CMR INSTITUTE OF TECHNOLOGY	USN											CMRIT

Internal Assesment Test II – December -2022									
Sub:	Transformers andGenerators						Code:	21EE34
Date:	27/12/2022	Duration:	90 Min	Max Marks:	50	Sem:	3	Section:	A & B

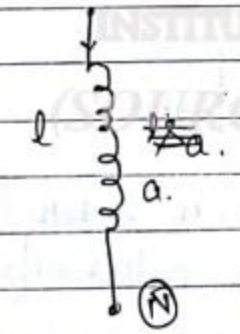
Note: Answer any **FIVE FULL** Questions

Sketch Neat Figures Wherever Necessary.

		Marks	OBE CO	OBE RBT
1	**What is an Auto transformer? Derive an expression for the saving of copper in an Auto transformer as compared to an equivalent two winding transformers. What are advantages and limitations?**	[10]	CO3	L2

Auto Transformer is a special type of transformer which has only one winding such that part of the winding is common to the primary and secondary. The two windings are electrically connected and it works on the principle of conduction as well as induction. Auto transformer is economical where the voltage ratio is less than two and the transformer is fully inductively while in autotransformer the power is transferred from primary to secondary by both inductively as well as conductively.

Expression for Copper Saving in Autotransformer :-



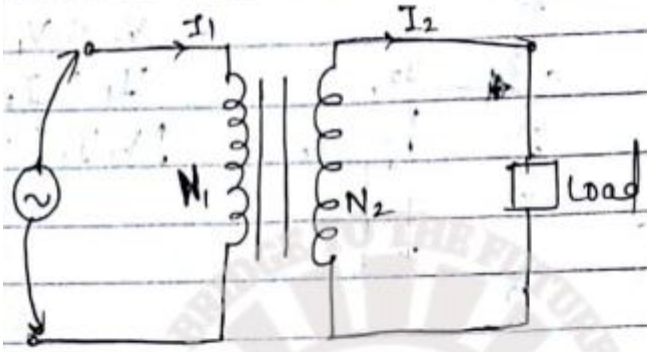
l → N

a → I.

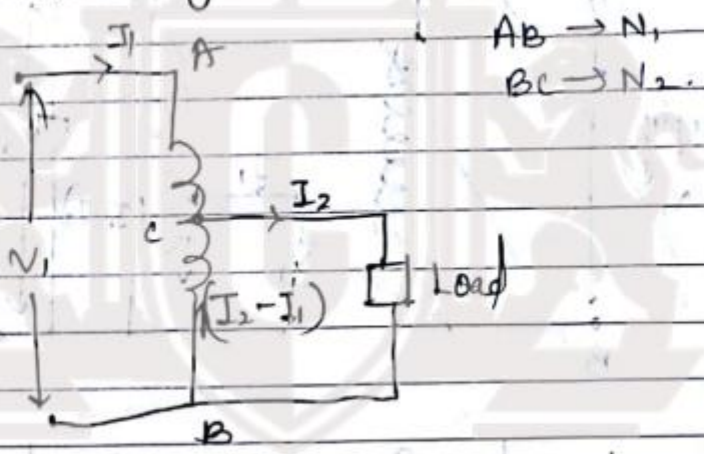
weight of Cu ∝ NI.

for any winding the cross section of winding is proportional to current I whereas the totale length of winding depends on N. Hence the weight of Cu depends upon the product of N and I where N = No. of turns in winding I = current in winding.

Consider a 2 winding T/F and a step down auto T/F as shown in figure below:-



2 winding T/F



Step down auto T/F.

Saving of Cu in autotransformer:

Let W_{TW} = wt. of Cu in 2 winding T/F.
W_{AT} = Wt of Cu in autotransfer.

In 2 winding T/F :-

Wt of Cu in 1° winding $= N_1 I_1$
Wt. of Cu in 2° winding $= N_2 I_2$.
$W_{TW} = N_1 I_1 + N_2 I_2$ (Total wt. of Cu).

In case of auto T/F :-

Wt. of Cu in portion AC = $I_1(N_1 - N_2)$.

Wt. of Cu in section BC = $N_2(I_2 - I_1)$

Total wt. of Cu in auto T/F $W_{AT} = (N_1 - N_2)I_1 + N_2(I_2 - I_1)$

Taking the ratio of 2 weights :-

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

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

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

We know $k = \frac{N_2}{N_1} = \frac{I_1}{I_2}$.

