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FACULTY OF ENGINEERING & TECHNOLOGY

Electrical Machine-1

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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 η.

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

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

$$\eta = \frac{V_2 I_2 \text{Cos}\varphi_2}{V_2 I_2 \text{Cos}\varphi_2 + P_i + P_c}$$

Where,

V_2 – Secondary terminal voltage

I_2 – Full load secondary current

$\text{Cos}\phi_2$ – 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

$$\eta_x = \frac{x \text{ X output}}{x \text{ X output} + P_i + x^2 P_c} = \frac{x V_2 I_2 \text{Cos}\varphi_2}{x V_2 I_2 \text{Cos}\varphi_2 + P_i + x^2 I_2^2 R_{es}}$$

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

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

$$\eta = \frac{V_2 I_2 \text{Cos}\varphi_2}{V_2 I_2 \text{Cos}\varphi_2 + P_i + I_2^2 R_{es}} = \frac{V_2 \text{Cos}\varphi_2}{V_2 \text{Cos}\varphi_2 + P_i/I_2 + I_2 R_{es}} \ldots\ldots\ldots(1)$$

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.

$$\frac{d}{dI_2} = \left(V_2 \text{ Cos}\varphi_2 + \frac{P_i}{I_2} + I_2 R_{es} \right) = 0 \qquad \text{or} \qquad 0 - \frac{P_i}{I_2^2} + R_{es} = 0$$

Or

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

i.e Copper losses = Iron losses

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

$$\eta_{max} = \frac{V_2 I_2 \text{Cos}\varphi_2}{V_2 I_2 \text{Cos}\varphi_2 + 2P_i} \qquad as\ (P_c = P_i)$$

SINGLE PHASE TRANSFORMER

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^2P_c (where P_c is the full load copper losses)

Iron losses = P_i

For maximum efficiency

$x^2 P_c = P_i$

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

Thus, output KVA corresponding to maximum efficiency

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

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

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

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