Transformers.

* Electrical Transformer is a static electrical machine which transforms electrical power from one circuit to another circuit, without changing the frequency. Transformer can increase or decrease the voltage with corresponding decrease or increase in current

* Working Principle of transformer.
The basic principle behind working of of transformer is the phenomenon of mutual induction between two windings linked by common magnetic flux.
Mutual inductance :- Current through primary coil changes with respect to time, magnetic flux will also change in both primary and secondary coil

* Working of transformer
A transformer consists of 2 inductive coils :- primary and secondary. The coils are electrically separated but magnetically linked to each other. When, primary winding is connected to a source of alternating voltage, alternating magnetic flux is produced around the winding. The core provides magnetic path for flux, to get linked with the secondary winding. Most of flux gets linked with secondary winding is called useful flux and flux which doesnot get linked with secondary winding is called as "leakage flux". As the flux produced is alternating, EMF gets induced in secondary winding due to Faraday's law of EMI. Emf is called "mutually induced emf", and

the frequency of mutually induced ~~current~~ emf is same as that of supplied emf. If secondary winding is closed circuit, the mutually induced current flows through it, and hence electrical energy is transferred from primary to secondary

Transformation Ratio

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{E_1}{E_2} = \frac{I_2}{I_1} = k$$

If $N_1 > N_2$ or $V_1 > V_2$ (Step down) $k<1$

If $N_2 > N_1$ or $V_2 > V_1$ (Step Up) $k>1$

- Ideal Transformer (No loss) Infinite permeability, No leakage flux, zero winding resistance, 100% efficience,

$$V_1 I_1 = V_2 I_2$$

* Construction

(1) Magnetic core Eg:- Soft iron, Al, Al-Ni-Co

→ Low reluctance path path

→ Thin laminations

→ Formed by pure magnetic material

→ High thermal coefficient and well insulated

→ medium of Higher relative permeability

(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

* Losses in Transformer

1) Copper loss :- Due to ohmic resistance of transformer windings. Cu Loss for Primary is $I_1^2 R_1$
" " " Secondary is $I_2^2 R_2$

It is clear that Cu loss is proportional to square of current and current depends on load. Hence, copper loss in transformer varies with load.

2) Eddy current loss - When flux generated by primary links with secondary, it produces induced emf in it. But some part of this flux also gets linked with other conducting parts like steel core or iron body or transformer, which will result in induced emf in those parts, causing small circulating current in them. This current is called as eddy current. Due to these eddy currents, some energy will be dissipated in form of heat.

3) Hysteresis loss :- Due to reversal of magnetization in transformer core.

4) Leakage flux

* EMF equation of transformer

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

$$\varepsilon = -N\frac{d\phi}{dt} = -N\frac{d(\phi_0 \sin\omega t)}{dt}$$

$$= -N\phi_0 \omega \cos\omega t$$

$$= -2\pi f N \phi_0 \cos\omega t$$

Max EMF, $\varepsilon_0 = 2\pi f \phi_0 N$

$\mathcal{E}_{max} = 2\pi f \Phi_0 N$

Dividing both sides by $\sqrt{2}$

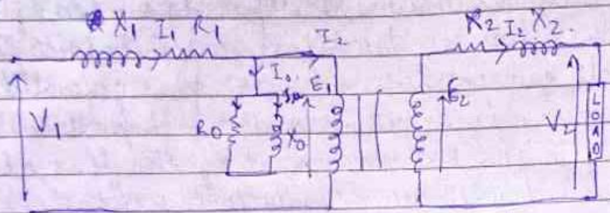
$$\mathcal{E}_{rms} = \frac{2\pi}{\sqrt{2}} \Phi_0 f N$$

$$\mathcal{E}_{rms} = 4.44\ \Phi_0 f N$$

If $N = N_1$, $\mathcal{E}_1 = 4.44\ \Phi_0 f N_1$

$N = N_2$, $\mathcal{E}_2 = 4.44\ \Phi_0 f N_2$

* Equivalent Circuit



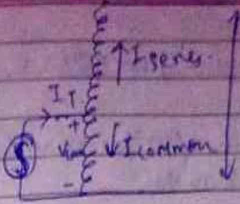
R_1 and R_2 represent copper loss.

X_1 and X_2 represent leakage flux

$X_1 \propto I_1$, $X_2 \propto I_2$

I_μ = Hysterisis Loss.

