Chittagong University of Engineering & Technology

Department Of Electrical & Electronic Engineering

Report on

407 KVA Distribution Transformer Design

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Objective

To design a 407 kVA, 6.6 KV/415 V, delta/star 3 phase, 50 Hz distribution transformer.

The considerations to be taken in the design:

- Tapping ± 2.5%, ± 5% on high voltage side.
- Cooling O N (self-oil cooled)
- Temperature rise over oil less than 60^0C.
- Load loss not more than 6 KW
- Percentage impedance %Z= 4.50%
- We also Calculated: Efficiency at 75^0C on full load,75% load, and 50% load at unity power factor. Regulation on full load at 75^0C at unity power factor and 0.8 power factor lagging.

Solution:

1 Voltage per turn ($\boldsymbol{E_T}$)

An empirical expression that gives voltage per turn fairly accurately for transformers is

$$E_t = \frac{1}{40}\sqrt{\frac{KVA \times 1000}{No.of\ legs}}$$

So, E_t = 9.2075 volts/turn

We choose 9 volts/turn.

2 Specific Magnetic Loading

B_{max} = 1.6 Wb / m2

Here, material for core is chosen as cold rolled grain oriented (CRGO) steel laminations of 0.35 mm thickness; core construction is used; mitered at 45^0 Cross Section of the core :

E_t= (4.44 B_m f A_i) Volts

B_m = flux density in Wb/m2 (taken as 1.6 Wb/m2)

f= 50 Hz

$A_{i=}$ net cross-sectional area of the core in the m2

Ai = (9×10^6) / (4.4×1.6×50)
= 2.53378×10^4 mm^2

3 The diameter of the circumscribing circle for the core, d

Here, we have chosen 7 step cores.

So, the area should be nearly circular. In the case of a 7 step core, The core space factor, Ki= 0.88

Stacking factor for laminations, Ks= 0.92

If, d = diameter of the core section,

$A = 0.88 \times 0.92 \times \pi d^2$

So, d = 199.6202 mm

We choose it, d = 200 mm

$\therefore$ $A_i = 2.5434 \times 10^4$ mm^2

And $B_m = 1.5939$ Wb/m2

4 Window area A_W

We know, S = 3.33 * Ai * Aw * Kw* δ * Bm * f * 10^{-3}

Here,

Window space factor (kw) is taken approximately as 0.2732

Aw = Window area;

δ = current density taken as 2.5 A / mm^2;

S = output in kVA;

Therefore,

$$Aw = \frac{407 \times 10^3 \times 10^6}{3.33*0.2732*2.5*1.60*50*25434}$$

$= 8.8274 \times 10^4$ mm^2

Now, we choose,

Window width = 215 mm

Then,

The height of the window = 2 × width of window (approximately)

= 2 × 215

= 430 mm

Now , Height of window = 88274÷215 mm

= 410.576 mm

≈ 411 mm

Checking clearance to yoke, this is later taken as **500 mm**

Now, window area = 215× 430

$= 92450 mm^2$

The main dimensions of the core are therefore:

Diameter, d = 215 mm

D = distance between the centers of the adjacent limbs

= (215 + 190) mm [the largest width of the core with d=200 mm is = 0.95*200 = 190 mm]

= 405 mm;

Fig: 1 shows the core and yoke assembly dimensions.

