LNCT GROUP OF COLLEGES

Name of Faculty: Prakhar Singh Bhadoria & Rohit Kumar Verma

Designation: Assistant Professor

Department: Electrical Engineering

Subject: Electrical Machine Design (EE-601)

Unit: 03

Topic: Output Equation of Transformer

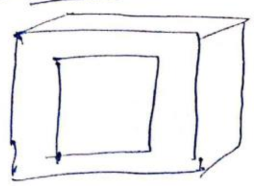
LNCT GROUP OF COLLEGES

UNIT-03/LECTURE- 01
SUBJECT: ELECTRICAL MACHINE DESIGN
TOPIC: OUTPUT EQUATION OF TRANSFORMER

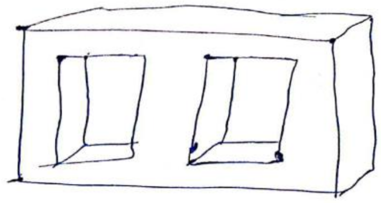
Transformer

UNIT – III

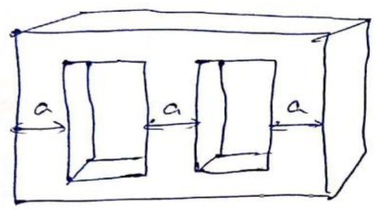
* Construction:



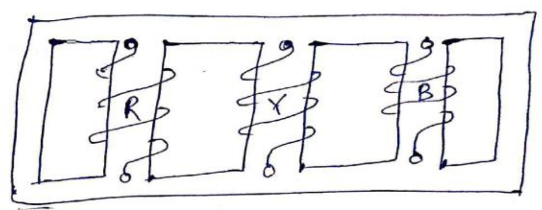
Single phase Core type transformer



Single phase shell type transformer

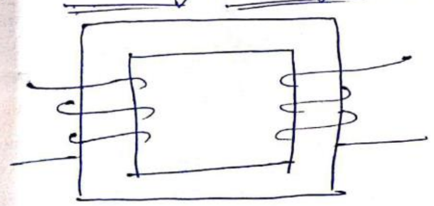


3-ϕ, 3-leg or limb, Core type transformer



5-limb, 3-ϕ Core type transformer

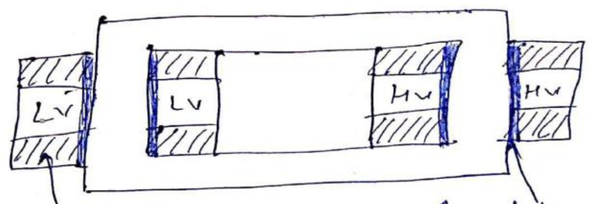
* Winding Arrangement:



LV to HV

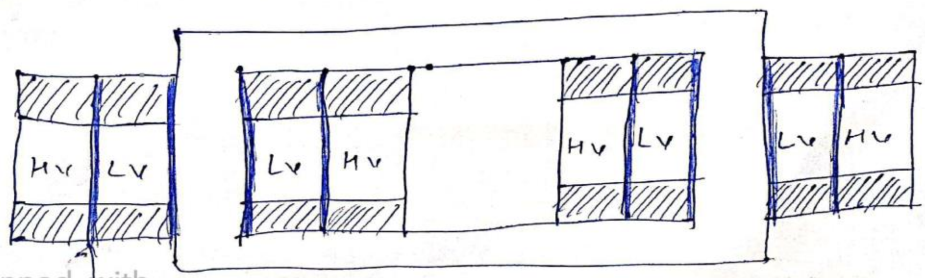
HV to LV

Primary Secondary



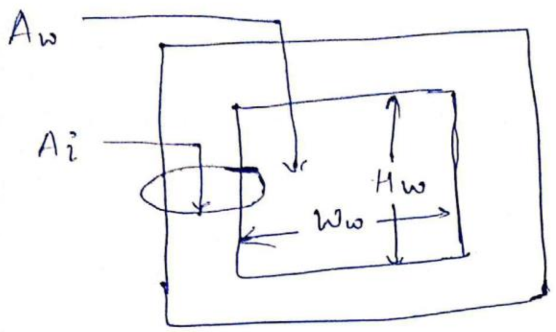
Packing material.

