Scientific Journal of Impact Factor (SJIF): 4.72
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 4, Issue 1, January -2017

Design 3-Phase Core Type of Transformer and Modification of Symmetrical Star Shaped Core

Ayushi Patel[1], Namrata Bapodariya[2], Himanshu Panchal[3], Nimesh Smart[4], Kshitij Bhatt[5]

[1,2,3] *Scohlar BE, Vidhyadeep Institute of Engineering & Technology, Surat,*
[4] *Asst. Professor, Vidhyadeep Institute of Engineering & Technology, Surat,*
[5] *Manager (SE Electrical), Transformer Unit, Suzlon,*

Abstract–*Determining the energy transforming from one source to another through a basic device is being used. Such a phenomenon device is used for transformation is defined as transformer. The basic conventional transformer core is being designed. In this research paper, we make a modification in the core of the transformer in the "Symmetrical star core". Comparing properties of the conventional, delta and star shaped cores of the transformer and its advantages, limitations and discuss the future aspects*

Keywords-3- *Phase transformer, star shape core, wound transformer, design and implementation*

I. INTRODUCTION

For high voltages when power is transfer in high or low i.e. steps up and step down of the voltage and current are the main functions of the transformer. It is a static device which transfers electrical energy from one circuit to another by magnetic coupling without requiring relative motion between its parts. An alternating voltage applied to one winding creates a time varying magnetic flux in the core, which induces a voltage in the other winding as per law of mutual induction. The transformer principle was demonstrated in 1831 by faraday. This device greatly reduces energy losses and so enables the economic transmission of over long distances and theoretically it the most efficient device which gives 99.85% results.

The aim is to design a three phase distribution transformer which also works on the above law of mutual induction by Michael Faraday. Distribution transformer used in distribution line to level used by the consumers as well as it involves many load feeders due to which thermal rating for distribution transformer reduces up to 70% and it does not operate at full load all the time. According to the Indian standardized i.e. Bureau of Indian Standard (BIS) tapping is compulsory on the high voltage side of the transformer [6]. The main reason for the extensive use of alternating power systems is on account of transformer as the transformer allows the power to be transferred from the most economical generator voltage, the most economical transmission voltage and power utilization at the most suitable voltage required for different application. Presently, most of the electric power for industrial and utility purposes is generated by large hydro-electrical plants and steam power stations in the power stations in the form of 3-phase A.C. at frequency of 50Hz. The voltages of the generators installed at the power plants usually varies from 6.6kV to 22kV. Basically transformers are of two types i.e. Core type & Shell type.

Hence, this paper contains the design construction of 3-phase core type of distributed transformer only. Distribution transformer is sized up to 500kVA, used to step down the distributed voltage to standard service voltage or from transmission voltage to distributed voltage are usually known as distribution transformers. They are kept in operation all the 24 hours a day while copper losses account for energy during on load condition while iron losses are throughout the day. Thus, transformer designed to have maximum efficiency at a load much lower than full load about 50%. Owing to low iron loss, the distribution transformers should have a good voltage regulation and small value of leakage.

Accordingly in this research paper also tapping is provided. Tapping are of two types as mentioned, first one is "On Load Tap Changer"; this type of tapping where tapper can be change during the on load conditions. They can draw voltage by a tap changer, at the on load condition and second is "Of Load Tap Changer"; this type of tapping gives the condition of tapping only in off load condition. When the load is removed from the transformer, then the tapping can be changed. Such transformer is designed in this research paper.

II. TRANSFORMER DESIGN

Definition of transformer:

A transformer is static piece of apparatus by means of which electric power in one circuit is transformed into electric power of the same frequency in another circuit. An ideal transformer is one which has no losses i.e. its windings have no ohmic resistance and no magnetic leakage hence no I^2R and core losses.[8]

Types of transformer: Following table gives an idea of difference in these two types of transformer design.

Sr. No.	Core Type	Shell Type
1.	The winding encircles the core.	The core encircles most of the part of the winding.
2.	Cylindrical type of coil.	Multilayer disc type of winding.
3.	Natural cooling is more effective.	The natural cooling does not exist.
4.	Single magnetic circuit.	Double magnetic circuit.
5.	For single phase- 2 limbs	For 1-phase-3 limbs.