Here, Height of window = 500 mm

Total width = (2 × 405) + 190 = 1000 mm

Total height =500 + (190×2) = 880 mm

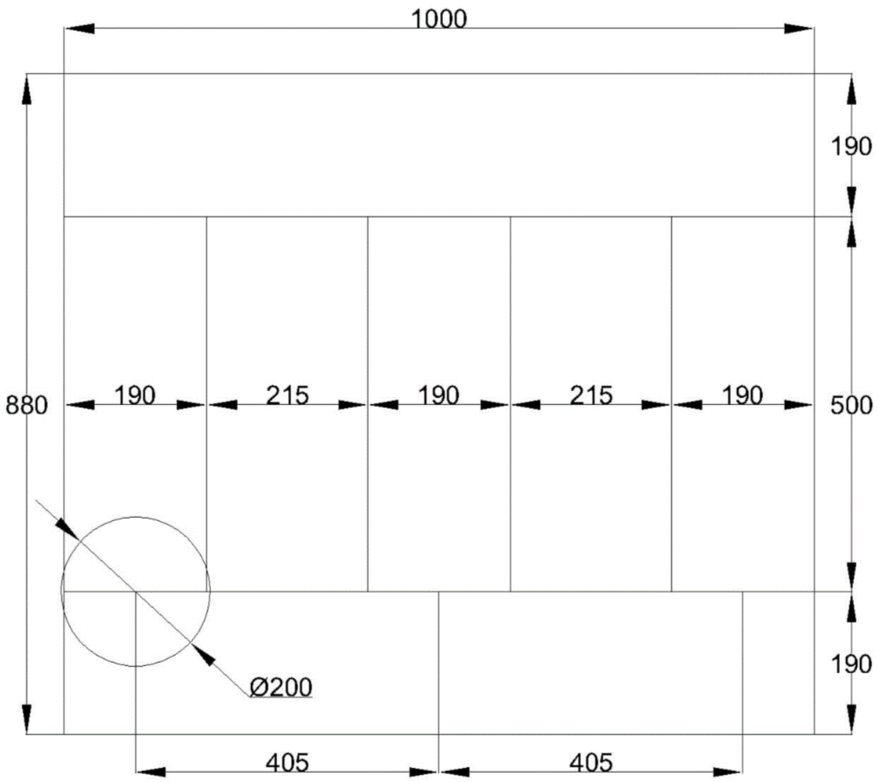

Figure 01. Core & Assembly

4 Number of turn in LV winding

Voltage per phase = 415 / √3 = 239.6 V (as the winding is star connected) ,

Turns per phase on LV winding, T_2 = 239.6 ÷ 9 = 26.62, chosen as 27 turns.

5 Number of turns of HV winding

Turns per phase on HV winding = $\frac{6.6*1000}{9}$ = 733

As the winding is delta connected, trappings of ± 5% and ± 2.5% are to be provided on the HV. winding.

Turns on HV winding for normal connections = 621 ;

5% more, 733 × 1.05 = 770

5% less, 733× 0.95 = 696

2.5% more, 733 × 1.025 = 751

2.5% less, 733 × 0.975 = 715

Thus, the turns for HV winding are:

	5%	Normal	2.5%
more	770 turns	733 turns	751 turns
less	696 turns	733 turns	715 turns

Table 1: Tapings

6 Low voltage winding

Current per phase = $\frac{407\times10^3}{\sqrt{3}\times415}$A

= 566.22 A

Here, we choose helical cylindrical coil.

Current density, δ = 2.5 A / mm^2; (assumed)

area of LV conductor, a_2 = 566.22 ÷ 2.5 mm2

= 226.48 mm^2

Choosing, rectangular copper conductor from IS 6160-1971 specs.

[For rectangular copper conductors for electrical machines, giving area near about the required one.]

Thus, 1.4*x^2= (226.48/2)
x= 8.99
width =1.4*9=12.6mm

∴ thickness = 9 mm
Choosing conductor of thickness 4.5 mm.
2 conductor strips for each layer, thickness = 4.5 * 2 = 9 mm

4 conductor strips farming conductor of LV area: a2 =2*9*12.6 =226.8 mm^2

7 High voltage winding

Here, we Choose disc coils.

