CMR INSTITUTE OF TECHNOLOGY

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Course Outcomes	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12

Internal Assesment Test - II

Sub:	Transformers and Generators							Code:	17EE33
Date:	22/11/2018	Duration:	90 mins	Max Marks:	50	Sem:	3	Branch:	EEE - B

Answer Any FIVE FULL Questions

		Marks	OBE CO	OBE RBT
1.a	List the conditions to be satisfied for satisfactory parallel operation of single phase transformers.	[4]	CO2	L1
1.b	Two transformers having equivalent impedances referred to secondary of (0.3 + j3) ohm and (0.2 +j02) ohm are sharing a common load of impedance (8 + j6)ohm. Determine the current delivered by each transformer if the open circuit emf are 6600 V and 6400 V	[6]	CO2	L3
2.	Explain the operation of Scott connection for balanced and unbalanced load with the help of neat figures and phasor diagrams.	[10]	CO1	L2
3.a	What are the advantages of a transformer bank of 3 single phase transformers over a unit of three phase transformer of the same rating?	[4]	CO1	L2
3.b	Two 110V single phase electric furnaces take loads of 500kW and 800kW respectively at a pf of 0.71 lagging and are supplied from 6600V, three phase 50Hz mains through a scott connected transformer combination. Calculate the currents in the three phase lines neglecting transformer losses. Draw the phasor diagrams.	[6]	CO2	L3
4.	Show that an auto -transformer will result in saving of copper instead of 2-winding transformer. List out the advantages of auto-transformer.	[10]	CO3	L3
5.a	Deduce expression for the load shared by two transformers in parallel when no-load voltages of these transformers are equal.	[5]	CO2	L2
5.b	The primary and secondary voltages of an autotransformer are 230V and 75V respectively. Calculate the currents in the different parts of the winding when load current is 200A. Also calculate saving of copper.	[5]	CO3	L2
6	With the help of sketches explain the working of on load tap changer	[10]	CO1	L1
7.a	Compare the working auto-transformer and two winding transformer.	[4]	CO3	L1
7.b	Obtain the equivalent circuit of an autotransformer	[6]	CO3	L2

CO1:	Describe the construction, operation and performance of single phase and three phase transformers	**3**	**2**	**2**	**2**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
CO2:	Explain the need of operating transformers in parallel and the procedure to do it.	**3**	**3**	**2**	**2**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
CO3:	Illustrate the concept of auto transformer; tap changing transformer and tertiary winding.	**3**	**2**	**2**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
CO4:	Analyze armature reaction and commutation and their effects in a dc machine.	**3**	**3**	**2**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
CO5:	Describe the construction, operation, characteristics and applications of synchronous generators	**3**	**2**	**2**	**2**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
CO6:	Perform the analysis of synchronous machines by using different methods	**3**	**3**	**2**	**2**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Cognitive level	KEYWORDS
L1	List, define, tell, describe, identify, show, label, collect, examine, tabulate, quote, name, who, when, where, etc.
L2	summarize, describe, interpret, contrast, predict, associate, distinguish, estimate, differentiate, discuss, extend
L3	Apply, demonstrate, calculate, complete, illustrate, show, solve, examine, modify, relate, change, classify, experiment, discover.
L4	Analyze, separate, order, explain, connect, classify, arrange, divide, compare, select, explain, infer.
L5	Assess, decide, rank, grade, test, measure, recommend, convince, select, judge, explain, discriminate, support, conclude, compare, summarize.

PO1 **-** *Engineering knowledge*; PO2 **-** *Problem analysis*; PO3 **-** *Design/development of solutions*; PO4 **-** *Conduct investigations of complex problems*; PO5 **-** *Modern tool usage*; PO6 **-** *The Engineer and society*; PO7- *Environment and sustainability*; PO8 – *Ethics*; PO9 **-** *Individual and team work*; PO10 **-** *Communication*; PO11 **-** *Project management and finance*; PO12 **-** *Life-long learning*

ANSWERS

1.a

3.2 Conditions for Satisfactory Parallel Operation

VTU : July-06, 07, 09, 10, 11, 12, 14, 16, Jan.-07, 10, 13, 15, 17

The conditions that must be followed for satisfactory parallel operation of transformers are as follows :

1) The supply system voltage and frequency must suit the primary windings of the transformers.

