CHAPTER 9

UNIT IV

Single Phase Transformer

Syllabus :

Principle of operation, Construction, Emf equation, Equivalent circuit, Power losses, Efficiency (simple numerical problems), Introduction to auto transformer.

9.1 Introduction :

- The **transformer** is a static device (i.e. the one which does not contain any rotating or moving parts) which is used to transfer electrical energy from one ac circuit to another ac circuit, with increase or decrease in voltage / current but without any change in frequency.
- This is shown in Fig. 9.1.1.

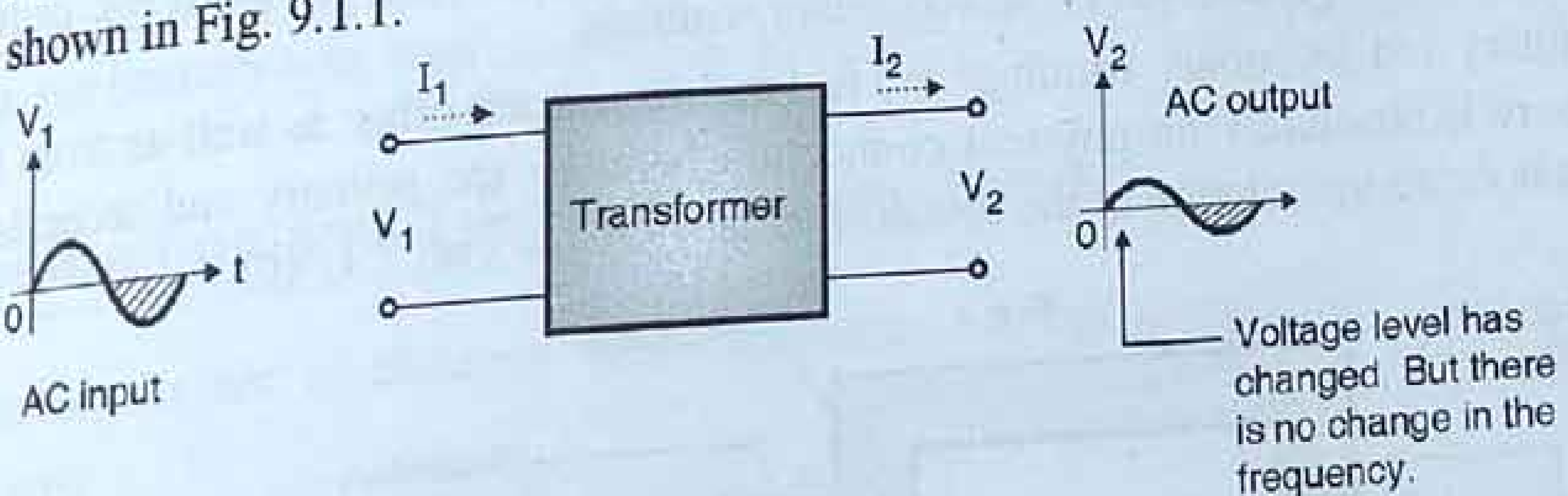


Fig. 9.1.1

- It is important to remember that input to a transformer and output from a transformer both are alternating (AC) quantities.
- The electrical energy is generated and transmitted at an extremely high voltages. The voltage is to be then reduced to a lower value for its domestic and industrial use.
- This is done by using a transformer. Thus it is possible to reduce the voltage level using a transformer (then the transformer is called as a step down transformer).
- On the other hand, we can also use the transformer to increase the voltage level (step up transformer).
- The power transmission system using transformers is shown in Fig. 9.1.2. When the transformer changes the voltage level, it changes the current level also.