Now,

current in HV winding per phase = $\frac{407\times1000}{3\times6.6\times1000}$; (being delta connected)

= 20.55 A

Cross section of conductor for H.v. winding , $a_1 = \frac{20.55}{2.5}$ = 8.22 mm2

Choosing round conductor where, d = diameter of conductor

We know,

$a_1 = \pi d2 \div 4$

$d = \sqrt{\frac{4\times a1}{\pi}}$

= 3.2355 mm

Now choosing, d = 3.25 mm;

we get,

Then area, a1 = $\frac{\pi}{4} \times 3.25^2$ mm^2

=8.2957 mm^2

Copper area in window = 2 (a1T1 + a2T2)

= $2.5121*10^4$ mm^2

Now for this dimension, we get

window space factor, kw =$2.5121\times10^4 \div 92450$ = 0.2717 ,which is near about 0.2732chosen.

8 Design the layout of LV winding

Number of turns 27

Size of conductor : 2 strips of 9 × 12.6 mm ,copper rectangular conductors. With paper insulation for conductors, the size of each conductor will be:

(9+.5) mm × (12.6+ 0.25) mm

= 122.075 mm^2

Choosing 1 layer for LV winding,

Turns per layer = 27/1 = 27

Width of conductor 19 mm is taken along the winding, with 4 conductor sides 9.5*2 = 19 mm forming conductor per layer.

height LV winding in window = 347 mm

thickness of LV. coil = 37 mm

inside diameter of LV coil = 207 mm

outside diameter of LV winding = 281 mm

mean diameter of LV coil = 244 mm

mean length of turn of LV coil = 766.54 mm
layout of LV winding is shown in Fig:

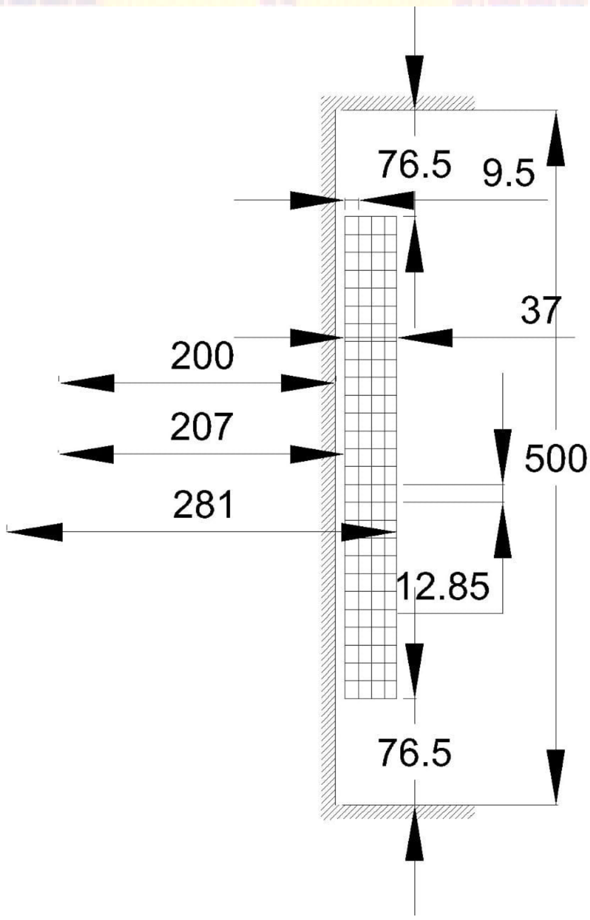

Figure 02: Layout of LV winding.

9 Design and layout of HV. winding

The distance between LV and HV = 12 mm

Inside diameter of HV winding = 281 + (12× 2) = 305 mm
Now, Split HV winding in 4 coils each with turns = 733/4 = 183

The size of conductor = 2.5 mm diameter.