2) The transformers that are connected must have same polarity. In case of three phase transformers the transformers should have same angular displacement and same phase sequence.

3) The voltage ratios of primaries and secondaries of the transformers must be same.

4) The percentage impedances should be equal in magnitude and have same X/R ratio in order to avoid circulating currents and operating at different power factors.

5) If the transformers have the different kVA ratings, the equivalent impedances should be inversely proportional to individual kVA rating to avoid circulating currents.

1. b

Example 3.5.7 *Two transformers A and B are joined in parallel to the same load. Determine the current delivered by each transformer given open circuit emf is 6600 V for A and 6400 V for B. Equivalent impedance on secondary are (0.3 + j3) Ω for A and (0.2 + j1) Ω for B and load impedance is (8 + j6) Ω. Also find the circulating current at no load.*

VTU : Feb.-09, Marks 6

Solution : $Z_L = 8+j6\ \Omega$, $Z_A = 0.3 + j3\ \Omega$, $Z_B = 0.2 + j1\ \Omega$, $E_A = 6600\ \angle 0°$ V, $E_B = 6400\ \angle 0°$ V

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

$$= \frac{(6600\angle 0°)(0.2+j1)+(8+j6)[6600\angle 0° - 6400\angle 0°]}{(0.3+j3)(0.2+j1)+(8+j6)[0.3+j3+0.2+j1]}$$

$$= \frac{(6600\angle 0°)(1.019\angle 78.69°)[10\angle 36.86°]\times[200\angle 0°]}{[3.0149\angle 84.29°\times 1.019\angle 78.69°]+[10\angle 36.86°]\times[4.0311\angle 82.875°]}$$

$$= \frac{1320+j6600+1600+j1200}{-2.9375+j0.8992-19.9938+j35} = \frac{2920+j7800}{-22.9313+j35.8992}$$

$$= \frac{8328.649\angle 69.476°}{42.5975\angle 122.568°} = \mathbf{195.519\angle -53.092°\ A}$$

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

$$= \frac{(6400\angle 0°)(0.3+j3)-(8+j6)[6600\angle 0° - 6400\angle 0°]}{(0.3+j3)(0.2+j1)+(8+j6)[0.3+j3+0.2+j1]}$$

$$= \frac{1920+j19200-[1600+j1200]}{42.5975\angle 122.568°} = \frac{320+j18000}{42.5975+\angle 122.568°}$$

$$= \frac{18002.8442\angle 88.98°}{42.5975\angle 122.568°} = \mathbf{422.6267\angle -33.588°\ A}$$

The circulating current on no load is,

$$I_C = \frac{E_1 - E_2}{Z_A + Z_B} = \frac{6600\angle 0° - 6400\angle 0°}{0.3+j3+0.2+j1} = \frac{200\angle 0°}{(-2.9375+j0.8992)}$$

$$= \frac{200\angle 0°}{3.072\angle 162.98°} = \mathbf{65.1041\angle -162.98°\ A}$$

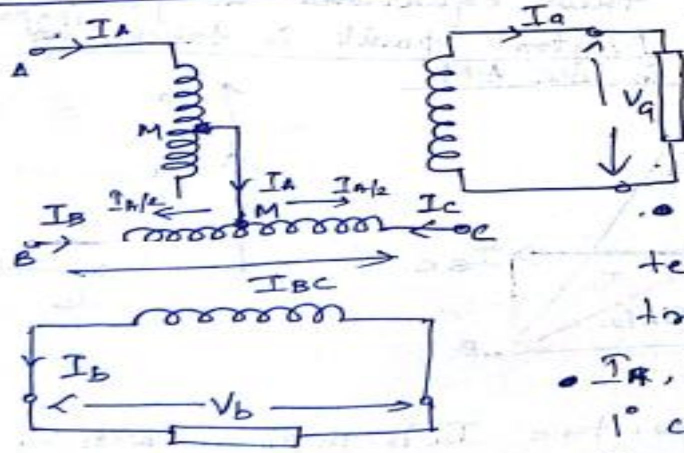
2

So to make $|\vec{V_a}| = |\vec{V_b}|$

- Teaser transformer turns ratio must be $\sqrt{3}/2 \, N_1 / N_2$
- Main transformer turns ratio is N_1/N_2

