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Que) Design of Transformer with following parameters:-

Rating (Q) : 500kVA
Voltage Ratio : 6.6kV / 400V
Frequency : 50Hz
No. of Phases : Three Phase
Type : Core
Class : Distribution
Mean Temp. Rise : 35°C

* Calculation of design parameters

(I) Core Design

(i) Assume $k = 0.45$ (output coefficient)

$\therefore$ Volt per Turn $(E_t) = k\sqrt{Q}$

$$\therefore E_t = 0.45\sqrt{500}$$

$$\therefore E_t = 10.06 \text{ V/turn}$$

(ii) Assume Flux Density $(B_m) = 1.5T$

$\therefore$ Net Iron Area $A_i = \dfrac{E_t}{4.44 f B_m} = \dfrac{10.06}{4.44 \times 50 \times 1.5}$

$$\therefore \boxed{A_i = 0.0302 m^2}$$

(iii) Assume 2-stepped Core:-
Let 'd' be diameter of circumscribing circle.

Hence for 2-stepped core,

$A_i = 0.56 d^2$

$\therefore d = \sqrt{\frac{A_i}{0.56}} = \sqrt{\frac{0.0302}{0.56}}$

$\therefore \boxed{d = 0.232 m}$

(iv) Let's denote the width of largest stamping by 'a'

$\therefore a = 0.85 d$ (for 2-Stepped Core)

$\therefore a = 0.85 \times 0.232$

$\therefore \boxed{a = 0.1972 m}$

(v) Let's donate the width of middle stamping by 'b'

$\therefore b = 0.53 d$ (for 2-stepped Core)

$\therefore b = 0.53 \times 0.232$

$\therefore \boxed{b = 0.123 m}$

(II) Window Area

(i) Let's denote 'Aw' as Window Area

Assuming Current Density 'δ' = 3.2 A/mm²

Assuming constant 'kw' = 0.3278

$\therefore$ From the output eqn of a 3-ϕ X'mer:-

$$A_w = \frac{Q}{3.33 f B_m A_i \delta k_w \times 10^{-3}}$$

$$\therefore A_w = \frac{500}{3.33 \times 5 \times 1.5 \times 0.0302 \times 3.2 \times 10^6 \times 0.3278 \times 10^{-3}}$$

$\therefore \boxed{A_w = 0.0632 m^2}$

~~(ii) Assume $\frac{Hw}{Ww} = 2$~~

(ii) Assume ratio of height of window (Hw) to width of window (Ww) as

$$\frac{Hw}{Ww} = 2$$

$$\therefore \quad Hw = 2\,Ww$$

But Hw & Ww can be represented as areas

$$Aw = Hw \times Ww$$

$$\therefore \quad Aw = 2 \times Ww \times Ww$$

$$\therefore \quad Ww = \sqrt{\frac{0.0632}{2}}$$

$$\therefore \quad \boxed{Ww = 0.177m}$$

$$\therefore \; Hw = 2 \times Ww = 2 \times 0.177$$

$$\therefore \quad \boxed{Hw = 0.357m}$$

III Yoke Dimensions

(i) Depth of Yoke $Dy = a = 0.1972m$

(ii) Height of Yoke $Hy = a = 0.1972m$

IV Overall Dimensions

(i) Distance between centre of cores;

$$D = d + Ww;$$

$$\therefore \quad D = 0.232 + 0.177$$

$$\therefore \quad \boxed{D = 0.409m}$$

∴ overall width

$W = 2D + a$ (for a $3\text{-}\phi$ X'mer)

∴ $W = 2(0.4009) + 0.1972$

∴ $\boxed{W = 1.0152\,m}$

(ii) Overall Height,

$H = 2H_y + H_w$

$= 2(0.1972) + 0.357$

∴ $\boxed{H = 0.7514\,m}$

(v) L.V. Winding (Y Connection)

(i) Phase Voltage $V_S = \frac{V_{Line}}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 230V$

Turns of Secondary Winding $T_S = \frac{V_S}{E_t} = \frac{230}{10.06} = 22.9$

∴ $\boxed{T_S = 23 \text{ turns}}$

(ii) Secondary Current $I_S = \frac{Q \times 10^3}{3 V_S}$

$I_S = \frac{500 \times 10^3}{3 \times 230}$

$\boxed{I_S = 721.68 \text{ Amps}}$

(iii) Area of Secondary Conductor

$a_s = \frac{I_S}{\delta} = \frac{721.68}{3.2} = 225.525\ mm^2$

Taking reference of standard sized conductors from table 17.1 (IS: 1897-1962)
(~~Refer~~ Reference :- Electrical Machine Design by AK Shawney)

The standard area near to calculated area is

$a_s = 224 \, mm^2$

After several iterations of ~~taking~~ considering different thickness & width of standard conductors, we ~~are~~ are using the size of (25×9) mm as it satisfies the acceptable clearance and radial depth.

