TRANSFORMER DESIGN

EMF induced in transformer winding in V/turn, $(E_t) = k \cdot \sqrt{KVA}$

Maximum value of magnetic flux in weber, $(\phi_m) = \frac{E_t}{4.44 \cdot f}$

where,

k= constant for output voltage per turn

KVA= rating of distribution transformer in KVA

Design of core:

Net iron core area, $(A_i) = \frac{\phi_m}{Bm}$

where,

B_m=Maximum flux density in coil

core calculation not performed

Design of window:

Total area of window$(A_w) = \frac{Q}{3.33 \times Bm \times f \times kw \times \delta \times Ai \times 10^6}$

Width of the window, (W_w)= $\sqrt{\frac{Aw}{ratioHtW}}$

Height of the window, $(H_w) = ratioHtW \times Ww$

where,

k_w= Window space factor such that,

k_w= $\frac{8}{30+KVA}$ for $KVA < 50$

k_w= $\frac{10}{30+KVA}$ for $50 < KVA < 200$

δ= current density which is the same for both primary and secondary winding

ratioHtW= ratio of window height to window weight

Design of yoke:

For hot rolled silicon steel, $A_y = 1.15 - 1.20A_{gi}$

For cold rolled silicon steel, $A_y = A_{gi}$

Here we have assumed hot-rolled silicon steel.

Area of yoke, (A_y)= $1.20 \times A_{gi}$

For the rectangular yoke,

$D_y = a$

$H_y = \frac{A_y}{D_y}$

where,

$A_{gi} = \frac{A_i}{k}$; k= Staking factor

D_y= Depth of yoke

H_y= Height of yoke

Overall dimension of frame:

Distance between adjacent limbs, $D = W_w + d$
Overall height of frame, $H = H_w + 2H_y$
Overall length of frame, $W = 2D + a$

Design of LV winding:

No. of turns of secondary winding, (T_s)= $\frac{V_s}{E_t}$
Secondary current, (I_s)= $\frac{Q(\text{in VA})}{m*V_s}$
Area, (A)= $\frac{I_s}{\delta}$
Using bare conductor of (w $\times$ t) m^2 (From the table)
Area of bare conductor, (a_s)= $t \times w$
Current density in secondary winding, (δ_s)= $\frac{I_s}{a_s}$ *We take paper insulation of 0.5mm and add it to the width and thickness.*
No. of turns in one layer= $\frac{H_w}{w}$
Minimum nos. of layer= $\frac{T_s}{\textit{no of turns in one layer}}$
No of turns in a layer= $\frac{T_s}{\textit{minimum no. of layers}}$
We used helical winding so no. of turns in a layer increases by 1.
Axial depth, (L_{cs})= no. of turns in a layer $\times$ w
Clearance on each side of winding= $\frac{(H_w - L_{cs})}{2}$
Using 0.5 pressboard cylinder layer
Radial depth of LV winding, (b_s)= no. of layers$\times$ radial depth+insulation between layers
Width between core and LV winding= $5 + 0.9KV$
Inside diameter of LV winding, ($D_{in,s}$)= $d + 2y$
External diameter of LV winding, ($D_{ext,s}$)= $D_{in,s} + 2b_s$
The mean diameter of LV winding, (D_{mts})= $\frac{D_{ext,s}+D_{in,s}}{2}$
Mean length of LV winding, (L_{mts})= $\pi \times D_{mts}$

where,
V_s= Phase voltage of LV winding
δ= current density of material
δ_s= Current density of LV winding
d= Diameter of core
y= Insulation between core and LV winding
b_s= Radius of LV winding

Design of H.V winding

Number of primary turns (T_p) =($\frac{V_p}{V_s}$)$\times$ T_s
Primary current (I_p) = $\frac{Q}{3 \times V_s}$ [For Delta connection]

Taking $\delta_p = 1.05\delta$
Area (a) = $\frac{I_s}{\delta_p}$
Also,
Area (a) = $\frac{\pi}{4} \times d^2$ [To find d]
Now, we use nearest standard conductor size for bare diameter (d') and insulated diameter (d'_s),

Modified area of conductor $(a_p) = \frac{\pi}{4} \times (d')^2$
Actual current density $(\delta_p) = \frac{I_p}{a_p}$
Numbers of turns in layer = $\frac{H_w}{d'_s}$
Axial depth of one coil = Turns per layer $\times\ d'_s$

Spacers used between adjacent coils are 5mm in height. so,
Axial length of H.V winding (LC_p) :
LC_p = No. of coils × (axial depth of each coil + depth of spacers)
Clearance on each side = $\frac{H_w - LC_p}{2}$
Insulation between H.V and L.V (z) = 5 + 0.9 K.V
Inside diameter of H.V winding ($D_{in,p}$) = Outside diameter of L.V winding + 2 × z
External diameter of H.V winding ($D_{ext,p}$) = $D_{in,p}$ + 2 × b_p
Mean diameter (D_{mtp}) = $\frac{D_{in,p}+D_{in,p}}{2}$
Mean length of H.V winding (L_{mtp}) = $\pi \times D_{mtp}$
Clearance between windings of two adjecent limbs = D - $D_{ext,p}$

Operating Characteristic

Resistance:

Total resistance referred to primary side $(R_p) = r_p +$ [$r_s \times (\frac{T_p}{T_s})^2$]
Per Unit resistance $(\epsilon_r) = \frac{I_p \times R_p}{V_p}$
where,
r_p = Resistance of Primary winding
r_s = Resistance of Secondary winding
T_p = No. of turns in Primary
T_s = No. of turns in Secondary

Leakage Reactance:

Leakage Reactance referred to primary side (X_p)
$= 2\pi f \mu_0 T_p^2 \times \frac{L_{mt}}{L_c} \times$ (a + $\frac{b_p+b_s}{3}$)$\times\ 10^{-3}$
Per unit reactance $(\epsilon_x) = \frac{I_p \times Xp}{V_p}$
where,
permeability $(\mu_0) = 4\pi \times 10^{-7}$

f = frequency

L_{mt} = length of mean turn

L_c = height of winding

b_p = Radial Depth of H.V coil

b_s = Radial Depth of L.V coil

PU voltage regulation :

PU voltage regulation at 0.8 pf (ϵ)

$= \epsilon_r \; cos(\phi) + \epsilon_x \; sin(\phi)$