Table1. Selection for Core Design

The magnetic circuit is the main core of the transformer which is being designed. Core made of laminated sheets provides the magnetic circuit for the flow of flux linking the magnetic circuits. As against the air core, iron core provides a comparatively low reluctance path to magnetic flux with consequent benefit of smaller magnetizing current, increase in the total flux linkage and a high ratio of mutual to leakage flux resulting in reduction of stray losses. It was subsequently found at very small quantities silicon alloyed with low carbon content steel produced a material with low hysteresis losses and high permeability. This core steel known as CRGOS (cold rolled grain oriented silicon steel) has minimum losses and susceptible to impaired performance due to clamping pressure, bolt holes, jointing of limb with yokes, etc. Also reduces eddy current losses, thinner laminations and material annealed at 800-900°c in natural gas environment. [1]
Core Assembly: Core building from the finished lamination sheets through horizontal position on specially raised platforms. The lamination sheets supports the stress developed i.e. bending, twisting, impact, etc. Figure shows the core building operations typically for the 3-phase multi-limbs. Earlier clamp plates and end frame structure of one side of core are brought out.

Guide pins are used at suitable positions for proper alignment while oil ducts are formed through sticking strips on lamination and placed in position. For each packet, the laminations are manufactured in two different length and then alternately, keeping at 2 to 4 laminations together. It also provides overlapping at the corner joints and clamp to each other in tight grip.

Area percentage of circumscribing circle	Square	Cruciform	Three stepped	Four stepped
Gross core area *Agi* Net core area *Ai*	64 58	79 71	84 75	87 78
Net core area *Ai=kd2, Kc*	0.45	0.56	0.6	0.62

Table 2. Configuration for K constant for net core area

When the entire core laminations, clamped plates and end frames is structured; then the core secured by bolts and steel bands at number of positions. In this process, core is spared from the mechanical strain of lifting and rising in vertical position. Two commonly used methods of holding the laminations together i.e. resinglass tape and using skin stressed Bakelite cylinders. The latest development is to assemble the core without top yokes and insert the top yokes after lowering all the windings in the core leg. [3] Here, Equation (1) to (4) represents the net core area.

Gross Area of Core
$$Agi = a^2 \quad (1)$$
$$Agi = 0.5d^2 \quad (2)$$
Net Area of Core
$$Ai = stackingfactor \times grossironarea \quad (3)$$
$$Agi = 0.9 \times 0.5d^2 \quad (4)$$

Winding: Winding form the electrical circuit of a transformer. Their construction ensures safety under normal and faulty conditions. The windings must be electrically and mechanically strong to withstand both over-voltages under transient surges, and mechanical stress during short circuit, and not attain temperatures beyond the limit under rated and overloaded conditions. For core type transformer, the windings are cylindrical and arranged concentrically. Circular coils offer the greatest resistance to radial component of emf, as such shape which coil will tend to assume under short circuit stresses.

Spiral Winding: This the type winding used in the low voltage side in the mentioning transformer calculation in below. This type winding is normally used up to 33kV and low current ratings. Strip conductors are wound closely in the axial direction without radial ducts between turns. Spiral coils are normally wound on a Bakelite or pressboard cylinder and they are wound sometimes on the edge. The thickness of the conductor must be sufficient compared to its width; hence the winding remains twist-free. These winding may be single or multilayer type.

Sr. No.	Types of winding	Rating kVA	Voltage kV	Maximum current/ conductor A	Conductor cross-section mm2	No. of conductors (strips) in parallel
1.	Cylindrical (circular conductor)	5000-10000	Up to 33	Up to 80	Up to 30	1 to 2
2.	Cylindrical (rectangular conductor)	500-8000	Up to 0.433	10-600	5-200	1 to 4
3.	Cross over	Up to 1000	Up to 33	Up to 40	Up to 15	1
4.	Helical	From 160 to tens of thousands	Up to 15 but sometimes up to 33	300 and above	75 to 100 and above	4 to 16 (sometimes more)
5.	Continuous disc	From 200 to tens of thousands	33-220 kV	12 and above	From 4 to 200 and above	1 to 4 (sometimes more)

Table 3. Type of Winding According to Ratings.

