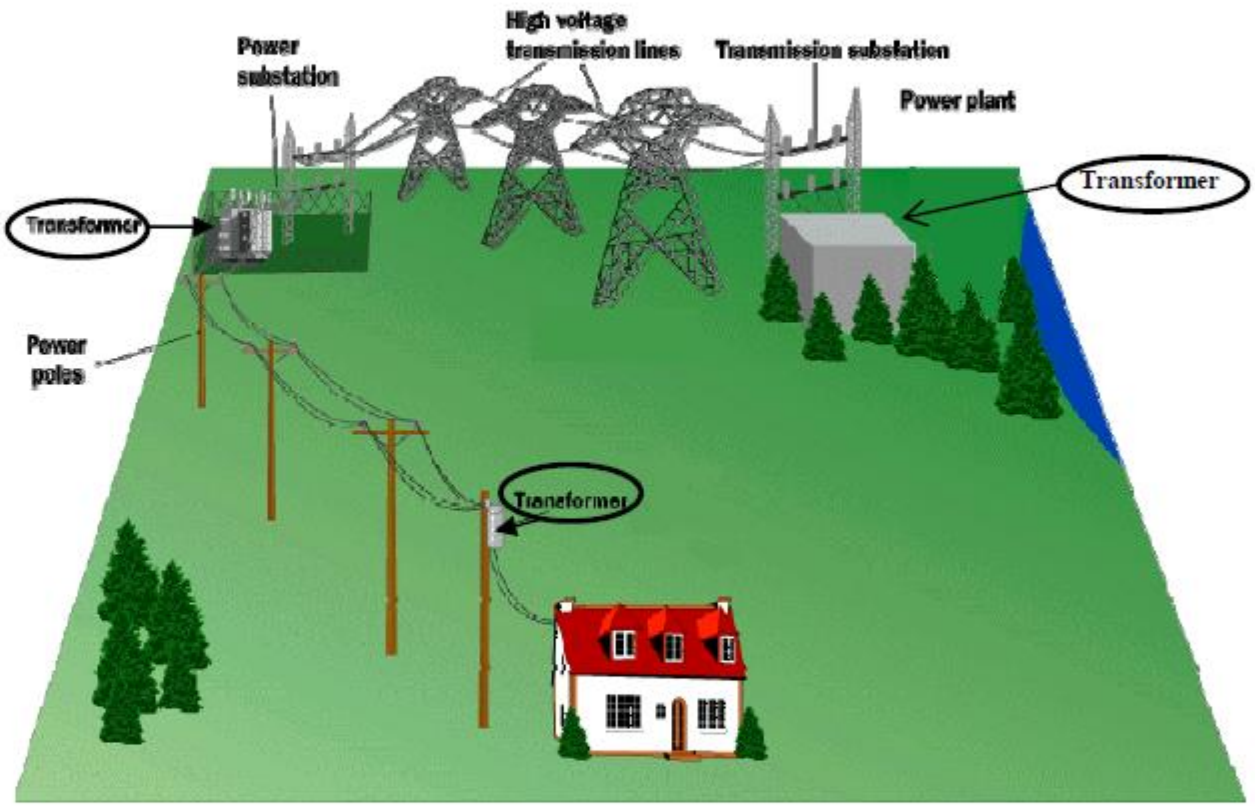
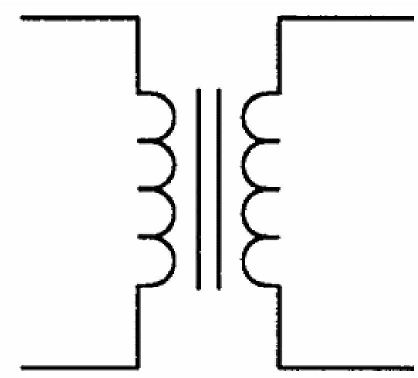
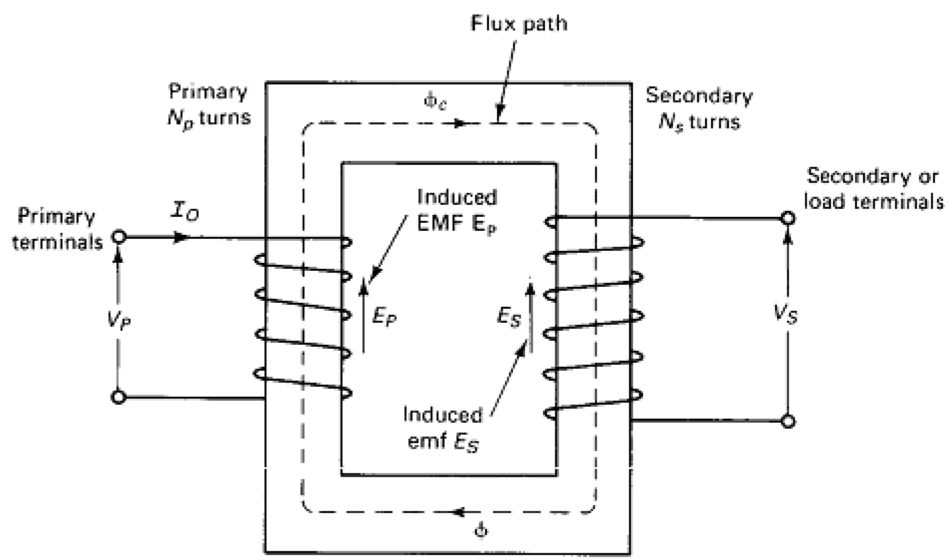
Transformers