For step-up transformer :-

Saving of Cu $= \frac{1}{k}(W_{TW})$.

The saving of Cu will ↑ as value of k approaches to unity.

$$\frac{W_{TW}}{W_{AT}} = \frac{N_1 I_1 + kN_1\left(\frac{I_1}{k}\right)}{N_1 I_1 + kN_1\left(\frac{I_1}{k}\right) - 2I_1(kN_1)}$$

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

$$= \frac{2 N_1 I_1}{N_1 I_1 (2 - 2k)}$$

$$= \frac{2}{2(1-k)} = \frac{1}{1-k}.$$

step up / step down ⇒ $\boxed{W_{AT} = (1-k) W_{TW}}$

Saving of Copper $= W_{TW} - W_{AT}$.

$= W_{TW} - (1-k) W_{TW}$,

$= W_{TW}(+k) = k W_{TW}$,

for step-down Auto Tr

ADVANTAGES OF AUTOTRANSFORMER:-

1. Saving of Copper.
2. Size and Cost is less.
3. O/P and efficiency is high
4. VA rating is high.
5. Resistance and Reactance is less. So losses are reduced.
6. Lower value of voltage regulation.

DISADVANTAGES:-

1. Direct connection b/w 1° and 2°.
2. The leakage flux between the primary and secondary windings is small and hence the impedance is low. This results into severer short circuit currents under fault conditions.
3. The connections on primary and secondary sides have necessarily needs to be same, except when using interconnected starring connections. This introduces complications due to changing primary and secondary phase angle particularly in the case of delta/delta connection.
4. Because of common neutral in a star/star connected auto transformer it is not possible to earth neutral of one side only. Both their sides should have their neutrality either earth or isolated.

2(a)	**Two transformers A and B are connected in parallel to a load of (2+j1.5) Ω, their impedance in secondary terms is (0.15 + j0.5) Ω and (0.1+ j0.6) Ω respectively. Their no load terminal voltages are 207 V and 205 V. Find the output power and the PF of each transformer and also the current drawn by each transformers.**	[6]	CO2	L3

Solution : Given $Z_L = (2 + j1.5)\ \Omega$

$Z_A = (0.15 + j0.5)\ \Omega$, $Z_B = (0.1 + j0.6)\ \Omega$

$E_A = 207 \angle 0°$ volts, $E_B = 205 \angle 0°$ volts.

Using the formulae for I_A and I_B,

$$I_A = \frac{E_A Z_B + Z_L (E_A - E_B)}{Z_A Z_B + Z_L (Z_A + Z_B)} \quad \text{and} \quad I_B = \frac{E_B Z_A - Z_L (E_A - E_B)}{Z_A Z_B + Z_L (Z_A + Z_B)}$$

$$I_A = \frac{[207\angle 0°][0.1 + j0.6] + (2 + j1.5)[207\angle 0° - 205\angle 0°]}{(0.15 + j0.5)(0.1 + j0.6) + (2 + j1.5)[(0.15 + j0.5) + (0.1 + j0.6)]}$$

Solving, $I_A = (42.196 \angle -38.84°)\ A = (32.866 - j26.463)\ A$

Similarly, $$I_B = \frac{E_B Z_A - Z_L (E_A - E_B)}{Z_A Z_B + Z_L (Z_A + Z_B)}$$

$$= \frac{(205\angle 0°)[0.15 + j0.5] - (2 + j1.5)(207\angle 0° - 205\angle 0°)}{(0.15 + j0.5)(0.1 + j0.6) + (2 + j1.5)[(0.15 + j0.5) + (0.1 + j0.6)]}$$

