Z_2 = 1.5 + j3.33 + 0.9 + j4$

$= 2.4 + j7.33 = 7.713\angle 71.87°$

$S_1 = S\left(\frac{Z_2}{Z_1+Z_2}\right) = 500\angle -45.008 \times \left(\frac{4.1\angle 77.32°}{7.713\angle 71.87°}\right)$

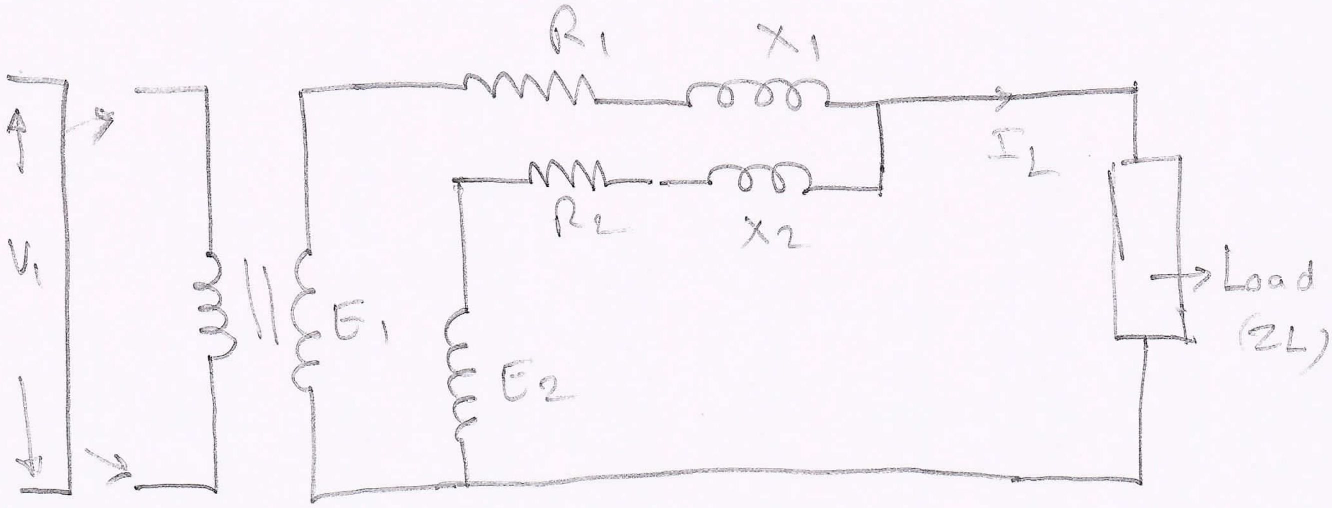
$S_1 = 265.78\angle -39.558$

$S_2 = 500\angle -45.008 \left\{\left(\frac{Z_1}{Z_1+Z_2}\right) \times \frac{3.65\angle 65.751}{7.713\angle 71.880}\right\}$

$S_2 = 236.09\angle -50°$

KVA load shared is 265 and 236

4 (a) Obtain the Expression for Current shared by two transformer with unequal voltage ratios connected in parallel. The transformer have unequal internal impedance. Also draw the phasor diagram. [08 marks]



let voltage Ratio of Transformer1 is more than 2nd Transformer.

So $E_1 > E_2$

Terminal voltage $\simeq (E_1 - E_2)$

$$I_c = \text{Circulating Current} = \frac{E_1 - E_2}{Z_1 + Z_2}$$

$E_1 = V_2 + I_1 Z_1 \qquad E_2 = V_2 + I_2 Z_2$

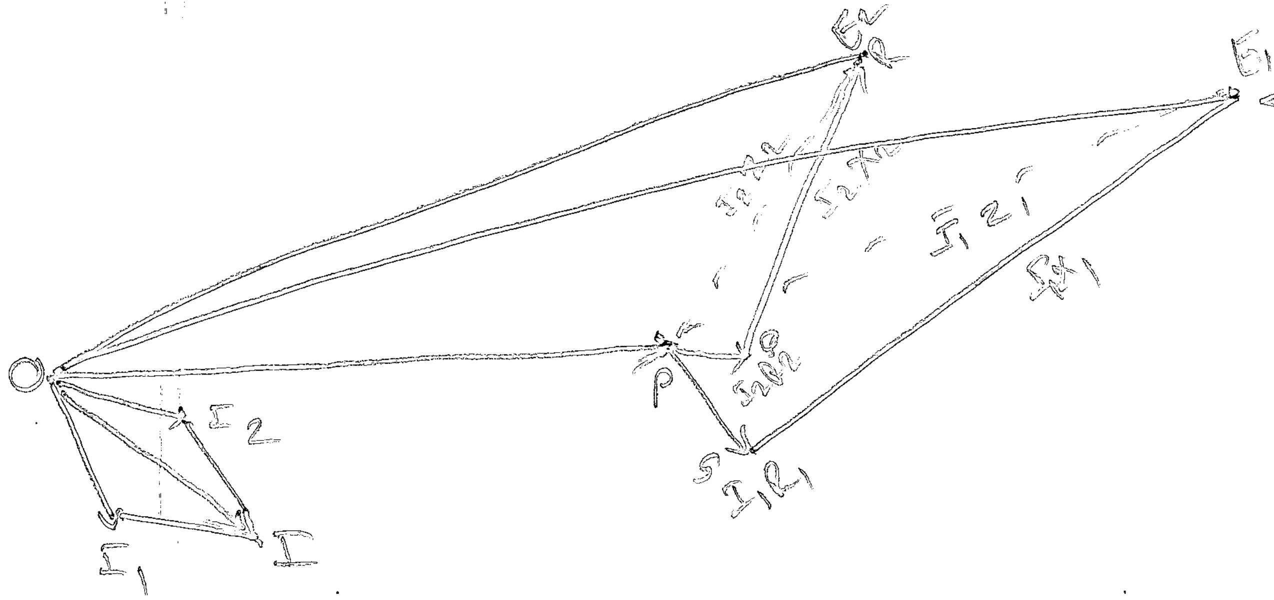
let $I_L = I_1 + I_2$

$$I_1 = \frac{(E_1 - E_2) + I_2 Z_2}{Z_1}$$

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

$$I_1 + I_2 = \frac{E_1 Z_2 + E_2 Z_1}{Z_1 Z_2 + Z_L(Z_1 + Z_2)}$$

Phasor Diagram



$$V_2 = \frac{\frac{E_1}{Z_1} + \frac{E_2}{Z_2}}{\frac{1}{Z_L} + \frac{1}{Z_2} + \frac{1}{Z_1}}$$

