LESSON
6

Transformer

P98FV

LEARNING OBJECTIVES

The main objective of learning this lesson is to know in detail about Transformer, its construction, types, operation, emf equation, losses, testing method, protective devices of transformer, which are existing under new technique.

Table of Content

6.1 TRANSFORMER- INTRODUCTION

A Transformer is a static device which transfers electrical energy from one circuit to another circuit without changing voltage and frequency. It works on the principle of mutual induction. The transformer works only on AC supply.

Generating stations generate electricity at a voltage of 11KV. The electric power from the generating station is to be brought to the consumers end from 33KV, 66KV etc through various transmission stages.The transformer is used to step down (or) step up the voltage required according to the requirement.

6.2 CONSTRUCTION AND TYPES OF TRANSFORMER CORE

Based on the construction, it is classified into 3 types. They are:

i) Core type

ii) Shell type and

iii) Berry type

6.2.1 Core type

The winding surrounds the core is called core type transformer. The fig. 6.1 represents the core type.

The magnetic circuit is made up of laminated iron core. Silicon steels are used to reduce the hysteresis loss in the iron core. Laminated sheets are insulated from by a layer of varnish for insulation.

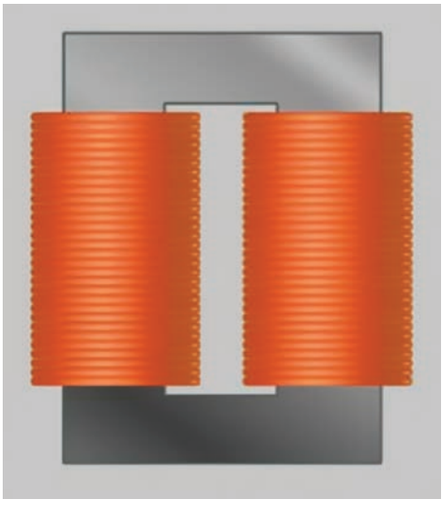


Fig 6.1 *Core type construction*

Advantages

i) Easily handled and maintained.

ii) The coils are in the outside, so it gets cooled easily.

Disadvantages

i) High magnetic loss.

ii) High leakage flux.

6.2.2 Shell type

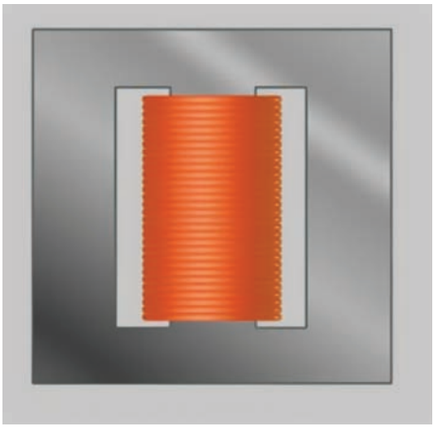


Fig 6.2 *Shell type transformer*

The core surrounds the winding is known as shell type transformer. The fig. 6.2 represents the shell type.

The primary and secondary windings are placed on the central limb one above the other. This gives a better magnetic coupling.

Advantages

i) More economical for low voltage.

ii) Low current at the time of no load.

Disadvantages

i) Little complicated to make winding.

ii) Less cooling.

6.2.3 Berry type

Berry type is similar to shell type. In berry type magnetic path is placed around the coil. Normally this type is not used.

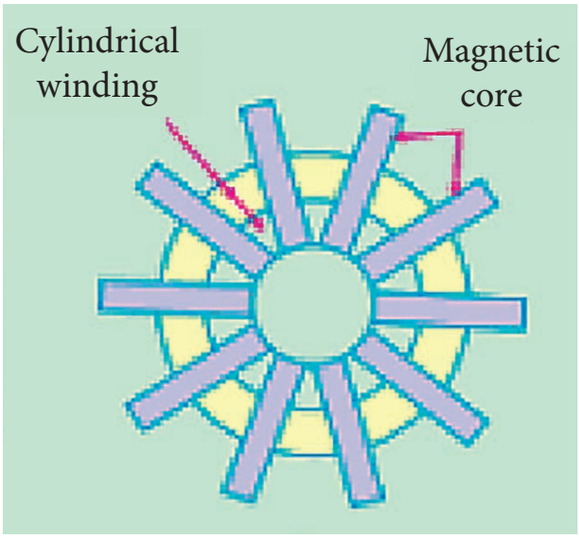


Fig 6.3 *Berry type transformer*

6.2.4 Comparison of core and shell type transformer

Core type transformer	Shell type transformer
1. The winding encircles the core.	The core encircles most part of the winding.
2. It has single magnetic circuit.	It has double magnetic circuit.
3. The cylindrical coils are used.	The multilayer disc (or) sandwichs type of coils are used.
4. The coils can be easily removed for maintenance.	The coils cannot be removed easily.

