UNIT – IV

SINGLE PHASE TRANSFORMERS

TRANSFORMERS

The transformer is a device that transfers electrical energy from one electrical circuit to another electrical circuit. The two circuits may be operating at different voltage levels but always work at the same frequency. Basically transformer is an electro-magnetic energy conversion device. It is commonly used in electrical power system and distribution systems.

SINGLE PHASE TRANSFORMERS

INTRODUCTION

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 (Refer Figure 4.1). 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 E2 in the second winding (called secondary winding). [Note that this alternating flux linking with primary winding will also induce a voltage in the primary winding, denoted as E1. Applied voltage V1 is very nearly equal to E1]. If the number of turns in the primary and secondary windings is N1 and N2 respectively, we shall see later in this unit that

$$\frac{E_1}{E_2} = \frac{N_1}{N_2}.$$

The load is connected across the secondary winding, between the terminals a1, a2. Thus, the load can be supplied at a voltage higher or lower than the supply voltage, depending upon the ratio N1/N2

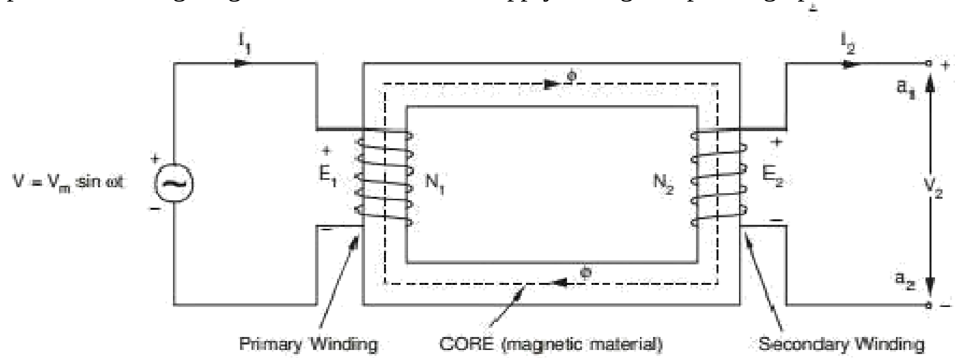


Figure 4.1 : Basic Arrangement of Transformer

When a load is connected across the secondary winding it carries a current I2, called load current. The primary current correspondingly increases to provide for the load current, in addition to the small no load current. The transfer of power from the primary side (or source) to the secondary side (or load) is through the mutual flux and core. There is no direct electrical connection between the primary and secondary sides.

In an actual transformer, when the iron core carries alternating flux, there is a power loss in the core called core loss, iron loss or no load loss. Further, the primary and secondary windings have a resistance, and the currents in primary and secondary windings give rise to I 2 R losses in transformer windings, also called copper losses. The losses lead to production of heat in the transformers, and a consequent temperature rise. Therefore, in transformer, cooling methods are adopted to ensure that the temperature remains within limit so that no damage is done to windings' insulation and material.

In the Figure 4.1 of a single-phase transformer, the primary winding has been shown connected to a source of constant sinusoidal voltage of frequency f Hz and the secondary terminals are kept open. The primary winding of N1 turns draws a small amount of alternating current of instantaneous value i0, called the exciting current. This current establishes flux φ in the core (+ve direction marked on diagram). The strong coupling enables all of the flux φ to be confined to the core (i.e. there is no leakage of flux).

CONSTRUCTION OF A TRANSFORMER

There are two basic parts of a transformer:

1. Magnetic core
2. Winding or coils

MAGNETIC CORE:

The core of a transformer is either square or rectangular in size. It is further divided in two parts. The vertical portion on which the coils are bound is called limb, while the top and bottom horizontal portion is called yoke of the core as shown in fig. 2.

Core is made up of laminations. Because of laminated type of construction, eddy current losses get minimized. Generally high grade silicon steel laminations (0.3 to 0.5 mm thick) are used. These laminations are insulated from each other by using insulation like varnish. All laminations are varnished. Laminations are overlapped so that to avoid the airgap at the joints. For this generally _L' shaped or _I' shaped laminations are used which are shown in the fig. 3 below.

