Transformer

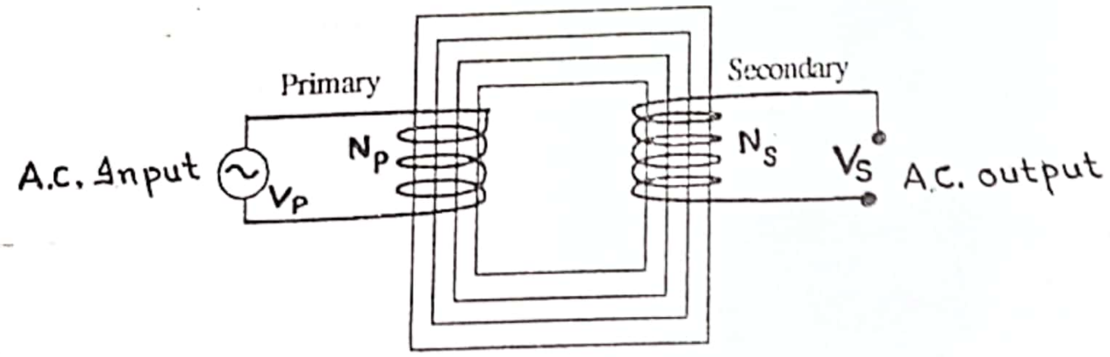
A device which is used to change a given alternating emf into a larger or smaller alternating emf is called transformer. OR It is an electric device which is used to convert A.C. of low voltage and high current into A.C. of high voltage and low current and vice versa.

Principle:

The transformer works on the principle of mutual induction between the two coils. A changing current in the primary induces an emf in the secondary.

Construction:

It consists of an iron core (circular or rectangular) on which two separate coils of insulated copper wire are wound. The core consists of several thin soft iron strips called laminations, insulated from one another. The coil to which the A.C. power is supplied is called "primary coil" and the coil across which voltage is induced is called "Secondary coil". There is no electrical connection between the two coils but they are magnetically linked.



Suppose 'N_P' is the number of turns (Loops) in the primary and 'N_S' is the number of turns in secondary.

Working:

Suppose an A.C. voltage 'V_p' applied to the primary causes a current 'I_p' in it. This current produces a changing magnetic flux in the iron core which causes an opposing (back) induced emf in the primary. The magnitude of induced emf depends upon the number of turns 'N_p' in the primary and the rate of change of magnetic flux $\frac{\Delta\Phi}{\Delta t}$. If the resistance of the primary is negligible,

$\therefore$ Applied voltage = Induced emf

$$V_p = -N_p \frac{\Delta\Phi}{\Delta t} \longrightarrow (1)$$

Since the two coils are tightly coupled so A.C. voltage developed across secondary is,

$$V_s = -N_s \frac{\Delta\Phi}{\Delta t} \longrightarrow (2)$$

Dividing Eq (2) by Eq (1), we have,

$$\frac{V_s}{V_p} = \frac{-N_s \Delta\Phi/\Delta t}{-N_p \Delta\Phi/\Delta t}$$

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \longrightarrow (3)$$

This Equation is known as "Transformer Equation".

Since electrical power in transformer is transformed from primary to secondary coil by means of changing flux. Thus for an "Ideal Transformer" we have,

power input = power output

$$V_p I_p = V_s I_s$$

$$\frac{V_s}{V_p} = \frac{I_p}{I_s} \longrightarrow (4)$$

Now combining Eq (3) and (4), we get,

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s} \longrightarrow (5)$$

This shows that number of turns are directly and current is inversly proportional to respective voltage.

Types of Transformer

There are two main types of transformer

1- Step up transformer:

If $N_s > N_p$ then $V_s > V_p$.

It means that voltage across secondary is greater than the voltage across the primary coil. This type of transformer is known as step up transformer. In step up transformer, primary coil is made of thick copper wire.

2- Step down transformer:

If $N_p > N_s$ then $V_p > V_s$.

It means that voltage across secondary coil is less than the voltage across the primary coil. such a transformer is called step down transformer. In step down transformer, secondary is made of thick copper wire to carry large current.

Application:

The transformer has made it possible that the power can be transmitted over long distances without much power loss on the transmission lines.

We know that in a step-up transformer when voltage across the secondary coil increases then current through it decreases i.e. $I_s \propto 1/V_s$. This principle is used in long distance transmission to reduce power losses.

Economical transmission requires low current and high voltage. since power loss through heating is I^2R, where 'R' is the resistance of transmission line. In order to minimize the loss it is not possible to reduce 'R'. This is possible only by reducing 'I' which can be done as, at generating station voltage is increased to a very high value and so current 'I' is reduced. This reduces the power loss I^2R.