6.3 WORKING PRINCIPLE OF A TRANSFORMER

Transformer consists of two inductive coils which are electrically separated but magnetically coupled to a core as shown in fig. 6.4. It operates on the principle of mutual induction between two (or) more inductively coupled coils. If the coil is connected to a AC source, an alternating flux is setup. Most of the flux is linked with the other coil. This flux is called mutual flux.

As per Faraday's laws of electromagnetic induction, an emf is induced in the second coil. The first coil which is connected to AC supply is called as primary winding. The second coil is connected to the load is called as secondary winding.

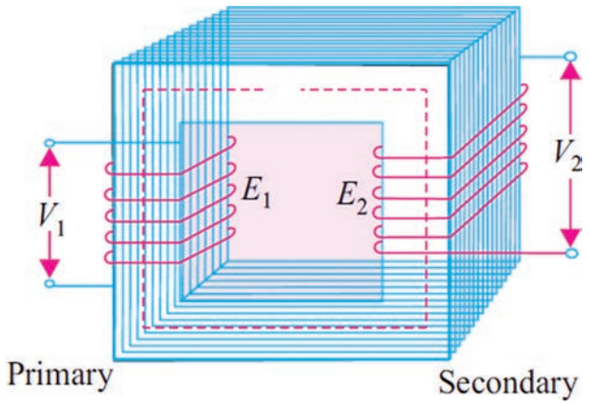


Fig 6.4 *Construction of an ideal transformer*

6.3.1 Step up/ step down transformer

step up transformer – If the output voltage in secondary winding is higher than the input voltage, it is called step up transformer as in fig. 6.5.

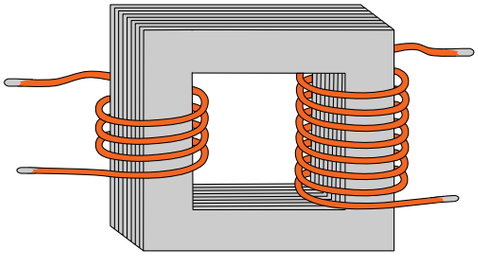


Fig 6.5 *Step-up transformer*

Step down transformer – If the output voltage in the secondary winding is lesser than the input voltage, it is called step down transformer as in fig. 6.6.

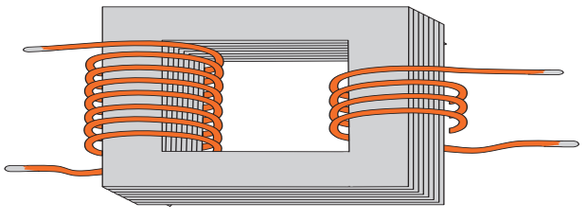


Fig 6.6 *Step-down transformer*

6.3.2 Advantages of transformers

i. The transformer is a static machinery. Hence there is no wear and tear and no friction losses in it.
ii. Maintenance cost is low.
iii. As there is no rotating part in it, extra high voltage can be transferred easily by providing a good insulation to its winding.

