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Unit-5

Testing of Single Phase Transformer, Autotransformer and Poly phase Transformers

Testing of Transformers

We will discuss the following test in this chapter

1. Open Circuit Test
2. Short Circuit Test
3. Sumpner's Test

Purpose of Testing

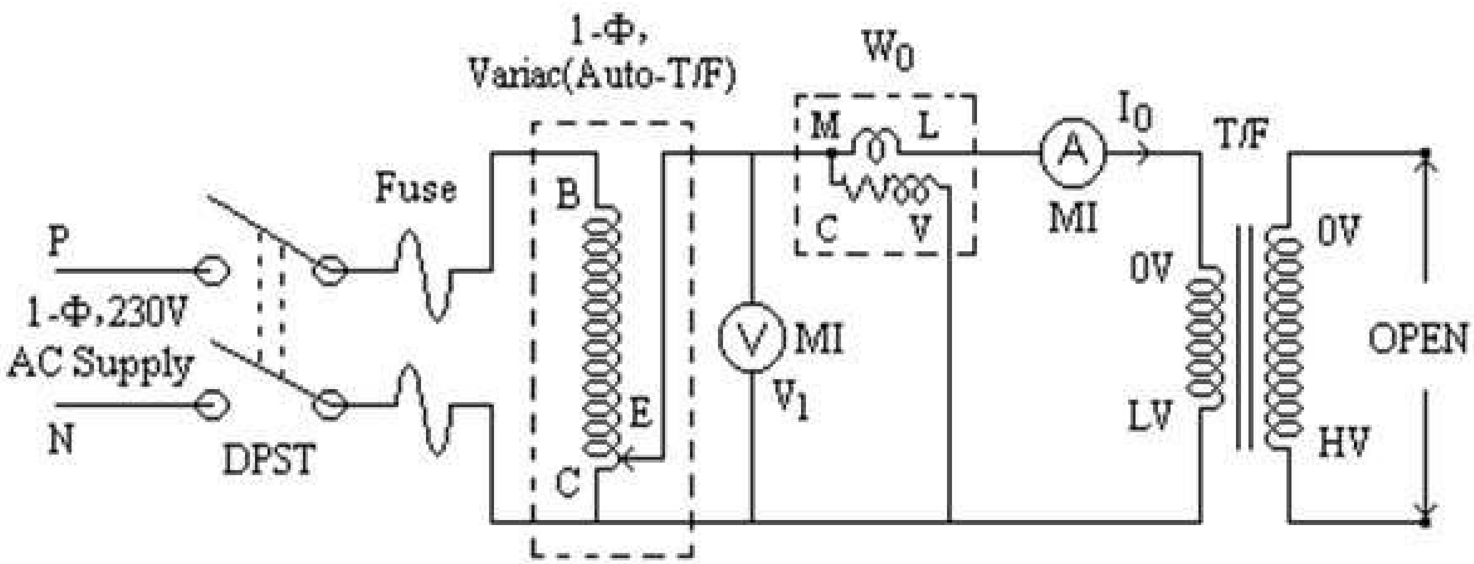
To Find

1. Equivalent Circuit Parameters
2. Losses
3. Efficiency
4. Regulation

Open Circuit Test

Purpose : To Find the Core Losses.

Circuit Diagram



Apparatus Required

1. 1-Φ Transformer
2. Voltmeter (MI)
3. Ammeter (MI)
4. Wattmeter (LPF)
5. 1-Φ Variac

Procedure for O.C test

- Connections are made as per the circuit diagram, and HV terminals are open for O.C test.
- Initially set the variac to zero output and switch ON the supply, by closing DPST.
- Increase the variac output voltage gradually till the rated voltage is reached. With rated voltage applied to the primary side, the readings of the voltmeter, wattmeter and ammeters are noted down in the tabular form as shown below.
- Calculate R_0 and X_0 from these readings.

