SHAMBHUNATH INSTITUTE OF ENGINEERING AND TECHNOLOGY

SOLUTION

Subject Code : KEE - 402 **Subject : Electrical Machine – I**

B.Tech. IV Semester

FIRST SESSIONAL EXAMINATION, EVEN SEMESTER, (2019-20)

Branch : Electrical Engineering

SECTION – A

1. **Attempt all question in brief.**

a. In dc. Supply, the magnetic flux established is constant in nature, so in secondary winding the induced emf. will be zero.

b. The voltage regulation of a transformer is defined as the arithmetical difference in the secondary terminal voltage between no-load and full rated load at a given power factor with the same value of primary voltage for both rated load and no-load.

c. **Voltage regulation**

$$= R_{epu} \cos \phi_2 + X_{epu} \sin \phi_2$$

$$= 0.02 \times 0.8 + 0.05 \times 0.6 = 0.046 \text{ pu} = 4.6\%$$

d. In case of an open circuit in the common winding, the full primary voltage would be applied to the load on the secondary. This high voltage may burn out or seriously damage the equipment connected to the secondary side.

e. The efficiency of a transformer for a given power factor is a maximum when the variable copper loss is equal to the constant iron loss.

SECTION – B

2. **Attempt any TWO of the followings.**

a.

$$\frac{I_2 Z_{e_2}}{V_2} \times 100 = 10$$

$$I_2 Z_{e_2} = \frac{10\, V_2}{100} = \frac{10 \times 200}{100} = 20 \text{ V}$$

$$\frac{I_2 R_{e_2}}{V_2} \times 100 = 5$$

$$I_2 R_{e_2} = \frac{5\, V_2}{100} = \frac{5 \times 200}{100} = 10 \text{ V}$$

$$I_2 X_{e_2} = \sqrt{(I_2 Z_{e_2})^2 - (I_2 R_{e_2})^2} = \sqrt{20^2 - 10^2} = 17.32 \text{ V}$$

(*a*) Approximate voltage regulation at lagging power factor

$$= \frac{I_2 R_{e_2} \cos \phi_2 + I_2 X_{e_2} \sin \phi_2}{V_2}$$

$$= \frac{10 \times 0.8 + 17.32 \times 0.6}{200} = 0.0919 \text{ pu} = 0.0919 \times 100\% = 9.19\%$$

(*b*) For zero regulation, the power factor must be *leading*

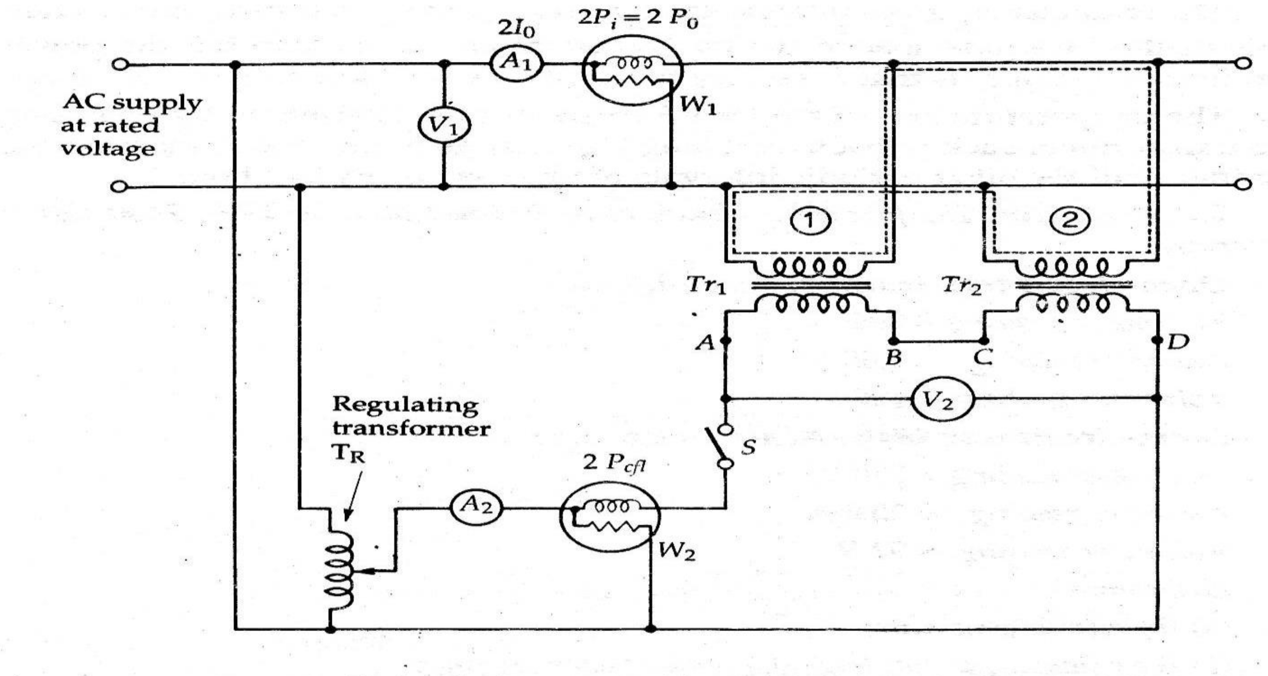
$$\therefore \quad \frac{I_2 R_{e_2} \cos \phi_2 - I_2 X_{e_2} \sin \phi_2}{V_2} = 0$$