Disc Winding: Here, coils consist of a number of sections placed in the axial direction, with ducts between them. Each section is a flat coil, having more than one turn, while each turn itself may comprise one or more conductors in parallel and sections are in series without any joints in between them as it is not necessary to provide a cylindrical former in coils. Each coil is mechanically strong and exhibits good withstand of axial forces. It contains integral or fractional number of turns. [5]

Laminations/ Insulation/ Safety Parameters: The low voltage windings of small and medium size transformers are insulated from the core by pressboard or a synthetic resin bonded paper cylinder. The cooling duct between the core and inside cylindrical surface of the core is formed by axial bars arranged around the cylinder. The bars can be placed around the outer surface of the low voltage winding between layers of helical winding. A practical formula for determining the thickness of insulation between a winding earth and between L.V. and H.V. winding i.e. Insulation thickness= (5+0.9 kV) mm. [4]

The width thickness includes the width of oil duct also about 6mm in small transformers and 7.5-12 mm in large capacity transformers. Insulation at the two ends of the windings consists of blocks keyed at the axial bars. The conductors are paper covered. The increase in dimensions on account of paper covering is 0.5 mm. These blocks are in line with the axial spacers and form a series of columns with winding can be clamped. *The thickness of insulation at each end of the winding varies from 6mm for winding below 500v to about 150 mm for 66kV transformer.* Inward radial forces are passed on the formers, packing pieces and cores. Outward axial forces must be withstood by end insulation. Well-constructed transformers have suitable choice of conductor dimensions and inter turn insulation and the coils well supported and braced with compressive stresses kept. The end supports are not easily arranged to give good insulation and at better mechanical strength.

Bushing: The bushing consists of current carrying part in the form of conducting rod, bus or cable, a porcelain cylinder installed in a hole in the transformer cover and used for insolating the current carrying part. Porcelain bushings used for voltages up to 33kV and have a smooth surface or slightly finned surface. The outside of the bushing used for transformer working outdoors is made with petticoats to protect the lower fins against water in rainy weather.[4]

Protection safety: Winding Temperature Indicator (WTI) with Alarm/Trip contacts and 4-20mA output for Remote WTI (RWTI), Oil Temperature Indicator (OTI) with Alarm/Trip contacts and 4 -20mA output for Remote OTI (ROTI), Buchholz Relay with Alarm/Trip contacts, Silica Gel Breather (1 kg) in clear polycarbonate casing and all other standard fittings, Pressure Release Valve (PRV)

Losses: The main losses of transformer i.e. iron loss (no-load loss) and copper loss (on-load loss). Iron Loss: This loss occurs because of flow of main flux in the core. It depends upon grade of steel, frequency, flux density, type and weight of core and manufacturing techniques. Modern core-steel used has got different magnetic properties in the direction of grain orientation and cross-grain direction. At joints, flux travels in cross-grain direction, giving increase in losses. For accurate estimation of no load loss, core weight for cross-grain and along grain portion is calculated separately.

Copper Loss: Winding conductor weight depends upon this gravity of conductor material, number of turns in the winding and cross-sectional area of conductor. It is calculated as follows:

$G = DALN$ G= weight of conductor material (kg)

D= density (kg/m3) = 8900 kg/m3 for copper A= area of cross-section (m2)
L= mean length of winding turn (M) N= number of turns.

Substituting the values for different winding, their conductor material weight can be worked out. In the alternating current flow, in winding which is associated with load-loss comprising I^2Rloss and eddy current loss in the windings and stray losses in tank, clamping gear, etc. The resistive loss in the windings, i.e. I^2R loss depends on resistivity of conductor material, no. of turns, and cross sectional area and length of mean turn of conductor.

$$R = \frac{DLN}{A} \quad (5)$$

The load-loss of transformer is a function of temperature and generally expressed at the reference temperature of 75°c.Total losses= no load loss + on load loss; Stray loss is the 15% of total losses. Hence, overall parameters of transformer can be obtained by these input values. A well designed transformer with the detailing of selection of core, windings with laminations, oil of transformer, overall dimensions, etc. to obtain the output. Following are some of the equations used in the calculating parameters of the transformer. [4][5]

