EE3010 – Electrical Devices and Machines

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Lecture Notes on

Transformers

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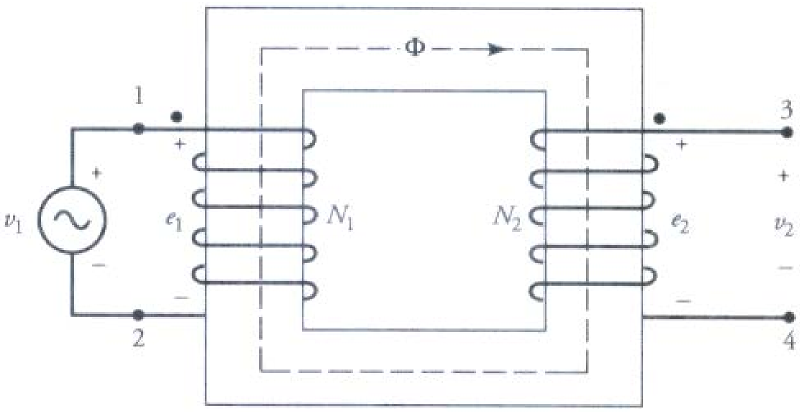
INTRODUCTION

- A simplest transformer consists of two coils wound on a common magnetic core:
  - Primary Winding
  - Secondary Winding



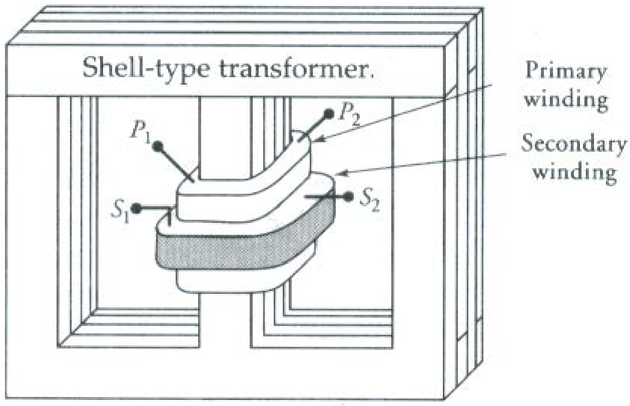
- A time varying current produced by a time varying voltage connected one winding establishes a time varying flux in the coil. The flux links the secondary winding inducing a voltage in the secondary winding.
  - Step-up transformer, e.g. 110 Vac ⇒ 220 Vac
  - Step-down transformer, e.g. 220 Vac ⇒ 110 Vac

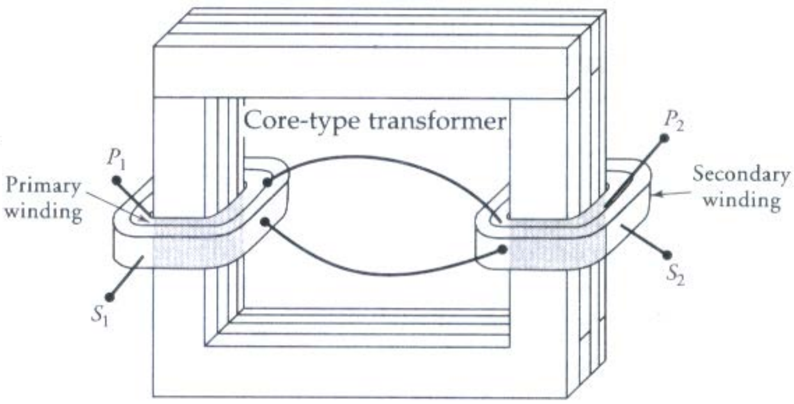
  Either winding can be connected to the source or the load.
- Power transfer from one winding to the secondary winding occurs through the magnetic field/magnetic flux in the core.
- The frequency in the secondary winding is the same as in the primary winding, i.e. $f_1 = f_2$.

CONSTRUCTION

- The core is made of thin 'electrical steel' laminations in order to reduce the core (eddy current and hysteresis) losses. The core is of two types:

(a) Shell type (b) Core type





- The windings may be directly wound on the core in small transformers. However, for high-power transformers, the windings are usually form-wound and then assembled over the core.

- A cooling system is an integral part of the transformer. Usually a transformer may be cooled by natural air or forced air circulation. When natural air or forced air circulation is not enough, the whole transformer is immersed in a transformer oil tank.