4 (b) In a 400V, 50 Hz Transformer, total iron loss is 2500 W. When supply voltage and frequency reduced to 200V, 25 Hz respectively, corresponding loss is 850W. Calculate the eddy current loss at normal voltage and frequency. [06 marks]

Soln: Total iron loss = 2500 W

$$P_i = P_h + P_e = Af + Bf^2$$

$$2500 = A \times 50 + B(50)^2$$

$$850 = A \times (25) + B(25)^2$$

$$\frac{2500}{850} = \frac{(50A + 50^2 B)}{(25A + 25^2 B)}$$

$$2500(25A + 25 \times 25B) = 850(50A + 50 \times 50B)$$

$$62500A + 1562500B = 42500A + 2125000B$$

$$20000A = 562500B$$

$$1 = \frac{562500B}{20000A}$$

$$A = 28.125B$$

$$2500 = 28.125B \times 50 + 2500B$$

$$2500 = 3906.25B$$

$$B = 0.64 \qquad A = 18$$

Eddy current loss at normal V & frequency

$$P_e = Bf^2 = 0.64 \times 50 \times 50 = 1600W$$

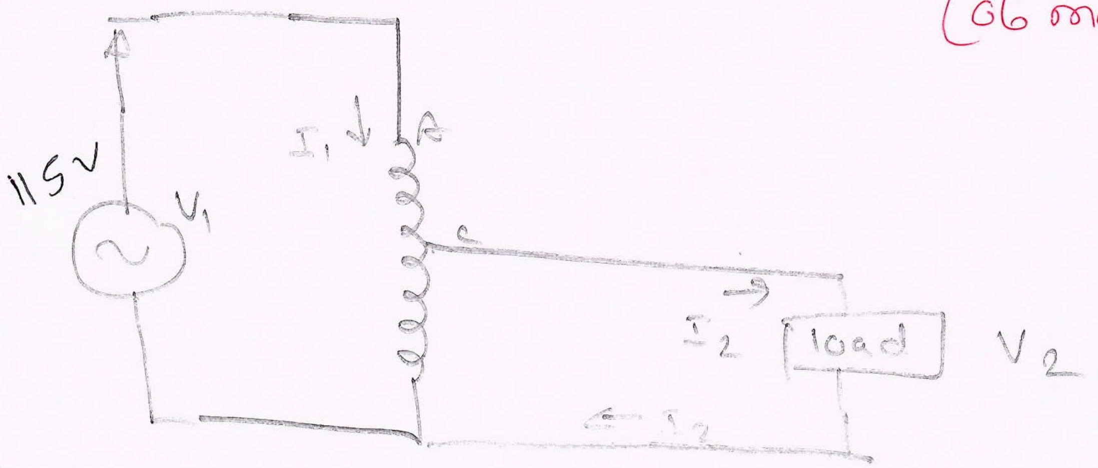
$$\boxed{P_e = 1600W}$$

4 c

An Auto Transformer supplies a load of 3 kW at 115 V, unity power factor. If voltage is 230 V, Calculate power transferred to load i) Inductively ii) Conductively

(06 marks)

Soln:



115 V

230 V

$\cos\phi = 1 = \cos\phi_2$ load $= 3$ kW

$P_{out} = V_2 I_2 \cos\phi_2$

$3\,kW = 115 \times I_2 \times 1$

$I_2 = 26.086$ A

Inductively let us Assume $\cos\phi_2 = 0.8$

$P_{out} = V_2 I_2 \cos\phi_3$

$= 230 \times 26.086 \times 0.8$

$P_{out} = 4799$ watt

$P_{out} = 4.8$ kW

Conductively load

$P_{out} = V_2 I_2 \cos\phi_4$

$= 230V \times 26.086 \times E0.8)$

$P_{out} = -4.8$ kW

Module - 3

5 (a) What is Cooling of Transformer? List different methods of cooling and Explain any two of them. (06 marks)

Cooling of Transformer is the protection applied against the heat developed in transformer due to iron losses and copper losses. Coolant is External air or transformer oil or external fans.

List of differents Cooling methods

1) Air Natural (AN) - Dry Type Transformer
2) Air Blast (AB) - Compressed Air, Blower, fans
3) Oil Natural (ON) - oil filled Transformer
4) Oil Natural Air Forced (ONAF) - "
5) Oil Natural Water Forced (ONAWF) - "

Oil forced methods with Heat Exchanger

6) Oil Forced Air Natural (OFAN)
7) Oil Forced Air Forced (OFAF)
8) Oil Forced Water Forced (OFWF)

Oil Forced Air Forced method uses heat Exchanger. At higher loads, both Fans & Pumps are switched on. Efficiency is high. Example is 100MVA Transformer having Conservator Tank.

Oil Forced water Forced method uses heat Exchanger and water inlet is provided. more than 30 MVA rating, this method is applied

5 (b) A 8 pole D.C Generator has 480 armature conductors. I_a is 200 A. Find armature reaction demagnetizing and cross magnetizing ampere turns per pole, if the brushes are shifted 6° electrical from geometrical neutral axis. (06 marks)