Voltage per turn	Et= K√Q	(6)
Flux in core	Φ= Et/ 4.44 × f	(7)
Net iron area	$Ai = 0.62d^2$	(8)
Window space factor	$Kw = \frac{8}{30 + kV}$	(9)
Output equation	$Q = 3.33\, fBmKw\delta AwAi10^{-3}$	(10)
Ratio	Hw/Ww= 2 to 5	(11)
Depth of frame	Dy=a	(12)
Height of frame	H=Hw+2Hy	(13)
Width of frame	W=2D+a	(14)
Radial depth	Bs= no. of layers× radial depth of conductor + insulation between layers	(15)
Number of turns per phase	T_p= No. .of conductors × no. of turns+ reinforced coil	(16)
	L_{cp}= No. of coil× axial depth + depth of spacers	(17)
Inside diameter	Outside diameter L.V. winding + 2× thickness of insulation	(18)
Outside diameter	Inside diameter + 2 × radial depth	(19)

The major problem which has been observed in the design of the core in transformer i.e. traditional design of the core limbs which leads to leakage current, reluctance, etc. The problems in the large transformer ratings from 33kV and more experiences these problem due to which winding loss, life span reduction, loss of insulating property in oil of transformer. In this paper, the design of limb is described and simultaneously a new design is introduce to reduce the size of this device, less air gap, equal flux linkage in limbs can be seen. Air gap between the limbs of primary and secondary voltages works on mutual induction but due this the flux is unequally distributed and the output given in secondary side contains many losses. To reduce this problem in the commercial problem an introduction to the new design of transformer is develop in this paper.

MATLAB: MATLAB is the mathematical high performance language for technical commutating. It contains computation of numerical problems in an easy way, less time consuming, etc. MATLAB basically stands for matrix laboratory. It is easy access for matrix software. It include high level commands for two dimensions and three dimensions data visualization, image processing, animation and presentation graphics.

Google Sketch Up: Google sketch is the basic design of the internal view of the design in two dimension or three dimension graphics. The uses of this software includes 3D modeling in computer program for a wide range of drawing applications of architectural, interior design, civil and mechanical engineering, film, and video game design. The two dimensional planer faces created by user can be pushed and pulled by editing tools within environment to easily modeled 3-D volumes and geometries.

III. STATEMENT OF DESIGN

Here, core type delta star connection is considered. Primary side delta connection and secondary side star connection.Dyn11 type of distribution transformer is used. Its configuration is given below.The figure shows the primary side as the delta connected and secondary side as star connected along with the phase different in the configuration having phase difference of 30° in between them. Such distributed core type transformer's core, output, losses, windings, yoke dimensions, laminations, tank dimensions, efficiency, reluctance, leakage current, etc. are calculated through the MATLAB software which has mathematical commands describe in the programming section.

Sr. No.	Parameters	Ratings
1.	Rating	1000 KVA
3.	No load voltage ratio	11KV/433V
4.	Vector group	Dyn11
5.	Maximum permissible losses	Max. losses at 50% loading 3KW Max. losses at 100 % loading 9KW
6.	Tap changer (HV side)	+5% to -15% in steps of 1.25%
7.	Winding	Copper (HV & LV)
8.	Current density	< 2.8 Amps/sq.mm for HV & LV winding
9.	Core lamination	M4 grade or better
10.	Flux density	<1.9 Tesla at rated voltage and frequency
11.	Cooling	Oil natural, air natural
12.	Max. Temperature rise	Of Oil: 40°C over Ambient Temperature of 50°C Of Winding: 45°c over Ambient Temperature of 50°C
13.	Mountings	Outdoor

Table 4. Datasheet for Design

Process for the design is expressed through this flowchart.

