UNIVERSITY OF DIYALA

COLLEGE OF ENGINEERING

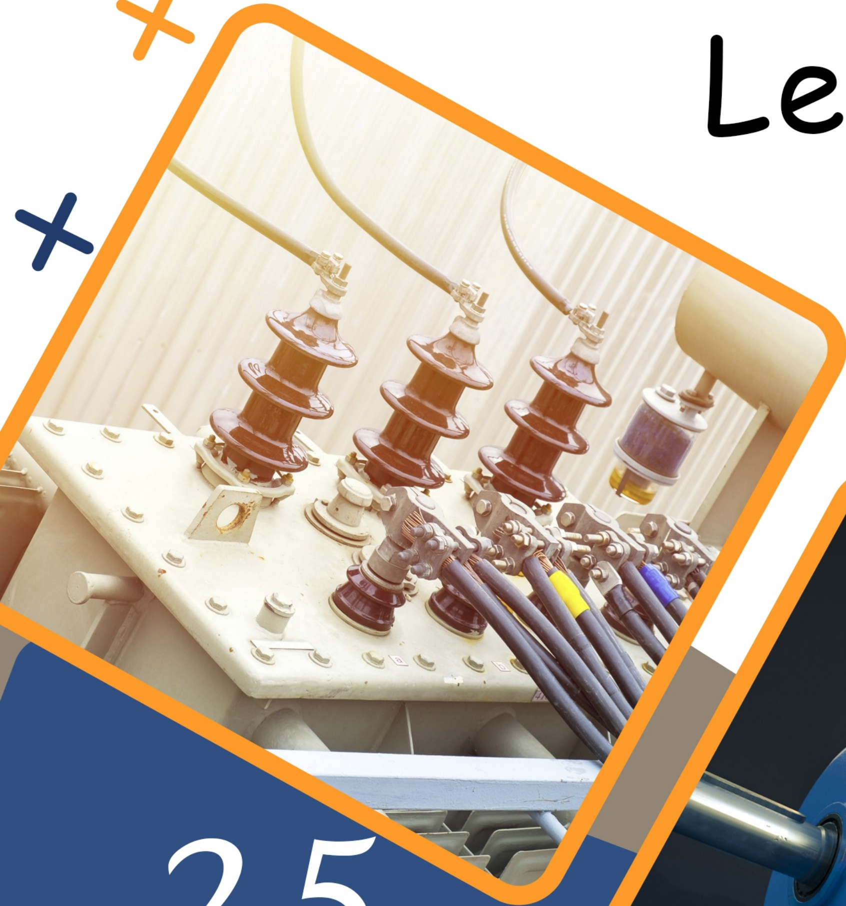
DEPARTMENT OF THE ELECTRICAL POWER AND MACHINES ENGINEERING

Second Stage

ELECTRICAL MACHINES

Lecture: 8

Lecturer
Mayyadah Sahib



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THREE-PHASE TRANSFORMER:

A Three-Phase system in used to generate and transmit electric power. Three-Phase voltages are raised or lowered by means of *Three-Phase transformers*. A Three-Phase transformer can be built in two ways:

1. By suitably connecting a bank of three Single-Phase transformers see Figure (1).
2. By constructing a Three-phase transformer on a common magnetic structure see Figure (2).