$\therefore$ $a_s = 224 \, mm^2$, Bare Conductor Size = (25×9) mm

$\therefore$ New Current Density

$$\therefore \delta_{(New)} = \frac{I_s}{a_s} = \frac{721.68}{224} = 3.22 \, A/mm^2$$

(iv) Assuming an insulation of 0.5 mm, dimensions of insulated conductor = (25.5×9.5) mm

→ ~~Assuming~~ Considering Helical Winding with 2 layers

Space ~~[illegible]~~ has to be provided for

$$\frac{23 \text{ turns}}{2 \text{ layers}} + 1 \simeq 12 + 1 = 13 \text{ turns along the axial depth}$$

(v) Axial Depth of Secondary Winding

$$\boxed{L_s = 13 \times 25.5 = 331.5 \, mm}$$

(vi) Clearance $= \frac{H_w - L_s}{2} = \frac{357 - 331.5}{2} = \frac{25.5}{2}$

$\therefore \boxed{\text{Clearance} = 12.75 mm}$

As Clearance is more than the recommended min. limit of 6mm, the conductor selection is a viable option.

(vii) Considering a 0.5mm thick press board between the layers,
the radial depth of secondary winding
$b_s = [(0.5) + (2 \times 9.5)] mm$

$\therefore \boxed{b_s = 19.5 mm}$

(viii) Inside diameter of L.V. Winding :-

$= d + 2$ (Insulation between Core & L.V. winding)
$= 232 mm + 2(1.5) mm$
$= 235 mm$

(ix) Outside diameter of L.V. Winding :-

$=$ Inside diameter of L.V. winding $+ 2 \times b_s$
$= 235 + (2 \times 19.5)$
$= 274 mm$

(V) H.V. Winding Design:-

$V_{HV} = 6600\,V$

(i) H.V. Winding Turns $= T_{HV} = \dfrac{V_{HV}}{V_{LV}} \times T_{LV}$

$$= \frac{6600}{\frac{440}{\sqrt{3}}} \times 13$$

$$\therefore \boxed{T_{HV} = 372 \text{ turns}}$$

(ii) Primary Current : $I_P = \dfrac{Q \times 10^3}{3 \times V_P}$

$$= \frac{500 \times 10^3}{3 \times 6600}$$

$$\therefore \boxed{I_P = 25.25 \text{ Amps}}$$

(iii) Area of Primary Conductor

$$a_P = \frac{I_P}{\delta} = \frac{25.25}{3.2} = 7.89\, mm^2$$

Taking reference of standard sized conductors from table 17.1 (IS: 1897 - 1962), the most viable conductor size for necessary clearance, radial depth and area is obtained as follows:-

Area of Primary Conductor $a_p = 7.79 mm^2$
Size of Bare Conductor → ~~5mm~~ 4.5mm × 1.8mm

(iv) Considering an insulation thickness of 0.5mm,

Size of insulated conductor = 5mm × 2.3mm

→ Considering 6 layer Helical Winding, space has to be provided for

$\frac{372}{6}$ turns + 1 = 63 turns along the axial depth

Designers Note :- The helical winding is considered for H.V. winding based on conductor area, current and sizing constraints. However, crossover windings are generally used as H.V. winding in modern industries.

(v) Radial depth of primary winding (b_p)
Considering 0.5mm paper tape

$b_p = (0.5 \times 5) + (2.5 \times 6)$
$\therefore \boxed{b_p = 17.5mm}$

(vi) Axial depth of primary ~~cond~~ winding

$L_p = 5 \times 63$
$\boxed{L_p = 315mm}$

(vii) Clearance of H.V. winding = $\frac{W_w - L_D}{2}$

$= \frac{357 - 315}{2}$

$= 21\,mm$

As it is more than the minimum recommended clearance (6mm), the design is viable.

(viii) Inside diameter of H.V. winding:-

Considering 8mm Insulation between L.V. & H.V. winding

$= (2 \times 8mm) +$ Outside Dia. of L.V. Winding

$= 290\,mm$

(ix) Outside Diameter of H.V. winding

= Inside Diameter of H.V. winding + $2 \times b_P$

$= 290 + (2 \times 17.5)$

$= 325\,mm$

(VI) Design of Tank

(i) Weight of Tank

Allowing 50mm at base & 150mm for oil

$W_T = W + 150 + 50 + 200$

$W_T = (751.4 + 150 + 50 + 200)\,mm$

$\boxed{H_T = 0.951\,m}$

(ii) Width of Tank:-

$W_T = 2D +$ Outside Diameter of H.V. Winding $+ 2L$

$= 2(409) + \cancel{339}\ 325 + 2(40)$

$\therefore \boxed{W_T = 1.237 m}$

(iii) Length of Tank:-

$L_T =$ Outside Diameter of H.V. Winding $+ 2(50)$

$= (\cancel{339}\ 325 + 100)$ mm

$\therefore \boxed{L_T = 0.425 m}$