Insulation between LV & HV



Insulation between LV & HV

SIZE OF THE TRANSFORMER:-



As the iron Area of the leg A_i and the window area A_w = (height of the window H_w × width of the window W_w) increases the size of the transformer also increases. The size of the transformer increases as the output of the transformer increases.

OUTPUT EQUATION OF TRANSFORMER:-

The voltage Induced in a transformer winding with 'T' turns and excited by a source having a frequency 'f' Hz is given by:

$$\text{Voltage per Turn, } E_t = \frac{E}{T} = 4.44 f \phi_m \quad (1)$$

The window in a single phase transformer contains one primary and one secondary winding

∴ Total copper area in window

A_c = Copper area of primary winding + Copper area of Secondary winding.

= Primary turns × area of primary conductors + Secondary turns × area of secondary Conductors

$$\boxed{A_c = T_p a_p + T_s a_s} \quad \text{--- (2)}$$

Taking the Current density 'δ' to be same in both primary and secondary windings.

$$a_p = \frac{I_p}{\delta} \quad \& \quad a_s = \frac{I_s}{\delta}$$

$\therefore$ Total Conductor area in window :-

$$A_c = T_p \frac{I_p}{\delta} + T_s \frac{I_s}{\delta}$$

$$= (T_p I_p + T_s I_s) \frac{1}{\delta}$$

$$= \frac{2AT}{\delta} \quad \text{.... } (T_p I_p = T_s I_s = AT, \text{ if magnetizing mmf is neglected}) \quad \text{--- (3)}$$

The window space factor K_w is defined as the ratio of Copper area in window to total area of window.

$\therefore$ Conductor area in window,

$$A_c = K_w A_w \quad \text{--- (4)}$$

Equating (3) & (4) we get

$$\frac{2AT}{\delta} = K_w A_w$$

$$\boxed{AT = \frac{K_w A_w \delta}{2}} \quad \text{--- (5)}$$

→ **Single phase Transformer:-**

Rating of a single phase transformer in kVA,

$$Q = V_p I_p \times 10^{-3} = E_p I_p \times 10^{-3} \ldots (\text{as } V_p \simeq E_p)$$

$$= E_t T_p I_p \times 10^{-3} = E_t \, AT \times 10^{-3} \ldots (AT = T_p I_p)$$

$$= E_t \frac{K_w A_w \delta}{2} \times 10^{-3} \; \ldots \text{(from equ}^n \text{ 5)}$$

$$= 4.44 f \phi_m \frac{K_w A_w \delta}{2} \times 10^{-3} \ldots \text{(from eq}^n \text{ 1)}$$

$$Q = 2.22 f \phi_m K_w A_w \delta \times 10^{-3}$$

$$\because \phi_m = B_m A_i$$

$$\boxed{\therefore Q = 2.22 f B_m A_i K_w A_w \delta \times 10^{-3} \text{ kVA}} \quad \text{— 6}$$

So equ^n 6 is the required output equation of the single phase transformer.

→ **Three phase transformer:-**

In this case, each window contains two primary and two secondary windings.

Proceeding as in the case of single phase transformer,

Total conductor area in each window,

$$A_c = 2(a_p T_p + a_s T_s)$$

$$= \frac{2(I_p T_p + I_s T_s)}{\delta}$$

$$= \frac{4\,AT}{\delta} \quad \ldots \ldots (I_p T_p = I_s T_s = AT)$$

So Total conductor area is equal to $K_w A_w$

$$\frac{4\,AT}{\delta} = K_w A_w$$

$$AT = \frac{K_w A_w \delta}{4}$$

Rating of a 3-ϕ transformer in KVA

$$Q = 3 V_p I_p \times 10^{-3} \simeq 3 E_p I_p \times 10^{-3}$$

$$= 3 E_t T_p I_p \times 10^{-3} = 3 E_t AT \times 10^{-3}$$

$$= 3 \times 4.44 f \phi_m \frac{K_w A_w \delta}{4} \times 10^{-3}$$

$$= 3.33 f \phi_m K_w A_w \delta \times 10^{-3}$$

or $\boxed{Q = 3.33\, B_m \delta K_w A_w A_i \times 10^{-3}\ \text{KVA}}$ — (7)

So Eqn (7) is the required output Equation for 3-ϕ Transformer. //

* EMF PER TURN :-

→ The transformer design starts with selection of an appropriate value for emf per turn.