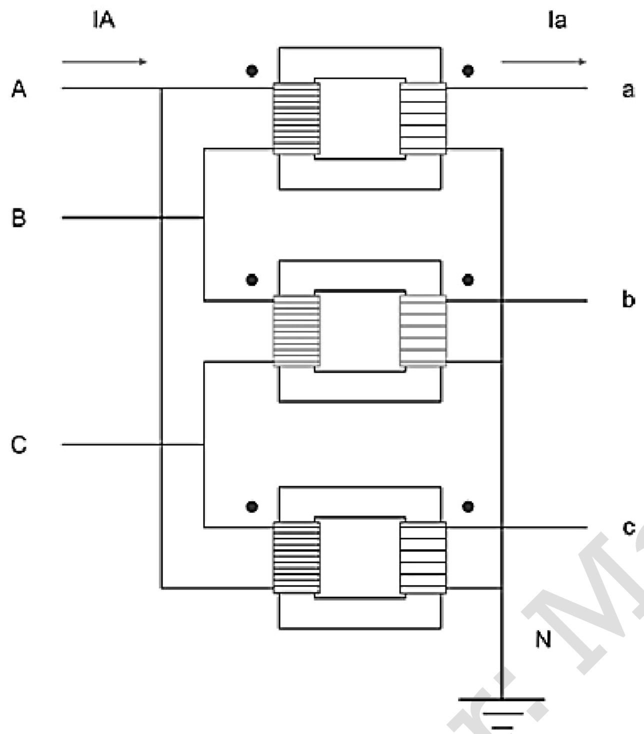


Figure (1)
Three Single-Phase transformer connected for realizing one 3-Phase transformer

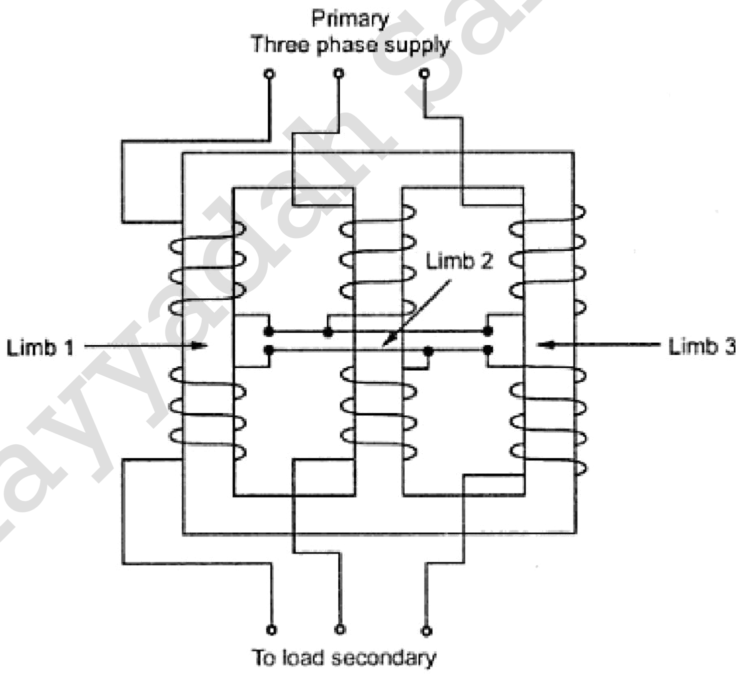


Figure (2)

Three-Phase Transformer Connections:

There are various methods available for transforming 3-Phase voltages to higher or lower 3-Phase voltages $i.e.$ for handling a considerable amount of power. The most common connections are:

(i) Star–Star $(Y - Y)$ connection
(ii) Delta–Delta $(\Delta - \Delta)$ connection
(iii) Star–Delta $(Y - \Delta)$ connection
(iv) Delta–Star $(\Delta - Y)$ connection
(v) Open–Delta or $(V - V)$ connection
(vi) Scott connection or $(T - T)$ connection

Important relations in Three-Phase connected system:

Star-connections	Delta- connections
$E_L = \sqrt{3}E_{ph}$ (1) ; $I_L = I_{ph}$ (2)	$E_L = E_{ph}$ (3) ; $I_L = \sqrt{3}I_{ph}$ (4)
Power, (5) $P = \sqrt{3}V_L I_L \cos\Phi = 3V_{ph}I_{ph}\cos\Phi$	Both for Star and Delta (5)

In Three-Phase transformer	
Primary	**Secondary**
$E_{ph\,1} = 4.44f\Phi_m N_1$ (6)	$E_{ph\,2} = 4.44f\Phi_m N_2$ (7)
$E_{ph\,1} = 4.44fB_m A_i N_1$ (8)	$E_{ph\,2} = 4.44fB_m A_i N_2$ (9)
Transformation ratio, $K = \frac{E_{ph\,2}}{E_{ph\,1}} = \frac{N_2}{N_1}$ (10)	

Example 1: A Three-Phase transformer has delta connected primary and a star connected secondary working on 50Hz Three-Phase supply. The line voltages of primary and secondary are 3,300V and 400V respectively. The line current on the primary side is 12A and secondary has a balanced load at 0.8 lagging p.f. Determine the secondary phase voltage, line current and the output.