Soln

$P = 8 \qquad Z = 480 \qquad I_a = 200\ A$

$$I = \frac{I_a}{2} = \frac{200}{2} = 100\ A$$

Since D.C Generator is wave wound

$A = 2$

Since brushes are shifted 6° electrical from GNA

$$\theta_m = \frac{\theta_e}{P/2} = \frac{6}{8/2} = \frac{6}{4} = 1.5^\circ$$

Demagnetizing AT are

$$AT_d/\text{pole} = Z I \frac{\theta_m}{360} = \frac{480 \times 100 \times 1.5}{360}$$

$$\boxed{AT_d/\text{pole} = 200}$$

Cross magnetizing AT_c/pole

$$AT_c/\text{pole} = Z I \left[\frac{1}{2P} - \frac{\theta_m}{360}\right]$$

$$= 480 \times 100 \left[\frac{1}{16} - \frac{1.5}{360}\right]$$

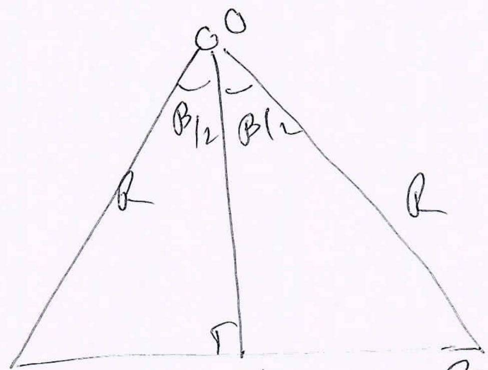
$$\boxed{AT_c/\text{pole} = 2800}$$

5c Define
i) Distribution Factor ii) Pitch Factor
Derive Expression for the Factor.
(08 marks)

Soln: i) Distribution Factor (kd)
The Factor by which there is reduction in the emf due to distribution of coils is called distribution Factor (kd)

Derivation
let m = No of phase = ex: 3
n = slots / pole
let r = no of coils under pole / phase and in series.
E = induced emf / coil
let C = no of slots / pole / phase

$$\beta = \frac{180^\circ}{C}$$



E_R = Resultant emf
$= C\beta$

$E = 2R\sin\left(\frac{\beta}{2}\right)$

$E_R = 2CR\sin\left(\frac{\beta}{2}\right)$

$$Kd = \frac{E_R \text{ when coils are distributed}}{E_R \text{ when coils are connected}}$$

$$= \frac{\sin\left(\frac{C\beta}{2}\right)}{C\sin\left(\frac{\beta}{2}\right)}$$

* Kd = Always less than (1)

ii) Pitch Factor

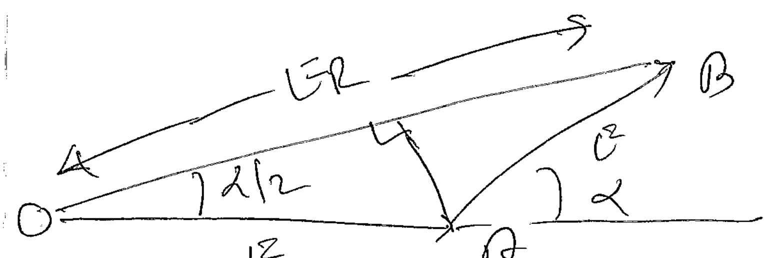
It is defined as ratio of resultant emf when coil is short pitch to the resultant emf, when coil is full pitched

a = Angle of short pitch

a = β × No of slots by which coils are short pitched.

a = 180° − Actual coil span of coils.

$$K_c = \frac{E_R \text{ when coil (short pitched)}}{E_R \text{ when coil (is full pitched)}}$$



$$E_R = 2E\cos(\alpha/2)$$

When coils are short pitched, two emf in two coil sides no longer remains in phase.

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

Pitch Factor = Coil Span Factor

6 (a) Define Armature Reaction in D.C Generator. What are the Effects of Armature Reaction? Explain [06 Marks]

Soln: Definition of Armature Reaction

The Effect of Armature Flux provided by armature conductor on the distribution of main field Flux [by field coil] is called Armature Reaction.

Effects of Armature Reaction

1) Generated EMF is reduced due to decrease in Flux/pole value.

2) Iron losses in teeth and pole shoes are more on load than without any load.

3) Bmax Increases, in turn Vmax between adjacent commutator segment at load. If voltage exceeds 30V, then sparking occurs.

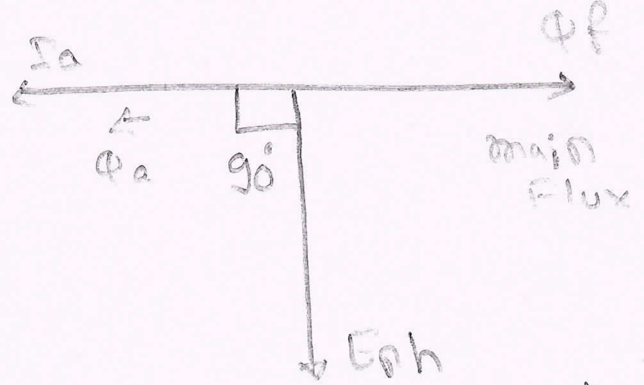
4) Brush Axis is shifted from GNA there will be induced emf in coil undergoing commutation which will try to maintain current in original direction. So overall commutation is delayed.

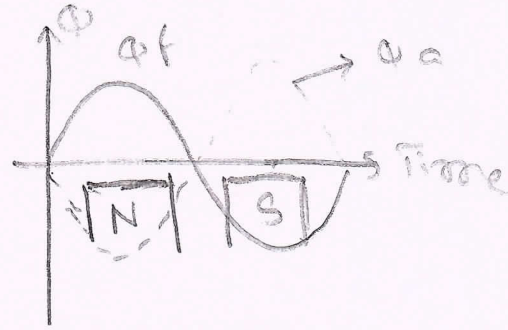
The pole tip which is met first during rotation by armature conductor is known as leading pole tip and other is known as trailing pole tip.

6 (b) With necessary diagrams, Explain armature Reaction for lagging, unity and leading power factor for alternator (06 marks)

Soln

Armature Reaction for lagging P.f

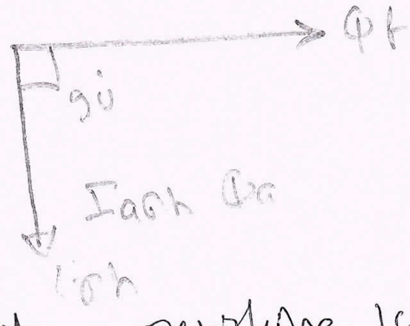


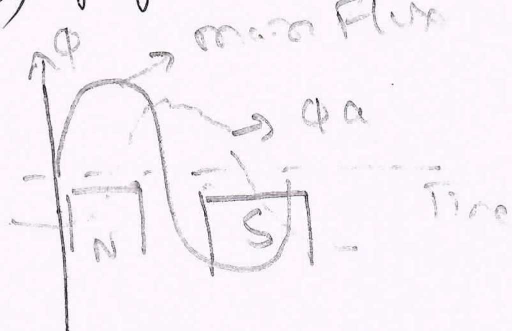


Purely inductive load. Iaph lags Eph by 90°

Φa is in same direction as that of Ia. Armature Flux and main Flux are in opposite Direction. We call it as Demagnetizing effect.

