INTRODUCTION

Transformers are the key enabling component of the power system. Without transformers, the existence of the current power system will not be possible. It helps deliver power to long distances without major loss of power. Apart from core sectors (Generation, transmission, and distribution), transformers find use in various other sectors. Industries, Distributed generation units, testing equipment, converters, locomotives, welding etc. Almost every day to day electronics equipment requires transformers.

Although, transformer is a very energy efficient device, it requires periodic maintenance. For example, a 5 KVA single phase transformer requires repair nearly every four years. That's why transformer manufacturing has a huge demand and this industry will continue to thrive until superconductors are feasible.

Manufacturing a transformer consists of three main stages. Design, Assemble and Test. "Design" is the most crucial stage here. It determines whether the transformer meets the requirements provided by the customer. On the basis of type of transformer, design approach varies. Owing to the fact that there are at least 14 different types of transformers, manual design is a Herculean task that needs a huge amount of time investment. Designing a single energy efficient 100 kVA transformer can take weeks for novice designers. Also, since the entire process depends upon calculations, human error is found to be common. Designing through software helps reduce the efforts and nullifies human error.

The goal is to explore and analyze various design methods and develop a software to design distribution / power transformers. The effectiveness of the proposed method is compared with the manual calculations.

OBJECTIVE:

The prime objective of the project is to develop Power and Distribution Transformer designing software using python Tkinter GUI. The steps are as follows.

- To understand and explore existing techniques and standards of transformer design.
- To visit a transformer manufacturing unit.
- To start designing from the simplest transformer. Then make manual designs of the following.
    1. Three-phase distribution transformer with capacity 15 KVA, rating 400 / 230V, YnD1, AN-AN, Energy efficient.
    2. Three-phase distribution transformer with capacity 66 KVA, rating 11000 / 433V, DYn11, ON-AN, Balanced.
    3. Three-phase distribution transformer with capacity 100 KVA, rating 11000 / 433 V, DYn11, ON-AN, Economic.
- To understand cost estimation and finalize possible designs under the available budget.
- Finalize software for designing 3 phase transformers with capacity limit up to 100 KVA then compare the results. In the result section both manual design sheet and software outputs are given one after another for comparison.
- The correctness of the result is determined by the following parameters.
    (i) Cost reduction
    (ii) Efficiency
    (iii) % Impedance
    (iv) Voltage regulation
    (v) Temperature gradient

If we can design a transformer that gives better efficiency but utilizes less material that is good, the efficiency is expected to be more than 90% even for economic transformers, % Impedance should come around 2% and voltage regulation at unity power factor should come around 2-3%. Gradient should be less than 14 ^{0}C That way we can say if the results are correct.

PRE-REQUISITES:

To start designing a transformer we need to know the following basic things.

- Single phase or three phase.
- Distribution transformer or power transformer.
- Economic or energy efficient.
- Required capacity.
- LV and HV ratings.
- Vector Group.
- Available materials in India.

In our case we will do three manual designs that encompasses various design categories such as different capacity, efficiency markers, build material etc.

Design of the transformer can be categorized into following strategic steps.

- Core design.
- LV winding design.
- HV winding design.
- Final dimension and weight.
- Cost Estimation
- Performance parameter calculation.

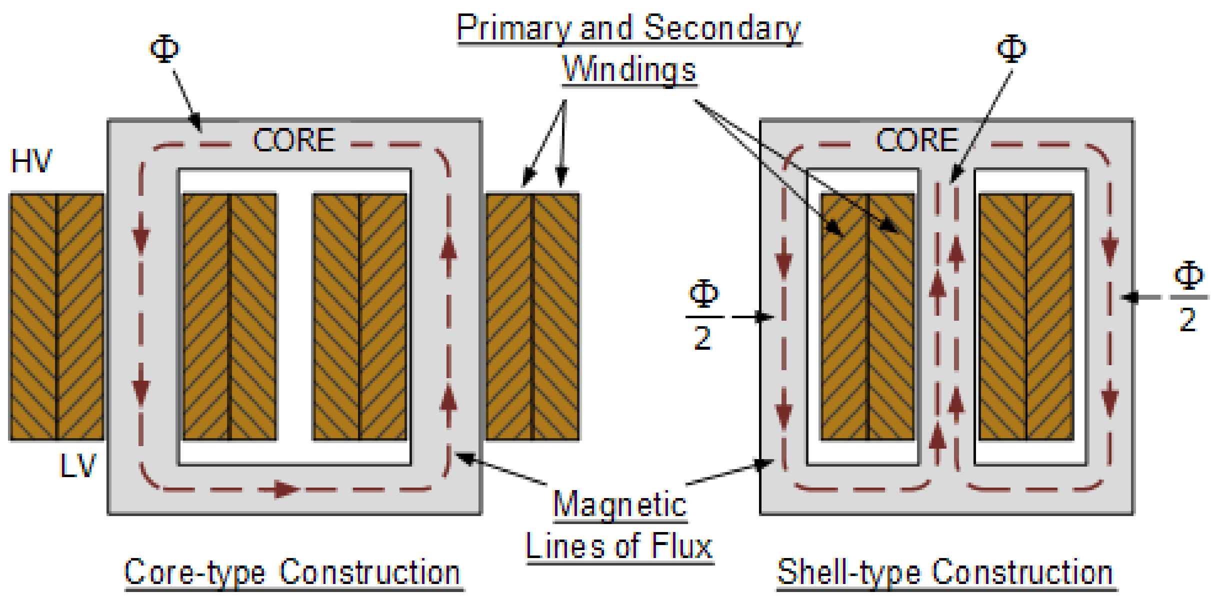
Core design consists of selection of core material and estimating the diameter depending upon the prescribed specifications. In our case we are using CRGO silicon steel. With Indian standard flux density of 1.7333 Wb / m2.

With the help of core parameters, i.e. diameter. We proceed toward calculation of LV winding design. Similarly, HV winding design proceeds and the rest. For selection of materials, it is done on the basis of current per phase in winding. For higher current we normally go for copper and for lower current aluminium is selected.

CHAPTER 1: STRUCTURE OF A TRANSFORMER

1.1 TRANSFORMER CORE

Generally, the name associated with the construction of a transformer is dependent upon how the primary and secondary windings are wound around the central laminated steel core. The two most common and basic designs of transformer construction are the Closed-core Transformer and the Shell-core Transformer.



In both types of transformer core design, the magnetic flux linking the primary and secondary windings travels entirely within the core with no loss of magnetic flux through air. In the core type transformer construction, one half of each winding is wrapped around each leg (or limb) of the transformers magnetic circuit as shown above.

The coils are not arranged with the primary winding on one leg and the secondary on the other but instead half of the primary winding and half of the secondary winding are placed one over the other concentrically on each leg in order to increase magnetic coupling allowing practically all of the magnetic lines of force go through both the primary and secondary windings at the same time. However, with this type of transformer construction, a small percentage of the magnetic lines of force flow outside of the core, and this is called “leakage flux”.

Shell type transformer cores overcome this leakage flux as both the primary and secondary windings are wound on the same center leg or limb which has twice the cross-sectional area of the two outer limbs.

The advantage here is that the magnetic flux has two closed magnetic paths to flow around external to the coils on both left- and right-hand sides before returning back to the central coils.

This means that the magnetic flux circulating around the outer limbs of this type of transformer construction is equal to $\Phi/2$. As the magnetic flux has a closed path around the coils, this has the advantage of decreasing core losses and increasing overall efficiency.

1.2 TRANSFORMER WINDING ARRANGEMENTS

Transformer windings form another important part of a transformer construction, because they are the main current-carrying conductors wound around the laminated sections of the core. In a single-phase two winding transformer, two windings would be present. The one which is connected to the voltage source and creates the magnetic flux called the primary winding, and the second winding called the secondary in which a voltage is induced as a result of mutual induction.

If the secondary output voltage is less than that of the primary input voltage the transformer is known as a “Step-down Transformer”. If the secondary output voltage is greater than the primary input voltage it is called a “Step-up Transformer”.

The type of wire used as the main current carrying conductor in a transformer winding is either copper or aluminium. While aluminium wire is lighter and generally less expensive than copper wire, a larger cross-sectional area of conductor must be used to carry the same amount of current as with copper so it is used mainly in larger power transformer applications.

Small kVA power and voltage transformers used in low voltage electrical and electronic circuits tend to use copper conductors as these have a higher mechanical strength and smaller conductor size than equivalent aluminium types. The downside is that when complete with their core, these transformers are much heavier.

Transformer windings and coils can be broadly classified into concentric coils and sandwiched coils. In core-type transformer construction, the windings are usually arranged concentrically around the core limb with the higher voltage primary winding being wound over the lower voltage secondary winding.

Sandwiched or “pancake” coils consist of flat conductors wound in a spiral form and are so named due to the arrangement of conductors into discs.

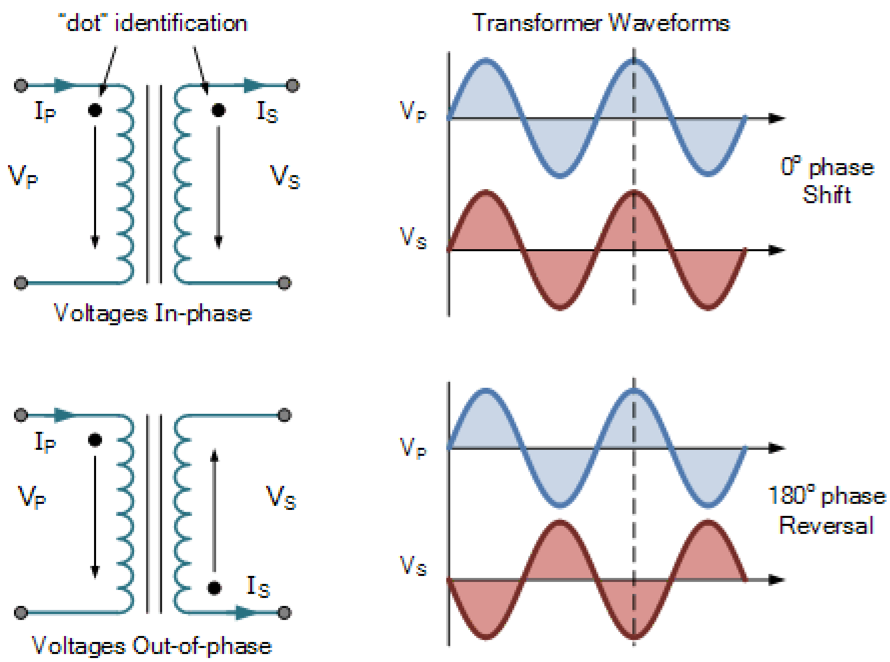
Alternate discs are made to spiral from outside towards the center in an interleaved arrangement with individual coils being stacked together and separated by insulating materials such as paper or plastic sheet. Sandwich coils and windings are more common with shell type core construction.

Helical Windings also known as screw windings are another very common cylindrical coil arrangement used in low voltage high current transformer applications. The windings are made up of large cross-sectional rectangular conductors wound on its side with the insulated strands wound in parallel continuously along the length of the cylinder, with suitable spacers inserted between adjacent turns or discs to minimize circulating currents between the parallel strands. The coil progresses outwards as a helix resembling that of a corkscrew.

1.3 INSULATION

The insulation used to prevent the conductors shorting together in a transformer is usually a thin layer of varnish or enamel in air cooled transformers. This thin varnish or enamel paint is painted.

1.4 TRANSFORMER CONSTRUCTION USING DOT ORIENTATION



The first transformer shows its two "dots" side by side on the two windings. The current leaving the secondary dot is "in-phase" with the current entering the primary side dot. Thus, the polarities of the voltages at the dotted ends are also in-phase so when the voltage is positive at the dotted end of the primary coil, the voltage across the secondary coil is also positive at the dotted end.

The second transformer shows the two dots at opposite ends of the windings which means that the transformers primary and secondary coil windings are wound in opposite directions. The result of this is that the current leaving the secondary dot is 180º "out-of-phase" with the current entering the primary dot. So, the polarities of the voltages at the dotted ends are also out-of-phase so when the voltage is positive at the dotted end of the primary coil, the voltage across the corresponding secondary coil will be negative.

Then the construction of a transformer can be such that the secondary voltage may be either “in-phase” or “out-of-phase” with respect to the primary voltage. In transformers which have a number of different secondary windings, each of which is electrically isolated from each other it is important to know the dot polarity of the secondary windings so that they can be connected together in series-aiding (secondary voltage is summed) or series-opposing (the secondary voltage is the difference) configurations.

The ability to adjust the turns ratio of a transformer is often desirable to compensate for the effects of variations in the primary supply voltage, the regulation of the transformer or varying load conditions. Voltage control of the transformer is generally performed by changing the turns ratio and therefore its voltage ratio whereby a part of the primary winding on the high voltage side is tapped out allowing for easy adjustment. The tapping is preferred on the high voltage side as the volts per turn are lower than the low voltage secondary side.

