UNIT-III

Transformers

INTRODUCTION

Transformer is a static device which transfers electrical energy from one electrical circuit to another electrical circuit without change in frequency through magnetic medium. The winding which receives energy is called primary winding and the winding which delivers energy to the load is called secondary winding.

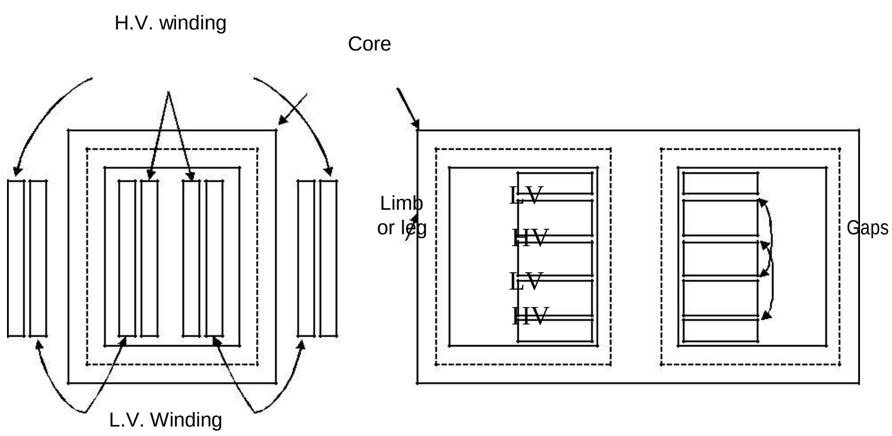
Based on the voltage levels transformers are classified into two types

i. Step down transformer ii. Step up transformer.

CONSTRUCTION

CORE-TYPE AND SHELL-TYPE CONSTRUCTION

Depending upon the manner in which the primary and secondary windings are placed on the core, and the shape of the core, there are two types of transformers, called (a) core type, and (b) shell type. In core type transformers, the windings are placed in the form of concentric cylindrical coils placed around the vertical limbs of the core. The low-voltage (LV) as well as the high-voltage (HV) winding are made in two halves, and placed on the two limbs of core. The LV winding is placed next to the core for economy in insulation cost. Figure a shows the cross-section of the arrangement. In the shell type transformer, the primary and secondary windings are wound over the central limb of a three-limb core as shown in Figure b. The HV and LV windings are split into a number of sections, and the sections are interleaved or sandwiched i.e. the sections of the HV and LV windings are placed alternately.



(a) core type **(b)** Shell Type

CORE

The core is built-up of thin steel laminations insulated from each other. This helps in reducing the eddy current losses in the core, and also helps in construction of the transformer. The steel used for core is of high silicon content, sometimes heat treated to produce a high permeability and low hysteresis loss. The material commonly used for core is CRGO (Cold Rolled Grain Oriented) steel.

Conductor material used for windings is mostly copper. However, for small distribution transformer aluminium is also sometimes used. The conductors, core and whole windings are insulated using various insulating materials depending upon the voltage.

INSULATING OIL

In oil-immersed transformer, the iron core together with windings is immersed in insulating oil. The insulating oil provides better insulation, protects insulation from moisture and transfers the heat produced in core and windings to the atmosphere. The transformer oil should posses the following quantities:

(a) High dielectric strength,

(b) Low viscosity and high purity,

(c) High flash point, and

(d) Free from sludge.

Transformer oil is generally a mineral oil obtained by fractional distillation of crude oil.