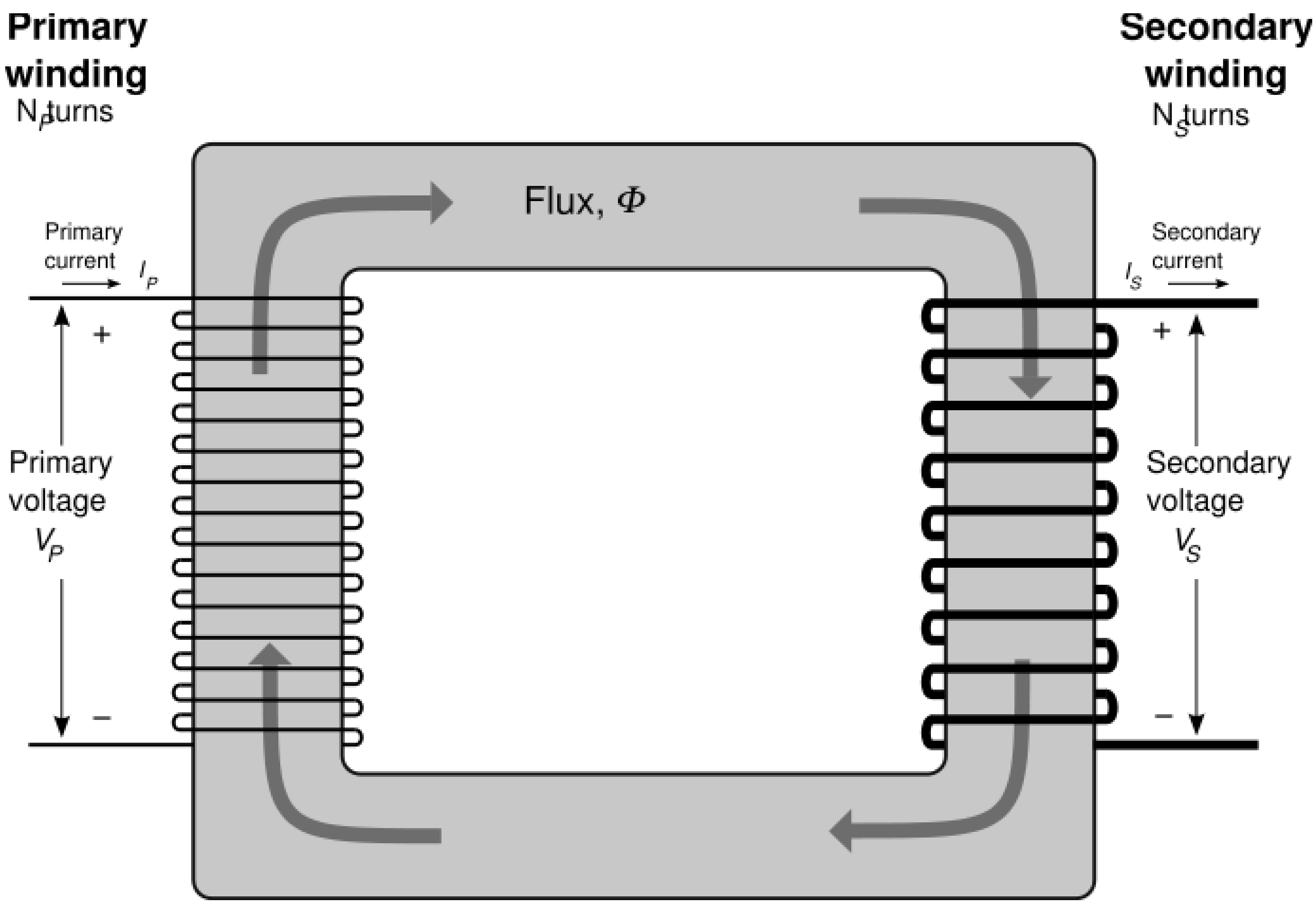
- Static electromagnetic device which converts AC from one voltage to another without change in frequency.
- Consists of two windings that are electrically isolated from each other.
- AC voltage when applied to one winding sets up alternating flux in the magnetic core.
- This flux links with the other magnetic core and induces emf which circulates current when connected to load.