Load Conditions

Balanced load. (Resistive load)



When a balanced resistive load is connected across the secondaries,

- I_a, I_b is the teaser and main transformer 2° current
- I_A, I_B, I_C is the 1° currents input to the terminals A, B, C for teaser and main transformer.
- I_{BC} is the total 1° current in main transformer

Then from the fig:-

$$\vec{I}_A = \frac{N_2}{N}\vec{I}_a \Rightarrow \vec{I}_A = \frac{N_2}{\sqrt{3}/2 \, N_1}\vec{I}_a$$

or $$\boxed{\vec{I}_A = \frac{2}{\sqrt{3}}\frac{N_2}{N_1}\vec{I}_a}$$

ie :- $\vec{I}_A$ is in phase with 2° current $\vec{I}_a$.

Similarly, $$\boxed{\vec{I}_{BC} = \frac{N_2}{N_1}\vec{I}_b}$$

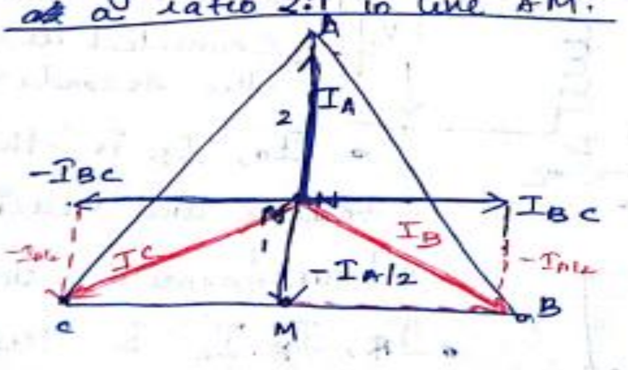
ie :- $\vec{I}_{BC}$ is in phase with 2° current $\vec{I}_b$.

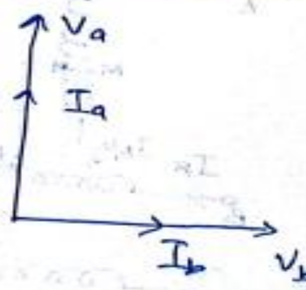
Also $$\boxed{\vec{I}_B = \vec{I}_{BC} - \vec{I}_{A/2}}$$

[As M is the midpoint I_A divides equally at point M]

$$\boxed{I_c = -\vec{I}_{BC} - \vec{I}_{A/2}}$$

To represent these equations in phasor diagram, Neutral point is taken at a point with a ratio 2:1 in line AM.



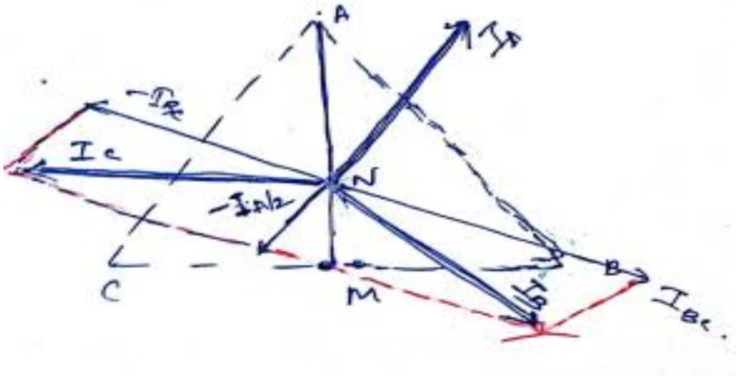


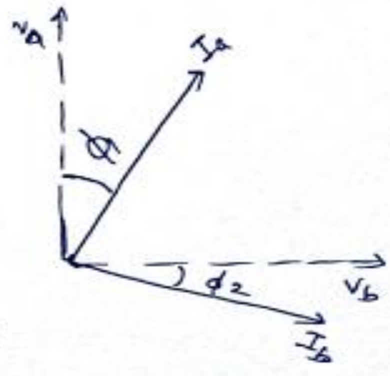
- As load is resistive I_a is in phase with V_a
  I_b is in phase with V_b

Draw I_A in direction I_a & I_{BC} in direction I_b

Unbalanced Load

For unbalanced load. I_a lags V_a by angle ϕ_1 and I_b lag V_b by angle ϕ_2 and $\phi_1 \neq \phi_2$.