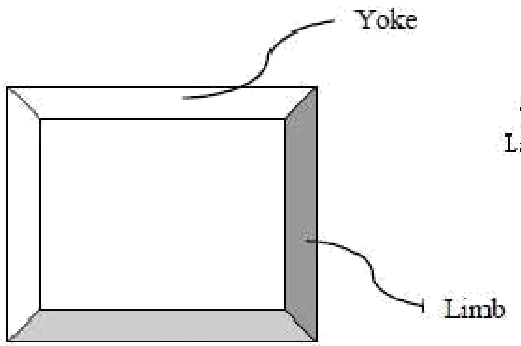


Fig. 2

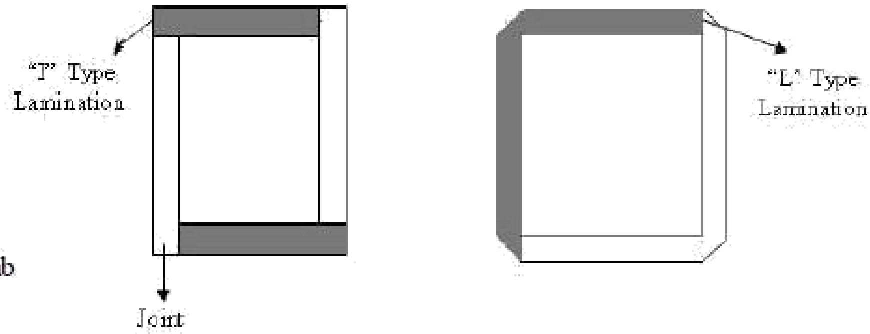


Fig. 3

WINDING:

There are two windings, which are wound on the two limbs of the core, which are insulated from each other and from the limbs as shown in fig. 4. The windings are made up of copper, so that, they possess a very small resistance. The winding which is connected to the load is called secondary winding and the winding which is connected to the supply is called primary winding. The primary winding has N_1 number of turns and the secondary windings have N_2 number of turns.

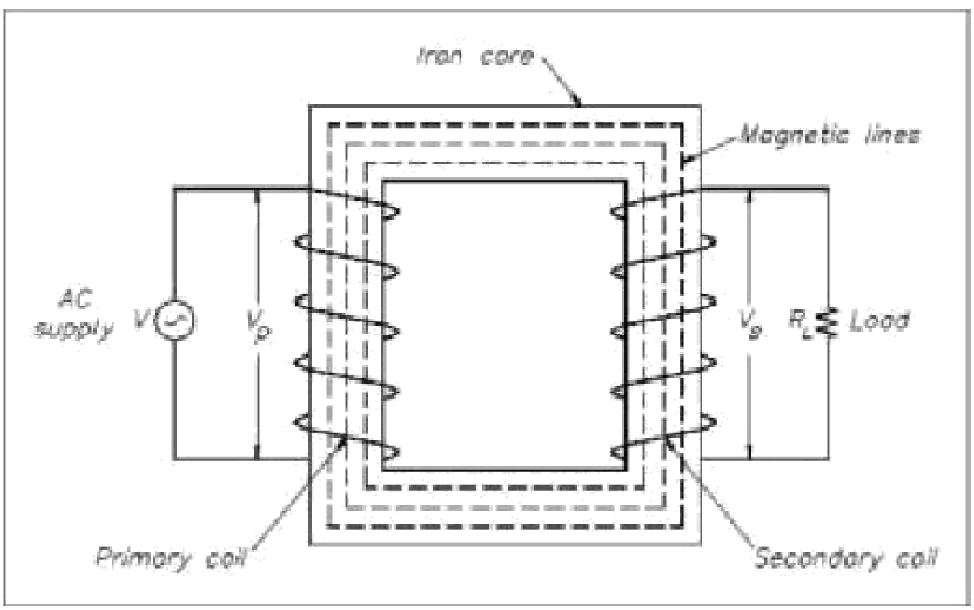
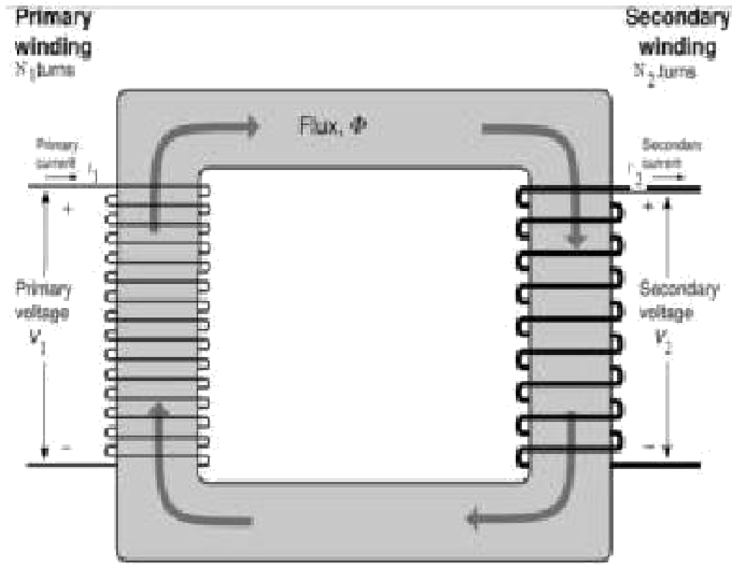