$$\tan \phi_2 = \frac{I_2 R_{e_2}}{I_2 X_{e_2}} = \frac{10}{17.32} = \frac{1}{\sqrt{3}} = \tan 30^\circ$$

$\therefore$ power factor $\cos \phi_2 = \cos 30^\circ = 0.866$ (leading)

b. Sumpner's test

The back to back test on single phase transformers requires two identical transformers. Below figure shows the circuit diagram for the Sumpner's test. The primary windings of the two transformers are connected in parallel and supplied at rated voltage and rated frequency.



Back-to-back test on two identical single-phase transformers

The secondaries are connected in series with their polarities in phase opposition. If the primary circuit is now closed, the total voltage across the two secondaries in series will be zero. The transformers will behave as if their secondary windings are open circuited. Hence the reading of wattmeter W_1 gives the iron losses of both the transformers.

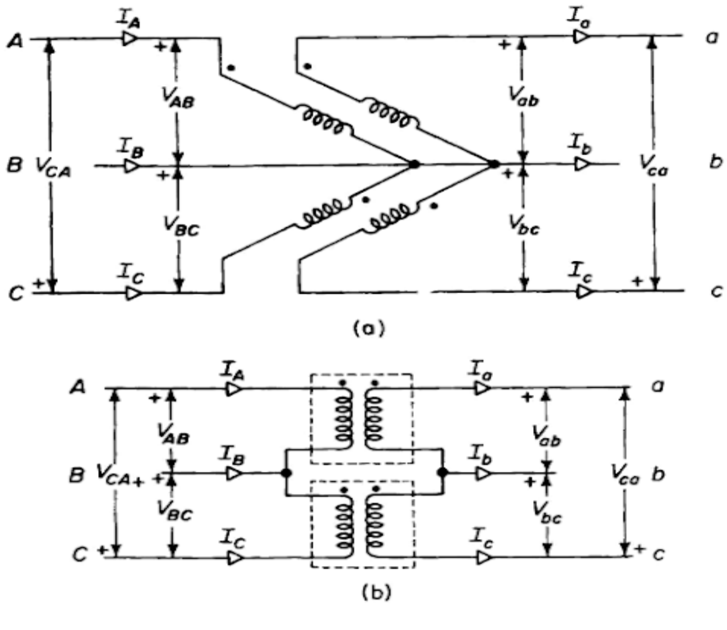
A small voltage is injected in the secondary circuit by a regulating transformer T_R excited by the main supply. The magnitude of the injected voltage is adjusted till the ammeter A_2 reads full load secondary current. The secondary current produces full load current to flow through the primary winding. Thus wattmeter W_2 gives the full load copper losses of the two transformers.

