1 DESIGN CONSTRUCTION AND PRELIMINARY TESTING OF A DISTRIBUTION TRANSFORMER

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1.1 List of Symbols

S: Power rating of transformer in kilovolt-amperes
B: Flux desnity in Wb/m^2
w: Width of Lamination in mm
h: Height of Lamination limb in mm
p: Density of copper in kg/m^2
t: Thickness of lamination in mm
J: Current density in A/mm^2
V: Terminal voltage in volts
f: Frequency of operation in Hertz (Hz)
A_i: Cross sectional area of core in m^2
V_t: Volts per turn
A_g: Gross Cross sectional area of core in m^2
D: Diameter of circle enclosing the core in m
H: Height of winding in mm
A_w: Window area in m^2
N: Number of turns of primary or secondary windings
N_L: Number of Laminations
N_{HV}: Number of high voltage turns
N_{LV}: Number of Low voltage turns
n: Turns Ratio of transformer
I: Current specification
I_{LV}: Current Rating of Low Voltage Side in amperes
I_{HV}: Current Rating of high voltage side in amperes
A_c: Conductor Cross Sectional area in mm^2
A_{CLV}: Area of low voltage conductor in mm^2
A_{CHV}: Area of high voltage conductor in mm^2
Dc_{LV}: Diameter of high voltage conductor
L_m: Mean length of one turn
l_{mHV}: Mean length of one high voltage turn
l_{mLV}: Mean length of one low voltage turn
R_N: Mean Radius of one high voltage turn
R_n: Mean Radius of one low voltage turn
R: Radius of core in m
r: Radius of low voltage coil in mm
n: Number of low or high voltage coil group
t_1: Thickness of low voltage former and low voltage coil group separator mm.
t_2: Thickness of the major separator between low and high voltage, coil groups respectively in mm.
r': Radius of high voltage coils
t_3: Thickness of isulation separating high voltage coils
M: Mass of Copper in kg
X: Number of turns per layer
X_{LV}: Number of low voltage turns per layer
X_{HV}: Number of high voltage turns per layer
Y: NUmber of layers
Y_{LV}: Number of layers of low voltage coil groups.

1.2 Introduction

The work is based on the principle copy creativity using certain standard formulae with slight modifications based on practical experience. The rating of 10KVA was chosen such that small communities might easily afford one. The voltage rating of 11/0.415KV and the frequency rating of 50HZ are with the supply authority specifications. The core-type is based on the rigidity of its build and compactness (1,2). The designed model compromises standard existing ones; theoretical designs, specific practical works on power and distribution transformer transdesigns, refurbishing and repairs. The design specifications are as specified with other details in subsequent sections.

1.3 DESIGN PARAMETERS/SPECIFICATIONS

KVA Rating, S	-	10KVA
Voltage Rating	-	11000/415V.
Operation frequency	-	50 Hz
Cooling	-	ONAN
Number of phases	-	3
Winding connection/type	-	Dy 11.

1.4 Other Specifications

Flux density, $B = 1.7\ wb/m^2$., (1)

Lamination Dimension: width, w - 89mm
Height, $h = 223$mm

Lamination type: 3-phase

Density of copper Q: $8930 kg/m^3$

Thickness of lamination, t:0.5mm, (1) - (4)

Current density, J: $3.5 A/mm^2$, (1) - (4)

1.5 BASIC DESIGN EQUATIONS (1) - (4)

Voltage Equation, $V = 4.44fBAgN$ ...(1)

Volts per turn Equation, $V_t = 4.44f\ BAg$: (2)

Cross Core area, $Ag = \Pi D^2/4$ (for this design) ..(3)

$= 0.5D^2$ (theoretical) (2) ..(4)

winding height, $H = 0.97h$ ..(5)

window area, $Aw = 0.97hw$ ..(6)

1.6 DESIGN CONSIDERATION/ANALYSIS

Consider the lamination shown in Fig. 1

For a circle, $Ag = \Pi^2 D^2/4$

$= \Pi w^2/4 = 3.142 \times 89^2 \times 0.25$

$= 6222 mm^2$ $(62.22 \times 10^{-4} m^2)$

This is approximately the useful core area, A_i

Therefore $A_i = 62.22 \times 10^{-4} m^2$.