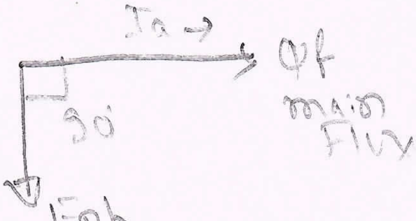
Armature Reaction for Unity P.f





Purely resistive load, Average Flux in airgap remains constant but its distribution gets distorted. We call it as Cross Magnetizing Effect.

Armature Reaction For leading P.f



Purely Capacitive load

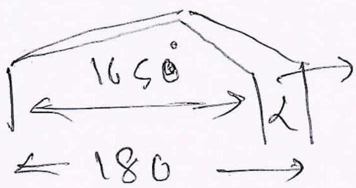
Iaph leads Eph by 90°. Each flux help each other. Magnetizing effect.

6 (C) A 3φ, 8 pole star connected Alternator has armature coils short chorded by 1 slot. Coil span is 165° Electrical. Alternator is driven at speed of 750 r.p.m. If there are 12 conductor/slot, and flux/pole is 50 mwbs, Calculate value of induced emf across the terminals [08 marks]

Soln:

$P = 8$ 3φ, 50 Hz, star connected

$N_S = 750$ r.p.m   Coil span = 165°



→ chorded by 1 slot

$\alpha = 180° - 165° = 15°$

$\alpha = \beta = 15°$

$\beta = \frac{180°}{n} = \frac{180°}{15°} = 12$ = slots/pole

1 slot = 12 conductors

slots/pole = 12

Total poles = 8

Total slots = ~~3~~ × 8 × 12 = ~~288~~ = 96

Z = Total conductors = 96 × 12 = 1152

$K_d = \frac{\sin \frac{m\beta}{2}}{m \sin \beta/2} = \frac{\sin\left(\frac{4 \times 15°}{2}\right)}{4 \sin\left(\frac{15°}{2}\right)} = 0.9576$

$K_c = \cos \frac{\alpha}{2} = \cos\left(\frac{15°}{2}\right) = 0.9914$

$f = \frac{750 \times 8}{120} = 50$ Hz

$T_{ph} = \frac{Z_{ph}}{2} = \frac{1152/3}{2} = 1152/6 = 192$

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

$= 4.44 \times 0.9914 \times 0.9576 \times 50 \times 10^{-3} \times 50 \times 192$

$= 2.023$ kV

$E_{line} = \sqrt{3} \times 2.023 = 3.504$ kV

Module - 4

7 (a) Define Voltage Regulation of Alternator and Explain Ampere Turn method of predetermination of regulation. [08 marks]

Soln: Definition of Voltage Regulation

: Voltage Regulation of Alternator is defined as the change in it's terminal voltage when full load is removed, keeping field excitation and speed constant, divided by rated Terminal voltage.

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

E_{ph} = No load induced emf

V_{ph} = Rated Terminal voltage

It depends on Load currents and Power Factor. For lagging and unity p.f, there is drop in terminal voltage, hence regulation values are always +ve. For leading p.f, Regulation is -ve.

Explanation for Ampere Turn Method

This method needs Results of Open Circuit Test and Short Circuit Test. It is also called Rothert's m.m.f method.

magnetomotive Force (m.m.F) = Field current × Turns

i) m.m.F necessary to induce rated Terminal voltage on open circuit.

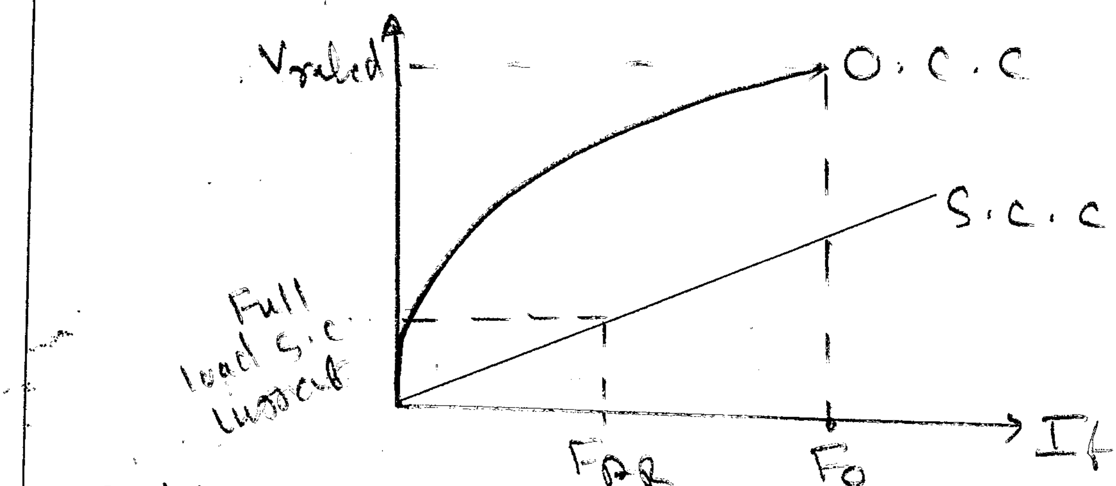
ii) m.m.F Equal and Opposite to that of Armature Reaction m.m.f.

$Z_s = R_a + jX_s$

$X_s = X_{L\,leakage} + X_L$ (Armature Reaction)

In short circuit test, m.m.f is necessary to overcome drop across Ra and XL and to overcome effect of Armature Reaction. Field m.m.f circulates I.F.L balancing armature reaction effect.

FAR = Ampere Turns Required to circulate I.F.L from S.C test.



Field m.m.f is used for overcoming Armature reaction which is demagnetising.