With paper insulation on conductor,

the diameter = (2.5+ 0.25) = 2.75 mm

Chosen 5 layers
turns per layer = 183/5= 37
height of winding in each HV coil = 37*2.75 = 101.75 mm
thickness of each coil = 5 × 2.75 =13.75 mm
outside diameter of HV coil = 13.75*2+305 mm=332.5mm
mean diameter of HV coil = 318.75 mm
mean length of turn = 318.75 × π = 1.00138×10^3
mm height of HV coils in window = 431 mm
The space required between coils and core on either side is taken as 26 mm.
The height of window required = 483 mm which is acceptable
layout of HV winding is shown in Fig:

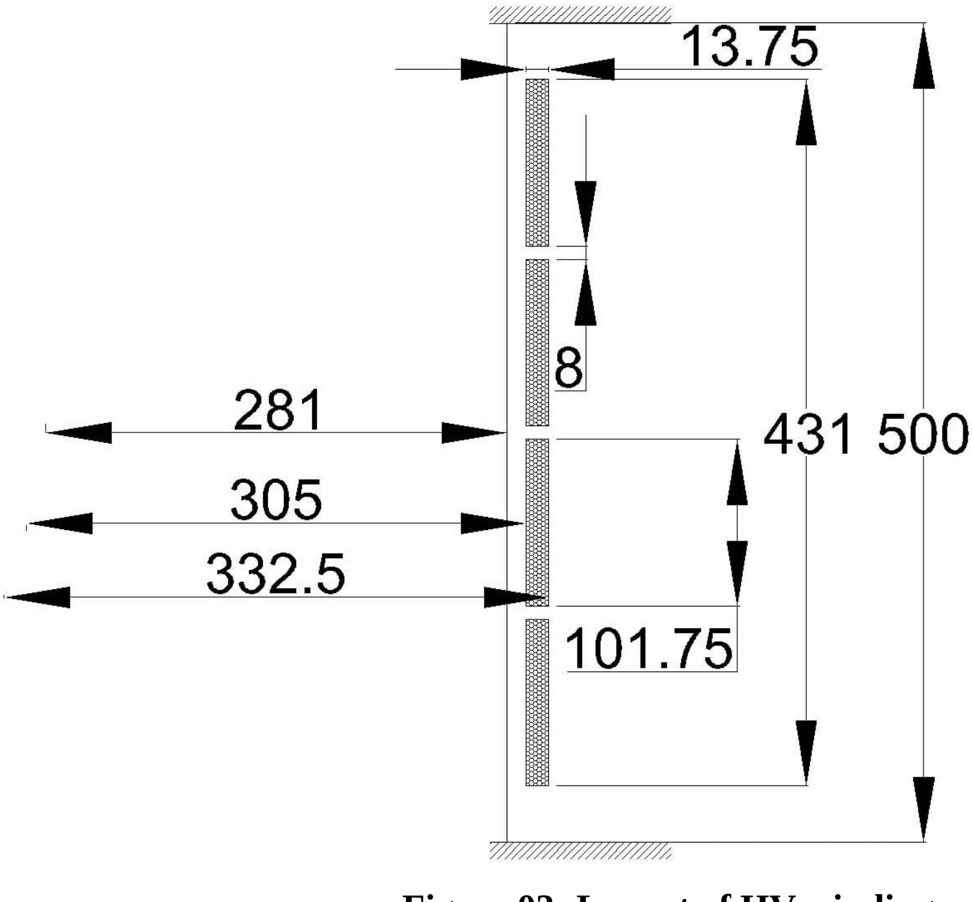

Figure 03: Layout of HV winding.

10 Percentage Reactance

LV. mean length of turn = 766.54 mm

HV mean length of turn =1.00138×10^3 mm

average Lmt = ($766.54+1.00138\times10^3$) ÷ 2= 883.96 mm

AT = 15287.95689 [LV ampere & LV turn]

mean height of coils h_c= 0.389 m Here,

a = 12 mm

b1 = width of HV=13.75

b2 = width of LV = 37

Now,

$a+\frac{b1+b2}{3}$

=28.91 mm

Reactance, %X = $\frac{2\times\pi\times f\times\mu0\times \mathrm{L}mt\times AT}{hc\times Et}\times\left(a+\frac{b1+b2}{3}\right)$

