Chittagong University of Engineering & Technology

Department of Electrical &Electronics Engineering

Electrical Machine Design
EEE-240
Name of the Experiment

565 KVA Distribution Transformer design

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Remarks

1. Table of Contents

Objective:

To design a 516 kVA, 3 phase, 50 Hz, 6.6 KV/415 V, delta/star distribution transformer. Here we will take,

- Tapping 2.5%, 5% on high voltage side.
- Cooling O N (self oil cooled);
- Temperature rise over oil 60^0C.
- We also Calculated: the no load current, 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 at 0.8 power factor lagging.

Solution:

Preliminary Calculations:

1.Voltage per turn: E_t

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

Et =.√(KVA*1000/No.of legs)/40; [here, KVA = 516, No.of legs=3]

= 10.368volts/turn,(taken as 10.4 volts/turn)
=10.4 volts/turn

2.Specific magnetic loading

Chosen, B_{max} = 1.7 Wb / m^2;

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

E_t= (4.44 B_m f A_i) Volts

Where, B_m = flux density in wb/m^2, taken as 1.7 wb/m^2
f = 50 c/s and A_i is net

As, E_t= 10.4 volts/turn

Cross sectional area of the core in the m^2

$A_i = (10.4X\ 10^6) / (4.44\ X\ 1.7\ X\ 50) = 2.756X\ 10^{-4}\ m^2 = 27556.97\ mm^2$

3.Diameter of the circumscribing circle for the core: d

Here, we have chosen seven step cores.

So, the area should be nearly circular. In the case of a 7 step core,

The core space factor, K_i= 0.88 and

Stacking factor for laminations, K_s= 0.92

If, d = diameter of the core section,

$Ai = (0.88)\ x\ (0.92)\ X\ (\pi d^2/4)$

Therefore,

d = 208.178 mm

we choose it, d = 208 mm

Then area, $A_i = 27509.776\ mm^2 = 2.7509X\ 10^4\ mm^2$

With this area, we will now check B_m .

Here,

Et = 10.4 f=50 $A_i = 2.7509X10^4\ mm^2$
$B_m = 1.7030 Wb/m^2$;

4.Window area A_w :

We know, $S = 3.33\ Ai\ Aw\ Kw\ \delta\ Bm\ f\ 10^{-3}$ Here, kw=10/(30+(11000/1000))=0.29
Aw = Window area;

δ =current density taken as 2.5 A / mm^2;
S = 516 kVA;

Therefore,

$$Aw = 516*10^3 / (3.33* 27509*0.29 * 2.5*1.7030 * 50)\ mm^2$$

$$= 91244.775\ mm^2$$

Now, we choose,

Window width = 0.88*208=183 mm = 190 mm(assume)

Then,

Height of window = 91244.775 ÷190

= 480.236 mm(assume 480 mm)

The main dimensions of the core are therefore:

Diameter, d = 208 mm;

D = distance between the centers of the adjacent limbs

= (190 + 197.6 approximate) mm; [with a 9 step core, the largest width of the core with d = 208 mm is, 0.95*208 =197.6 mm]

= 387.6 mm; (assume 390 mm)

Fig: 1 shows the core and yoke assembly dimensions.

Here, Height of window = 480+30*2=540 mm;

Total width = (2*390) + 197.6= 977.6 mm;(assume 980 mm)

