TRANSFORMER

1. A electrostatic device which is used to transfer electrical energy from one circuit to another by mutual induction of two electric circuits without change in frequency which is working under the principle of Electromagnetic Induction.

→ CONSTRUCTION

1) MAGNETIC CORE

- Low reluctance path
- Medium of higher relative permeability
- Formed by pure magnetic material
- High thermal coefficent and well insulated.
- Eg. SOFT IRON, Al, Al-Ni-Co.
- Thin laminations

2) WINDINGS

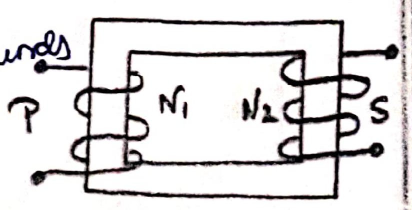
- Less resistivity
- Insulated

3) TIME VARYING MAGNETIC FLUX

→ TYPES

1) CORE TYPE

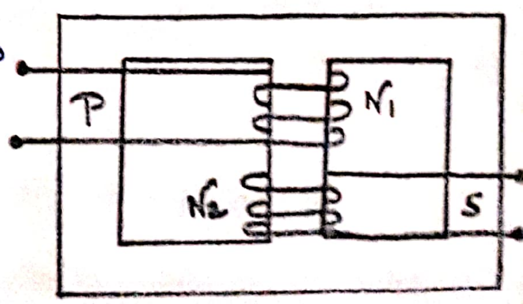
- Winding surrounds core



- Low output
- More losses
-

2) SHELL TYPE

- Core surrounds windings



- High Output
- Less Losses
-

→ WORKING

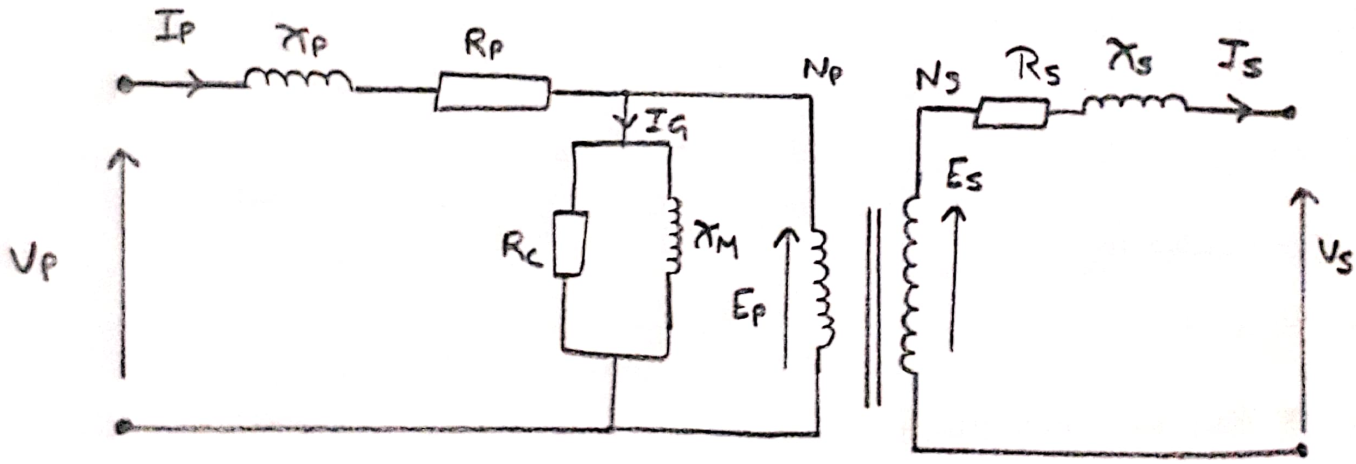
- If one winding is connected to an A.C source, an alternating flux is setup in the core. This flux links with the other coil producing induced EMF.

- According to Faradays law of EMI, $\mathcal{E} = M\frac{dI}{dt}$.

- If second coil is closed, a current flows through it.

- The coil connected to AC source is Primary winding/coil.