Solution:

Primary side connected with delta

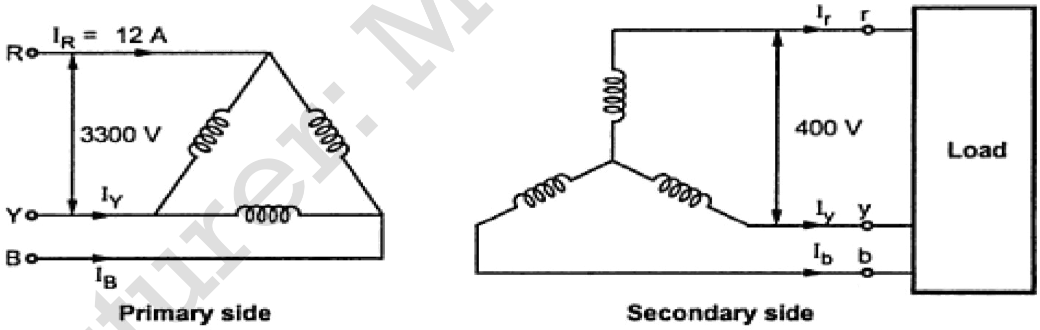


Figure (3)

$V_{L1} = 3{,}300V$; $I_{L1} = 12A$

Secondary side star connected with p.f. 0.8

Primary side: $V_{ph\,1} = V_{L1} = 3{,}300V$

Secondary side: $V_{ph\,2} = \frac{V_{L2}}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 230.94V$

Transformation Ratio, $K = \frac{V_{ph\,2}}{V_{ph\,1}} = \frac{230.94}{3{,}300} = 0.0699$

Primary side: $I_{L1} = 12A$

$I_{ph\,1} = \frac{I_{L1}}{\sqrt{3}} = \frac{12}{\sqrt{3}} = 6.928A$

Secondary side: $K = \frac{I_{ph\,1}}{I_{ph\,2}}$

$\therefore \quad I_{ph\,2} = \frac{I_{ph\,1}}{K} = \frac{6.928}{0.0699} = 99.11\text{A}$

Since secondary is connected in star

$I_{ph\,2} = I_{L2} = 99.11\text{A}$

Output

$= \sqrt{3}V_{L2}I_{L2}\cos\Phi = \sqrt{3} \times 400 \times 99.11 \times 0.8 = 54932.34\text{W} = 54.92\text{kW}$

Example 2: A 500kVA, Three-phase, 50Hz transformer has a voltage ratio (line voltages) of 33/11 kV and is delta/star connected. The resistances per phase are: high voltage 35Ω, low voltage 0.876Ω and the iron loss is 3,050W. Calculate the value of efficiency at full-load and one-half of full-load respectively (a) at unity p.f. and (b) 0.8 p.f.

Solution:

Transformation ratio $K = \frac{11{,}000}{\sqrt{3}\times 33.000} = \frac{1}{3\sqrt{3}}$ or 0.1924

Per phase $R_{02} = 0.876 + \left(\frac{1}{3\sqrt{3}}\right)^2 \times 35 = 2.172\Omega$

Secondary phase current $= \frac{500{,}000}{\sqrt{3}\times 11{,}000} = \frac{500}{11\sqrt{3}}\text{A}$ or 26.24A

Full-load condition:

Full load total Cu loss $= 3 \times \left(\frac{500}{11\sqrt{3}}\right)^2 \times 2.172 \cong 4{,}490\text{W}$; Iron loss $= 3{,}050\text{W}$