Total height = 480 + 30×2 =540 mm

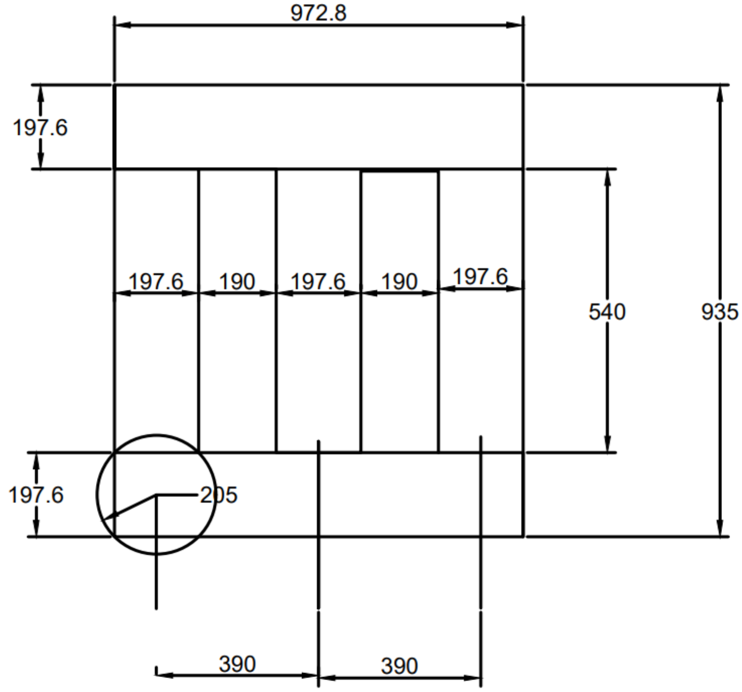

Fig 01: Core & Assembly

5.Number of turn in I.v. winding:

Voltage per phase = 415 / √3 = 240V (as the winding is star connected) ,

Turns per phase on l.v winding = 240 ÷ 10.4 = 23.077 , chosen as 24 turns.

6.Number of turns of h.v. winding:

Turns per phase on h.v. winding = 6.6 X 10^3 ÷ 10.4 = 634.6, chosen as 635 turns As the winding is delta connected, trappings of 5% and 2.5% are to be provided on the h.v. winding.

Turns on h.v. winding for normal connections =635

5% more, 635* 1.05=666.75=667; 2.5% more, 635*1.025 = 650.875=651;

5% less, 635* 0.95 =603.25=604; 2.5% less, 635* 0.975 = 619.125=620;

Thus, the turns for h.v. winding are:

	5%	Normal	2.5%
more	667 turns	635turns	651turns
less	604turns	635 turns	620turns

Table-01:Tapping

7.Low voltage winding :

Current per phase = $(516 * 10^3) \div \{(\sqrt{3}) * 415\}$ = 717.86A

Here, we choose helical cylindrical coil.

Current density, $\delta = 2.5\ A / mm^2$; (assumed)

area of l.v. conductor, a_g = 717.86÷ 2.5

= 287.145 mm^2

Choosing, rectangular copper conductor from IS : 1.4:1specs.

[For rectangular copper conductors for electrical machines, giving area near about the required one.] Now, choosing section 10.127 mm thickness 14.177 mm width ; 2 conductor strips

Therefore,

forming conductor of l.v. area, a_2 = 10.127*14.177*2

= 287.15mm^2 choose 288 mm^2

8.High voltage winding

Here, we Choose disc coils.

Now,

current in h.v. winding per phase = $(516*10^3)\div(3* 6.6* 10^3)$; (being delta connected) = 26.06 A

Cross section of conductor for h.v. winding, a_1 = 26.06 ÷ 2.5 =10.42mm^2

Choosing round conductor where, d = diameter of conductor

We know,

$$a1 = \pi d^2 \div 4$$

Therefore, d = 3.64 mm=4mm(assume)
Now choosing, d = 4 mm;

we get,

Then area, $a_1 = 12.566\ mm^2$

Copper area in window = $2\ (a_1T_1 + a_2T_2)$

$= 2\ (10.42*635 + 288*24)$

$= 27057.4\ mm^2$

Now for this dimensions, we get

window space factor, k_w =27057.4÷ 107100= 0.296,which is near about 0.29 chosen.

9.Design the layout of l.v. winding :

Number of turns 24.

Size of conductor : 2 strips of 6.3*4.5 mm ,copper rectangular conductors.

