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FACULTY OF ENGINEERING & TECHNOLOGY

Electrical Machine-1

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# SINGLE PHASE TRANSFORMER

## Transformer Efficiency

The Efficiency of the transformer is defined as the ratio of useful output power to the input power. The input and output power are measured in the same unit. Its unit is either in Watts (W) or KW. Transformer efficiency is denoted by  $\eta$ .

$$\eta = \frac{\text{output power}}{\text{input power}} = \frac{\text{output power}}{\text{output power} + \text{losses}}$$

$$\eta = \frac{\text{output power}}{\text{output power} + \text{iron losses} + \text{copper losses}}$$

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + P_c}$$

Where,

$V_2$  – Secondary terminal voltage

$I_2$  – Full load secondary current

$\cos\phi_2$  – power factor of the load

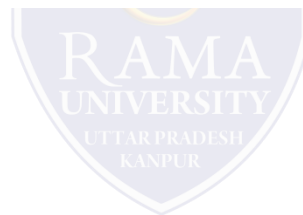
$P_i$  – Iron losses = hysteresis losses + eddy current losses

$P_c$  – Full load copper losses =  $I_2^2 R_{es}$

Consider, the  $x$  is the fraction of the full load. The efficiency of the transformer regarding  $x$  is expressed as

$$\eta_x = \frac{x \text{ X output}}{x \text{ X output} + P_i + x^2 P_c} = \frac{x V_2 I_2 \cos\phi_2}{x V_2 I_2 \cos\phi_2 + P_i + x^2 I_2^2 R_{es}}$$

The copper losses vary according to the fraction of the load.



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## Maximum Efficiency Condition of a Transformer

The efficiency of the transformer along with the load and the power factor is expressed by the given relation

$$\eta = \frac{V_2 I_2 \cos \phi_2}{V_2 I_2 \cos \phi_2 + P_i + I_2^2 R_{es}} = \frac{V_2 \cos \phi_2}{V_2 \cos \phi_2 + P_i / I_2 + I_2 R_{es}} \dots \dots \dots (1)$$

The value of the terminal voltage  $V_2$  is approximately constant. Thus, for a given power factor the Transformer efficiency depends upon the load current  $I_2$ . In equation (1), the numerator is constant and the transformer efficiency will be maximum if the denominator with respect to the variable  $I_2$  is equated to zero.

$$\frac{d}{dI_2} = \left( V_2 \cos \phi_2 + \frac{P_i}{I_2} + I_2 R_{es} \right) = 0 \quad \text{or} \quad 0 - \frac{P_i}{I_2^2} + R_{es} = 0$$

Or

$$I_2^2 R_{es} = P_i \dots \dots \dots (2)$$

i.e Copper losses = Iron losses

Thus, the transformer will give the maximum efficiency when their copper loss is equal to the iron loss.

$$\eta_{\max} = \frac{V_2 I_2 \cos \phi_2}{V_2 I_2 \cos \phi_2 + 2P_i} \quad \text{as } (P_c = P_i)$$

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From equation (2) the value of output current  $I_2$  at which the transformer efficiency will be maximum is given as

$$I_2 = \sqrt{\frac{P_i}{R_{es}}}$$

If  $x$  is the fraction of full load KVA at which the efficiency of the transformer is maximum then,

Copper losses =  $x^2 P_c$  (where  $P_c$  is the full load copper losses)

Iron losses =  $P_i$

For maximum efficiency

$$x^2 P_c = P_i$$

Therefore  $x = \sqrt{\frac{P_i}{P_c}} \dots \dots \dots (3)$

Thus, output KVA corresponding to maximum efficiency

$$\eta_{\max} = x \times \text{full load KVA} \dots \dots \dots (4)$$

$$\eta_{\max} = \sqrt{\frac{P_i}{P_c}} \times \text{full load KVA}$$

$$\eta_{\max} = \text{Full load KVA} \times \sqrt{\frac{\text{iron losses}}{\text{copper losses at full load}}} \dots \dots \dots (5)$$

The above equation (5) is the maximum efficiency condition of the transformer.