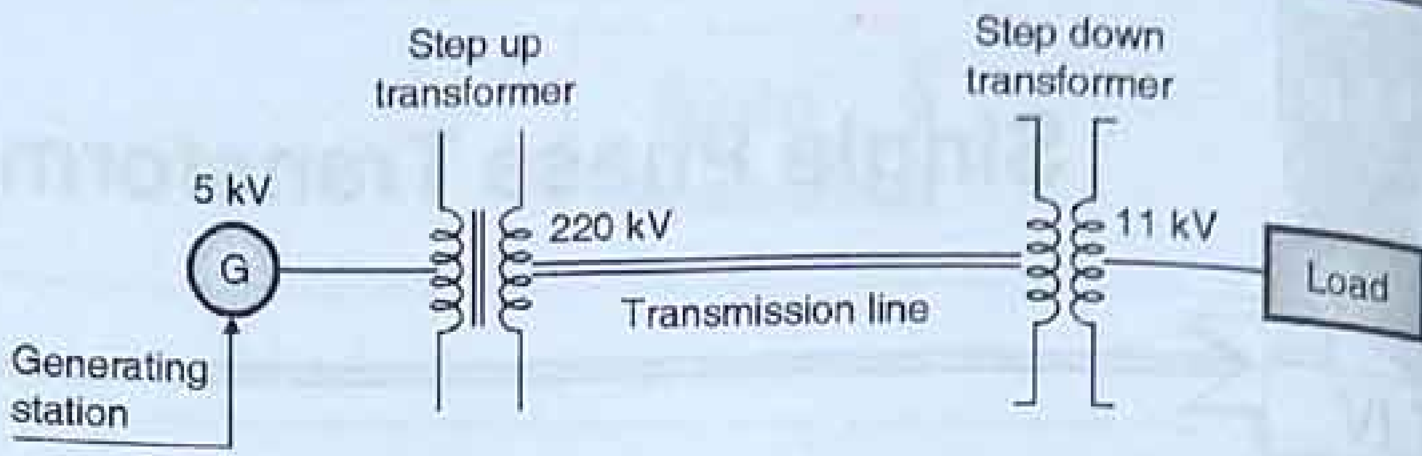


Fig. 9.1.2 : Transmission system

9.1.1 Types of Transformer :

- Transformers are designed for either single-phase or three-phase supply. Accordingly they are called as **single-phase transformers or three-phase transformers**.
- However the principle of operation for both the types is same.

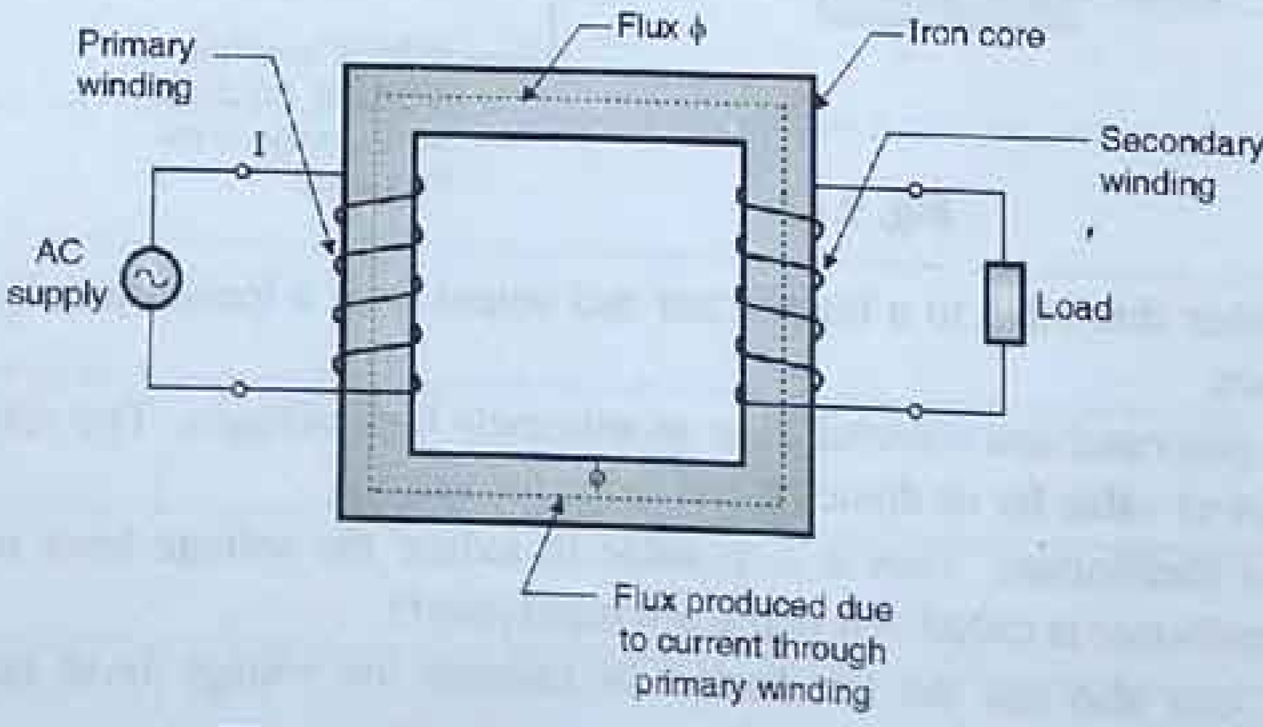
9.1.2 Principle of Operation :