3.a

1. A three phase transformer occupies less space for same rating, compared to a bank of three single phase transformers.
2. It weighs less.
3. Its cost is less.
4. Only one unit is required to be handled which makes it easy for the operator.
5. It can be transported easily.
6. The core will be of smaller size and the material required for the core is less.
7. Single three phase unit is more efficient.
8. In case of three single phase units, six terminals are required to be brought out while in case of one three phase unit, only three terminals are required to be brought out.
9. The overall busbar structure, switchgear and installation of single three phase unit is simpler.

In contrast to above, a bank of three single phase transformers is used in underground work such as in mines as it is easier to transport these units. The bank of three single phase transformers also offers the advantage of open delta operation with reduced rating when one of the units in the bank is inoperative.

But it is common practice to use a single three phase transformer unit due to its reduced cost.

3. b

Example 2.9.6 *Two 110 volts single phase electric furnaces take loads of 500 kW and 800 kW respectively at a power factor of 0.71 lagging and are supplied from 6600 V, 3-phase, 50 Hz mains through a Scott - connected transformer combination. Calculate the currents in the 3-phase lines neglecting transformer losses. Draw the phasor diagram.*

VTU : June-10, Marks 7

Solution : Secondary voltage = 110 volts, Primary line voltage = 6600 volts.

Load on furnace 1 = 800 kW , Load on furnace 2 = 500 kW.

The p.f. of loads = 0.71 lagging.

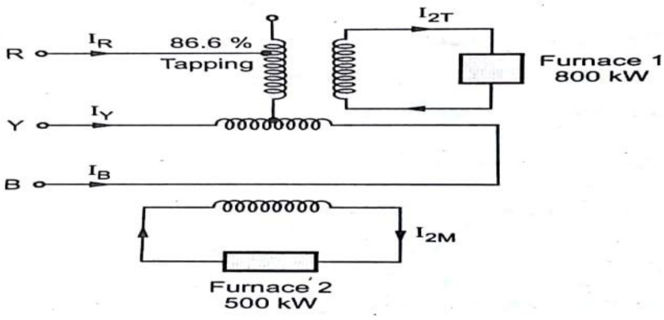


Fig. 2.9.14

Secondary current of teaser transformer,

$$I_{2T} = \frac{P}{V \cos \phi} = \frac{800 \times 10^3}{110 \times 0.71} = 10243.27 \text{ A}$$

$$\text{Transformation ratio for K} = \frac{V_2}{V_1} = \frac{110}{6600} = \frac{1}{60} = 0.0166$$

Transformation ratio for teaser transformer = 1.1547 × Transformation ratio for main transformer

$= 1.1547 \times 0.0166 = 0.019245$

Primary current in teaser transformer , I_{1T} = Transformation ratio for teaser transformer $\times I_{2T}$

$= 0.019245 \times 10243.27 = 197.13$ A

∴ Line current, I_R = **197.13 A**

Secondary current transformer of main, $I_{2M} = \frac{P}{V \cos \phi} = \frac{500 \times 10^3}{110 \times 0.71}$

$= 6402.04$ A

Primary current of main transformer ,

I_{1M} = Transformation ratio for main transformer × I_{2M}

$= 0.0166 \times 6402.04 = 106.27$ A

In addition to this, each half of the primary winding of the main transformer carries half of teaser primary currents I_{1T}.

$$I_{1T} = 197.13 \text{ A and } \frac{I_{1T}}{2} = \frac{197.13}{2} = 98.565 \text{ A}$$

$$\text{Total current carried by main transformer} = \sqrt{(I_{1M})^2 + \left(\frac{I_{1T}}{2}\right)^2}$$

$$= \sqrt{(106.27)^2 + (98.565)^2}$$

∴ $I_Y = I_B$ = **144.94 A**

∴ The three line currents are respectively,

I_R = **197.13 A** and $I_Y = I_B$ = **144.94 A**

The phasor diagram is as shown in the Fig. 2.9.15.

