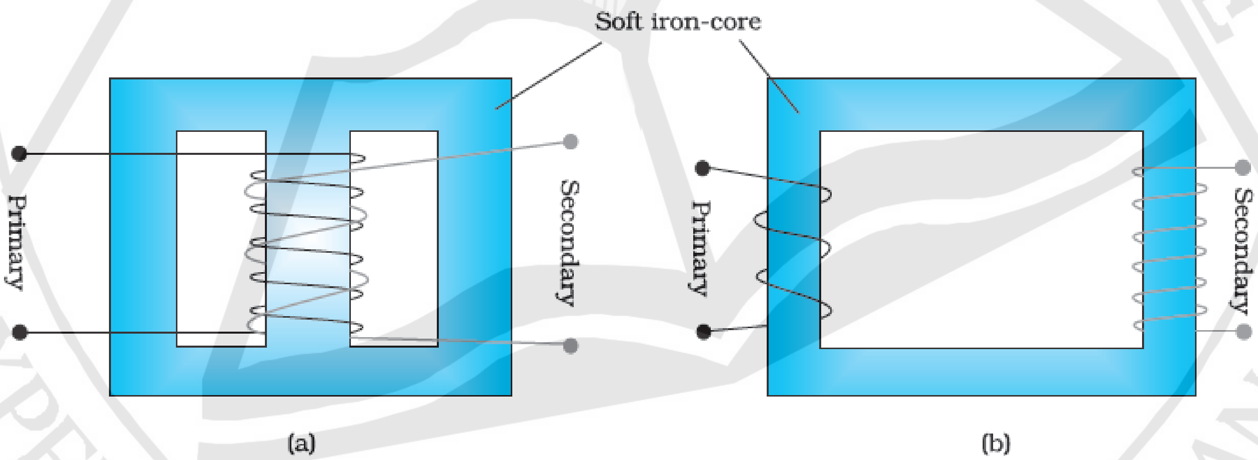
Transformer

Introduction: It is a device used to convert low alternating voltage at high current to high alternating voltage at low current to and vice versa

Principle: If two coils are inductively coupled, and when current or magnetic flux is changed through one of the coils, then induced emf is produced through the other coil

Construction: A transformer consists of two sets of coils, insulated from each other. They are wound on a soft-iron core, either one on top of the other, or on separate limbs of the core. One of the coils called the *primary coil* has N_p turns. The other coil is called the *secondary coil*; it has *Ns* turns. Often the primary coil is the input coil and the secondary coil is the output coil of the transformer.



Theory➔

When an alternating voltage is applied to the primary, the resulting current produces an alternating magnetic flux which links the secondary and induces an emf in it. The value of this emf depends on the number of turns in the secondary. We consider an ideal transformer in which the primary has negligible resistance and all the flux in the core links both primary and secondary windings. Let φ be the flux in each turn in the core at time *t* due to current in the primary when a voltage V_p is applied to it. Then the induced emf or voltage ε_s, in the secondary with N_s turns is

$$\varepsilon_s = -N_s \frac{d\phi}{dt} \qquad \mathbf{1}$$

The alternating flux also induces an emf, called back emf in the primary. This is

$$\varepsilon_p = -N_p \frac{d\phi}{dt} \qquad \mathbf{2}$$

But $\varepsilon_p = v_p$. If this were not so, the primary current would be infinite since the primary has zero resistance (as assumed). If the secondary is an open circuit or the current taken from it is small, then to a good approximation

$$\varepsilon_s = v_s$$

where v_s is the voltage across the secondary. Therefore,

$$v_s = -N_s \frac{d\phi}{dt} \quad and \quad v_p = -N_p \frac{d\phi}{dt} \qquad \mathbf{3}$$

Thus from equations 1,2 and 3

$$\frac{v_s}{v_p} = \frac{N_s}{N_p}$$

Note that the above relation has been obtained using three assumptions:

- The primary resistance and current are small
- The same flux links both the primary and the secondary as very little flux escapes from the core
- The secondary current is small.

If the transformer is assumed to be 100% efficient (no energy losses), the power input is equal to the power output, and since

$$P = IV$$

$$I_p V_p = I_s V_s \qquad \mathbf{4}$$

Although some energy is always lost, this is a good approximation, since a well designed transformer may have an efficiency of more than 95%. Combining Eqs. 3 and 4, we have

$$\frac{I_p}{I_s} = \frac{v_s}{v_p} = \frac{N_s}{N_p}$$

Since *I* and *v* both oscillate with the same frequency as the ac source, Eq.5 also gives the ratio of the amplitudes or rms values of corresponding quantities.

How a transformer affects the voltage and current.

We have:

$$v_s = \left(\frac{N_s}{N_p}\right) v_p \quad and \quad \mathrm{I}_s = \left(\frac{N_P}{N_s}\right) I_p$$

That is,

- If the secondary coil has a greater number of turns than the primary $N_s > N_p$, the voltage is stepped up $v_s > v_p$. This type of arrangement is called a **step-up transformer**. However, in this arrangement, there is less current in the secondary than in the primary $\left(N_p / N_s < 1 \text{ and } \mathrm{I_s} < I_p \right)$.
- If the secondary coil has less turns than the primary $N_p > N_s$, we have a **step-down transformer**. In this case, $v_p > v_s$ and *Is* > *Ip*. That is, the voltage is stepped down, or reduced, and the current is increased.

Energy losses

The equations obtained above apply to ideal transformers (without any energy losses). But in actual transformers, small energy losses do occur due to the following reasons:

1. Flux Leakage: There is always some flux leakage; that is, not all of the flux due to primary passes through the secondary due to poor design of the core or the air gaps in the core. It can be reduced by winding the primary and secondary coils one over the other.
2. *Resistance of the windings*: The wire used for the windings has some resistance and so, energy is lost due to heat produced in the wire (I^2R). In high current, low voltage windings, these are minimised by using thick wire.
3. *Eddy currents*: The alternating magnetic flux induces eddy currents in the iron core and causes heating. The effect is reduced by having a laminated core.
4. *Hysteresis*: The magnetisation of the core is repeatedly reversed by the alternating magnetic field. The resulting expenditure of energy in the core appears as heat and is kept to a minimum by using a magnetic material which has a low hysteresis loss.

The large scale transmission and distribution of electrical energy over long distances is done with the use of transformers. The voltage output of the generator is stepped-up (so that current is reduced and consequently, the I^2R loss is cut down). It is then transmitted over long distances to an area sub-station near the consumers. There the voltage is stepped down. It is further stepped down at distributing sub-stations and utility poles before a power supply of 240 V reaches our homes.