→ EQUIVALENT CIRCUIT



- R_p & R_s represent (resistive) Copper losses

- x_p & x_s represent leakage flux. where $x_p \propto I_p$
  $x_s \propto I_s$

- I_m is proportional to voltage applied to core, lags the applied voltage by $90°$. It is modelled by x_m. (CORE EXCITATION)

- $I_{h+e} \propto$ applied voltage and is inphase with V_p. It is modelled by R_c.
  where $I_{h+e} \rightarrow$ Hysteresis + eddy current

→ LOSSES:

1) COPPER LOSS (I^2R)

Resistive heating losses in primary and secondary winding of transformer.

2) EDDY CURRENT LOSS:

Resistive heating losses in core of transformer. Directly proportional to square of voltage applied to transformer.

3) HYSTERESIS LOSSES:

Associated with the rearrangement of magnetic domain in core during each half cycle. Complex, non linear functions of applied voltage.

4) LEAKAGE FLUX

The fluxes which escape the core and pass through only one of the transformer windings are leakage flux. The escaped fluxes produce a self inductance in primary & secondary coils.

→ EFFICIENCY

$$\boxed{\eta = \frac{\text{Power Output}}{\text{Power Input}}}$$

or

$$\boxed{\eta = \frac{\text{Output Power}}{\text{O.P} + \text{Iron Loss} + \text{Cu Loss}}}$$

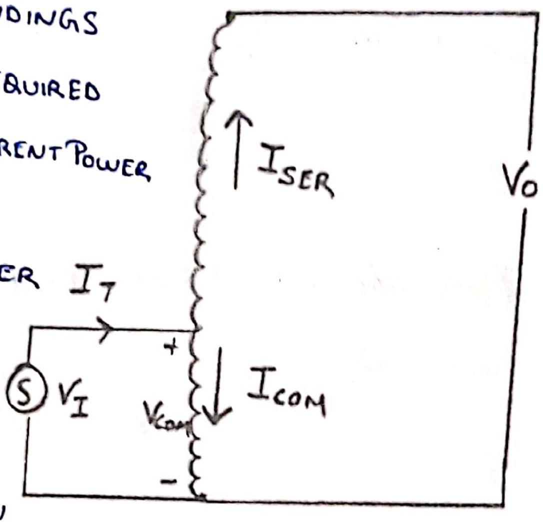
→ VOLTAGE REGULATION

Percentage voltage difference b/w no load and full load.

$$\boxed{\%\ V.R = \frac{E_{\text{NO LOAD}} - V_{\text{FULL LOAD}}}{V_{\text{FULL LOAD}}}}$$

AUTO TRANSFORMER

- COMMON WINDINGS
- LESS COPPER REQUIRED
- INCREASED APPARENT POWER
- EASY REGULATION
- SMALLER & CHEAPER
- NO MAGNETIC ISOLATION
- BREAKING CAN CAUSE OVERLOAD IN CASE OF STEP-DOWN



- TRANSFORMED APPARENT POWER:

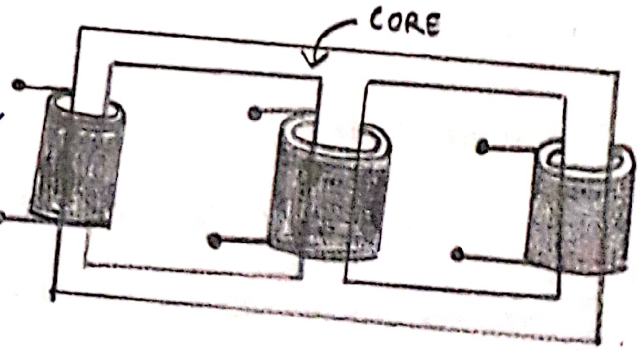
$$\boxed{S_{TRANS} = V_{COM} \cdot I_{COM}}$$

- CONDUCTED APPARENT POWER

$$\boxed{S_{COND} = V_{COM} \cdot I_{SER}}$$

3 PHASE TRANSFORMER

- USED TO TRANSFER HIGH AMOUNTS OF ENERGY
- THREE PAIRS OF WINDINGS
- MORE EFFICIENT
- SMALLER CORE SIZE



- Primary winding of transformer is energised from a three phase supply. Flux is produced by the ~~core~~ primary windings in the core. Any two limbs act as return path for flux in third limb.

