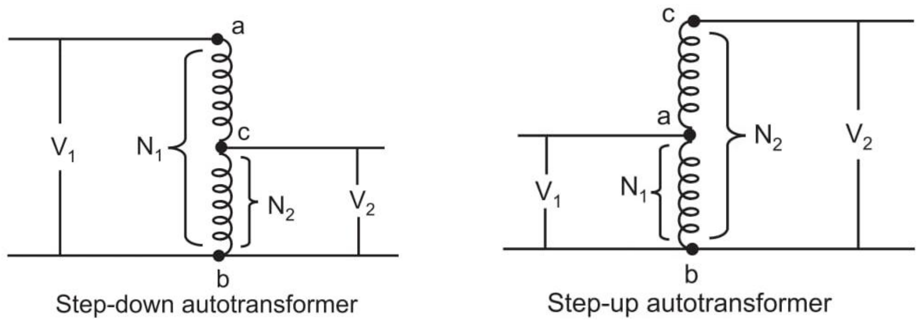
Syllabus up to single phase transformer has been completed in classroom and in continuation of that we have next topic Auto transformer

INTRODUCTION TO AUTO TRANSFORMER

An auto transformer is a special type of transformer in which a part of winding is common to both the primary and secondary. The operating principle and general construction of an auto transformer is the same as that of two winding transformer. In a two winding transformer, primary and secondary windings are electrically isolated, but in an auto transformer the two windings are not electrically isolated. Due to only one winding, auto transformer requires less copper for winding, hence it is cheaper. It provides variable a.c. voltage and a single winding transformer.

There are two types of auto transformer

1. Step-up Auto transformer
2. Step-down Auto transformer



The connections of a step-down and step-up auto transformer are shown in the figure. In either case, the winding ab having N1 turns is the primary winding and winding bc having N2 turns is the secondary winding.

The voltage transformation ratio k of an ideal auto transformer is $K = \frac{N_2}{N_1} = \frac{V_2}{V_1}$

Advantages of Autotransformer

1. An autotransformer required less winding material (copper) than a 2-winding transformer.
2. The efficiency is higher compare to two winding transformer.
3. An autotransformer is smaller in size and cheaper than the two winding transformer of the same output.
4. Since there is a reduction in conductor material and core material, the copper losses in conductor and the core are small.
5. The resistance and leakage reactance is less compared to two winding transformer.
6. VA rating is more compared to two winding transformer.
7. A smooth and continuous variation of voltage is possible.

Limitations of Autotransformer

1. The secondary winding is not electrically insulated with primary winding.
2. The short circuit current in an autotransformer is large than that for the two winding transformer.
3. No electrical separation between primary and secondary which is risky in case of high voltage levels.

Applications of Autotransformer

1. Autotransformer is used as a variac (variable a.c) in laboratory and other situation that require continuously variable voltage over broad range.
2. It can be used as a regulating transformer.
3. It can be used as a Voltage Booster in distribution System.
4. It can be used as a starter for safely starting of the machines like induction motor, synchronous motor.

Solved Example on Transformer

EXAMPLE 9.1: *A 3000/300 V, 60 KVA transformer has 86 turns in the secondary winding calculate:*

(a) Primary turns

(b) Primary and secondary full load current. Neglect the losses.

SOLUTION :

Given:

$$V_1 = 3000 \text{ V}$$
$$V_2 = 300 \text{ V}$$
$$N_2 = 86 \text{ Turns}$$
$$\text{Rating} = 60 \text{ KVA}$$

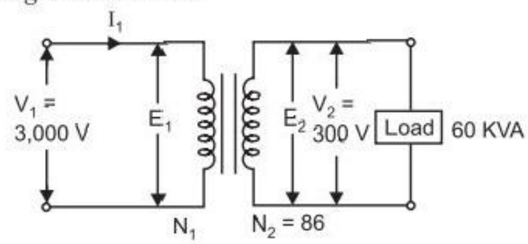


Figure 9.30

Step 1: We know that the transformer ratio is given by

$$K = V_2/V_1$$
$$= 300/3000 = 1/10$$

And

$$N_2/N_1 = K = 1/10$$
$$N_1 = N_2 \times 10 \; (N_2 = 86 \text{ Turns})$$
$$= 86 \times 10 = 860 \text{ turns}$$