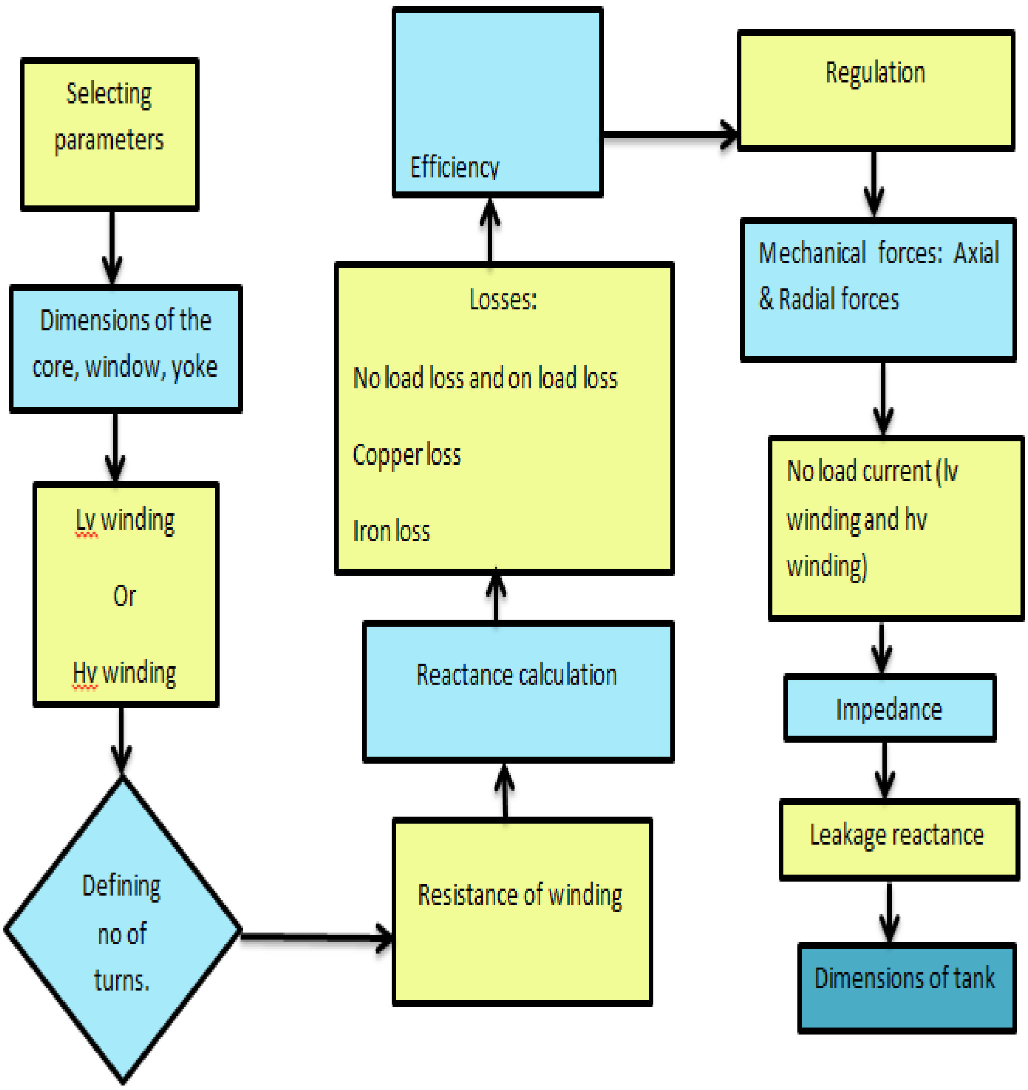

Figure 1. Flowchart for design

IV. PROGRAMING AND RESULT

Programming for the output of transformer core design:

```
Q=input ('enter the value of KVA rating'); %in our case 1000KVA;
f=input ('enter nominal frequency'); % may be use to design pulse transformer
Vhv= 11; %high voltage winding voltage in KV
K=0.45; %for 3 phase core type distribution transformer
Et=k*sqrt (Q); phim=Et/(4.44*f);
Bm=input ('enter the value of magnetic flux density');
Ai= 38768.64; %net iron area in mm2; d=234;
%diameter of circumscribing circle in mm(Ai=0.6*d^2 (for 12stepped core);
a= 219.8; %width space factor for rating in kVA; Kw=0.38;%window space factor for rating in kVA
Aw=Q*1e6/(3.33*f*Bm*Kw*cd*Ai*0.001); %Q=3.33*f*Bm*Kw*cd*Ai*0.001
D=Ww+d; %distance b/w adjacent limbs
Ay=a*a;%area of yoke(we have assumed depth and height of yoke as same)
Agy=Ay/0.9;%stacking factor=0.97; Dy=a;%taking yoke as rectangular
Hy=a;%height of yoke; H=Hw+2*Hy;%overall height
W=2*D+a;%overall width; Vlv=433;%lv winding line voltage in volts
%of insulation is taken as 0.5mm; %axial conductor=4, radial conductor=3
%If we take Hw/Ww=3.5, then window clearance is below permissible limit
%if we usep 533.48 mm2 strip it doesn't effectively fit in the window using
%two layer cylindrical winding, that's why we use 533.48 mm2 strip and two
%if we take Hw/Ww=3.5,then
%we get clearance on each side=22.5mm, which is the permissible clearance
%required, that why are using the Hw/Ww=3.5 with 2 layer winding
Nlv=Vlv/(1.731*Et);%no  of turns per phase on lv winding
Nlvl=round(Nlv/2);%no of turns per phase per layer in secondary winding
thelb=(12.5*13*3);%total height of the conductor in one layer of secondary
clrs=(Hw-thelv)/2;%clearance on each side of the layer
%clearance are within standard limits
Rlv= (Tlv*0.021*lmtlv) / (alv*1000);
R=Rhv+Rlv*(Thv/Tlv) ^2; %total R referred to primary
TOL=1.08*ohmloss; %total ohmic losses
%density of laminations=2.5*1e3kg/m3
wty=2*w*Ai*1.2*2.5*1e3;
%Bm in yoke=1.59Wb/m2 so specific core loss=4.95w/kg
Vlv=433;%lv winding line voltage in volts
Vlvph=vlv/sqrt(3);%lv per phase voltage
