Transformer - Principle - Classification - EMF Equation

Objectives: At the end of this lesson you shall be able to
- **define a transformer**
- **explain the construction of two winding transformer**
- **state the reasons for laminated silicon steel being used as core material.**

Transformer

Transformer is a static electric device which transfer the electric energy from one circuit to other without changing the frequency and power.

The three-phase synchronous generator is used extensively to generate bulk power. The voltage levels at which this power is generated is typically in the range 11 kV to 22 kV. Electrical power is to be provided at a considerable distance from a generating station. It is possible to transmit the generated power directly but this results in unacceptable power losses and voltage drops.

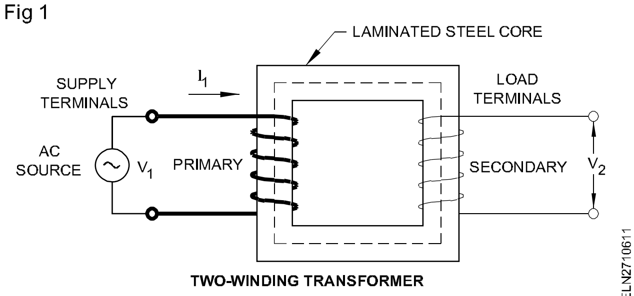
Transmission voltages vary up to the 400 kV level. This is made possible by power transformers. At the receiving end this high voltage must be reduced because ultimately it must supply three phase load at 415V or single phase load at 240V.

The transformer makes it possible for various parts of a power system to operate at different voltage levels.

Standard safety norms: Trainees can be instructed to refer the standard safety norms related with transformer in the International Electrotechnical commission (IEC - 60076-1) for the further details.

Two-winding transformers: A transformer consists of two stationary windings generally called as high voltage and low voltage sides which are electrically isolated but magnetically coupled (Fig 1). The coils are said to be magnetically coupled because they link a common flux.

Fig 1



TWO-WINDING TRANSFORMER

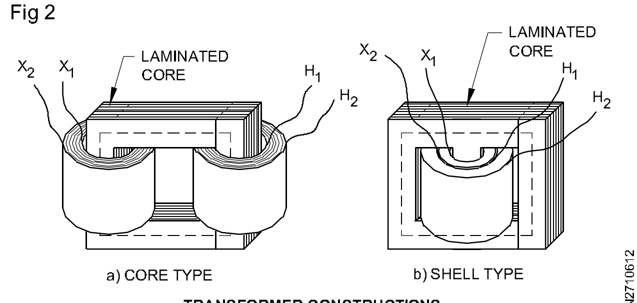
Laminated steel core transformers are used in power applications. Fig 1, the current flowing in the coil connected to the AC source is called the primary winding or simply primary. The primary is the input to a transformer. It sets up the flux in the core, which varies periodically both in magnitude and direction. The flux links the second coil, called the secondary winding or simply the secondary.

The flux is changing; therefore, it induces a voltage in the secondary by electromagnetic induction. Thus the primary receives its power from the source while the secondary supplies this power to the load. This action is known as transformer action. There is no electrical connection between these two coils.

Transformers are efficient and reliable devices used mainly to change voltage levels. Transformers are efficient because the rotational losses are absent; so little power is lost when transforming power from one voltage level to another. Typical efficiencies are in the range of 92 to 99%. The higher values apply to the large power transformers. There is no change in frequency of voltage.

Construction: There are basically two types of iron-core construction. Fig 2a shows core type already represented in Fig 1. It consists of two separate coils, one on each of the two opposite legs of a rectangular core.

Fig 2



TRANSFORMER CONSTRUCTIONS

Normally, this is not a desirable design. Its disadvantage is the large leakage fluxes associated with it. The large leakage fluxes cause poor voltage regulation. Therefore, to ensure that most of the flux set by the primary will link the secondary, the construction Fig 2b is employed. This is called shell type construction.

Here the two windings are wound concentrically. The higher voltage winding is wound on top of the lower voltage winding. The low-voltage winding is then located closer to the steel. This arrangement is preferable from an electrical insulating point of view. From the electrical viewpoint there is not much difference between the two constructions.

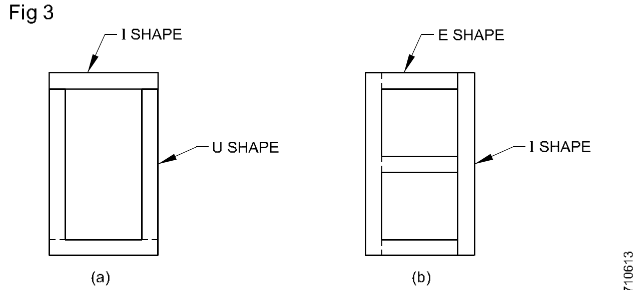
Cores may be built up of lamination silicon steel sheet.

Most laminating materials have an approximate alloy content of 3% silicon and 97% iron. The silicon content reduces the magnetizing losses. Particularly, the loss due to hysteresis is reduced. The silicon makes the material brittle. The brittleness causes problems in stamping operation.

Most laminated materials are cold-rolled and often specially annealed to orient the grain or iron crystals. This provides very high permeability and low hysteresis to the flux in the direction of rolling. Transformer laminations are usually 0.25 to 0.27 mm thick for 50 Hz. operation. The laminations are coated on one side by a thin layer of varnish or paper to insulate them from each other.

Coils are pre-wound, and the core design must be such that it permits placing the coil on the core. Ofcourse, the core must then be made in atleast two sections. The laminations for the core-type transformer of Fig 2a may be made up of (L and ⅂) shaped laminations, as shown in Fig 3a. The core for the shell type transformer of Fig 2b is normally made up of E and I shaped laminations Fig 3b.

Fig 3

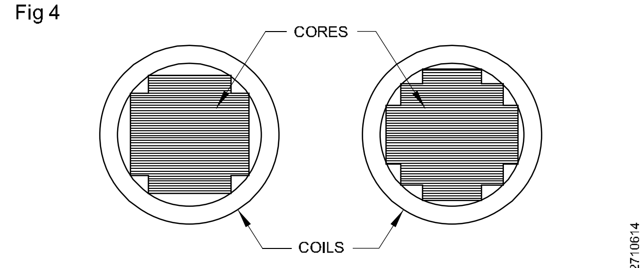


CORE CONSTRUCTION BUILT OF SEPARATE LAMINATIONS

Core construction : As a rule, the number of butt joints is to be limited. The joints are tightly made and laminations interleaved so as to minimize the reluctance of the magnetic circuit. The stacking of laminations to the required core cross-section results in the core legs of square or rectangular cross-section. This permits coils to be fitted on the core legs with either square, rectangular, or circular coil spools or forms.

In larger transformers, a stepped-core arrangement is used to minimise the use of copper and reduce copper loss. (Fig 4) This construction guarantees that each length of copper conductor embraces the maximum cross-sectional area of steel.

Fig 4



STEPPED TRANSFORMER CORES

In practice, the primary and secondary windings of a transformer have two or more coils per leg. They may be arranged in series or parallel. The laminations are pressed together by clamping in such a way as to prevent any fluttering or shifting.

The coils are impregnated. Insufficient clamping of laminations usually results in a humming sound. This generates objectionable and audible noise by the iron core of the transformer.

Transformers are usually air-cooled. Larger transformers are placed in tanks with a special transformer oil. The oil serves a dual purpose as an insulating medium as well as a cooling medium.

The heat generated in the transformer is removed by the transformer oil surrounding the source and is transmitted either to atmospheric air or water. No matter what size of transformer is dealt with, they all operate on the same principle.

Transformer principle

Objectives: At the end of this lesson you shall be able to
- **describe an ideal transformer and its operation on load and noload**
- **explain the principle of the operation of a transformer**
- **derive the EMFequation of a two-winding transformer**
- **derive the transformation ratio of a transformer.**

An ideal transformer: An ideal transformer is one which has no losses, ie. its windings have no ohmic resistance and there is no magnetic leakage. An ideal transformer consists of two coils which are purely inductive and wound on a loss-free core.

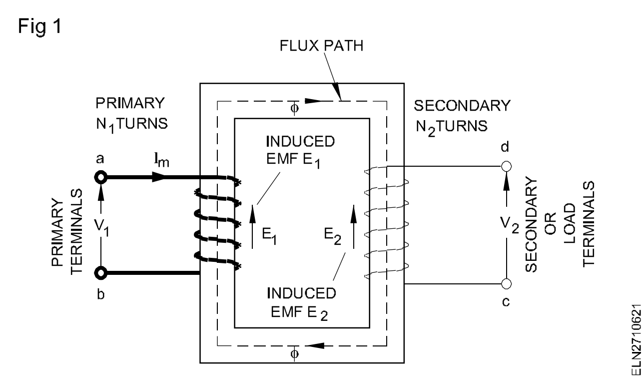
However, it may be noted that it is impossible to realize such a transformer in practice; yet for convenience, we will first analyse such a transformer and then an actual transformer.

Let us consider an ideal transformer (Fig 1) whose secondary is open and whose primary is connected to a sinusoidal voltage V_1.

Working principle

The transformers work on the principle of mutual induction of Faraday's law of electro - magenetic induction.

Fig 1



The applied voltage causes a small current to flow in the primary winding. This no-load current is meant to build up a counter-electromotive force equal and opposite to the applied voltage.

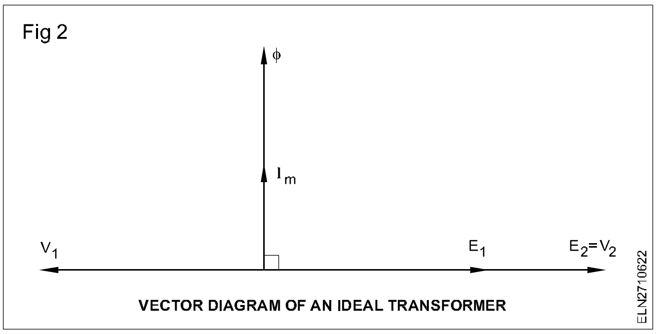
Since the primary winding is purely inductive and there is no output, the primary draws the magnetizing current I_m only. The function of this current is merely to magnetise the core. The I_m is small in magnitude and lags V_1 by 90°. This alternating current I_m produces an alternating flux ϕ which is proportional to the current and hence is in phase with it (I_m). This changing flux is linked with both the windings. Therefore, it produces self-induced EMF $(E)_1$ in the primary which lags the flux 'ϕ' by 90^0. This is shown in vector diagram Fig 2.

The flux 'ø' produced by the primary links with the secondary winding and induces an EMF (E_2) by mutual induction which lags behind the flux 'ø' by 90°Fig 2. As the EMF induced in primary or secondary per turn is same the secondary EMFwill depend on the number of turns of the secondary.

When secondary is open circuit, its terminal voltage 'V_2' is the same as the induced EMF (E_2). On the other hand, the primary current at no load is very small, hence the applied voltage 'V_1' is practically equal and opposite to the primary induced EMF (E_1). The relationship between primary and secondary voltages Fig 2.

Hence we can say that

Fig 2



Ideal Transformer on Load: When the secondary is connected to a load, secondary current flows this in turn makes the primary current to increase. How this happens is explained below.

The relationship between primary and secondary currents is based upon a comparison of the primary and secondary ampere turns.

When the secondary is open circuit, the primary current is such that the primary ampere turns are just sufficient to produce the flux 'ø' necessary to induce an EMF (E_1) that is practically equal and opposite to the applied voltage 'V_1'. The magnetising current is usually about 2 to 5 percent of the full load primary current.

When a load is connected across the secondary terminals, the secondary current - by **Lenz's law** - produces demagnetising effect. Consequently the flux and the EMFinduced in the primary are reduced slightly.

But this small change may increase the difference between applied voltage 'V_1' and the induced EMF (E_1) by say 1 percent in which case the new primary current would be 20 times the no load current.

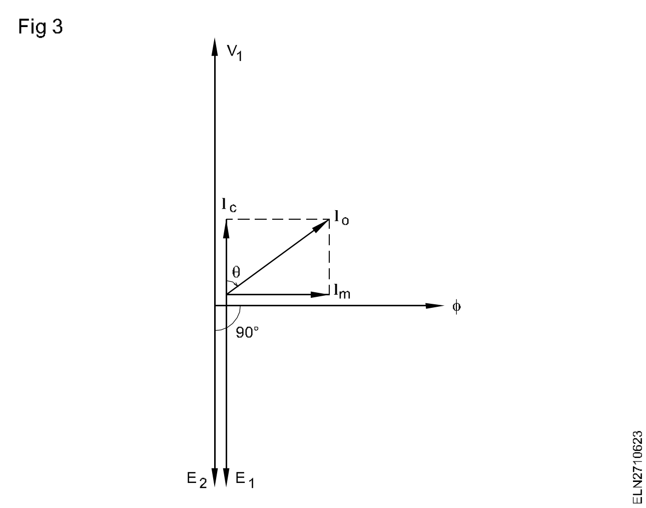
The demagnetising ampere turns of the secondary are thus nearly neutralized by the increase in the primary ampere turns and since the primary ampere turns on no load are very small compared with the full load ampere turns.

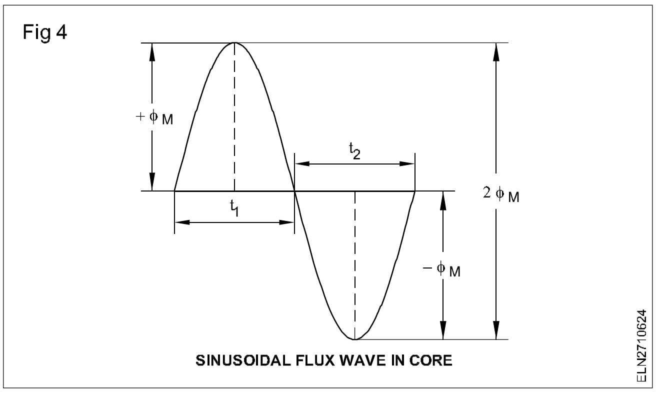
Therefore Full load primary ampere turns $\simeq$ full load secondary ampere turns

i.e $I_1N_1 \simeq I_2N_2$

so that $\frac{I_1}{I_2} \simeq \frac{N_2}{N_1} \simeq \frac{V_2}{V_1}$ Transformation ratio

From the above statement, it is clear that the magnetic flux forms the connecting link between the primary and secondary circuits and that any variation of the secondary current is accompanied by a small variation of the flux and therefore of the EMFinduced in the primary, thereby enabling the primary current to vary approximately, proportional to the secondary current.





Theory of No-load Operation: With the secondary winding open-circuited, the no-load current I_o flows in the primary winding. This no-load current has two functions:

1) It produces the magnetic flux in the core, which varies sinusoidally between zero and $\pm ø_m$ where $ø_m$ is the maximum value of the core flux; and

2) It provides a component to account for the hysteresis and eddy current losses in the core. These combined losses are normally referred to as the core losses or iron losses.

The no-load current I_o is usually a small percentage of the rated full load current of the transformer (about 2 to 5%). Since at no-load the primary winding acts as a large reactance due to the iron core, the I_o will lag the primary voltage 'V_1' by nearly 90°. Fig 3 illustrates this relationship where θ^0 is the no-load power factor angle.

Magnetising current = $I_m = I_o \sin\theta$ is 90° in phase behind the primary voltage V_1. It is this component that sets up the flux in the core; ø is therefore in phase I_m.

The second component, $I_c = I_o \cos ø_o$ is 90° is in phase with the primary voltage V_1. It is the current component that supplies the iron-loss plus a small quantity of primary Cu-loss. As I_o is very small, the no-load primary copper-loss is negligibly small.