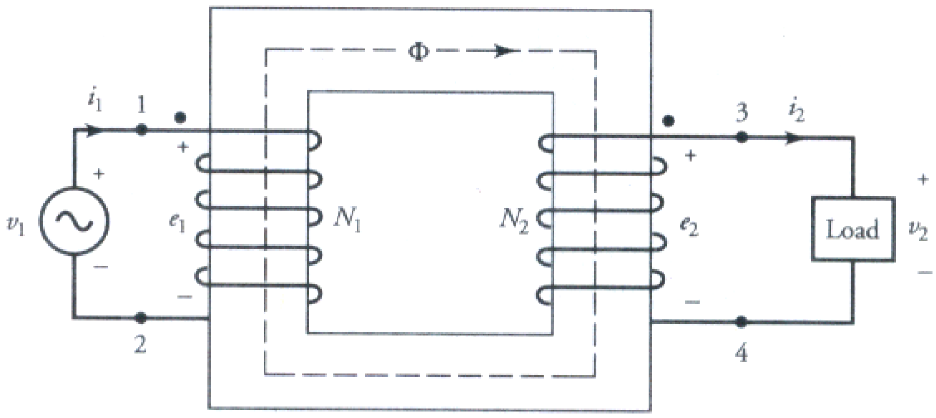
IDEAL TRANSFORMER

- The ideal condition assumptions are:
  - The windings have negligible resistance $\Rightarrow$ no copper losses in the windings, no voltage drops.
  - All the flux is confined the core and therefore the same flux links both the windings. **As $\mu_c \to \infty$, $R_c = (l/\mu_c A) \to 0$**
  - The permeability of the core is infinitely high, which implies that a vanishingly small mmf (current) is required to set up the flux φ. $\boldsymbol{N i \downarrow = \varphi R_c \downarrow}$
  - The core does not incur any hysteresis or eddy current loss $\Rightarrow$ no core losses.

- If the number of turns in the two windings be N_1 and N_2, then Faraday's Law gives

$$v_1 = e_1 = N_1 \frac{d\varphi}{dt}$$

$$v_2 = e_2 = N_2 \frac{d\varphi}{dt}$$



$$\frac{v_1}{v_2} = \frac{e_1}{e_2} = \frac{N_1}{N_2} = a \text{ (say)}$$

where '***a***' is called the turns ratio.

IDEAL TRANSFORMER (CONT'D)

- As the core material is ideal, the total mmf required to create the flux would be vanishingly small, so that

$$N_1 i_1 - N_2 i_2 = 0 \quad \Rightarrow \quad N_1 i_1 = N_2 i_2 \quad \Rightarrow \quad \frac{i_2}{i_1} = \frac{N_1}{N_2} = a$$

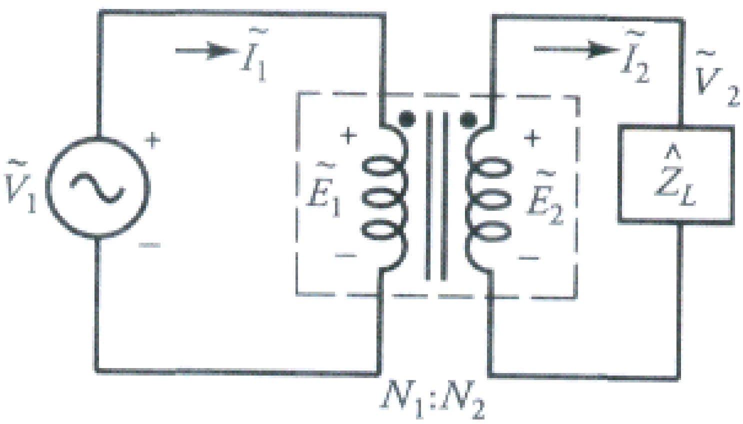
- From the above two equations,

$$\frac{v_1}{v_2} = a = \frac{i_2}{i_1} \quad \Rightarrow \quad v_1 i_1 = v_2 i_2$$

- Expressing these equations in effective or rms quantities,

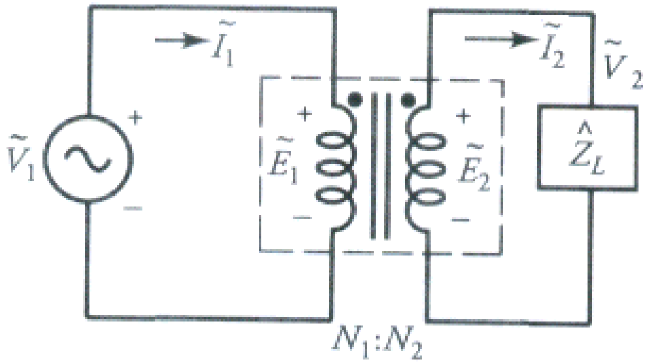
$$\frac{V_1}{V_2} = a, \quad \frac{I_2}{I_1} = a, \quad \text{and,} \quad V_1 I_1{*} = V_2 I_2{*} \quad (\text{also } V_1 I_1 = V_2 I_2)$$

- An ideal transformer connected to a source on one side and a load on the other side can be schematically represented as shown, where



$$\frac{V_1}{V_2} = \frac{E_1}{E_2} = a, \quad \text{and} \quad \frac{I_2}{I_1} = a \Rightarrow \frac{I_2}{a} = I_1$$

REFERRED VALUES



- For a voltage V_2 in the secondary side of the transformer, the primary voltage will be: $V_1 = aV_2 = V_2'$ *(say)*
- And, for a current I_2 in the secondary side the current in the primary will be: $I_1 = I_2/a = I_2'$ (say)
- V_2' and I_2' are called the referred values of V_2 and I_2 referred to the primary side respectively.
- If Z_2 is the load impedance on the secondary side, then, $Z_2 = \dfrac{V_2}{I_2}$

  On the primary side the impedance will appear to be:

$$Z_1 = \frac{V_1}{I_1} = \frac{aV_2}{I_2/a} = a^2\frac{V_2}{I_2} = a^2 Z_2 = Z_2' \ (say)$$

  Z_2' is the referred value of Z_2 referred to the primary side.
- Similarly, V_1, I_1, and Z_1 when referred to the secondary side become:

$$V_1' = V_1/a, \quad I_1' = aI_1, \quad \text{and} \quad Z_1' = Z_1/a^2$$