Tlv=Vlvph/Et;%turns per phase
Ilv=Q*1000/(3*Vlvph);%secondary phase current
alv=Ilv/cd;%area of secondary phase conductor in mm2
%standard area=533.48mm2 size of wire (13.58*3)*(3.7*3) and the thickness
%of insulation is taken as 0.5mm
%axial conductor=4, radial conductor=3
%If we take Hw/Ww=3.5, then window clearance is below permissible limit
%if we usep 533.48 mm2 strip it doesn't effectively fit in the window using
%two layer cylindrical winding, that's why we use 533.48 mm2 strip and two
core loss=4.95*Wty;
TCL=core loss1+core loss;%total core loss
%EFFICIENCY
Tcfl=TOL+TCL;%total loss of full load
eff=(Q*1000) / (Q*1000+Tcfl); %efficiency at unity pf and full load
%for max efficiency
```

Results of the transformer are obtained with the usage of the MATLAB software which has been mentioned earlier in the paper. Following is the excel sheet containing the output of the transformer obtained by the mathematical software as following. Hence, results obtained are as follows:

Core parameters	Yoke design	Low voltage winding	High voltage winding	Frame parameter
Output constant= 0.45	Depth(Dy)= 21.8mm	Connection= spiral/ star	Connection= disk/ delta	Distance b/t adjacent limb= 219.8mm
Voltage/ turn= 14.23	Height(Hy)= 230mm	Conductor dimension= 13.5×3.7	Conductor dimension= 7.5×1.5	Height= 460.05mm
Circumference circle diameter=234mm	Yoke area (Ay)= 39179.5m	No. of parallel conductor= 4× 3	No. of parallel= 1	Depth= 219.3mm
Net iron area(Ai)=38768.64 mm2	Flux density(Bm)= 1.59 T	Depth = 27.2mm	Depth= 30.2mm	Window parameters
No. of layer= 2		Turns/ phase= 18	Turns/ phase= 831	Height=591mm
Flux density(Bm)= 1.59 T	Current density= 2.5	Turns/ coil= 18	Turns/ coil= 831	Width=168mm
Flux (Φm)= 64.09mWb	Total coil/ core leg= 1	Internal dia (I.D)= 244mm	Internal dia(I.D)= 328.4mm	Area=999.16mm2
Impedance P.U resistance=0.005 P.U reactance=0.052 P.U impedance=0.05	Insulation in layers= 0.5mm	Outer dia (O.D)= 298.4mm	Outer dia(O.D)= 388.8mm	
No. of window= 1	Total loss at full load= 9690.187mm	Length of mean= 0.851mm	Length of mean= 0.993mm	
Window space factor= 0.38		Resistance= 6.59ohm	Resistance=1.80o hm	