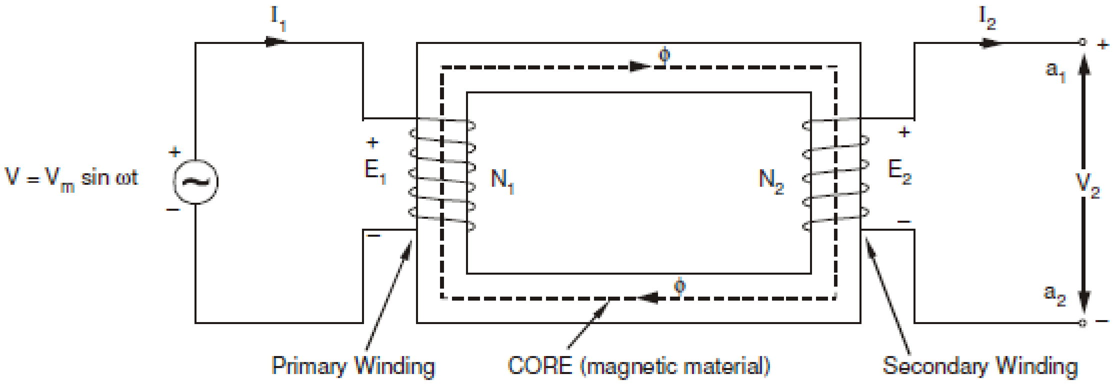
TANK AND CONSERVATOR

The transformer tank contains core wound with windings and the insulating oil. In large transformers small expansion tank is also connected with main tank is known as conservator. Conservator provides space when insulating oil expands due to heating. The transformer tank is provided with tubes on the outside, to permits circulation of oil, which aides in cooling. Some additional devices like breather and Buchholz relay are connected with main tank.

Buchholz relay is placed between main tank and conservator. It protect the transformer under extreme heating of transformer winding. Breather protects the insulating oil from moisture when the cool transformer sucks air inside. The silica gel filled breather absorbs moisture when air enters the tank. Some other necessary parts are connected with main tank like, Bushings, Cable Boxes, Temperature gauge, Oil gauge, Tapings, etc.

WORKING PRINCIPLE

In its simplest form a single-phase transformer consists of two windings, wound on an iron core one of the windings is connected to an ac source of supply *f*. The source supplies a current to this winding (called primary winding) which in turn produces a flux in the iron core. This flux is alternating in nature If the supplied voltage has a frequency *f*, the flux in the core also alternates at a frequency *f*. the alternating flux linking with the second winding, induces a voltage E_2 in the second winding (according to faraday's law). [Note that this alternating flux linking with primary winding will also induce a voltage in the primary winding, denoted as E_1. Applied voltage V_1 is very nearly equal to E_1]. If the number of turns in the primary and secondary windings is N_1 and N_2 respectively, we shall see later in this unit that E1/N1 = E2/N2. The load is connected across the secondary winding, between the terminals a_1, a_2. Thus, the load can be supplied at a voltage higher or lower than the supply voltage, depending upon the ratio N_1/N_2.



IDEAL TRANSFORMER

Under certain conditions, the transformer can be treated as an ideal transformer. The assumptions necessary to treat it as an ideal transformer are :

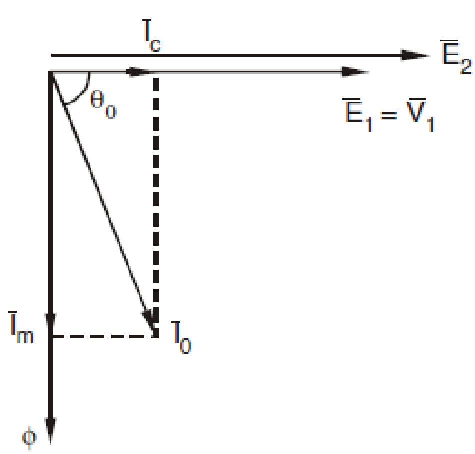
(a) Primary and secondary windings have zero resistance. This means that ohmic loss ($I^2 R$ loss), and resistive voltage drops in windings are zero.

(b) There is no leakage flux, i.e. the entire flux is mutual flux that links both the primary and secondary windings.

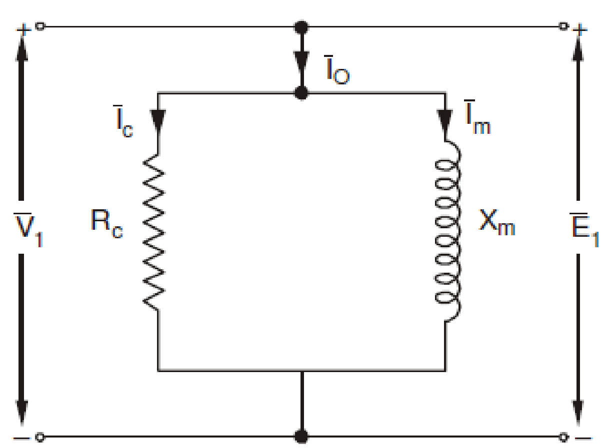
(c) Permeability of the core is infinite this means that the magnetizing current needed for establishing the flux is zero.

(d) Core loss (hysteresis as well as eddy current losses) are zero.