UPTU : 06-07

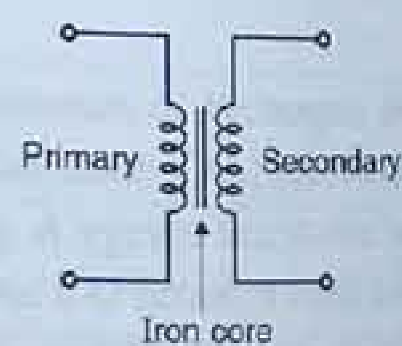
University Questions

Q. 1 Explain basic principle of operation of a single phase transformer. Where are they used ? **(Sem.-II : 06-07)**

- The construction of a single-phase transformer is as shown in Fig. 9.1.3(a). It consists of two highly inductive coils (windings) wound on an iron or steel core.
- The winding (coil) connected to the ac supply is called as **primary winding** whereas the other one is called as the **secondary winding**. The ac supply is connected to the primary winding whereas the load is connected to the secondary winding.
- The primary and secondary windings are isolated from each other as well as from the iron core. Thus there is absolutely no physical connection between the primary and secondary windings. The symbolic representation of the transformer is shown in Fig. 9.1.3(b).



(a) Elementary transformer



(b) Symbol of transformer

Fig. 9.1.3

- The principle of operation of a transformer has been explained in the Table 9.1.1.

Table 9.1.1 : Operating principle of a transformer

1. As soon as the primary winding is connected to the single - phase AC supply, an ac current starts flowing through it.

↓

2. The ac primary current produces an alternating flux ϕ in the core.

↓

3. Most of this changing flux gets linked with the secondary winding through the core.

↓

4. The varying flux will induce voltage into the secondary winding according to the Faraday's laws of electromagnetic induction.