Total Field m.m.f = vector sum of Fo and FAR

Zero lagging p.f (Demagnetising) = FR = Fo + FAR

Zero leading p.f (Magnetising) = FR = Fo - FAR

Unity p.f (Cross Magnetising) = FR = $\hat{F_o} + \hat{F_{AR}}$

If p.f = $\cos\phi$

$\cos\phi$ (lagging) $= (F_R)^2 = (F_o + F_{AR}\sin\phi)^2 + (F_{AR}\cos\phi)^2$

$\cos\phi$ (leading) $= (F_R)^2$
$= (F_o - F_{AR}\sin\phi)^2 + (F_{AR}\cos\phi)^2$

% Regulation = (Eph - Vph)/Vph × 100
Optimistic method (less value)

7 (b) Define Short Circuit Ratio (SCR) Explain it's Significance [08 marks]

Soln: Definition of Short Circuit Ratio

It is the ratio of 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.

$$S.C.R = \frac{I_f \text{ rated O.C. Voltage}}{I_f \text{ rated S.C Current}}$$

$$Z_S = \frac{V_{oc}\ (\text{phase})}{I_a(s.c)\ (\text{phase})} = X_S$$

Neglecting R_a

$$X_S(p.u) = X_S / \text{Base Impedance}$$

$$\text{Base Impedance} = \frac{V_{rated}/\text{phase}}{I_a(\text{rated})/\text{phase}}$$

$$S.C.R = \frac{1}{X_S\ (\text{per unit})}$$

Significance

1) Low S.C.R ⇒ X_S is high, $(I_a X_S)$ is more ⇒ large changes in excitation for small changes in load.

2) Low S.C.R ⇒ Smaller Air Gap and poor voltage regulation.

3) Low S.C.R ⇒ X_S is high Synchronizing power decreases, stability decreases

4) By increasing air gap, S.C.R can be increased.

7 (c) A 3 phase 2000 KVA, star connected 50 Hz, 2300 V alternator has a resistance between each pair of terminals as measured by direct current is 0.16 Ω (ohms). Alternator gave a short circuit current of 600 A for excitation. With same excitation the open circuit voltage is 900 V (line). Determine full load regulation at i) unity p.f ii) 0.8 p.f lagging

Soln: Data given

2000 KVA, star connection, 2300 V

$R_a = \frac{0.16}{2} = 0.08\ \Omega/\text{phase}$

$I_{SC} = 600\ A$ $\quad V_{OC}\ (\text{line}) = 900\ V$

$Z_S = \frac{V_{OC}\ (\text{phase})}{I_a (S.C)(\text{phase})} = \frac{\frac{900}{\sqrt{3}}}{600} = \frac{519.33}{600}$

$Z_S = 0.8655\ \Omega/\text{phase}$

$X_S = \sqrt{(Z_S)^2 - (R_a)^2} = \sqrt{(0.8655)^2 - (0.08)^2}$

$X_S = \sqrt{0.7490 - 0.0064} = \sqrt{0.7426}$

$X_S = 0.86168\ \Omega/\text{phase}$

$I_{F.L} = \frac{2000 \times 1000}{2300} = 869.56\ A$

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

$(E_{ph})^2 = (1342 \times 1 + (~~869.56~~\ 600 \times 0.08))^2 + (~~869.56~~\ 600 \times 0.86168)^2$ 267297.22

$= (1342 + ~~69.56~~\ 69 ...)^2 + ~~561423.56~~$

$(E_{ph})^2 = ~~3,82,07,975.586~~$ 1938701, 1932100 $+ ~~561423.56~~$

$E_{ph} = ~~38,769,349.04~~ = 1483.03\ V$

$E_{ph} = \sqrt{2199392.22}$ $\quad E_{ph} = ~~\sqrt{2199392.22}~~ = ~~872.48~~$

(28)

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

$$= \frac{1483.03 - 1342}{1342} \times 100$$

$= 10.52\% \Rightarrow 11\%$

For 0.8 p.f lagging

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

$$= \sqrt{(1342 \times 0.8 + 600 \times 0.08)^2 + (1342 \times 0.6 + 600 \times 0.8616)^2}$$

$$= \sqrt{(1073.6 + 48)^2 + (805.2 + 517.08)^2}$$

$$= \sqrt{1257986.56 + 1748233.99}$$

$$= \sqrt{3006220.55}$$

$E_{ph} = 1733.84$

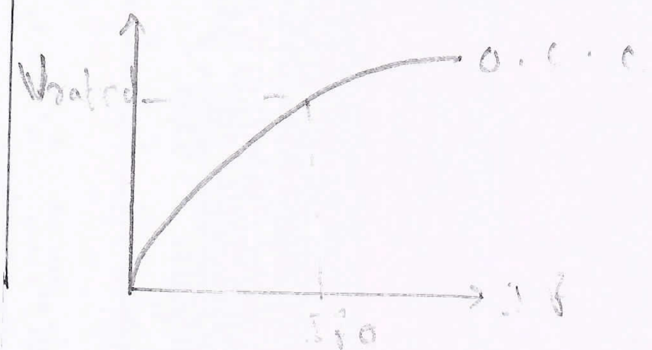
$$\% \text{ Regulation} = \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100$$

$$= \frac{1733.84 - 1342}{1342} \times 100$$

$= 29.19\%$

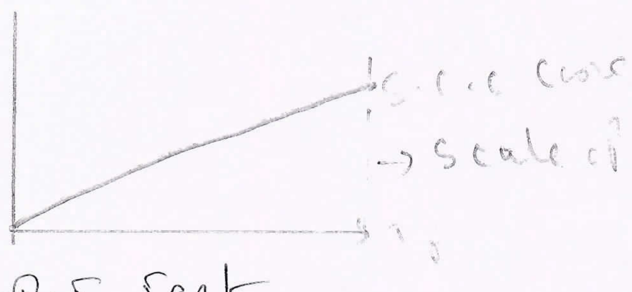
8a Explain the zero power factor method of predetermination of regulation of an Alternator [08 marks]

Soln: Zero Power Factor method is also known as Potier Triangle method.
In this method, $I_a R_a$ drop and $I_a X_L$ drop are emf quantities, but armature reaction is basically mmf quantity.
X_L => Potier reactance.
For Z.P.F method, we need O.C Test data, S.C Test data