IDEAL TRANSFORMER ON NO LOAD

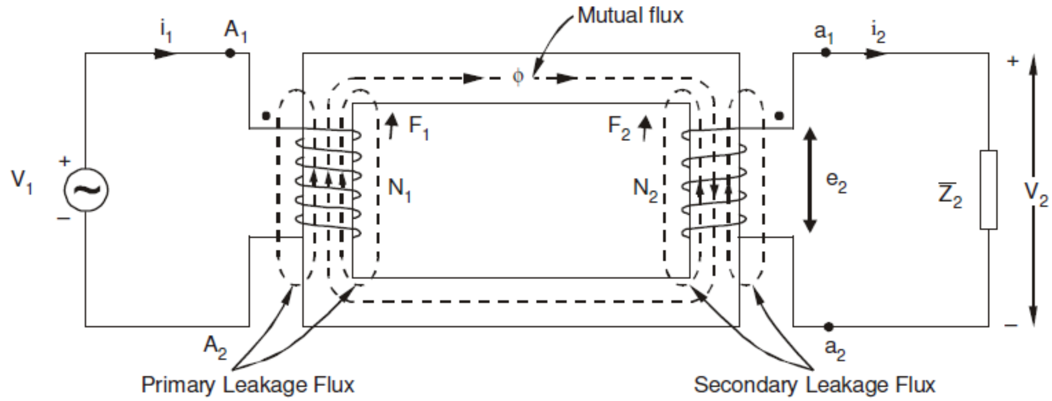


(a) Phasor Diagram at No Load



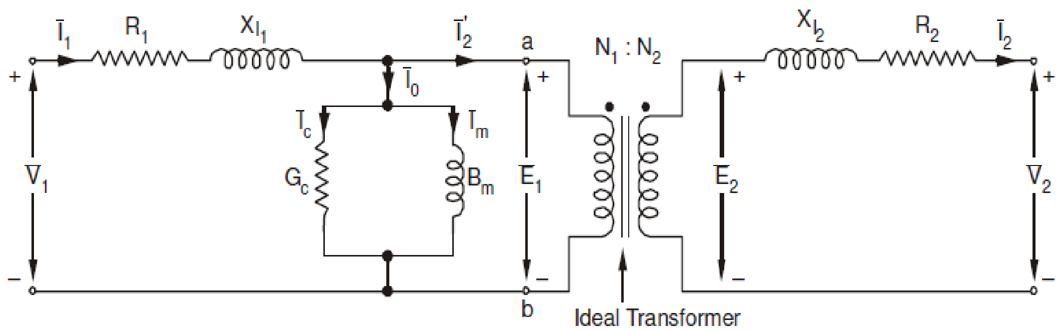
(b) Equivalent Circuit at No Load

IDEAL TRANSFORMER ON LOAD



$V_1/V_2=N_1/N_2=I_1/I_2$

EQUIVALENT CIRCUIT OF REAL TRANSFORMER



REGULATION OF TRANSFORMER

Voltage regulation of a transformer is defined as the drop in the magnitude of load voltage (or secondary terminal voltage) when load current changes from zero to full load value. This is expressed as a fraction of secondary rated voltage

(%) Regulation = (Secondary terminal voltage at no load − Secondary terminal voltage at any load)/ secondary rated voltage.

Percentage voltage regulation =$(V-E_0)*100/V$

LOSSES AND EFFICIENCY OF TRANSFORMER

A transformer does't contains any rotating part so it is free from friction and windage losses.

In transformer the losses occur in iron parts as well as in copper coils. In iron core the losses are sum of hysteresis and eddy current losses. The hysteresis losses are

$P_h \, \alpha \, f B^x_{max}$ and eddy current loss is equal to $P_e \, \alpha \, f^2 B_{max}$.

Where "f" is frequency "B_{max}" is maximum flux density.

IRON LOSSES OR CORE LOSSES

To minimize hysteresis loss in transformer, we use Cold Rolled Grain Oriented (CRGO) silicon steel to build up the iron core.

EDDY CURRENT LOSS

When the primary winding variable flux links with iron core then it induces some EMF on the surface of core. The magnitude of EMF is different at various points in core. So, there is current between different points in Iron Core having unequal potential.

These currents are known at eddy currents. $I^2 R$ loss in iron core is known as eddy current loss. These losses depend on thickness of core. To minimize the eddy current losses we use the Iron Core which is made of laminated sheet stampings. The thickness of stamping is around 0.5 mm.