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Observations of O.C test

S.No	Voltage (V_1) Volts	Current (I_0) Amps	Power (W_0) Watts

Calculations of O.C test

$V_1 I_0 \cos\Phi_0 = W_0$

$I_w = I_0 \cos\Phi_0$ $I_\mu = I_0 \sin\Phi_0$ $X_0 = V_1/I_\mu$ & $R_0 = V_1/I_w$

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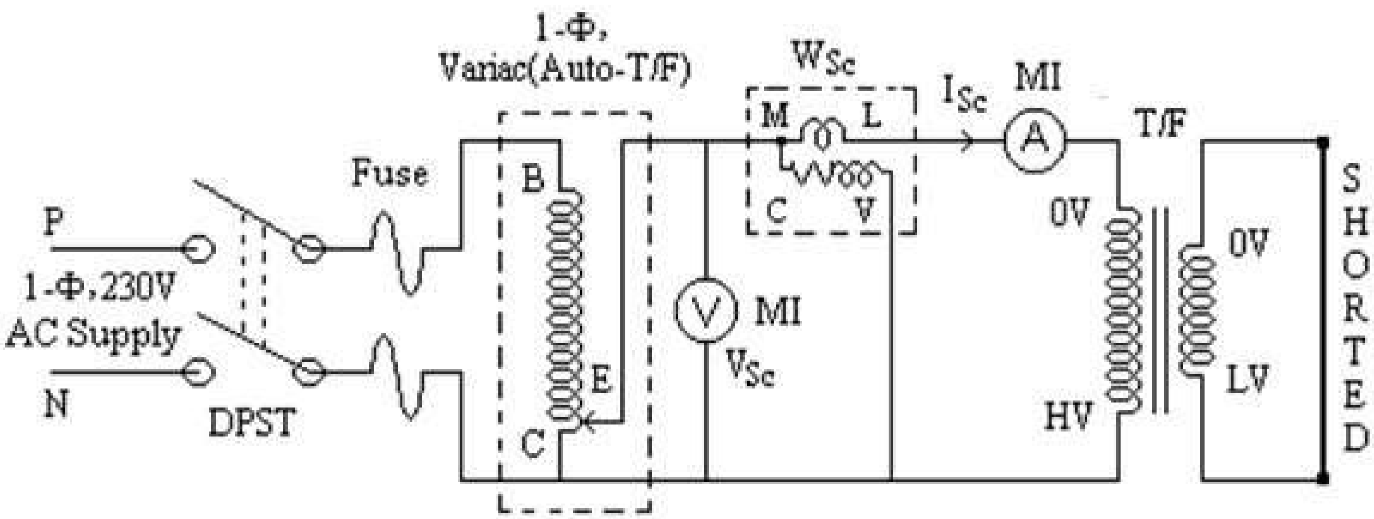
Short Circuit Test

Purpose : To Find the Copper Losses.

Circuit Diagram



Apparatus Required

1. 1-Φ Transformer
2. Voltmeter (MI)
3. Ammeter (MI)
4. Wattmeter (UPF)
5. 1-Φ Variac

Procedure for S.C test

- Connections are made as per the above circuit diagram, and LV side terminals are shorted for S.C test.
- Initially set the variac to zero output and switch ON the supply by closing DPST.
- Slowly apply a low voltage with the help of the variac which circulates the rated current in the circuit, which is read by the ammeter.
- The readings of the voltmeter, wattmeter and the ammeters are noted down in the tabular form as shown below.
- Calculate the total resistance (R_{02}) and reactance (X_{02}) from these readings.

Observations of S.C test

S.No	Voltage (V_1) Volts	Current (I_{sc}) Amps	Power (Wsc) Watts

Calculations of O.C test

$$W_{Sc} = V_{Sc} I_{Sc} \cos\Phi_{Sc} \qquad \therefore \cos\Phi_{Sc} = \frac{W_{Sc}}{V_{Sc} I_{Sc}}$$

$$Z_{02} = \frac{V_{Sc}}{I_{Sc}} \; ; \qquad Z_{01} = \frac{Z_{02}}{K^2}$$

•

$$W_{Sc}^{2} = I_{Sc}^{2} R_{02} \quad \therefore R_{02} = \frac{W_{Sc}}{I_{Sc}^{2}} \; ; \qquad R_{01} = \frac{R_{02}}{K^2} \qquad \text{Where } K = \frac{H.V}{L.V}$$

$$\therefore X_{02} = \sqrt{Z_{02}^{2} - R_{02}^{2}} \qquad X_{01} = \sqrt{Z_{01}^{2} - R_{01}^{2}}$$