EMF equation of a transformer: Since the magnetic flux set up by the primary winding links the secondary winding, an EMF will be an induced E_2, in the secondary, in accordance with Faraday's law, namely, $E = N (\delta ø/\delta t)$. The same flux also links the primary itself, inducing in it an emf, E_1. The induced voltage must lag the flux by 90°, therefore, they are 180° out of phase with the applied voltage V_1.

Since there is no current in the secondary winding, $E_2 = V_2$. The primary voltage and the resulting flux are sinusoidal; thus the induced quantities E_1 and E_2 vary as a sine function. The average value of the induced voltage is given by

$$E_{avg} = \text{turns} \times \frac{\text{change in flux in a given time}}{\text{given time}} \quad ...(1)$$

Referring to Fig 4, it is seen that the flux change in time interval t_1 to t_2 is $2\phi_m$ where ϕ_m is the maximum value of the flux, in webers. The time interval represents the time in which this flux change occurs and equals one-half cycle of $\left(\frac{1}{2f}\right)$ seconds, where f is the supply frequency, in hertz. It follows that

$$E_{avg} = N \times \frac{2\phi_m}{\frac{1}{2f}} = 4fN\phi_m \quad ...(2)$$

where N is the number of turns on the winding.

The effective or rms voltage for a sine wave is 1.11 times the average voltage, thus

$$E = 4.44\, f N\phi_m \quad ...(3)$$

Since the flux links with the primary and secondary windings, the voltage per turn in each winding is the same. Hence

$$E_1 = 4.44\, f N_1\phi_m \quad ...(4)$$

and

$$E_2 = 4.44\, f N_2\phi_m \quad ...(5)$$

where N_1 and N_2 are the number of turns in the primary and secondary windings respectively.

Voltage Transformation Ratio (K): From the equations 4 and 5, we get

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = K \text{ (Constant)} \quad ...(6)$$

This constant is known as voltage transformation ratio. Although the true transformation ratio is constant, the ratio of terminal voltages varies somewhat depending on the load and its power factor. In practice, the transformation ratio is obtained from the name plate data refers the voltages of primary and secondary on full load condition.

When the secondary voltage V_2 is less compared to the primary voltage, the transformer is said to be step down transformer. If the secondary voltage is higher it is called a step-up transformer. In other words

(a) $N_2<N_1$ i.e $K<1$, then the transformer is called a step-down transformer

(b) $N_2>N_1$ i.e $K>1$, then the transformer is called a step-up transformer

Assume that the power output of a transformer is equal to its input i.e we are dealing with an ideal transformer.

Thus $P_{in} = P_{out}$ (or)

$V_1 I_1$ x primary PF = $V_2 I_2$ x secondary PF

where PF is the power factor. For the above stated assumption it means that the power factor on primary and secondary sides are equal. (It is possible when I_o is neglected). Therefore,

$V_1 I_1 = V_2 I_2$ (or)

$$\frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{E_2}{E_1} = \frac{N_2}{N_1} = K \qquad ...(7)$$

Equation 7 shows that as an approximation the terminal voltage ratio equals the turns ratio.

Transformer - simple calculations

Objective: At the end of this lesson you shall be able to
- **define the rating of transformer**
- **calculate the voltage, current and turns of primary from the secondary data and vice versa.**

Rating of transformer

The capacity of the transformers are always rated by its apparent power (volt amp - VA (or KVA), not by its true power (watt (or) KW) (ie.) KW = KVA x Cosϕ . The transformer can be loaded with either resistive, inductive, capacitive (or) combined. The power factor (Cosϕ) depends on the load of the transformer. If the PF. is known of the specific load, then only the load current can be calculated otherwise the load current may be more than rated. If the transformer rating is in KVA the load current can be determined directly by knowing its voltage.

Hence the transformer are rated in VA (or) KVA, because the safety maximum load current can be calculated without knowing power factor.

The KVA of the primary must equal to the KVA of the secondary under the ideal transformer concept. We know that the terminal voltage ratio is equal to turns ratio. The primary and secondary currents are inversely related to the turns ratio.

Example 1: A 100 KVA 2400/240V, 50 Hz. transformer has 300 turns on the secondary winding. Calculate (a) the approximate value of primary and secondary currents (b) the number of primary turns and (c) the maximum flux ϕ_m in the core.

Data given : Transformer rating 100 KVA

Frequency $f = 50$ Hz

Primary voltage $V_P = 2400$ V

Secondary voltage $V_S = 240$ V

Secondary turns $N_S = 300$

Known: $E_P = (4.44 \times f \times N_P \times \phi_m)$ volts

$$\frac{V_P}{V_S} = \frac{I_S}{I_P} \cong \frac{E_P}{E_S} \cong \frac{N_P}{N_S}$$

$V_P I_P = V_S I_S$ = KVA

Find: Primary current I_P

Secondary current I_P

Primary turns N_P

Maximum flux Φ_m

Solution

(a) I_P (full load) $= \frac{KVA \times 1000}{V_p} = \frac{100000}{2400} = 41.7A$

and $I_S = \frac{100000}{240} = 417A$

(b) $\frac{V_P}{V_S} = \frac{2400}{240} = 10 = \frac{N_P}{N_S}$

Therefore, $N_P = 10 \times N_S$

$= 10 \times 300 = 3000$ turns.

(c) $4.44 \times f \times N_P \times \phi_m = E_P$

$$\Phi_m = \frac{2400}{4.44 \times 50 \times 3000} = 0.0036 \text{ Wb.}$$

Example 2: In a transformer the number of turns per volt (i.e N/V) is 8. The primary voltage is 110V. Find the primary and secondary turns of wire if V_2 is to be 25 volts.

Data given: V_1 = 110V

$$\frac{\text{Primary turns}}{\text{Primary volts}} = \frac{N_1}{V_1} = 8$$

V_2 = 25

Known: $\frac{V_1}{V_2} = \frac{N_1}{N_2}$ or $\frac{N_1}{V_1} = \frac{N_2}{V_2}$

Find: N_1 and N_2

Solution: Primary turns $\frac{N_1}{V_1} = 8$

N_1 = 8 x 110 = 880 turns

Secondary turns N_2 = 8 x 25 = 200 turns

Classification of transformers

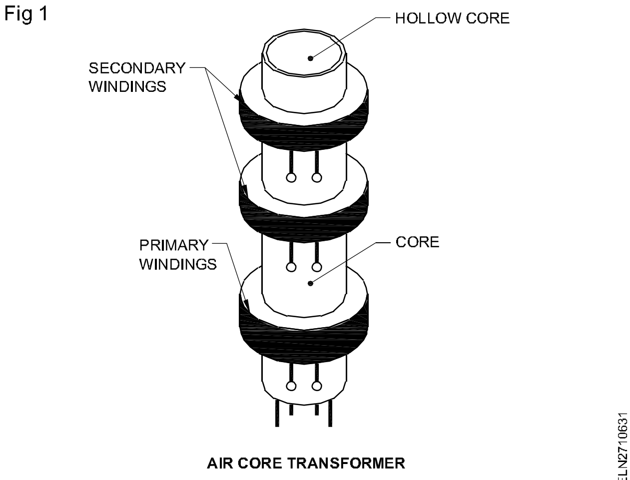
Objectives : At the end of this exercise you shall be able to
- **state the classification of transformers based on various factors**
- **state about the dry type transformers.**

Classification of Transformers

1. Classification based on the type of Core Material used

- **Air core transformers** : Fig 1, air core transformers consists of a hollow non magnetic core, made of paper or plastic over which the primary and secondary windings are wound. These transformers will have values of k less than 1. Air core transformers are generally used in high frequency applications because these will have no iron-loss as there is no magnetic core material.

Fig 1



AIR CORE TRANSFORMER

Iron-loss is a type of transformer loss due to core material.

- **Iron core transformers**: Fig 2 shows a laminated iron-core transformer. This is the most common type of transformer used with mains power supply transformers,

- **Ferrite core transformers**: Fig 3, these transformers have Ferrite material as its core Fig 3. In most cases, the primary and secondary windings are wound on a hollow plastic core and the ferrite material is then inserted into the hollow core. These transformers are used in high frequency to very high frequency applications as they have the advantage of introducing minimum losses.

Fig 2

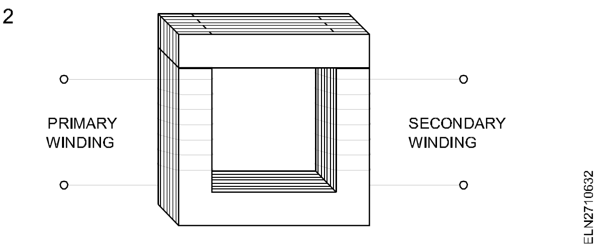
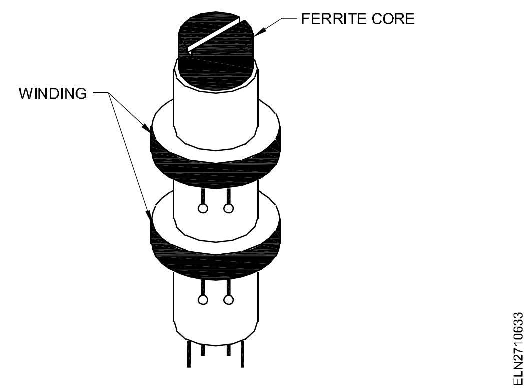


Fig 3



2 Classification based on the shape of core

- **Core type transformers**: In Core type of transformer, the primary and secondary windings are on two separate sections/limb of core. (Fig 1 in chart 1)

- **Shell type transformers**: In this type, both the primary and the secondary windings are wound on the same section/limb of the core.These are widely used as voltage and power transformers. (Fig 2 in chart 1)

- **Ring type transformers**: In this, the core is made up of circular or semicircular laminations (Fig 3). These are stacked and clamped together to form a ring. The primary and secondary windings are then wound on the ring. The disadvantage of this type of construction is the difficulty involved in winding the primary and secondary coils. Ring type transformers are generally used as instrument transformers for measurement of high voltage and current.

3 Classification based on the Transformation ratio

- **Step-up Transformers**: Transformers in which, the induced secondary voltage is higher than the source voltage given at primary are called step-up transformers.
- **Step-down Transformers**: Transformers in which, the induced secondary voltage is lower than the source voltage given at primary are called step-down transformers.
- **Isolation transformers**: Transformers in which, the induced secondary voltage is same as that of the source voltage given at primary are called one-to-one or isolation transformers. In these transformers the number of turns in the secondary will be equal to the number of turns in the primary making the turns ratio equal to 1.

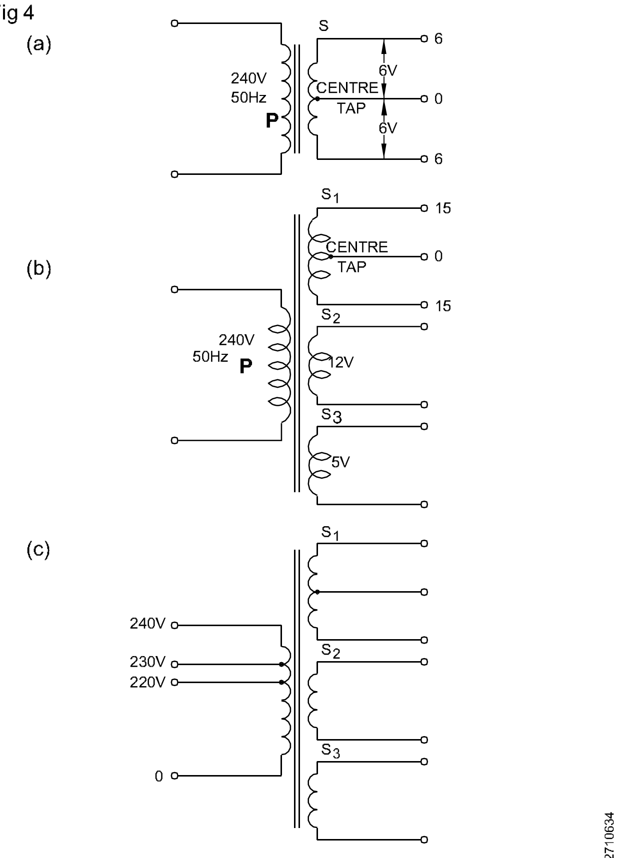
4 Classification based on the operating frequency

- **Mains frequency transformer**: These are basically, iron-core shell type transformers. These transformers form the link between AC mains source and other devices requiring AC or DC power example, radius receivers. The secondary winding of these transformers may have a centre tap as shown in Fig 4a or may have more than one secondary windings Fig 4b. These transformers may also have more than two terminals at primary winding Fig 4c to accommodate for different AC mains levels. Tapped primary also allows changes in the secondary-primary turns ratio. All the power transformers are generally designed to work at mains supply frequency(50 Hz).

Power transformers use colour coding scheme to identify the primary and secondary windings. (Fig 5)

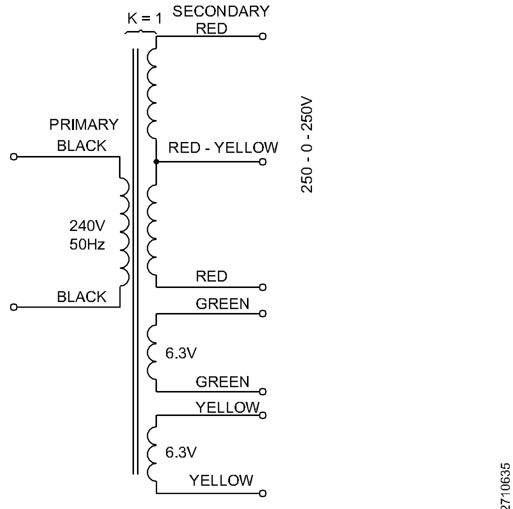
- **Audio frequency (AF) transformers**: Refer Fig 5 in Chart 1. These AF transformers are very small in size. Most AF transformers are of PCB mounting type. These transformers are designed to operate over the audio frequency range of 20 Hz to 20 KHz. Audio transformers are used in,
- coupling the output of one stage of audio amplifier to the input of the next stage (interstage coupling)
- the amplified audio signal from an amplifier to the speaker of a sound system.
- **High frequency transformers**: Refer Fig 6 in Chart 1. The core of high frequency transformers are made of powdered iron or ferrite or brass or air core(hollow core) Fig 1 and 3. These transformers are called Radio frequency transformers (RFTs) and Intermediate frequency transformers (IFTs).

Fig 4



CENTRE TAPPED SECONDARY

Fig 5



A TYPICAL COLOUR CODING SCHEME FOR POWER TRANSFORMERS

These transformers are used for coupling any two stages of high frequency circuits such as radio receivers. The upper frequency limit of these transformers is 30 MHz.

Another speciality of these transformers is that the position of the core can be altered, which results in varied coupling and energy transfer. These transformers also have a capacitor connected across the windings in parallel. This results in a different behavior of the transformer at different frequencies. Hence these transformer are also called Tuned transformers.

These transformers are smaller than even audio frequency (AF) transformers. These transformers will generally be shielded/screened using a good conductor.

- **Very high frequency transformers**: These transformers also have air or ferrite or brass as core material. These transformers are constructed specially to minimize energy losses at very high frequencies. Some of these find wide application in Television receivers.

5 Single phase and three phase transformers

Transformers Fig 4 of Chart 1 are designed for use with single phase AC mains supply. Such transformers are known as single phase transformers. Transformers are also available for 3 phase AC mains supply. These are known as poly-phase transformers. Refer Fig 7 in Chart 1. Three phase transformers are used in electrical distribution and for industrial applications.