Different Causes of Power Loss

There are two main causes of power loss in transformer, which are given below.

i- Eddy Current

ii- Magnetic Hysteresis

i- Eddy Current:

If the core is of solid soft iron then changing magnetic flux produced an induced emf, which set up electric current inside the material of core. This current which is induced in the body of the core due to changing magnetic flux is known as "Eddy current". Not only there is a power loss due to eddy current but also core is heated. This loss is to some extent minimized by using a laminated core in which iron strips are separated by inserting insulating sheets between the strips.

ii- Magnetic hysteresis:

The energy used in magnetization and demagnetization of core during one cycle of A.C. is called hysteresis loss. This loss can be reduced by using such a material for the core whose hysteresis loop is of small area.

Efficiency of Transformer

The ratio of output power to input power is known as efficiency. Mathematically.

$$E = \frac{\text{output power}}{\text{Input power}} \times 100$$

practically no transformer is an ideal one i.e. 100% efficient. output power is always less than input power. It means there is always some power loss. Efficiency of a transformer can be increased by decreasing the power losses i.e. eddy current losses and hysteresis losses.

(b)- Silver, then tolerance is ±10%.
(C)- If no band is present, then tolerance is ±20%.

Tolerance:

The possible variation of resistance from the marked value is known as tolerance.

For example,

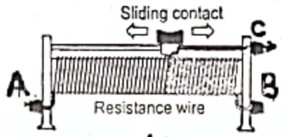
If there is a resistor of 1000 Ω with ±10% tolerance, then its actual resistance can be in between 900Ω and 1100Ω.

Rheostat

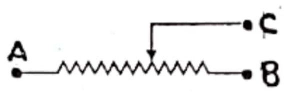
Rheostat is a wire wound variable resistance OR It is a resistor whose resistance can be changed.

Construction:

It consists of a wire of high resistance wound over an insulating cylinder. The ends of the wire are connected to the two fixed terminals 'A' and 'B' where as third terminal 'C' is connected to the sliding contact which can be moved over the wire as shown in fig (a) & (b).



(a)



(b)

Uses:

A rheostat can be used as a,

i- Fixed resistor.
ii- Variable resistor.
iii- Potential divider.

i- Fixed resistor:

It can be used as a fixed resistor when only its terminal 'A' and 'B' are used.

ii- Variable resistor:

A rheostat can be used as a variable resistor when its terminal 'A' and the sliding terminal 'C' are connected in circuit.

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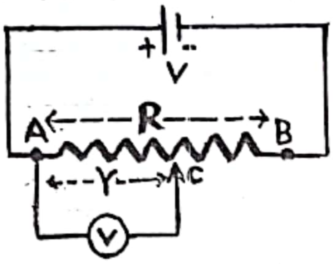
as shown in fig (b) above. If the sliding contact is moving towards 'A' then resistance will decreases in the circuit and when it moving away from 'A', then length and hence the resistance in the circuit will increases. Thus in this way, the resistance of the wire between 'A' and 'C' can be used.

iii - potential divider:

The rheostat can be used as a potential divider if the terminals 'A' and 'B' are connected across a battery of potential difference 'V', the desired potential difference can be obtained across the terminals 'A' and 'C'.



If 'R' is the resistance of the wire AB then current flowing through it is given by,

$$I = \frac{V}{R} \longrightarrow (1)$$

Let 'r' be the resistance between A and C. Then potential difference across the wire AC is given by,

$$V_{AC} = I \times r$$

$$V_{AC} = \frac{V}{R} \times r$$

$$V_{AC} = \frac{r}{R} \times V \longrightarrow (2)$$

This equation shows that as 'C' slides from 'A' to 'B', 'r' changes from '0' to 'R' and the potential drop between 'A' and 'C' changes from '0' to 'V'. This device by which potential can be varied continuously from '0' to 'V' is known as potential divider and the instrument which uses this device for measuring the potential is called potentiometer.

Application:

Wheatstone bridge can be used to find the unhnow resistance. If three resistances R_1, R_2, R_3 are known to us, then fourth one can be found out by using the relation

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

provided the current passing through the galvanometer is zero.

Potentiometer

A very simple instrument which is used to measure and compare potential difference accurately without drawing any current from the main circuit is known as potentiometer.

Explanation:

Potential difference across any resistor or battery can be measured with the help of a voltmeter, but it cannot measure it accurately because it draws some current from the main circuit. 100% accuracy can only be achieved if voltmeter's resistance is infinite.