Drawbacks of OC & SC Test

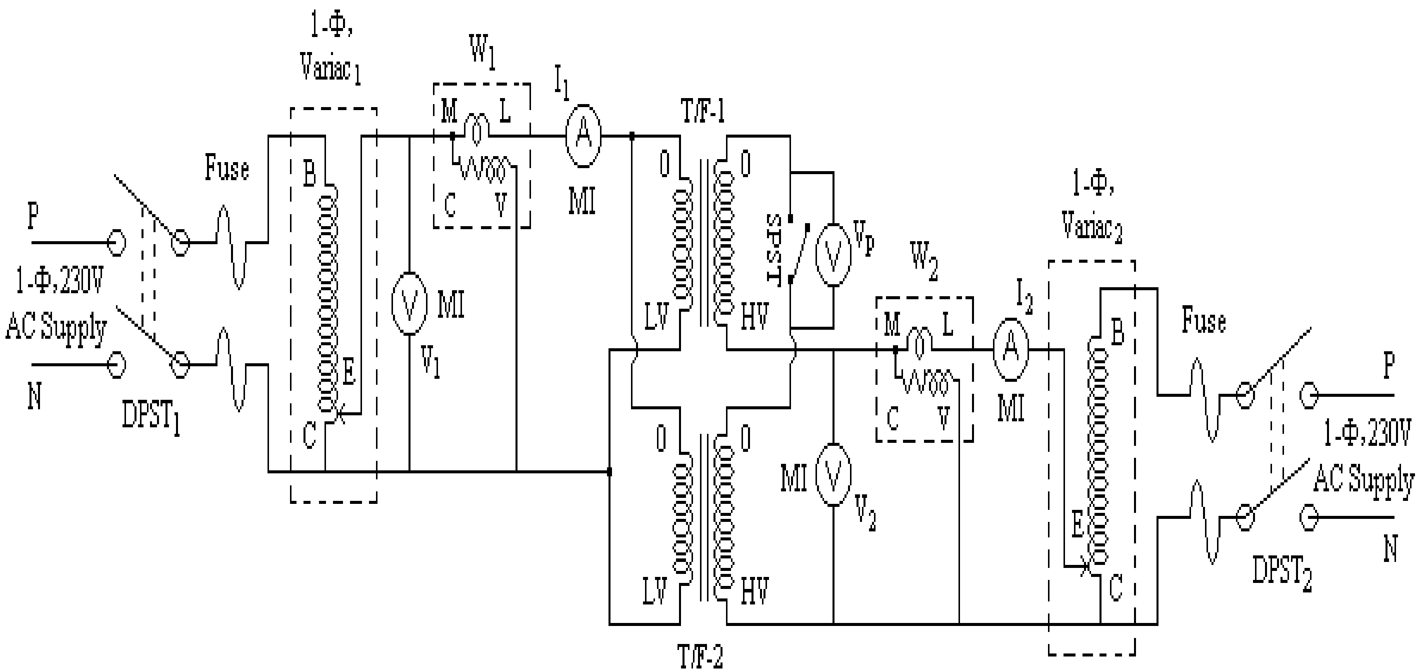
- In O.C. test, there is no load on the transformer while in S.C. circuit test only fractional load gets applied. In all O.C. and S.C. tests, the loading conditions are absent. Hence the results are inaccurate.
- In open and short circuit test iron losses and copper losses are determined separately but in actual use both losses occurs simultaneously.
- The temperature rise in the transformer is due to total loss that occurs simultaneously during actual use, it cant be determined by
  O.C and S.C tests.

Sumpner's Test

- The Sumpner's test (back to back test) is the very practical, convenient, efficient and minimum power consumption test which is done without actual loading to find regulation and efficiency of large power transformer.

- The Sumpner's test (back to back test) is the very practical, convenient, efficient and minimum power consumption test which is done without actual loading to find regulation and efficiency of large power transformer.

Circuit diagram of Sampner's test :



Procedure:

1. Connections are made as shown in fig (1).Initially open $DPST_2$ & SPST, keep both I-ϕ variacs at zero volts o/p position and close $DPST_1$.Increase the o/p voltage of $variac_1$ so that rated voltage is applied across LV windings of both transformers.
2. Check for the polarity of the Transformer secondary i.e. V_p must read zero volts . If the paralleling voltmeter V_p in the secondary is not showing zero reading, the terminals of either primary or secondary must be interchanged after opening $DPST_1$. Then V_1 , I_1 & W_1 are noted.
3. Now close SPST & $DPST_2$.Slowly increase the o/p of $variac_2$ such that rated current I_2 flows through HV winding. Then I_2 & W_2 are noted.