Fig. 4 Single Phase Transformer

PRINCIPLE OF OPERATION OF A SINGLE PHASE TRANSFORMER



A single phase transformer works on the principle of mutual induction between two magnetically coupled coils. When the primary winding is connected to an alternating voltage of r.m.s value, V1 volts, an alternating current flows through the primary winding and setup an alternating flux in the material of the core. This alternating flux ϕ, links not only the primary windings but also the secondary windings. Therefore, an e.m.f e1 is induced in the primary winding and an e.m.f e2 is induced in the secondary winding, e1 and e2 are given:

$$e1 = -N1\frac{d\varphi}{dt} \text{ --------- (a)}$$

$$e2 = -N2\frac{d\varphi}{dt} \text{ ----------(b)}$$

If the induced e.m.f is e1 and e2 are represented by their rms values E1 and E2 respectively, then

$$E1 = -N1\frac{d\varphi}{dt} \text{ ---------(1)}$$

$$E2 = -N2\frac{d\varphi}{dt} \text{ ----------(2)}$$

$$\text{Therefore, } \frac{E2}{E1} = \frac{N2}{N1} = k \text{ ---------------(3)}$$

K is known as the transformation ratio of the transformer. When a load is connected to the secondary winding, a current I2 flows through the load, V2 is the terminal voltage across the load. As the power transfered from the primary winding to the secondary winding is same, Power input to the primary winding = Power output from the secondary winding.

The directions of emf‘s E1 and E2 induced in the primary and secondary windings are such that, they always oppose the primary applied voltage V1.

EMF Equation of a transformer:

Consider a transformer having,

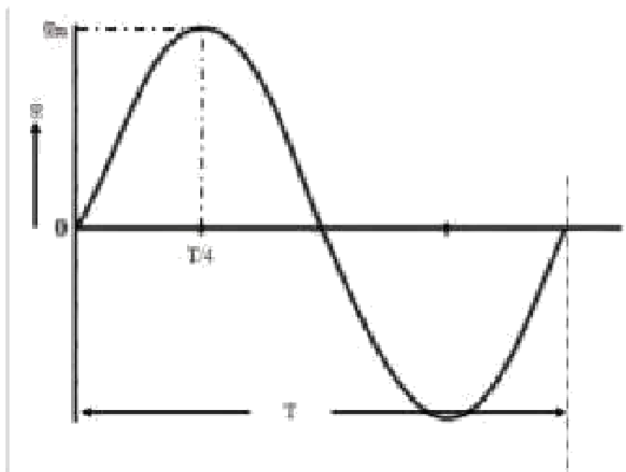
N1 =Primary turns

N2 = Secondary turns

Φm = Maximum flux in the core

Φm = Bm × A webers

f= frequency of ac input in hertz (Hz)



The flux in the core will vary sinusoidal as shown in figure, so that it increases from zero to maximum “ϕm” in one quarter of the cycle i.e, 1/4f second.

Therefore, average rate of change of flux = $\phi m / _{1/4f}$

$= 4f\varphi_m$

We know that, the rate of change of flux per turn means that the induced emf in volts.

Therefore, average emf induced per turn $= 4f\varphi_m$ volts.

Since the flux is varying sinusoidally, the rms value of induced emf is obtained by multiplying the average value by the form factor .

Therefore, rms value of emf induced per turns $= 1.11 \times 4f \times \varphi_m$

$= 4.44 f\varphi_m$ volts

i.e, $E_1 = 4.44f\varphi_m \times N_1 = 4.44fB_m \times A \times N_1$

Similarly;

$E_2 = 4.44\ f\ \varphi_m \times N_2 = 4.44\ f\ B_m \times A \times N_2$

Transformation Ratio:

(1) Voltage Transformation Ratio
(2) Current Transformation Ratio

Voltage Transformation Ratio:

Voltage transformation ratio can be defined as the ratio of the secondary voltage to the primary voltage denoted by K.