The ability of iron or steel to carry magnetic flux is much greater than it is in air, and this ability to allow magnetic flux to flow is called permeability. Most transformer cores are constructed from low carbon steels which can have permeabilities in the order of 1500 compared with just 1.0 for air. It means that a steel laminated core can carry a magnetic flux 1500 times better than that of air.

However, when a magnetic flux flows in a transformer's steel core, two types of losses occur in the steel. One termed “eddy current losses” and the other termed “hysteresis losses”.

CHAPTER 2: LOSSES IN A TRANSFORMER

Transformers are the most efficient devices on planet earth as of today. However, they too fall short due to various losses. The most prominent are core losses, which include hysteresis loss caused by the continual magnetization and demagnetization of the core, and eddy current loss arising from circulating currents induced within the core material. Copper losses occur in the windings due to electrical resistance and increase with load current. Stray losses result from leakage flux inducing currents in nearby conductive parts, while dielectric losses arise in the insulation under high voltages. Together, these losses determine a transformer's efficiency and influence its thermal management and design requirements. The following are the major losses in Transformers we will discuss in detail below.

Hysteresis loss	Eddy current loss	Copper loss

2.1 HYSTERESIS LOSSES

Transformer Hysteresis Losses are caused because of the friction of the molecules against the flow of the magnetic lines of force required to magnetize the core, which are constantly changing in value and direction first in one direction and then the other due to the influence of the sinusoidal supply voltage.

This molecular friction causes heat to be developed which represents an energy loss to the transformer. Excessive heat loss can overtime shorten the life of the insulating materials used in the manufacture of the windings and structures. Therefore, cooling of a transformer is important.

Also, transformers are designed to operate at a particular supply frequency. Lowering the frequency of the supply will result in increased hysteresis and higher temperature in the iron core. So, reducing the supply frequency from 60 Hertz to 50 Hertz will raise the amount of hysteresis present, decreasing the VA capacity of the transformer.

2.2 EDDY CURRENT LOSSES

Transformer Eddy Current Losses on the other hand are caused by the flow of circulating currents induced into the steel caused by the flow of the magnetic flux around the core. These circulating currents are generated because to the magnetic flux the core is acting like a single loop of wire. Since the iron core is a good conductor, the eddy currents induced by a solid iron core will be large.

Eddy currents do not contribute anything towards the usefulness of the transformer but instead they oppose the flow of the induced current by acting like a negative force generating resistive heating and power loss within the core.

Laminating the Iron Core

Eddy current losses in a transformer core cannot be completely removed, but they can be reduced by replacing a solid iron core with thin steel laminations. These laminations divide the magnetic path into many narrow sections, limiting the area in which circulating currents can form.

Each lamination is coated with an insulating layer such as varnish or paper, which increases the core's overall resistivity. This insulation restricts the magnitude of eddy currents, lowering the heat they produce and improving efficiency.

Together with hysteresis loss, eddy current loss contributes to what are called transformer core or iron losses. These losses occur whenever the primary winding is energized, even when the transformer is unloaded, because the alternating magnetic flux remains present at all times.

2.3 COPPER LOSSES

But there is also another type of energy loss associated with transformers called "copper losses". Transformer Copper Losses are mainly due to the electrical resistance of the primary and secondary windings. Most transformer coils are made from copper wire which has resistance in Ohms, (Ω). This resistance opposes the magnetizing currents flowing through them.

When a load is connected to the transformer's secondary winding, large electrical currents flow in both the primary and the secondary windings, electrical energy and power (or the I2 R) losses occur as heat. Generally copper losses vary with the load current, being almost zero at no-load, and at a maximum at full-load when current flow is at maximum.

A transformer's VA rating can be increased by better design and transformer construction to reduce these core and copper losses. Transformers with high voltage and current ratings require conductors of large cross-section to help minimize their copper losses. Increasing the rate of heat dissipation (better cooling) by forced air or oil, or by improving the transformers insulation so that it will withstand higher temperatures can also increase a transformers VA rating.

Then we can define an ideal transformer as having:

No Hysteresis loops or Hysteresis losses → 0

Infinite Resistivity of core material giving zero Eddy current losses → 0

Zero winding resistance giving zero I2*R copper losses → 0.

CHAPTER 3: SOFTWARE DEVELOPMENT

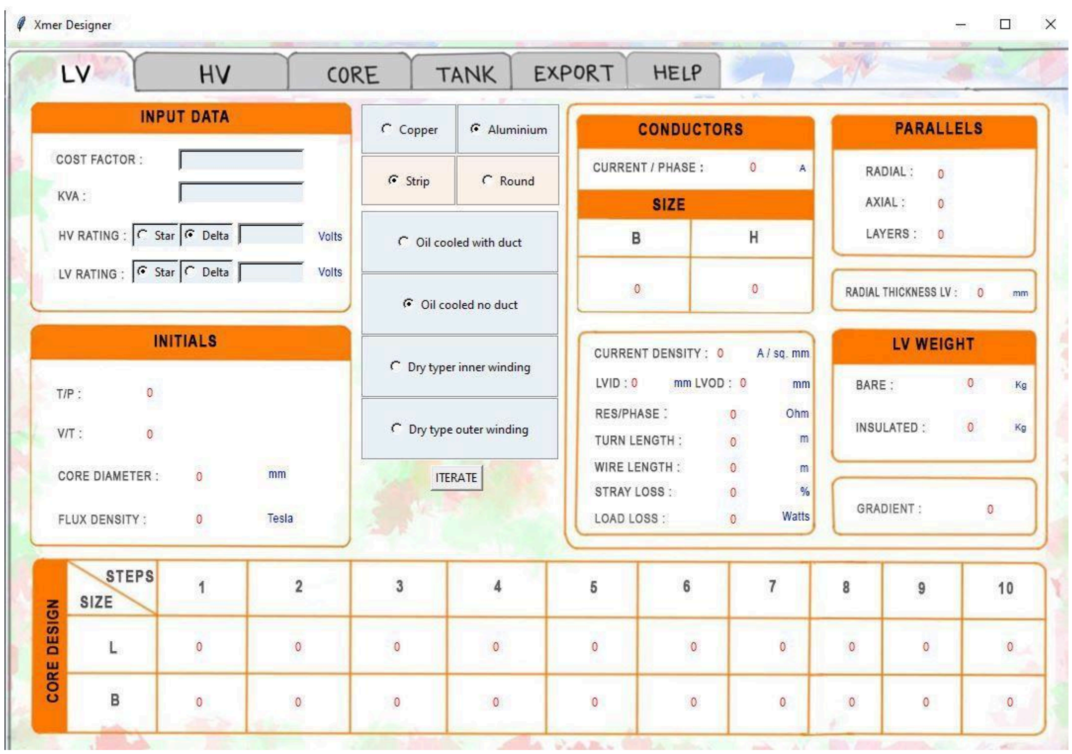
A software has been developed for automatic calculation of parameters for power and distribution 3-phase transformers of capacity up-to 100KVA. The design language is python and Tkinter GUI is utilized for graphical user interface. The development process is given below.

- Explore software development field
- Learn to design software using python tkinter
- Make lengthy and error prone calculation easy and accessible at a single click

The features of the software are provided below.

- LV design window
- HV design window
- Core design window
- Tank design window
- Export Tab
- Help Tab

The first four windows have their usual meaning and function. Export Tab prints the result sheet in a pdf file.



3.1 DESIGN PROCESS

The software consists of a predefined looping window that houses the widgets that we see. The widgets can be anything that are present or anchored to the window, for example Texts, Text Boxes, Labels, Buttons etc. are widgets. Following are the widgets that have been incorporated into the software.

(i) Label
(ii) Entry box
(iii) Image
(iv) Button
(v) Radio button
(vi) Frame
(vii) Notebook

3.1.1 Label

A label can be a defined text or image. Anything that we want to put as a display is a label. The display has the option of being a constant or a variable. For example, the result after calculation;

Core Diameter: 120 **mm**

The black bold part of the result should not change; hence they are constant labels. On the other hand, "120" has to change each time. Hence, a variable label.

Syntax

w = Label (master, option)

Parameters

master − This represents the parent window.

options − Here is the list of most commonly used options for this widget. These options can be used as key-value pairs separated by commas.

3.1.2 Entry Box

Entry Box is used to take input data. Input data can be either text or number. The data type has to be specified properly. Also, a variable would be required to store the input data.

Syntax

w = Entry (master, option)

3.1.3 Button

It allows users to execute commands. For example, "calculate", "send", "share" etc. There are infinite possibilities available based on how we program it. The command has to be defined aforehand.

Syntax

w = Button (parent, options)

3.1.4 Radio Button

Radio Buttons are used for multiple choice selection. These buttons can select only one button out of the given options. For selecting more than one option, check button widgets are used.

Syntax

w = RadioButton (parent, options)

3.1.5 Frames

Frames are used to organize the window. One example is that to place two different sets of Radio Buttons we have to use two frames.

Syntax

w = Frame (master, options)

Cu Al Round Strip

In this case, we have to separate both sets with two frames. Otherwise only one selection out of four will be possible.

3.1.6 Note Book

This widget is useful for making Tabs in the widow. This widget belongs to the ttk package only. Whereas the rest are available on both tk and ttk packages.

Syntax

note = ttk.Notebook(parent)

3.2 INITIALIZATION

As explained previously a predefined looping window is generated at the very outset. Then with the available/defined geometry placing of the rest of the widgets are planned. Each widget is very flexible and allows an infinite level of configuration and styling. It is very much necessary that the software meets modern design criteria and is ergonomic. Following codes are used to initialize the window.

from tkinter import*

root = Tk()

root.title('Xmer Designer')

root.geometry('1080x720')

root.mainloop()

This will create a window of size 1080x720 pixels. In which we will place the rest of the widgets.

3.3 PLACEMENT

To place the widgets in the widow, three methods are available.

(i) Pack
(ii) Grid
(iii) Place

We have used the place method which is the most advanced method till date. It uses pixel dimensions to locate the position. The rest of the methods use a relative positioning system. The proper code of the software is provided in the appendix.

CHAPTER 4: RESULTS AND DISCUSSION

The manual designs of the proposed transformers are done using pen and paper. A variability in design criteria has been provided so as to push the software to an extended range. Right after manual calculation, software output sheets are provided to compare the results. The verification of correctness of the software is done using the criteria that has been explained in the objective of the project.

4.1 MANUAL DESIGN 1

$\textbf{Transformer}1:\ 3-\text{Phase},\ 15\ \text{KVA},\ 430/220\text{V},\ \text{YnD1},\ \text{Energy Efficient},\ \text{ANAN.}$

4.1.1 LV WINDING DESIGN

LV Current/phase $= \dfrac{15\times10^3}{3\times230} = 21.74 \cong 22\text{Amps}$

Current density =2.4 A/mm², Flux density = 1.5 T

$\therefore$ Cross Section area of conductor $= \dfrac{\text{Lv\_current/phase}}{\text{Current density}}$

$$= \frac{22}{2.4} = 9.177\text{mm}^2$$

Voltage/turn(V/T) $=\text{k}\sqrt{KVA}$, we take k = 0.5 (for energy efficient, higher values near to 0.7 are preferred, 0.5 is good)

$$=0.5\sqrt{15}$$

$$= 1.94$$

LV Voltage = 230 Volt

LV Voltage per phase = 230 Volt (Since LV side is delta connected)

$\therefore$ LV turns/phase(T/P) $= \dfrac{\text{LV}_\text{p}}{\text{V/T}} = \dfrac{230}{1.94} = 118.56 \cong 118$

LV volts/turns $= \dfrac{\text{LV}_\text{P}}{\text{T/P}} = \dfrac{230}{118} = 1.9492$ Again,

$$e = 4.44\times f\times B\times A_i\times T\times10^{-6}$$

$$A_i = \frac{e/T}{4.44\times f\times B\times10^{-6}} = 5853.31\,mm^2 \cong 5853\,mm^2$$

$\therefore$ Gross area of the core $= \dfrac{5853}{0.85} = 6651.136 \cong 6651\, mm^2$

$\therefore$ Diameter of the core $= \sqrt{\dfrac{6651 \times 4}{\Pi}} \cong 92\, mm$