With paper insulation for conductors,

the size of each conductor will be:

(10.127+ 0.25) mm*(14.177 + 0.25) mm

= 149.7089mm^2

choosing 1 layers for l.v. winding,

Turns per layer = 24/ 1 = 24

Width of conductor 14.427 mm is taken along the winding,

with 2 conductor sides 14.177+0.25= 14.427mm forming conductor per layer.

For one layer, the dimension of conductors,

width wise is 20.754mm and

height of window wise 11.25 mm for each conductor.

height of l.v. winding in window = 24* 14.427= 346.248mm; thickness
of l.v. coil = 20.754* 2 = 41.508 mm =42mm(approx.)

distance between core and l.v. coil = 3.5 mm

inside diameter of l.v. coil = 208+ (2* 3.5) = 215mm

outside diameter of l.v. winding = 215+ (2*42)

= 299mm

mean diameter of l.v. coil = 215 + 42 = 257 mm

mean length of turn of l.v. coil = 257*π = 807.3893mm layout

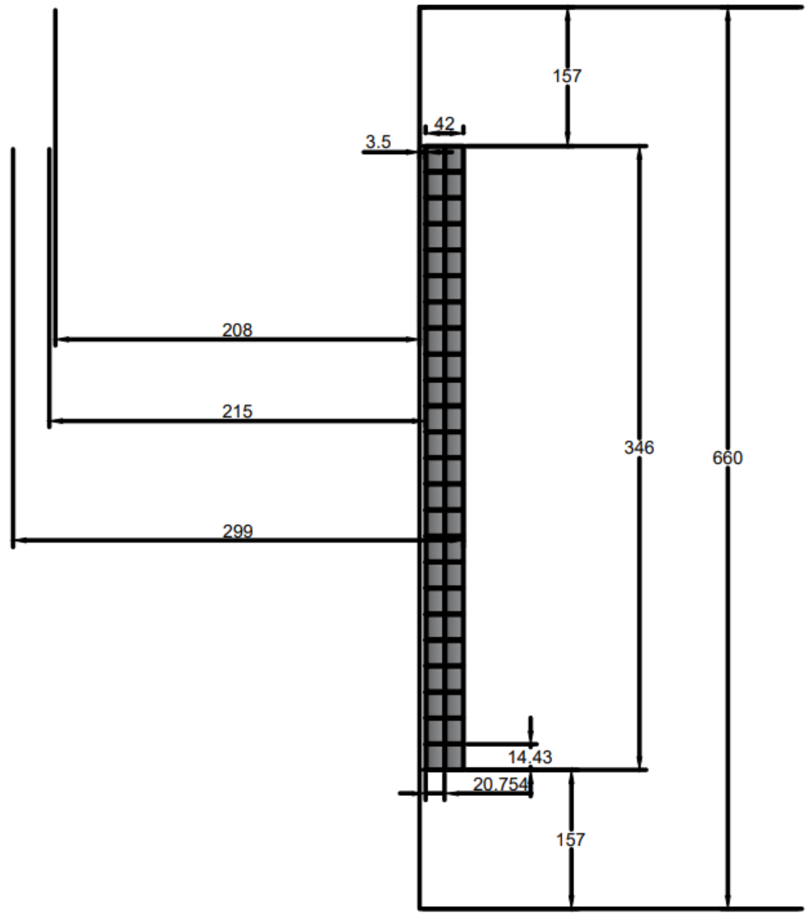

Fig. 02: Layout of LV winding

10.Design and layout of h.v. winding :

The distance between l.v. and h.v. = 12 mm

Inside diameter of h.v. = 299 + (12*2) = 323 mm

Now, Split h.v. winding in 4 coils each with turns = 667/4 =166.75(assume 167) The size of conductor = 4 mm diameter.