Solving, $I_B = (33.5534 \angle -42.89°)\ A = (24.5832 - j22.8362)\ A$

Now total current is given by,

$\bar{I}_L = \bar{I}_A + \bar{I}_B = (32.866 - j26.463) + (24.5832 - j22.8362)$

$= (57.4492 - j49.2992)\ A = 75.70 \angle -40.63°\ A$

The load voltage, $V_L = I_L Z_L = (75.70 \angle -40.63°)(2 + j1.5)$

$= (75.70 \angle -40.63°)(2.5 \angle 36.86°) = 189.25 \angle -3.77°$ volts

The angle between V_L and I_A can be calculated as,

$\phi_A = (-38.84°) - (-3.77°)$

$= -35.07°$

$\therefore$ p.f. $= \cos \phi_A = \cos(35.07)$

$= 0.8184$ **(lagging)**

Fig. 3.5.3

The angle between V_L and I_B can be calculated as,

$\phi_B = (-42.89°) - (-3.77°)$

$= -39.12°$

p.f. $= \cos \phi_B = \cos(39.12)$

$= 0.7758$ **(lagging)**

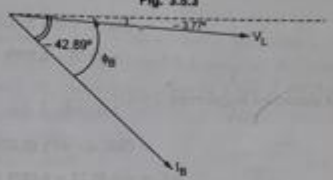


Fig. 3.5.4

Power output of transformer A $= V_L I_A \cos \phi_A = 189.25 \times 42.196 \times 0.8184$

$= 6535.40$ W $= 6.5354$ kW

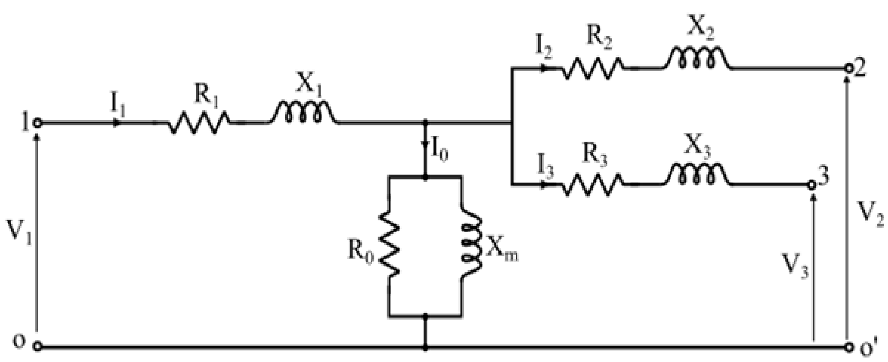
Power output of transformer B $= V_L I_B \cos \phi_B = (189.25)(33.5534)(0.7758)$

$= 4926.31$ W $= 4.9263$ kW

2(b) | [4] | CO3 | L1

How do you obtain the equivalent circuit of a three winding transformer? Explain.

The equivalent circuit of the 3-winding transformer is shown in the figure. The equivalent circuit of a 3-winding transformer can be represented by the 1-phase equivalent circuit, in which each winding of the transformer can be represented by its equivalent resistance and reactance.



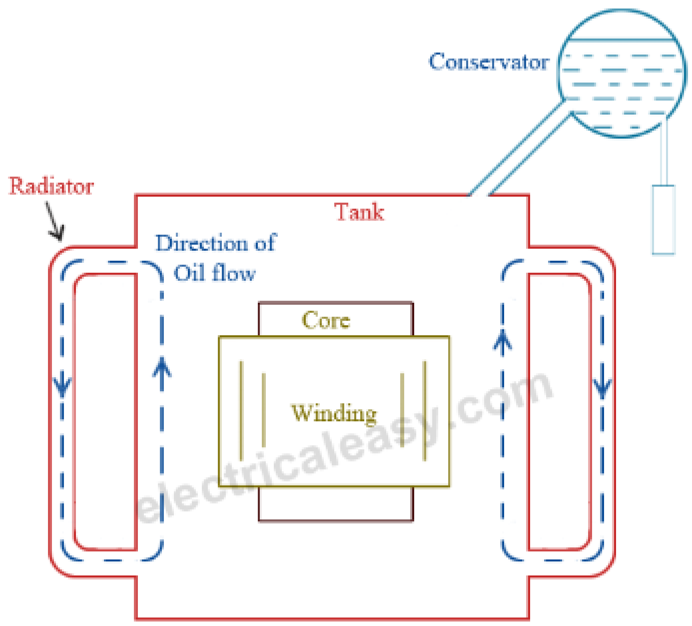
Here, the terminals 1, 2, 3 indicate primary, secondary and tertiary winding terminals respectively. The resistances R1, R2 and R3 are the resistances of primary, secondary and tertiary windings respectively. The reactances X1, X2 and X3 are the leakage reactances of the primary, secondary and tertiary windings respectively. If the no-load current is

	also considered, then the core loss resistance R0 and magnetising reactance Xm are also connected.			