Thus the following readings of all meters are noted:

$W_1 = 2P_i$ where P_i = Iron losses of each transformer

$W_2 = 2P_{SC}$ where P_{SC} = Copper losses of each transformer

8. Total losses of each Transformer

$$= \frac{W_1 + W_2}{2} \text{ at full load}$$

Let x be the fraction of full load, Then total losses at x times full load = $P_i + x^2 P_{Sc}$

Output at x times full load = $x \times$ full load output = $x \times$ F.L.O/P

9. Then η is calculated using the formula. $$\%\,\eta = \frac{O/p}{O/p + \text{Total Losses}} \times 100$$

Tabular form

Sl No	V_1 Volts	V_2 Volts	I_1 Amps	I_2 Amps	W_1 Watts	W_2 Watts	$P_i = \frac{W_1}{2}$ Watts	$P_{sc} = \frac{W_2}{2}$ Watts	Total Losses $P_i + x^2 P_{sc}$ Watts	O/P = $x \times$ F.L.O/P Watts	I/P = o/p + Total losses Watts	% η
1.												
2.												

Advantages

- The power required to carry out the test is small.
- The transformers are tested at full-load conditions.
- As the test results gives the value of core and copper losses occurring simultaneously so heat run test can be conducted on two transformers.
- The secondary current(i.e I2) can be varied to any value using regulating transformer. Hence we can determine the copper losses at full load condition or at any load.

Drawbacks

- Only limitation is that two identical transformers are required. In practice exact identical transformers cannot be obtained and as two transformers are required, the test is not economical.

Conclusion

- In many electrical machines its seen that sumpner's test or back to back test is done in one or other way. As it is important to test every electrical machines at its rated capacity and its inconvenient for machines of large rating to actually fully load the equipment's and test. So for all electrical machines some form of back to back test becomes important.

UNIT -V

Parallel Operation of a Transformer

Parallel Operation of a Transformer

Reasons/Advantages of Parallel Operation

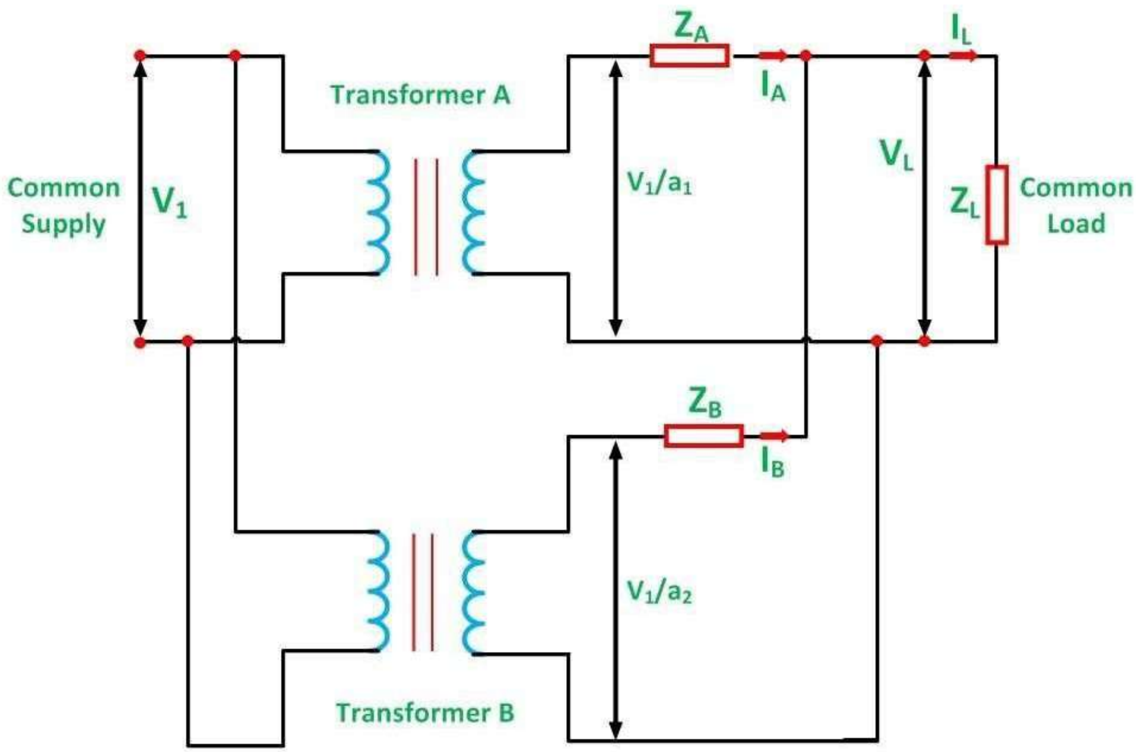
- It is impractical and uneconomical to have a single large transformer for heavy and large loads. Hence, it will be a wise decision to connect a number of transformers in parallel.
- In substations, the total load required may be supplied by an appropriate number of the transformer of standard size. As a result, this reduces the spare capacity of the substation.
- If the transformers are connected in parallel, so there will be scope in future, for expansion of a substation to supply a load beyond the capacity of the transformer already installed.
- If there will be any breakdown of a transformer in a system of transformers connected in parallel, there will be no interruption of power supply, for essential services.
- If any of the transformer from the system is taken out of service for its maintenance and inspection, the continuity of the supply will not get disturbed.