6.4 E.M.F EQUATION OF A TRANSFORMER

a) Construction

b) Wave form

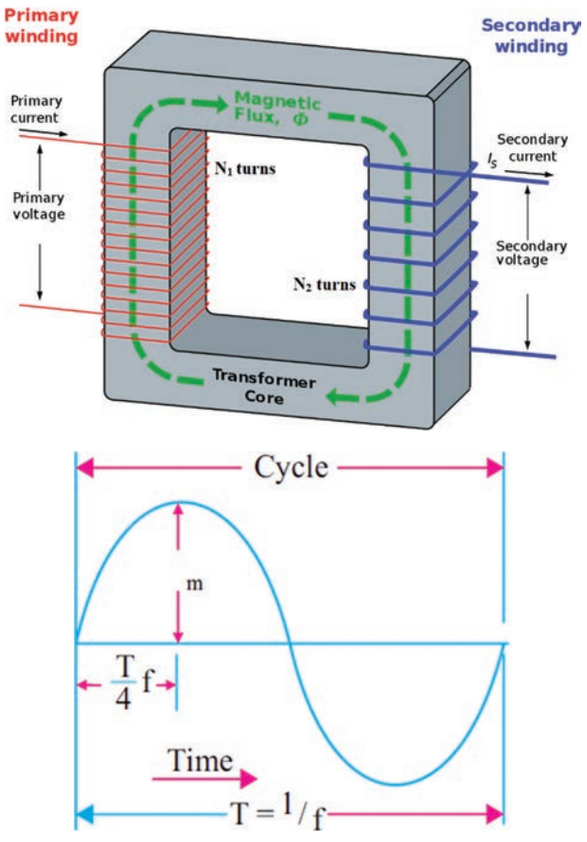


Fig 6.7 *Single phase transformer and wave form*

No. of turns in primary winding = N_1

No. of turns in secondary winding = N_2

Maximum value of flux = ϕ_m webers

Frequency of AC input = f in Hz

The flux in the core will vary sinusoidally as shown in the above fig 6.8.

The flux in the core increases from zero to a maximum value in one quarter cycle (1/4f second)

i.e, Average rate of change of flux $= \frac{Øm}{\frac{1}{4f}} = 4fØm$

i.e average EMF induced per turn = $4f\,\phi_m$ volts.

The flux varies sinusoidally. Hence the, RMS value of induced voltage is obtained by multiplying the average value by form factor which is equal to 1.11 for a sine wave.

i.e, RMS value of induced EMF per turn= $1.11 \times 4f\,\phi m$ volts.

$= 4.44\ f\ \Phi m$ volts.

The primary/secondary windings have N_1/N_2 turns respectively,

RMS value of induced emf in primary $E_1 = 4.44\ f\ \phi m\ N_1$ volts
RMS value of induced emf in secondary $E_2 = 4.44\ f\ \phi m\ N_2$ volts

6.4.1 Voltage transformation ratio (k)

The ratio of secondary voltage to primary voltage is called voltage transformation ratio. It is represented by 'k'.

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

6.4.2 Current ratio

By neglecting the losses

Input volt × ampere = output volt × ampere

$$V_1 I_1 = V_2 I_2 \quad \text{or} \quad \frac{V_1}{V_2} = \frac{I_2}{I_1}$$

$$\frac{I_2}{I_1} = \frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{1}{K}$$

6.4.3 Application of a transformer

- It is used to step up or step down the voltages and currents in an electrical circuit.
- Used in modern electrical transmission and distribution systems.
- It boost voltage levels so as to decrease line losses during transmission.

6.5 TYPES OF INSTRUMENT TRANSFORMER

6.5.1 Potential transformer

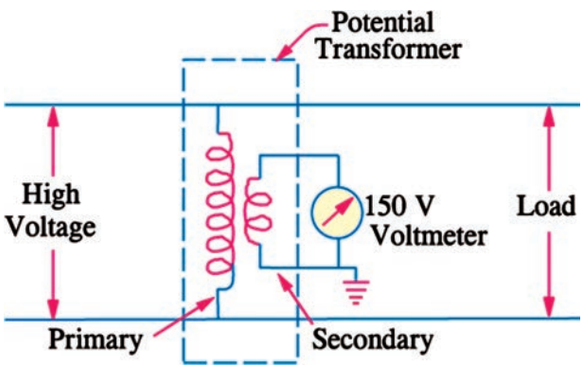


Fig 6.8 *Potential transformers*

Potential transformer do not differ much from the ordinary two winding transformer as shown in fig. 6.8. Hence it is called step down transformers. The primary winding is connected directly across the power circuit. The secondary is usually rated for 110 (or) 220 volts. Voltage ratio is depenting upon primary voltage .

6.5.2 Current transformer

The current transformer has a primary coil of only few turns of thick wire connected in series with the line whose current is to be measured. The secondary coil consisting large number of turns is connected to the terminals of a low range ammeter as in fig. 6.9. Mostly the secondaries of all CT are made wound for 5 amperes.