The steps are taken as-

85, 80, 75, 70, 60, 50, 40

Applying work back method for verification,

$$\sqrt{92^2 - 85^2} = 35 \xrightarrow{AREA} 35 \times 85 \times 0.97 = 2885.75 \cong 2885$$

$$\downarrow^{+\text{ previous}} \qquad \xrightarrow{+\text{ previous}} 2885$$

$$\sqrt{92^2 - 80^2} - 35 = 10 \xrightarrow{AREA} 10 \times 80 \times 0.97 \cong 776$$

$$\downarrow^{+\text{previous}} \qquad \xrightarrow{+\text{previous}} 3661$$

$$\sqrt{92^2 - 75^2} - 45 = 8 \xrightarrow{AREA} 8 \times 75 \times 0.97 \cong 582$$

$$\downarrow^{+\text{previous}} \qquad \xrightarrow{+\text{previous}} 4243$$

$$\sqrt{92^2 - 70^2} - 53 = 6 \xrightarrow{AREA} 6 \times 70 \times 0.97 \cong 407$$

$$\downarrow^{+\text{previous}} \qquad \xrightarrow{+\text{previous}} 4650$$

$$\sqrt{92^2 - 60^2} - 59 = 10 \xrightarrow{AREA} 10 \times 60 \times 0.97 \cong 582$$

$$\downarrow^{+\text{previous}} \qquad \xrightarrow{+\text{previous}} 5253$$

$$\sqrt{92^2 - 50^2} - 69 = 8 \xrightarrow{AREA} 8 \times 50 \times 0.97 \cong 388$$

$$\downarrow^{+\text{previous}} \qquad \xrightarrow{+\text{previous}} 5652$$

$$\sqrt{92^2 - 40^2} - 77 = 4 \xrightarrow{AREA} 8 \times 40 \times 0.97 \cong 155$$

$$\xrightarrow{+\text{previous}} 5775$$

$A = 5775\, mm^2$

$$B = \frac{\text{V/T}}{4.44 \times 50 \times 5775 \times 10^{-6}}$$

$= 1.521\,\text{Tesla}$

Conductor size

5.3 x 1.8 → bare

5.6 x 2.1 → FG Insulation (0.3 mm Insulation)

Area available = (5.3 x 1.8) – 0.363 [0.363 is the corner reduction]

= 9.177 mm^2

Ct. density $= \dfrac{\text{Current}}{\text{Conductor\_Area}} = 22 \div 9.177 = 2.389\, A / mm^2$

LV turns/limb = 118

Number of Layers = 3

Turn/layer = 40 (40,40,38)

Radial thickness(mm)

$(2.1\times3) + 8.7$

=15 mm

Turn length (m)

$$= \frac{\Pi \times \dfrac{(ID + OD)}{2}}{1000}$$

$$= \frac{\Pi \times \dfrac{(108 + 122)}{2}}{1000} = 0.361m$$

Wire length (m)

Turn Length × Turns per Limb × Number of Limbs

$= 0.3612 \ \times 118 \ \times 3$

=130.032m

Resistance (R15 / R28)

$$= \frac{() - (5.3 \times 1.8)}{5.3 \times 1.8}$$

Winding Length

$= (10\times1) \times 5.6$

=229.6 = 230mm

End Clearance

$$= 2 \times 20 = 40 \text{ mm}$$

Window_height

= (230+40) = 270mm

Weight in kg

$$= 8.89 \times 0.3612 \times 118 \times 9.117 \times 3 \times 10^{-3} = 10.60 \ kg$$

Insulated weight

$$= \left[\frac{(5.6 \times 2.1) - (5.3 \times 1.85)}{(5.3 \times 1.8)} \times \frac{1.85}{8.89} + 1 \right] \times 10.6$$

$$\cong 10.9 \ kg$$

$$\text{taking} 1\% \text{ extra} = 0.109 \ kg$$

Total Weight

$$= 10.9 \times 0.109 \cong 11.2 \ kg$$

Stray Loss

$$= \left(\sqrt{\frac{5.3 \times 40}{5.6 \times 40 - 0.3}} \times 0.9622 \times \frac{2.1}{10} \right)^4 \times \frac{3^2 - 0.2}{9} \times 10^2$$

$$= 0.15\%$$

Load loss

$$= 2.9 \times 10.6 \times 2.369^2 \times \left(\frac{0.0632}{100} + 1 \right)$$

$$= 142.86 \ W \cong 145 \ W$$

Gradient

$$= \frac{145}{3 \times 3 \times 6 \times 0.3612 \times \frac{230}{1000}}$$

$$= 32.32 \ {}^0C$$

4.1.2 HV WINDING DESIGN

Area according to Standards $= \frac{\text{ct\_per\_phase}}{\text{ct\_density}}$

$= 9.1384 mm^2$

$\pi d^2/4 = 9.14$

$d = 3.41mm$

Turns/phase or limb=118

Layers = 3

Turn per layer = 40 (40,40,38)

Current/phase $= \frac{15\times10^3}{400/\sqrt{3}} \cong$ 22 Amp

Area Recalculated = 22/2.4

$=9.177mm^2$

Conductor size

5.3x1.8 →bare

5.6x2.1→ insulated

Area = (5.3 x 1.8 - .363) [0.363 is the corner reduction]

$=9.177mm^2$

Radial Thickness = (3.40 x 3) + 4.8 = 15mm

Turn Length

$$= \frac{\Pi\times\frac{(ID+OD)}{2}}{1000}$$

$$= \frac{\Pi\times\frac{(146+176)}{2}}{1000} = 0.5058\ m$$

Wire length

$$= 5058\times118\times3 = 182.1$$

Resistance

$$R_{15} = \rho \times \frac{l}{A} = \frac{0.2128 \times (0.5058 \times 118)}{9.177} = 1.383 \cong 1.4$$

$$R_{28} = \frac{235+28}{235+75} \times R_{15} \approx 2.036\ \Omega$$

Weight in kg

$$= (8.89 \times 0.5058 \times 118 \times 9.177) \times 3 \times 10^{-3}$$

$$= 14.96\ kg \longrightarrow bare$$

Insulated weight

$$= \left[\frac{(5. \times 2.1) - (5.3 \times 1.8)}{5.3 \times 1.8} \times \frac{1.85}{8.89} + 1 \right] \times 14.9$$

$$= 15.3\ kg$$

Total weight $= 15.2 + 0.152$

$other\ case$

$15.42\ kg$

$\downarrow$

$d = 5.34\, mm$

$\downarrow$

0.922%

$\downarrow$

$102\, w$

Stray loss

$$= \left(\sqrt{\frac{5.3 \times 40}{5.6 \times 40 - 0.3}} \times 0.9622 \times \frac{2.1}{10} \right)^4 \times \frac{3^2 - 0.2}{9} \times 10^2$$

$$= 0.15\%$$

Load loss

$$= 2.4 \times 14.9 \times 2.369^2 \times \left(\frac{0.0632}{100} + 1 \right)$$

$$= 201\, w$$

Gradient

$$= \frac{201}{3 \times 3.25 \times 8 \times 0.5058 \times \frac{230}{1000}}$$

$$\cong 42\ {}^{0}C$$

4.1.3 CORE DESIGN

L = 270 (230 + 2 x 10)

A = 190

D = 92

Length of the core

= 2D + 3L + 4A

= (2 x 92) + (3 x 270) + (4 x 190)

=1754mm

Area of the core = 5775 mm^2

Weight of the core = 1754 x 5775 x 7.65 x 10^{-6} kg = 77.5 kg

Core loss

$$= wt.\ of\ the\ core \times sp.\ loss \times build\ \ factor$$
$$= 77.5 \times 0.89 \times 1.3$$
$$= 89.67 \cong 90\ w$$

4.1.4 IMPEDANCE / REGULATION/ EFFICIENCY

$$e_k = \sqrt{e_x{}^2 + e_r{}^2}$$

Where,

$$e_x = \frac{1.24 \times H \times \Delta' D_s \times 10^{-4}}{V / T \times l_s}$$

Where,

H = Ampere Turns.

$\Delta' = \Delta + \frac{1}{3}(h_2 + h_1)$

h_2 = radial thickness of outer winding representation.

= HVOD – [duct thickness + insulation]

Δ = gap between LV and HV + half LV insulation + half HV insulation.

h_2 = radial thickness of inner winding representation.

= HVID – [duct thickness + insulation]

D_s = LVOD + Δ + 1/3($h_2 - h_1$)

$$l_s = \frac{l}{K_R}$$

l = 0.5 [(b_i x turns per layer) No. of Axial Parallel + Transposition – LV insulation + Winding length – HV insulation]

$$K_R = 1 - \frac{e^{-\Pi \frac{l}{b}}}{\Pi \frac{l}{b}}$$

Where,

$$b = \frac{OD\ of\ HV - ID\ of\ LV}{2}$$

Ampere turns

= current ×no. of turns (in LV coil)

= 22×118

= 2596 AT

Δ = gap between LV and HV + half LV insulation + half HV insulation

=24+0.15+0.15

= 24.3

h_2=radial thickness – (duct thickness with insulation)

= 15- (8.7 + 0.3)

= 6

h_1=15-(8.7+0.5)

=6

$\Delta' = 24.3 + \frac{1}{3}(6+6)$

=28.3

$$D_s = OD\ of\ LV + \Delta + \frac{1}{3}(h_2 - h_1)$$

$$= (122 - 0.3) + 24.3 + \frac{1}{3}(0)$$

$$= 146$$

$$l_s = \frac{l}{K_R}$$

$$K_R = 1 - \frac{e^{-\Pi \frac{l}{b}}}{\Pi \frac{l}{b}}$$

$$l \quad = \frac{\{(5.6 \times 118) - 0.15\} + \{(5.6 \times 118) - 0.15\}}{2}$$

$$= 660.5$$

$$b \quad = \frac{OD\, of\ HV - ID\, of\ LV}{2}$$

$$= \frac{(176 - 0.3) - (112 - 0.3)}{2} = 32$$

$$K_R = 1 - \frac{e^{\Pi \frac{l}{b}}}{\Pi \times \frac{l}{b}}$$

$$= 0.9854$$

$$\sim 0.985$$

$$l_s \quad = \frac{l}{K_R} = 670.558$$

Now,

$$e_x = \frac{1.24 \times H \times \Delta' D_s \times 10^{-4}}{v / T \times l_s}$$

$$= \frac{1.24 \times 2596 \times 28.3 \times 146 \times 10^{-4}}{1.94 \times 670.558}$$

$$= 1.02$$

and

$$e_R = \frac{\text{load loss}}{\text{capacity}} \times 100$$

load loss=LV loss+HV loss+Tank loss

$$= 145 + 201 + 100$$

$$= 446\ watts$$

Hence,

$$e_R = \frac{446}{15 \times 10^3} \times 100$$

$$= 2.97$$

Finally,

$e_k = \sqrt{(1.02)^2 + (2.97)^2}$

$= 3.14\ \%$ is the impedance.

Maximum efficiency

$$= \sqrt{\frac{90}{466}} \times 100$$

$$= 43.9469$$

$$= \frac{43.9469}{43.9469 + (2 \times 0.90)}$$

$$= \frac{43.9469}{43.9469 + 1.8} \times 100\%$$

$$= 96.06\ \%$$

<u>Regulation</u>

$e_R = 2.97 / e_x = 1.02$

(i) @UPF and 100% load

$$= e_R + \frac{e_x{}^n}{200}$$

$$= 2.975$$

(ii) 0.8 PF lag@100% local

$$= e_R \cos\phi + e_x \sin\phi + \frac{\left(e_x \cos\phi - e_R \sin\phi\right)^2}{200}$$

$$= 2.9986\%$$

<u>Efficiency</u>

(i) @UPF and 100% load	(ii) 0.8PF @50% load
$= \frac{15 \times 103}{15 \times 103 + \text{load loss} + neL} \times 100$ $= \frac{15 \times 103}{15 \times 103 + 90 + 446}$ $= 96.549\ \%$	$= \frac{0.8 \times 15 \times 1000 \times 0.5}{(0.8 \times 15 \times 1000 \times 0.5) + 90 + (0.25 \times 446)}$ $= 96.751\ \%$

4.1.5 RESULT 1 (MANUAL)

SPECIFICATION

3 PHASE, 15KVA, 400/230 V, DISTRIBUTION TRANSFORMER, ECONOMIC, DRY TYPE, Ynd1, AN-AN.

DIMENSIONS

Core Diameter: 92 mm	2×8 (core to LV gap)
Internal Diameter LV: 108 mm	2×7 (LV thickness)
Outer Diameter LV: 122 mm	2×12 (LV to HV gap)
Internal Diameter HV: 146 mm	2×15 (HV thickness)
Outer Diameter HV: 176 mm	14 mm
Centre Distance: 190 mm	

DESIGN SHEET

PARAMETERS	UNIT	LV DESIGN	HV DESIGN
CURRENT/P	A	22 A	224
VOLTAGE/P	V	230 V	230 V
TURNS/P		118	118
LAYERS		3	3
TURNS/LAYER		40 × 2 + 38 on last layer	40×2+38 on last layer
CONDUCTOR SIZE	mm	5.3 × 1.8 → bare 5.6 × 2.1 → Insulated	5.3 × 1.8 → bare 5.6 × 2.1 → Insulated
CROSS-SECTION	mm2	9.177 mm2	9.177 mm2
CURRENT DENSITY	A/mm2	2.369 A/mm2	24.408 A/mm2
RADIAL THICKNESS	mm	15 mm	15 mm
TURN LENGTH	m	0.3612 m	0.5058
WIRE LENGTH	m	130.032	182.1 m
WEIGHT	kg	11.2 kg	15.5 kg
R28/R75	Ω	0.1005 Ω/0.0853 Ω	2.036 Ω/2.4 Ω
STRAY LOSS	%	0.15%	0.15%
LOAD LOSS	W	145 w	201 w
GRADIENT	℃	32.32℃	42℃
WINDING LENGTH	mm	230 mm	230 mm
END CLEARANCE	mm	2 × 20 mm	2 × 20 mm
WINDOW HEIGHT	mm	270 mm	270 mm
AMPERE TURNS	AT	2596	2596