=4.3055%

11 Percentage Resistance

Here,

ρ20 = 0.0172 ohm/mm^2/m

α20 =0.0039

At 75°C, ρ75 = ρ20{1+ α20(75-20)}

=0.021 ohm/mm^2/m

Resistance of low voltage (l.v.) winding: (per phase)

= 0.0019163 Ω (per phase)

Resistance of high voltage (h.v.) winding: (per phase)

= 1.85731 Ω (per phase)

So, Ratio of transformation = (6.6×10^3) ÷ (239.6) = 27.54

Now,

Equivalent resistance referred to HV winding (per phase)

R = 3.31073 Ω

percentage resistance, $\%R = \frac{equivalent\ resistant}{base\ resistant}$

$=1.028\%$

Here,

$\% X = 4.3055\%$;

$\% R = 1.028\ \%$

Therefore,

Percentage impedance, $\%Z = \sqrt{4.3055^2+1.028^2}$

$= 4.4265\ \%$

12 Weight of iron in core and yoke assembly

From Fig 4 the volume of the core and yoke:

Weight of core and yoke = (Ai*(2*Total Width + 3*height)* 7.85)/(1000*1000)

= 698.79915 kg

=698.8 kg

Core loss at Bmax is 1.3 watts/kg

Core loss in transformer = 908.44 Watts

13 Magnetizing volt amperes

For Bmax = 1.60 wb/m^2,

VA / kg from the curve is 10 VA/kg

Magnetizing volt amperes = $698.8 \times 10 = 6988$ VA

14 Weight of l.v. winding

We know, density of copper 8.89 g/cm^3

Number of turns = 27 & a2 = 226.8 mm^2

Mean length of turn = 766.54 mm

Weight of l.v. winding (per limb) = $(8.89 \times 226.8 \times 766.54 \times 27) \div (1000 \times 1000) = 41.72$ kg

15 Weight of h.v. winding (per limb)

Number of turns =733

a1 = 8.2957 mm^2

Mean length = 1001.38 mm

Weight of 4 coils ,5% more (one limb) = (8.89 ×8.2957 × 1001.38 × 733) ÷ (1000 × 1000) kg = 54.132 kg ; for all turns

16 Total weight of copper in transformer

We can write,

3(l.v. + h.v.) = 3 (41.72+54.132) =287.55 kg

17 Copper loss and load loss at 75^0C

h.v. current per phase = 20.55 A

Copper loss for 3 phases = $3 \times I^2 \times r$

= 4194.38 watts

Let, Stray load loss about 7%,

Then load, loss (at 75^0C) = 4194.38× 1.07

= 4487.99watts

=4488watts

Iron loss =

908.44watts

Therefore,

total loss = 5396.43 watts

18 Calculation of performance

- Efficiency on full load at unity power factor :

Output = 407 × 1000 watts. =542000 w

Efficiency = 407×1000/(407×1000+5396.43) × 100%

= 98.69144%

Efficiency on 75% full load at unity power factor:

Core loss = 908.44 watts;

Load loss on 3/4 load = 4488 × $(3/4)^2$ =

2524.5W

Total loss = 908.44+2524.5

= 3432.94 watts

Efficiency on 3/4th of full load = 99.16%

Efficiency on ½ of full load at unity power factor:

Core loss = 908.44watts;

Load loss on 1/2 load = $4488\times (1/2)^2 = 1122$ W

Total loss = 908.44+1122

= 2030.44 watts

Efficiency on 1/2th of full load = 99.50%

19 Regulation on full load at unity power factor

E^2= (1 + 0.01028)^2+ 0.04305^2

Now, E= 1.011196 V

Regulation = (1.011196 – 1)*100%

= 1. 11 %

20 Regulation on full load at 0.8 power factor lagging

= [IR cos φ + IX sin φ] %

= [1.028 × 0.8 + 4.305× 0.6] %

= 3.4054 %

21 Core loss current, magnetizing current, no load current

Core loss = 908.44 watts.