1.7 Number of Lamination, N_L

The number of lamination put together to give a thickness of 89mm in approximately the required total number of laminations.

$\therefore\ tN_L = w = D$.

N_L : w or $D/t = 89/0.5 = 178$ laminations.

1.8 Volts per turn, V_t (1) - (4)

V_t = 4.44fBA:

= 4.44 x 50 x 1.7 x 62.22 x 10^{-4}

V_t = 2.35 volts per turn.

1.9 Number of turns per phase, N/ph; (1) - (4)

For the high voltage, coil (delta connected), each phase must withstand the 11KV impressed on it.

.. $N_{HV}/ph = V_{HV}/V_t$

= 11000/2.35 = 4685 Turns

For the low voltage coil, the turns per phase is given as N_{LV} /ph = $V_{LV}/ph/V_t$ = 415/ 3 x 1/2.35 = 102 Turns

1.10 Turns Ratio, n (1) - (4)

$n = N_{HV}/N_{LV} = V_{HV}/V_{LV} = I_{LV}/IHV$

= 11000 3/415 = 4685/102

= 45.9 = 46

1.11 Current Specification, I, (1) - (4)

For the low voltage, I_{LV} = KVA/ $3V_{LV}$ = 10 x 1000/1.732 x 415

I_{LV} = 13.9A

for the high voltage, I_{HV} = KVA/$3V_{HV}$ per phase

(I_{HV} = 0.30 3A)

1.12 Conductor Area, A_c, Wire guage, conductor diameter, D_c (1)-(4)

A_c = current/Current density = I/J.

For the L.V.

A_{cLV} = 13.91/3.5 = 1.974mm²

$A_c = iiD_c^2\ 2/4$: $D_c\ 4/iiA_c = 2\ \ A_c/ii$

D_cLV = 3.974/3.142 = 2.25mm

(2.3mm used)

For the H.V.

A_{cHV} = 0.303/3.5 = 0.0867mm

D_{cHV} = 0.0867/3.142 = 0.332mm

(0.45mm used)

The wire guages are respectively 13 and 26 for the low and high voltage sides, due to the diameter specification as computed and dictated by the nearest possible wire sizes (in mm) available, this being a function of the current rating.

1.13 Mean Length of turn

The idea of how long averagely each turn per coil will be, leads us to the idea of the mean length of turn. There are fifteen to sixteen coil groups with insulators of various thickness interposed. The low voltage coil has two layer each of fifty-one turns with three insulators of identical thickness while the high voltage coils (14 coil groups in number) sandwich thirteen insulator layers of identical thickness. For this design a mean radius R_N, was computed for, given by the formulae. these formulae are derived based on experience and knowledge obtained from mathematics.

$R_N = (R + r) + 2(n'-1)r + (2t_1+t_2) + 15r' + 7t_3$ ...(1)

$R = (R + r) + 2(n'-1)r + (t_1 + t_2)$ ...(2)

After substituting the values as specified for the various parameters, R_N = 6.2×10^{-2}m

R_{n1} = 49.6×10^{-3}m

R_{n2} = 53.45×10^{-3}m

In general the mean length of turns of radii R_N, Rn1, Rn2 is given as $l_m = 2iiR$ (3)

where R is either R_N, Rn1, Rn2.

BY substituting values of R_N, Rn1 and Rn2 into equation 3.

lm_{RV1} = 0.312m for the two coil groups of the low voltage coil side respectively.

lm_{LV2} = 0.336m .

1.14 Mass of Copper, M (in kg) (1) - (4)

M/ph = number of turns per phase x conductor Area x conductor mean length x specific gravity of copper.

= $NA_c \ l_{me}$

where, for copper, specific gravity = 8930kg/m³,

lm, N are as given in design analysis.

The computed mass of copper is 4kg per phase with high voltage coil. The practical weight of coils plus insulation was 6kg meaning the isulation weight is 2kg.