The ammeter A_1 gives total no load current of the two transformers. Thus in this method we have loaded the two transformers to full load but the power taken from the supply is that necessary to supply the losses of both transformers.

c. Open delta system

In open delta system, two instead of three single phase transformers are used for three phase operation. V_{AB}, V_{BC} and V_{CA} be the applied voltage of the primary. The voltage induced in secondary side be V_{ab} and V_{bc}. There is no winding between a and c, but there is a potential difference between a and c.

$$V_{ab} + V_{bc} + V_{ca} = 0$$



$V_{ca} = - V_{ab} - V_{bc}$

Let $V_{AB} = V_p\angle 0^0$

$V_{BC} = V_p \angle{-120^0}$, $\quad V_{CA} = V_p \angle{+120^0}$

If the leakage impedances of the transformers are negligible, then

$V_{ab} = V_s \angle 0^0$, $V_{bc} = V_s \angle{-120^0}$ $\quad V_p$ and V_s is primary and secondary line voltages respectively

Substituting the values of V_{ab} and V_{bc}

$V_{ca} = - V_s \angle 0^0 - V_s \angle{-120^0} = V_s \angle{+120^0}$

It is seen that V_{ca} is equal in magnitude to the secondary transformer voltage and 120^0 apart in time from both of them.

If V_{2B} and I_{2B} are the rated secondary voltage and rated secondary current of the transformers, the line current to the load of a closed delta system is $\sqrt{3}I_{2B}$.

Closed delta load VA $\quad S\Delta - \Delta = \sqrt{3}$ x line voltage x line current = 3 V_{2B} I_{2B}

In open delta system the line is in series with the windings of the transformers and therefore in this case the line current is equal to $I_{2B.}$ $S_{V\text{-}V} = \sqrt{3}$ V_{2B} I_{2B}

$$\frac{SV - V}{S\Delta - \Delta} = \frac{\sqrt{3}\ V2B\ I2B}{3\ V2B\ I2B} = \frac{1}{\sqrt{3}} = 0.577$$

Thus it is seen that the load that can be carried by the open delta bank without exceeding the ratings of the transformers is 57.7% of the original load carried by the $\Delta - \Delta$ bank.

Application –

1. As a temporary measure when one transformer of a delta-delta system is damaged and removed for repair and maintenance.
2. To provide service in new area where the full growth of load may require several years.

d. Open circuit test $V_1 = 250$ V, $I_0 = 1$ A, $P_i = 80$ W

$P_i = V_1 I_0 \cos\Phi_0$

$$\cos\phi_0 = \frac{P_i}{V_1 I_0} = \frac{80}{250 \times 1} = 0.32$$

$$I_W = I_0 \cos\phi_0 = 1 \times 0.32 = 0.32 \text{ A}$$

$$I_\mu = 1_0 \sin\phi_0 = \sqrt{I_0^2 - I_W^2} - \sqrt{1^2 - (0.32)^2} = 0.947 \text{ A}$$

$$R_0 = \frac{V_1}{I_W} = \frac{250}{0.32} = 781.25\ \Omega$$

$$X_0 = \frac{V_1}{I_\mu} = \frac{250}{0.947} = 264\ \Omega$$

Short circuit test

$$V_{2sc} = 20\text{ V}, P_{cfl} = 100\text{ W}, I_{2sc} = 12\text{ A}$$

$$\frac{T_1}{T_2} = \frac{V_1}{V_2} = \frac{250}{500} = 0.5$$

Voltage applied on the l.v. side

$$V_{1sc} = V_{2sc}\frac{T_1}{T_2} = 20 \times \frac{250}{500} = 10\text{ V}$$

Primary (l.v.) full-load current

$$I_{1sc} = I_{2sc}\frac{T_2}{T_1} = 12 \times \frac{500}{250} = 24\text{ A}$$

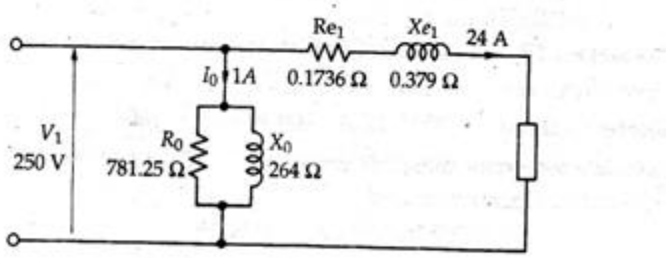
$$P_{cfl} = I_{1sc}^2 R_{e_1}$$

$$R_{e_1} = \frac{P_{cfl}}{I_{ISC}^2} = \frac{100}{(24)^2} = 0.1736\ \Omega$$

$$Z_{e_1} = \frac{V_{1sc}}{I_{1sc}} = \frac{10}{24} = 0.417\ \Omega$$

$$X_{e_1} = \sqrt{Z_{e_1}^2 - R_{e_1}^2} = \sqrt{(0.417)^2 - (0.1736)^2} = 0.379\ \Omega$$

The equivalent circuit is shown in Fig. 1.29.