4

3.7.3 Copper Saving in Autotransformer

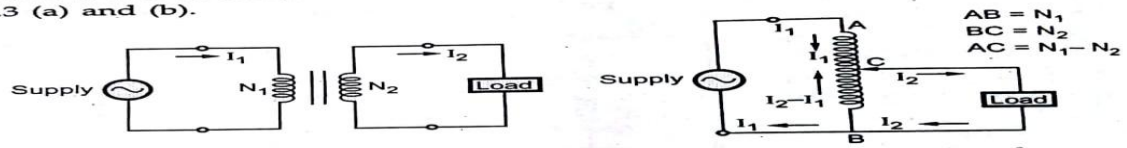
For any winding, the cross-section of winding is proportional to the current I. Whil the total length of the winding is proportional to the number of turns N. Hence th weight of copper is proportional to the product of N and I.

$\therefore$ Weight of copper $\propto$ NI

where I = Current in the winding

and N = Number of turns of the winding

Consider a two winding transformer and step down autotransformer as shown in th Fig. 3.7.3 (a) and (b).



(a) Two winding transformer (b) Step down autotransformer

Fig. 3.7.3

Let 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 $\propto N_2 I_2$

$\therefore$ $W_{TW} \propto N_1 I_1 + N_2 I_2$ ... Total weight of C

In case of step down autotransformer.

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

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

$\therefore$ $W_{AT} \propto (N_1 - N_2) I_1 + N_2 (I_2 - I_1)$ ... Total weight of Cu

Taking ratio of the two weights,

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

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

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

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

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

$\therefore$ Saving of copper = $W_{TW} - W_{AT} = W_{2T} - (1 - K) W_{TW}$

Saving of copper = $K W_{TW}$ ... **For step down autotransformer**

Thus saving in copper is K times the total weight of copper in two winding transformer.

And **Saving of copper = $\frac{1}{K} W_{TW}$** ... **For step up autotransformer**

3.7.7 Advantages of Autotransformer

The various advantages of an autotransformer are,

1. Copper required is very less.
2. The efficiency is higher compared to two winding transformer.
3. The size and hence cost is less compared to two winding transformer.
4. The resistance and leakage reactance is less compared to two winding transformer
5. The copper losses I^2R, are less.
6. Due to less resistance and leakage reactance, the voltage regulation is superior th the two winding transformer.
7. VA rating is more compared to two winding version.
8. A smooth and continuous variation of voltage is possible.

5.a

3.4 Parallel Operation of Transformers with Equal Voltage Ratios

VTU : Jan.-09, 11, 14, July-12

Let us now consider the case of two transformers connected in parallel having equal voltage ratios. The two transformers are having no load secondary voltage same. i.e. $E_1 = E_2 = E$. These voltages are in phase with each other. This is possible if the magnetizing currents of the two transformers are not much different. With this case the primaries and secondaries of the two transformers can be connected in parallel and no current will circulate under no load condition. This is represented in the Fig. 3.4.1.

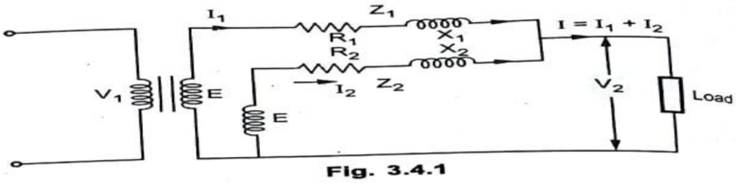


Fig. 3.4.1

If we neglect magnetizing components, the two transformers are represented as shown in the Fig. 3.4.2.

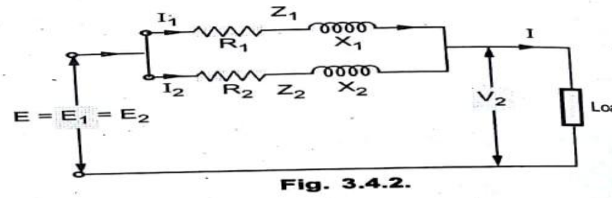


Fig. 3.4.2.

The phasor diagram under this case is shown in the Fig. 3.4.3. The two impedances Z_1 and Z_2 are in parallel. The values of Z_1 and Z_2 are with respect to secondary.