4.1.6 RESULT 1 (SOFTWARE)

DIMENSIONS

Core Diameter: 92 mm	2×8 (core to LV gap)
Internal Diameter LV: 108 mm	2×7 (LV thickness)
Outer Diameter LV: 122 mm	2×12 (LV to HV gap)
Internal Diameter HV: 146 mm	2×15 (HV thickness)
Outer Diameter HV: 176 mm	14 mm
Centre Distance: 190 mm	

DESIGN SHEET

PARAMETERS	UNIT	LV DESIGN	HV DESIGN
CURRENT/P	A	22 A	224
VOLTAGE/P	V	230 V	230 V
TURNS/P		118	118
LAYERS		3	3
TURNS/LAYER		40 × 2 + 38 on last layer	40×2+38 on last layer
CONDUCTOR SIZE	mm	5.3 × 1.8 → bare 5.6 × 2.1 → Insulated	5.3 × 1.8 → bare 5.6 × 2.1 → Insulated
CROSS-SECTION	mm2	9.177 mm2	9.177 mm2
CURRENT DENSITY	A/mm2	2.369 A/mm2	24.408 A/mm2
RADIAL THICKNESS	mm	15 mm	15 mm
TURN LENGTH	m	0.3612 m	0.5058
WIRE LENGTH	m	130.032	182.1 m
WEIGHT	kg	11.2 kg	15.5 kg
R28/R75	Ω	0.1005 Ω/0.0853 Ω	2.036 Ω/2.4 Ω
STRAY LOSS	%	0.15%	0.15%
LOAD LOSS	W	145 w	201 w
GRADIENT	℃	32.32℃	42℃
WINDING LENGTH	mm	230 mm	230 mm
END CLEARANCE	mm	2 × 20 mm	2 × 20 mm
WINDOW HEIGHT	mm	270 mm	270 mm
AMPERE TURNS	AT	2596	2596

4.2 MANUAL DESIGN 2

Transformer2 : 3 – Phase, 66 KVA, 11000 / 433V, DYn11, Balanced , ON-AN.

4.2.1 LV WINDING DESIGN

LV Current/phase $= \dfrac{66 \times 10^3}{3 \times \dfrac{433}{\sqrt{3}}} = 88.00 \cong 88\text{Amps}$

Current density =1.88 A/mm^2 , Flux density = 1.461 T

$\therefore$ Cross Section area of conductor $= \dfrac{\text{Lv\_current/phase}}{\text{Current density}}$

$$= \frac{88}{1.88} = 46.81\text{mm}^2$$

Voltage/turn(V/T) $= k\sqrt{KVA}$, we take k = 0.55

$= 0.55\sqrt{66}$

$= 4.46$

LV Voltage = 433 Volt

LV Voltage per phase = $\dfrac{433}{\sqrt{3}} = 249.99$ Volt (Since LV side is star connected)

$\therefore$ LV turns/phase(T/P) $= \dfrac{LV_p}{V/T} = \dfrac{249.99}{4.47} = 55.9 \cong 56.0$

LV volts/turns $= \dfrac{LV_P}{T/P} = \dfrac{249.99}{56} = 4.46$

Again,

$$e = 4.44 \times f \times B \times A_i \times T \times 10^{-6}$$

$$A_i = \frac{e/T}{4.44 \times f \times B \times 10^{-6}} = 13750.92\,mm^2 \cong 13751\,mm^2$$

$\therefore$ Gross area of the core $= \dfrac{13751}{0.90} = 15278.89 \cong 15279\,mm^2$

$\therefore$ Diameter of the core $= \sqrt{\dfrac{15279 \times 4}{\Pi}} \cong 132\,mm$

The steps are taken as follows.

125, 115, 105, 90, 65, 55, 40

Applying work back method for verification,

$$\sqrt{132^2 - 125^2} = 42 \xrightarrow{AREA} 42 \times 125 \times 0.97 = 5092.50 \cong 5093$$

$$\downarrow + \text{previous} \qquad \xrightarrow{+\text{ previous}} 5093$$

$$\sqrt{132^2 - 115^2} - 42 = 22 \xrightarrow{AREA} 22 \times 115 \times 0.97 \cong 2454$$

$$\downarrow + \text{previous} \qquad \xrightarrow{+\text{previous}} 7547$$

$$\sqrt{132^2 - 105^2} - 64 = 15 \xrightarrow{AREA} 15 \times 105 \times 0.97 \cong 1528$$

$$\downarrow + \text{previous} \qquad \xrightarrow{+\text{previous}} 9075$$

$$\sqrt{132^2 - 90^2} - 79 = 17 \xrightarrow{AREA} 17 \times 90 \times 0.97 \cong 1484$$

$$\downarrow + \text{previous} \qquad \xrightarrow{+\text{previous}} 10559$$

$$\sqrt{132^2 - 65^2} - 96 = 18 \xrightarrow{AREA} 18 \times 65 \times 0.97 \cong 1135$$

$$\downarrow + \text{previous} \qquad \xrightarrow{+\text{previous}} 11694$$

$$\sqrt{132^2 - 55^2} - 114 = 5 \xrightarrow{AREA} 5 \times 55 \times 0.97 \cong 267$$

$$\downarrow + \text{previous} \qquad \xrightarrow{+\text{previous}} 11961$$

$$\sqrt{132^2 - 40^2} - 119 = 6 \xrightarrow{AREA} 6 \times 40 \times 0.97 \cong 233$$

$$\xrightarrow{+\text{previous}} 12194$$

$$A = 12194\,mm^2$$

$$B = \frac{\text{V/T}}{4.44 \times 50 \times 12194 \times 10^{-6}}$$

$$= 1.461\,\text{Tesla}$$

Conductor size

10.0 x 2.4 → bare

10.3 x 2.7 → FG Insulation (0.3 mm Insulation)

Area available = (10.0 x 2.4) – 0.55 [0.55 is the corner reduction]

= 23.45 mm^2

Ct. density $= \frac{\text{Current}}{\text{Conductor\_Area}} = 88 \div 23.45 = 3.753\, A/mm^2$

LV turns/limb = 112

Number of Layers = 3

Turn/layer = 40 (40,40,32)

Radial thickness(mm)

(2.7×3) + 13.9

=22 mm

Turn length (m)

$$= \frac{\Pi \times \frac{(ID + OD)}{2}}{1000}$$

$$= \frac{\Pi \times \frac{(149 + 172)}{2}}{1000} = 0.504\, m$$

Wire length (m)

Turn Length × Turns per Limb × Number of Limbs

= 0.504 ×112 × 3

=169 m

Resistance (R15 / R28)

R15= $R15 = p \times \frac{l}{a} = 0.212 \times \frac{0.504 \times 112}{23.45} = 0.51$

$$R28 = \frac{235 + 28}{235 + 75} \times 0.51 = 0.43$$

Winding Length

= 132 x 3

=396mm

End Clearance

$= 2 \times 25 = 50$ mm

Window_height

= (396-50) = 346mm

Weight in kg

$$= 8.89 \times 0.3612 \times 112 \times 9.117 \times 3 \times 10^{-3} = 9.84\ kg$$

Insulated weight

$$= \left[\frac{(10.3 \times 2.7) - (10.0 \times 2.4)}{(10.0 \times 2.4)} \times \frac{1.85}{8.89} + 1 \right] \times 9.84$$

$\cong 10.2\ kg$

taking 1% extra $= 0.102\ kg$

Total Weight

$= 10.2 + 0.102 \cong 10.3\ kg$

Stray Loss

$$= \left(\sqrt{\frac{10.0 \times 40}{10.3 \times 40 - 0.3}} \times 0.9622 \times \frac{2.7}{10} \right)^4 \times \frac{1^2 - 0.2}{9} \times 10^2$$

$= 0.04\%$

Load loss

$$= 2.9 \times 9.84 \times 3.753^2 \times \left(\frac{0.0632}{100} + 1 \right)$$

$$= 402.18\ W \cong 402\ W$$

Gradient

$$= \frac{402}{3 \times 3 \times 6 \times 0.3612 \times \frac{230}{1000}}$$

$$= 89.61\ {}^0C$$

4.2.2 HV WINDING DESIGN

Area according to Standards $= \frac{\text{ct\_per\_phase}}{\text{ct\_density}}$

$= 9.1384 mm^2$

$\pi d^2/4 = 9.14$

$d = 3.41mm$

Turns/phase or limb=112

Layers = 3

Turn per layer = 40 (40,40,32)

Current/phase $= \frac{15 \times 10^3}{400/\sqrt{3}} \cong$ 22 Amp

Area Recalculated = 22/2.4

$=9.177 mm^2$

Conductor size

5.3x1.8 →bare

5.6x2.1→ insulated

Area = (5.3 x 1.8 - .363) [0.363 is the corner reduction]

$=9.177 mm^2$

Radial Thickness = (3.40 x 3) + 4.8 = 15mm

Turn Length

$$= \frac{\Pi \times \frac{(ID+OD)}{2}}{1000}$$

$$= \frac{\Pi \times \frac{(146+176)}{2}}{1000} = 0.5058\ m$$

Wire length

$$= 5058 \times 118 \times 3 = 182.1$$

Resistance

$$R_{15} = \rho \times \frac{l}{A} = \frac{0.2128 \times (0.5058 \times 118)}{9.177} = 1.383 \cong 1.4$$

$$R_{28} = \frac{235+28}{235+75} \times R_{15} \approx 2.036\ \Omega$$

Weight in kg

$$= (8.89 \times 0.5058 \times 118 \times 9.177) \times 3 \times 10^{-3}$$

$$= 14.96\ kg \longrightarrow bare$$

Insulated weight

$$= \left[\frac{(5.\times 2.1) - (5.3 \times 1.8)}{5.3 \times 1.8} \times \frac{1.85}{8.89} + 1 \right] \times 14.9$$

$$= 15.3\ kg$$

Total weight = $15.2 + 0.152$

other case

$15.42\ kg$

$\downarrow$

$d = 5.34\,mm$

$\downarrow$

0.922%

$\downarrow$

$102\,w$

Stray loss

$$= \left(\sqrt{\frac{5.3\times 40}{5.6\times 40-0.3}}\times 0.9622\times \frac{2.1}{10} \right)^4 \times \frac{3^2-0.2}{9}\times 10^2$$
$$= 0.15\%$$

Load loss

$$= 2.4\times 14.9\times 2.369^2\times \left(\frac{0.0632}{100}+1\right)$$
$$= 201w$$

Gradient

$$= \frac{201}{3\times 3.25\times 8\times 0.5058\times \frac{230}{1000}}$$
$$\cong 42\ {}^0C$$

4.2.3 CORE DESIGN

L = 270 (230 + 2 x 10)

A = 190

D = 92

Length of the core

= 2D + 3L + 4A

= (2 x 92) + (3 x 270) + (4 x 190)

=1754mm

Area of the core = 5775 mm^2

Weight of the core = 1754 x 5775 x 7.65 x 10^{-6} kg = 77.5 kg

Core loss

$$= wt.\ of\ the\ core \times sp.\ loss \times build\ \ factor$$
$$= 77.5\times 0.89\times 1.3$$
$$= 89.67 \cong 90\ w$$

4.2.4 RESULT 2(MANUAL)

SPECIFICATION

3 PHASE, 66KVA, 11000/433 V, DISTRIBUTION TRANSFORMER, BALANCED, DYn11, ON-AN.

DIMENSIONS

Core Diameter: 132 mm	2×8 (core to LV gap)
Internal Diameter LV: 108 mm	2×7 (LV thickness)
Outer Diameter LV: 122 mm	2×12 (LV to HV gap)
Internal Diameter HV: 146 mm	2×15 (HV Thickness)
Outer Diameter HV: 176 mm	14 mm
Centre Distance: 190 mm	

DESIGN SHEET

PARAMETERS	UNIT	LV DESIGN	HV DESIGN
CURRENT/P	A	88 A	224
VOLTAGE/P	V	230 V	230 V
TURNS/P		118	118
LAYERS		3	3
TURNS/LAYER		40 × 2 + 38 on last layer	40×2+38 on last layer
CONDUCTOR SIZE	mm	5.3 × 1.8 → bare 5.6 × 2.1 → Insulated	5.3 × 1.8 → bare 5.6 × 2.1 → Insulated
CROSS-SECTION	mm2	9.177 mm2	9.177 mm2
CURRENT DENSITY	A/mm2	2.369 A/mm2	24.408 A/mm2
RADIAL THICKNESS	mm	15 mm	15 mm
TURN LENGTH	m	0.3612 m	0.5058
WIRE LENGTH	m	130.032	182.1 m
WEIGHT	kg	11.2 kg	15.5 kg
R28/R75	Ω	0.1005 Ω/0.0853 Ω	2.036 Ω/2.4 Ω
STRAY LOSS	%	0.15%	0.15%
LOAD LOSS	W	145 w	201 w
GRADIENT	℃	32.32℃	42℃
WINDING LENGTH	mm	230 mm	230 mm
END CLEARANCE	mm	2 × 20 mm	2 × 20 mm
WINDOW HEIGHT	mm	270 mm	270 mm
AMPERE TURNS	AT	2596	2596

