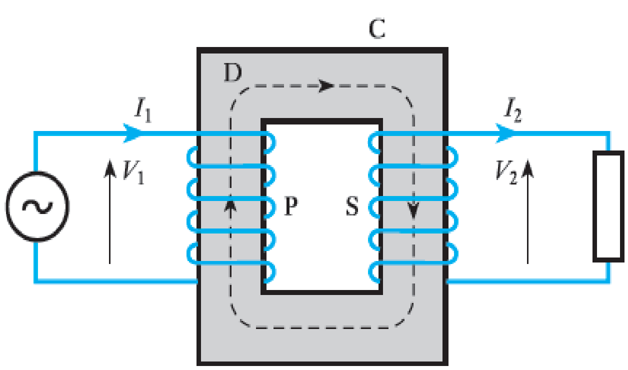
Chapter Six
Transformers

Introduction

One of the main advantages of a.c. transmission and distribution is the ease with which an alternating voltage can be increased or reduced. For the general practice there is step up transformers to higher voltages for the transmission lines and other transformers are introduced to step the voltage down to values suitable for motors, lamps, heaters, etc.

Principle of action of a transformer

Figure 6.1 shows the general arrangement of a transformer. A steel core C consists of laminated sheets insulated from one another. The purpose of laminating the core is to reduce the eddy-current loss. The vertical portions of the core are referred to as limbs and the top and bottom portions are the yokes. Coils P and S are wound on the limbs. Coil P is connected to the supply and is therefore termed the primary; coil S is connected to the load and is termed the secondary. A transformer is a static (or stationary) piece by means of which electric power in one circuit is transformed into electric power of the same frequency in another circuit.



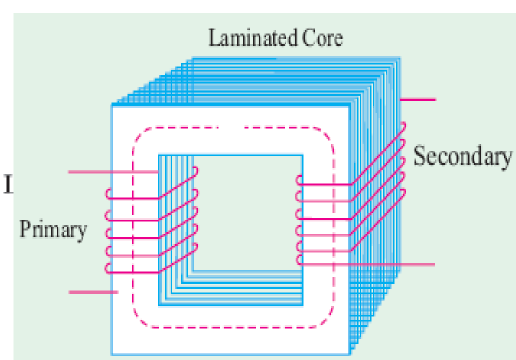


Fig.6.1. A transformer

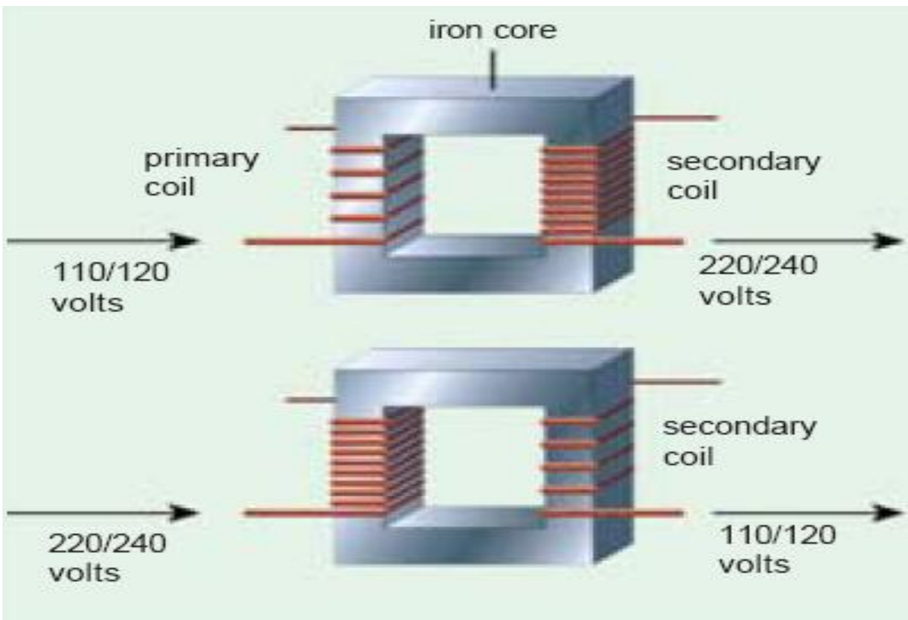
An alternating voltage applied to P circulates an alternating current through P and this current produces an alternating flux in the steel core, the mean path of this flux being represented by the dotted line D. If the whole of the flux produced by P passes through S, the e.m.f. induced in each turn is the same for P and S. Hence, if N_1 and N_2 are the number of turns on P and S respectively,

$$\frac{\text{Total e.m.f. induced in S}}{\text{Total e.m.f. induced in P}} = \frac{N_2 \times \text{e.m.f. per turn}}{N_1 \times \text{e.m.f. per turn}} = \frac{N_2}{N_1}$$

$$\frac{V_2}{V_1} \simeq \frac{N_2}{N_1} \quad \text{………..(6.1)}$$

$$\frac{I_1}{I_2} \simeq \frac{V_2}{V_1} \quad \text{………..(6.2)}$$

$$\frac{I_1}{I_2} \simeq \frac{N_2}{N_1} \simeq \frac{V_2}{V_1} \quad \text{………..(6.3)}$$