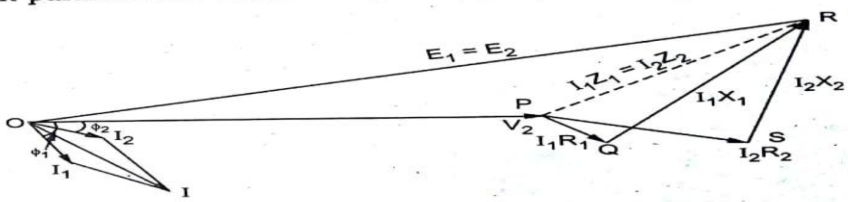


Fig. 3.4.3

Z_1 and Z_2 are in parallel therefore the equivalent impedance is given by,

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

As seen from the phasor diagram, $I_1 Z_1 = I_2 Z_2 = I \cdot Z_{eq}$

$$I_1 = \frac{I Z_{eq}}{Z_1} = \frac{I Z_2}{Z_1 + Z_2} \quad \text{and} \quad I_2 = \frac{I Z_{eq}}{Z_2} = \frac{I Z_1}{Z_1 + Z_2}$$

Multiplying both terms of above equation by voltage V_2,

$$V_2 I_1 = V_2 I \frac{Z_2}{Z_1 + Z_2} \quad \text{and} \quad V_2 I_2 = V_2 I \frac{Z_1}{Z_1 + Z_2}$$

But $V_2 I \times 10^{-3}$ is Q i.e. the combined load in kVA

From this kVA carried by each transformer is calculated as,

$$Q_1 = Q \cdot \frac{Z_2}{Z_1 + Z_2} = Q \cdot \frac{1}{1 + \frac{Z_1}{Z_2}}$$

and

$$Q_2 = Q \cdot \frac{Z_1}{Z_1 + Z_2} = Q \cdot \frac{1}{1 + \frac{Z_2}{Z_1}}$$

The above expressions are useful in determining the values of Q_A and Q_B in magnitude and in phase.

Key Point *The equation contains impedance ratio hence ohmic values of resistances and reactances are not required.*

The two transformers work at different power factors. One operates at high p.f. while the other at low p.f. If the impedances Z_1 and Z_2 are equal both in magnitude and quality i.e. $\left(\frac{X_1}{R_1} = \frac{X_2}{R_2}\right)$, both transformers operate at the same p.f. which is the p.f. of the load.

5. b

ected to

ample 3.7.3 *The primary and secondary voltages of an autotransformer are 230 V and 75 V respectively. Calculate the currents in the different parts of the winding when load current is 200 A. Also calculate the saving of copper.* **VTU : Jan.-07, Marks 6**

ution : The arrangement is shown in the Fig. 3.7.18.

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

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

$$I_1 = KI_2 = 0.326 \times 200$$

$$= \mathbf{65.217\ A} \quad \text{...Part AC}$$

$$I_2 - I_1 = \mathbf{134.783\ A} \quad \text{...Part BC}$$

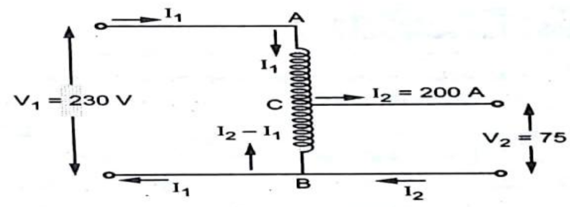


Fig. 3.7.18

Copper saving $= K\ W_{TW}$

$= 0.326\ W_{TW}$ ... W_{TW} = Copper weight in 2 winding

% Copper saving = **32.6 %**

6

3.9.4 On Load Tap Changing

Under the load conditions, it is required to maintain the voltage on the secondary side of the transformer with the help of certain arrangement when transformer is connected to a system. If this arrangement works without making the load off from the transformer then it is called on load tap changing. Without interruption in the supply, the tap changing gear should change the turns ratio.

Normally in case of on load tap changing the tappings are connected at the neutral end of high voltage winding. The tap changer is normally in the form of selector switch. There are various ways by which tap changer is operated viz. motor operated mechanism, remote control or with the help of handle for manual operation in case of emergency.