6 Classification based on application

Transformers can also be classified depending upon their application for a specialized work. There are innumerable number of applications, However a few of these are listed below:

Instrument Transformers - used in clip - on current meters, overload trip circuits etc.,

Constant voltage transformers - used to obtain stabilized voltage supply for sensitive equipments

Ignition transformers - used in automobiles

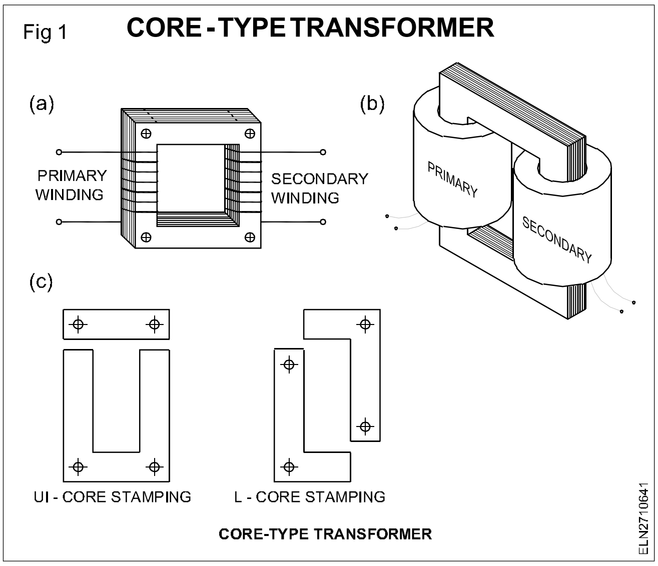
Welding transformers - used in welding equipments

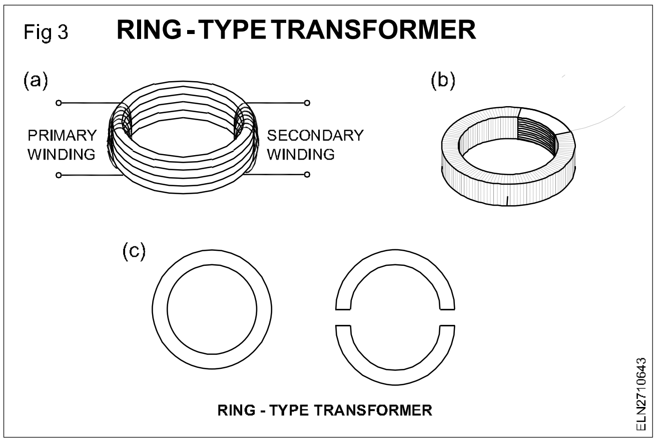
Pulse transformers - used in electronic circuits

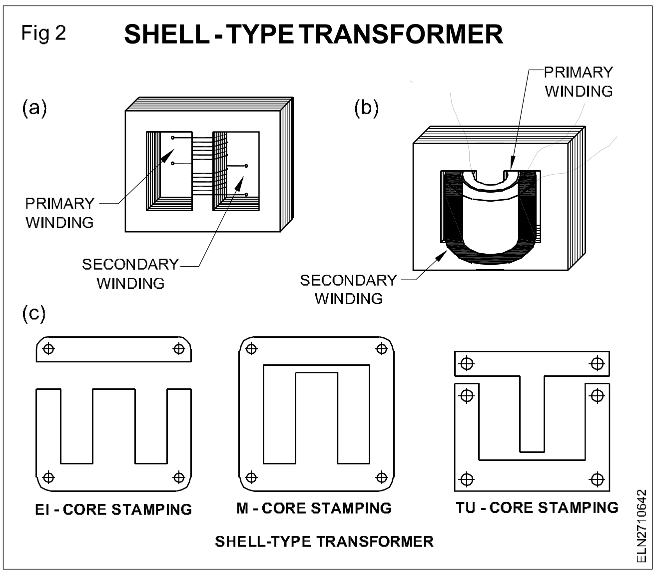
Dry Type Transfomers

Dry type, or air-cooled, transformers are commonly used for indoor applications where other transformer types are considered too risky.

Chart - 1
Types of transformers







MAINS FREQUENCY TRANSFORMER

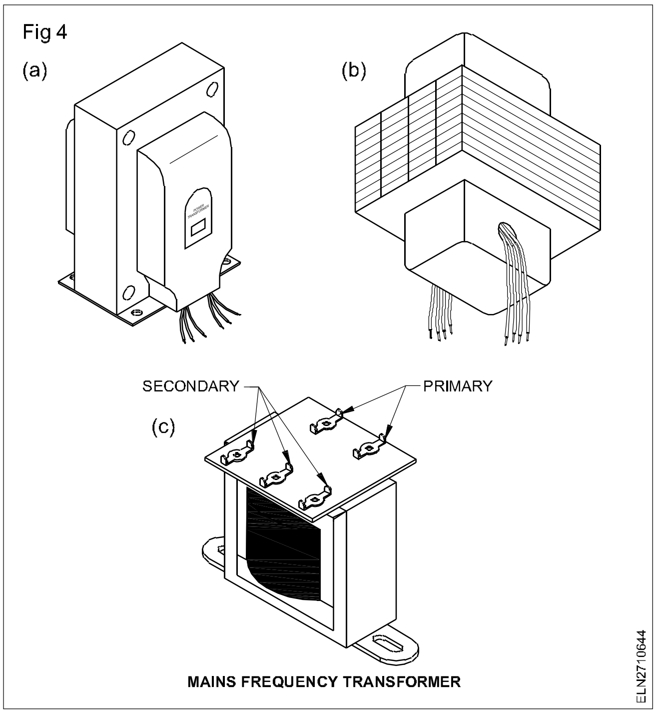
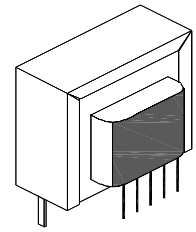


Chart - 1 Continued....
Types of transformers

AUDIO FREQUENCY TRANSFORMER

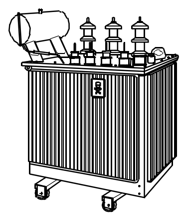
Fig 5



AUDIO FREQUENCY TRANSFORMER

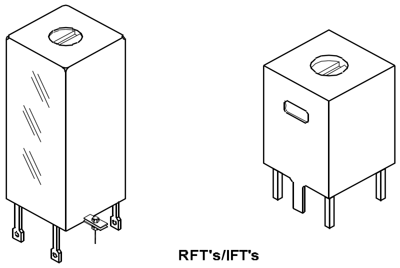
POLY - PHASE TRANSFORMER

Fig 7



POLY - PHASE TRANSFORMER

Fig 6 **HIGH FREQUENCY TRANSFORMER**



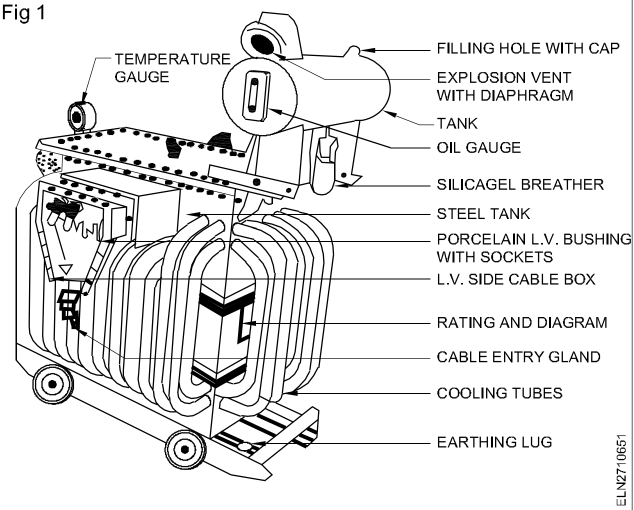
HIGH FREQUENCY TRANSFORMER

Parts and their functions of transformer

Objectives: At the end of this lesson you shall be able to
- **list out the mainparts of transformer**
- **explain the parts of a distribution transformer.**

Distribution transformer: Fig 1 shows the essential parts of a distribution transformer.

Fig 1



The important components of a distribution transformer are briefly described below:-

The important components of transformer are : -

1 Steel tank

2 Conservation tank

3 Temperature gauge

4 Explosion vent

5 Cooling tubes

6 Tap changer

7 Bushing termination

8 Silical gel breather

9 Buchholz relay

1 Steel tank

It is a fabricated M.S plate tank used for housing the core, winding and for mounting various accessories required for the operation of a transformer. Core is built from cold rolled grain oriented silicon steel lamination. The L.V winding is normally close to the core and the H.V winding is kept around the L.V winding.

2 Conservator tank

It is in the shape of a drum, mounted on the top of the transformer. An oil level indicator is fitted to the conservator tank. Conservator is connected to the transformer tank through a pipe. The conservator carries the transformer oil to a specified level. When transformer is heated up due to normal load operation, the oil expands and the level of oil in conservator tank is increased or vice versa. A pipe connected to the top of the conservator tank allows the internal air to go out or get in through the breather.

It reduces the oxidation of oil when it get contact with air.

3 Temperature gauge

It is fitted to the transformer which indicates the temperature of the transformer oil.

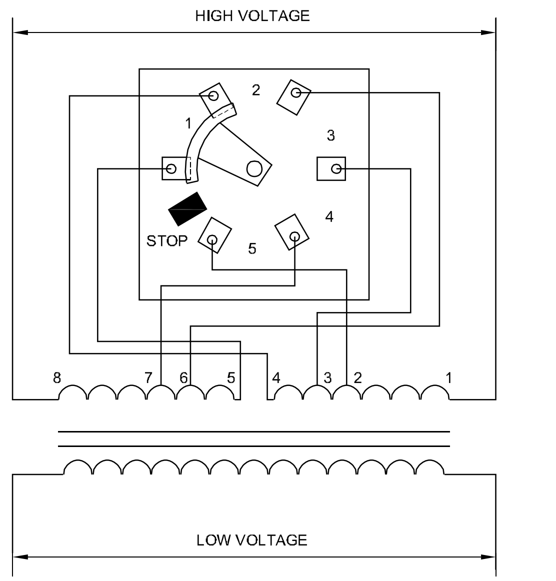
4 Cooling tubes

In earlier discussions, we found that the transformer is heated up, when the transformer is connected to the supply is due to iron loss and copper loss. To keep down the temperature of the windings, when the transformer is put on load, the heat generated inside the transformer should be radiated to the atmosphere. To dissipate the heat produced inside the winding and core, the transformer tank is filled with an insulating oil. The oil carries the heat to the cooling pipes where the heat is dissipated to atmosphere due to surface contact with air.

5 Tap changer

When voltages are transmitted over long distances there will be voltage drop in the conductors, resulting in lower voltage at the receiving end. To compensate this line voltage drops in the conductors, it is customary to increase the sending end voltage by tap changing transformers. These transformers may have several winding taps in their primary winding (Fig 2).

Fig 2



MANUALLY OPERATED TAP - CHANGING

There are two methods of tap changing. In one method, these taps are manually changed through a tap changing switch. (Fig 2) In this method load switch has to be opened, before the tap changing operation is to avoid heavy sparking at the contact points. This method is often referred to as "OFF-LOAD" tap changing method.

In another method the tap changing is done with the load called as ON-LOAD' tap changer. In this method the following parameters are met.

- The load current must not be interrupted during a tap change.
- The tap changing must be carried out without short circuiting a tapped section of the winding.

To meet both criteria some form of bridging or transfer impedance is required during the tap changing operation.

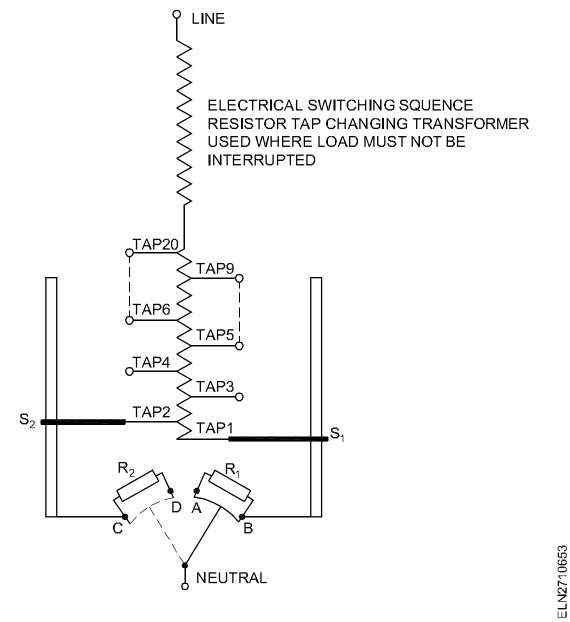
The tap changer has two main units. The tap selector switch is the unit responsible for selecting the tap on the transformer winding as shown in Fig 3, but does not make or break the load current. The diverter switch is where the actual switching of the load takes place.

The selector switch first moves to the desired tap position by the internal mechanism as selected either by automatic voltage regulator or by manual method. Then the diverter switch operates at a faster rate to the desired setting.

The operation of the ON-LOAD tap changer could be explained as below. (Only single phase operation is shown)

Referring to Fig 3, in the initial position selector switch S_1 is on tap 1 and S_2 on tap 2. The diverter switch connects tap 1 to the neutral point of the transformer winding. The sequence of operation in changing to tap 2 is as follows.

Fig 3



- The mechanism operates, the moving contact starts to travel from one side of the diverter to the other; contact 'B' is opened and the load current flows through resistor R_1 to contact 'A'.
- The moving contact 'D' then closes. Both resistors R_1 and R_2 are now in series across tap 1 and 2 and the load current flows through the mid point of these resistors.
- Further travel of the moving contact opens contact 'A' and the load current then passes from tap 2 through resistor R_2 and contact 'D'.

- Finally when moving contact reaches the other side of the diverter switch, contacts 'C' is closed and resistor R_2 is shorted out. Load current from tap 2 now flows through contact 'c' the normal running position of tap2.

The change from position 1 to 2 as described involves the movement of selector switch. If any further change in the same direction is required i.e from 2 to 3, the selector switch ST travels to tap 3 before the diverter switch moves and the diverter switch then repeats the above sequence but in the reverse order.

If a change in the reverse direction, the selector switches remain stationary and the tap change is carried out by the movement of the diverter switch only.

6 Bushing termination

High voltage Power transformers are used in transmission and distribution sector. The windings of such transformers are energised with very high voltage. Generally, when an energized conductor (may be Copper or Aluminium) is passing through a metallic section.

The metallic part is directly connected with earth, then the potential of it will be equal to the earth potential. Therefore the field of the charged conductor gets distorted with the effect of the earth potential.

The electric field of the conductor will interact with the earth potential. To prevent this, Transformer Bushings are provided with each input and output terminals. So, Transformer Bushings are used to provide a electrical isolation for the winding terminals, when any earthed material is present near to the conductors.

Generally, Transformer Bushings are designed to withstand the high electrical energy of the charged conductors passing through them. Therefore they should have sufficient dielectric strength.

Porcelain bushing of transformer

This type of Transformer Bushings are used in several power industries for their robustness and they are also very cheap. Porcelain offers very good and reliable electrical insulation for a wide range of voltages as well as they have high dielectric strength too.

A porcelain bushing is a hollow cylindrical shaped arrangement made by porcelain discs which is fitted to the top portion of the transformer. And the energised conductors are passed through the centre portion of the bushings.

After inserting the conductor, the ends of the porcelain bushings are tightly sealed with glaze and this arrangement ensures a prevention from any type of moisture.