So,

$$N_1 = \mathbf{860\ turns.}$$

Step 2: We know that

$$V_1 I_1 = V_2 I_2$$
$$= 60 \times 10^3 \qquad (60 \text{ KVA} = 60 \times 10^3 \text{ VA})$$
$$I_2 = 60 \times 10^3/V_2 = 60 \times 10^3/300 = 200 \text{ A}$$

Similarly,

$$I_1 = 60 \times 10^3/V_1 = 60 \times 10^3/3000 = 20 \text{ A}$$
$$I_1 = 20 \text{ A}$$

$$I_2 = \mathbf{200\ A}$$

Note: Alter natively we can cross check the value of follows.

$$I_1/I_2 = K \text{ and } I_1 = I_2/K$$
$$I_1 = 200 \times 1/10 \text{ K} = 1/10$$
$$I_1 = 20 \text{ A}$$

EXAMPLE 9.2: *A 3000/200 V, 50 Hz single phase transformer is built on a core having an effective cross-sectional area of 150 cm² and has 80 turns is low voltage winding. Calculate the maximum flux density in the core.*

SOLUTION:

Given: $E_1 = 3000$ V, $E_2 = 200$ V, $f = 50$ Hz, a = 150 cm²

$N_2 = 80$ turns (low voltage winding, i.e., secondary winding)

Step 1: We know that E_2 is given by

$$E_2 = 4.44\ \phi_m f N_2$$

Hence,

$$\phi_m = \frac{E_2}{4.44\ f\ N_2} = \frac{200}{4.44 \times 50 \times 80} = 0.0112\ wb$$

Step 2: Maximum value of flux density, $B_m = \phi_m/a = 0.0112/150 \times 10^{-4} = 0.75\ wb/m^2$

$$B_m = 0.75\ wb/m^2$$

EXAMPLE 9.3: *An ideal 25 KVA transformer has 500 turns on the primary winding and 40 turns on the secondary winding. The primary is connected to 3000 volt, 50 Hz supply. Calculate*

(i) primary and secondary current at full load

(ii) secondary emf

(iii) The maximum core flux

SOLUTION:

Given: $N_1 = 500$, $N_2 = 40$, $E_1 = 3000$ volt, $f = 50$ Hz

Step 1: The primary and secondary current calculated as:

$$K = N_2/N_1 = 40/500 = 4/50$$

$$I_1 = \frac{\text{Volt Ampere}}{V_1} = \frac{25 \times 10^3}{3000} = 8.33 \text{ A}$$

$$\boldsymbol{I_1 = 8.33\ \mathbf{A}}$$

$$I_2 = I_1/K = 8.33/4/50 = 104.2 \text{ A},$$

$$\boldsymbol{I_2 = 104.2\ \mathbf{A}}$$

Step 2: We know that

$$K = E_2/E_1,$$
$$E_2 = K\ E_1 = 4 \times 3000/50 = 240 \text{ V}$$
$$\boldsymbol{E_2 = 240\ \mathbf{V}}$$

Step 3: The e.m.f equation of transformer is given by

$$E_1 = 4.44 \phi_m f N_1$$
$$3000 = 4.44 \times \phi_m \times 50 \times 500$$

Hence,

$$\phi_m = \frac{3000}{4.44 \times 50 \times 500} = 27 \times 10^{-3} \text{ wb} = 27 \text{ mwb}$$

$$\phi_m = \mathbf{27\ mwb}$$

EXAMPLE 9.4: *A 25 KVA, 3300/230 V, 50 Hz single phase transformer draw no load current of 15 A when excited on load voltage side and consumes 350 watts. Calculate two components of current.*

SOLUTION:

Given: Rating $= 25$ KVA, $f = 50$ Hz, $I_0 = 15$ A,

$W_0 = 350$ W, $V_0 = 230$ V

Step 1: The no-load power factor is given by

$$\cos\phi_0 = \frac{W_0}{V_0 I_0} = \frac{350}{15 \times 230} = 0.1014 \text{ lag}$$

$$\cos\phi_0 = \mathbf{0.1014\ lag}$$

$$\therefore \quad \sin\phi_0 = \mathbf{0.9948}$$

Step 2: The two components of no-load current is given by

Active component, $I_c = I_0 \cos\phi_0 = 15 \times 0.1014 = 1.521$ A

$$I_c = \mathbf{1.521\ A}$$

Magnetizing component, $I_m = I_0 \sin\phi_0 = 15 \times 0.9948 = 14.922$ A

$$I_m = \mathbf{14.922\ A}$$

EXAMPLE 9.5: *A 15 KVA, 2200/110 V transformer has $R_1 = 1.75\ \Omega$. $R_2 = 0.0045\ \Omega$. The leakage reactance are $X_1 = 2.6\ \Omega$ and $X_2 = 0.0075\ \Omega$. Calculate*

(a) Equivalent Resistance referred to primary and secondary

(b) Equivalent Reactance referred to primary and secondary

(c) Equivalent Impedance referred to primary and secondary

SOLUTION:

Given $V_1 = 2200$, $V_2 = 110$ V $R_1 = 1.75\ \Omega$, $R_2 = 0.0045\ \Omega$, $X_1 = 2.6\ \Omega$, $X_2 = 0.0075\ \Omega$

Step 1: First we find the value of K

$$K = \frac{V_2}{V_1} = \frac{110}{2200} = 0.05$$

Now we can easily calculate Resistance referred to primary and secondary

$$R_{1e} = R_1 + R'_2 = R_1 + R_2/k^2$$

$$= 1.75 + 0.0045/(0.05)^2 = 3.55\ \Omega$$

$$\mathbf{R_{1e} = 3.55\ \Omega} \quad \text{(Refer to primary)}$$

Now $R_{2e} = R_2 + R'_1 = R_2 + k^2 R_1$

$$= 0.0045 + (0.05)^2 \times 1.75 = 0.00887\ \Omega$$

$$\mathbf{R_{2e} = 0.00887\ \Omega} \quad \text{(Refer to secondary)}$$

Step 2: We can Calculate Reactance referred to primary and secondary as follows:

$$X_{1e} = X_1 + X'_2 = X_1 + X_2/k^2$$

$$= 2.6 + \frac{0.0075}{(0.05)^2} = 5.6\ \Omega$$

$$X_{1e} = 5.6\ \Omega \quad \text{(Refer to primary)}$$

$$X_{2e} = X_2 + X'_1 = X_2 + K^2 X_1$$

$$= 0.0075 + (0.05)^2 \times 2.6 \simeq 0.014\ \Omega$$

$$X_{2e} = \mathbf{0.014\ \Omega} \qquad \text{(Refer to secondary)}$$

Step 3: Equivalent Impedance referred to primary and secondary can be calculated as follow :

$$Z_{1e} = R_{1e} + j\,X_{1e} = 3.55 + \text{j}\ 5.6$$

$$\therefore \quad |Z_{1e}| = \sqrt{(R_{1e})^2 + (X_1 e)^2} = \sqrt{(3.55)^2 + (5.6)^2}$$

$$\mathbf{Z_{1e} = 6.6304\ \Omega}$$

$$Z_{2e} = R_{2e} + jX_{2e} = 0.00887 + j\,0.014$$

$$|Z_{2e}| = \sqrt{(0.00887)^2 + (0.014)^2} = 0.01657\ \Omega$$

$$\mathbf{Z_{2e} = 0.01657\ \Omega}$$

EXAMPLE 9.6: *A 100 KVA, 2200/440 volt transformer has $R_1 = 0.3\ \Omega$, $X_1 = 1.1\ \Omega$, $R_2 = 0.01\ \Omega$ and $X_2 = 0.035\ \Omega$. Calculate*

(a) The equivalent impedance of the transformers referred to the primary and

(b) Total copper losses

Solution:

Given: $V_1 = 2200$ V, $V_2 = 440$ V, $R_1 = 0.3\ \Omega$, $R_2 = 0.01\ \Omega$,
$X_1 = 1.1\ \Omega$ and $X_2 = 0.035\ \Omega$