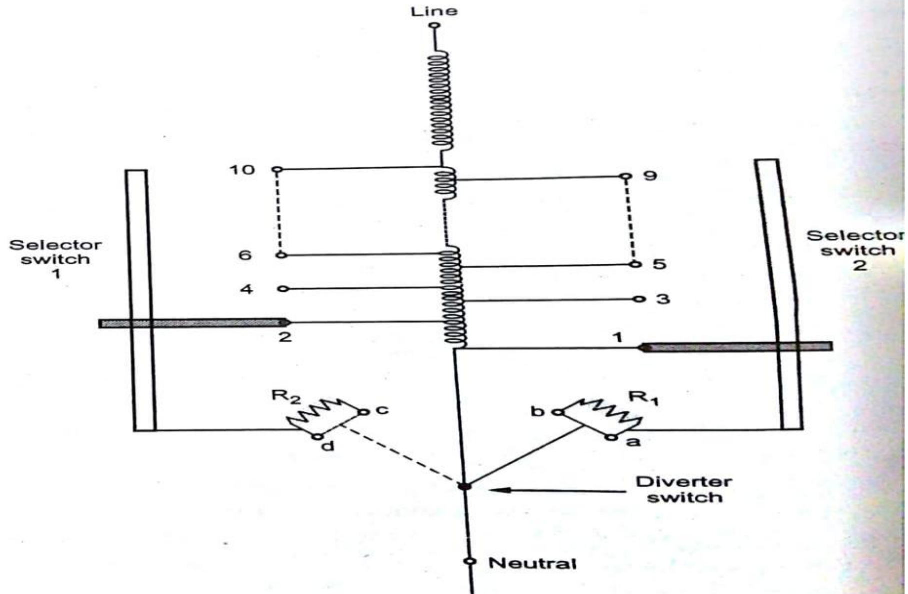


Fig. 3.9.5 On load tap changer

The most vital factor in case of on load tap changing is continuity of circuit throughout the operation of tap changing. If the circuit is disconnected, the continuity of supply to load will be lost. As the selector switch should not break current, additional separate oil filled compartment is used to mount diverter switch which breaks the load current by interrupted arc which can form carbon. It should not be mixed with the oil in the main tank to decrease its dielectric strength.

The main consideration is that when one tapping is opened, the contact must be established to other tapping. Hence make before break switch is used and in the transition period connection is made to adjacent taps which may result into short circuit of turns between adjacent tappings. This short circuit current can be limited by using resistors or reactors. The reactors which were used in old days are replaced by resistors now.

The on load tap change in shown in the Fig. 3.9.5.

The selector switch 1 and 2 are provided on taps 1 and 2 respectively. The diverter switch is connecting tap 1 to the neutral terminal of the transformer winding.

If we want to change the tap from position 1 to 2 then following is the sequence of operation :

i) The resistance R_1 is short circuited as contacts a and b are closed. The load current flows through contact a from tap. This is nothing but the running position at the tap 1.

ii) With the help of external operating mechanism, the diverter switch is moved to open the contact a. The load current now flows through resistance R_1 and contact b.

iii) The contact c closes to open the resistance R_1 when the moving contact of diverter switch continues its movement to the left. The resistances R_1 and R_2 are now connected across taps 1 and 2 so that the load current flows through these resistances to mid point of junction of b and c.

iv) With further movement of diverter switch to the left makes contact b to open. Now the load current flows from tap 2 through resistance R_2 and contact c.

v) At last the diverter switch moves to the extreme left position which closes the contact d. This short circuits resistance R_2. The load current flows from tap 2 through contact d which is the running position of tap 2.

It can be seen that the change of tap from position 1 to 2 does not involve the movement of selector switches 1 and 2. But if it is desired to have further tap change from tap 2 to tap 3 then the selector switch S_2 is moved to tap 3 before the movement

	of diverter switch. Then the same sequence as described above but in reverse order is to be followed and the diverter switch is moved. As the resistances are included in the circuit there will be some loss of energy which can be reduced by keeping these resistances in circuit for minimum time as possible. For economical considerations, as the resistors are designed for short time rating, they should be kept in the circuit for minimum time. This needs some form of energy storage in driving mechanism which ensures the completion of tap change once initiated under the failure of control supply. Modern on load tap changers use springs as energy storage elements which reduce the time of resistor in a circuit to minimum. This type of tap changer is compact in size while due to high speed breaking, contact wear reduces.
7.a	(table below)