Total full-load losses $= 4{,}490 + 3{,}050 = 7{,}540\text{W}$

Output at unity p.f. $= 500\text{kW}$

$\therefore \quad$ F.L. efficiency $= \frac{500{,}000}{507{,}540} = 0.9851$ or 98.514%

Output at 0.8 p.f. $= 400\text{kW}$

$\therefore \quad$ Efficiency $= \frac{400{,}000}{407{,}540} = 0.981$ or 98.14%

Half-load condition:

Output at unity p.f. $= 250\text{kW}$

Cu losses $= \left(\frac{1}{2}\right)^2 \times 4{,}490 \cong 1{,}223\text{W}$

Total losses $= 3{,}050 + 1{,}123 = 4{,}173\text{W}$

$\therefore \quad \eta = \frac{250{,}000}{254{,}173} = 0.9835$ or 98.35%

Output at 0.8 p.f. $= 200\text{kW}$

$\therefore \quad \eta = \frac{200{,}000}{204{,}173} \cong 0.98$ or 98%

AUTO TRANSFORMER

Is a special type of transformer having only one winding such that part of the winding is common to the primary and secondary.

Obviously the two windings are electrically connected and it works on the principle of conduction as well as induction. The power transfer in 2 winding transformer is fully inductively while in autotransformer the power is transferred from primary to secondary by both inductively as well as conductively.

In autotransformer the output voltage can be stepped down (see Figure (4-a) below) or stepped up (see Figure (4-b) below)

In step down autotransformer, the entire winding acts as a primary while the part of the winding is used common to both primary and secondary. Thus AB forms the primary having N_1 turns while BC forms the secondary with N_2 turns. As $N_2 < N_1$, the output voltage $V_2 < V_1$ and it acts as a step down autotransformer.

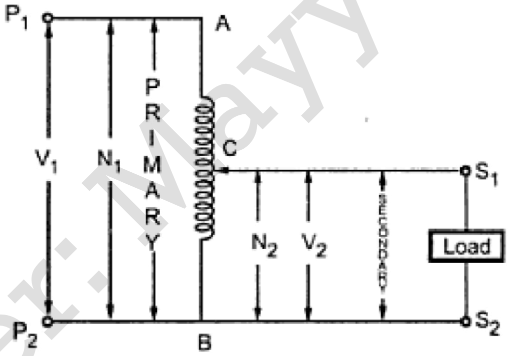


Figure (4-a) Step down autotransformer

In step up autotransformer, the entire winding acts as secondary while the part of the winding is used common to both primary and secondary. Thus AB forms the secondary having N_2 turns while BC forms the primary with N_1 turns. As $N_2 > N_1$, the output voltage $V_2 > V_1$ and it acts as a step up autotransformer.

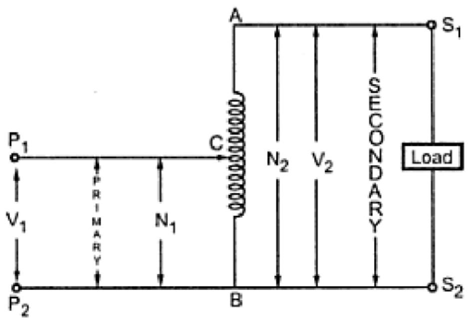
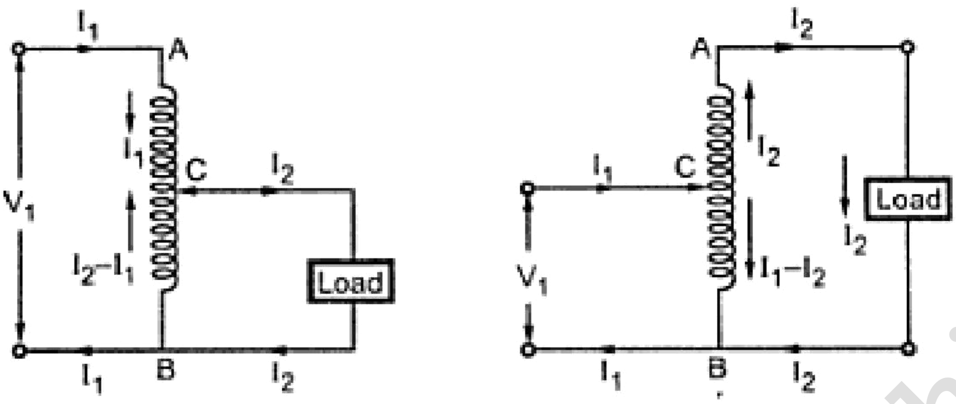