1.15 Winding height, H

The total available window height is 223mm. To avoid short circuits between the end conductors per layer of the various coils and between conductor per layer a slight excess overhang is allowed above and below the wound coil. this results in a reduction in the height of the lamination by about 3.5%. The winding height is therefore given as

H = 0.965h

= 0.965 x 223

= 215mm (0.215m).

This is shown in figure 2. The assumption made is based on experience.

1.16 Number of turns per layer (TPL), X

The ratio of the total available winding height to the conducto diameter, gives a figure for the total number of turns of conducto that can be accomodated in any particular layer. If the given symbol are considered

$XD_C = H$

$X = H/D_C$

For the low voltage side

$X_{LV} = H/D_{CLV}$ = 215/2.3 = 95 Turns/layer.

If a single layer of 102 turns was to be accommodated then

H = 2.3 x 102 = 235mm.

But two layers each of fifty-one turns was considered i.e. H = 2. x 51 = 117mm

X_{Hr} = 117/0.332 = 352 Turns/layer

1.17 Number of Layers, Y

Y = Number of turns/turns per layer

Y_{Lv} = 102/51 = 2 layers

Y_{Hv} = 4685/352 = 13.3 layers (14 layers).

1.18 Coil Thickness (or Coil Width)

This is required in order to ensure that the available window space can accommodate the three coils of the various phases. Consider the spatial outlay of fig. 3.

The core thickness	=	89mm
Thickness of low voltage former = 2x4mm	=	8mm
Thickness of low voltage conduction = 4x2.3mm	=	9.2mm
Low voltage coils separator = 2x2mm	=	4mm
Major separator = 2x4mm	=	8mm
High voltage coil thickness = 2x14x0.45	=	12.6mm
High voltage internal insulation = 2x13x0.1	=	2.6mm
	=	133.4mm

.. Coil thickness with core inclusive = 134mm and without the core it is two halves each of 22.5mm thick on either side of the core. Thus the central limb provides two halves of 22.5mm thick coils and the outer limbs provide 22.5mm respectively. Each window is occupied by two layers of 22.5mm thick coils and thus the window width of 89mm can adequately occupy 45mm thick coils.

1.19 Window Space Factor, Wsp (1) - (4)

This is the ratio of the window area available to accommodate the winding (A_w) to the total available window area, Aw.

Wsp = A'w/Aw x 100

Aw = 223 x 89 = 19847mm

A'w = 117 x 45 = 526mm.

Hence Wsp = 5265/19847 x 100 = 27%.

1.20 Tank Design

1.21 Tank Length (L): This should be such that the end limb coils are adequately isolated from the tank side walls. An addition is made to the total core-coil length to achieve this goal.

But core length of 1	=	445mm (0.45m)
Overhang end coils	=	45mm (0.045)
L'	=	490mm (0.490)

If a third of this is allowed as guard, then the tank length will be L = 1.33L'

= 1.33 x 490 = 651.7mm (0.6517m).

Thus a clearance of 80mm is made on both sides of the side walls.

1.22 Tank Width (W_t): By a similar analysis the tank width, Wt can be computed.

W_t = 2 x 80 + 89 + 2x22.5

= 168 + 89 + 45

W_t = 294mm (0.29m)

1.23 Tank Height, H_t: The core is isolated from the tank, some overhang is allowed for end connections.

H_t = 401 + 2 x 80

= 401 + 160 = 561mm (0.561m)

1.24 **Quantity of oil** (by volume) (1)-(4)

Volume of oil = Volume of tank

= LW_tH_t = 0.490 x 0.294 x 0.561

= $0.0808m^3$ (81 litres)

1.25 Design Table: 1.1 Transformer Design Specification

S/N	Parameters per phase	High Voltage Winding	Low Voltage Winding
1.	Number of turns	4685	102
2.	Wire gauge	26	13
3.	Current Rating	0.820A	12.87A
4.	Volts per turn	2.35	2.35
5.	Number of lamination	356	
6.	Mass of copper	2.6-3kg	1.2-1.4kg
7.	Number of layers	14	2
8.	Window space factor	<----- 27% ---------->	
9.	Conductor diameter	0.45mm	2.3mm
10.	Winding height	<----- 117mm -------->	
11.	Directio of winding	<----- Counter clockwise --->	
12.	Tank Dimension	$544x288x537mm^3$	

1.26 **Winding Outlay/Connection:** The high voltage windings are connecte in star and the low voltage windings are connected in delta. Thi is as shown in Figure 4.