4.2.5 RESULT 2 (SOFTWARE)

DIMENSIONS

Core Diameter: 132 mm	2×8 (core to LV gap)
Internal Diameter LV: 108 mm	2×7 (LV thickness)
Outer Diameter LV: 122 mm	2×12 (LV to HV gap)
Internal Diameter HV: 146 mm	2×15 (HV Thickness)
Outer Diameter HV: 176 mm	14 mm
Centre Distance: 190 mm	

DESIGN SHEET

PARAMETERS	UNIT	LV DESIGN	HV DESIGN
CURRENT/P	A	88 A	224
VOLTAGE/P	V	230 V	230 V
TURNS/P		118	118
LAYERS		3	3
TURNS/LAYER		40 × 2 + 38 on last layer	40×2+38 on last layer
CONDUCTOR SIZE	mm	5.3 × 1.8 → bare 5.6 × 2.1 → Insulated	5.3 × 1.8 → bare 5.6 × 2.1 → Insulated
CROSS-SECTION	mm2	9.177 mm2	9.177 mm2
CURRENT DENSITY	A/mm2	2.369 A/mm2	24.408 A/mm2
RADIAL THICKNESS	mm	15 mm	15 mm
TURN LENGTH	m	0.3612 m	0.5058
WIRE LENGTH	m	130.032	182.1 m
WEIGHT	kg	11.2 kg	15.5 kg
R28/R75	Ω	0.1005 Ω/0.0853 Ω	2.036 Ω/2.4 Ω
STRAY LOSS	%	0.15%	0.15%
LOAD LOSS	W	145 w	201 w
GRADIENT	℃	32.32℃	42℃
WINDING LENGTH	mm	230 mm	230 mm
END CLEARANCE	mm	2 × 20 mm	2 × 20 mm
WINDOW HEIGHT	mm	270 mm	270 mm
AMPERE TURNS	AT	2596	2596

4.3 MANUAL DESIGN 3

Transformer 3 : 3 – Phase, 100 KVA, 11000 / 433V, Dy_n11, Economical, ONAN.

3.3.1 LV WINDING DESIGN

LV Current/phase $= \dfrac{100 \times 10^3}{3 \times \dfrac{433}{\sqrt{3}}} = 133.33 \cong 134\text{Amps}$

Current density =2.4 A/mm^2 , Flux density = 1.73 T

$\therefore$ Cross Section area of conductor $= \dfrac{\text{Lv\_current/phase}}{\text{Current/Phase}}$

$$= \frac{134}{2.37} = 56.54\text{mm}^2$$

Voltage/turn(V/T) $= k\sqrt{KVA}$, we take k = 0.4

$$=0.4\sqrt{100}$$

$$= 14$$

LV Voltage per phase = $\dfrac{433}{\sqrt{3}}V$

$\therefore$ LV turns/phase(T/P) $= \dfrac{\text{LV}_\text{p}}{\text{V/T}} = \dfrac{\frac{433}{\sqrt{3}}}{4} = 62.5 \cong 62$

LV volts/turns $= \dfrac{\text{LV}_\text{P}}{\text{T/P}} = \dfrac{\frac{433}{\sqrt{3}}}{62} = 4.03$

Again,

$$e = 4.44 \times f \times B \times A_i \times T \times 10^{-6}$$

$$A_i = \frac{e/T}{4.44 \times f \times B \times 10^{-6}} = 10477.98\,mm^2 \cong 10478\,mm^2$$

$\therefore$ Gross area of the core $= \dfrac{10478}{0.9} \cong 11642\,mm^2$

$\therefore$ Diameter of the core $= \sqrt{\dfrac{11642 \times 4}{\pi}} \cong 121\,mm$

The steps are taken as-

115,110,105,100,95,90,80,70,55,35

Applying work back method for verification,

$$\sqrt{121^2 - 115^2} = 37 \xrightarrow{AREA} 37 \times 115 \times 0.97 \cong 4127$$

$$\downarrow{+\text{ previous}} \qquad \xrightarrow{+\text{ previous}} 4127$$

$$\sqrt{121^2 - 110^2} - 37 = 12 \xrightarrow{AREA} 12 \times 110 \times 0.97 \cong 1280$$

$$\downarrow{+\text{previous}} \qquad \xrightarrow{+\text{previous}} 5407$$

$$\sqrt{121^2 - 105^2} - 37 - 12 = 10 \xrightarrow{AREA} 10 \times 105 \times 0.97 \cong 1018$$

$$\downarrow{+\text{previous}} \qquad \xrightarrow{+\text{previous}} 6425$$

$$\sqrt{121^2 - 100^2} - 37 - 12 - 10 = 8 \xrightarrow{AREA} 8 \times 100 \times 0.97 \cong 776$$

$$\downarrow{+\text{previous}} \qquad \xrightarrow{+\text{previous}} 7201$$

$$\sqrt{121^2 - 95^2} - 37 - 12 - 10 - 8 = 6 \xrightarrow{AREA} 6 \times 95 \times 0.97 \cong 552$$

$$\downarrow{+\text{previous}} \qquad \xrightarrow{+\text{previous}} 7753$$

$$\sqrt{121^2 - 90^2} - 37 - 12 - 10 - 8 - 6 = 6 \xrightarrow{AREA} 6 \times 90 \times 0.97 \cong 523$$

$$\sqrt{121^2 - 80^2} - 37 - 12 - 10 - 8 - 6 - 6 = 10 \xrightarrow{AREA} 10 \times 80 \times 0.97 \cong 776$$

$$\xrightarrow{+\text{previous}} 9052$$

$$\sqrt{121^2 - 70^2} - 37 - 12 - 10 - 8 - 6 - 6 - 10 = 8 \xrightarrow{AREA} 8 \times 70 \times 0.97 \cong 543$$

$$\xrightarrow{+\text{previous}} 9595$$

$$\sqrt{121^2 - 55^2} - 37 - 12 - 10 - 8 - 6 - 6 - 8 = 10 \xrightarrow{AREA} 10 \times 55 \times 0.97 \cong 533$$

$$\sqrt{121^2-35^2}-37-12-10-8-6-6-8-10=10 \xrightarrow{AREA} 10\times35\times0.97\cong271$$

$$\xrightarrow{+\text{previous}} 10128$$

$$\xrightarrow{+\text{previous}} 10399$$

$A=10399\,mm^2$

$$B=\frac{\text{V/T}}{4.44\times50\times10399\times10^{-6}}$$

$=1.746\,\text{Tesla}$

Conductor size

10.9 x 2.7→ bare

11.25 x 3.05→ FG Insulation (0.35 mm Insulation)

Number in parallel= 2 Radial x 1 Axial

Cross-section = ((10.9 x 2.7) – 0.55) x 2 [0.55 is the corner reduction]

= 57.76 mm^2

Ct. density $=\frac{\text{Current}}{\text{Conductor\_Area}}=134\div57.76\cong2.31\,A/mm^2$

LV turns/limb = 62

Number of Layers = 2

Turn/layer = 31

No. of oil duct = 3

Radial thickness(mm)

(3.05 x 2 x 2) + 3

=15.02 mm ≅ 16 mm

Turn length (m)

LV ID= 125mm

LV OD= 125 + (2 x 16) =157 mm

$$=\frac{\Pi\times\frac{(ID+OD)}{2}}{1000}$$

$$=\frac{\Pi\times\frac{(125+157)}{2}}{1000}=0.443\,m$$

Wire length (m)

Turn Length × Turns per Limb × Number of Limbs

= 0.443 × 62 × 2 × 3

≅165m

Resistance (R75 / R28)

$$R_{75}=\frac{0.443\times 62\times 0.0346}{57.76}=0.0164\Omega$$

$$R_{28}=\left[\frac{225+28}{225+75}\right]\times R_{75}\cong 0.014\Omega$$

Winding Length

= (10×1) ×5.6

=229.6 = 230mm

End Clearance

$=2\times 20=40$ mm

Window height

= (230+40) =270mm

Weight in kg

$$=Density\times Area\times length$$
$$=2.703\times 0.443\times 62\times 57.76\times 3\times 10^{-3}$$
$$=12.9kg$$

Insulated weight

$$= \left[\frac{(11.25 \times 3.05) - (10.9 \times 2.7)}{(10.9 \times 2.7)} \times \frac{1}{2.703} + 1 \right] \times 12.9$$

$$\cong 13.7\, kg$$

$$\text{taking } 2\% \text{ extra } = 0.274\, kg$$

Total Weight

$$= 13.7 + 0.274 \cong 13.974\ kg$$

Stray Loss

$$= \left(\sqrt{\frac{10.9 \times 31 + 120}{(11.25 \times 31) + 20 - 0.35}} \times 0.76 \times \frac{2.7}{10} \right)^4 \times \frac{(2 \times 2)^2 - 0.2}{9} \times 10^2$$

$$= 0.294\%$$

Load loss

$$= 12.79 \times 12.9 \times 2.31^2 \times \left(\frac{0.294}{100} + 1 \right)$$

$$\cong 885\ W$$

Gradient

$$= \frac{885}{3 \times 3 \times 60 \times 0.443 \times \left(\frac{360 + 20}{1000} \right)}$$

$$= 9.73\ {}^0C$$

4.3.2 HV WINDING DESIGN

Current density = 2.2835 A/sq. mm ≅ 2.29 A/sq. mm

Current/phase $= \dfrac{100\times10^3}{3\times11000} \cong 3.03$ Amp

Voltage/turn= $\dfrac{11000}{62\times44}$ ≅ 4.03

Turns/phase or limb= $\dfrac{11000}{\dfrac{11000}{62\times44}}$ =2728

Number of coils per limb=4

Number of turns per coil=682

Conductor size

1.3 mm→ bare diameter

1.52 mm→ insulated diameter

Cross section= 1.327 sq. mm (considering diameter 1.3)

Number of layers in a coil (assume) = $\dfrac{682}{52}$ =13.11 ≅ 13

Turn per layer = $\dfrac{80}{1.5}$ -1 ≅ 49

Number of layers in a coil (effective) = $\dfrac{682}{49} = 13.91 \cong 14$

Winding length of a coil = (49+1) × 1.52

=76 mm

Total Winding length=76 × 4

=304 mm

Window height= 400 mm

End clearance= (25 × 2) =50 mm

Coil to coil gap= $\dfrac{350-304}{3}$

=15.33 ≅ 15

Radial Thickness = 0.065 x (14 - 1) + (1.52 x 14) = 22.125 ≅ 23mm

HV Inner diameter (ID) =173 mm

HV Outer diameter (OD) =173+ (22 x2) =217

Turn Length

$$= \frac{\Pi \times \frac{(ID + OD)}{2}}{1000}$$

$$= \frac{\Pi \times \frac{(173 + 217)}{2}}{1000} = 0.616\ m$$

Wire length

$$= 2728 \times 3 \times 0.616 = 5041.34 \cong 5040m$$

Resistance

$$R_{75} = \rho \times \frac{l}{A} = \frac{0.0346 \times (0.616 \times 2728)}{1.327} = 43.81\Omega$$

$$R_{28} = \frac{225 + 28}{225 + 75} \times R_{75} \approx 37\ \Omega$$

Insulation between layers=0.065 x (14-1) = 0.845mm

Weight in kg

$$= (2.703 \times 0.616 \times 2728 \times 1.327) \times 3 \times 10^{-3}$$

$$= 18.1\ kg \longrightarrow bare$$

Insulated weight

$$= \left[\frac{(1.52^2 - 1.3^2)}{1.3^2} \times \frac{1}{2.703} + 1 \right] \times 18.1$$

$$\cong 20.6\,kg$$

Total weight= $20.6 + (20.6\,X\,0.01) \cong 21$ kg

Stray loss

$$= \left(\sqrt{\frac{1.3 \times 44 \times 4}{350 - 0.22}} \times 0.63 \times \frac{1.3}{10} \right)^4 \times \frac{14^2 - 0.2}{9} \times 10^2$$

$= 0.05194\%$

$\cong 0.052\%$

Load loss

$$= 12.79 \times 18.1 \times 2.29^2 \times \left(\frac{0.052}{100} + 1 \right)$$

$= 1214.63w$

$\cong 1215w$

Gradient

$$= \frac{1215}{3 \times 3.25 \times 60 \times 0.616 \times 0.35}$$

$\cong 9.63\ {}^0C$

4.3.3 CORE DESIGN

L = 400

A = 230

D = 121

Length of the core

= 2D + 3L + 4A

= (2 x 121) + (3 x 400) + (4 x 230)