Step 1: First we calculate voltage transformation ratio as follows:

$$K = \frac{440}{2200} = 0.2$$

Step 2: Calculate full load primary and secondary current

$$\text{Full load primary current, } I_1 = \frac{\text{Volt Ampere Rating}}{\text{Voltage}}$$

$$= \frac{100 \times 10^3}{2200} = 45.45\ \text{A}$$

$$I_1 = 45.45\ \text{A}$$

$$\text{Full load secondary current, } I_2 = \frac{\text{Volt Ampere rating}}{\text{Voltage}}$$

$$= \frac{100 \times 10^3}{440} = 227.25\ \text{A}$$

$$\mathbf{I_2 = 227.25\ A}$$

Alternatively: We can cross check the value of I_1 and I_2

$$I_2 = I_1/\text{K} = 45.45 \times 5 = 227.25$$

$$I_2 = \mathbf{227.25\ A}$$

Step 3: The equivalent impedance referred to primary and secondary is as follows:

$$R_{1e} = R_1 + R_2/K^2 = 0.3 + 0.01/(0.2)^2 = 0.55\ \Omega$$

$$X_{1e} = X_1 + X_2/K^2 = 1.1 + 0.035/(0.2)^2 = 1.975\ \Omega$$

$$Z_{1e} = \sqrt{(R_{1e})^2 + (X_{1e})^2} = \sqrt{(0.55)^2 + (1.975)^2} = 2.05\ \Omega$$

$$\mathbf{Z_{1e} = 2.05\ \Omega}$$

Step 4: Total copper losses is given by

$$I_1^2 R_{1e} = (45.45)^2 \times 0.55 = 1136.14\ \text{W}$$

$$I_1^2 R_{1e} = \mathbf{1136.14\ W}$$

Alternatively: We can cross check

Total copper losses is given by

$I_1{}^2R_1 + I_2^2R_2$

$(45.45)^2 \times 0.3 + ((227.25)^2 \times 0.01 = 1136.14$ W

$\therefore$ **Total copper loss = 1136.14 Watt**

EXAMPLE 9.7: *Find the efficiency of a 150 KVA transformer at 25% full load at 0.8 power factor lagging. The copper loss at full load is 1600 watt and the iron loss is 1400 watt. Ignore the effect of temperature rise and magnetizing current.*

SOLUTION:

Given: KVA rating = 150 kVA, cos ϕ = 0.8, P_{cu} = 1600 watt

$$P_i = 1400 \text{ watt}$$

Step 1: First we calculate total losses at 25% load as follows

$$n = 1/4 = 0.25$$

Copper loss at 0.25 load = $n^2P_{cu} = (0.25)^2 \times 1600 = 100$ watt

$$P_{cu} = 100 \text{ watt.}$$

Total losses of 25% load = $P_i + n^2P_{cu} = 1400 + 100 = 1500$ watt

Step 2: The efficiency of transformers of 25% load is given by

$$\%\ \eta \text{ at } 25\% \text{ load} = \frac{n \times KVA \text{ rating} \times \cos\phi}{n \times KVA \text{ rating} \times \cos\phi + P_i + n^2P_{cu}} \times 100$$

$$= \frac{0.25 \times 150 \times 0.8}{0.25 \times 150 \times 0.8 + 1400 + 100} \times 100 = 95.24\%$$

$$\eta\% = \mathbf{95.24\ \%}$$

EXAMPLE 9.8: *In a 25 KVA, 2000/200 V transformer, the constant and variable losses are 350 watt and 400 watt respectively. Calculate the efficiency on unity power factor at:*

(a) full load (b) half load

SOLUTION:

Given: Rating = 25KVA, V_1 = 2000V, V_2 = 200 V,

Constant loss *i.e.* P_i = 350 W = 0.35 KW, variable loss *i.e* P_{cu} = 400 W = 0.4 kW, cos ϕ = 1