core loss current, Ic = (908.44) ÷ ($3 \times 6.6 \times 10^3$)

= 0.04588 A

Magnetizing VA = 6988 ;

magnetizing current, Im = (6988) ÷ ($3 X 6.6 X 10^3$)

= 0.3529 A

No load current per phase , Io = $\sqrt{(0.04588^2 + 0.3529^2)}$

= 0.3558 A

Current per phase = 20.55 A

No load current = (0.3558) ÷ (20.55) × 100 %

= 1.73% ; of full load current

22 Design of tank

Outside diameter of HV = 332.5 mm
The distance between coils on adjacent limbs = (215+190)-332.5 mm;

=72.5mm;

Clearance at each end is 40 mm.

Thus, the breadth of the tank = (332.5)+60*2;
= 452.5mm
We choose 455mm;
length of the tank = 332.5*3 + 40*2 +72.5*2
= 1222.5 mm
Height = 880+ 50 mm for base + 250 oil level above core+250mm for leads;
=1430 mm
Inside dimensions of the tank of the transformer
= 1222.5× 455 ×1430

= 795419625 mm^3

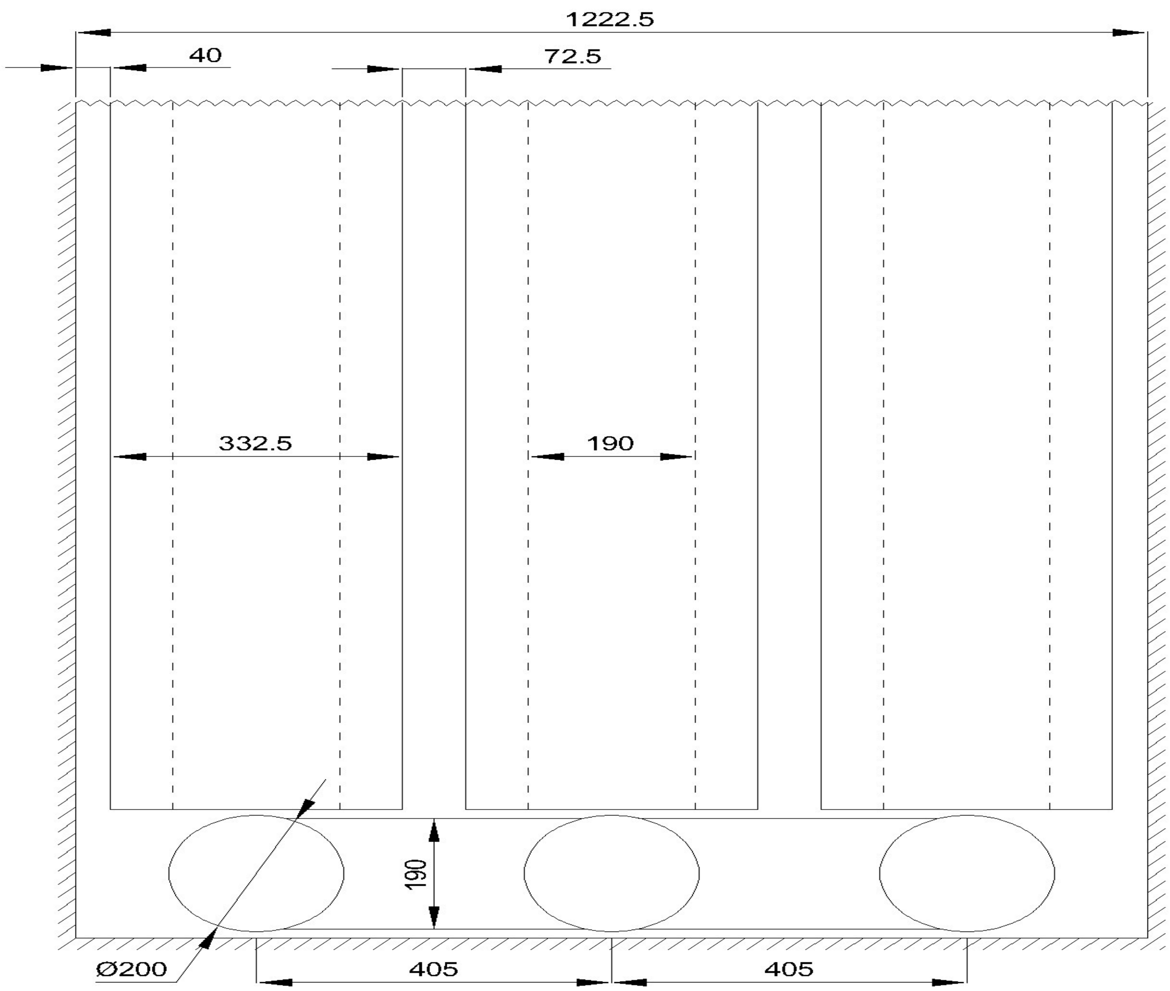

Figure 04: Tank Dimensions.

23 Temperature rise

Now, for dissipation of heat only 4 surfaces of a tank are taken into consideration. The top and the bottom are not considered.

Surface of tank = (1430/1000) × (455/1000) × 2

$=1.3013\ m^2$

Again, (1430/1000) × (1222.5/1000) × 2

$= 3.49635\ m^2$

Total = $4.797\ m^2$

Full load loss to be dissipated = 5396.43watts

Now, If 12.5 per m^2per ^{0}C temperature rise is taken as dissipation due to convention and radiation, The temperature rise = (5396.44) /(12.5 x 4.797) = 90 ^{0}C which needs to be cooled down. The cooling has been introduced in order to lower this temperature. Now, to maintain the temperature of transformer walls limited to 35^{0}C,