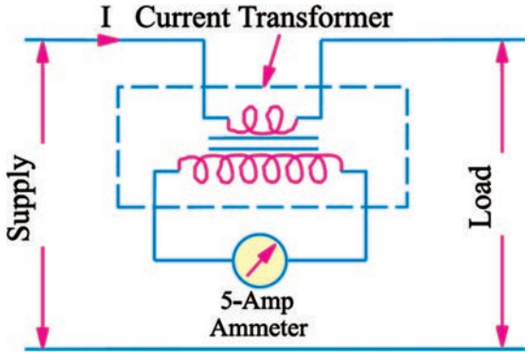


Fig 6.9 *Current transformers*

6.5.3 Auto transformer (VARIAC)

An auto transformer is a single winding transformer which is used to get varying AC voltage. Consider a single winding BA of N_1 turns wound on an iron core as shown in fig. 6.10. The core loss, copper loss, magnetizing current and leakage reactance are negligible. If this winding is connected to an AC voltage V1, a flux will set up in the core and emf E1 will be induced in the winding. Such induced e.m.f is taken by tapping at point C. There are N2 turns between B and C, an e.m.f E2 is induced B and C.

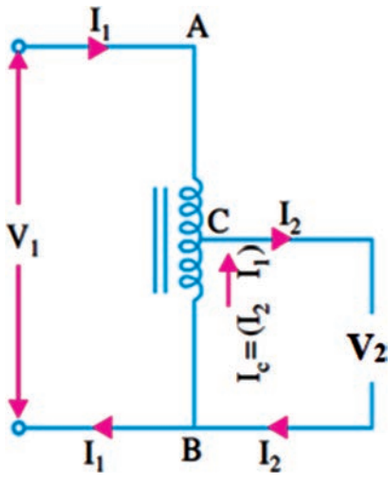


Fig 6.10 *Auto transformer*

When load is connected across the terminals B and C a current I2 flows. The m.m.f due to I2 will be balanced by m.m.f due to I1. This arrangement is referred as an Auto transformer. If point C is sliding contact, a continuously variable output voltage can be made available.

So,

$$\frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1} = K$$

Advantages

1. Copper required is very less.
2. The efficiency is higher.
3. Required less conducting material and hence cost is less.
4. More smooth and continuous variation of voltage.

Disadvantages

1. Direct link between high voltage and low voltage sides there is no isolation as in the case of a two winding transformer.
2. The short circuit current is greater than that of a two winding transformer.

6.5.4 Applications of Auto transformer

1. As a booster of supply voltage to a small extent.
2. Auto transformers are used to start an induction motor.
3. It can be used to vary the voltage to the load, smoothly from zero to the rated voltage.

6.6 LOSSES IN A TRANSFORMER

The losses in a transformer consists of I^2R loss (or) copper loss and iron loss (or) core loss.

I^2R loss (or) Copper loss

These losses occur in primary and secondary windings. Copper loss in a transformer is a variable loss. It varies as the square of the load current (From short circuit test this can be determined).

Iron loss (or) Core loss

Iron loss consists of hysteresis and eddy current losses. They occur in the transformer core due to the alternating flux (from open circuit test, this can be determined.)

Hysteresis loss

When the iron core is subjected to an alternating flux hysteresis loss takes place.

Eddy current loss

Eddy current is induced in the cores. This loss is due to the flow of eddy current. Thin laminations are used to reduce the eddy current loss.

6.6.1 Efficiency of a transformer

The efficiency of a transformer is the ratio of output power to input power.

$$\text{Input} = \text{output} + \text{losses}$$

$$\% \text{ Efficiency } (\eta) = \frac{\text{output power}}{\text{input power}} \times 100$$

$$= \frac{\text{output power}}{\text{output power} + \text{losses}} \times 100$$

$$(\text{iron loss} + \text{copper loss})$$

$$= \frac{\text{input power} - \text{losses}}{\text{input power}} \times 100$$

6.6.2 Why transformer rating in KVA?

Already know that copper loss of a transformer depends on current and iron loss equal to voltage. Hence total transformer losses depends on volt ampere (VA) and not on phase angle between voltage and current i.e, it is independent of load power factor. Therefore the rating of transformer is in KVA.