- Winding to which input is applied is called primary winding.
- Winding which is connected to the load is called secondary winding.



Principle of Operation



- Alternating voltage V_p is applied at primary coil , a current I_p flows producing magnetic flux in the core.
- As per Faraday's laws of electromagnetic induction, self-induced emf is set up in primary given by,

$$E_p = -N_p \frac{d\phi}{dt}$$

- Assuming that there is no leakage flux, ϕ will link with each turn of secondary coil S.
- This sets up a mutually induced emf given by,

$$E_s = -N_s \frac{d\phi}{dt}$$

- This emf will circulate current in the load circuit

Ideal transformer

- Core is highly permeable so that it requires very small magnetomotive force(mmf) to set up flux in the core.
- Leakage flux is zero, i.e. entire flux is confined to the core and links with both windings.
- Resistance of primary and secondary winding is negligible.
- There are no losses due to resistance, hysteresis and eddy currents.

- For an ideal transformer,

$$I_p N_p = I_s N_s \ (mmf\ of\ the\ windings)$$

$$V_p I_p = V_s I_s$$

$$\frac{E_p}{E_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s} = a \ (turns\ ratio)$$

emf equation

emf induced due to change of main flux is $e_p = -N_p \frac{d\phi}{dt}$

Main flux is $\phi = \phi_{\max} \sin \omega t$

$$e_p = -N_p \frac{d}{dt}(\phi_{\max} \sin \omega t)$$

$$= -N_p \omega \phi_{\max} \cos \omega t$$

$$E_{p\max} = N_p \omega \phi_{\max}$$

$$rms value is given by,$$

$$E_p = \frac{E_{p\max}}{\sqrt{2}} = \frac{N_p \omega \phi_{\max}}{\sqrt{2}} = \frac{N_p 2\pi f \phi_{\max}}{\sqrt{2}}$$

$$= 4.44\, f N_p \phi_{\max}\ volts$$

$$= 4.44\, f N_p B_m A_i\ volts$$

Emf in secondary is $= 4.44\, f N_s B_m A_i\ volts$

f- frequency

B_m –maximum flux density

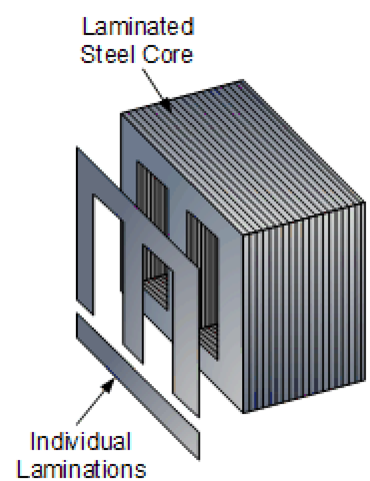
A_i - cross-sectional area

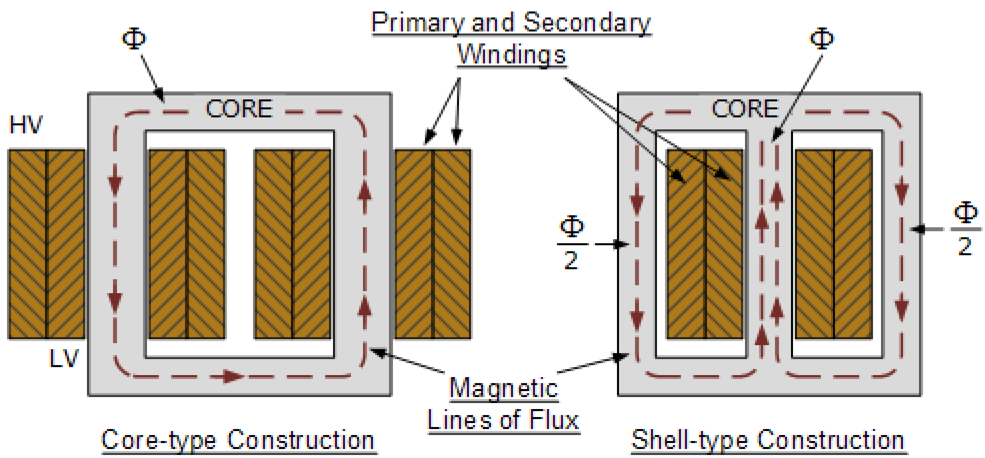
- When a voltage is applied to the primary keeping the secondary open circuited, a current I_m ~ 0 phase shifted 90°(lagging) w.r.t the primary voltage would be present.
- The current I_m and induced flux are in phase.
- We already know that flux lags e_p by 90°.
- Therefore e_p lags v_p by 180°.