The entire bushing arrangement is checked and it should not contain any leakage paths. If the operating voltage level is very high then the vacuum space of the Transformer Bushing is filled with insulating oil.

Capacitance graded bushing of transformer (capacitor bushings)

Basically, capacitance graded bushing is the modification of Paper Bushing. Here, very fine layers of smooth metallic foils are inserted into the paper during the winding process. The inserted foils are metallic. so they are conductive in nature.

Therefore, when these foils are interacting with charged conductors, then they develop a capacitive effect which dissipates the electrical energy more evenly throughout the Bushing.

In this way, the electric field stress is distributed throughout the Bushing and this causes lesser chance of Insulation Puncture. This type of bushing is also known as Capacitor Bushing.

There are 4 types of Capacitance graded Bushing, namely:-

- Resin Bounded Paper Bushing.
- Oil Impregnated Paper Bushing.
- Resin Impregnated Paper Bushing.
- Epoxy Resin Impregnated Paper Bushing.

Testing and maintenance of transformer bushing

There are several types of tests for transformer bushing. Some of them are done before the installation and some of them are used for routine maintenance.

1 **Measurement of tangent delta (tan δ) or capacitance:** This is a routine maintenance test. Initially, the transformer is separated from service and a strong local earthing is done for operator safety. In this test, electrical connection in between the transformer tank and bushing flange is checked for instance with a buzzer. For capacitance measurement, a capacitor test kit is required.

   The transformer capacitance has negligible value so it can be ignored during the measurement of bushing capacitance. This measurement is carried out for each phase of the transformer. The measured capacitance is further compared with the rating chart.

2 **Measurement of Partial Discharge:** This is also a routine checking process for maintenance purpose. This measurement of Partial Discharge indicates the week points of insulation. As per the new technology the partial discharges are located by using sophisticated acoustic sensors.

3 **Dissolved gas analysis:** This test is only for oil filled bushings. After opening the seal oil sample is collected from the bushing and then the necessary procedures are carried out. After the sample collection, the glaze seal of bushing should br properly placed. This test is commonly known as the DGA test of transformer bushing.

4 **Moisture analysis:** This is an important test for oil filled bushings are any type of moisture is harmful for proper operation. The oil bushings of transformer are tightly sealed.

After some period the oil sample is collected to measure the moisture content. Depending on the operating temperature, the moisture of bushings will move from paper to oil or oil to paper.

5 **Maintenance of Porcelain:** The porcelain part of bushings sometime chipped or cracked, or the glaze seal sometime eroded. So, proper maintenance of porcelain is necessary and the defected porcelain should be replaced with new one.

Beside of these, the metal parts, taps and oil levels are checked as routine maintenance.

7 Protective - devices / parts of transformers:

1 Breather

Transformer oil deterioration takes place due to moisture. Moisture can appear in a transformer from three sources, viz. by leakage through gasket, by absorption from air in contact with the oil surface or by its formation within the transformer as a product of deterioration as insulation ages at high temperature.

The effect of moisture in oil is to reduce the di-electric strength, especially if loose fibres or dust particles are present.

Methods available to reduce oil contamination from moisture are:

- by the use of silica gel breather
- by the use of rubber diaphragm
- by using sealed conservator tank
- by using gas cushion
- by using thermosyphon filter

Silica gel breather

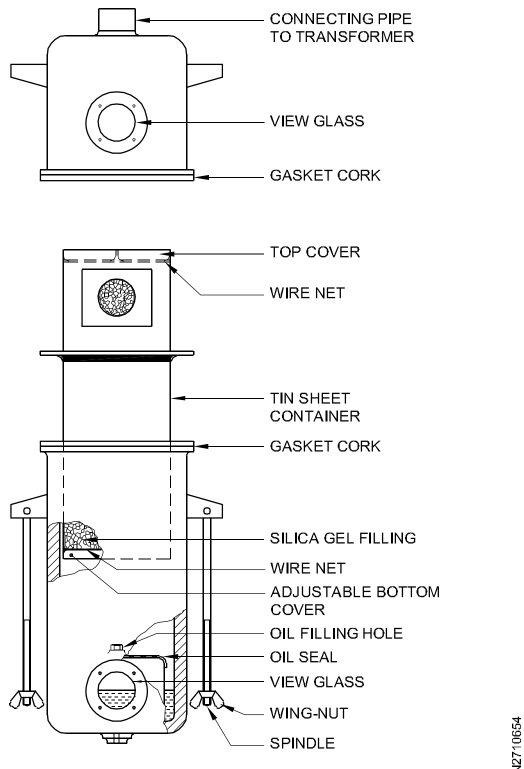
Silica gel breather is a protective device fitted to the conservator through a pipe and allows the moisture free air to and fro into the conservator when the transformer oil get heated and cools down.

As the load and heat on a transformer reduces, air is drawn in to the conservator through a cartridge pakced with **silica gel crystals**.

The silica gel effectively dries the air and thus prevent the moistured dust entering into transformer oil. The fresh silica gel is available in blue colour. The colour of the silica gel changes to pure white or light pink colour as it absorbs moisture from air.

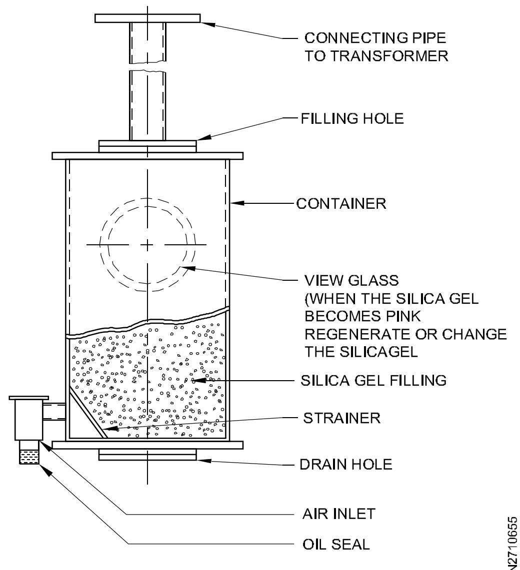
To recondition silica gel either it can be dried in sun or it could be dry roasted on a frying pan kept over a stove.Fig 4 & 5 show a cross-sectional view of such a silica gel breather.

Fig 4



SILICA GEL BREATHER

Fig 5



SILICAL GEL BREATHER

The oil seal at the bottom of the breather absorbs the dust particles that are present in the air entering the conservator.

2 Buchholz relay

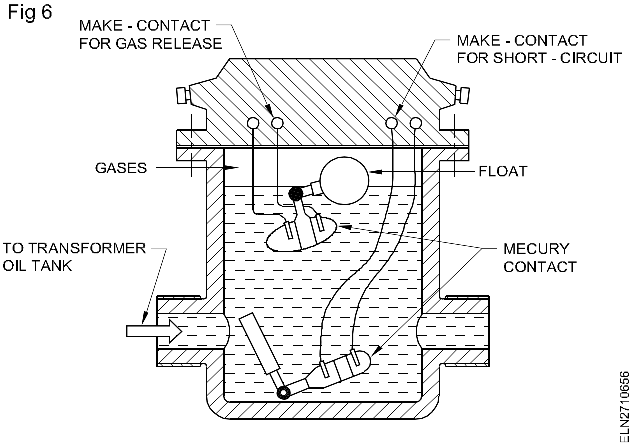
Buchholz relay is a gas operated - protective device which is connected between the transformer oil tank and the conservator tank.

If a fault is present inside a transformer, it may be indicated by the presence of bubbles (gas) in the transformer oil. Presence of gas could be viewed from class in window of by the Buchholz relay.

The relay comprises of a cast iron chamber which have two floats Fig 6. Top float assembly operates during initial stages of gas/air bubble formation due to minor fault in the transformer.

When sufficient gas bubbles formed around the top float, the float operates in pneumatic pressure principle to close an electric circuit through mercury switch which causes the siren or alarm bell to operate to caution the operator.

Fig 6



On hearing the alarm sound the operator takes necessary preventive steps to safeguard the transformer.

If any major fault like earth, fault etc, occurs in the transformer then the production of gas bubbles are more severe and hence the bottom float activates the mercury switch and closes the relay contacts.

Closing of the bottom relay contacts trips the transformer circuit breaker and opens the transformer from main line to protect the transformer from further damage.

3 Explosion vent

It is a pressure release device fitted to the transformer. The mouth of the explosion pipe is tightly closed using either a thin glass or laminated sheet.

If, by any, chance the transformer is overheated either due to short circuited or sustained overload, the gases produced inside the transformer tank creates tremendous pressure which may damage the tank.

On the other hand the pressure built inside the transformer may break the glass/laminated diaphragm of the explosion pipe and thereby the tank can be saved from total damage.

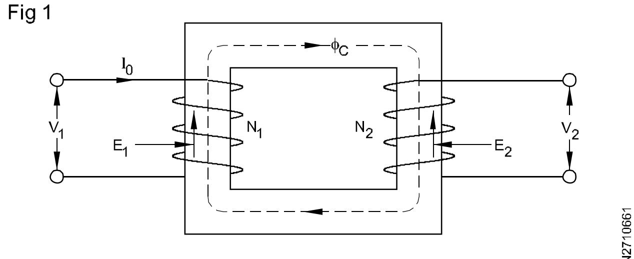
Transformer on load

Objectives: At the end of this lesson you shall be able to

- **explain how the loading of a transformer takes place considering instantaneous value**
- **describe leakage flux and leakage reactance.**

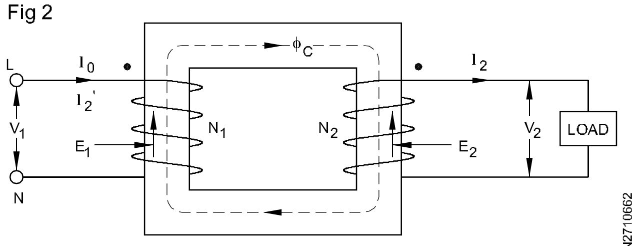
Fig 1 shows the equivalent circuit of a transformer with-out load. Fig 2 shows the equivalent circuit of a transformer supplying a load. The primary and secondary voltages shown have similar polarities, as indicated by the dot-marking convention.

Fig 1



EQUIVALENT CIRCUIT OF TRANSFORMER WITH-OUT LOAD

Fig 2



EQUIVALENT CIRCUIT OF TRANSFORMER WITH LOAD

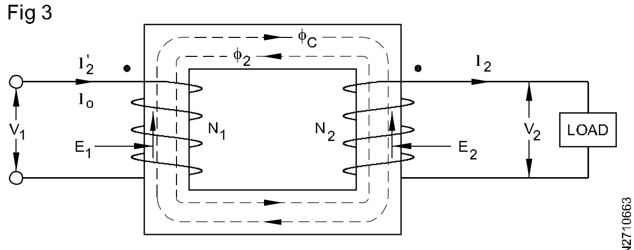
The marked terminals have the same polarity. Thus when the load is connected to the secondary, the instantaneous load current is in the direction shown.

Since the secondary voltage depends on the core flux f_c, it must be clear that the flux should not change appreciably if E_2 is to remain essentially constant. With the load connected, current I_2 will flow in the secondary circuit, because the induced EMF (E_2) will act as a voltage source. The magnitude of I_2 is determined by the characteristic of the load.

The secondary current sets up its own mmf ($N_2 I_2$), that is, a flux f_2. This flux has such a direction that at any instant it opposes the main flux f_c, that created it in the first place. This is Lenz's law in action. (Fig 3) If we assume that f_c increases, the current I_2 must have the direction indicated in Fig 3, if its resulting flux is to oppose the core flux.

Thus the mmf represented by $N_2 I_2$ tends to reduce the core flux f_c. This means that the flux linking the primary winding reduces and consequently the primary induced voltage E_1. This reduction in E_1 causes a greater difference between the impressed voltage and the counter-induced emf, thereby allowing more current to flow in the primary. The fact

Fig 3



CURRENT DIRECTION OF I_2 DEPENDS AN ϕ_c

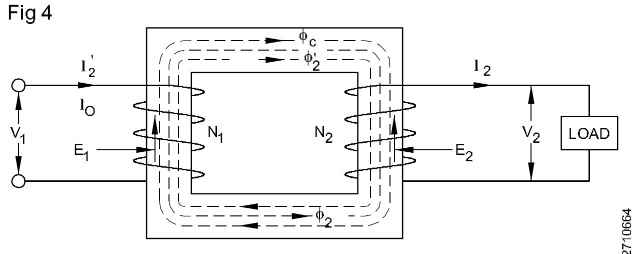
that the primary current (I_2') increases means the following two conditions are fulfilled.

- The power input increases to match the power output.
- The primary mmf increases to offset the tendency of the secondary mmf to reduce the flux.

In general, it will be found that the transformer reacts almost instantaneously to keep the resultant core flux essentially constant. The current I_2' is known as load component of primary current. This current is in phase opposition to current I_2.

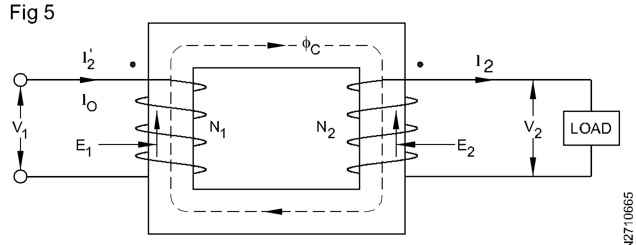
The additional primary mmf $N_1 I_2'$ sets up a flux f_2' which opposes f_2 and is equal in magnitude. Thus, the magnetic effect of I_2 gets neutralised immediately by the additional primary current I_2'. (Fig 4) Hence, whatever may be the load condition, the net flux passing through the core is approximately the same as at no-load (Fig 5).

Fig 4



CURRENT I_2 NEUTRALISED BY ADDITIONAL CURRENT I_2

Fig 5

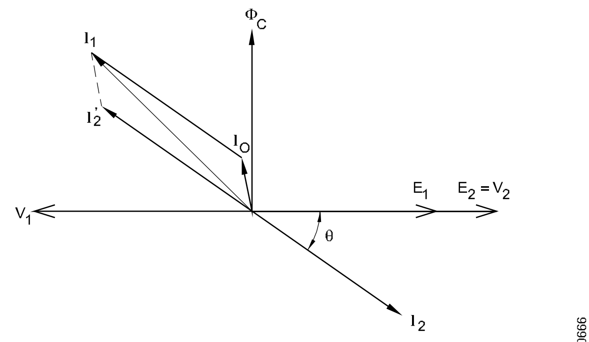


NET FLUX THROUGH CORE IS SAME AT NO-LOAD

When the transformer is in no-load, the primary winding has two currents I_o and I_2'. The total primary current I_1 is the vector of I_o and I_2'. The elementary vector diagram of the transformer with load (Fig 6)

Because the no-load current is relatively small, it is correct to assume that the primary ampere-turns equal the seconadry ampere-hours. Thus, $N_1 I_1 = N_2 I_2$. We will assume that I_o is negligible, as it is only a small component of the full load current.

Fig 6



ELEMENTRARY PHASOR DIAGRAM OF TRANSFORMER WITH LOAD. ONLY CORE LOSSES ARE CONSIDERED IN THIS DIAGRAM.

Leakage fluxes: When a current flows in the secondary winding, the resulting mmf ($N_2 I_2$) creates a separate flux, apart from the flux f_c produced by I_o, which links the secondary winding only. This flux does not link with the primary winding and is therefore not a mutual flux.

In addition, the load current that flows through the primary winding creates a flux that links with the primary winding only, it is called the primary leakage flux.