Table 5. Result of MATLAB simulations obtaining all parameters

V. PROBLEM DEFINE

The change in the design of core in transformer is due to more leakage current, more air gap length, and unequal distribution of flux in primary and secondary side. Though, transformer is the most efficient device in the transmission line but it need to modified for betterment. Due such design developed in the limb air gap length reduces which leads to less leakage reluction. Hence, more life span and equal distribution of flux on the linkages in distribution transformer for transmission purposes. In this paper, a determination of modification in design of core is defined in a symmetrical star shaped core which has its own merits on the conventional design of transformer. [2]

Why 'Y' shaped core is selected?

A "Y"-shaped transformer includes a "Y" shaped magnetic core that includes a top portion and bottom portion. The top portion and the bottom portion both include a plurality of "Y"-shaped laminates stacked on top of one another and bent to form a plurality of core limbs.

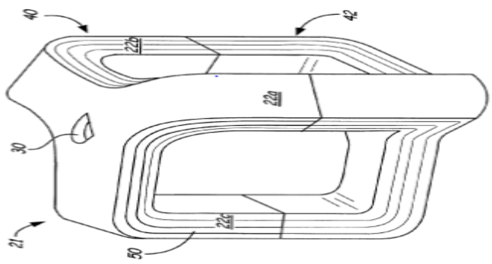

Figure 2. Symmetrical configurations developed of star shaped core of transformer

A plurality of input windings is wound around each conductor containing flux in the core limbs. Therefore, this gives an approximation modifying in design of core in this device.

VI. MODIFICATION IN CORE

Some of the output equations developed for the symmetry of star shaped core.

Sr. No.	Equations	Parameters
1.	$L = 0.4\pi(N \times N)Ae10^{-5}$ H	Inductance induced in each limb
2.	$L = 2\mu(N \times N)2.5\ Hln\frac{OD}{LD}10^{-9}$H	Inductance induced in each limb
3.	$L = N^2Al$	Inductance induced in each limb
4.	$B = \frac{E}{4.44AeNf}10^8$	Magnetic flux
5.	$tan\frac{\delta}{\mu} = \frac{1}{\mu Q} = \frac{R}{\mu z\pi fL}$	Angle of cross section

Table 6. Approximate equations.

Where,

Ae = Effective magnetic path length   ln = Cross section area of core.

N = No. of turns   Z = Impedance

Hence, an approximate equal flux is obtained through this formulation. Comparison between convention, delta, and star shaped core design of transformer:

Sr. No.	Parameters	Conventional	Delta	Star
1.	Core	Traditional	Continuously wound 1-piece core ring. Assembled using automatic winding machine.	Continuously wound of 3- piece core ring. Assembled manually
2.	No. of joints	More	Negligible	Negligible
3.	Shape	Rectangular	Delta	Star/toroid
4.	Flux distribution	Traditional	Optimized magnetic flux distribution	Distributed flux distribution
5.	Resulting flux	Mutual inductance flux obtained having less efficiency result into losses.	At the midpoint flux becomes zero due to its shape. Hence overall flux is zero.	Flux is uniformly distributed in all the limbs.[2]

Table 7.Difference between conventional, delta and star shaped core.

VII. CONCLUSION

An observation and calculative detailed study of the industrial transformer core is developed through MATLAB Simulink successfully is examined. A modification in the design of the core other than rectangle, square, delta is introduce i.e. star shaped or 'Y' shaped core with advantage of flux linkage and less air gap in between the limb structure is represented. This paper includes the phenomenon of designation of core in conventional transformer for large and bulky sized transformer along with star shaped core transformer reducing the losses and the compact size of the device.

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