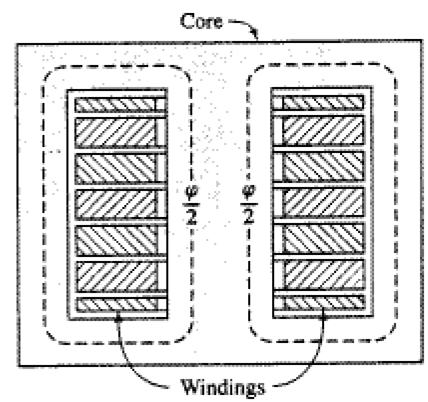
Construction

1. Magnetic circuit (core)
2. Electric circuit (primary and secondary windings)
3. Dielectric circuit consisting of insulation
4. Tank and accessories

1. Magnetic circuit(cores)
   - Provides path to the flow of magnetic flux
   - Cores are laminated to reduce eddy current loss
   - The iron core is made of thin laminated silicon steel (2-3 % silicon)
   - Transformers types based on magnetic circuit :- a) core type b) shell type




Primary and Secondary Windings
Φ
CORE
HV
LV
Φ
CORE
Φ/2
Φ/2
Magnetic Lines of Flux
Core-type Construction
Shell-type Construction


Core
φ/2
φ/2
Windings

- Electric circuit
  - Primary and secondary winding(copper)
  - Insulation may be double cotton or single cotton with layer of enamel
- Dielectric circuit
  - Used to insulate conducting parts b/w magnetic and electric parts
  - Insulators used are paper, bakelite or pressboard

- Tank and accessories
  - Tank
    - Assembled transformer with magnetic frame and windings are housed in proper tank that contains transformer oil. Tanks are fabricated from welded sheet steel. Lids from cast iron. Water-proof gasket used at joints
  - Accessories
    - Conservator:- airtight cylindrical metal drum supported horizontally. Used for oil expansion and contraction volume compensation while over loading.
    - Breather:- Mainly calcium chloride or silica gel which extracts moisture from the air which enters the tank during expansion and contraction of air.
    - Bushing:- Current carrying rod and porcelain cylinder for isolation.

Losses in a transformer

- Iron losses
  - caused by varying magnetization
  - constant
  - sub divided as hysteresis and eddy current losses
    - Hysteresis loss: The energy used by core for alignment with the varying flux is dissipated as heat within the iron core.
    - Eddy current loss: Varying magnetic field cuts the conducting core material and induces a voltage into it. The induced voltage causes random currents to flow through the core which dissipates power in the form of heat.
- Copper loss: I^2R loss

Efficiency

$$efficiency, \eta = \frac{output\ power}{input\ power}$$

$$input\ power = output\ power + total\, losses$$

$$total\, losses = iron\, losses + copper\, losses$$

$$= W_i + (I_p^2 R_p + I_s^2 R_s)$$

$$output\ power = V_s I_s \cos\theta$$

$$\therefore efficiency\,(\eta) = \frac{V_s I_s \cos\theta}{V_s I_s \cos\theta + W_i + (I_p^2 R_p^2 + I_s^2 R_s^2)}$$

Condition for maximum efficiency

Total copper losses= $I_S^2 \overline{R_S}$

$$\eta = \frac{V_s I_s \cos\theta}{V_s I_s \cos\theta + W_i + I_s^2 \overline{R}_s}$$

efficiency maximum when the denominator is minimum, i.e.

$$\frac{d}{dI_s}\left(V_s \cos\theta + \frac{W_i}{I_s} + I_s \overline{R}_s \right) = 0$$

$$W_i = I_s^2 \overline{R}_s$$

Total copper loss= iron loss

All day efficiency

$$all\ day\ efficiency, \eta = \frac{output\ \ in\ kWh\ over\ 24\ hours}{input\ \ in\ kWh\ over\ 24\ hours}$$

$$= \frac{output\ \ in\ kWh\ over\ 24\ hours}{output\ \ in\ kWh\ \ over\ 24\ hrs + 24 * W_i + (copper\ losses\ in\ kWh\ in\ 24\ hrs)}$$