Fig 7 illustrates these fluxes. On account of the leakage flux, both the primary and secondary windings have leakage reactance, that is, each will become the seat of an emf of self-induction.

The magnitude of this EMF is equal to a small fraction of the emf due to the main flux. The terminal voltage V_1 applied to the primary must, therefore, have a component $I_1 X_1$ (where X_1 is leakage reactance of primary) to balance the primary leakage EMF.

The primary and secondary coils in Fig 7 are shown on separate limbs. This arrangement would result in exceptionally large leakage. Leakage between primary and secondary could be eliminated if the windings could be made to occupy the same space.

This, of course, is physically impossible. By placing the coils of the primary and secondary concentrically, an approximation is achieved with very low leakage.

Transformer with resistance and leakage reactance

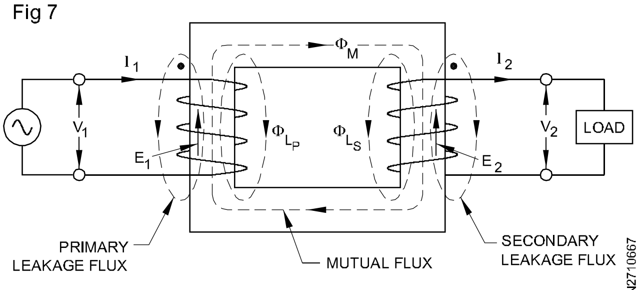
The primary impedance is given by

$$Z_1 = \sqrt{R_1^2 + X_1^2}$$

and the secondary impedance is given by

$$Z_2 = \sqrt{R_2^2 + X_2^2}.$$

Fig 7



PRIMARY AND SECONDARY ARE IN SEPERATE LIMBS

Autotransformer - principle - construction - advantages - applications

Objectives: At the end of this lesson you shall be able to
- **state the principle of auto-transformer**
- **describe the construction of auto-transformer**
- **state the advantages, disadvantages and appliations of auto-transformer.**

Auto transformer

- The auto transformer is a transformer having single winding which acts as primary as well as secondary winding.
- The auto transformer works on the principle of self inductance of Faraday's Law of electro - magnetic induction.

It may be recalled that in the discussion of transformer operation a counter emf was induced in the winding which acted as primary.

The induced voltage per turn was the same in each and every turn linking with the common flux in the core.

Therefore, fundamentally it makes no difference in the operation whether the secondary induced voltage is obtained from a separate winding linked with the core, or from a portion of the primary turns. The same voltage transformation results in both the situations.

Construction

An ordinary two winding transformer may also be used as an auto-transformer by connecting the two windings in series and applying the voltage across the two, or merely to one of the windings.

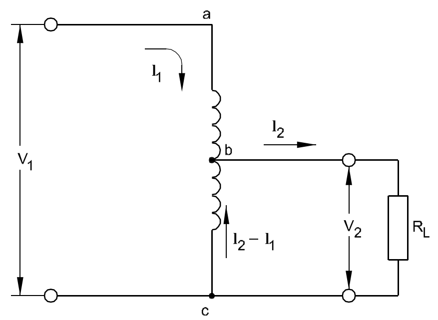
It depends on whether it is desired to keep the voltage down or up, respectively.

Figs 1 and 2 show these connections.

Considering Fig 1, the input voltage V_1 is connected to the complete winding a - c and the load R_L is across a portion of the winding, that is, b - c. The voltage V_2 is related to V_1 as in a conventional two winding transformer, namely,

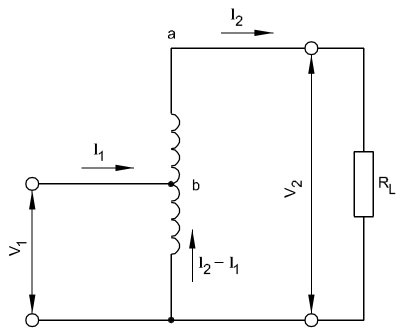
$$V_2 = V_1 \times \frac{N_{bc}}{N_{ac}} \qquad \text{..........(1)}$$

Fig 1



AUTOTRANSFORMER STEP-DOWN

Fig 2



AUTOTRANSFORMER STEP-UP

where N_{bc} and N_{ac} are the number of turns on the respective windings. The ratio of voltage transformation in an autotransformer is the same as that for an ordinary transformer, thus

$$a = \frac{N_{bc}}{N_{ac}} = \frac{V_2}{V_1} = \frac{I_1}{I_2} \qquad \text{..........(2)}$$

with a < 1 for step down.

Assume a resistive load for convenience and the secondary current, $I_2 = V_2 / R_L$ further, the assumption is made that the transformer is 100% efficient, the power output is

$$P_L = V_2 I_2 \qquad ....(3)$$

Note that I_1 flows in the portion of the winding **ab**, whereas the current $(I_2 - I_1)$ flows in the remaining portion bc. The resulting current flowing in the winding **bc** is always the arithmatical difference between I_1 and I_2, since they are always in the opposite direction. Remember that the induced voltage in the primary opposes the primary applied voltage. As a result, the current caused by the induced voltage flows opposite to the input current. In an auto-transformer, the secondary current is thus induced that is

$$I_1 + (I_2 - I_1) = I_2 \qquad ....(4)$$

Hence the ampere turns due to section bc, where the substitution $I_2 = \frac{I_1}{a}$ and $N_{bc} = N_{ac} \times a$ are made according to Fig 2 we have

Ampere turns of

$$bc = (I_2 - I_1) N_{bc} = \left(\frac{I_1}{a} - I_1 \right) N_{bc} = \frac{I_1 N_{bc}}{a} - I_1 N_{bc}$$

$$= I_1 N_{ac} - I_1 N_{bc} = I_1 N_{ab}$$

(ie) ampere turns due to ab.

Thus the ampere turns due to sections bc and ab balance each other, a characteristic of all transformers.

Power delivered: Equation (3) gives the power determined by the load. To see how this power is delivered, the equation is written in a slightly modified form. Substituting the equation (4) in equation (3), the following result is obtained.

$$P_L = V_2 (I_1 + (I_2 - I_1))$$

$$= V_2 I_1 + V_2 (I_2 - I_1) \text{ watts}$$

This indicates that the load power consists of two parts.

The first part is $P_c = V_2 I_1$ = conducted power to load through ab.

The second part is $P_{tr} = V_2 (I_2 - I_1)$ = transformed power to load through bc.

Advantages : Auto-transformers:

- less cost
- have better voltage regulation
- are smaller
- are lighter in weight
- are more efficient when compared with two winding transformers of the same capacity.

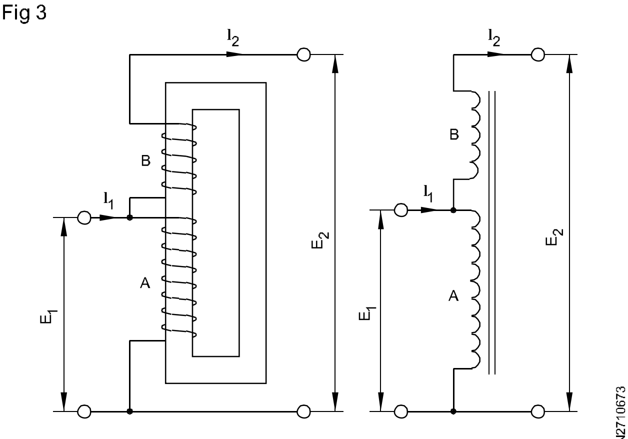
Disadvantages: Auto-transformers have two disadvantages.

- An auto-transformer does not isolate the secondary from the primary circuit.
- If the common winding bc becomes open circuit, referring to Fig 1 or 2, the primary voltage can still feed the load. With a step-down auto-transformer this could result in burnt out secondary load and/or a serious shock hazard, particularly if the step down ratio is high.

Application: The common applications are:

- fluorescent lamps (where supply voltage is less than the rated voltage)
- reduced voltage motor starter
- series line boosters for fixed adjustment of line voltage (Fig 3)
- servo-line voltage correctors.

Fig 3



BOOSTER CIRCUIT

Instrument transformers - current transformer

Objectives: At the end of this lesson you shall be able to
- **state the necessity, types and principle of the instrument transformer**
- **explain the construction and connection of the current transformer**
- **state the general terms like accuracy, phase displacement, burden and output with respect to the current transformer**
- **identify the I.S. symbols and markings used in the current transformer**
- **state the precautions to be followed while using the current transformer**
- **specify the current transformer.**

Necessity of instrument transformers: Transformers used in conjunction with measuring instruments for measurement purposes are called **'instrument transformers'**. the actual measurements are done by the measuring instruments only.

Where the current and voltage are very high, direct measurements are not possible as, these current and voltage are too large for reasonably sized instruments and the cost of the meter will be high.

The solution is to step-down the current and voltage with instrument transformers, so that, they could be metered with instruments of moderate size.

These instrument transformers electrically isolate the instruments and relays from high current/voltage lines thereby reducing danger to the men and equipment. To obtain perfect isolation, the secondary of the instrument transformers and the core should be grounded.

Type of instrument transformers: Three are two types of instrument transformers.

- Current transformer
- Potential transformer

The transformer used for measurement of high current is called 'current transformer' or simply 'CT'

the transformer used for high voltage measurement is called 'voltage transformer or potential transformer' or simply 'PT' in short.

Instrument transformers can be further divided according to their use as a) instrument transformer used as measuring instruments and b) instrument transformers used for control relays.

The instrument transformer used for measurement purposes should have high accuracy. But for control and protective relays instrument transformers of moderate accuracy are sufficient but high reliability and ruggedness are essential.

Principle: Instrument transformers work on the principle of mutual induction similar to the two winding transformers.

In the case of an instrument transformer, the following design features are to be considered.

Core: In order to minimise the error, the magnetizing current must be kept low. This means the cores should have low reactance and low core losses.

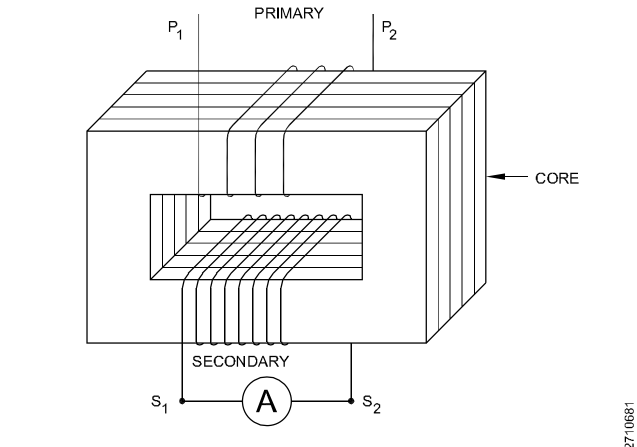
Winding: The winding should be close together to reduce the secondary leakage reactance; otherwise the ratio error will increase. In the case of a current transformer the winding must be so designed as to withstand the large short circuit current without damage.

Current transformers - types of construction and connection

The following are the different types of current transformers.

Wound type current transformer: This is one in which the primary winding is having more than one full turn wound on the core (Fig 1)

Fig 1



WOUND TYPE CURRENT TRANSFORMER

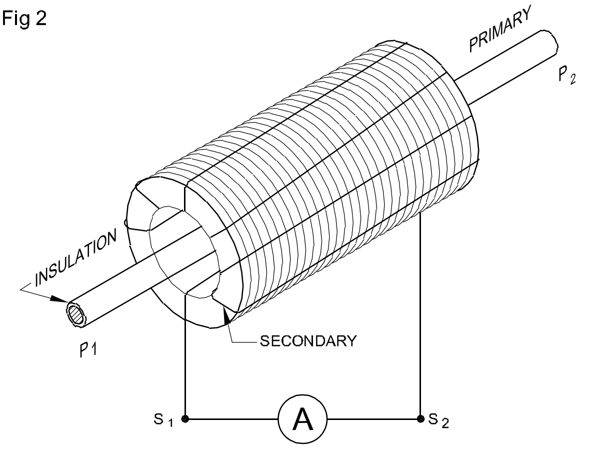
Fig 1 shows the connections of a wound type current transformer having a rectangular type of core. In general the ammeter is arranged to give full scale deflection with 5A or 1A when connected to the secondary of the current transformer.

The ratio between the primary and secondary turns of the current transformer decides the primary current which could be measured with fixed secondary current rating of 5 or 1 amp.

For example if the primary current is 100 amps and there are two turns in the primary, then the full load primary ampere turns is 200. Consequently, to circulate 5 amps in the secondary, the number of secondary turns must be 200/5, that is 40 turns.

Ring type current transformer: This has an opening in the centre to accommodate a primary winding through it Fig 2 shows a ring type current transformer with single turn primary. In this current transformer, the insulated conductor that carries the current to be measured passes directly through an opening in the transformer assembly.

Fig 2



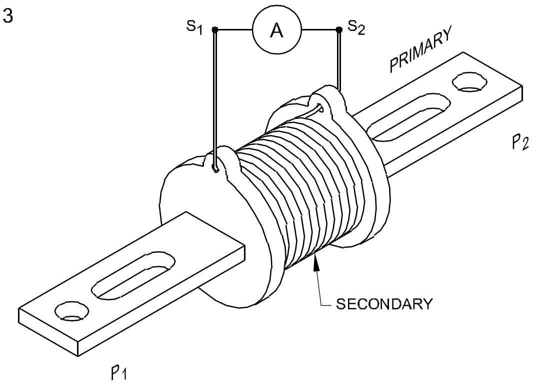
RING TYPE CURRENT TRANSFORMER

If there are 20 turns in the secondary having a current range of 5 amps, this current transformer according to the transformation ratio, could measure a primary current of 100 amps.

Clamp on or clip on ammeters work on this principle only but the core is made such that it can open to pass the insulated conductor and then get closed to complete the magnetic circuit.

Bar type current transformer: This is one in which the primary winding consists of a bar of suitable size and secondary winding and core assembly material forming an integral part of the current transformer (Fig 3).

Fig 3



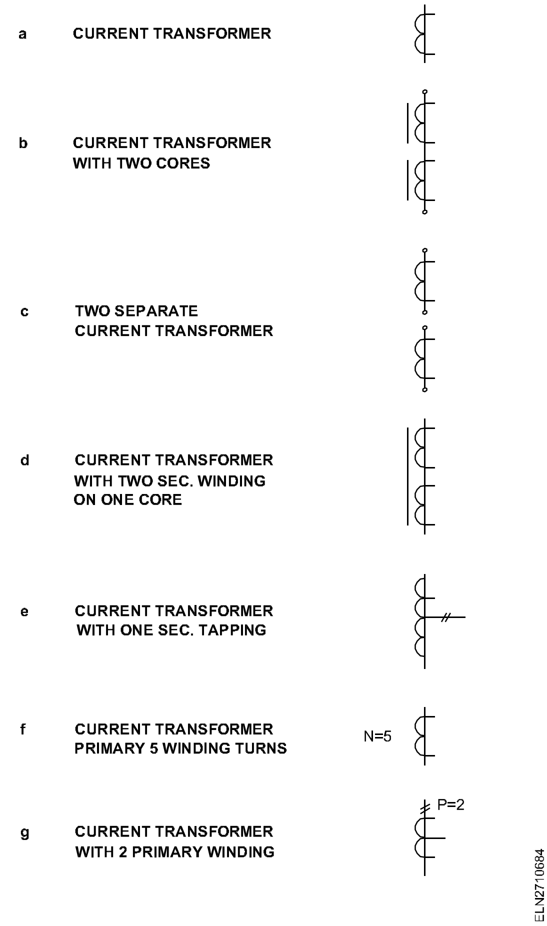
BAR TYPE CURRENT TRANSFORMER

Dry type current transformer :This is one which does not require the use of any liquid or semi-liquid material for the purpose of cooling.