Figure (4-b) Step up autotransformer

The current distribution in step-up and step-down transformer is shown Figure (5).



(a) Step down autotransformer (b) Step up autotransformer
Current distribution in autotransformer
Figure (5)

Transformation Ratio of Autotransformer:

The transformation ratio of autotransformer can be obtained as:

$$K = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}$$

Note: K is greater than unity for *step up autotransformer* while K is less than unity for *step down autotransformer*.

Advantages and Disadvantages of Autotransformer:

Advantages of an Autotransformer:

(*i*) An autotransformer requires less Cu than a two-winding transformer of similar rating.

(*ii*) An autotransformer operates at a higher efficiency than a two-winding transformer of similar rating.

(*iii*) An autotransformer has better voltage regulation than a two-winding transformer of the same rating.

(*iv*) An autotransformer has smaller size than a two-winding transformer of the same rating.

Disadvantages of an Autotransformer:

Apart from its advantages, an autotransformer suffers from following limitations,

(*i*) Low impedance hence high short circuit currents for short circuits on secondary side.

(*ii*) If a section of winding common to primary and secondary is opened, full primary voltage appears across the secondary resulting in higher voltages on secondary and danger of accidents.

(*iii*) No electrical separation between primary and secondary which is risky in case of high voltage levels.
(*iv*) Economical only where the voltage ratio is less than 2.

Applications of Autotransformer:

The various applications of an autotransformer are,

1. For safely starting the machines like induction motors, synchronous motors $i.e.$ as a starter.
2. To give a small boost to a distribution cable to compensate for a voltage drop $i.e.$ as a booster.
3. As a furnace transformer to supply power to the furnaces at the required supply voltage.
4. For interconnecting the systems which are operating roughly at same voltage level.
5. It can be used to vary the voltage to the load, smoothly from zero to the rated voltage.