1.27 **Design of the low voltage former/wooden block**

The former thickness is specified by the voltage stress betwe the low voltage coils and the tank. The physical dimensions a specified by the core stack thickness (89mm x 89mm), and t lamination dimensions. The size of the wooden block should be su that the lamination stack can conveniently be accommodated af the coil is wound. Thus the actual former dimension is sligh bigger than the dimension of the lamination. The diagrams are sh in figure 5.

1.28 **Making the Low and High Voltage Coils, (1), (3), (4):**

The low voltage former was tightly fitted unto the wooden b by means of a masking tape and securely clamped on the win machine. Another layer of insulation paper (about 0.1mm thick) introduced to level off the surface. The wire bobbin (2.3mm) fitted into the bobbin carrier such that smooth, parallel runs c be made. Insulating sleeve was introduced at the start of the which is rightly marked and hinged in the proper direction to comm the winding. The machine rail is adjusted to move front and within 117mm. With the left leg on the trottle pedal, the r leg as support with the hands as wire guide and tensioner, the wi is commenced. The turns counter records the number of turns layer. At the end of the first layer another thick insulatio introduced to act as base for the next layer. The procedure repeated until 102 turns was recorded. The end was secure means of masking tape and sleeved to mark the end of the low vo winding. A thick insulation was introduced securely in pla serve as base for the high voltage coil. The exercise was re on its merit until 4685 turns were wound. Three identical

1.29 Core-Coil Assembly; (1), (3), (4)

The core was arranged per layer (E's and corresponding I's). The coils were put horizontally on a smooth insulated surface. The E's were introduced with the corresponding I's alternately such that a smooth interleave was made. When all the laminations were fitted, the core-coil assemble was faised and kept in a vertical position. In this position the core was compacted by smooth steady taps, this together with the interleave, reduce possible air spaces, thereby reducing the reluctance of the magnetic circuit. The core was then clamped with the aid of treated wooden blocks with bolts and nuts.

2.1 Tests

D.C.Resistance Test

This was carried out using an avometer (analogue) and digital meter for both the high voltage and low voltage coil. The rsults are shown in table 1.

Table 1.2: D.C. Resistance Test Results

Coil Number	High Voltage Winding (Ohms)	Low Voltage Winding (Ohms)
I	275	0.3
II	275	0.3
III	275	0.3

2.2 Megger Test

The insulation resistance between coils and between coils and earth were taken. The result was as shown in table 2.

Table 1.3: Results of Insulation Resistance Test

Coil Number	L.V to earth (M)	High Voltage to earth (M)	High Voltage to low voltage
I	1000	00	00
I	1000	00	00
I	1000	00	00

2.3 No Load Test (Voltage Ratio)

This was carried out and the results are shown on table 3.

Table 3: No Load test Results (per phase

Input Voltage (V)	Coil I Output Voltage (V)	Coil II Output Voltage (V)	Coil III Output Voltage (V)	Turn Ratio
10	300	300	300	30
20	650	650	650	32.5
30	988	988	988	32.9
40	1325	1325	1325	33.1
50	1675	1675	1675	33.5
60	2050	2050	2050	34.2
70	2413	2413	2413	34.5

3.1 CONCLUSION

The results in Tables 1, 2, and 3 fall within acceptable limits. A three phase, power/distribution, 10KVA, ONAN, 11/0.415KV transformer prototype without, tappings has been designed, constructed and partially commissioned. More work is still being done on the prototype. From the design table any searching mind and skillful rewinder can immitate the prototype design by meticuluosly putting in place the specified items. At full commissioning it might be reasonably ascertained that this local prototype will perform to a fair efficiency of above eighty percent like an imported model of same capacity.