6.6.3 Why transformer does not work on DC supply?

The transformer works on the principle of mutual induction, for which current in one coil change uniformly. If DC supply is given, the current will not change due to constant supply and transformer will not work. This makes the coil burns due to extra heat generated and may cause permanent damage to the transformer. Thus DC supply should not be connected to the transformer.

6.7 TESTING METHODS OF A TRANSFORMER

There are two tests performed on a transformer to determine the power. They are:

1. Open circuit test
2. Short circuit test

These two tests are used for finding out the power loss occurring in the transformer.

6.7.1 Open circuit test on transformer

The open circuit test on transformer is used to determine core losses in transformer.

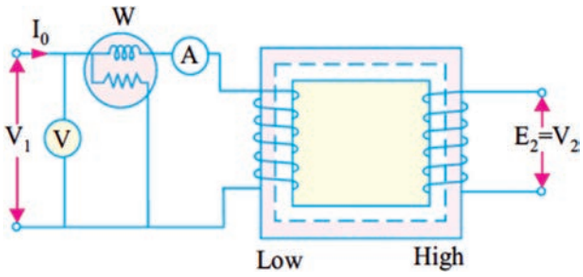


Fig 6.11 *Open circuit test*

The connection diagram for open circuit test on transformer is shown in fig. 6.11. A voltmeter, wattmeter, and an ammeter are connected in primary side of the transformer. The voltage at rated frequency is applied to the primary side with the help of a variac (or) variable ratio auto transformer.

The secondary side of the transformer is kept open. Now with the help of variac, applied voltage gets slowly increased until the voltmeter gives reading equal to the rated voltage of the primary side. After reaching at rated primary side voltage, all three instrument readings (voltmeter, ammeter and wattmeter readings) are recorded.

The ammeter reading gives no load current (I_o) being secondary is open the transformer draws very less current. Hence copper loss are negligible. As no load current (I_o) is quite small compared to rated current of the transformer, the voltage drop due to this current that can be taken as negligible. As the transformer is open circuited, there is no output. Hence the input power consist of core losses and copper loss in transformer during no load condition.

6.7.2 Short circuit test on transformer

The short circuit test on transformer is used to determine copper loss in a transformer.

The connection diagram for short circuit test on transformer is shown in fig. 6.12. A voltmeter, wattmeter, and an ammeter are connected in primary side of the transformer as shown below. A reduced voltage at rated frequency is applied to the primary side with the help of a variac of variable ratio of auto transformer.

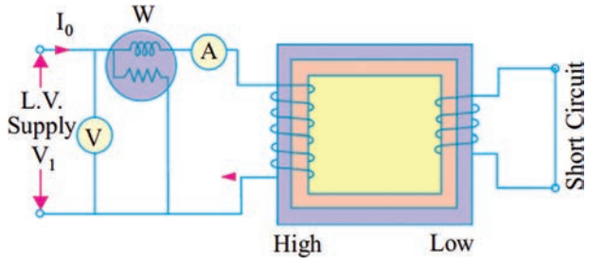


Fig 6.12 *Short circuit test*

The secondary side of the transformer is short circuited. Now with the help of variac applied voltage is slowly increased until the ammeter gives reading equal to the rated current in the primary side. Then three instruments reading (voltmeter, ammeter and watt-meter) are recorded. The voltmeter reading is very small compared to the rated primary voltage of the transformer. Here the core losses in transformer can be taken as negligible.

Let the, voltmeter reading is V1. The input power during test is indicated in

wattmeter. As the transformer is short circuited, there is no output, hence the input power consist of copper loss in the transformer.

6.8 PROTECTIVE DEVICES OF TRANSFORMER

The following are the protective devices in transformer and are explained below:

a) Conservator
b) Breather
c) Explosion vent
d) Buchholz relay
e) Transformer oil

Fig 6.13 *Protective devices of transformer*

a) Conservator

Transformer oil losses its insulating properties and is oxidised when it is in contact with the atmosphere. For this reason, the oil must not come in direct contact with the air outside. Conservators or oil expansion chambers are provided to prevent this absorption.