Oil immersed current transformer: This is one which requires the use of an oil of suitable characteristic as insulating and cooling medium.

Recommended symbols and terminal marking as per I.S. 2012(Part XX11)-1978 (Fig 4)

Fig 4



Method of marking

Marking should be done following the guidelines given below. (I.S. 2705(Part I) - 1981)

The terminals shall be marked clearly and indelibly either on their surface or in their immediate vicinity.

The marking shall consist of letters, followed or preceded where necessary, by numbers. The letters shall be in block capitals.

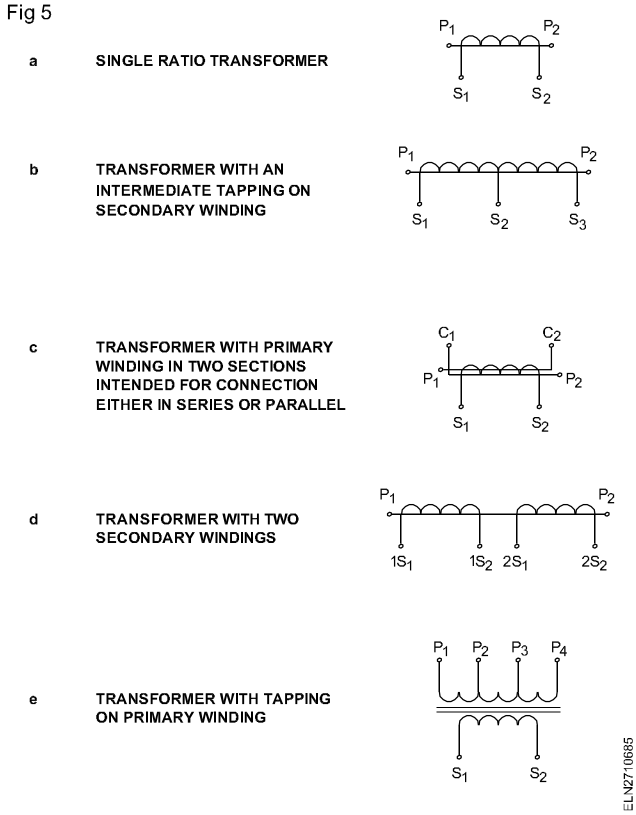
The marking of current transformers shall be as indicated in Figs 5a to 5e.

All the terminals marked P1, S1 and C1 shall have the same polarity at any instant.

General terms used

Accuracy class: Accuracy class is a designation assigned to a current transformer the errors of which remain within the specified limits under prescribed conditions of use. The standard accuracy classes for measuring current transformers shall be 0.1, 0.2, 0.5, 1.0, 3.0 and 5.0.

Fig 5



Phase displacement: This is the difference in phase between primary and secondary current vectors, the direction of the vector being so chosen that the angle is zero for a perfect transformer.

The phase displacement is said to be positive when the secondary current vector leads the primary current vector. It is usually expressed in minutes.

The above definition is strictly for sinusoidal currents only. The phase displacement is an important factor to be considered when connecting several current transformers together in a circuit for various measurements.

Burden: Burden is usually expressed as the apparent power in **volt amperes** absorbed at a specified power factor and at the rated secondary current. Rated burden is the value on which the accuracy requirement of this specification is based.

Rated output: This is the value of the apparent power (in volt amperes at a specified power factor) which the current transformer is intended to supply to the secondary circuit at the rated secondary current and with the rated burden connected to it. The standard values of rated outputs are 2.5, 5.0, 7.5, 10, 15 and 30 VA.

Precautions while using the current transformer: In the case of an ordinary transformer the supply voltage almost remains constant and the magnitude of primary current depends upon the load current.

However in a current transformer the secondary current depends upon the primary current. Futher the secondary of the current transformer could be assumed to be almost short circuited as the ammeter resistance is extremely low.

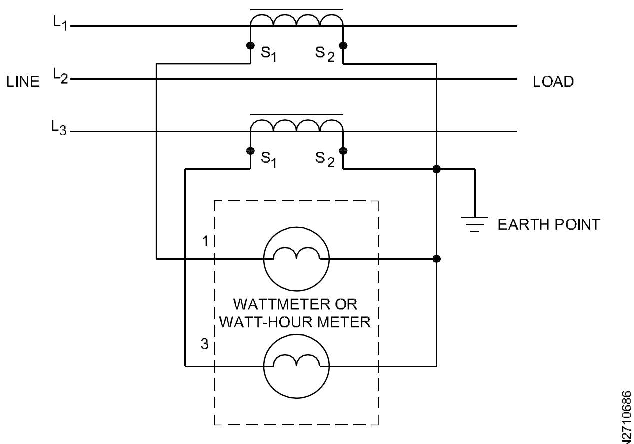
In any case, the secondary winding of the current transformer should not be open circuited. This may happen when the ammeter become open circuited or when the ammeter is removed from the secondary.

In such cases the secondary should be short circuited. If the secondary is not short circuited, in the absence of secondary ampere-turns, the primary current will produce abnormally high flux in the core thereby heating up the core and resulting in burning out the transformer.

Further secondary will produce a high voltage across its open terminals endangering safety. In addition to earthing non-current carrying metal parts of the current transformer, we have to earth one end of the secondary of the current transformer to prevent a high static potential difference in case of open circuit. It also serves as a safeguard in case of insulation failure.

While using more than one current transformer in a circuit, the grounding should be done by connecting the similar polarity ends of the current transformer and grounding the circuit at a point (Fig 6)

Fig 6



GROUP OF CURRENT TRANSFORMER WITH GROUNDING POINT

Specification of a current transformer: While purchasing a current transformer, the following specifications need to be checked.

- Rated voltage, type of supply and earthing conditions (for example, 7.2 kV, three phase, whether earthed through a resistor or solidly earthed).
- Insulation level
- Frequency
- Transformation ratio
- Rated output
- Class of accuracy

- Short time thermal current and its duration
- Service conditions including, for example, whether the current transformer is for use indoors or outdoors, whether for use at unusually low temperature altitudes (if over 1000 metres), humidity and any special conditions likely to exist or arise, such as exposure to steam or vapour, fumes, explosive gases, vibrations excessive dust etc.
- Accuray limit factor and any other additional requirement for current transformers for protective purposes.
- Special features, such as limiting dimensions.

Standard values of rated primary current: The standard values in amperes of rated frequency are 10, 15, 20, 30, 50, 75 amperes and their decimal multiples.

Standard values of rated secondary current: The standard values of rated secondary current shall be either 1 ampere or 5 amperes.

Potential transformer

Objectives: At the end of this lesson you shall be able to
- **explain the construction and connection of the potential transformer**
- **identify the I.S. symbols and markings used in the potential transformer**
- **state the general terms like accuracy, phase displacement, burden and output with respect to the potential transformer**
- **specify the potential transformer.**

Potential transformer

Construction and connection: The construction of a potential transformer is essentially the same as that of a power transformer. The main difference is that the volt-ampere rating of a potential transformer is very small.

To reduce the error in a potential transformer, it is required to provide a short magnetic path, good quality of core materials, low flux density and proper assembling and interlaying of cores.

To reduce resistance and leakage reactance, thick conductors are used and the two windings are kept as close as possible.

The core may be of shell or core type construction. Shell type construction is normally used for low voltage transformers.

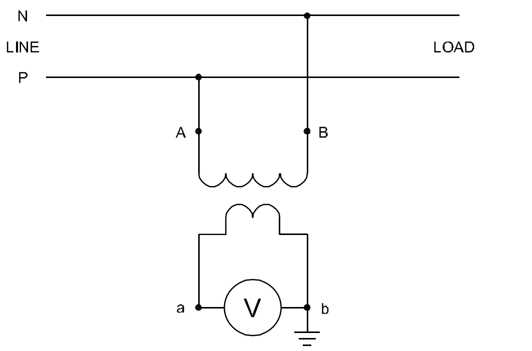
The primary and secondary windings are coaxial to reduce the leakage reactance to the minimum. In order to simplify the insulation problem, generally a low voltage winding (secondary) is put next to the core.

The primary winding may be of a single coil in the case of low voltage transformers but in the case of high voltage transformers the winding is divided into a number of short coils.

Fig 1 shows the connections of a potential transformer. In general, the voltmeter connected to the secondary of the potential transformer is arranged to give full scale deflection at 110 volts.

The ratio between the primary and secondary turns of the potential transformers decides the primary voltage which could be measured with the fixed secondary voltage rating of 110 volts (Fig 1).

Fig 1

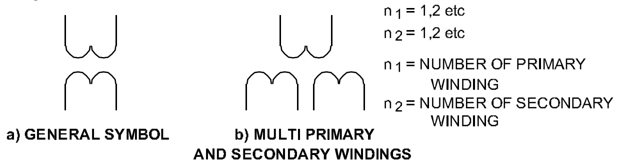


CONNETION OF POTENTIAL TRANSFORMER

If the primary turns are four, the secondary turns are two and the primary is connected to a voltage source of magnitude 220 volts, the secondary voltage will be 110 volts according to the transformation ratio.

Recommended symbols and terminal marking as per I.S. 3156 (Part I) 1978 Fig 2

Fig 2



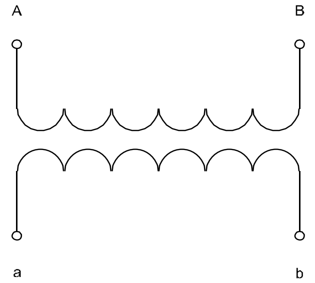
Method of marking

Marking the terminals should be done following the guidelines given below (I.S. 3156 (Part - I) -1978.)

Figs 3 to 10 give the recommended markings used in a potential transformer as per I.S.

Marking shall be in accordance with Figs 3 to 10 as appropriate. Capital A,B,C and N denote the primary winding terminals and the lower case letters a,b,c and n the corresponding secondary winding terminals.

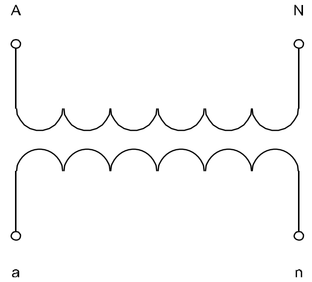
Fig 3



SINGLE PHASE TRANSFORMERS
WITH FULL INSULATED TERMINALS
AND A SINGLE SECONDARY

ELN2710693

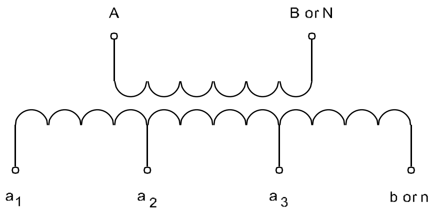
Fig 4



SINGLE PHASE TRANSFORMER WITH A NEUTRAL PRIMARY
TERMINAL WITH REDUCED INSULATION AND A SINGLE SECONDARY

ELN2710694

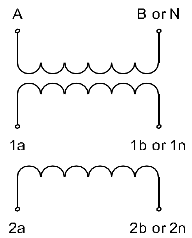
Fig 5



SINGLE PHASE TRANSFORMER WITH
ONE MULTI-TAP SECONDARY

ELN2710695

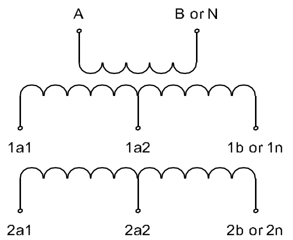
Fig 6



SINGLE PHASE TRANSFORMER
WITH TWO SECONDARIES

ELN2710696

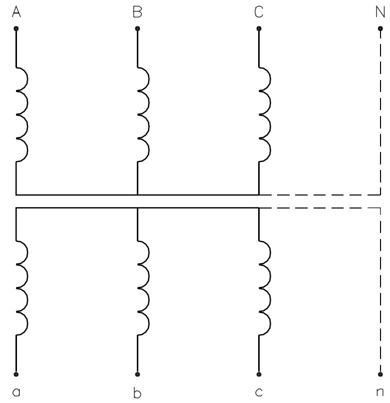
Fig 7



SINGLE PHASE TRANSFORMER
WITH TWO MULTI-TAP SECONDARIES

ELN2710697

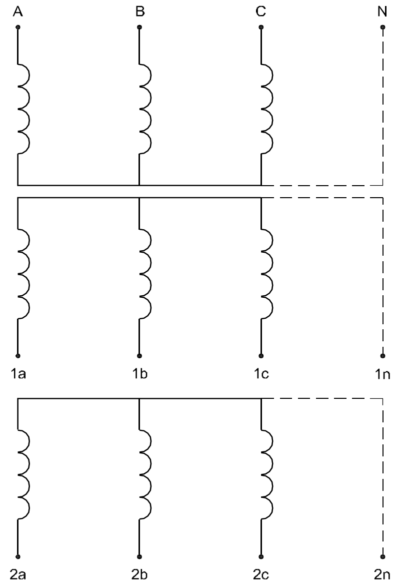
Fig 8



THREE PHASE ASSEMBLY
WITH A SINGLE SECONDARY

ELN2710698

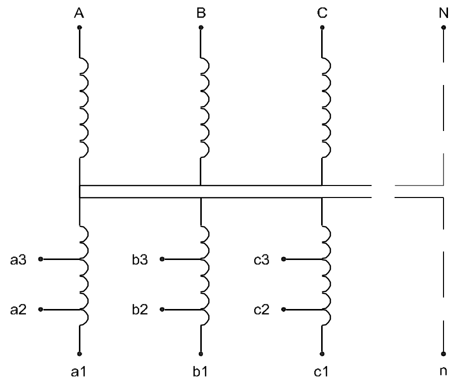
Fig 9



THREE PHASE ASSEMBLY
WITH TWO SECONDARIES

ELN2710699

Fig 10



THREE PHASE ASSEMBLY WITH ONE MULTI-TAP SECONDARY

ELN271069A

The letters A,B,C denote fully insulated terminals and the letter N denotes a terminal intended to be earthed and the insulation of which is less than that of the other terminals.

Accuracy class designation: For measuring voltage transformers, the accuracy class is designated by the highest permissible percentage voltage error at the rated voltage and with the rated burden, prescribed for the accuracy class concerned.

The standard accuracy classes for single phase measuring voltage transformers shall be 0.1, 0.2, 0.5, 1.0 and 3.0.

Phase displacement: This is the difference in phase between the primary voltage and the secondary voltage vectors. The direction of the vectors is so chosen that the angle is zero for a perfect transformer.

Phase displacement is an important factor to be considered when several potential transformers are to be connected in a system for various measurements.

Burden: The rated burden of a voltage transformer is usually expressed as the apparent power in volt amperes absorbed at the rated secondary voltage.

The burden is composed of the individual burdens of the associated voltage coils of the instruments, relays or trip coils to which the voltage transformer is connected.

When the individual burdens are expressed in ohmic values, the total burden may be computed by adding the admittance values. This admittance value should then be converted to VA burden by multiplying the admittance value by the square of the rated voltage.

Rated output: This is the value of the apparent power (in volt-amperes at a specified power factor) which the transformer is intended to supply to the secondary circuit at the rated secondary voltage and with the rated burden connected to it.

The rated output at a power factor of 0.8 lagging, expressed in volt-amperes should be one of the values given here: 10, 15, 25, 30, 50, 75, 100, 150, 200, 300, 400 and 500 VA.

Typical values of VA burden imposed by different meters are given below.