Then temperature rise of the oil will be 50^{o}C and of coils 55 ^{0}C.

In that case the surface of the tank for cooling has to be increased

either by “radiators” or “tubes” attached to the tank.

If the total surface area is considered, ‘***x***’ times the tank surface area, we get

x *4.797* {8.8 + 3.7/x} * 35 = 5396.43

from which, x = 3.23

Thus, additional area to be provided = 2.23 x 4.797 = $10.697m^2$

As,1430-250=1180 mm is height up to oil level;

Surface of 1 tube of 50 mm diameter = π x 50 x 1180 x $l0^{-6}$

$= 0.1853m^2$

Number of tubes required = 10.697/0.1853

=58 approximately

24 Volume and weight of oil

Volume of tank up to oil level of 1180 mm

=(1180/1000) x (1222.5/1000) x (455/1000)

= .6563 m^3

25 Volume of transformer core and copper

Volume of transformer core and copper = 698.8/(7.85 X 1000)} + {(287.55) ÷ (8.89 X 1000)

= 0.1213 m^3

Volume of oil = 0.6563 - 0.1213

= 0.535m^3

Oil required in transformer = 0.535x 1000 liters

= 535 liters .

Therefore,

weight of oil required = (535 x 0.89) kg

= 476.15 kg

26 Weight of tank

If the thickness of the tank walls is taken as 5 mm.,

Weight of tank = 0.005 x [(1222.5/1000) x (455/1000) x 2 +(1430/1000) x (455/1000) x 2 + (1222.5/1000) x (1430/1000) x 2] x 1000 x 7.85

= 207.4938 kg

=207.5 kg

27 Volume and weight of oil in tubes

Here,

58 tube each of 50 mm diameter and 1.18 m length.

Therefore, Volume = π x $(50/1000)^2$ x 1.180x(58÷ 4)

= 0.1343m^3,

Volume of oil in tubes = 0.1343m^3x 1000 = 134.38 liters.