Step 1: At full load and unity power factor, the efficiency is given by

$$\%\ \eta = \frac{\text{output}}{\text{output + losses}} \times 100 = \frac{\text{output}}{\text{output} + P_i + P_{cu}} \times 100$$

$$= \frac{25}{25 + 0.35 + 0.4} \times 100$$

(output in KW = KVA × cos ϕ = 25 × 1 = 25 KW)

$$= \frac{25}{25.75} \times 100 = 97.08\ \%$$

$\therefore$ $\%\ \eta = \mathbf{97.08\ \%}$

Step 2: At half load and unity power factor, the efficiency is

$$\%\ \eta = \frac{\text{output}}{\text{output} + P_i + P_{cu}} \times 100$$

But for half load, the output power and copper losses will become

$$\text{output power} = \text{KVA rating} \times \frac{1}{2} = 25 \times \frac{1}{2} = 12.5 \text{ KW}$$

and

$$P_{cu} = P_{cu} \times \left(\frac{1}{2}\right)^2 = 400 \times \left(\frac{1}{2}\right)^2 = 100 \text{ W} = 0.1 \text{ KW}$$

$\therefore$

$$\% \eta = \frac{12.5}{12.5 + 0.35 + 0.1} \times 100 = 96.53 \%$$

$\therefore$ **% η at half load = 96.53 %**

EXAMPLE 9.9: *A 250 KVA single phase transformers has iron loss of 1.8 KW. The full load copper loss is 2000 watt. Calculate :*

(a) Efficiency at full load 0.8 lagging power factor

(b) KVA supplied at maximum efficiency

(c) Maximum efficiency at 0.8 lagging power factor

SOLUTION:

Given: Rating = 250 KVA, P_i = 1.8 KW, $P_{cu}(f_l)$ = 2000 W

Step 1: The efficiency at full load at 0.8 lagging power factor is given by

$$\% \eta = \frac{(VA\text{rating}) \times \cos\phi}{(VA\text{rating}) \times \cos\phi + P_i + P_{cu(fl)}} \times 100$$

$$= \frac{250 \times 10^3 \times 0.8}{250 \times 10^3 \times 0.8 + 1800 + 2000} \times 100 = 98.13 \%$$

$$\% \eta = \mathbf{98.13 \%}$$

Step 2: KVA supplied at maximum efficiency is given by

$$\text{KVA at } \eta_{max} = \text{KVA rating} \times \sqrt{P_i/P_{cu}(f_l)} = 250 \times \sqrt{\frac{1800}{2000}} = 237.17 \text{ KVA}$$

$$\eta_{\mathbf{max}} = \mathbf{237.17 \text{ KVA}}$$

Step 3: The maximum efficiency at 0.8 lagging power factor is given by

$$\% \eta_{max} = \frac{KVA \ at \ \eta_{max} \times \cos\phi}{KVA \ at \ \eta_{max} \times \cos\phi + P_i + P_{cu}} \times 100$$

(At max efficiency $P_i = P_{cu}$ = 1800 watt)

$$= \frac{237.17 \times 1000 \times 0.8 \times 100}{237.17 \times 1000 \times 0.8 + 1800 + 1800}$$

$$= 98.137 \%$$

$$\% \eta_{\mathbf{max}} = \mathbf{98.137 \%}$$

EXAMPLE 9.10 : *A single phase transformer working at unity power factor has an efficiency of 90% at half of full load and full load of 500 KW. Determine its iron and full load copper loss.*

SOLUTION: Given: $\cos\phi = 1$, % η = 90 %, P_{out} = 500 kW

Step 1: For both half and full load, the efficiency is 90%

Let P_i = Iron loss

$P_{cu}(f_l)$ = full load copper loss

$$\therefore \quad \% \eta (fl) = \frac{P_{out}}{P_{out} + P_i + P_{cu(fl)}} \times 100$$

$$0.9 = \frac{500 \times 10^3}{500 \times 10^3 + P_i + P_{cu(fl)}} \times 100$$

$$\therefore \quad P_i + P_{cu\ (fl)} = 55555.55 \qquad ...(i)$$

Step 2: We know that for half load, $\eta = \frac{1}{2} = 0.5$

$$\% \eta_{(hl)} = \frac{n P_{out}}{n P_{out} + P_i + n^2 P_{cu(fl)}} \times 100$$