With paper insulation on conductor, the diameter = (4 + 0.25) mm= 4.25 mm
Choose 5 layers ;

turns per layer = 167/5 =33.4 choose 34

height of winding in each h.v. coil = 34*4.25 = 144.5mm=144

thickness of each coil = 5*4.25 = 21.25 mm=21 mm

outside diameter of h.v. coil = 323 + (2*21) = 365 mm approximate mean diameter of h.v. coil = 323+ 21 = 344 mm

mean length of turn = 344π = 1080.71 mm

height of h.v. coils in window = (144.5*4) +10.12+10.127+10.127=608.381mm=608mm

The space required between coils and core on either side is taken as 8 mm.

the space required between coils and core on either side is taken 26 mm

The height of window required:= 608 + 26* 2 = 660 mm ; Which is acceptable of h.v layout.

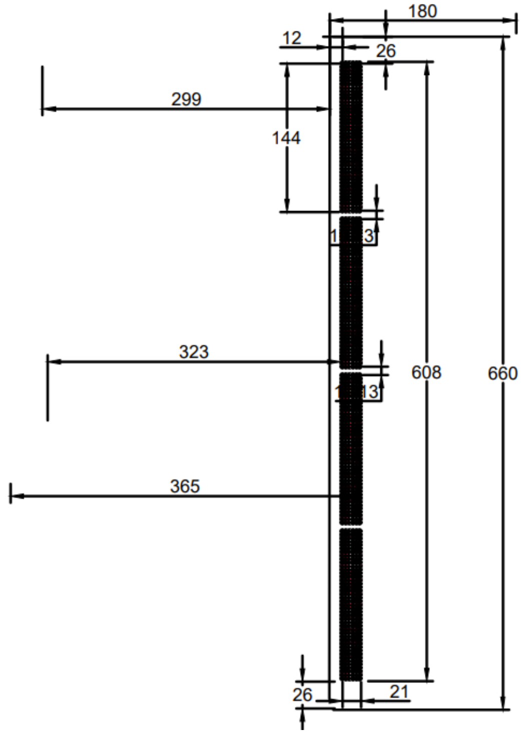

Fig 03: Layout of HV winding

11.PercentageReactance

l.v. mean length of turn =807.3893 mm

h.v. mean length of turn =1080.71 mm

average L_{mt} =(807.3893+1080.71) ÷ 2= 944.0495 mm

AT = 717.8*24 =17228.64 ; approximate

mean height of coils = (608+346.248) ÷ 2 = 477 mm

Here, a = 12 mm ; b_1 = width of h.v. = 21 mm; b_2 = width of l.v. = 42mm

Now,

$a + (b_1 + b_2) \div 3$

=12 + (21+ 42) ÷ 3

=33 mm

% reactance, $X = (2\pi \times 50 \times 4\pi \times 10^{-7} X (944.0495/1000)X17228.64X(33/1000)$

X = 4.27% ; [its acceptable as its between 4% to 5%]

12.Percentage Resistance:

Here,

$\rho_{20} = 0.01724$ ohm/mm^2/m

$\alpha_{20} = 0.00393$

At 75°C, $\rho75 = \rho20\{1+ \alpha20(75-20)\}$

=0.021 /mm^2/m

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

= (0.021 * 807.3893 * 24) ÷ (287.15* 1000)

= $1.417X10^{-3}$ **Ω** (per phase)

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

= (.021 *1080.71*24)÷(635 *1000) **Ω**

= 1.1425**Ω** (per phase)

So, Ratio of transformation = (635) ÷ (24) = 27.5459

Now,

Equivalent resistance referred to h.v. winding (per phase)

$R = 1.417X10^{-3} + 1.1425\Omega\ (27.5459)^2$

$= 2.1699\Omega$

percentage resistance, $\%R = (6.8948) \div (11*10^3/14.85)*100\%$

$= 0.8568\%$

Here,

$\% X = 4.3350\%$;

$\% R = 0.8568\%$

Therefore,

Percentage impedance, $\%Z = \sqrt{(0.8568^2 + 4.3350^2)} *100\%$

$=4.4198\%$

13.Weight of iron in core and yoke assembly:

From Fig 4 the volume of the core and yoke is given by:

$A_i*\{ (980*2) + (935*3) \}$ mm3

$= 131080385mm^3$

Weight of iron = $7.85*1000\ kg/m^3 .=7850kg/m^3$

Weight of core and yoke = $(131080385*7.85) \div (1000*1000)$

= 731.1262 kg

Core loss at B_{max} = 1.7030 wb/m is 1.5 watts/kg

Core less in transformer = 731.1262* 1.7030] = 1245.1 watts ; approximate

14.Magnetizing volt amperes:

F or $B_{max} = 1.7030\ wb/m^2$,

VA / kg from the curve is 12 VA/kg

Magnetizing volt amperes = 731.1262*12 = 8773.5144VA

15.Weight of l.v. winding :

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

Number of turns = 24 & a_2 = 287.15 mm^2
Mean length of turn = 1080.71 mm

Weight of l.v. winding (per limb) = (8.89*287.15*1080.71*24)/(1000*1000)

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

Number of turns = 667; normal= 635 ; a_1 = 10.42 mm^2 ; Mean length of turn = 1080.71 mm Weight of 4 coils (one limb) = (8.89 X10.42 X 1080.71 X 667) ÷ (1000 X 1000)kg

= 66.7736kg ; for all turns

For normal turns,

weight of the coils (one limb) = (8.89 X10.42 X 1080.71 X 635)÷(1000 X 1000)kg
= 63.57 kg

17.Total weight of copper in transformer:

We can write,

3(l.v. + h.v.) = 3 (66.21+63.71) =389.34 kg say

18.Copper loss and load loss at 75 ^{0}C :

h.v. current per phase = 26.06 A

Copper loss for 3 phases = $3*I^2*r$

$=(3*2.1699*26.06^2)=4420.89$ Watts

Let, stray load loss about 7%,

Then, load loss (at 75^0C) = 4420.89*1.07

= 4730.35watts

Iron loss = 1245.1 watts

Therefore,

total loss = (1245.1 + 4730.35)

= 5975.45 watts

19.Calculation of performance:

- Efficiency on full load at unity power factor :

Output = ((516*1000)/(516*1000+5975.45))*100%
= 98.85%

- Efficiency on 3/4th full load at unity power factor: Core loss = 1245.1watts;

Load loss on 3/4 load = $4730.35*(3/4)^2$ = 2660.82W

Total loss = 1245.1+ 2660.82watts

= 3905.92 watts

Efficiency on 3/4th of full load =75000/(75000+3905.92)*100%

= 95.05%

Efficiency on ½ of full load at unity power factor:

Core loss = 1245.1 watts;

Load loss on 1/2 load = $4730.35*(1/2)^2$=1182.58W

Total loss = (1182.58 + 1245.1)

= 2427.68 watts

Efficiency on 1/2 of full load = 50000×1000/(50000+2427.68)*100%

= 95.35%

20.Regulation on full load at unity power factor:

% R = 0.8568%

% X = 4.3360%;

Now,

$(V+IR)^2 + (IX)^2 = E^2$

Or, $(1.0 + .008568)^2 + (.004336)^2 = E^2$

Or, E = 1.0095=1.01

Regulation = (1.0095 – 1.0)*100%

= 0.95% =1%

21.Regulation on full load at 0.8 power factor lagging

= [IR cos φ + IX sin φ] %

= [0.8568* 0.8 + 4.3360* 0.6] %

= 3.28704%

22.Core loss current, magnetizing current, no load current :

Core loss = 1245.1 watts.

core loss current, $I_c = (1245.1) \div (3*11*10^3)$

= 0.0377A

Magnetizing VA = 8773.5144;

magnetizing current, $I_m = (8773.5144) \div (3 \times 11 \times 10^3) = 0.266A$

No load current per phase , $I_o = (0.03677^2 + 0.266^2) = 0.2686$ A

23.Design of tank:

Fig: 4 show the spacing of outside diameters of h.v. coils on the cores.