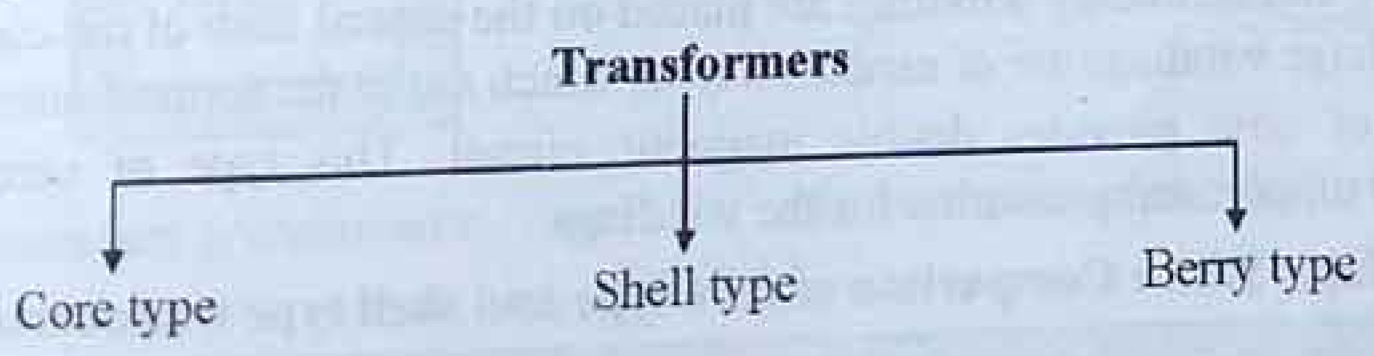
- Thus due to primary current, there is an induced voltage in the secondary winding due to mutual induction.
- Hence the emf induced in the secondary is called as the mutually induced emf.

Can the transformer operate on DC ?

- The answer is no. The transformer action does not take place with a direct current of constant magnitude.
- Because with a DC primary current, the flux produced in the core is not alternating but it is of constant value.
- As there is no change in the flux linkage with the secondary winding, the induced emf in the secondary winding is zero.
- If dc is applied to the primary then there is a possibility of transformer core saturation. If core saturates, the primary will draw excessively large current. Therefore application of DC should be avoided.

9.2 Construction and Types of Transformers :

The transformers are of different types depending on the arrangement of the core and the windings as follows :



9.2.1 Core Type Transformer :

- The construction of core type transformer is shown in Fig. 9.2.1(a).
- The core of this transformer is in the form of a rectangular frame made from laminations. It provides a single magnetic circuit as shown in Fig. 9.2.1(b).