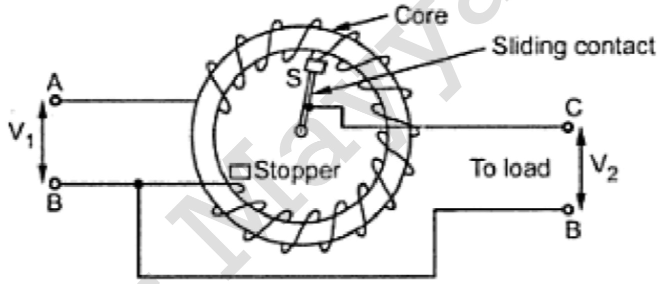


Figure (6): Autotransformer as variac

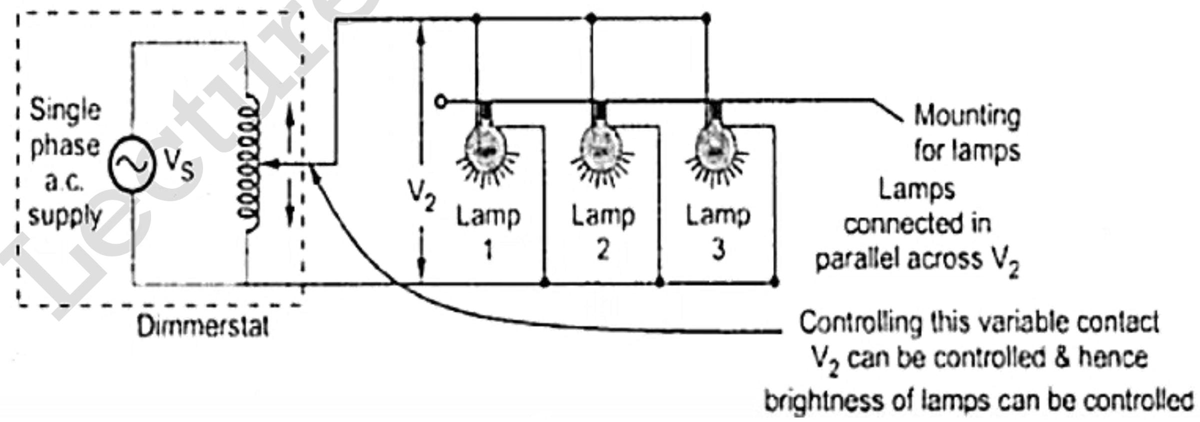


Figure (7)

Example 4: The Figure (8) shows an autotransformer used to supply a load of 2kW at 230V from a 400V A.C. supply. Find the currents in parts AC and BC, neglecting losses and no load current. Assume purely resistive load.

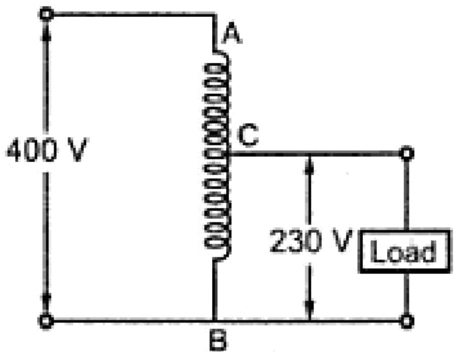


Figure (8)

Solution:

As the load is resistive, $\cos\phi_2 = 1$

$\therefore \quad P_{out} = 2\text{kW} = V_2 I_2 \cos\phi_2$

$2 \times 10^3 = 230 \times I_2 \times 1$

$I_2 = 8.6956\text{A}$

Now, $V_1 = 400\text{V}$ and $V_2 = 230\text{V}$

$\therefore \quad K = \frac{V_2}{V_1} = \frac{230}{400} = 0.575$

And, $K = \frac{I_1}{I_2} = 0.575 = \frac{I_1}{8.6956}$

$\therefore \quad I_1 = 4.99997 \cong 5\text{A}$

$\therefore$ Current in part AC = 5A

$\therefore$ Current in part $BC = I_2 - I_1 = 3.6956\text{A}$

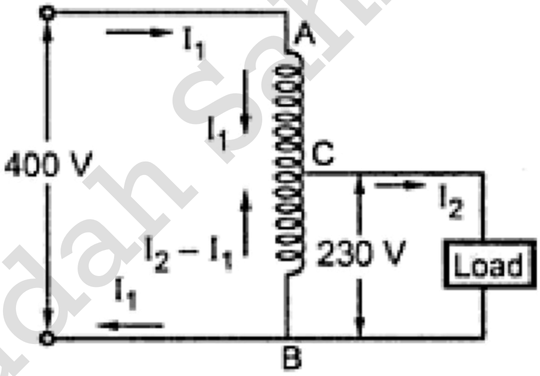


Figure (9)

Example 5: A 10kVA, 230/110 V transformer is to be used as an autotransformer. What will be the voltage ratio and output rating of an autotransformer?

Solution:

The given values are,

Two winding transformers = 230/110 V

kVA rating = 10kVA

$\therefore$ Current through 230V winding $= \frac{\text{VA rating}}{230} = \frac{10\times10^3}{230} = 43.478\text{A}$

And current through 110V winding $= \frac{\text{VA rating}}{110} = \frac{10\times10^3}{110} = 90.909\text{A}$

Now as secondary voltage of two winding transformer is 110V, let us assume that autotransformer output voltage required is 110V. So it can be connected as autotransformer as shown in the Figure (10).

The part AC is primary of two winding while BC is secondary of two winding transformer.