Necessary Conditions For Parallel Operation

- For the satisfactory parallel operation of the transformer, the two main conditions are necessary. One is that the **Polarities** of the transformers must be same. Another condition is that the **Turn Ratio** of the transformer should be equal.

The other two desirable conditions are as follows

- The voltage at full load across the transformer internal impedance should be equal.
- The ratio of their winding resistances to reactances should be equal for both the transformers. This condition ensures that both transformers operate at the same power factor, thus sharing their active power and reactive volt-amperes according to their ratings.


Transformer A
Common Supply
V_1
V_1/a_1
Z_A
I_A
I_L
V_L
Z_L
Common Load
Z_B
I_B
V_1/a_2
Transformer B

- a_1 is the turn ratio of the transformer A
  a_2 is the turn ratio of the transformer B
  Z_A is the equivalent impedance of the transformer A referred to secondary
  Z_B is the equivalent impedance of the transformer B referred to secondary
  Z_L is the load impedance across the secondary
  I_A is the current supplied to the load by the secondary of the transformer A
  I_B is the current supplied to the load by the secondary of the transformer B
  V_L is the secondary load voltage
  I_L is the load current

Applying Kirchhoff's Current Law

$$I_A + I_B = I_L \dots\dots\dots (1)$$

By Kirchhoff's Voltage Law

$$V_L = \frac{V_1}{a_1} - I_A Z_A \dots\dots\dots (2) \text{ and}$$

$$V_L = \frac{V_1}{a_2} - I_B Z_B \dots\dots\dots (3)$$

Now putting the value of I_B from the equation (1) in equation (3) we will get

$$V_L = \frac{V_1}{a_2} - (I_L - I_A)\ Z_B \ldots\ldots\ldots. (4)$$

Solving equations (2) and (4) we will get

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$$I_A = \frac{Z_B I_L}{Z_A + Z_B} + \frac{V_1 (a_2 - a_1)}{a_1 a_2 (Z_A + Z_B)} \dots\dots\dots (5)$$

$$I_B = \frac{Z_A I_L}{Z_A + Z_B} + \frac{V_1 (a_2 - a_1)}{a_1 a_2 (Z_A + Z_B)} \dots\dots\dots (6)$$

- The current I_A and I_B has two components. The first component represents the transformers share of the load currents and the second component is a circulating current in the secondary windings of the single phase transformer.
- **The undesirable effects of the circulating currents are as follows**
- They increase the copper loss.
- The circulating current overload the one transformer and reduce the permissible load kVA.

- **Equal Voltage Ratio**
- In order to eliminate circulating currents, the voltage ratios must be identical. That is $a_1=a_2$
- Under this condition,