3(a)

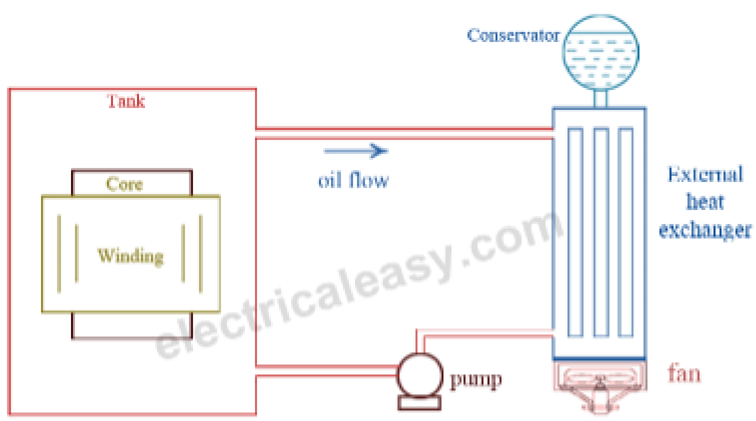
Explain any two types of cooling of transformers with neat diagram.

Oil Natural Air Natural (ONAN)



This method is used for oil immersed transformers. In this method, the heat generated in the core and winding is transferred to the oil. According to the principle of convection, the heated oil flows in the upward direction and then in the radiator. The vacant place is filled up by cooled oil from the radiator. The heat from the oil will dissipate in the atmosphere due to the natural air flow around the transformer. In this way, the oil in transformer keeps circulating due to natural convection and dissipating heat in atmosphere due to natural conduction. This method can be used for transformers upto about 30 MVA.

Oil Forced Air Forced (OFAF)



In this method, oil is circulated with the help of a pump. The oil circulation is forced through the heat exchangers. Then compressed air is forced to flow on the heat exchanger with the help of fans. The heat exchangers may be mounted separately from the transformer tank and connected through pipes at top and bottom as shown in the figure. This type of cooling is provided for higher rating transformers at substations or power stations.

[5] CO3 L2

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<td>3(b)</td>
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Define Commutations and explain in detail any one method of commutation.

The currents induced in the armature conductors of a DC generator are alternating in nature. The change from a generated alternating current to the direct current applied involves the process of **Commutation**. When the conductors of the armature are under the north pole, the current which is induced flows in one direction. While the current flows in the opposite direction when they are under the south pole.As the conductor passes through the influence of the north pole and enters the south pole, the current in them is reversed. The reversal of current takes place along the MNA or brush axis. When the brush span has two commutator segments, the winding element connected to those segments is short-circuited.The term **Commutation** means the change that takes place in a winding element during the period of a short circuit by a brush.

Resistance Commutation

In this method of improving commutation, the low resistance copper brushes are replaced by high resistance carbon brushes.

From the Fig. 5.9.1 it can be seen that the current I from coil C when passing through commutator segment 'b' has two parallel paths. One is straight from 'b' to brush while the other is through short circuited coil B to segment 'a' and then to the brush. By using low resistance copper brush the current will not prefer second path as it will prefer first low resistance path.

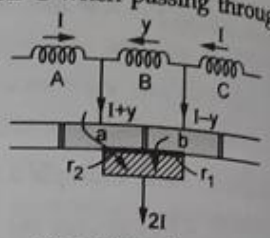

Fig. 5.9.1 Resistance commutation

When carbon brushes having comparatively high resistance are used then current I through coil C will select the second path as resistance r_1 of first path will be increasing due to decrease in contact area of 'b' with brush and resistance r_2 of second path will be decreasing due to increase in contact area of 'a' with brush.

Thus by increasing contact resistance between commutator segment and brushes, will limit short circuit current and reduce time constant (L/P) of the circuit which will help in quick reversal of current in the desired direction.

</td>
<td>[5]</td>
<td>CO4</td>
<td>L1</td>
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Explain with neat diagrams the armature reaction in a synchronous machine with different power factor loads.

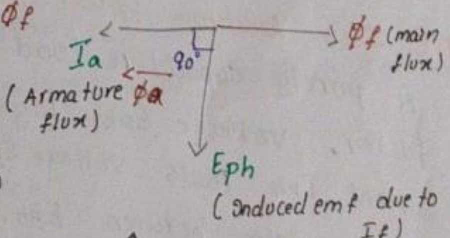
i) Zero lagging power factor load:

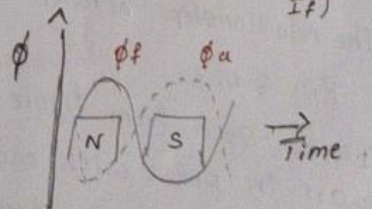
A purely Inductive load gives us zero lagging power factor. i.e Current I_{aph} lags voltage E_{ph} by exact 90°. (Fig 8.4.1)

Induced e.m.f E_{ph} lags main flux ϕ_f by 90°. ϕ_a is in phase with I_a.