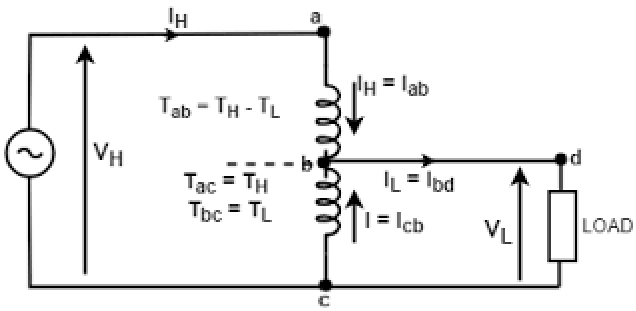


SECTION – C

3. Attempt any <u>ONE</u> part of the followings.

a. <u>Saving in conductor material</u>

The cross-section of a conductor is proportional to the current through it and the length of the conductor in a winding is proportional to the number of turns. Hence the weight of conductor material in a winding is proportional to the product of current and number of turns.



For a two winding transformer, weight of conductor material in primary α $I_H T_H$

Weight of conductor material in secondary α $I_L T_L$

Total weight of conductor material α $(I_H T_H + I_L T_L)$

For the autotransformer, the portion ab has $(T_H - T_L)$ turns and the current through it is I_H. Therefore the weight of conductor material in section ab α $I_H(T_H - T_L)$

The portion bc has T_L turns and the current through it is I $(= I_L - I_H)$

The weight of conductor material in section bc α $(I_L - I_H)\, T_L$

Total weight of conductor material α $[I_H(T_H - T_L) + (I_L - I_H)\, T_L]$

$$\frac{\text{Wauto}}{\text{W2w}} = \frac{\text{IH(TH} - \text{TL)} + \text{(IL} - \text{IH) TL}}{\text{IHTH} + \text{ILTL}} = 1 - \frac{\text{TL}}{\text{TH}}$$

$$= 1 - \frac{1}{\text{aA}}$$

Saving of conductor material in using autotransformer = $W_{2W} - W_{auto} = \frac{1}{aA} W_{2W}$

b. A three phase system is used to generate and transmit large amount of power. Transformers for three phase circuits can be constructed in one of the following ways:

1. Three separate single phase transformers are suitably connected for three phase operation. Such an arrangement is called a three phase bank of transformer.
2. A single three phase transformer in which the cores and windings for all the three phases are combined in a single structure.

Advantages of a 3-phase unit transformer

1. It takes less space.
2. It is lighter, smaller and cheaper.
3. It is slightly more efficient.
4. The costly high voltage terminals to be brought out of the transformer housing are reduced to three rather than six necessary three separate single phase transformers.

4. Attempt any ONE part of the followings.

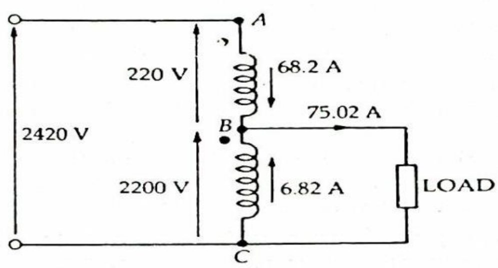
a.

Rated current of 2200 V winding $= \frac{15 \times 1000}{2200} = 6.82$ A

Rated current of 220 V winding $= \frac{15 \times 1000}{220} = 68.2$ A

Output current of autotransformer $= 6.82 + 68.2 = 75.02$ A

The current distribution is shown in Fig.