$$I_A = \frac{Z_B I_L}{Z_A + Z_B} \quad \dots \dots \dots (7)$$

$$I_B = \frac{Z_A I_L}{Z_A + Z_B} \quad \dots \dots \dots (8)$$

Equating equation (7) and (8) we will get

$$\frac{I_A}{I_B} = \frac{Z_B}{Z_A} \quad \dots \dots \dots . (9)$$

$$I_A Z_A = I_B Z_B \dots \dots \dots (10)$$

We know that

The total load in volt-ampere (VA) is

$$S_L = V_L I_L$$

The volt-ampere of transformer A is

$$S_A = V_L I_A$$

Similarly, the volt-ampere of transformer B is

$$S_B = V_L I_B$$

Hence, the various equations will be written as shown below

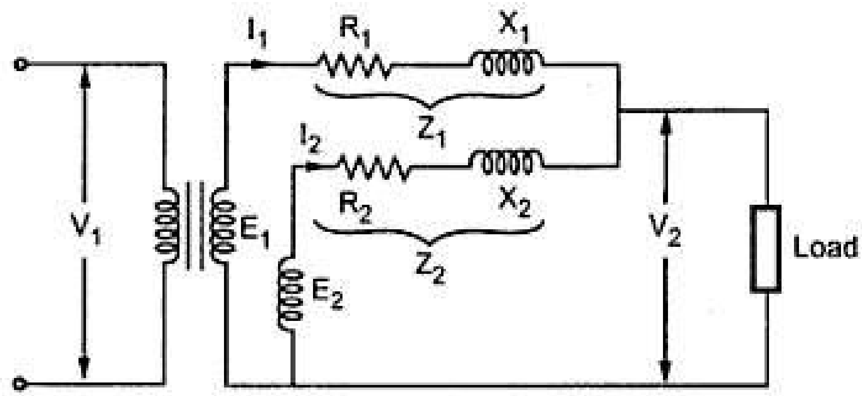
$$S_A = \frac{Z_B}{Z_A + Z_B} S_L \quad \ldots\ldots\ldots(11)$$

$$S_B = \frac{Z_A}{Z_A + Z_B} S_L \quad \ldots\ldots\ldots(12)$$

Equating the equation (11) and (12) we will get

$$\frac{S_A}{S_B} = \frac{Z_B}{Z_A} \quad \ldots\ldots\ldots(13)$$

Parallel Operation of Transformers with Unequal Voltage Ratios



Let us consider voltage ratio of transformer 1 is slightly more than 2. So that induced e.m.f.. $E_1$is greater than E_2. Thus the resultant terminal voltage will be E_1 - E_2 which will cause a circulating current under no load condition.

$$I_c = (E_1 - E_2)/(Z_1 + Z_2)$$

From the circuit diagram we have,

$$E_1 = V_2 + I_1 Z_1$$

$$E_2 = V_2 + I_2 Z_2$$

Also, $$I_L = I_1 + I_2$$

$$V_2 = I_L Z_L = (I_I + I_2) Z_L$$

$$E_1 =(I_1 + I_2) Z_L + I_I Z_1 \qquad ....(a)$$

$$E_2 =(I_1 + I_2) Z_L + I_2 Z_2 \qquad ....(b)$$

Subtracting equations (a) and (b) we have,

$$E_1 - E_2 = I_1 Z_1 - I_2 Z_2$$

$$I_1 = ((E_1 - E_2) + I_2 Z_2) /Z_1$$

Subtracting this value in equation (b),

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

$I_2 = (E_2 Z_1 - (E_1 - E_2)Z_L) / (Z_1 Z_2 + Z_L (Z_1 + Z_2))$

Similarly,

$I_1 = (E_1 Z_2 + (E_1 - E_2)Z_L)/ (Z_1 Z_2 + Z_L (Z_1 + Z_2))$

Adding the above equations,

$I_1 + I_2 = (E_1 Z_2 + E_2 Z_1) / (Z_1 Z_2 + Z_L (Z_1 + Z_2))$ ....(c)

But $I_L = I_1 + I_2$

Load voltage, $V_2 = I_L Z_L$

Dividing both numerator and denominator of equation (c) by $Z_1 Z_2$,

$$I_L = \frac{\frac{E_1}{Z_1} + \frac{E_2}{Z_2}}{1 + \frac{Z_L\,(Z_1 + Z_2)}{Z_1\,Z_2}}$$

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

$$V_2 = I_L\,Z_L = \left[\frac{E_1/Z_1 + E_2/Z_2}{1 + \frac{Z_L}{Z_2} + \frac{Z_L}{Z_1}}\right] Z_L$$

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

If impedances Z_1 and Z_2 are small in comparision with load impedance Z_L then product $Z_1\,Z_2$may be neglected so we get,