- Voltmeters, voltage coils of wattmeters power factor meter and recording voltmeter - 5 VA.
- Voltage coils of frequency meters (pointer and reed type), voltage coils of KWH, KVAR meters, voltage coils of recording power factor meters and wattmeters - 7.5 VA.
- Voltage coils of synchroscope - 15 VA.

Precautions to be followed while using a potential transformer: The assembly comprising of the chasis frame work and the fixed part of the metal casing of the voltage transformer shall be provided with two separate, readily accessible, corrosion-free terminals marked legibly as earth terminals.

Specification of a potential transformer: While purchasing a potential transformer, the following specifications need to be checked.

- Rated voltage, type of supply and earthing conditions (for example 6.6 KV, 3 phase solid earthed)
- Insulation level
- Frequency
- Transformation ratio
- Rated output
- Accuracy class
- Winding connection
- Rated voltage factor
- Service conditions including whether voltage transformers are for indoor or outdoor use, whether for use at unsually low temperatures, altitudes (if over 1000 metres), humidity and any special conditions likely to exist or arise, such as exposure to steam or vapour, fumes, explosive gases, excessive dust, vibrations etc.
- Special features, such as limiting dimensions.
- Whether the voltage transformer is required for connection between the star point of the generator and earth.
- Any additional requirement for voltage transformers for protective purposes.
- Whether the installation is electrically exposed or not.
- Any other information.
- Fig 10 shows three phase assembly with one multi-tap secondary

Standard rating of potential transformer

Rated frequency: The rated frequency shall be 50 Hz.

Rated primary voltage: The rated primary nominal system voltage of a 3-phase transformer. 0.6, 3.3, 6.6, 11, 15, 22, 33, 47, 66, 110, 220, 400, and 500 KV.

The standard value of primary voltage of a single phase transformer connected between one line of a 3-phase system and neutral point shall be $\frac{1}{\sqrt{3}}$ times of the above values of the nominal system voltages.

The rated secondary voltage: The rated value of secondary voltage for a single phase transformer or for a 3-phase transformer shall be either 100 and 110V.

Measurement of power in single phase circuit using CT and PT

Objective: At the end of this lesson you shall be able to
- **solve the problem pertaining to power measurement in multirange watt meter in single phase circuit using CT and PT.**

Reading multi-range wattmeters: Multi-range wattmeters will have a meter constant which has to be taken into account while measuring the power. Meter constant (multiplication factor MF) normally is written on the inner side of the top cover. In the absence of such information, we can calculate the meter constant as explained below.

Pressure coil range x Current coil range

Meter constant (Multiplication factor) =

$$\frac{\text{Pressure coil range x Current coil range}}{\text{Maximum dial reading in watts(Full scale reading in watts)}}$$

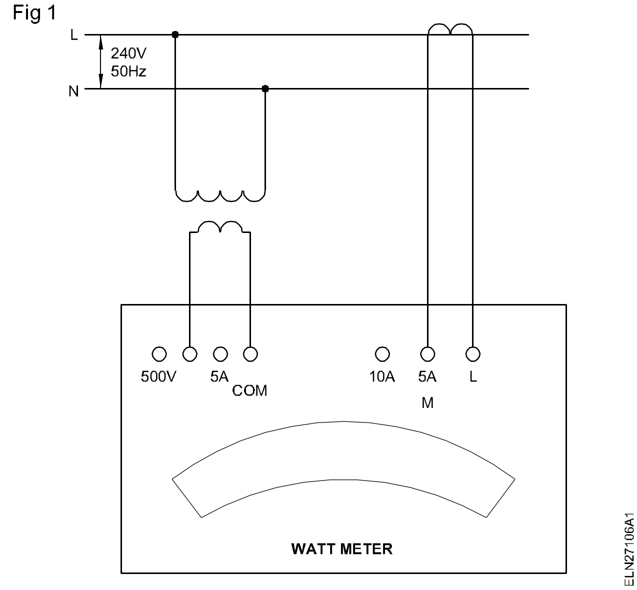
The following example will guide the trainees in finding the meter constant while using a multi-range wattmeter.

Example: A wattmeter has the following multi-ranges.

Pressure coil 500/250/125 volts

Current coil 20/10/5 amps (Fig 1)

Fig 1



The maximum dial reading (Full scale deflection FSD) indicates 625 watts. Find the meter constant and actual power if the meter reads 600watts against the following ranges.

A 500V, 10A

B 125V, 5A

RANGE A 500V, 10A

$$\frac{\text{Pressure coil range x Current coil range}}{\text{Maximum dial reading in watts(Full scale reading in watts)}}$$

$$= \frac{500 \times 10}{625} = 8$$

Actual power = Wattmeter reading x Meter constant (Multiplication factor MF)

= 600 x 8 = 4800 watts

RANGE B 125V, 5 A

Meter constant $= \frac{125 \times 5}{625} = 1$

(Multiplication factor MF)

Actual power = 600 x 1= 600 watts

Reading multiscale wattmeters when connected to CT and PT: In case the wattmeter is connected to a circuit through CT and PT to measure the power dissipated in the circuit, we have to take into consideration the CT ratio and PT ratio.

In such cases the actual power consumed in the circuit

P = Wattmeter reading x Multiplication factor MF (Meter constant MC) x CT ratio x PT ratio = ... watts.

Example: A single phase mutiscale watt meter is having the following ranges.

500/250/125V and 10A / 5A .

This watt meter is connected to a circuit of 240V rating through CT and PT and their ranges are 25/5 and 250/110 respectively.

The watt meter pressure coil is connected at 125V range and current coil is in 5 Amps range. Calculate the power consumed in the circuit if the wattmeter reads 500 watts at its maximum dial reading of 625 watts.

The Multiplication factor MF $= \frac{\text{Voltage range} \times \text{Current range}}{\text{Maximum dial reading}}$

Meter constant $= \frac{125 \times 5}{625} = 1$

Actual power consumed in the circuit P

= Watt meter reading x MF x CT ratio x PT ratio

$$= 500 \times 1 \times \frac{25}{5} \times \frac{250}{110}$$

$$= 500 \times 1 \times 5 \times 2.272$$

$$= 5680 \text{ W or } 5.68 \text{ KW}$$

Measurement of three phase energy using CT and PT

Objectives: At the end of this lesson you shall be able to
- **state the method of selecting the ranges of CT and PT according to load and meter requirement**
- **differentiate between CT and PT with a 3-phase energy meter.**

CTs and PTs with 3-phase energy meter: Standard ratings of energy meters are 10, 20, 30, 50 and 100 A and of voltages 120 or 240V or 415V. Current transformers and potential transformers are also used along with 3-phase energy meters when used to measure energy with higher current and voltages.

For selecting CT for an energy meter the primary current of the CT should be rated to that of the maximum line current or the next higher standard rating, while secondary should be that of the meter's maximum current rating. For selecting PT the primary voltage of PT should be that of line voltage and the secondary voltage should be that of the meter pressure coil voltage.

The instrument transformer-operated 3-phase and 1 phase energy meter should have separate terminals for pressure and current coils.

When an usual energy meter is used, its pressure coil links are to be disconnected, before connecting CTs and PTs.

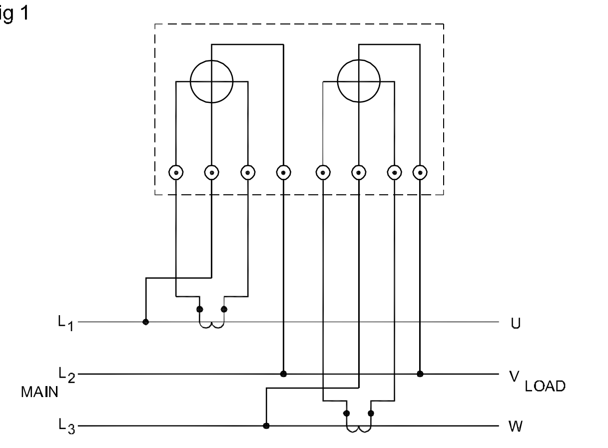
For standard instrument transformer-operated energy meters the current coils are rated for 5A or 1A, while potential coils are rated for 110V or 100V.

A current transformer is used when the load current rating is higher than the available meter rating.

CTs with 2-element energy meter: The method of connecting a two element energy meter with 2 CTs suitable for 3-phase 3-wire system.(Fig 1)

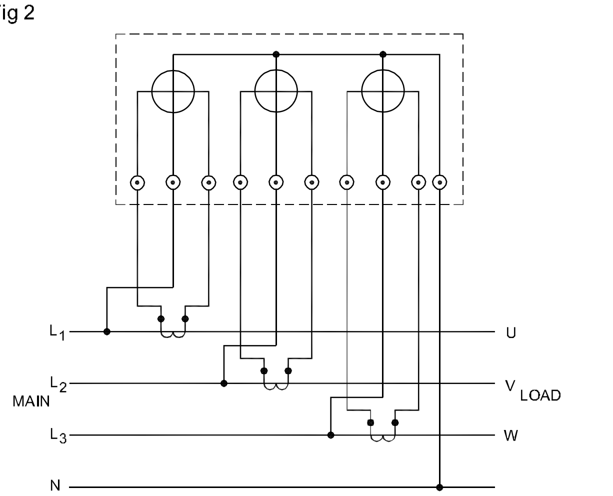
CTs with 3-element energy meter: Fig 2 shows the method of connecting a 3-element energy meter with 3 CTs. This arrangement is suitable for a 3-phase 4-wire system.

Fig 1



3-PHASE TWO ELEMENT ENERGY METER WITH CURRENT TRANSFORMERS USED ON A 3-PHASE 3-WIRE SYSTEM. SEQUENCE IS UVW.

Fig 2



3-PHASE TWO ELEMENT ENERGY METER WITH CURRENT TRANSFORMERS USED ON A 3-PHASE 4-WIRE SYSTEM. SEQUENCE IS UVW.

Example 1: An industry has a connected load of 200 HP for 400V 3-phase 50Hz. What should be the current rating of the current transformer and its ratio? Assume PF is unity.

Connected load = 200 HP

Supply voltage = 400V 3-phase

$$I_L = \frac{HP \times 746}{\sqrt{3}\ V \times PF} = \frac{200 \times 746}{\sqrt{3} \times 400 \times 1} = 215A$$

Rating of CT $\frac{215}{5}$ = 43

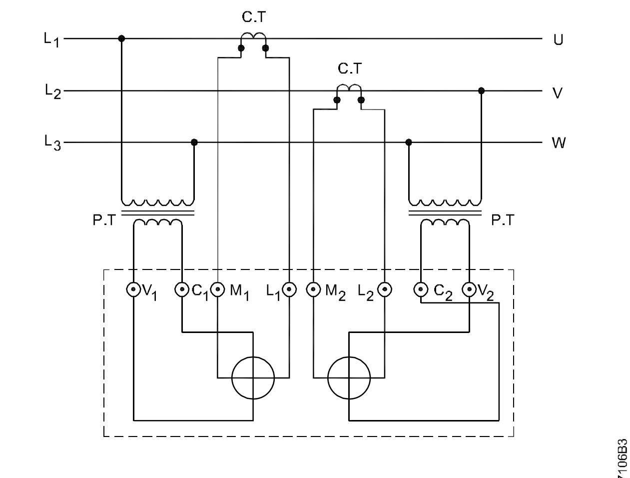
CT ratio = 43: 1 or 50:1 or 250A/5A.

CT and PT with 2-element energy meter: A connection diagram for a 2-element energy meter with 2 CTs and 2 PTs. (Fig 3)

A three phase P.T and two C.Ts connected with a two element energy meter used in a 3-phase, 3-wire system (Fig 4)

CT and PT with 3-element energy meter: A 3-element energy meter with C.T and P.T connected to a 3-phase 4-wire system is shown in Fig 5.

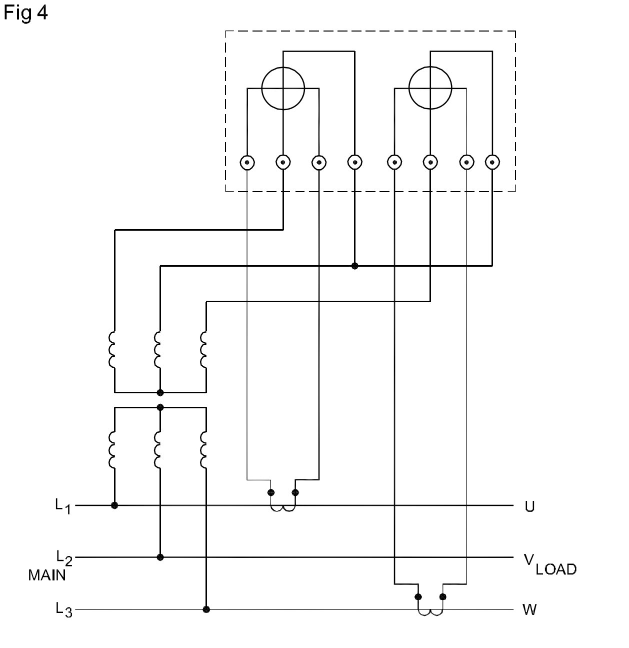
Fig 3



3-PHASE, 2 ELEMENT ENERGY METER WITH CT & PT

The metering cubicle used along with HT line of 11KV or higher voltages consists of 2 or 3 CTs and a three phase PTs known as a kiosk.

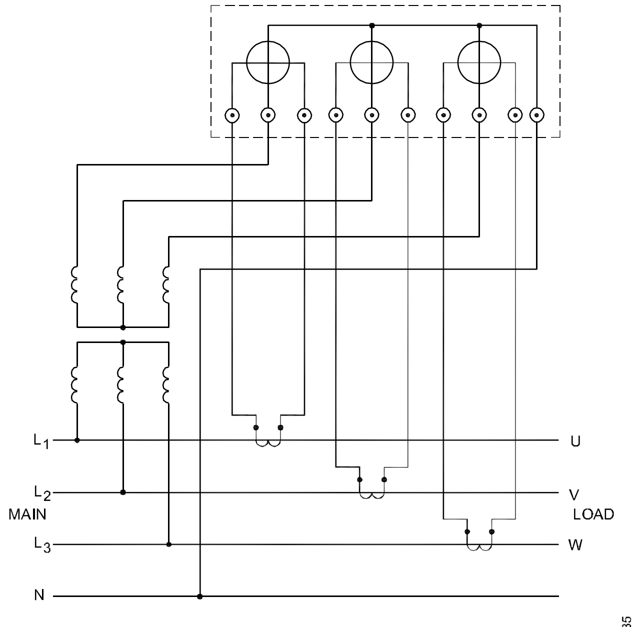
Fig 4



3-PHASE THREE ELEMENT ENERGY METER WITH CURRENT AND VOLTAGE TRANSFORMERS USED ON A 3-PHASE 3-WIRE SYSTEM. SEQUENCE IS UVW.

From the kiosks, cables are run to the meter panel. Normally to measure KWH, KVARH, MD and KVAH, a trivector meter is used.

Fig 5



3-PHASE THREE ELEMENT ENERGY METER WITH CURRENT AND VOLTAGE TRANSFORMERS USED ON A 3-PHASE 4-WIRE SYSTEM. SEQUENCE IS UVW.

Tri vector meter is an instrument used to measure the energy used by the load in terms of KWH, KVARH , MD and KVAH.

Maximum demand (MD): This trivector meter also has a maximum demand indicator to show the maximum reactive power persists in the load in term of KVA.

The tariff will be charged for this maximum demand in KVA. A penalty will be levied if this rating exceeds the sanctioned KVA rating of the factory.

Example 2: An industry is supplied with 800KVA 11KV 3-phase energy to be recorded through a 5A 110V 3-phase energy meter. Calculate the ratio of PT and CT.