Two winding transformer		Auto transformer
It has two windings.	1.	It has single winding
There is electric isolation between primary and secondary.	2.	There is no electric isolation between primary and secondary.
The copper required is more.	3.	There is substantial saving in copper.
Efficiency is less compared to autotransformer.	4.	Efficiency is high compare to two winding transformer.
The size and cost is high	5.	The size and cost is less.
Voltage regulation is poor compared to autotransformer.	6.	Voltage regulation is superior compared to two winding transformer.
The resistance and leakage reactance values are more.	7.	The resistance and leakage reactance values are less.
Copper losses are more.	8.	Copper losses are less.
The power transfer is fully by induction.	9.	The power transfer is by induction as well as conduction.
The kVA rating is less than the corresponding auto transformer version.	10.	The kVA rating is more than the corresponding two winding version.
It can not be used as variac.	11.	It can be used as variac.

7. b

3.7.11 Equivalent Circuit of Autotransformer

Consider an autotransformer as shown in the Fig. 3.7.14.

R_1 and X_1 are the resistance and inductance of that part of the winding which carries only current I_1.

R_2 and X_2 are the resistance and inductance of that part of the winding which behaves as secondary.

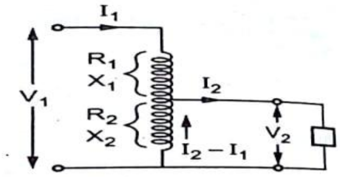


Fig. 3.7.14

Applying Kirchhoff's law,

$$V_1 = E_1 + I_1(R_1 + jX_1) - (I_2 - I_1)(R_2 + jX_2) \quad ...(3.7.1)$$

$$E_2 = V_2 + (I_2 - I_1)(R_2 + jX_2) \quad ... (3.$$

$$K = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{I_1}{I_2} = \text{Transformation ratio}$$

$\therefore \quad E_1 = \frac{E_2}{K}, \quad I_2 = \frac{I_1}{K}$ and using in (3.7.1),

$$\therefore \quad V_1 = \frac{E_2}{K} + I_1(R_1 + jX_1) + I_1(R_2 + jX_2) - \frac{I_1}{K}(R_2 + jX_2) \quad ... (3$$

Using equation (3.7.2) in (3.7.3),

$$\therefore \quad V_1 = \frac{V_2 + (I_2 - I_1)(R_2 + jX_2)}{K} + I_1(R_2 + jX_2) + I_1(R_1 + jX_1) - \frac{I_1}{K}(R_2 + jX_2)$$

Use $I_2 = \frac{I_1}{K}$ and combining the terms of I_1 we get,

$$\therefore \quad V_1 = \frac{V_2}{K} + I_1\left\{R_1 + R_2\left(\frac{1}{K^2} - \frac{2}{K} + 1\right) + j\left[X_1 + X_2\left(\frac{1}{K^2} - \frac{2}{K} + 1\right)\right]\right\}$$

$$\therefore \quad V_1 = \frac{V_2}{K} + I_1\left\{R_1 + R_2\left(\frac{1}{K} - 1\right)^2 + j\left[X_1 + X_2\left(\frac{1}{K} - 1\right)^2\right]\right\}$$

$$V_1 = V_2' + I_1R_{1e} + I_1jX_{1e} \quad ... (3.7.4)$$

The equation (3.7.4) gives equivalent circuit as ɩwn in the Fig. 3.7.15 where

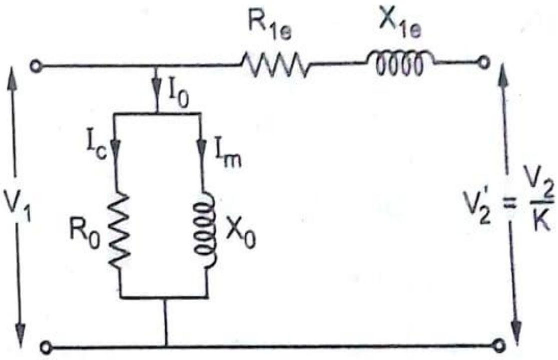


Fig. 3.7.15

$$R_{1e} = R_1 + R_2\left(\frac{1}{K} - 1\right)^2$$

= Equivalent resistance referred to primary

$$X_{1e} = X_1 + X_2\left(\frac{1}{K} - 1\right)^2$$

= Equivalent inductance referred to primary

For the analysis, magnetising branch is neglected which can be added across the tage V_1.