The conservator is cylindrical vessel. It is fitted on the top of the tank. The tank is entirely filled up with oil. The conservator is filled with oil partially (about 50%). The transformer oil gets heated due to the losses in a transformer. The volume increases due to heat and the level of oil in conservator increases. Air is expelled from the conservator through the breather. When the coil cools down, the volume decreases and the level of the oil in the conservator comes down.

This is referred to a ”breathing”. The oil surface in the conservator is only exposed to oxidation. The sludge is thus confined to the oil surface in the conservator. If there is no conservator the sludge will stick to the cooling tubes. This will spoil the cooling effort.

b) Breather

The breather is a small vessel. It is connected between conservator and air outlet. It contains silica-gel. It is a dehydrating agent. The moisture in the incoming air is removed. The colour of the silica-gel is **blue** when wet and **pink** when damp.

c) Explosion vent

In the event of an accidental internal short circuit in the transformer, an arc is formed between the turns of the winding. Heat is produced by the arc. Due to this, a large volume of gas is produced. Provision must be made for rapid release of gas. Otherwise high pressure will be built up inside leading to the lip of the tank blown off. For this reason an

explosion vent is provided on the tap of the tank. Under normal conditions air is not allowed to come in contact with the oil. Under short circuit conditions, it is ruptured due to high pressure. The gas is expelled to atmosphere. If the high pressure gas releasing a portion of the hot oil may get splashed and cause injury to the workers in the transformer yard.

The explosion vent's mouth is covered by a glass or aluminium.

d) Buchholz relay

This is a device which is attached to an oil immersed transformer. It is fitted in the pipe connecting the transformer tank with the conservator.

It consists of two floats as shown in Fig. 6.14.

Two pairs of electrical contacts are provided. These contacts may get short circuited under certain situations.

When an insulation breaks down in a transformer, gas is generated in the oil. Quick generation of this gas leads to a serious fault. The gas rushes through the pipe and pushes the lower float to the right. The two lower contacts bridge together and closes to trip the circuit of circuit breaker. Now the transformer is disconnected from the supply. If the fault develops slowly, gas will also generated slow. This may not be sufficient to move the lower float. This gas gets collected gradually in the top of the relay chamber. The oil level gets lowered. This causes the upper float to sink. It finally closes the second pair of contacts. This trips the circuit breaker or it makes ring an alarm bell for caution. A fault can thus be detected and the transformer is disconnected from the circuit.

e) Transformer oil

Transformer oil is a mineral oil. It is obtained by refining crude petroleum. It is a good insulator. Its tendency to form, a sludge is very much less. The dielectric strength of oil is affected to a great extent by the presence of moisture. So it should be kept dry. Transformer oil serves two functions,

1. Cooling
2. Insulation

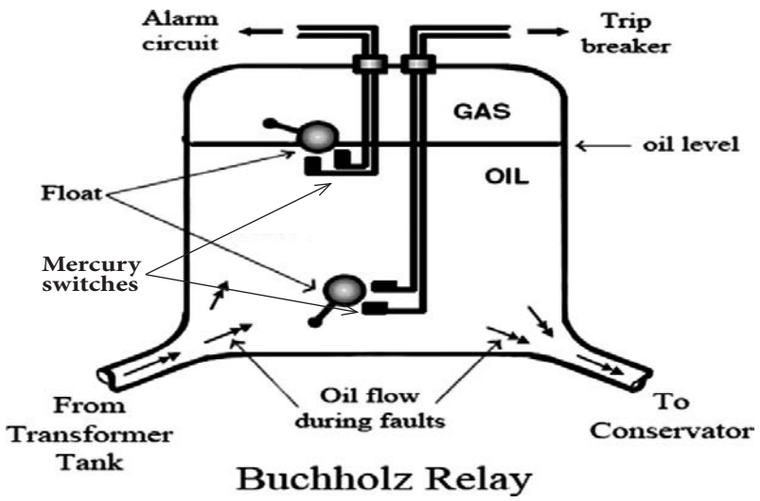


Fig 6.14 *Buchholz relay*

Points to remember:

1. Transfer electrical energy from one circuit to another circuit.
2. It works without changing the frequency.
3. Transformer works on the principle of mutual induction.
4. Transformer works on AC supply only, not in DC.
5. E. M. F induced in primary winding = $(E_1) = 4.44\ N_1\ f\emptyset_m$ Volts.
6. E. M. F induced in secondary winding = $(E_2) = 4.44\ N_2\ f\emptyset_m$ Volts.
7. $$\% \text{ Efficiency } (\eta) = \frac{\text{output power}}{\text{input power}} \times 100$$
8. Voltage transformation ratio (K)

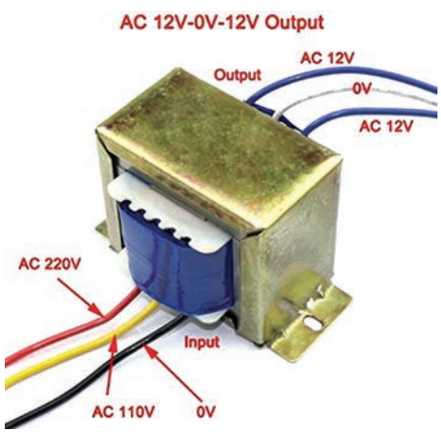
$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = k = \frac{V_2}{V_1} = \frac{I_1}{I_2}$$

GLOSSARY

Transformer	—	மின்மாற்றி
Step-up transformer	—	உயர்வழுத்த மின்மாற்றி
Step-down transformer	—	குறைவழுத்த மின்மாற்றி

Activities

1. Measure the output voltage of given transformer below.
2. Construct 6V transformer with centre tapping connection.
3. Calculate the losses occuring in the transformers by OC and SC tests.



Q A

PART A

3QFAH

Mark 1

Choose the correct answer:

1. The transformer may represent as
   a) rotating device
   b) electronic device
   c) static device
   d) computing device
2. Transformer operates on the principle of
   a) self induction
   b) mutual induction
   c) ohm's law
   d) len's law
3. To find the RMS value of transformer, EMF is to be multiply with
   a) 2.22 b) 1.12
   c) 1.11 d) 1.14
4. Transformer core is laminated to reduce the
   a) copper loss
   b) eddy current loss
   c) wintage loss
   d) hysteresis loss
5. Transformer oil serves the function of
   a) lubrication
   b) insulation and cooling
   c) only insulation
   d) only cooling
6. Silicon steel sheets are used to reduce the
   a) Frictional loss
   b) Mechanical loss
   c) Hysteresis loss
   d) Eddy current loss
7. The transformer will work on
   a)AC only c) Both AC & DC
   b) DC only d) UPS
8. The iron core is used to …… of the transformer,
   a) increase the weight
   b) provide tight magnetic coupling
   c) reduce core losses
   d) increase copper loss
9. The primary and secondary of a transformer are ….. coupled
   a) electrically
   b) magnetically
   c) electrically and magnetically
   d) thermo
10. Conservator is a
    a) main tank of transformer
    b) protective device of transformer
    c) earthing system of transformer
    d) cooling device
11. The purpose of conducting open circuit test (OC) is to determine
    a) eddy current loss
    b) core loss
    c) hysteresis loss
    d) copper loss

PART B

Mark 3

Answer the following questions in briefly:

1. What is called a transformer?
2. What is meant by step up transformer?
3. What is meant by step down transformer?
4. What are the advantages of a transformer?
5. What is the voltage transformation ratio of a transformer?
6. Mention the advantages of core type transformer.
7. Write down the types of instrument transformer.
8. Write down the applications of auto transformer.
9. What are the protective devices of transformer?
10. Why transformer is rating in KVA?
11. Define efficiency of a transformer.
12. What are the type of transformer according to cooling method?

PART C

Mark 5

Answer the questions not exceeding one page

1. Explain the construction of shell type transformer.
2. Explain why transformer does not works on DC supply.
3. Compare core and shell type transformer.
4. Explain about auto transformer.
5. Explain the losses occuring in a transformer.

PART D

Mark 10

Answer the questions not exceeding two page

1. Draw and explain the construction and working principle of a transformer.
2. Derive the EMF equation of a transformer.
3. Draw and explain the working principle of potential and current transformer.
4. Draw and explain the various tests conducted in a transformer

Reference book

1. 'A text book of Electrical Technology' Volume II and Volume III by B.L. Theraja and A.K. Theraja, S. Chand & Company Ltd.

Internet resource

https://en.wikipedia.org/wiki/Transformer