Thus for an autotransformer,

Primary = AB, secondary = BC

$\therefore \quad V_1 = 230 + 110 = 340\text{V}$

$V_2 = 110\text{V}$

I_1 = Current through 230V winding = 43.478A

$K = \frac{V_2}{V_1} = \frac{110}{340} = 0.3235$

And, $K = \frac{I_1}{I_2} = \frac{43.478}{I_2}$

$\therefore \quad I_2 = \frac{43.478}{0.3235} \cong 134.4\text{A}$

$\therefore \quad$ output rating $= V_2 I_2 = 110 \times 134.4 = 14784\text{VA} = 14.784\text{kVA}$

So, voltage ratio $= 0.3235 = \frac{11}{34}$

And, output rating = 14.784kVA

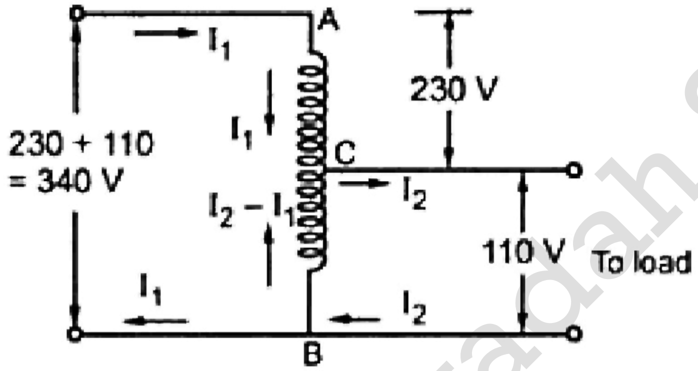


Figure (10)

Example 6: A 2,200/220 V, 20kVA, two winding transformer is connected as an autotransformer to transform 2,200V to 2,420V. Find:

(*i*) The transformation ratio of autotransformer

(*ii*) The kVA rating of autotransformer

(*iii*) The currents in various parts of winding

Solution:

The given values are,

Two winding transformer = 2,200/220 V

VA rating = 20kVA

Current in 2,200V winding $= \frac{\text{VA rating}}{2{,}200} = \frac{20\times10^3}{2{,}200} \cong 9.091\text{A}$

Current in 220V winding $= \frac{\text{VA rating}}{220} = \frac{20\times10^3}{220} \cong 90.91\text{A}$

(*i*) The transformation ratio is,

$K = \frac{V_2}{V_1} = \frac{2{,}420}{2{,}200} = 1.1$

$K > 1$ as used as step up transformer.

(*ii*) The part AB acts as secondary while part BC acts as primary.

The current through part $AC = I_2$ which is $(2{,}420 - 2.200)$ $i.e.$ 220V winding of the two winding transformer. The current through it is 90.91A, as it is loaded fully.

$\therefore \quad I_2 = 90.91\text{A}$

$\therefore$ kVA rating $= V_2 I_2 = 2{,}420 \times 90.91 = 220.0022\text{kVA}$

(iii) Current through part $AC = I_2 = 90.91\text{A}$

Current through part $BC = I_1 - I_2$

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

$\therefore$ $I_1 = KI_2 = 1.1 \times 90.91 = 100.001\text{A}$

$\therefore$ Current through part $BC = 100.001 - 90.91 = 9.091\text{A}$

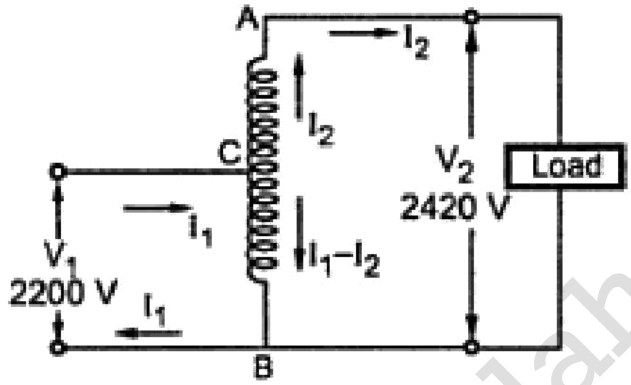


Figure (11)