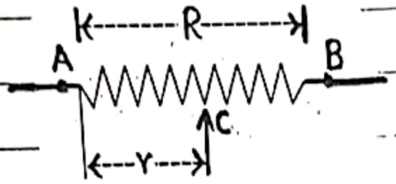
Devices like digital voltmeter and cathode ray oscilloscope with infinite resistance can measure the potential difference accurately but they are not only expensive but at the same time difficult to operate.

Potentiometer is very simple and cheaper instrument which can be use to measure and compare potential difference accurately and easily.

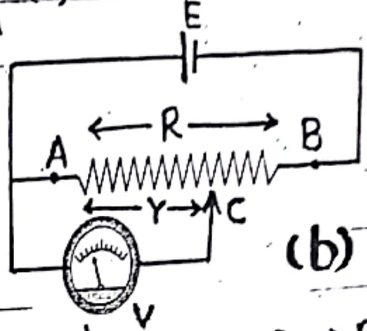
Construction:

It consists of 4m long wire AB

having uniform resistance 'R'. There is a sliding contact 'C' which is slidable over the resistance wire AB as shown in fig (a). The resistance



(a)



(b)

between A and C can be changed from $0 \rightarrow R$ with the help of sliding contact 'C' in moving from $A \rightarrow B$.

If a battery of emf 'E' is connected across the resistance wire as shown in fig (b), then current flowing through 'R' is given by,

$$I = \frac{E}{R} \longrightarrow (1)$$

If the resistance between A and C is 'r' then voltage drop across AC will be

$$V_{AC} = I \times r$$

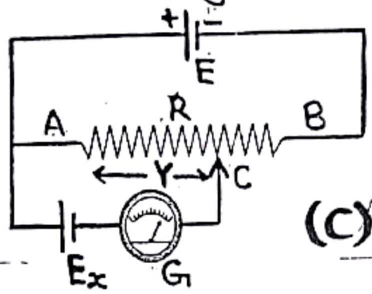
$$V_{AC} = \frac{E}{R} \times r$$

$$V_{AC} = \frac{r}{R} \times E \longrightarrow (2)$$

Voltage between A and C can be changed from $0 \rightarrow E$ with the help of sliding contact 'C'. This arrangement is known as a potential divider and can be used to find out the emf of an unknown source, by using the circuit shown in fig 'c'.

e.m.f of a cell or battery:

To measure the emf of a cell or battery, we make use of the following diagram. The source with unknown e.m.f. 'E_x' is connected in such a way that its positive terminal and the positive terminal of battery are connected at point 'A' and negative terminal is connected with the sliding contact 'C' through a galvanometer as shown in Fig (C). The wire of the potentiometer is straight and is of uniform crossectional area.



(C)

Galvanometer gives deflection when switch of the battery is closed. But when the sliding contact is moved then deflection of the galvanometer changes and a stage will come when galvanometer deflection becomes zero. In this condition electrical potential at 'C' is equal to the potential of negative terminal of 'E_x'. At this stage, the emf 'E_x' of the cell is equal to the potential difference between A and C i.e.

$$E_x = V_{AC} = Ir = \frac{E}{R} \times r$$

$$E_x = \frac{r}{R} \times E \longrightarrow (3)$$

As the resistance of wire is directly proportional to its length, therefore

$$R \propto L \quad \text{and} \quad r \propto l$$

So $$\frac{r}{R} = \frac{l}{L}$$

Thus Equation (3) can be written as,

$$E_x = \frac{l}{L} \times E \longrightarrow (4)$$

where 'L' is total length of the wire AB and 'l' is length of wire from A→C.

N.B.

The value of 'E_x' should not be greater than the e.m.f of the battery. If 'E_x' is greater than 'E' then null point will not be obtained

Method to compare emfs E_1 & E_2

The method used above to find 'E_x' can also be used to compare emfs E_1 and E_2 of two cell. For this we have to calculate the balancing length 'l_1' for E_1 first then balancing length 'l_2' for E_2.

For one cell we can write,

$$E_1 = \frac{l_1}{L} \times E$$

also For 2nd cell we can write,

$$E_2 = \frac{l_2}{L} \times E$$

By dividing these two Eqs we get

$$\frac{E_1}{E_2} = \frac{\frac{l_1}{L} \times E}{\frac{l_2}{L} \times E}$$

$$\frac{E_1}{E_2} = \frac{l_1}{l_2} \longrightarrow (5)$$

This shows that ratio of emfs is equal to the ratio of their balancing lengths. This formula is used to compare emf. of the two given cells.