→ CONNECTIONS

Δ-Δ (0° or 180°)

- GOOD FOR BALANCED & UNBALANCED LOADING
- IF ONE TRANSFORMER STOPS WORKING THE OTHER TWO STILL WORK
- NO NEUTRAL POINT

Y-Y

- NOT SUITABLE FOR UNBALANCED LOADING
- MAGNETIZING CURRENT IS VERY NON-SINUSOIDAL

Δ-Y

- $V_P^P = V_L^P$
- $V_L^S = \sqrt{3}\, V_P^S$

Y-Δ

- $V_L^P = \sqrt{3}\, V_P^P$
- $V_L^S = V_P^S$

EMF EQUATION OF TRANSFORMER

Since applied voltage is sinusoidal at primary, the flux, so produced by exciting current, is also sinusoidal.

Thus core flux is given by,

$$\phi = \phi_0 \sin\omega t$$

If coil has N turns then instantaneous EMF,

$$\varepsilon = -N\frac{d\phi}{dt}$$

$$= -N\frac{d(\phi_0 \sin\omega t)}{dt} = -2\pi f \phi_0 \cos\omega t \cdot N \left[\because \cancel{\frac{d\phi_0}{dt} \cdot V} \ \& \ \omega = 2\pi f \right]$$

$\Rightarrow$ MAX EMF, $\varepsilon_0 = 2\pi f \phi_0 \cdot N$

dividing both sides by $\sqrt{2}$,

$$\varepsilon_{RMS} = \frac{2\pi}{\sqrt{2}} \phi_0 \cdot fN$$

$$\Rightarrow \boxed{\varepsilon_{RMS} = 4.44\, \phi_0 \cdot (fN)}$$

If $N = N_1$, $\boxed{\varepsilon_1 = 4.44\, \phi_0 f N_1}$

If $N = N_2$, $\boxed{\varepsilon_2 = 4.44\, \phi_0 f N_2}$

where, $\varepsilon_1 \rightarrow$ INDUCED VOLTAGE AT PRIMARY

$\varepsilon_2 \rightarrow$ INDUCED VOLTAGE AT SECONDARY

No Load Transformer.

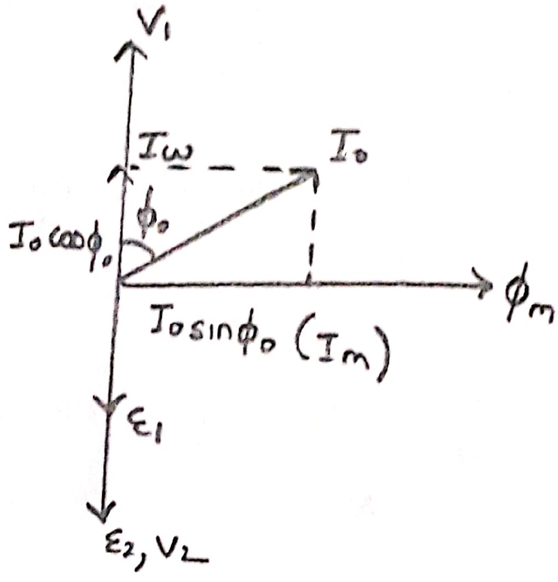
- When secondary winding is open.
- E_1 & E_2 lag behind ϕ_m by a phase angle $\pi/2$
- V_1 leads by $\pi/2$.
- I_0 lags behind applied voltage by ϕ_0.
  It consists of two components,

  $I_w \rightarrow I_0 \cos\phi_0$

  $I_m \rightarrow I_0 \sin\phi_0$

$$\boxed{\phi_0 = \tan^{-1}\frac{I_m}{I_w}}$$

$\phi \rightarrow$ No Load Power Factor Angle



- I_m (Magnetising component) is in phase with ϕ_m.
- I_w (Hysteresis + Eddy).

Loaded Transformer

- Load current I_2 flows through secondary winding.