Industry supply voltage = 11kV

Rating of transformer = 800kVA

Therefore, the current

$$= \frac{800}{11 \times \sqrt{3}} = \frac{800 \times \sqrt{3}}{11 \times \sqrt{3} \times \sqrt{3}}$$

$$= \frac{800 \times 1.732}{33} = \frac{1385.600}{33} = 42A$$

3-phase energy meter available = 5A, 110V.

CT ratio = 42/5 = 8.4 or say 10 = 10:1

PT ratio = 11000/110 = 100 = 100:1

Example 3: An energy meter connected through C.T and P.T to an industry recorded a reading of 369 units on 1st May. On 31st May the reading is found to be 426. If the C.T ratio is 50A/5A and the P.T ratio is of 11000V/110V calculate the metering constant and the energy consumed during the month.

Metering constant = CT ratio x PT ratio

$$= \frac{50}{5} \times \frac{11000}{110} = 10 \times 100 = 1000$$

Energy consumed = Difference in reading x MC

= (426 - 369) x 1000

= 57 x 1000 = 57000 Units.

Transformer losses - OC and SC test - efficiency - Voltage Regulation

Objectives: At the end of this lesson you shall be able to
- **state the type of losses occured in transformer**
- **explain Iron (No - load) losses and copper (load) losses in transformer.**

Losses

There are two type of losses occured in the transformer such as iron (core) loss (Hysterisis + eddy current) and copper (Ohmic) or load loss

Iron (or) No-load losses: The no load losses consist of two components i.e hysteresis and eddy current loss.The hysteresis loss due to the cyclic variation of the magnetic flux in the ferrous metal.

The eddy current occurs because of the changing flux in the core,(according to Lenz's law) inducing a voltage in the core. As a result, circulating eddy currents set up in the core with subsequent I^2R loss. This is also called as **iron loss (or) core loss (or) constant losses**.

As the core flux in a transformer remains practically constant at all loads, the core-loss is also constant at all loads. This is also known as no-load losses.

Hysteresis loss $W_h = K_h B^{1.6}{}_m$ watts

Eddy current loss $W_e = K_e f^2 K_f B_m{}^2$

where K_h = the hysteresis constant

K_f = the form factor

K_e = the eddy current constant

These losses are minimised by using steel of high silicon content (from 1.0 to 4.0 percent) for the core and by using very thin laminations.

Silicon steel has a high saturation point, good permeability at high flux density, and moderate losses. Silicon steel is widely used in power transformers, audio output transformers and many other applications.

The input power of a transformer, when on no-load, measures the core-loss.

Copper (or) Load losses: This loss is mainly due to the ohmic resistance of the transformer windings. The load current through the resistances of the primary and secondary windings creates I^2R losses that heat up the copper wires and causes voltage drops. This loss is also called **copper losses (or) variable losses**. Copper losses are measured by the short circuit test.

The core loss in a transformer is a constant loss for all load conditions. The copper loss varies proportionally to the square of the current.

Open Circuit (O.C) test of a transformer

Objective: At the end of this lesson you shall be able to
- **explain the method of conducting an open circuit test**
- **calculate the exact iron loss.**

The open circuit

The open circuit test is performed to determine the no-load losses or the core losses.

In this test, a rated voltage is applied to one winding, usually the low-voltage winding for safety reasons, while the other is left open-circuited. The input power supplied to the transformer represents mainly core losses. Since the no-load current is relatively small the copper loss may be neglected during this test.

The circuit instruments are shown in Fig 1. The wattmeter indicates the core loss. The voltmeter will register the rated voltage. The ammeter reading in conjunction with voltage will provide the necessary data to obtain information about the magnetizing branch.

The core loss can be measured on either side of the transformer. For instance, if a 3300/240V transformer were to be tested the voltage would be applied to the secondary side, since 240V is more readily available.

The core loss measured on either side of the transformer would be the same, because 240V is applied to a winding that has fewer turns than the high voltage side. Thus the volt/turn ratio is the same. This implies that the value of the maximum flux in the core is the same in either case. The core loss depends on the maximum flux.

The frequency of the o.c. test supply should be equal to the rated frequency of the transformer.

The actual (exact) iron loss (W_i) can be calculated by the formula

Iron loss $= W_i = W_0$ - no load copper loss

$W_i = W_o - (I_0)^2 R$

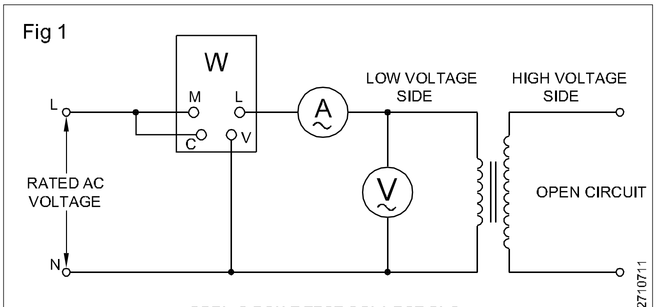
W0 = Wattmeter reading on no load

No Load copper loss = $(I_0)^2 R$

R = Resistance of winding in which the OC test calculated

I_0 = No - load current

Fig 1



OPEN CIRCUIT TEST CONNECTIONS

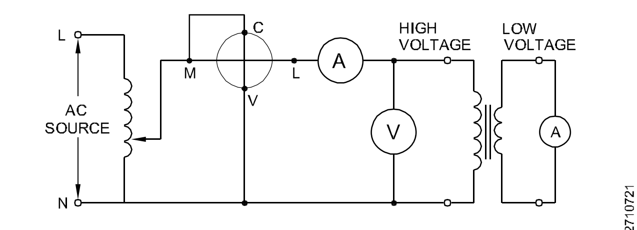
Short circuit (S.C) test of a transformer

Objectives: At the end of this lesson you shall be able to
- **explain the method of conducting the short circuit test on a single phase transformer**
- **calculate the equivalent resistance and equivalent reactance of the transformer, with respect to high voltage circuit**
- **calculate the copper loss.**

Short circuit test:

A short circuit test is required to determine the transformer equivalent circuit parameters and copper losses. The connected diagram for the short circuit test is shown in Fig 1.

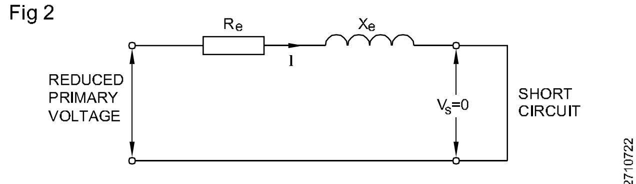
Fig 1



CONNECTION DIAGRAM

The low voltage side of the transformer is short circuited. A reduced voltage applied on the high voltage winding of the transformer such that the rated current flows through the ammeter. In this condition the impedance of the transformer is merely as equivalent impedence (Fig 2).

Fig 2



EQUIVALENT CIRCUIT

The test is performed on the high voltage side because it is convenient to apply a small percentage of the rated voltage. In the case of a 3300V/240V transformer, it is easier and more accurate to deal with 5% of 3300V than with 5% of 240V.

With the primary voltage greatly reduced, the flux will be reduced to the same extent. Since the core loss is somewhat proportional to the square of the flux, it is practically zero.

Thus a wattmeter used to measure the input power will indicate the copper losses only; the output power is zero. From the input data obtained from the instruments, the equivalent reactance, can be calculated. All the values calculated are in terms of high voltage side.

R_e is equivalent resistance

X_e is equivalent reactance

R_{eH} is equivalent resistance on high voltage side

X_{eH} is equivalent reactance on high voltage side

Z_{eH} is equivalent impedance on high voltage side

$$R_{eH} = \frac{P_{SC}}{I^2_{SC}} \text{ ohms}$$

$$Z_{eH} = \frac{V_{SC}}{I_{SC}} \text{ ohms}$$

$$\text{and } X_{eH} = \sqrt{Z^2_{eH} - R^2_{eH}} \text{ ohms}$$

where I_{sc}, V_{SC} and P_{SC} are the short circuit amperes, volts and watts respectively, and R_{eH}, Z_{eH} and X_{eH} are equivalent Resistance, Impedance and Reactance respectively in terms of high voltage side.

Example

The following data were obtained in a short circuit test on a 20 KVA 2400V/240V 50 Hz. transformer.

V_{SC}, = 72V, I_{SC} = 8.33A, P_{SC} = 268W.

Instruments were placed in the high voltage side and the secondary is short-circuited. Obtain the equivalent transformer parameters of the high voltage side.

Solution

$$R_{eH} = \frac{P_{SC}}{I^2_{SC}} = \frac{268}{(8.332)^2} = 3.86\,\Omega$$

$$Z_{eH} = \frac{V_{SC}}{I_{SC}} = \frac{72}{8.33} = 8.64\,\Omega$$

$$\text{and } X_{eH} = \sqrt{Z^2_{eH} - R^2_{eH}}$$

$$= \sqrt{8.64^2 - 3.86^2} = 7.73\,\Omega$$

Efficiency of transformer

Objectives: At the end of this lesson you shall be able to
- **calculate efficiency from the losses**
- **state the condition for maximum efficiency**
- **define all-day efficiency of a distribution transformer.**

Efficiency of transformer:

In general, the efficiency of any electrical apparatus is

$$\eta = \frac{\text{output power}}{\text{input power}} = \left|\frac{\text{output power}}{\text{output power} + \text{losses}}\right| \;.....(1)$$

where η is the symbol used to denote efficiency. When equation (1) is multiplied by the factor 100, the efficiency will be in percent.

The efficiency of a transformer is high and in the range 95 to 98%. This implies that the transformer losses are as low as 2 to 5% of the input power.

While calculating the efficiency, it is generally much better to determine the transformer losses rather than measured the input and output powers directly.

In transformer, the open circuit test yields the core losses and the short circuit test provides the copper losses. Thus the efficiency can be determined from these data with reasonable accuracy.

The transformer ratings are based on output KVA (MVA). Therefore, the equation for efficiency may be written as

$$\eta = \left|\frac{KVA_{out} \times PF}{(KVA_{out} \times PF) + \text{Copper loss} + \text{core loss}}\right|$$

Condition for maximum efficiency:

The efficiency of a transformer is at a maximum when the fixed losses are equal to the variable losses. In other words, when the copper losses is equal to the iron losses, the efficiency is maximum.

Example: A transformer with a rating of 10 KVA 2200/220V 50 Hz was tested with the following results.

Short circuit test power input = 340 W

Open circuit test power input = 168 W

Determine

(i) the efficiency of this transformer at full load

(ii) the load at which maximum efficiency occurs.

The load power factor is 0.80 lagging.

Solution

(i) Efficiency at full load, η_{FL}

$$\eta = \frac{P_{out}}{P_{in}} = \frac{(10 \times 10^3 \times 0.8)\ 100}{(10 \times 10^3 \times 0.8) + \text{Cu loss} + \text{Iron loss}}$$

$$= \frac{(10000 \times 0.8)\ 100}{(10000 \times 0.8) + 340 + 168}$$

= 94.0%.

(ii) The maximum efficiency occurs at a load when the copper loss = core loss.

Thus the copper loss = core loss = 168 W.

Let the current at full load = I.

The current at maximum efficiency = I'.

Then, the copper loss at full load = $I^2 R_{eq}$ = 340 W

the copper loss at h_{max} = $(I')^2 R_{eq}$ = 168 W.

Therefore, $\frac{I^2 R_{eq}}{I'^2 R_{eq}} = \frac{340}{168}$

or $I' = I\sqrt{\frac{168}{340}}$

This is the factor by which the power decreases,

Therefore, $P_{atmax\eta} = \sqrt{\frac{168}{340}} \times (10000 x 0.8)$

$= 5623$ W

$P_{atmax\eta} = 5623$ W

$= 70.26\%$ of 8000 W

$= 0.7026$ of full load.

or

Therefore, $\eta_{max} = \frac{5623}{5623 + 168 + 168} \times 100$

$= 94.36\%$.

All day efficiency

Lighting transformers and most distribution transformers will not have full load for all the 24 hours in a day. To keep the operational efficiency of such distribution transformers are designed to have their maximum efficiency at a lower value than full load.

Allday efficiency

$$\frac{\text{Output in24hours}}{\text{Output in24hours} \quad \text{losses in24hours}}$$

η_{allday}

$$= \frac{\text{Output KWh 24 hours}}{\text{Output KWh(24 hours)} + \text{losses KWh (24 hours)}}$$

Here, the iron loss is considered through out the period where as copper loss depends up on the period for which transformer is loaded and percentage load.

Example: A 100 KVA distribution transformer has a full load loss of 3 KW. At full load the losses are equally divided between iron and copper loss. During a certain day the transformer connected to the lighting load operated with loads as given below.

a) On full load, unity PF 3 hours.

b) On half full load, unity PF 4 hours.

c) Negligible and during the remaining part of the day.

Calculate the all day efficiency.

Solution

As the load is primarily lighting, the PF = 1.0.

(a) Output energy at FL in 3 hours

= 100 KVA x 1 x 3 = 300 KWh

(b) Output energy at 1/2 FL in 4 hours

= 100 x 1/2 x 1 x 4 = 200 KWh.

Energy wasted in kWh during full load

= 3 KW x 3h = 9 KWh.

At full load

Iron loss = copper loss = 3.0¸2 = 1.5 KW.

Copper loss at 1/2 full load

= 1.5 x $(1/2)^2$ = 1.5/4 KW.

Total energy loss during half full load

= iron loss for 4 hours + copper loss for 4 hours

= (1.5 x 4) + (1.5/4 x 4)

= 6 + 1.5 = 7.5 KWh.

The transformer has no load for

= (24 - 7) hours = 17 hours.

Constant loss for 17 hours

= 1.5 x 17 = 25.5 KWh.

The total loss for 24 hours= (9 + 7.5 + 25.5) KWh = 42

η_{allday}

$$= \frac{\text{Output KWh 24 hours}}{\text{Output KWh(24 hours)} + \text{losses (24 hours)}}$$

KWh $\frac{(300 + 200)}{(300 + 200) + 42} = 0.922$

$\eta_{allday} = 92.2\%$

Voltage regulation of transformers

Objectives: At the end of this lesson you shall be able to
- **define the voltage regulation of a transformer**
- **calculate the voltage regulation of a transformer.**

Voltage regulation:

The voltage regulation of a transformer is the difference between the no-load and full load secondary voltage expressed as a percentage of the full load voltage. The primary or applied voltage must remain constant.

This is an additional condition that must be fulfilled in the case of transformers.

Also, the power factor of the load must be stated since the voltage regulation does depend on the load power factor.

In general,

$$\text{Voltage regulation} = \frac{V_{noload} - V_{load}}{V_{load}} \times 100\%$$

Let V_0 = Secondary terminal voltage at no-load

V_S = Secondary terminal voltage at load.

$$\text{Then \% regulation} = \frac{V_o - V_S}{V_S} \times 100$$

The numerical values employed in the calculations depend on which winding is used as a reference for the equivalent circuit. Similar results are obtained whether all impedance values are transferred to the primary or to the secondary side of the transformer.

Example:

The secondary voltage of 11KV/440V, 100KVA transformer is 426 V at no-load. Under the full load condition, the same is 410V at 0.92 Power factor. Calculate the percentage voltage regulation of the transformer.

solution:

$$\text{\% of Voltage regulation} = \frac{V_o - V_S}{V_S} \times 100$$

$$\text{\% of Voltage regulation} = \frac{426 - 410}{410} \times 100$$

$$= \frac{16}{10} \times 100$$

$$= 3.9\%$$