3.4.6 REGULATION LOSSES AND EFFICIENCY

3.4.6.1 REGULATION OF A TRANSFORMER : The Regulation of a Transformer is defined as the variation of second voltage between No load and Full load voltage. The Formulae for percentage of Voltage Regulation is given by

For 'Down' Regulation

$$\% \text{ Voltage Regulation} = \frac{\text{No load voltage} - \text{Full load voltage}}{\text{No load voltage}} \times 100 \quad (3.48)$$

For 'Up' Regulation

$$\% \text{ Voltage Regulation} = \frac{\text{No load voltage} - \text{Full load voltage}}{\text{Full load voltage}} \times 100 \quad (3.49)$$

$$\% \text{ Regulation} = \frac{V_1 - V_2}{V_1} \times 100 \quad (3.50)$$

Where

V_1 = No load voltage

V_2 = Full load voltage

3.4.6.2 LOSSES IN A TRANSFORMER

In static transformer, there are no friction or windage losses. The power losses in a transformer are of two types, such as

1. Core or Iron losses
2. Copper losses

These losses appear ... temperature (ii) Reduces the efficiency.

1. **Core or Iron losses :** It includes both hysteresis and eddy current losses and the above losses occurs due to transformer core alternative flux.

Hysteresis loss $W_h = \eta B_m^{1.6} fV$ watts/m^3 (3.51)

Eddy current loss $W_e = K_e f^2 B_m^2 t^2$ watts/m^3 (3.52)

The above mentioned hysteresis and Eddy current losses depends on

(i) Maximum flux density (B_m) in core

(ii) Supply frequency (f)

Iron or core loss (P_i) = Hysteresis losses + Eddy current losses

Hysteresis loss can be minimised by steel of high silicon content. Similarly, Eddy current losses can be reduced by core of thin lamination.

The Iron or core loss is found from Open circuit test. The input of the transformer when no load condition the core loss is obtained.

2. **Copper losses :** Normally Copper losses occurs both primary and secondary winding due to their Ohmic resistance. The Copper loss can be determined by Short circuit test

Total copper loss $P_c = I_1^2 R_1 + I_2^2 R_2 = I_1^2 R_{01} + I_2^2 R_{02}$

Copper loss $\propto$ (current)^2 (kVA)^2

The copper losses account of total losses.

The total losses in transformation = $P_i + P_c$ = Constant loss + Variable loss (3.53)

3.4.6.3 EFFICIENCY OF TRANSFORMER

The **Efficiency of Transformer** is defined as the ratio of Output power (kW) to Input power (kW).

$$\% \text{ Efficiency} = \frac{\text{Output power}}{\text{Input power}} \times 100$$

The Efficiency can be calculated by (i) Open circuit test (ii) Short circuit test

1. Open circuit test F.L Iron loss = P_i
2. Short circuit test FL Copper loss = P_c

Total losses = $P_i + P_c$ = Iron loss + Copper losses

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{\text{Output} + \text{Losses}}$$

$$= \frac{\text{Input} - \text{Losses}}{\text{Input}} = 1 - \frac{\text{Losses}}{\text{Input}} \quad (3.54)$$

Condition for Maximum Efficiency

The output power of the transformer is given by

Total loss = $P_{iron\ loss} + P_{copper\ loss}$

$$\text{Transformer efficiency } \eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{02}} = \frac{V_2 \cos\phi_2}{V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{02}} \quad (3.5$$

The numerator depends the constant terms such as V_2 and $\cos\phi_2$ for that the efficiency need to be maximum and denominator need to be minimum.

$$\frac{d}{dI_2}(\text{Denominator}) = 0$$

$$d\left(V_2 \cos\phi_2 + \frac{P_i}{I_2} I_2 R_{02}\right) = 0$$

$$0 - \frac{P_i}{I_2^2} + R_{02} = 0$$

$$P_i = I_2^2 R_{02}$$

Iron loss = Copper loss

Hence, the efficiency need to be maximum and the load current is given by

$$I_2 = \sqrt{\frac{P_i}{R_{02}}} \quad (3.5$$

All day Efficiency: The **All day efficiency** of a transformer is defined ratio of Output power to Input power

$$\text{All day efficiency} = \left.\frac{\text{Output Power}}{\text{Input Power}}\right|_{For 24 Hours} \quad (3.5$$

Ratio of output in kωh to input of a transformer over a 24-hour period known a **All day efficiency**.

3.5 THREE PHASE TRANSFORMER