**Transformer specifications**

| Quantity | Symbol | Values |
|---|---|---|
| Power | $S$ | 400 KVA |
| Frequency | $f$ | 50 Hz |
| Primary exciting voltage | $V_1$ | 15 KV |
| Secondary exciting voltage | $V_2$ | 400 V |

$\frac{\mathbf{15\ KV}}{\mathbf{400\ V}}$ **, 400 KVA, 50 Hz**

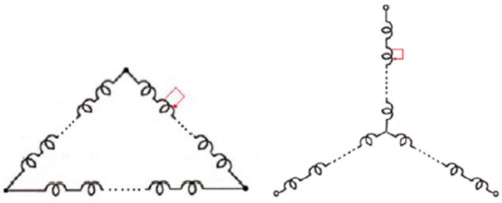

Fig.3: Δ and Y convections of 3-phase transformer.

The k - coefficient is 0.5 to 0.45 for a three-phase distribution column transformer according to the table:

$$\mathbf{k = 0.45 \ \rightarrow \ E_t = k \times \sqrt{\frac{KVA}{phase}} = 0.45 \times \sqrt{\frac{400}{3}} = 5.2\ v}$$

-The flux density is considered to be 1.4 Tesla with respect to the distribution transformer and the cros sheet:
-The net cross-sectional area of the core is equal to:

$$\mathbf{E_t = 4.44\ fB_mA_i \rightarrow A_i = \frac{E_t}{4.44\ fB_m} = \frac{5.2}{4.44 \times 50 \times 1.4} = 0.01671m^2}$$

-Diameter of the peripheral circle:
According to the table of the number of steps, k_(i) is 0.64, considering that there are 5 steps:

$$\mathbf{A_i = kd^2 \rightarrow d = \sqrt{\frac{A_i}{k}} = \sqrt{\frac{0.01671}{0.64}} = 0.1615\ m}$$

$$\mathbf{a = 0.93 \times d = 0.85 \times 0.1458 = 0.15\ m}$$

-Calculating window and yoke dimensions:

$$\mathbf{Q = 3.33\ fB_mA_iA_wK_w\delta}$$

According to the table, we consider C_F to be 1.2 and also consider the current density to be 2.2:

$$\mathbf{K_w = \frac{10}{30 + KV}C_F = \frac{10}{30 + 15} \times 1.2 = 0.26}$$

$$\mathbf{A_w = \frac{Q}{3.33\ fB_mA_iK_w\delta} = \frac{400 \times 10^3}{3.33 \times 50 \times 1.4 \times 0.01615 \times 0.26 \times 2.2 \times 10^6} = 0.1857m^2}$$

$$\mathbf{2.5 \leq \frac{H_w}{W_w} \leq 4 \rightarrow \frac{H_w}{W_w} = 2.5 \rightarrow H_w = 2.5W_w}$$

$$\mathbf{A_w = H_w \times W_w = 2.5{W_w}^2 = 1857 \rightarrow W_w = \sqrt{\frac{1857}{2.5}} = 27.25\ cm = 0.2725\ m}$$

$$\mathbf{H_w = 2.5 \times 27.25 = 68.125\ cm = 0.6812\ m}$$

$$\mathbf{D = W_w + d = 27.25 + 16.15 = 46.4\ cm = 0.464\ m}$$

$$\mathbf{W = 2\ D + a = 2 \times 46.4 + 15 = 107\ cm = 1.07\ m}$$

$$\mathbf{H = H_w + 2\ a = 68.125 + 2 \times 15 = 98.125\ cm = 0.9812\ m}$$

-Flux density in the yoke:

$$\mathbf{\emptyset_m = B_mA_i = 1.4 \times 0.01615 = 0.0234\ wb}$$

$$\mathbf{A_y = (1.1\ to\ 1.15)A_i = 1.1 \times 0.01671 = 1.83\ cm = 0.01838\ m}$$

$$\mathbf{B_y = \frac{\emptyset_m}{A_y} = \frac{0.0234}{0.01838} = 1.27\ T}$$
$$\mathbf{b_y = 0.9\ d = 0.9 \times 0.1615 = 14.53\ m = 0.1453\ m}$$
$$\mathbf{H_y = \frac{A_y}{b_y} = \frac{0.01838}{0.1453} = 12.64\ cm = 0.1264\ m}$$

**Winding design:**

$$\mathbf{E_t = 5.2 \frac{v}{turns}}$$
$$\mathbf{d = 16.15\ cm}$$
$$\mathbf{A_i = 0.01671\ m^2}$$
$$\mathbf{B = 1.4\ T}$$
$$\boldsymbol{\delta} \mathbf{= 2.3}$$
$$\mathbf{H_w = 68.125\ cm}$$
$$\mathbf{W_w = 27.25\ cm}$$

**1- Weak pressure:**

$$\mathbf{T_2 = \frac{V_2}{E_t} = \frac{400/\sqrt{3}}{5.2} = 44.41}$$

We consider the number of rounds to be 45.

$$\mathbf{I_2 = \frac{400000}{3 \times 400/\sqrt{3}} = 577\ A}$$
$$\mathbf{a_2 = \frac{I_2}{\delta} = \frac{577}{2.3} = 250\ mm^2}$$

Conductor with this cross-section is not possible. Using the table, we use 6 strands of 14×3 conductors.