→ Hence an equation for emf per turn can be developed by relating output kVA, magnetic and Electric loading.

→ In transformers, the ratio of specific magnetic and Electric loading is specified rather than actual value of specific loadings.

→ Let the ratio of specific magnetic and Electric loading be,

$$r = \frac{\phi_m}{AT} \quad \begin{matrix} \rightarrow \text{Specific magnetic} \\ \rightarrow \text{Electric (Specific)} \end{matrix} \qquad (8)$$

→ The volt-ampere per phase of a transformer is given by the product of voltage & current per phase.

→ Considering the primary voltage and current per phase we can write,

$$Q = V_p I_p \times 10^{-3}$$

$$= 4.44 f \phi_m T_p I_p \times 10^{-3} \quad (\because V_p \simeq E_p = 4.44 f \phi_m T_p)$$

$$= 4.44 f \phi_m AT \times 10^{-3} \ldots (\because T_p I_p = AT)$$

$$= 4.44 f \phi_m \frac{\phi_m}{r} \times 10^{-3} \ldots \left(\because AT = \frac{\phi_m}{r}\right)$$

$$\therefore \phi_m^2 = \frac{Q r}{4.44 f \times 10^{-3}}$$

$$\phi_m = \sqrt{\frac{Q r \times 10^3}{4.44 f}} \quad \text{--- (9)}$$

* We know that emf per turn

$$E_t = 4.44 f \phi_m$$

Substituting for ϕ_m from eqn (9)

$$E_t = 4.44 f \sqrt{\frac{Q r \times 10^3}{4.44 f}}$$

$$= \sqrt{4.44 f r \times 10^3}\,\sqrt{Q}$$

$$\boxed{E_t = K\sqrt{Q}} \quad \text{--- (10)}$$

where, $K = \sqrt{4.44 f r \times 10^3} = \sqrt{4.44 f \times \frac{\phi_m}{AT} \times 10^3}$

The value of K is different for different types of transfer, listed below

	Transformer Type	K
1.	Single phase shell type	1.0 to 1.2
2.	Single phase core type	0.75 to 0.85
3.	Three phase shell type	1.3
4.	Three phase core type, distribution transformer	0.45
5.	Three phase core type, Power transformer	0.6 to 0.7

* Examples for output Equation of Transformer:-

1). Calculate the core and window areas required for a 1000 KVA, 6600/400V, 50Hz, Single phase core type transformer. Assume a maximum flux density of 1.25 wb/m^2 & a current density of 2.5 A/mm^2. Voltage/turn = 30V, window space factor = 0.32.

Sol. Given data

KVA = 1000 . f = 50 Hz . $B_m = 1.25\ wb/m^2$

$V_p = 6600\,V$, $V_s = 400\,V$, $\delta = 2.5\ A/mm^2$

$E_t = 30\,V$, $K_w = 0.32$, $1-\phi$.

So, Emf per turn, $E_t = 4.44 f \phi_m$

$$\therefore \phi_m = \frac{E_t}{4.44 f} = \frac{30}{4.44 \times 50} = 0.1351\ wb$$

flux density,

$$B_m = \frac{\phi_m}{A_i}$$

$\therefore$ The net area of cross section of core,

$$A_i = \frac{\phi_m}{B_m} = \frac{0.1351}{1.25} = 0.108\ m^2$$

$$\text{or}\ \boxed{A_i = 0.108 \times 10^6\ mm^2}$$

The KVA rating of transformer,

$$Q = 2.22 f B_m A_i K_w A_w \delta \times 10^{-3}$$

$\therefore$ window Area,

$$A_w = \frac{Q}{2.22 f B_m A_i K_w \delta \times 10^{-3}}$$

$$= \frac{1000}{2.22 \times 50 \times 1.25 \times 0.108 \times 0.32 \times 2.5 \times 10^{6} \times 10}$$

$$= 0.0834 \ m^2$$

$$\boxed{A_i = 0.0834 \times 10^{6} \ mm^2}$$

$\therefore$ Results:-

Net core area, $A_i = 0.108 \times 10^{6} \ mm^2$

Window area, $A_w = 0.0834 \times 10^{6} \ mm^2$