9.3 EMF Equation of a Transformer :

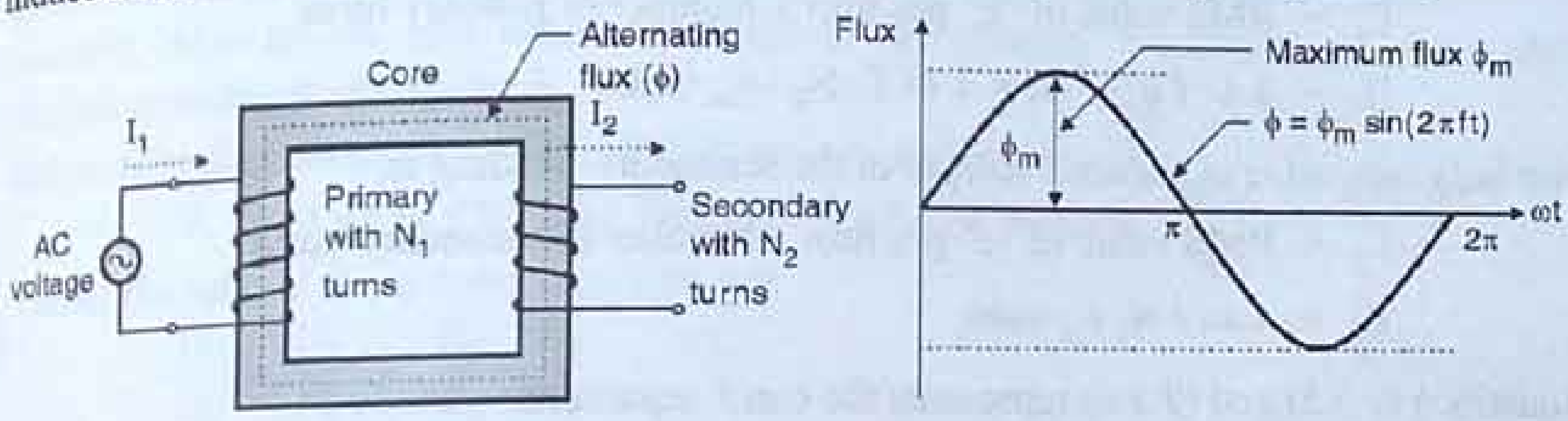
UPTU : 02-03, 09-10, GBTU : 11-12

University Questions

Q. 1 Derive the e.m.f. equation of a single-phase transformer. **(Sem.-I : 02-03, 09-10)**

Q. 2 Derive an emf expression of power transformer. **(GBTU : 11-12)**

- For deriving the emf equation of a transformer refer to Fig. 9.3.1(a). The primary winding is connected across the ac supply. This forces an alternating current through the primary winding to produce an alternating flux (ϕ) in the core.
- This varying flux gets linked with the secondary and primary windings to induce the mutually induced and self induced emfs in the secondary and primary windings respectively.



(a) Elementary transformer (b) Variation of the flux with time

Fig. 9.3.1

9.3.1 Expressions for the Induced Voltages :

Let us now obtain the expressions for the induced voltages in the primary and secondary windings.

Step 1 : Expression for the instantaneous flux ϕ :

As shown in Fig. 9.3.1(b), the instantaneous flux changes in a sinusoidal manner with respect to time. Its frequency "f" is same as that of the ac voltage applied to the primary winding.

$$\therefore \quad \phi = \phi_m \sin \omega t \qquad ...(9.3.1)$$

Where ϕ_m = Maximum value of the instantaneous flux

ω = $2\pi f$ where "f" is the frequency of the flux waveform

Step 2 : Obtain the expression for induced voltage :

According to the Faraday's laws of electromagnetic induction, the induced emf due to vary... flux is given by,

$$e = -N\frac{d\phi}{dt} \text{ volts}$$

Step 3 : Obtain the maximum value of "e" per turn :

The value of induced emf per turn can be obtained by substituting N = 1.

$$\therefore \quad e = -\frac{d\phi}{dt}$$

Substitute $\phi = \phi_m \sin \omega t$ to get,

$$e = -\frac{d}{dt}[\phi_m \sin \omega t] \quad \therefore e = -\phi_m \, \omega \cdot \cos \omega t \qquad \text{...(9.3.2)}$$

The maximum value of induced voltage per turn is given by substituting $\cos \omega t = \pm 1$.

$$\therefore e_{max} = \omega\, \phi_m = 2\,\pi f\, \phi_m \text{ volts} \qquad \text{...(9.3.3)}$$

Step 4 : Obtain the rms value of "e" per turn :

$$\text{RMS value of "e" per turn} = \frac{e_{max}}{\sqrt{2}} = \frac{2\,\pi\, f\, \phi_m}{\sqrt{2}} = \sqrt{2}\,\pi f\, \phi_m = 4.44\, f\, \phi_m \qquad \text{...(9.3.4)}$$

Step 5 : Obtain the expressions for induced voltages E_1 and E_2 :

Let E_1 be the rms induced voltage in the primary winding with N_1 turns and E_2 be the rms induced voltage in the secondary winding having N_2 turns.

$\therefore$ RMS value of induced voltage in primary is,

$$E_1 = \text{RMS value of "e" per turn} \times \text{Number of primary turns}$$

$$\therefore E_1 = 4.44\, f\, \phi_m \times N_1 = 4.44\, f \cdot N_1 \cdot \phi_m \text{ volts} \qquad \text{...(9.3.5)}$$

Similarly rms value of induced voltage in the secondary winding is,

$$E_2 = \text{RMS value of "e" per turn} \times \text{Number of secondary turns}$$

$$\therefore E_2 = 4.44\, f\, N_2\, \phi_m \text{ volts} \qquad \text{...(9.3.6)}$$

Equations (9.3.5) and (9.3.6) represents the e.m.f. equations.