* Auto transformers
  - Common windings.
  - Less copper required.
  - Increased Apparent Power.
  - Easy Regulation.
  - Smaller and Cheaper.
  - No magnetic isolation
  - Breaking can cause overload incase of stepdown



* 3 phase Transformers
  - Used to transfer high amount of energy.
  - 3 pairs of shell type windings.
  - More efficient.
  - Smaller core size

→ Connections

① Δ-Δ

Primary & secondary are connected in delta configuration

→ Advantages
  - Provides isolation b/w primary & secondary circuits
  - Suitable for unbalanced loads.

→ Disadvantages
  - Cannot supply a neutral wire
  - Donot provide voltage transformation.

② Δ-Y

Primary in Δ & Secondary in Y

→ Advantages.
  - Provides isolation
  - Can supply a neutral wire.
  - Can provide voltage transformation (step-down)

→ Disadvantages
  - Cannot supply a phase shift b/w primary & secondary circuits
  - May not be suitable for ~~balanced~~ unbalanced loads.

3) Y-Delta
Primary in Y and secondary in Delta

→ Advantages
- Can supply a phase circuit b/w primary & sec.
- Suitable for unbalanced loads
- Can provide voltage transformation (step-up)

→ Disadvantages
- ~~Can supp~~ Cannot supply a neutral wire.
- May not provide isolation b/w primary & sec.

4) Y-Y
Both sec & primary in Y config.

→ Advantages
- Provides isolation
- Can supply a neutral wire.
- Can provide votage transformation (step-down)

→ Disadvantage
- Cannot supply a phase shift b/w the primary and secondary.
- May not be suitable for unbalanced loads.

Not in syllabus

* Transformer ratings

① KVA rating $= \frac{E_1 I_1}{1000} = \frac{E_2 I_2}{1000}$ ... Full Load

② $I_1 = \frac{KVA\ rating \times 1000}{E_1}$

Q1 A 50 KVA, single phase transformer has 600 turns on primary windings & 40 turns on secondary. The primary winding is connected to a 2.2 kV, 50 Hz supply. Determine ① Secondary Volt at no load ② Primary & Secondary currents at full load

ϕ = Magnetic field × Area

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

$E_2 = \frac{40}{600} \times 2200 = 146.67V$

$I_1 = \frac{KVA\ rating \times 1000}{E_1} = \frac{50 \times 1000}{2200} = 22.73A$

$I_2 = \frac{KVA\ rating \times 1000}{E_2} = \frac{50 \times 1000}{146.67} =$

* % regulation = $\frac{\text{(Secondary terminal vtg on no load)} - \text{(Sec terminal vtg on given load)}}{\text{(Sec. terminal vtg on no load)}}$

$= \frac{E_2 - V_2}{E_2} \times 100$

% regulation $= \frac{I_2 R_{02} \cos\phi \pm I_2 X_{02} \sin\phi}{E_2} \times 100$

% efficiency = % η

$= \frac{x \times \text{full load KVA} \times \text{Power factor} \times 100}{(x \times \text{full load KVA} \times PF) + W_i + x^2 W_{cu}}$

Max efficiency $= x = \sqrt{\frac{W_i}{W_{cu}}}$

Q2 A 20 KVA transformer has iron loss of 450 W and full load copper loss of 900 W. If P.F of load is 0.8 lagging. Calculate ① Full load efficiency ② the load at which max efficiency occurs ③ Max efficiency.

Ans2) $W_i = 450W$, $W_{cu} = 900W$, P.F = 0.8 (lagging)

$\% \eta = \frac{1 \times 20 \times 0.8}{(1 \times 20 \times 0.8) + 0.45 + 1^2 \times 0.9} \times 100$

$= 92.22\%$

(2) Max efficiency $= x = \sqrt{\frac{W_i}{W_{cu}}} = \sqrt{\frac{450}{900}} = 0.707$.

At 70.7 % full load.

(3) For Max efficiency $= W_i + x^2 W_{cu}$ $[W_i = W_{cu}]$

$= W_i + W_i$

$= 2W_i$.

$$\% \eta = \frac{0.707 \times 20 \times 0.8}{(0.707 \times 20 \times 0.8) + 2 \times 0.45}$$

$= 92.63 \%$