Outside diameter of h.v. = 365 mm

The distance between coils on adjacent limbs = 390-365mm=25mm; Clearance at each end is 38 mm.

Thus, the length of the tank = 365*3+ 25 *2 + 2 *40 = 1225mm

Breadth of the tank = 365 + 60 X 2 mm

= 485 mm ;

Choose 490mm

Height = 604 + 50 mm for base + 250 oil level above core +250mm for leads;

= 904 mm up to oil level +250mm for leads

; =1154mm

Inside dimensions of the tank of the transformer

= (length * breadth * height)

= $(1225* \; 485* \; 1154) \text{ mm}^3$

= 854026800 mm^3

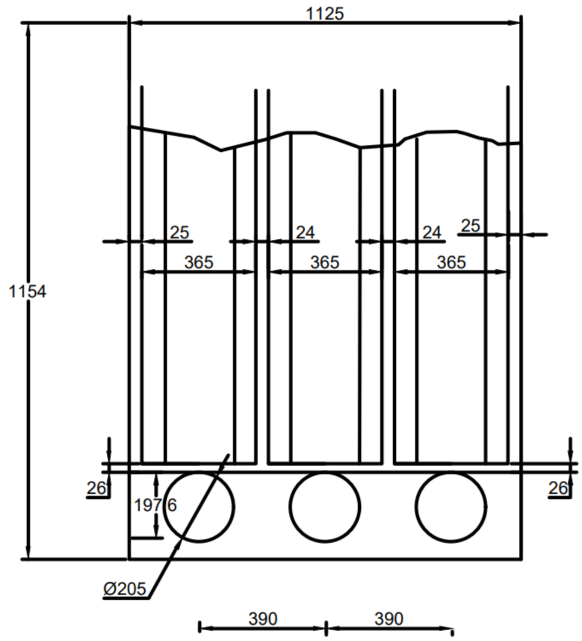

Fig. 04: Tank Dimensions

24.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 = (1154/1000) * (485/1000) * 2 = 1.11938^{m2}

(1154/1000) *(1225/1000) *2 = 2.8273 m^2

Full load loss to be dissipated = 5975.45 watts

Now, If 12.5 per m^2 per ^{0}C temperature rise is taken as dissipation due to convention and radiation, The temperature rise = (5975.45) /(12.5 X 2.8273) = 169.078^{0}C

Now, to maintain the temperature of transformer walls limited to 60^{0}C,

Then temperature rise of the oil will be 50 ^{c} 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:

$$(2.8273+1.11938)*(\boldsymbol{x})*(8.8 + 3.7/\boldsymbol{x})*60=5975.45$$

from which, $\boldsymbol{x} = 2.712$

Thus,

Additional area to be provided = (2.8273+1.11928) x (2.712-1) = 6.7565 m^2

As, 1137 mm is height up to oil level;

Height of tube is taken as 1000 mm

Surface of 1 tube of 50 mm diameter = π x 50 x 1000 x 10^{-6} = 0.1571m^2

Number of tubes required = 6.7565/0.1571

= 43; (43 approximately)

25.Volume and weight of oil:

Volume of tank up to oil level of 1137 mm

=(1125/1000) x (485/1000) x (1154/1000)

=0.6296 m^3

26.Volume of transformer core and copper:

389.34/(8.89 X 10^3)} + {(731.1262) ÷ (7.85 X 1000)

=0.1369

Volume of oil = 0.6296-0.1369

= 0.4927m^3

Oil required in transformer = 0.4927 x 1000 liters =492.7 liters .

Therefore,

weight of oil required = (492.7 x 0.89) kg

= 438.503 kg

27.Weight of tank:

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

Weight of tank = 0.005 x [(1225/1000) x (485/1000) x 2 +(1154/1000) x (1225/1000) x 2

+ (1154/1000) x (485/1000) x 2] x 1000 x 7.85

= 201.546 kg

28.Volume and weight of oil in tubes:

Here,

43 tube each of 50 mm diameter and 1 m length.