=2362 mm

Area of the core = 10399 mm^2

Weight of the core = 2362 x 10399 x 7.65 x 10^{-6}kg = 188 kg

Core loss

$= wt.\ of\ the\ core \times sp.\ loss \times build\ \ factor$

$= 188 \times 1.40 \times 1.3$

$\cong 345\ w$

Load Loss

=LV loss + HV loss + Tank loss

= 885 +1215 +100

=2200 w

4.3.4 TANK DESIGN

Cooling Calculation

$$kw_{55} = \left(\frac{55}{50}\right)^{\frac{1}{0.7}} \left[345 + (1.1 \times 2200)\right]$$

= 3170 w

Length of the Tank

25 + (2 x 230) + 219 +25

≅ 730 mm

Width of the Tank

25 + 219 +50

≅ 295 mm

Height of the Tank

10 + 121 +400 +121 +70

≅ 725 mm

Capacity of the tank

7.3 x 2.95 x 7.25 ≅ 157 litres

Cooling Calculation

Standard for oil cooled=500 w/sq. m

Area = {0.73 + 0.295}x 2 x 0.725 = 1.486 sq. m

Dissipation=1.486 x 500 =740 Watt

Total heat to be dissipated= 3170 W

Tank dissipation = 740 W

Radiator = (3170 – 740) = 2430 W

Radiator Area = 2430 ÷ 450 =5.4 sq. m

Size of Radiator = 0.500 x 0.300 sq. m

Total area of Radiator = 2 x (.500 x .300) = 0.30 sq. m

Number of Radiator fins =5.4÷0.3 = 18

Oil Calculation

Oil in Tank = 106 litre

Oil in Radiator = (5 x 3 x 0.1) x 20 = 30 litre

Oil in Conservator ≅5% = 6 litre

Total Oil = 142 litre

Weight of Oil = 142 x 0.889 = 130 kg

Conservator Design

Capacity = 10% of 142 litre = 14.2 litre

Volume of Conservator = $\frac{\pi d^2}{4} \times h$

$$\frac{\pi d^2}{4} \times 3d = 14.2$$

$$d = 180mm$$

$$h = 3d = 540mm$$

Overall Dimension

Length =730 + 150 +100 =980 mm

Width = 295 + (2 x 300) = 900 mm

4.3.5 IMPEDANCE / REGULATION/ EFFICIENCY

$$e_k = \sqrt{e_x^{\ 2} + e_r^{\ 2}}$$

$$\begin{aligned}\%e_r &= \frac{load.loss}{Capacity} \\ &= \frac{2220}{100 \times 10^3} \times 10^2 \\ &= 2.22\%\end{aligned}$$

$$e_x = \frac{1.24 \times H \times \Delta D_s \times 10^{-4}}{\frac{V}{T} \times l_s}$$

H= Ampere Turns

$$H = \left(\frac{100}{\sqrt{3} \times 0.433} \right) \times 62 \cong 8267\,AT$$

$$\begin{aligned}\Delta &= HV - LV\_Gap \\ &= 8 + \frac{0.35}{2} + \frac{0.22}{2} \\ &= 8.2285\end{aligned}$$

h_2 =Radial Thickness – HV Insulation

=23 - .22 =22.78

$$\begin{aligned}h_1 &= 16 - (\frac{3.35}{4} + 0.35) \\ &= 14.8125\end{aligned}$$

$$\begin{aligned}\Delta^{/} &= \Delta + \frac{1}{3}(h_2 + h_1) \\ &= 8.285 + \frac{1}{3}(22.78 + 14.8125) \\ &= 20.082\end{aligned}$$

D_s = OD of LV + $+\Delta + \frac{1}{3}(h_2 - h_1)$

=167.59

$$l_s = \frac{l}{K_R}$$
$$K_R = Ragoski\_Factor$$
$$= 1 - \frac{1 - e^{-\frac{\pi l}{b}}}{\pi \frac{l}{b}}$$
$$l = \frac{11.25 \times 31 + 20 - 0.35 + 350 - 0.22}{2}$$
$$= 359.09$$
$$b = \frac{(219 - 0.22) - (125 + 0.35)}{2}$$
$$= 46.715$$
$$K_R = 0.9586$$
$$l_s = \frac{359.09}{0.9586} = 374.6$$
$$e_x = \frac{1.24 \times 8267 \times 167.59 \times 20.82 \times 10^{-4}}{4.03214 \times 374.6} = 2.368\%$$
$$e_k = \sqrt{2.368^2 + 2.22^2} = 3.246\%$$

Regulation

- Unity power factor and 100% load

$$e_r + \frac{{e_x}^2}{200} = 2.22 + \frac{2.368^2}{200} = 2.248\%$$

- 0.8 pf lag and 100% load

$$e_r \cos\Phi + e_x \sin\Phi + \frac{\left(e_x \cos\Phi - e_r \sin\Phi\right)^2}{200} = 3.198\%$$

Efficiency

- UPF and 100% load

$$\frac{100}{100+0.345+2.22}\times 100\%$$
$$=97.5\%$$

- 0.8 pf 50% lag

$$\frac{0.8\times 100\times 0.5}{(0.8\times 100\times 0.5)+0.345+(0.5^2\times 2.22)}$$
$$\cong 97.8\%$$

Maximum Efficiency

$$\frac{39.42}{39.42+(2\times 0.345)}=98.28\%$$

4.3.6 RESULT 3(MANUAL)

SPECIFICATION

3 PHASE, 100KVA, 11000/433 V, DISTRIBUTION TRANSFORMER, ECONOMIC, DYn11, ON-AN.

DIMENSIONS

Core Diameter: 121 mm	2×2 (core to LV gap)
Internal Diameter LV: 125 mm	2×16 (LV thickness)
Outer Diameter LV: 157 mm	2×8 (LV to HV gap)
Internal Diameter HV: 173 mm	2×22 (HV thickness)
Outer Diameter HV: 217 mm	13 mm
Centre Distance: 230 mm	

DESIGN SHEET

PARAMETERS	UNIT	LV DESIGN	HV DESIGN
CURRENT/P	A	134 A	3.03 A
VOLTAGE/P	V	433/√3 V	11000 V
TURNS/P		62	2728 (4 coils are used)
LAYERS		2	13 (each coil)
TURNS/LAYER		31	49
CONDUCTOR SIZE	mm	10.9 × 2.7 → bare 11.25 × 3.05 → Insulated	1.3 mm → bare 1.52 mm → Insulated
CROSS-SECTION	mm2	57.76 mm2	1.327 mm2
CURRENT DENSITY	A/mm2	2.31 A/mm2	2.29 A/mm2
RADIAL THICKNESS	mm	16 mm	23 mm
TURN LENGTH	m	0.443 m	0.616 m
WIRE LENGTH	m	165 m	5040 m
WEIGHT	kg	13.974 kg	21 kg
R28/R75	Ω	0.014 Ω/0.0165 Ω	37 Ω/43.81 Ω
STRAY LOSS	%	0.294%	0.052%
LOAD LOSS	W	885 w	1215 w
GRADIENT	℃	9.73℃	9.63℃
WINDING LENGTH	mm	360 mm	304 mm
END CLEARANCE	mm	2 × 20 mm	2 × 25 mm
WINDOW HEIGHT	mm	400 mm	400 mm
AMPERE TURNS	AT	8267	8267

4.3.7 RESULT 3 (SOFTWARE)

DIMENSIONS

Core Diameter: 121 mm	2×2 (core to LV gap)
Internal Diameter LV: 125 mm	2×16 (LV thickness)
Outer Diameter LV: 157 mm	2×8 (LV to HV gap)
Internal Diameter HV: 173 mm	2×22 (HV thickness)
Outer Diameter HV: 217 mm	13 mm
Centre Distance: 230 mm	

DESIGN SHEET

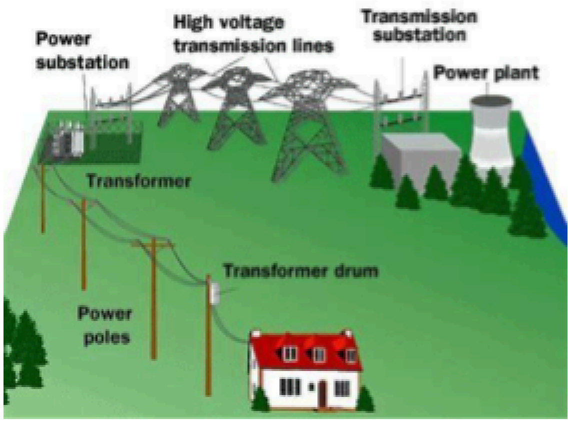
PARAMETERS	UNIT	LV DESIGN	HV DESIGN
CURRENT/P	A	134 A	3.03 A
VOLTAGE/P	V	433/√3 V	11000 V
TURNS/P		62	2728 (4 coils are used)
LAYERS		2	13 (each coil)
TURNS/LAYER		31	49
CONDUCTOR SIZE	mm	10.9 × 2.7 → bare 11.25 × 3.05 → Insulated	1.3 mm → bare 1.52 mm → Insulated
CROSS-SECTION	mm2	57.76 mm2	1.327 mm2
CURRENT DENSITY	A/mm2	2.31 A/mm2	2.29 A/mm2
RADIAL THICKNESS	mm	16 mm	23 mm
TURN LENGTH	m	0.443 m	0.616 m
WIRE LENGTH	m	165 m	5040 m
WEIGHT	kg	13.974 kg	21 kg
R28/R75	Ω	0.014 Ω/0.0165 Ω	37 Ω/43.81 Ω
STRAY LOSS	%	0.294%	0.052%
LOAD LOSS	W	885 w	1215 w
GRADIENT	℃	9.73℃	9.63℃
WINDING LENGTH	mm	360 mm	304 mm
END CLEARANCE	mm	2 × 20 mm	2 × 25 mm
WINDOW HEIGHT	mm	400 mm	400 mm
AMPERE TURNS	AT	8267	8267

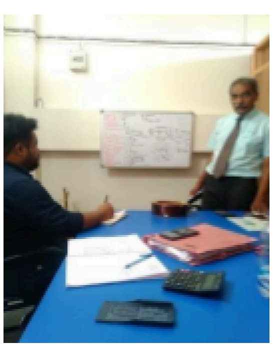
CONCLUSION

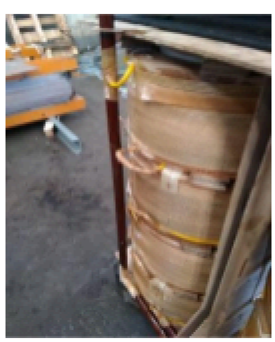
The transformer industry will continue to thrive until and unless the superconductors are feasible, which can be roughly estimated as more than a hundred years. The life expectancy of a distribution transformer is 4 to 5 years which necessitates the repairing of transformers more frequently than compared to other electrical machines. Hence continuous Research and Development work in this field to improve the situation is utmost necessary in this project. We learn to design transformers up to 1 MVA and explore key aspects which need to be taken into account to further improve efficiency, cooling, size reduction and hence improve overall life of the transformer. The results of the software come exactly the same to the manual design as the same algorithm has been utilized for the design of the software.

The next step will be to test, manufacture, explore the cooling aspects of the transformer by designing an automatic cooling system and hence improve the capacity of the transformer.

GALLERY


Power substation
High voltage transmission lines
Transmission substation
Power plant
Transformer
Transformer drum
Power poles





BIBLIOGRAPHY

BOOKS

- DESIGN OF TRANSFORMER by INDRAJIT DASGUPTA
- ELECTRICAL MACHINE DESIGN by A K SAWHNEY

WEBSITE

https://standards.ieee.org/standard

Standard values of certain parameters required for dry type Transformer.

www.python.org

Development Environment for software development and coding references.

CONSULTANCY

SARA CONSULTANCY www.saraconsultant.com

ANALYSIS FORMULAE

SIEMENS Proprietary Database.