REFERENCES

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2. Balbir Singh; electical Machine Design. VIKAS Publishing House PVT Ltd, 1982 Edition.
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4. Feinberg, R., Modern Power Transformer Practice. The Macmilla Press Ltd, 1979 edition.

2.4 Cost Estimate (As at December 1993)

S/N	Item	Quantity	Unit Price ₦	Total Cost ₦
1.	Insulation Tape	1 roll	350	350.00
2.	Insulation Sleeve	3 m	150	450.00
3.	Binding cloth	1 roll	375	375.00
4.	Copper Wire	36kg	300	10,800.00
5.	Flex Wire (4.5mm)	3m	10	30.00
6.	Laminations	356	15	5340.00
7.	Sheet steel (Gauge 18)	2 sheets	900	1800.00
8.	Low Voltage bushings (Porcelain) complete	8 Nos.	550	4400.00
9.	High voltage bushings (Porcelain) complete	6 Nos.	850	5100.00
10.	Connecting Rod (Earth Rods)	2 Nos.	100	200.00
11.	Bolts/Nuts	- -	- -	250.00
12.	Washers	- -	- -	100.00
13.	Transformer oil (Elf transfo 50)	1 drum (2051)	20,000	20,000.00
14.	Tank Construction and Spraying	2 tanks	- -	3500.00
15.	Insulation Paper (Normex)	20m	250	5000.00
16.	Miscellaneous	-	-	6000.00
17.	Labour	(20% of total cost)		12,739.00
		TOTAL		₦76,434.00