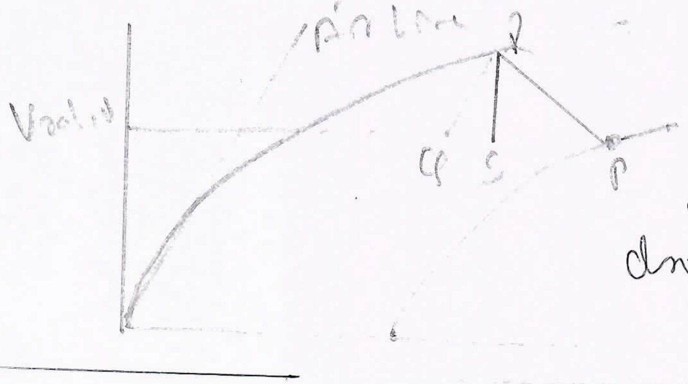


If0 is field current required for rated phase voltage on O.C.C curve

$$X_L = \frac{\text{Scale of } (PS)}{(I_{aph})\ F.L}$$



Z.P.F Test
1) Purely inductive load is connected p.f = ϕ = 90°
2) Alternator is run at synchronous value.
3) Excitation is varied till rated full load values are obtained.



scale of PS gives voltage drop due to X_L,
F.A.R = Scale (RS)

8b Compare Synchronous Impedance method and Ampere Turn method of predetermining of voltage Regulation

-[04 Marks]

Soln:

1) EMF method is also called as Synchronous Impedance method	1) MMF method is also called Ampere Turn method
2) Direct load connection not Required	2) Direct load connection not Required
3) Indirect method	3) Indirect method
4) Large X_s, Higher V.R than Actual. Pessimistic method	4) Lower V.R than Actual. Optimistic method
5) O.C Test and S.C Test	5) O.C Test, S.C Test
6) Regulation can be obtained for any load p.f	6) Regulation at desired power factor can be obtained.

8c A 3.5 MVA, star connected Alternator at 4160V at 50 Hz has open circuit characteristics

If	50	100	150	200	250	300	350
Voc volts line	1629	3150	4160	4750	5130	5320	5550

Field current of 200 A is found necessary to circulate full load current on short circuit. Calculate by Ampere Turn method full load V.R at 0.8 p.f lagging. [08 Marks]

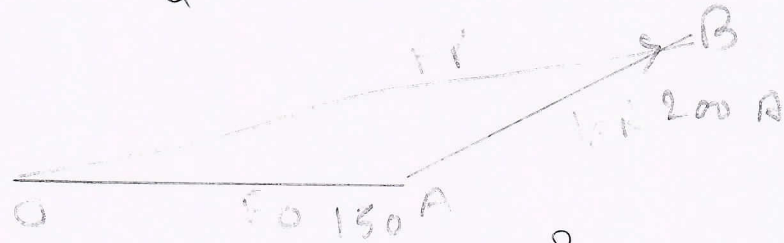
Soln:

Rated Terminal Voltage = 4160V

Field current = If = 150 A = F_O

Field current to get full load current on S.C => 200 A = F_{AR}

$\phi = \cos^{-1}(0.8) = 36.86^\circ$



$F_R^2 = F_O^2 + F_{AR}^2 - 2 F_O F_{AR} \cos(90+\phi)$

$= (150)^2 + (200)^2 - 2\times150\times200 \cos(90+36.86)$

$F_R = 313.847$ A

From table of Voc line for $F_R = 313.847$

the Voc(line) = 5400V (Referred value)