Output voltage = 2200 V

(*b*) kVA output $= \frac{2200 \times 75.02}{1000} = 165$ kVA

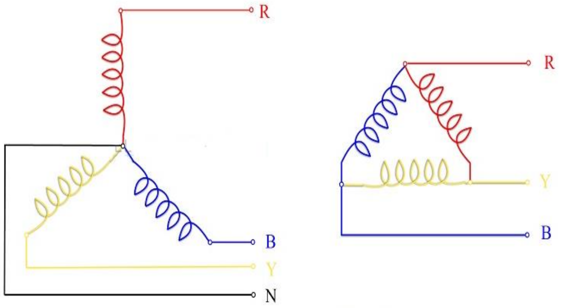
(*c*) kVA transferred conductively $= \frac{2200 \times 68.2}{1000} = 150$ kVA

kVA transferred inductively $= \frac{2200 \times 6.82}{1000} = 15$ kVA

(*d*) Saving in conductor material $= \frac{1}{a_A}$ pu $= \frac{V_L}{V_H} = \frac{2200}{2420}$

$= 0.909$ pu or 90.9%

b. Star-delta connection



This connection is commonly used for stepping down the voltage from a high level to medium or low level.
Line voltage = V
For per phase mmf balance $I_2N_2 = I_1 N_1$
Here primary phase current is I_1
Secondary phase current, $I_2 = \frac{N1}{N2} I_1 = a I_1$
Secondry line current = $\sqrt{3}\ I_2$

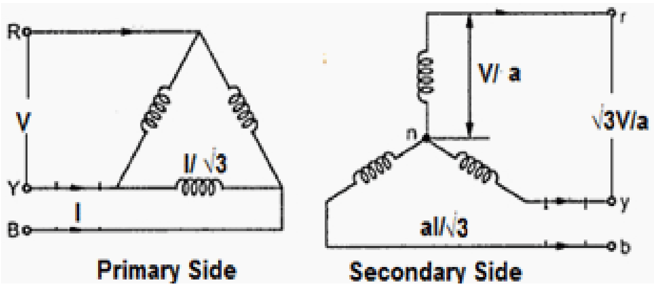
Voltage per turn in primary = Voltage per turn in secondary

$$\frac{V}{\sqrt{3}} X \frac{1}{N1} = \frac{V2}{N2}$$

Secondary phase current $V_2 = \frac{V}{\sqrt{3}a}$

Secondary line voltage = Secondary phase voltage

Delta-star connection



This type of connection is used for stepping up the voltage to a high level.
Delta star transformers are also generally used as distribution transformer for providing mixed line to line voltage to high power equipment and line to neutral voltage to single phase low power equipment.
For per phase mmf balance $I_2N_2 = I_1 N_1$
Primary phase current $I_1 = \frac{I}{\sqrt{3}}$
Secondary phase current $I_2 = \frac{N1}{N2}\frac{I}{\sqrt{3}} = \frac{aI}{\sqrt{3}}$
Also $\frac{V2}{N2} = \frac{V1}{N1}$
Secondary phase voltage $V_2 = \frac{V}{a}$
Secondary line voltage = $\frac{\sqrt{3}V}{a}$

5. Attempt any ONE part of the followings.

a.

Energy output = kVA × cos φ × hours kWh. Total energy output over the 24 hour period is given in the following table :

% rated load	*p.f.*	*kVA cos φ*	*kW*	*hours*	*output energy (kWh)*
20	0.7	$0.2 \times 500 \times 0.7$	70	4	280
50	0.8	$0.5 \times 500 \times 0.8$	200	4	800
80	0.9	$0.8 \times 500 \times 0.9$	360	5	1800
100	1.0	$1.0 \times 500 \times 1.0$	500	7	3500
125	0.85	$1.25 \times 500 \times 0.85$	531.25	2	1062.5
					7442.5

∴ total energy output over 24 hour period (excluding 2 hours at no load)

$$W_{out} = 7442.5 \text{ kWh}$$

Total energy loss in the core for 24 hours including 2 hours at no load

$$W_i = P_i \times t = \frac{1600}{1000} \times 24 = 38.4 \text{ kWh}$$

Copper loss at rated load = 7.5 kW

Copper loss at any other load = $m^2 \times$ copper loss at rated load .

where $m = \dfrac{\text{given load}}{\text{full load}}$

The various energy losses in the winding of the transformer can be calculated as given in the following table :

% rated load	*m*	*Copper loss $m^2 P_{cfl}$*	*hours (h)*	*Energy loss in the winding ($m^2 P_{cfl}\, h$) kWh*
20	0.2	$(0.2)^2 \times 7.5$	4	1.2
50	0.5	$(0.5)^2 \times 7.5$	4	7.5
80	0.8	$(0.8)^2 \times 7.5$	5	24.0
100	1.0	$(1.0)^2 \times 7.5$	7	52.5
125	1.25	$(1.25)^2 \times 7.5$	2	23.44
				108.64 kWh