The approximate cost per unit will be ₦38,217.00

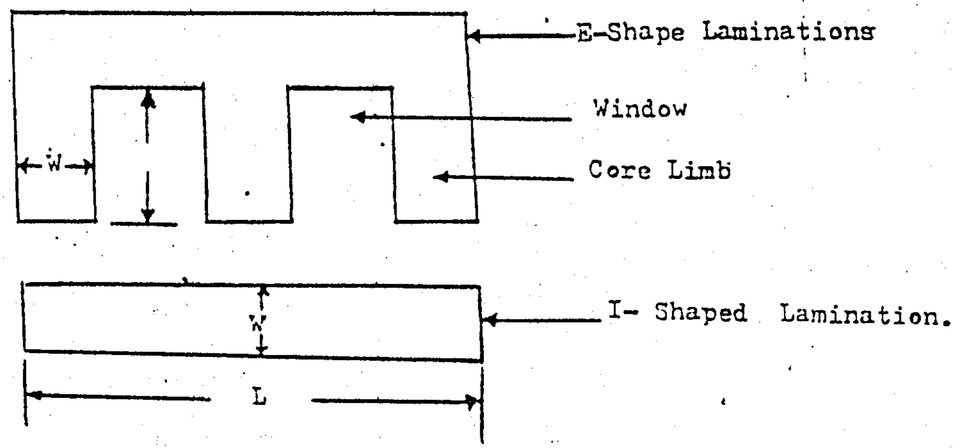

Fig.1: E/I-Shape Core Tye Lamination Blade

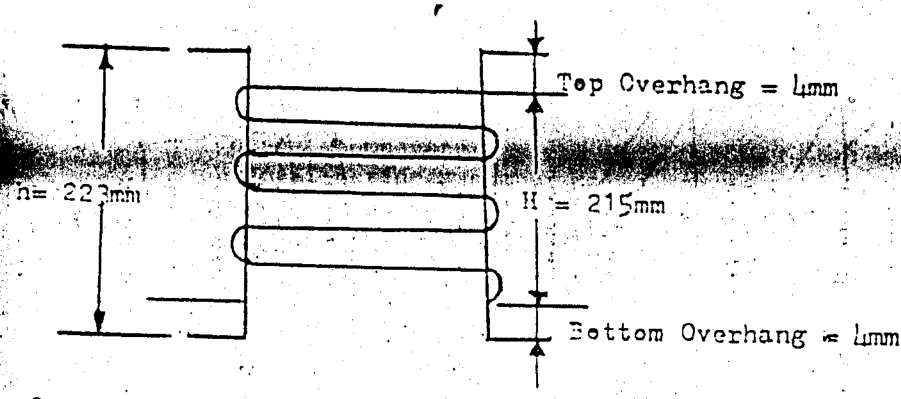

Fig.2: Winding Height Implications

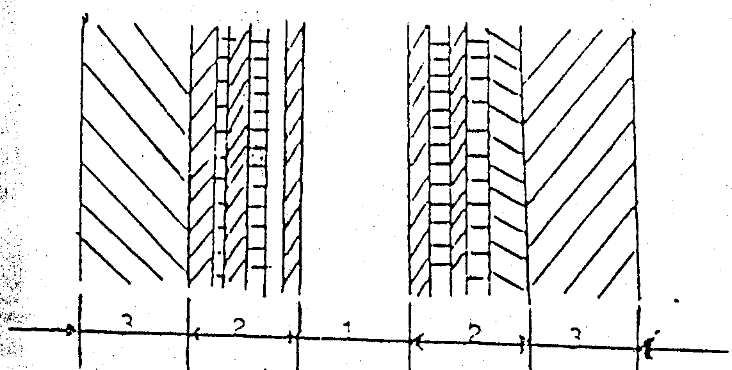

Fig.3: Spatial Outlay of Windings/Insulations

About The Core

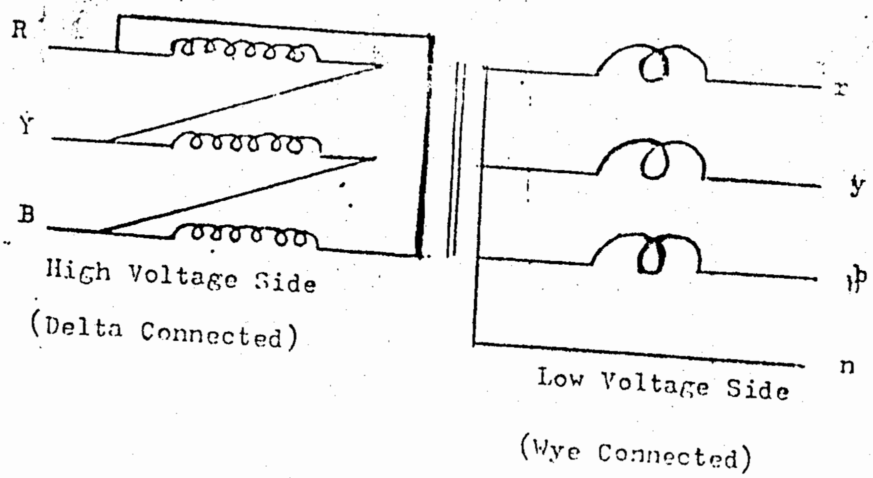

Fig.4: Winding Connection

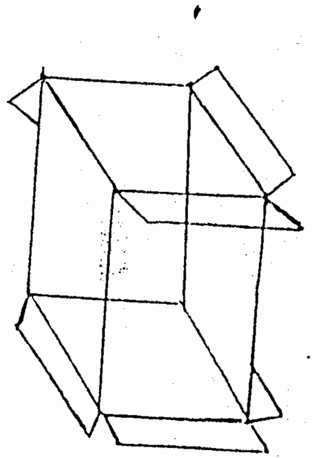

Fig. 5(a) L.V. Former

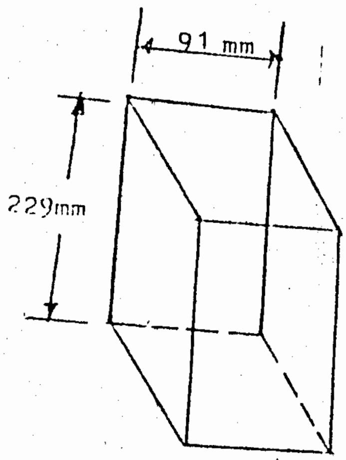

Fig.(b) Wooden block

Fig.5: L.V. Former & Wooden Block