Mathematically given as $K = \frac{Secondary\ Voltage}{PrimarPrimar\ Voltage} = \frac{V_2}{V_1}$

$$K = \frac{E_2}{E_1} = \frac{4.44\ f\ \varphi_m N_2}{4.44\ f\ \varphi_m N_1} = \frac{N_2}{N_1}$$

$$K = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

Current Transformation Ratio:

Consider an ideal transformer and we have the input voltampere is equal to output voltampere. Mathematically, Input Voltampere = Output Voltampere

$$V_1 I_1 = V_2 I_2$$

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

$$\therefore,\ K = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$

Losses in Transformer:

Losses of transformer are divided mainly into two types:

1. Iron Loss
2. Copper Losses

IRON LOSS:

This is the power loss that occurs in the iron part. This loss is due to the alternating frequency of the emf. Iron loss in further classified into two other losses.

a) Eddy current loss

b) Hysterisis loss

a) Eddy Current Loss:

This power loss is due to the alternating flux linking the core, which will induced an emf in the core called the eddy emf, due to which a current called the eddy current is being circulated in the core. As there is some resistance in the core with this eddy current circulation converts into heat called the eddy current power loss. Eddy current loss is proportional to the square of the supply frequency.

b) Hysterisis Loss:

This is the loss in the iron core, due to the magnetic reversal of the flux in the core, which results in the form of heat in the core. This loss is directly proportional to the supply frequency.

Eddy current loss can be minimized by using the core made of thin sheets of silicon steel material, and each lamination is coated with varnish insulation to suppress the path of the eddy currents. Hysterisis loss can be minimized by using the core material having high permeability.

COPPER LOSS:

This is the power loss that occurs in the primary and secondary coils when the transformer is on load. This power is wasted in the form of heat due to the resistance of the coils. This loss is proportional to the sequence of the load hence it is called the Variable loss where as the Iron loss is called as the Constant loss as the supply voltage and frequency are constants

EFFICIENCY:

It is the ratio of the output power to the input power of a

transformer Input = Output + Total losses

= Output + Iron loss + Copper loss

Efficiency =

$$\eta = \frac{outputpower}{outputpower + Ironloss + copperloss}$$

$$= \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + W_{eron} + W_{copper}}$$

Where, V_2 is the secondary (output) voltage, I_2 is the secondary (output) current and $\cos\Phi$ is the power factor of the load.

The transformers are normally specified with their ratings as KVA,

Therefore,

$$Efficiency; \eta = \frac{(KVA) \times 10^3 \times cos\varphi}{(KVA) \times 10^3 \times cos\varphi \times W_{iron} + W_{copper}}$$

Since the copper loss varies as the square of the load the efficiency of the transformer at any desired load n is given by

$$Efficiency; \eta = \frac{n \times (KVA) \times 10^3 \times cos\varphi}{n \times (KVA) \times 10^3 \times cos\varphi + W_{iron} + n^2 \times W_{copper}}$$

where,

Wcopper is the copper loss at full load

Wcopper = I^2 R watts

CONDITION FOR MAXIMUM EFFICIENCY:

In general for the efficiency to be maximum for any device the losses must be minimum. Between the iron and copper losses the iron loss is the fixed loss and the copper loss is the variable loss. When these two losses are equal and also minimum the efficiency will be maximum.

Therefore the condition for maximum efficiency in a transformer

is Copper loss = Iron loss

VOLTAGE REGULATION:

The voltage regulation of a transformer is defined as the change in the secondary terminal voltage between no load and full load at a specified power factor expressed as a percentage of the full load terminal voltage.

$$\%Voltage\ Regulation = \frac{(no\ load\ Sec.Voltage) - (full\ load\ Sec.Voltage)}{full\ load\ Sec.Voltage} \times 100$$

Voltage regulation is a measure of the change in the terminal voltage of a transformer between No load and Full load. A good transformer has least value of the regulation of the order of ±5%

O.C. and S.C. Tests on Single Phase Transformer

The efficiency and regulation of a transformer on any load condition and at any power factor condition can be predetermined by indirect loading method. In this method, the actual load is not used on transformer. But the equivalent circuit parameters of a transformer are determined by conducting two tests on a transformer which are,

1. Open circuit te[redacted]Test)
2. Short circuit test [redacted]t)

The parameters calc[redacted]om these tes[redacted]are effective in determining the regulation and efficiency of a transfo[redacted]an[redacted]d power factor condition, without actually loading the transformer. The adv[redacted]this method is that without much power loss the tests can be performed and results[redacted]Let us discuss in detail how to perform these tests and how to use the res[redacted]alculate e[redacted]t circuit parameters.

Open Circuit Test (O[redacted]st)

The experimental circuit[redacted]ct O.C test is shown in the Fig. 1.