COPPER LOSSES

In a transformer the primary and secondary winding currents increase with increases in load. Due to these currents there is some $I^2 R$ losses. These are known as copper losses or ohmic losses. The total $I^2 R$ loss in both windings at rated or full load current is equal to $I_1^2 \; R_1 = I_2^2 \; R_2$.

EFFICIENCY OF SINGLE PHASE TRANSFORMER

Efficiency (η)= output power/input power

=(input power –total losses)/input power

Alternatively η = output power/(output power + total losses)

In a transformer, if P_i is the iron loss, and P_c is the copper loss at full load (when the load current is equal to the rated current of the transformer, the total losses in the transformer are $P_i + P_c$. In any transformer, copper losses are variable and iron losses are fixed.

When the load on transformer is x times full load then

$$\eta = x V_2 \; I_2 \; \cos \varphi / (x V_2 \; I_2 \; \cos \varphi + P_i + x^{2*} P_c)$$

or

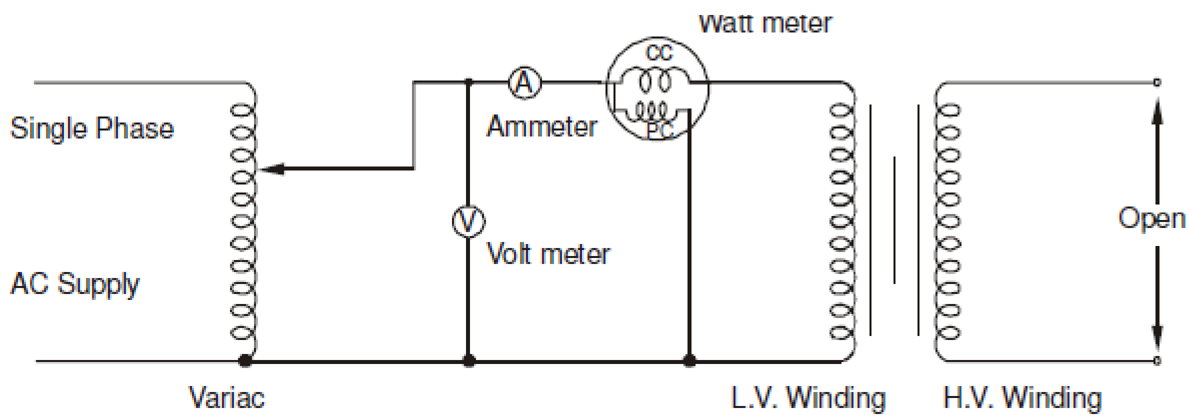
$$\eta = x KVA \; \cos \varphi / (x KVA \cos \varphi + P_i + x^{2*} P_c)$$

OPEN CIRCUIT TEST

Practically we can determine the iron losses by performing the open circuit test and also the core loss components of equivalent circuit.

We perform open circuit test in low voltage winding in transformer keeping the high voltage winding open. The circuit is connected as shown in Figure. The instruments are connected on the LV side. The advantage of performing the test from LV side is that the test can be performed at rated voltage.

When we apply rated voltage then watt meter shows iron losses [There is some copper loss but this is negligible when compared to iron loss]. The ammeter shows no load current I_0 which is very small [2-5 % of rated current]. Thus, the drops in R_1 and X_{l1} can be neglected.



We have W_0 = iron loss

I_0 = no load current

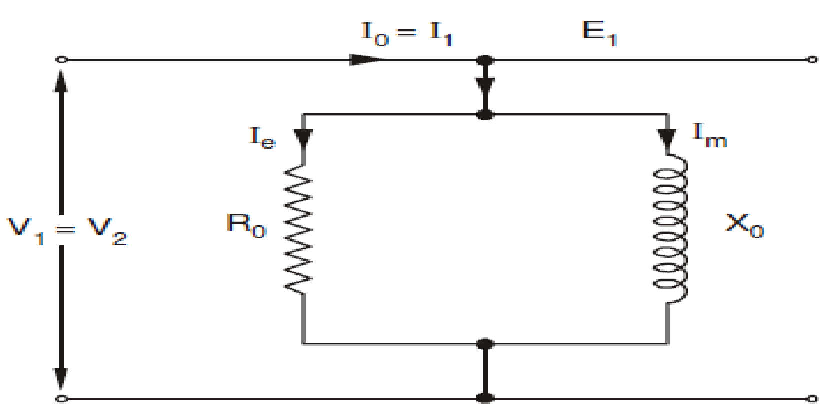
Then $\cos\varphi = \dfrac{W_0}{V_i I_0}$

So $I_e = I_0 \cos\varphi$

And $I_m = I_0 \sin\varphi$.