APPENDIX

Program

The variables have their usual meaning. A dictionary has been included within the program for easy understanding.

```
from tkinter import*
from tkinter import messagebox
def sel():
    str(winding_type.get())
def sel1():
    str(winding_type_lv.get())
def calculate():
    #clear screen
    t_p.set(0)
    v_t.set(0)
    c_d.set(0)
    f_d.set(0)
    L1.set(0)
    L2.set(0)
    L3.set(0)
    L4.set(0)
    L5.set(0)
    L6.set(0)
    L7.set(0)
    B1.set(0)
    B2.set(0)
    B3.set(0)
    B4.set(0)
```

```
B5.set(0)
B6.set(0)
B7.set(0)
p_c.set(0)
c_b.set(0)
c_h.set(0)
n_axi_v.set(0)
n_rad_v.set(0)
c_d_v.set(0)
lv_l.set(0)
lv_rad_t.set(0)
lv_id.set(0)
lv_od.set(0)
turn_l.set(0)
wire_l.set(0)
res_pp.set(0)
lv_w_b.set(0)
lv_w_i.set(0)
s_l.set(0)
l_l.set(0)
grd.set(0)
#++++++++++++++++++++++++++++++++++++++++++++++++++++++++

k = float(e1.get())
kva = float(e2.get())
hv = float(e3.get())
lv = float(e4.get())

#if(kva == 0):
```

```
			#messagebox.showinfo("Error","Please enter valid 
values")
		#elif(lv ==0):
			#messagebox.showinfo("Error","Please enter valid 
values")
		#elif(hv == 0):
			#messagebox.showinfo("Error","Please enter valid 
values")
		#elif(k == 0):
			#messagebox.showinfo("Error","Please enter valid 
values")
		#else:
			#pass


		vt = k*((kva)**0.5)
		tp = lv/(vt*(3**0.5))
		tpp = round(tp,0)
		vtt = round(lv/((3**0.5)*tpp),2)


		flx_density = 1.63
		A_net = (vtt/(4.44*50*flx_density))*1000000
		core_dia = ((A_net*4)/3.14)**0.5


	#core factor table
		if((core_dia>0) and (core_dia<=100)):
			core_factor=0.88
		elif((core_dia>100) and (core_dia<=150)):
			core_factor=0.90
		elif((core_dia>150) and (core_dia<=200)):
			core_factor=0.91
		elif((core_dia>200) and (core_dia<=250)):
```

```
        core_factor=0.92
    else:
        core_factor = 0.93

    A_gross = A_net/core_factor
    raw_core_dia = ((A_gross*4)/3.14)**0.5
    accepted_core_dia = int(raw_core_dia)

    #core area work back codes
    leng = []
    brd  = []

    r = int(accepted_core_dia/10) * 10

    brd1 = int((accepted_core_dia**2 - (r-5)**2)**0.5)
    brd2 = int((accepted_core_dia**2 - (r-15)**2)**0.5 -     brd1)
    brd3 = int((accepted_core_dia**2 - (r-25)**2)**0.5 -     brd1 - brd2)
    brd4 = int((accepted_core_dia**2 - (r-40)**2)**0.5 -     brd1 - brd2 - brd3)
    brd5 = int((accepted_core_dia**2 - (r-65)**2)**0.5 -     brd1 - brd2 - brd3 -
brd4)
    brd6 = max(0,int((accepted_core_dia**2 - (r-     75)**2)**0.5 - brd1 - brd2 -
brd3 - brd4 - brd5))
    brd7 = max(0,int((accepted_core_dia**2 - (r-     90)**2)**0.5 - brd1  - brd2 -
brd3 - brd4 - brd5 -   brd6))

    brd.extend((brd1, brd2, brd3, brd4, brd5, brd6, brd7))



    l1 = r
    l2 = r-5
    l3 = r-10
```

```
l4 = r-25
l5 = max(0,r-35)
l6 = max(0,r-55)
l7 = max(0,r-80)

leng.extend((l1,l2,l3,l4,l5,l6,l7))

a1 = l1*brd1*0.97
a2 = l2*brd2*0.97
a3 = l3*brd3*0.97
a4 = l4*brd4*0.97
a5 = l5*brd5*0.97
a6 = l6*brd6*0.97
a7 = l7*brd7*0.97

af = a1+a2+a3+a4+a5+a6+a7

ac = 0.25*3.14*(accepted_core_dia)**2

error = ac - af

core_dia_renewed = (af*4/3.14)**0.5
flx_density_renewed =           round((vtt/(4.44*50*af*0.000001)),3)
print(af)
print(ac)
print("Error\t", error)

I_phase = round(kva*1000 / (pow(3,0.5)*lv),1)
current_density = 1.807
conductor_area = I_phase/current_density
```

```
print("Current Per Phase :", I_phase)
print("Conductor Area :", conductor_area)

#now this conductor area will be distributed for        single or bunch of conductors
#Terms,
#s_c_a :  single conductor area
#lv_c_l : LV conductor layer
#t_l : turns per layer
#c_b_i :conductor breadth with insulation
#c_h_i : conductor height with insulation
#c_b_b : conductor breadth  bare
#c_h_b : conductor height bare
#n_axi : no. of axial conductor
#n_rad : no. of radial conductor
winding_length = 3*core_dia_renewed
insulation = 0.1

n_rad_0 = 1
n_axi_0 = 1
lv_c_l_0 = 3
s_c_a_0 = conductor_area/(n_axi_0*n_rad_0)
t_l_0 = tpp/lv_c_l_0
c_b_i_0 = winding_length/(t_l_0+1)
c_b_b_0 = round(c_b_i_0 - insulation,2)
c_h_b_0 = round(s_c_a_0/c_b_b_0,2)

n_rad_1 = 2
n_axi_1 = 1
s_c_a_1 = conductor_area/(n_axi_1*n_rad_1)
```

```
c_b_i_1 = winding_length/(t_l_0+1)
c_b_b_1 = round(c_b_i_1 - insulation,2)
c_h_b_1 = round(s_c_a_1/c_b_b_1,2)

n_rad_2 = 1
n_axi_2 = 2
s_c_a_2 = conductor_area/(n_axi_2*n_rad_2)
c_b_i_2 = winding_length/((t_l_0+1)*2)
c_b_b_2 = round(c_b_i_2 - insulation,2)
c_h_b_2 = round(s_c_a_2/c_b_b_2,2)


n_rad_3 = 2
n_axi_3 = 2
s_c_a_3 = conductor_area/(n_axi_3*n_rad_3)
c_b_i_3 = winding_length/((t_l_0+1)*2)
c_b_b_3 = round(c_b_i_3 - insulation,2)
c_h_b_3 = round(s_c_a_3/c_b_b_3,2)

n_rad_4 = 3
n_axi_4 = 2
s_c_a_4 = conductor_area/(n_axi_4*n_rad_4)
c_b_i_4 = winding_length/((t_l_0+1)*2)
c_b_b_4 = round(c_b_i_4 - insulation,2)
c_h_b_4 = round(s_c_a_4/c_b_b_4,2)

n_rad_5 = 2
n_axi_5 = 3
s_c_a_5 = conductor_area/(n_axi_5*n_rad_5)
c_b_i_5 = winding_length/((t_l_0+1)*3)
```

```
c_b_b_5 = round(c_b_i_5 - insulation,2)
c_h_b_5 = round(s_c_a_5/c_b_b_5,2)

n_rad_6 = 4
n_axi_6 = 4
s_c_a_6 = conductor_area/(n_axi_6*n_rad_6)
c_b_i_6 = winding_length/((t_l_0+1)*2)
c_b_b_6 = round(c_b_i_6 - insulation,2)
c_h_b_6 = round(s_c_a_6/c_b_b_6,2)

n_rad_7 = 1
n_axi_7 = 1
lv_c_l_1 = 4
s_c_a_7 = conductor_area/(n_axi_7*n_rad_7)
t_l_1 = tpp/lv_c_l_1
c_b_i_7 = winding_length/(t_l_1+1)
c_b_b_7 = round(c_b_i_7 - insulation,2)
c_h_b_7 = round(s_c_a_7/c_b_b_7,2)

n_rad_8 = 2
n_axi_8 = 1
s_c_a_8 = conductor_area/(n_axi_8*n_rad_8)
c_b_i_8 = winding_length/(t_l_1+1)
c_b_b_8 = round(c_b_i_8 - insulation,2)
c_h_b_8 = round(s_c_a_8/c_b_b_8,2)

n_rad_9 = 1
n_axi_9 = 2
s_c_a_9 = conductor_area/(n_axi_9*n_rad_9)
c_b_i_9 = winding_length/((t_l_1+1)*2)
```

```
c_b_b_9 = round(c_b_i_9 - insulation,2)
c_h_b_9 = round(s_c_a_9/c_b_b_9,2)


n_rad_10 = 2
n_axi_10 = 2
s_c_a_10 = conductor_area/(n_axi_10*n_rad_10)
c_b_i_10 = winding_length/((t_l_1+1)*2)
c_b_b_10 = round(c_b_i_10 - insulation,2)
c_h_b_10 = round(s_c_a_10/c_b_b_10,2)

n_rad_11 = 3
n_axi_11 = 2
s_c_a_11 = conductor_area/(n_axi_11*n_rad_11)
c_b_i_11 = winding_length/((t_l_1+1)*2)
c_b_b_11 = round(c_b_i_11 - insulation,2)
c_h_b_11 = round(s_c_a_11/c_b_b_11,2)

n_rad_12 = 2
n_axi_12 = 3
s_c_a_12 = conductor_area/(n_axi_12*n_rad_12)
c_b_i_12 = winding_length/((t_l_1+1)*3)
c_b_b_12 = round(c_b_i_12 - insulation,2)
c_h_b_12 = round(s_c_a_12/c_b_b_12,2)

n_rad_13 = 4
n_axi_13 = 4
s_c_a_13 = conductor_area/(n_axi_13*n_rad_13)
c_b_i_13 = winding_length/((t_l_1+1)*2)
c_b_b_13 = round(c_b_i_13 - insulation,2)
```

```
	c_h_b_13 = round(s_c_a_13/c_b_b_13,2)


	if((c_b_b_0 > (2+c_h_b_0)) and (c_b_b_0 <=(6*c_h_b_0)) and (c_b_b_0<15) and (c_h_b_0<3.5) and (c_h_b_0 >1.7)):
		print("conductor bare b_0 :", c_b_b_0)
		print("conductor bare h_0 :", c_h_b_0)
		n_axi = n_axi_0
		n_rad = n_rad_0
		conductor_breadth = round(c_b_b_0,1)
		conductor_height = round(c_h_b_0,1)
		lv_conductor_layers = lv_c_l_0
		lv_turns_per_layer = t_l_0
		single_conductor_area = s_c_a_0
	elif((c_b_b_1 > (2+c_h_b_1)) and (c_b_b_1 <=(6*c_h_b_1)) and (c_b_b_1<15) and (c_h_b_1<3.5) and (c_h_b_1 >1.7)):
		print("conductor bare b_1 :", c_b_b_1)
		print("conductor bare h_1 :", c_h_b_1)
		n_axi = n_axi_1
		n_rad = n_rad_1
		conductor_breadth = round(c_b_b_1,1)
		conductor_height = round(c_h_b_1,1)
		lv_conductor_layers = lv_c_l_0
		lv_turns_per_layer = t_l_0
		single_conductor_area = s_c_a_1
	elif((c_b_b_2 > (2+c_h_b_2)) and (c_b_b_2 <=(6*c_h_b_2)) and (c_b_b_2<15) and (c_h_b_2<3.5) and (c_h_b_2 >1.7)):
		print("conductor bare b_2 :", c_b_b_2)
		print("conductor bare h_2 :", c_h_b_2)
		n_axi = n_axi_2
		n_rad = n_rad_2
		conductor_breadth = round(c_b_b_2,1)
```

```
                conductor_height = round(c_h_b_2,1)
                lv_conductor_layers = lv_c_l_0
                lv_turns_per_layer = t_l_0
                single_conductor_area = s_c_a_2
        elif((c_b_b_3 > (2+c_h_b_3)) and (c_b_b_3 <=(6*c_h_b_3)) and (c_b_b_3<15)
and (c_h_b_3<3.5) and (c_h_b_3 >1.7)):
                print("conductor bare b_3 :", c_b_b_3)
                print("conductor bare h_3 :", c_h_b_3)
                n_axi = n_axi_3
                n_rad = n_rad_3
                conductor_breadth = round(c_b_b_3,1)
                conductor_height = round(c_h_b_3,1)
                lv_conductor_layers = lv_c_l_0
                lv_turns_per_layer = t_l_0
                single_conductor_area = s_c_a_3
        elif((c_b_b_4 > (2+c_h_b_4)) and (c_b_b_4 <=(6*c_h_b_4)) and (c_b_b_4<15)
and (c_h_b_4<3.5) and (c_h_b_4 >1.7)):
                print("conductor bare b_4 :", c_b_b_4)
                print("conductor bare h_4 :", c_h_b_4)
                n_axi = n_axi_4
                n_rad = n_rad_4
                conductor_breadth = round(c_b_b_4,1)
                conductor_height = round(c_h_b_4,1)
                lv_conductor_layers = lv_c_l_0
                lv_turns_per_layer = t_l_0
                single_conductor_area = s_c_a_4
        elif((c_b_b_5> (2+c_h_b_5)) and (c_b_b_5 <=(6*c_h_b_5)) and (c_b_b_5<15)
and (c_h_b_5<3.5) and (c_h_b_5 >1.7)):
                print("conductor bare b_5 :", c_b_b_5)
                print("conductor bare h_5 :", c_h_b_5)
                n_axi = n_axi_5
```

```
                n_rad = n_rad_5
                conductor_breadth = round(c_b_b_5,1)
                conductor_height = round(c_h_b_5,1)
                lv_conductor_layers = lv_c_l_0
                lv_turns_per_layer = t_l_0
                single_conductor_area = s_c_a_5
        elif((c_b_b_6> (2+c_h_b_6)) and (c_b_b_6 <=(6*c_h_b_6)) and (c_b_b_6<15)
and (c_h_b_6<3.5) and (c_h_b_6 >1.7)):
                print("conductor bare b_6 :", c_b_b_6)
                print("conductor bare h_6 :", c_h_b_6)
                n_axi = n_axi_6
                n_rad = n_rad_6