Total energy loss in the transformer winding for 24 hours (excluding 2 hours at no load)

$$W_c = 108.64 \text{ kWh}$$

Total energy loss in 24 hours = $W_i + W_C = 38.4 + 108.64 = 147.04$ kWh

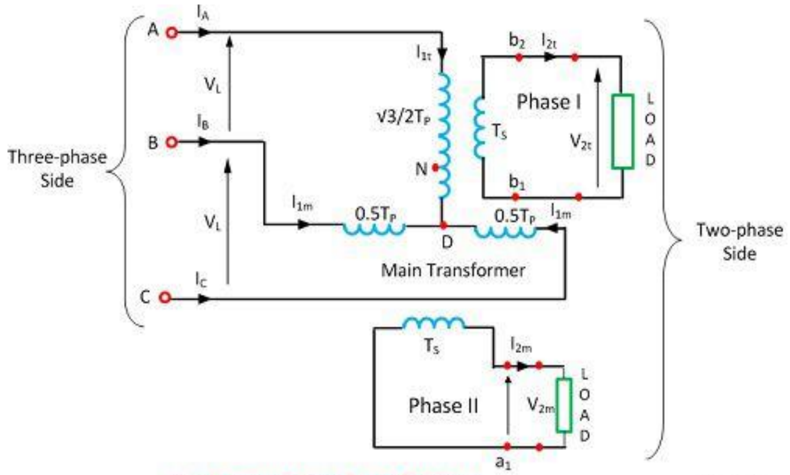
Total energy output in 24 hours, $W_{out} = 7442.5$ kWh

$$\text{All-day efficiency, } \eta_{AD} = \frac{W_{out}}{W_{out} + W_i + W_c} = \frac{7442.5}{7442.5 + 147.04} = 0.9806 \text{ pu}$$

$$= 98.06\ \%$$

b. Scott connection

The scott connection is the most common method of connecting two single phase transformer to perform the three phase to two phase conversion and vice-versa. The two transformer connected electrically but not magnetically. One transformer is called main transformer and other one is called teaser transformer. The main transformer is centre-tapped at D and is connected acroos the lines B and C. The teaser transformer is connected between the line terminal A and the centre tapping D.



Scott connection Transformers

For balanced line voltages

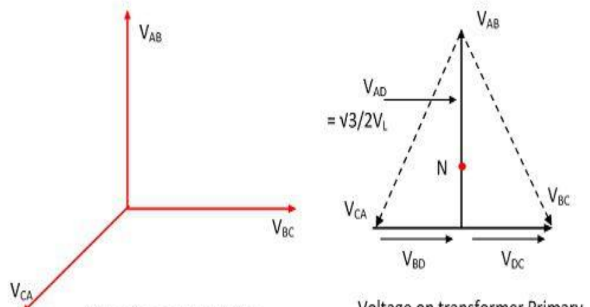
$|V_{AB}| = |V_{BC}| = |V_{CA}| = V_L$

From phasor

$V_{BC} = V_L\angle 0^0$

$V_{CA} = V_L\angle -120^0$

$V_{AB} = V_L\angle +120^0$



Three Phase Input Voltge

Voltage on transformer Primary Winding

$V_{BD} = V_{DC} = \frac{1}{2} V_{BC} = \frac{1}{2} V_L\angle 0^0$

The voltage between A and D is

$V_{AD} = V_{AB} + V_{BD} = 0.866\ V_L\angle 90^0$

Thus the voltage V_{AD} in the primary of the teaser transformer is 0.866 of that in main transformer and is 90^0 from it in time.

Voltage V_{AD} is applied to the primary of the teaser transformer and therefore the secondary voltage V_{2t} of the teaser transformer will lead the secondary terminal voltage V_{2m} of the main transformer by 90^0.

Magnitude of V_{2t} = Magnitude of V_{2m}

Thus the secondaries of both transformers have equal voltage ratings. Since V_{2t} and V_{2m} are equal in magnitude and 90^0 apart in time, they result in a balanced 2-phase system.