$E_{ph} = 5400/\sqrt{3} = 3117.69$ V

$\% \text{ Regulation} = \frac{3117.69 - 2401.77}{2401.77} \times 100$

$= 29.807 \%$

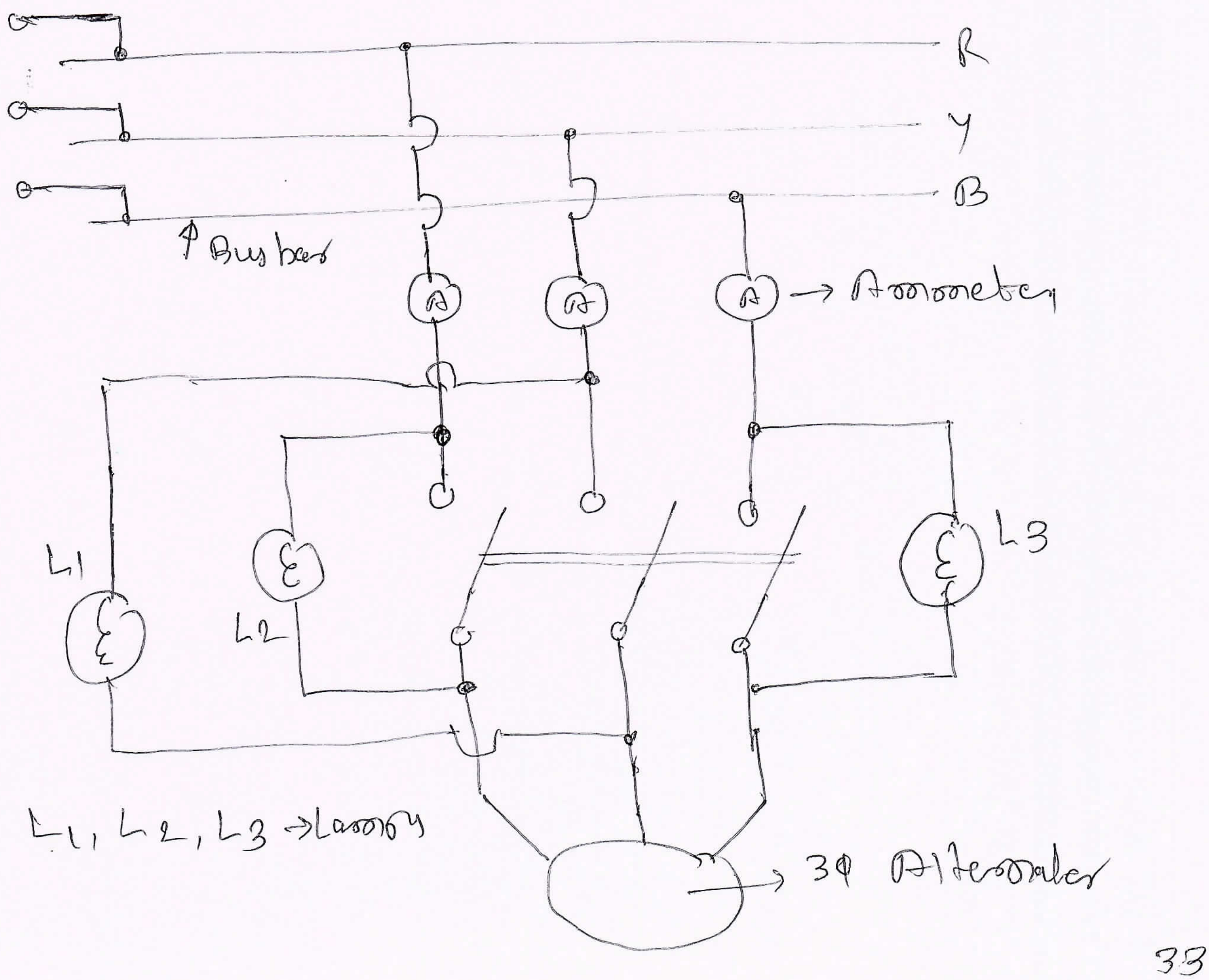
Module - 5

9 (a) What is Synchronization? Explain with help of neat sketch. The 3 lamps dark method of synchronization. [08 marks]

Soln The process of switching of an alternator to another alternator or with common bus bar without any interruption is called synchronization. The m/c synchronized is called as Incoming m/c.

1) Terminal voltage of incoming m/c must be same as that of bus bar voltage and frequency also.

2) Phases also should be identical with Bus bar voltage.



For unequal frequencies, L1, L2, L3 will flicker at a rate equal to difference in frequencies.

For phase sequence correct

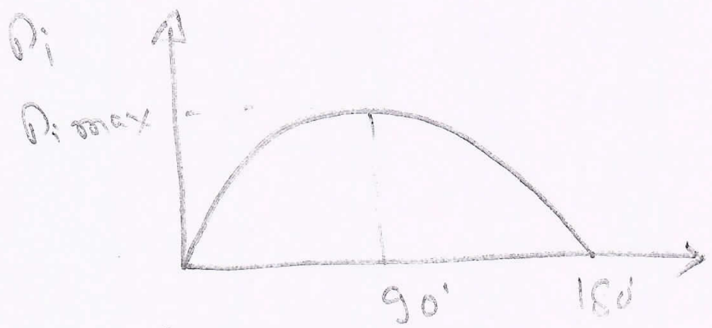
All lamps will become dark and bright simultaneously.

If not done,

Two terminals of incoming one are interchanged.

Correct instant of closing switch is middle of dark period of L1, L2, L3

9 (b) Derive an expression for the power angle characteristics of cylindrical rotor alternator. Sketch the power angle curve [06 marks]



$P = VI\cos\phi \Rightarrow$ power o/p per phase

$P = VI\cos\theta + I^2 R_a \Rightarrow$ power i/p

$\hat{E} = \hat{V} + \hat{I}\hat{Z_s}$

P_i = mechanical power i/p

$= \frac{E}{Z_s}[E\cos\theta - V\cos(\theta + \delta)]$

$P_o = \frac{-V^2}{Z_s}\cos\theta + \frac{VE}{Z_s}\cos(\theta - \delta)$

If R_a is neglected

$P_o = \frac{VE}{X_s}\sin\delta$

9c An alternator has a direct axis synchronous reactance of 0.7 p.u and quadrature axis synchronous reactance of 0.4 p.u. It is used to supply full load at rated voltage at 0.8 p.f. Find the induced emf on open circuit.

(06 marks)

Soln:

$X_d = 0.7$ p.u

$X_q = 0.4$ p.u

$\cos\phi = p.f = 0.8$ lag

$\phi = 36.86°$

let Rated Terminal Voltage = 1 p.u

Full load Armature Current I_a = 1 p.u

$R_a = 0$

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

$$= \frac{1 \times 0.6 + 1 \times 0.4}{1 \times 0.8 + 1 \times 0}$$

$= 1.25$

$\psi = \tan^{-1}(1.25) = 51.34°$

$I_d = I_a \sin\psi = 1 \times \sin 51.34$

$= 0.7808$

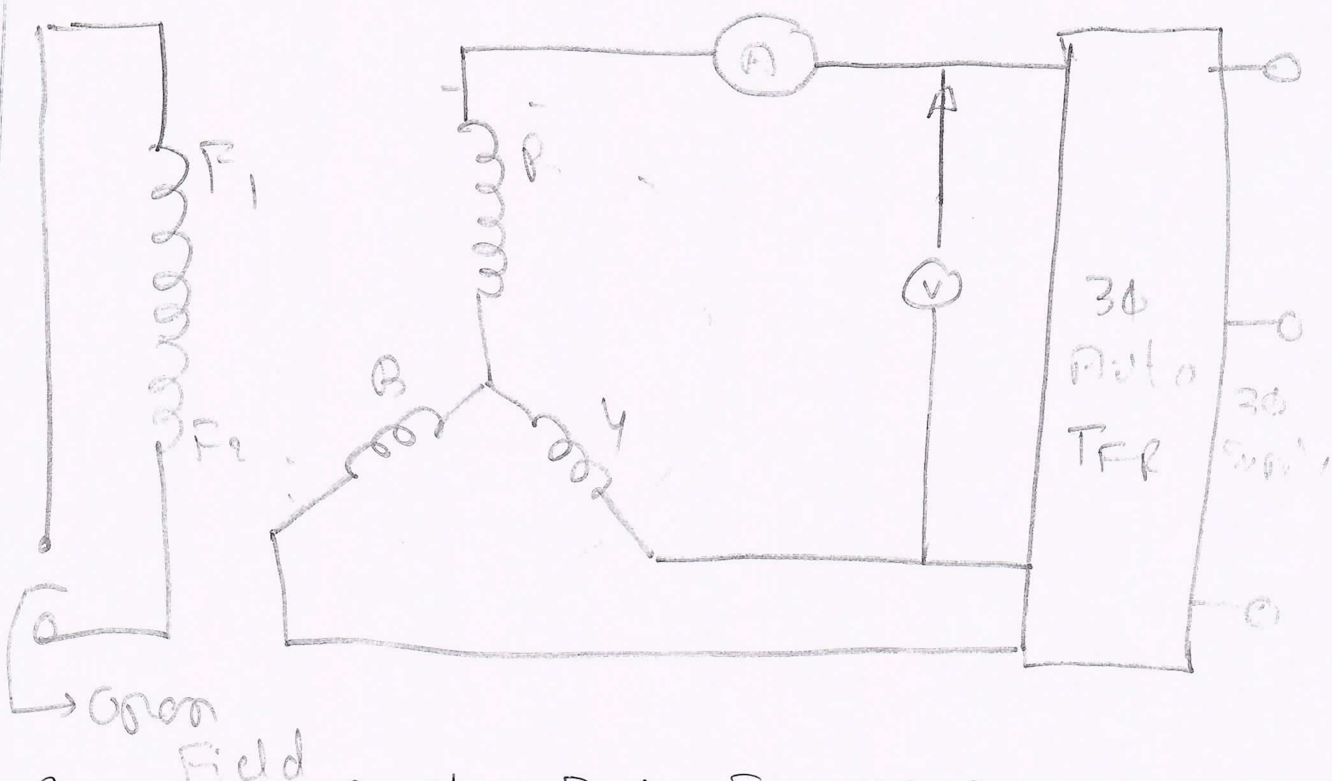
$E_f = V_t \cos\delta + I_d X_d + I_a R_a$