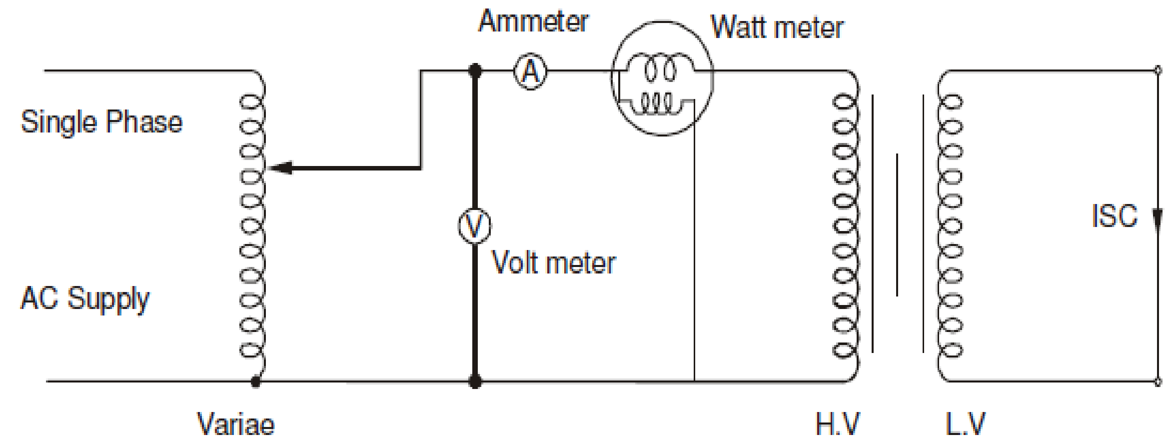
$R_0 = V_i/I_e$

$X_0 = V_i/I_m$

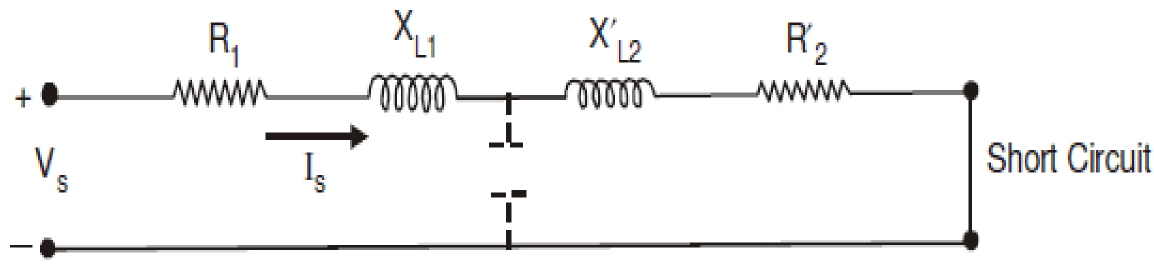


SHORT CIRCUIT TEST

From short circuit test we can determine copper losses and also the winding components of equivalent circuit. It's an indirect method to find out the copper losses. To perform this test, we apply a reduced voltage to the primary winding through instruments keeping LV winding short circuited. The connections are shown in Figure. We need to apply only 5-10% of rated voltage to primary to circulated rated current in the primary and secondary winding. The applied voltage is adjusted so that the ammeter shows rated current of the winding. Under this condition, the watt-meter reading shows the copper losses of the transformer. Because of low value of applied voltage, iron losses, are very small and can be neglected.



Connection diagram for short circuit test



Equivalent circuit under shot circuit

At a rated current watt meter shows full load copper loss. We have

W_{sc}= copper loss
I_{sc} = full load current
V_{sc} =supply voltage
$R_{eq} = W_{sc}/I_{sc}^2$
$Z_{eq} = V_{sc}/I_{sc}$
$X_{eq} = \sqrt{(Z_{eq}^2 - R_{eq}^2)}$

and equivalent impedance

So we calculate equivalent reactance. These R_{eq} and X_{eq} are equivalent resistance and reactance of both windings referred in HV side. These are known as equivalent circuit resistance and reactance.