It is seen from figure that armature flux is exactly opposite to main flux.

This effect is called demagnetizing effect of armature reaction.





</td>
<td>[10]</td>
<td>CO5</td>
<td>L2</td>
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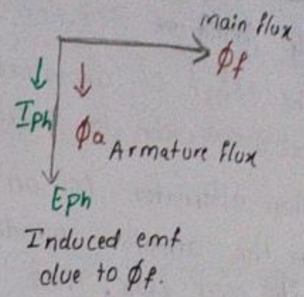
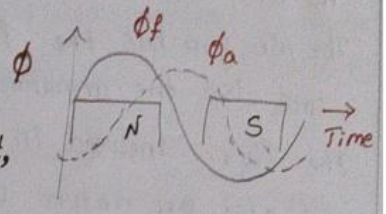
ii) Unity Power factor load.

A purely resistive load will give unity power factor. Voltage E_{ph} and current I_{ph} are in phase with each other

From phasor diagram we can see there exist 90° phase difference between armature flux (ϕ_a) and main flux (ϕ_f).



From graph we can see that both fluxes oppose each other on left half of each pole while assist each other on right half of each pole.



Average flux in air gap remains constant, but its distribution gets distorted.

Fig 8.4.2

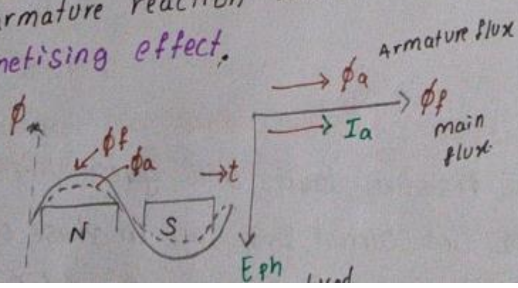
→ Such distorting effect of armature reaction under unity power factor condition is called cross magnetising effect.

iii) Zero Leading power factor load:

A purely capacitive load will give zero leading power factor. voltage E_{ph} lags current I_{ph} by 90° (or) Current I_{ph} leads voltage E_{ph} by 90°.

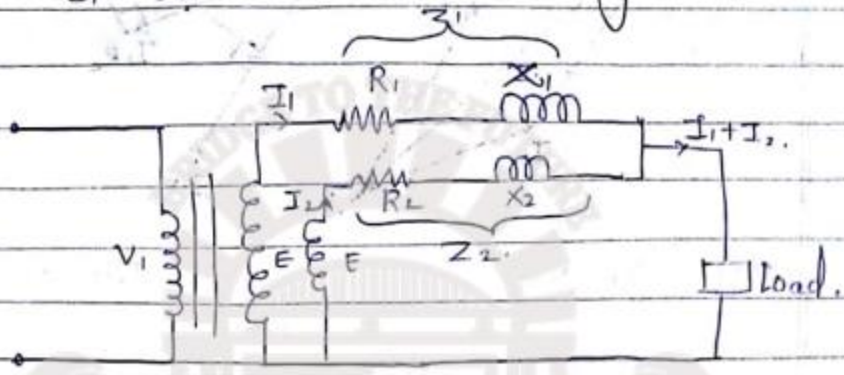
The relationship between E_{ph}, I_{ph}, ϕ_a and ϕ_f is shown in Fig 8.4.3.

It is seen from figure that voltage (E_{ph}) and current (I_{ph}) are in phase with each other thus helping each other. This effect of armature reaction which assists main flux is called magnetising effect.