$$0.9 = \frac{0.5 \times 500 \times 1000}{0.5 \times 500 \times 1000 + P_i + (0.5)^2 \ P_{cu(fl)}}$$

$$P_i + (0.5)^2 P_{cu}(\text{fl}) = 27777.77 \qquad ...(ii)$$

Subtracting equation (*ii*) from equation (*i*)

$$0.75 \ P_{cu(fl)} = 27777.77$$

$$\therefore \quad P_{cu(fl)} = 37037.03 \text{ W full load copper loss}$$

$$P_i = 18518.517 \text{ W Iron loss}$$

$$\boldsymbol{P_i = 18518.517, P_{cu(fl)} = 37037.03 \text{ W}}$$

Short Question on Transformer

Q. 1. What is transformer? What is the basic function of a transformer?

Ans. A transformer is a static electromagnetic device which transfers electrical energy from one circuit to another without changing its frequency. The basic function of a transformer is to transform voltage from one level to another. It may be from low to high voltage or vice versa.

Q. 2. What is the principle of operation of transformer?

Ans. The basic working principle of transformer is electromagnetic induction. When an a a.c supply is given to the primary winding then an alternating flux (f) is set up in the core. The alternating flux when links with the secondary winding then according to Faradays Laws of electromagnetic induction, am e.m.f E2 is induced in the secondary winding. If now load is connected to the secondary winding, this emf drives a current through it.

Q. 3. Why does a transformer has iron core? or The core of the transformer is not made of wood, why?

Ans. The core of the transformer is to carry the alternating flux produced by primary and secondary winding at the transformer. Therefore, it must be made of some suitable magnetic material which provide low reluctance path for the magnetic flux. Hence, it can never be made of wood.

Q. 4. Why the efficiency of a transformer is so high?

Ans. The transformer is a static device, so there are no friction and winding losses. The other losses such as iron losses are comparatively less because of better magnetic material, so efficiency of transformer is high.

Q. 5. What is the difference between an Ideal and practical transformer?
Ans. An ideal transformer is an imaginary transformer which has no winding resistance, no magnetic leakage, no iron loss while a practical transformer is an actual transformer which operates at a particular frequency and has winding resistance, magnetic leakage, iron loss and copper losses.

Q. 6. What will happen if the primary of a transformer is connected to d.c. supply?
Ans. If the primary of a transformer is connected to d.c supply, the flux produced in the transformer core will not vary but remain constant in magnitude and therefore no emf will be induced in the secondary winding. Practically winding resistance is very small so total impedance of winding is very low for d.c. This winding will draw very high current if dc supply is given to it. This may cause the burning of winding due to extra heat generated and may cause permanent damage to the transformer.

Q. 7. Why the rating of transformer is in KVA?
Ans. We know that as copper loss of a transformer depends on current and iron loss on voltage. Hence, total transformer losses depend on Volt-Ampere and not on phase angle between voltage and current i.e. it is independent of load power factor. That is why rating of transformers is in KVA and not in KW.

Q. 8. What are the losses occur in Transformer? Why are iron losses constant at all loads in a transformer?
Ans. There are two types of losses occur in transformer
1. Core or Iron losses
   (a) Eddy current loss
   (b) Hysteresis loss
2. Copper losses

Iron losses are constant losses because these are practically independent of load. They mainly depend upon the supply voltage and supply frequency which is almost constant.

Q. 9. Why is the efficiency of a transformer not determined by direct loading?
Ans. The efficiency of a transformer is not determined by direct loading as this method has the following disadvantages: (i) It requires a large supply of power (ii) It gives no information regarding the proportions of various losses. In practice, the efficiency of a transformer is determined by two simple test viz., open circuit test or short circuit test.

Q. 10. What are the advantages of open and short-circuit test on a transformer?
Ans. The efficiency of a transformer is always determined by open circuit and short circuit tests due to the following reasons: (i) The power required to carry out these tests is very small (ii) These tests give the core loss and copper losses separately.

IF YOU HAVE ANY DOUBT CONNECT ME ON WHATSAPP OR VOICE CALL @ 8687279734

Take Care

STAY AT HOME AND STAY SAFE