Principle of transformer

EMF Equation of a Transformer

Suppose the maximum value of the flux to be Φ_m webers and the frequency to be f hertz. From Fig.6.2 it is seen that the flux has to change from $+\Phi_m$ to $-\Phi_m$ in half a cycle, namely in $\frac{1}{2f}$ seconds.

∴ Average rate of change of flux

$$= 2\Phi_m \div \frac{1}{2f} = 4f\,\Phi_m \text{ webers / second}$$

and average e.m.f. induced per turn is:
$4f\,\Phi_m$ volts.

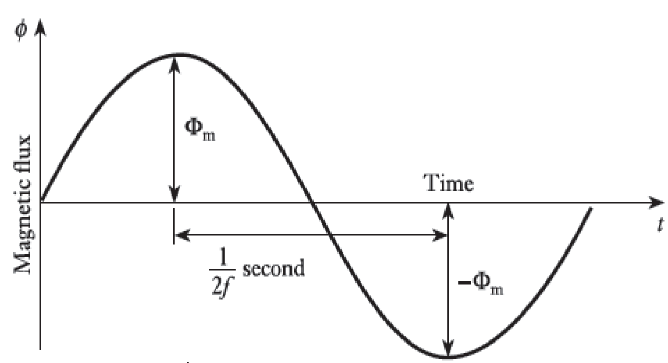


Fig.6.2. Waveform of flux variation

N_1 = No. of turns in primary
N_2 = No. of turns in secondary
Φ_m = Maximum flux in core in webers
$= B_m \times A$
f = Frequency of a.c. input in Hz

$$\text{Average e.m.f./turn} = 4 f \Phi_m \text{ volt}$$

But for a sinusoidal wave the r.m.s. or effective value is 1.11 times the average value,

$$\text{Form factor} = \frac{\text{r.m.s. value}}{\text{average value}} = 1.11$$

∴ RMS value of e.m.f. induced per turn $= 1.11 \times 4f\,\Phi_m$.
Hence, r.m.s. value of e.m.f. induced in primary is $E_1 = 4.44 N_1 f \Phi_m$ volts. ……..(6.4)
and r.m.s. value of e.m.f. induced in secondary is $E_2 = 4.44 N_2 f \Phi_m$ volts. ……..(6.5)

Voltage Transformation Ratio (K)

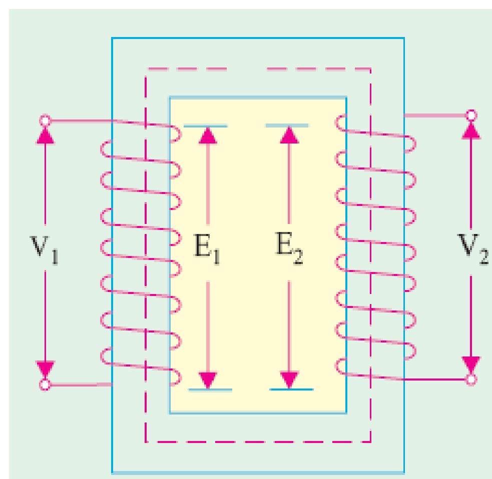
From equations (6.4) and (6.5), we get:

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

This constant K is known as voltage transformation ratio.

(*i*) If $N_2 > N_1$ *i.e.* $K > 1$, then transformer is called ***step-up*** transformer.

(*ii*) If $N_2 < N_1$ *i.e.* $K < 1$, then transformer is known as ***step-down*** transformer.



Example: A 250 kVA, 11000 V/400 V, 50 Hz single-phase transformer has 80 turns on the secondary. Calculate:
(a) the approximate values of the primary and secondary currents;
(b) the approximate number of primary turns;
(c) the maximum value of the flux.
Sol:

(a) Full-load primary current

$$\simeq \frac{250 \times 1000}{11\,000} = 22.7 \text{ A}$$

and full-load secondary current

$$= \frac{250 \times 1000}{400} = 625 \text{ A}$$

(b) No. of primary turns

$$\simeq \frac{80 \times 11\,000}{400} = 2200$$

(c) From expression [6.5.]

$$400 = 4.44 \times 80 \times 50 \times \Phi_m$$

$$\Phi_m = 22.5 \text{ mWb}$$