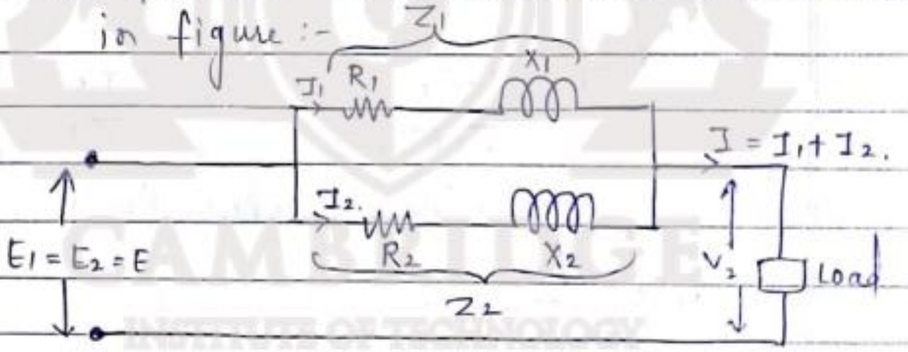


5(a)	**Derive an expression for the currents and load shared by two transformers connected in parallel supplying a common load when no load voltages of these are equal.**	[5]	CO2	L2

Consider 2 transformers connected in || having equal voltage ratios.
The 2 transformers are having No load 2° voltage
$E_1 = E_2 = E$.

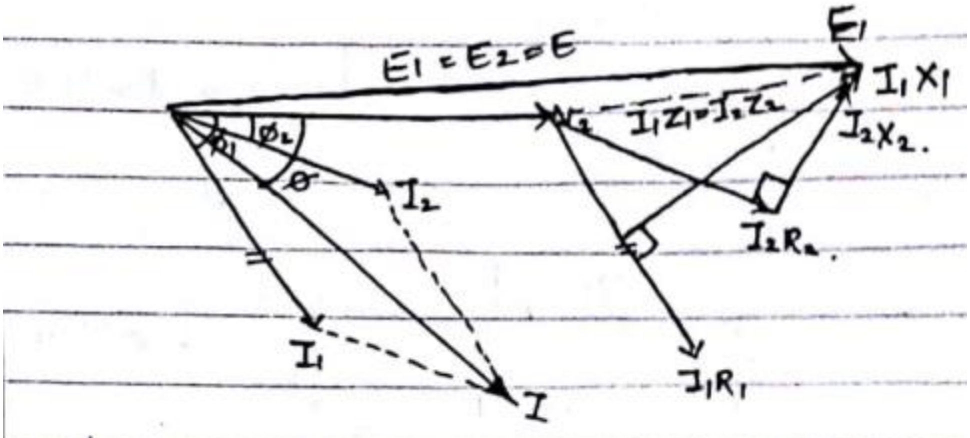


~~Here neglect~~ after neglecting the magnetizing current of 2 transformers, the 2 transformers can be connected in || as shown in figure :-



Phasor Diagram :- $E_1 = I_1 R_1 + j I_1 X_1 + V_2 = (E_2 = E_1)$

$E_2 = I_2 R_2 + j I_2 X_2 + V_2$.



As Z_1 and Z_2 are in parallel :-

$$\frac{1}{Z_{eq}} = \frac{1}{Z_1} + \frac{1}{Z_2}.$$

$$Z_{eq} = \frac{Z_1 Z_2}{Z_1 + Z_2}.$$

Using the current division rule.

$$I_1 = \frac{I \times Z_2}{Z_1 + Z_2} \qquad I_2 = \frac{I \times Z_1}{Z_1 + Z_2}.$$

Multiplying both the terms with V_2 :-

$$V_2 I_1 = \frac{I \times Z_2 V_2}{Z_1 + Z_2}$$

$$V_2 I_2 = \frac{I V_2 Z_1}{Z_1 + I_2}.$$

Here

$V_2 I_1 \times 10^{-3} \rightarrow Q_1$

$V_2 I_2 \times 10^{-3} \rightarrow Q_2$.