The available height is 80% for winding and 20% for insulation:
$$\mathbf{H_w = 0.8 \times 68.12 = 54.5\ cm}$$

Available height for each conductor round:
$$\mathbf{\frac{54.5}{22.5} = 2.42}$$

Available height for each string:
$$\mathbf{\frac{2.42}{2} = 1.21}$$

-Radial placement:
The thickness of a strand is 3 mm, so the radial thickness (2 strands): 3×3=9 mm
There is a 1 mm cylinder between the turns, so the axial thickness of the coil is equal to:
$$\mathbf{9 + 1 + 9 = 19\ mm}$$

The inner diameter of the insulating cylinder (the diameter of the peripheral circle) is 16.15 cm, and its thickness is assumed to be 0.4 cm:
$$\mathbf{16.15 + (2 \times 0.4) = 16.95\ cm}$$

The thickness of the insulating conduit is 1.5 cm, resulting in the inner diameter of the coil:
$$\mathbf{16.95 + (2 \times 1.5) = 19.95\ cm}$$

The radius of one turn of the coil is 1.9 cm. The outer diameter of the low-voltage coil is equal to:
$$\mathbf{19.95 + (2 \times 1.9) = 23.75cm}$$

The average diameter of a coil is equal to:
$$\mathbf{\frac{19.95 + 23.75}{2} = 21.85\ cm}$$

The average length of a coil is:
$$\mathbf{l = \pi \times 21.85 = 68.64\ cm}$$

The total resistance of the winding is equal to:
$$\mathbf{r_2 = \rho l \frac{T_2}{a_2} = \frac{0.02 \times 0.6864 \times 45}{250} = 0.00247\ \Omega}$$

**2- Strong pressure:**
$$\mathbf{T_1 = T_2 \frac{V_1}{V_2} = 45 \frac{15000}{400/\sqrt{3}} = 2922}$$
The number of turns of the high voltage is 2922 turns.
We consider a 2829-turn winding as 24 coils of 120 turns and one coil of 42 turns:
$$\mathbf{24 \times 120 + 42 = 2922}$$

$$\mathbf{I_1 = \frac{400000}{3 \times 15000} = 8.88\ A}$$
$$\mathbf{a_1 = \frac{I_1}{\delta} = \frac{8.88}{2.3} = 3.86\ mm^2}$$
$$\mathbf{a_1 = \pi \frac{{d_1}^2}{4} \quad \rightarrow d_1 = \sqrt{\frac{4 \times 3.86}{\pi}} = 2.22\ mm}$$
According to the table, we obtain the standard values:
$$\mathbf{a_1 = 4.17mm^2 \qquad d_1 = 2.3\ mm}$$

Available height for string and conductor:
$$\mathbf{H_w = 0.7 \times 68.125 = 47.68\ cm}$$

Available axial length for each coil: (Number of coils is 25)
$$\mathbf{\frac{47.68}{25} = 1.9\ cm = 19mm}$$

Number of turns of each coil axially:
$$\mathbf{\frac{19}{d_1} = \frac{19}{2.3} = 8.26 \sim 9}$$

Axial length for each coil:
$$\mathbf{d_1 \times 9 = 2.3 \times 9 = 20.7\ mm}$$

We arrange 120 turns of each coil into 9 axial and 13 radial turns.
Radial width of each coil:
$$\mathbf{13 \times 2.3 = 29.9\ mm}$$

Axial arrangement:
Axial length 25 coils:
$$\mathbf{25 \times 2.3 = 57.5\ cm}$$

Separator between coils:
$$\mathbf{24 \times 0.2 = 4.8\ cm}$$

End insulation:
$$\mathbf{2 \times 2 = 4\ cm}$$

End ring thickness:
$$\mathbf{1\ cm}$$

Compactness:
$$\mathbf{0.5\ cm}$$

The total axial length is 67.8 cm.

Radial arrangement:
Outer diameter of the low voltage coil:
$$\mathbf{23.75\ cm}$$

Thickness of oil insulation between low and high voltage windings:
$$\mathbf{0.4\ cm}$$

Inner diameter of high pressure insulation cylinder:
$$\mathbf{23.75 + (2 \times 0.4) = 24.55\ cm}$$

Radius thickness of insulating duct:
$$\mathbf{0.4\ cm}$$

External diameter of high pressure cylinder insulation:
$$\mathbf{24.55 + (2 \times 0.4) = 25.35\ cm}$$

Thickness of oil insulation between high-voltage insulation cylinder and high-voltage coil:
$$\mathbf{0.4\ cm}$$
Inner diameter of high voltage coil:
$$\mathbf{25.35 + (2 \times 0.8) = 26.15\ cm}$$

Radial thickness of a high voltage coil:
$$\mathbf{2.99\ cm}$$

External diameter of high voltage coil:
$$\mathbf{26.15 + (2 \times 2.99) = 32.13\ cm}$$

Average winding diameter:

$$\frac{\mathbf{26.15+32.13}}{\mathbf{2}}=\mathbf{29.14\ cm}$$

Average winding length:

$$\mathbf{l=\pi\times 29.14=91.55\ cm}$$

Total winding resistance:

$$\mathbf{r_1=\rho l\frac{T_1}{a_1}=\frac{0.02\times 0.9155\times 2922}{4.17}=12.83\ \Omega}$$