$= 1 \times \cos 14.48 + 0.7808 \times 0.7 + 0$

$E_f = 1.5148$ p.u = induced emf

Module 5

10 (a) With help of Circuit Diagram, Explain measurement of direct Axis and Quadrature Axis Reactance by slip Test [08 Marks]



Procedure of Slip Test For Xd & Xq

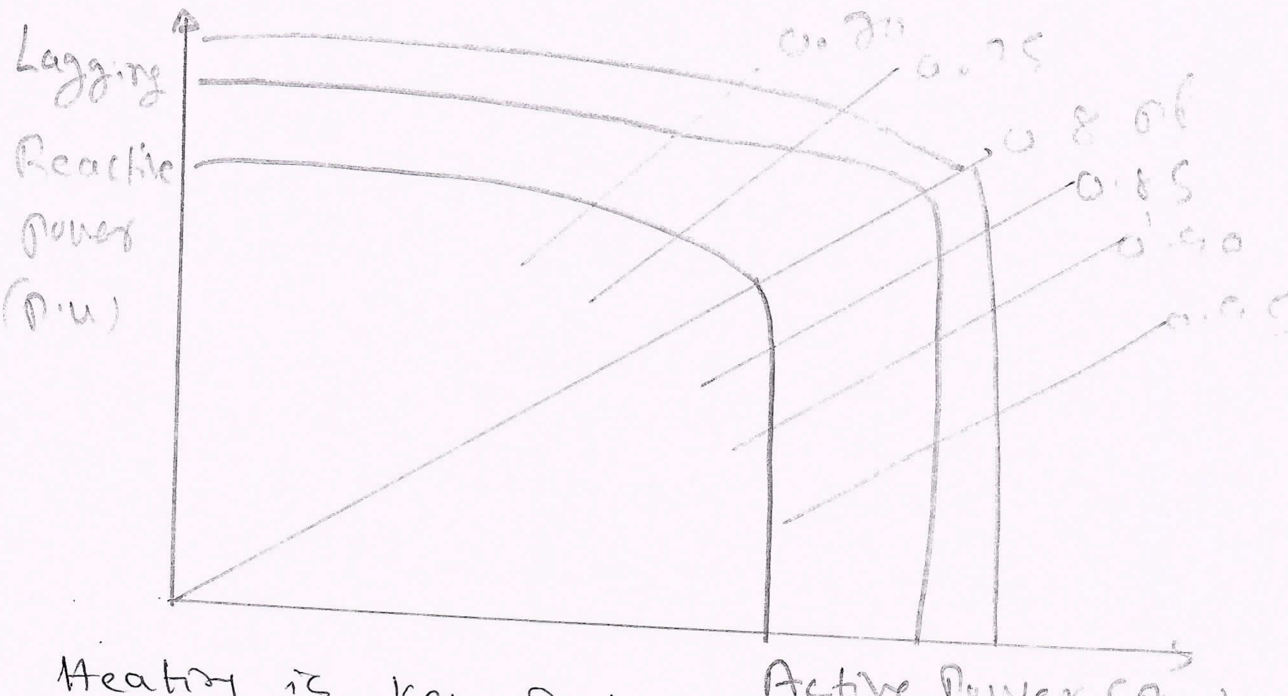
1) 3φ voltage is applied to armature (lesser than rated Voltage)
2) Field winding is kept open
3) Alternator is run at slightly lesser speed than N_s.
4) Stator m.m.f aligned with D-axis of field poles then Φd lode is setup. Effective reactance is Xd
5) Stator m.m.f aligned with q-axis Φq lode is set up and Effective reactance is Xq

$X_d = \frac{V_{max}}{I_{min}}$ $X_q = \frac{V_{min}}{I_{max}}$

10 (b) Draw the Capability Curve and Explain about the Curve of Synchronous Generator

(06 marks)

Soln:



Heating is key Factor for Rating of Alternator. Capability Curve specifies the bounds within which m/c can operate safely.
Turbine Rating is the Limiting Factor for MW loading.
Operation of Generator, should be away from Steady Stability limit ($\delta = 90°$)
Field Current also should be within limit.
For unity p.f to rated p.f,
Limiting Factor is armature heating
while for p.f of Low value,
field heating is the limiting Factor.

10 c What is Hunting in Synchronous m/c? How do you Eliminate hunting? (06 marks)

Soln:

Hunting in Synchronous m/c (phase swing)

A mechanical phenomenon, where pulsations are produced in voltage, current, and power due to angular velocity and due to oscillation of rotating parts of m/c.

Causes of Hunting

1) Sudden change in load 2) Change in Frequency
3) Sudden change in field current
4) A load consists of Harmonic Torques
5) A fault in supply system.

Undesirable Effects

1) Severe mechanical stress and large variation in I & P
2) Temp rise, Loss in m/c
3) Unstable machine

Elimination Methods of Hunting

1) Use of Damper windings - these will damp the oscillations.
2) Use of Flywheel
3) Design of m/c with suitable Stiffness Factor.

(S. M. Enamadar)

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