$V_2 I \times 10^{-3} \rightarrow$ load kVA

	$Q_1 = \frac{Q \times Z_2}{Z_1 + Z_2}$ $Q_2 = \frac{Q \times Z_1}{Z_1 + Z_2}$. If the 2 T/F are having impedances Z_1 and Z_2 are equal in magnitude then $\frac{X_1}{R_1} = \frac{X_2}{R_2}$ Then both the T/F operates @ same PF. and also they will share the load equally.			
5(b)	**Two 250 KVA transformers supplying a network are connected in parallel on both primary and secondary sides. Their voltage ratios are the same. The resistance drops are 1.5% and 0.9% and the reactance drops are 3.33% and 4% respectively. Calculate the KVA loading on each transformer and its PF when the total load on the transformers is 500 KVA and 0.707 lagging PF.** Since the voltage ratios of the two transformers are same, We have, $\frac{\% Z_2}{\% Z_1 + \% Z_2} = \frac{Z_2}{Z_1+Z_2} = \frac{0.9+j4}{(1.5+3.33)+(0.9+j4)}$ $= \frac{0.9+j4}{2.5+j7.33} = \frac{4.1\angle 77.31°}{7.71\angle 71.87°} = 0.5316\angle 5.44°$ Similarly $\frac{\% Z_1}{\% Z_1 + \% Z_2} = \frac{Z_1}{Z_1+Z_2} = \frac{1.5+j3.33}{(1.5+3.33)+(0.9+j4)}$ $= \frac{1.5+j3.33}{2.4+j7.33} = \frac{3.6522\angle 65.75°}{7.71\angle 71.87°} = 0.4736\angle -6.12°$ Load shared by transformer 1 $= Q\left(\frac{Z_2}{Z_1+Z_2}\right)$ $= (500\angle -45°)(0.5316\angle 5.44°) =$ **265.8 kVA** $\angle -39.55°$ p.f. = cos 39.55 = **0.7709 (lag)** Load shared by transformer 2 $= Q\left(\frac{Z_1}{Z_1+Z_2}\right)$ $= (500\angle -45°)(0.4736\angle -6.12°) =$ **236.8** $\angle -51.12°$ **kVA** p.f. = cos 51.12 = **0.6276 (lag)**	[5]	CO2	L3
6(a)	**Derive EMF equation of synchronous generator**	[5]	CO5	L2

	P = Number of poles. ϕ = flux per pole in wb N_s = Synchronous speed in r.p.m. f = frequency (Hz) Z = Total Conductors Z_{ph} = Conductors per phase $\frac{Z}{3}$ Average value of emf induced in a conductor $= \frac{d\phi}{dt}$ flux cut in one revolution $= \phi * P$ Time taken for one revolution is $\frac{60}{N_s}$ seconds $e_{avg} = \frac{P\phi}{\frac{60}{N_s}}$ $= \frac{P\phi N_s}{60}$ $\quad f = \frac{PN_s}{120}$ $= \frac{\phi}{60} 120f$ $e_{avg} = 2f\phi$ emf for 'Z_{ph}' conductors $K_f = \frac{Rms}{Average} = 1.11$ Average $E_{ph} = 2f\phi Z_{ph}$ $= 2f\phi(2T_{ph})$ $= 4f\phi T_{ph}$ Rms $E_{ph} = 4(1.11) f\phi T_{ph}$ $E_{ph} = 4.44 f\phi T_{ph}$ volts			
6(b)	**A 4 pole lap wound armature running at 1500 rpm delivers a current of 150A and has 64 commutator segments. The brush width is equal to 1.2 segments and inductance of each coil is 0.05 mH. Calculate the value of reactance voltage assuming (i) linear commutation (ii) sinusoidal commutation.**	[5]	CO4	L3

Solution : $I = 150$ A, $N = 1500$ r.p.m., $W_b = 1.2$ segments, $W_m = 0$,

$L = 0.05$ mH, 64 segments

There are total 64 segments on the entire periphery. It is necessary to calculate the peripheral speed in segments/second as W_b is given in segments.

Now the commutator speed is 1500 r.p.m. i.e.

$$n_s = \frac{1500}{60} = 25 \text{ r.p.s. i.e. revolutions per second}$$

And in one revolution, 64 segments get covered. Hence

v = Peripheral speed in segments/second

= Number of revolutions per second × Total segments on commutator

= 25 × 64 = 1600 segments/second

$$\therefore \quad T_c = \frac{W_b - W_m}{v} = \frac{1.2 - 0}{1600} = 7.5 \times 10^{-4} \text{ second}$$

$$I = \text{Current through a conductor} = \frac{I_L}{A} = \frac{150}{4} = 37.5 \text{ A}$$

For linear commutation,

Self induced e.m.f., $$E = L \times \frac{2I}{T_c} = 0.05 \times 10^{-3} \times \frac{2 \times 37.5}{7.5 \times 10^{-4}} = \mathbf{5\ V}$$

For sinusoidal commutation, $$E = 1.11\, L \times \frac{2I}{T_c} = 1.11\, E = \mathbf{5.53\ V}$$

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

Signature of CI   Signature of CCI   HOD - EEE