Therefore, Volume = $\pi \times (50/1000)^2 \times 1 \times 43 \div 4$

= 0.084 m_3,

Volume of oil in tubes = 0.084 x 1000 = 84 liters.

Weight of oil in tubes = 84 x 0.89 = 74.76 kg

Weight of tube = π x (50/1000) x 1 x 0.005 x 43x 7.85 x 1000 kg

=265.11 kg

29.Total weight of transformer:

Weight of core and yoke assembly	731.1262	kg
Weight of copper in windings	389.34	kg
Weight of tank	201.546	kg

Weight of tubes	265.11	kg
Weight of oil in tank and tubes	663.418	kg
	74.76	kg

Total weight= 2324.30 kg

30.Summary

30.1: Specifications

Transformer designed as per IS : 1.4:1

kVA 516 ; Volts H.V. 6600 volts; Volts L.V. (no load) 415 volts; Amperes H.V. 26.06A ; L.V. 717.86 A (line values); 3 phase, delta/star 50 c/s; temperature rise of oil 134.282903^0C ; type of cooling O N ; Vector group;

percentage impedance 4.4198%

2.5% and ±5% tappings on h.v. side.

30.2:Core and yoke

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

Flux density *Bmax=1.7030* Wb/m^2; Net area of cross section of core, 27509 mm^2; circumscribing circle diameter 208 mm.

Size of core, yoke and frame :width of the window, 980mm; height of window,935 mm;

Weight of core and yoke assembly 731.1262 kg; core loss at Bmax = 1.7 wb / m^2, 1.7030 watts per kg ; magnetizing VA = 12VA / kg

Windings	L.V	H.V
Type of winding	Helical	Disc
Current density	2.5	2.5 a/mm^2
Cross sectional area of conductor	288	12.566 mm^2
Conductor : Copper	2 strips of 0.127 mm 14.18 mm	4 diameter
Number Of Layers per limb	1	5

Number of turns	24	635 normal
Number of turns per layer	24	127
Height of winding in window	346.248mm	144 mm
Thickness of coil	41.508mm	21 mm
Inside diameter of coil	215mm	323mm
Outside diameter of coil	299mm	365mm
Mean length of turn	807.3893mm	1080.71 mm
Resistance at 75^0c	0.001417ohms	1.1425 ohms
Weight of copper for winding per limp	66.21	63.57
Total Weight Of Copper	66.21kg	63.57 kg

30.3: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 169.078^0C

Inside dimensions of tank : length 1225 mm; breadth :485 mm; height 1154 mm Tubes 20, each of 100 mm diam; 1000 mm long

Oil in transformer tank	492.7 liters
Oil in tubes	84 liters
Weight of oil in tank	485.05 kg
Weight of oil in tubes	139.80kg
Weight of tank	201.546 kg
Weight of tubes	265.11 kg
weight of complete transformer	2324.30 kg
Performance :	
Percentage resistance	0.8568%
Percentage reactance	4.3360%
Percentage impedance	4.41987%
Iron loss	1245.1 watts
Copper and stray load loss, i.e. load loss at 75^0C	4730.35watts
Total loss on full load	5975.45watts
Efficiency on full load at unity power factor	98.85%
Efficiency on 3/4 th full load at unity power factor	95.05%
Efficiency on 1/2 full load at unity power factor	95.36%
Regulation on full load at unity power factor	1.%

Regulation on full load at 0.8 power factor lagging	3.28704%
Core loss current per phase	0.0377A

Magnetizing current per phase	0.266A
No load current per phase	0.2676A

30.4:Tappings

667	651	635	620	604
5%	2.5%	normal	-2.5%	-5%

Conclusion:

A 516 KVA distribution transformer has been designed which made to be connected in delta wye and ratings of the voltage were 6.6KV and 415V.Compact feature of the transformer was maintained . While designing the transformer , cost efficiency factor was taken as top priority.