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

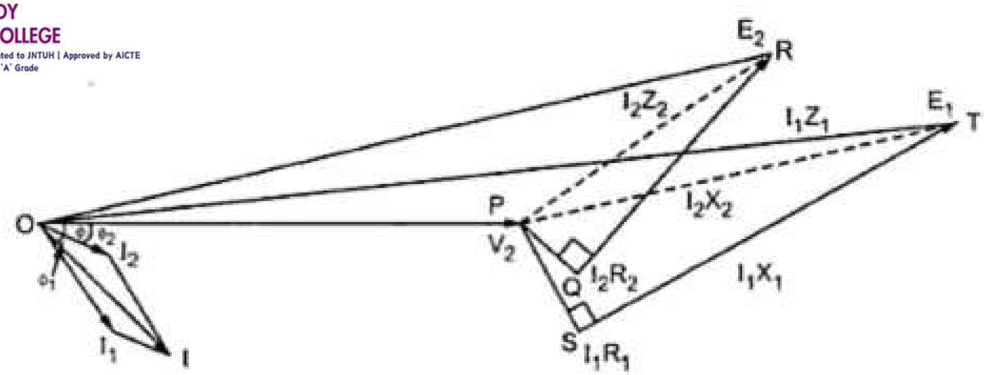
$$I_2 = \frac{E_2 Z_1}{Z_L (Z_1 + Z_2)} - \frac{E_1 - E_2}{Z_1 + Z_2}$$

But we know that

$$(E_1 - E_2) / (Z_1 + Z_2) = I_c$$

Key Point : This circulating current I_c adds to I_1 but subtracts from I_2. Hence transformer 1 gets overloaded. The transformers will not share the load according to their ratings.

The phasor diagram is shown in the Fig. 2.



The two transformers will operate at different power factor Φ_1 and Φ_2 are the power factor angles of these two transformers whereas Φ is the combined p.f. angle.

Here E_A and E_B have the same phase but there may be some phase difference between the two due to some difference of internal connection as for the connection in parallel of a Star/Star and a Star/Delta 3 phase transformers.

Key Point : While solving the problems on parallel operation of transformers it is convenient to work with numerical values of impedances instead of percentage values.

AutoTransformer

- An **autotransformer** (sometimes called ***auto step d*** An **autotransformer** (sometimes called ***auto step down transformer***)is an electrical **transformer** with only one winding. The "auto" (Greek for "self") prefix refers to the single coil acting on itself and not to any kind of automatic mechanism. ***own transformer***)is an electrical **transformer** with only one winding. The "auto" (Greek for "self") prefix refers to the single coil acting on itself and not to any kind of automatic mechanism.

Theory of Autotransformer

N1=primary turn(1-3)

N2=secondary turn(2-3)

I1=primary current

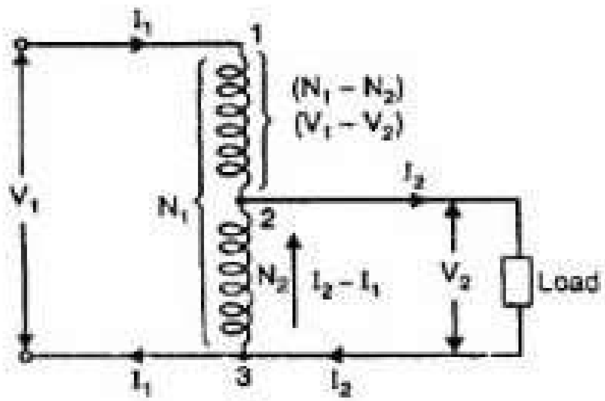
I2=secondary current

V1=primary voltage

V2=secondary votage

From the above fig.

We get



(i)

$$\frac{V_2}{V_1 - V_2} = \frac{N_2}{N_1 - N_2}$$

$$V_2(N_1 - N_2) = N_2(V_1 - V_2)$$

$$V_2N_1 - V_2N_2 = N_2V_1 - N_2V_2$$

$$V_2N_1 = N_2V_1$$

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

$$\frac{V_2}{V_1} = \frac{I_1}{I_2}$$

$$V_1 I_1 = V_2 I_2$$

OUT PUT

The primary and secondary windings of an autotransformer are

Connected magnetically as well as electrically. So the power transferred primary to secondary inductively as well as conductively.

$$\text{Output apparent power} = V_2 I_2$$

$$\text{Apparent power transferred inductively} = V_2(I_2 - I_1) = V_2(I_2 - K\,I_2)$$

$$= V_2 I_2 (1 - K) = V_1 I_1 (1 - K)$$

$$\text{Power transferred inductively} = \text{Input} \times (1 - K)$$

$$\text{Power transferred conductively} = \text{Input} - \text{Input}\,(1 - K)$$

$$= \text{Input}\,[1 - (1 - K)]$$

$$= K \times \text{Input}$$