Weight of oil in tubes = 134.38x 0.89 = 119.6 kg

Weight of tubes = π x (50/1000) × 1.18 × 0.005 × 7.85 × 1000 × 50 kg

= 421.95 kg

28 Total weight of transformer

Weight of core and yoke assembly	698.8 kg
Weight of copper in windings	287.5 kg
Weight of tank	207.5 kg
Weight of tubes	421.95 kg
Weight of oil in tank and tubes	476.15 kg
And	119.6kg

Total weight = 2211.5 kg

29 Summary

29.1 Specifications

Transformer designed as per IS: 1897:1962 ;
kVA 407.Volts, H.V. 6600 volts; L.V. (no load) 415 volts. Amperes H.V. 566.22 A; L.V. 20.55 A
3 phase, delta/star 50 c/s; temperature rise of oil 50°C; type of cooling ON;
Percentage impedance 4.4265%

29.2 Core and yoke

Material: CRGO (cold rolled grain oriented) steel laminations 0.35 mm thick; mitred core construction 45° cut.

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Voltage per turn 9 volts; Flux density Bmax=1.60 Wb/m^2; Net area of cross section of core 2.5434 x 10^4 mm^2; circumscribing circle diameter 200 mm.

Size of core, yoke and frame:

Width of the window= 215 mm; height of window= 500 mm;

Weight of core and yoke assembly 698.8 kg; core loss at Bmax = 1.60 Wb / m^2, 1.3 watts per kg;

Magnetizing VA = 10 VA / kg

29.3

Windings	L.V	H.V
Type of winding	Helical	Disc
Current density	2.5 A/mm^2	2.5 A/mm^2
Cross sectional area of conductor	226.8 mm^2	8.22 mm^2
Number Of Layers per limb	1	5
Number of turns	27	733
Number of turns per layer	27	183
Height of winding in window	347 mm	101.75 mm
Thickness of coil	37 mm	13.75 mm
Inside diameter of coil	207 mm	305 mm
Outside diam of coil	381 mm	332.5 mm
Mean length of turn	766.54mm	1.00138×10^3 mm
Resistance at 75^0c	0.0019163 Ω	1.85731 Ω
Weight of copper for winding per limb	41.72 kg	54.132 kg
Total Weight of Copper	287.55 kg	

Specifications

29.4 Insulation and Losses

Insulation between core and l.v. winding: pressboard paper
Insulation for conductors: paper

Insulation between layers : Crape paper

Insulation between l.v. and h.v. windings: Bakelized paper cylinder; Laminated pressed wood sticks for spacers for cooling. Class A insulation for O N type transformers.

Tank: Temperature rise of oil 90 ^{0}C where cooling has been applied

Inside dimensions of tank: length 1222.5 mm; breadth :455 mm; height 1430 mm

Tubes 58, each of 50 mm diameter with 1180 mm length

Oil in tubes	134.38 litres
Weight of oil in tank	476.15 kg
Weight of oil in tubes	119.6 kg
Weight of tank	207.5 kg
Weight of tubes	421.95 kg
Percentage reactance	4.4265%
Percentage impedance	4.3055%
Iron loss	908.88 watts
Copper and stray load loss, i.e. load loss at 75^0C	4488 W
Total loss on full load	5396.44 watts
Efficiency on full load at unity power factor	98.69%
Efficiency on 3/4 th full load at unity power factor	99.16%
Efficiency on 1/2 full load at unity power factor	99.50%
Regulation on full load at unity power factor	1.11%
Regulation on full load at 0.8 power factor lagging	3.4054%
Core loss current per phase	0.04588A
Magnetizing current per phase	0.3529A
No load current per phase	0.3558A

29.5 Tappings

30

	5%	Normal	2.5%
more	770 turns	733 turns	751 turns
less	696 turns	733 turns	715 turns

Conclusion

A 407 KVA distribution transformer was designed with the aim of having a compact structure and cost-effectiveness. The connection of the transformer was designed in delta wye with voltage ratings of 6.6KV and 415V. Upon completion, the performance was evaluated, and the results showed that the transformer was in a sound state with a performance efficiency of over 98%