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The power losses in a transformer are of two types:

1. **Core or Iron Losses (Pi)**
2. **Copper Losses (Pc)**

(i) Core or Iron Losses (Pi):

Iron or core losses consist of: P_i

$$ P_i = \text{Hysteresis loss} + \text{Eddy current loss} \quad = \text{Constant losses} $$

These can be determine by **open circuit test .**

- These occur in the Transformer core due to the **alternating flux**.

Hysteresis Loss:

- **Hysteresis Loss:** $$ Khf \mathrm{B}_{m}^{1.6} watt/m^{3} = Khf\mathrm{B}_{m}^{1.6}V $$

where:

- Kh = Hysteresis coefficient or Steinmetz constant
- f= frequency or no of cycles of magnetizing
- Bm = maximum flux density in the magnetic material
- V = volume of magnetic material

Eaddy Current Loss:

- **Eaddy Current Loss:**

$$ Khf ^{2}\mathrm{B}_{m}^{2}t^{2}watt/m^{3} = Khf ^{2}\mathrm{B}_{m}^{2}t^{2}V $$

where:

- Ke =coefficient of the eddy current
- f= frequency of reversal of the magnetic field
- Bm = maximum flux density in the magnetic material
- V = volume of magnetic material
- T=Thickness of material / Lamination

* The hysteresis loss can minimized by using Still of high silicon content , Where as eddy current loses can reduce by using core of thin Laminations

Minimization of Hysteresis Loss and Eddy Current Loss:

- Hysteresis loss → reduced by using **steel with high silicon content**
- Eddy current loss → reduced by using **thin laminations** in the core

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(ii) Copper Losses (Pc):

These occur in both the primary and secondary windings due to ohmic resistance. They are variable losses and can be determined by the **short-circuit test**.

Total Copper Loss

$$ P_c = I_1^2 R_1 + I_2^2 R_2 $$

$$
= I^2 R_{eq} \quad \text{(referred to secondary)}
$$

Total Loss in a Transformer: –

$$ P_{i}+P_{c} = \text{Constant losses + Variable Losses} $$

Efficiency of a Transformer

$$ Efficiency (\eta) =\frac{Output Power}{Input Power}$$

$$ =\frac{Output Power}{output Power Losses} $$

$$=\frac{Output Power}{output Power + Copper loss+core loss}$$

$$=\frac{Output Power}{output Power +P_{c}+P_{i}}$$

Full load Efficiency =

$$ (\eta)_{FL} = \frac{Full Load V_{a}\ast P_{f}}{(Full Load V_{a}\ast P_{f})+P_{c}+P_{i}}$$

Condition for Maximum Efficiency:

$$ Output Power = V_{2}I_{2}cos\phi_{2} $$

If R_{02} is the total resistance of the transformer reffed to secondary then,

Total copper loss (P_c)

$$ P_c = I_2^2 R_{02}
\ $$

$$Total Loss =P_{i}+P_{c}$$

Therfore,

Transformer efficiency (η)

$$ =\frac{Output Power}{Input Power} $$

$$= \frac{V_{2}I_{2}cos\phi_{2}}{V_{2}I_{2}cos\phi_{2}+P_{c}+P_{i}} $$

$$ = \frac{V_{2}I_{2}cos\phi_{2}}{V_{2}I_{2}cos\phi_{2}+I_2^2 R_{02}+P_{i}} $$

$$ \frac{\frac{V_{2}I_{2}cos\phi_{2}}{I_{2}}}{\frac{V_{2}I_{2}cos\phi_{2}+I_2^2 R_{02}+P_{i}}{I_{2}}} $$

$$ \frac{V_{2}I_{2}cos\phi_{2}}{V_{2}I_{2}cos\phi_{2}+\frac{P_{i}}{I_{2}}+I_{2} R_{02}} $$

V_2 si is approximately constant.for two loads, of give power factor, efficiency depends upon load current I_2. So, numerator is constant and the efficiency to be maximum, the denominator should be minimum.

$$ \frac{d(V_{2}cos\phi_{2}+\frac{P_{i}}{I_{2}}+I_{2}R_{02})}{dI_{2}} $$

$$\Rightarrow \frac{0+(-\frac{P_{i}}{I_{2}})+1.R_{02}}{1}=0 $$

$$\Rightarrow -\frac{P_{i}}{I_{2}^{2}}=-R_{02}$$

$$\Rightarrow P_c = I_2^2 R_{02} \ $$

Core loss = copper loss (Proved).

Hence,

efficiency of a transformer will be maximum when copper losses are equal to constant core losses.

Output KVA for maximum efficiency =$$ Full Load KVA \sqrt{\frac{Iron Loss}{Full Load Copper Loss}}$$

Types of Losses in Transformer

1. Hysteresis Loss (Ph):

$P_h = K_h f B_m^{1.6} V_e$

2. Eddy Current Loss (Pe):

$P_e = K_e f^2 B_m^2 t^2 V$

3. Copper Loss (Pc):

$P_c = I_1^2 R_1 + I_2^2 R_2$

or (referred to secondary):

$P_c = I_1^2 R_{01} + I_2^2 R_{02}$

4. Total Losses:

Total Losses = $P_i + P_c$

Total Losses = Constant Losses + Variable Losses