                conductor_breadth = round(c_b_b_6,1)
                conductor_height = round(c_h_b_6,1)
                lv_conductor_layers = lv_c_l_1
                lv_turns_per_layer = t_l_1
                single_conductor_area = s_c_a_6
        elif((c_b_b_7> (2+c_h_b_7)) and (c_b_b_7 <=(6*c_h_b_7)) and (c_b_b_7<15)
and (c_h_b_7<3.5) and (c_h_b_7 >1.7)):
                print("conductor bare b_7 :", c_b_b_7)
                print("conductor bare h_7 :", c_h_b_7)
                n_axi = n_axi_7
                n_rad = n_rad_7
                conductor_breadth = round(c_b_b_7,1)
                conductor_height = round(c_h_b_7,1)
                lv_conductor_layers = lv_c_l_1
                lv_turns_per_layer = t_l_1
                single_conductor_area = s_c_a_7
        elif((c_b_b_8> (2+c_h_b_8)) and (c_b_b_8 <=(6*c_h_b_8)) and (c_b_b_8<15)
and (c_h_b_8<3.5) and (c_h_b_8 >1.7)):
                print("conductor bare b_8 :", c_b_b_8)
```

```
            print("conductor bare h_8 :", c_h_b_8)
            n_axi = n_axi_8
            n_rad = n_rad_8
            conductor_breadth = round(c_b_b_8,1)
            conductor_height = round(c_h_b_8,1)
            lv_conductor_layers = lv_c_l_1
            lv_turns_per_layer = t_l_1
            single_conductor_area = s_c_a_8
        elif((c_b_b_9> (2+c_h_b_9)) and (c_b_b_9 <=(6*c_h_b_9)) and (c_b_b_9<15) and (c_h_b_9<3.5) and (c_h_b_9 >1.7)):
            print("conductor bare b_9 :", c_b_b_9)
            print("conductor bare h_9 :", c_h_b_9)
            n_axi = n_axi_9
            n_rad = n_rad_9
            conductor_breadth = round(c_b_b_9,1)
            conductor_height = round(c_h_b_9,1)
            lv_conductor_layers = lv_c_l_1
            lv_turns_per_layer = t_l_1
            single_conductor_area = s_c_a_9
        elif((c_b_b_10> (2+c_h_b_10)) and (c_b_b_10 <=(6*c_h_b_10)) and (c_b_b_10<15) and (c_h_b_10<3.5) and (c_h_b_10 >1.7)):
            print("conductor bare b_10 :", c_b_b_10)
            print("conductor bare h_10 :", c_h_b_10)
            n_axi = n_axi_10
            n_rad = n_rad_10
            conductor_breadth = round(c_b_b_10,1)
            conductor_height = round(c_h_b_10,1)
            lv_conductor_layers = lv_c_l_1
            lv_turns_per_layer = t_l_1
            single_conductor_area = s_c_a_10
```

```
    elif((c_b_b_11> (2+c_h_b_11)) and (c_b_b_11 <=(6*c_h_b_11)) and (c_b_b_11<15) and (c_h_b_11<3.5) and (c_h_b_11 >1.7)):
        print("conductor bare b_11 :", c_b_b_11)
        print("conductor bare h_11 :", c_h_b_11)
        n_axi = n_axi_11
        n_rad = n_rad_11
        conductor_breadth = round(c_b_b_11,1)
        conductor_height = round(c_h_b_11,1)
        lv_conductor_layers = lv_c_l_1
        lv_turns_per_layer = t_l_1
        single_conductor_area = s_c_a_11
    elif((c_b_b_12> (2+c_h_b_12)) and (c_b_b_12 <=(6*c_h_b_12)) and (c_b_b_12<15) and (c_h_b_12<3.5) and (c_h_b_12 >1.7)):
        print("conductor bare b_12 :", c_b_b_12)
        print("conductor bare h_12 :", c_h_b_12)
        n_axi = n_axi_12
        n_rad = n_rad_12
        conductor_breadth = round(c_b_b_12,1)
        conductor_height = round(c_h_b_12,1)
        lv_conductor_layers = lv_c_l_1
        lv_turns_per_layer = t_l_1
        single_conductor_area = s_c_a_12
    elif((c_b_b_13> (2+c_h_b_13)) and (c_b_b_13 <=(6*c_h_b_13)) and (c_b_b_13<15) and (c_h_b_13<3.5) and (c_h_b_13 >1.7)):
        print("conductor bare b_13 :", c_b_b_13)
        print("conductor bare h_13 :", c_h_b_13)
        n_axi = n_axi_13
        n_rad = n_rad_13
        conductor_breadth = round(c_b_b_13,1)
        conductor_height = round(c_h_b_13,1)
        lv_conductor_layers = lv_c_l_1
```

```
        lv_turns_per_layer = t_l_1
        single_conductor_area = s_c_a_13
else:
        print("We need to look for other options")
        messagebox.showinfo("Error","Try manual design")
        t_p.set(0)
        v_t.set(0)
        c_d.set(0)
        f_d.set(0)
        L1.set(0)
        L2.set(0)
        L3.set(0)
        L4.set(0)
        L5.set(0)
        L6.set(0)
        L7.set(0)
        B1.set(0)
        B2.set(0)
        B3.set(0)
        B4.set(0)
        B5.set(0)
        B6.set(0)
        B7.set(0)
        p_c.set(0)
        c_b.set(0)
        c_h.set(0)
        n_axi_v.set(0)
        n_rad_v.set(0)
        c_d_v.set(0)
        lv_l.set(0)
```

```
            lv_rad_t.set(0)
            lv_id.set(0)
            lv_od.set(0)
            turn_l.set(0)
            wire_l.set(0)
            res_pp.set(0)
            lv_w_b.set(0)
            lv_w_i.set(0)
            s_l.set(0)
            l_l.set(0)
            grd.set(0)

        #current density calculated

        current_density_after_design = round(I_phase / ((conductor_breadth*conductor_height - 0.55)*(n_axi*n_rad)),2)
        print("current density estimated :", current_density)
        print("current density new :", current_density_after_design)

        #Core_to_LV gap selection chart

        if(kva <= 100):
            CORE_LV_gap = 16

        #radial thickness of lv winding
        #checkpoint++++++++++++++++++++++++++++++++++++++++++++++++
        no_of_oil_duct = lv_conductor_layers -1
        radial_thickness = round((((conductor_height+0.2)*lv_conductor_layers*n_rad*2) + 3*no_of_oil_duct,0)
        LVID = round((core_dia_renewed + CORE_LV_gap)+0.5,0)
```

```
LVOD = round((LVID + radial_thickness)+0.5,0)
print("Radial Thickness :", radial_thickness,"LVID :", LVID,"LVOD :", LVOD)

one_turn_length = round((3.14*(LVID+LVOD)/2)*0.001,3)

lv_wire_length = round(one_turn_length*tpp*3*n_axi*n_rad,0)

#resistance per phase section
Ta_Al = 225
T_room = 30
res_per_phase = round((Ta_Al + T_room)/(Ta_Al + 75)*0.00281,6)

#LV weight section
cb_i = conductor_breadth+insulation
ch_i = conductor_height+insulation
metal_density = 2.703
insulation_density = 1.85
density_ratio = insulation_density/metal_density
lv_weight_bare = round(one_turn_length*metal_density*0.001*tpp*single_conductor_area*n_axi*n_rad*3,2)
just_var = (cb_i*ch_i-conductor_height*conductor_breadth)/(conductor_height*conductor_breadth)
lv_weight_with_insulation = round((just_var*density_ratio+1)*lv_weight_bare,2)
print("Lv weight bare:",lv_weight_bare)
print("LV weight with insulation:",lv_weight_with_insulation)

#stray_loss section
total_end_clearence = 30
transposition = n_rad * cb_i + 3
window_height = int(winding_length + total_end_clearence + transposition)
```

```
print("window Hieght :", window_height)
print("Transposition", transposition)

slf = 0.76
root_var = pow((n_axi*conductor_breadth*lv_turns_per_layer + transposition)/(n_axi*cb_i*lv_turns_per_layer-insulation),0.5)
out_var = ((lv_conductor_layers*n_rad)**2-0.2)/9

strayloss = pow(root_var*slf*conductor_height*0.1,4)*out_var*100
stray_loss_renewed = round(strayloss,3)
print("Stray loss :",strayloss)
lsf = 12.79
load_loss = int(lsf*lv_weight_bare*(current_density_after_design**2)*((strayloss/100) + 1))
print("load loss :", load_loss)

gradient = round(load_loss/(3*6*0.75*55*one_turn_length*window_height*0.001),2)
print("Gradient :",gradient)

#set the values
t_p.set(tpp)
v_t.set(vtt)
c_d.set(accepted_core_dia)
f_d.set(flx_density_renewed)
L1.set(l1)
L2.set(l2)
L3.set(l3)
```

```
L4.set(l4)
L5.set(l5)
L6.set(l6)
L7.set(l7)
B1.set(brd1)
B2.set(brd2)
B3.set(brd3)
B4.set(brd4)
B5.set(brd5)
B6.set(brd6)
B7.set(brd7)
p_c.set(I_phase)
c_b.set(conductor_breadth)
c_h.set(conductor_height)
n_axi_v.set(n_axi)
n_rad_v.set(n_rad)
c_d_v.set(current_density_after_design)
lv_l.set(lv_conductor_layers)
lv_rad_t.set(radial_thickness)
lv_id.set(LVID)
lv_od.set(LVOD)
turn_l.set(one_turn_length)
wire_l.set(lv_wire_length)
res_pp.set(res_per_phase)
lv_w_b.set(lv_weight_bare)
lv_w_i.set(lv_weight_with_insulation)
s_l.set(stray_loss_renewed)
l_l.set(load_loss)
grd.set(gradient)
```

```
#print("......................................................................")

#print("b_0 :", c_b_b_0,"h_0 :", c_h_b_0,"axial :",n_axi_0,"radial :",n_rad_0)
#print("b_1 :", c_b_b_1,"h_1 :", c_h_b_1,"axial :",n_axi_1,"radial :",n_rad_1)
#print("b_2 :", c_b_b_2,"h_2 :", c_h_b_2,"axial :",n_axi_2,"radial :",n_rad_2)
#print("b_3 :", c_b_b_3,"h_3 :", c_h_b_3,"axial :",n_axi_3,"radial :",n_rad_3)
#print("b_4 :", c_b_b_4,"h_4 :", c_h_b_4,"axial :",n_axi_4,"radial :",n_rad_4)
#print("b_5 :", c_b_b_5,"h_5 :", c_h_b_5,"axial :",n_axi_5,"radial :",n_rad_5)
#print("b_6 :", c_b_b_6,"h_6 :", c_h_b_6,"axial :",n_axi_6,"radial :",n_rad_6)
#print("b_7 :", c_b_b_7,"h_7 :", c_h_b_7,"axial :",n_axi_7,"radial :",n_rad_7)
#print("b_8 :", c_b_b_8,"h_8 :", c_h_b_8,"axial :",n_axi_8,"radial :",n_rad_8)
#print("b_9 :", c_b_b_9,"h_9 :", c_h_b_9,"axial :",n_axi_9,"radial :",n_rad_9)
#print("b_10 :", c_b_b_10,"h_10 :", c_h_b_10,"axial :",n_axi_10,"radial :",n_rad_10)
#print("b_11 :", c_b_b_11,"h_11 :", c_h_b_11,"axial :",n_axi_11,"radial :",n_rad_11)
#print("b_12 :", c_b_b_12,"h_12 :", c_h_b_12,"axial :",n_axi_12,"radial :",n_rad_12)
```

```
root = Tk()
root.title('Xmer LV Designer')
root.geometry('1080x720')
bg = PhotoImage(file='xmer bg.png')
bgLbl = Label(root, image = bg).place(x=0,y=0)

radio_frame_1 = Frame(width=109, height=30, bg="red", colormap="new")
radio_frame_1.place(x=128, y=185)

radio_frame_2 = Frame(width=109, height=30, bg="red", colormap="new")
radio_frame_2.place(x=128, y=222)


#radiobuttons
winding_type = IntVar()
radio_1 = Radiobutton(radio_frame_1, text="Star", bg="white", variable=winding_type, value=3**0.5, command=sel)
radio_1.pack(side=LEFT)
radio_2 = Radiobutton(radio_frame_1, text="Delta", bg="white", variable=winding_type, value=1, command=sel)
radio_2.pack(side=RIGHT)

winding_type_lv = IntVar()
```

```
radio_3 = Radiobutton(radio_frame_2, text="Star", bg="white", variable=winding_type_lv, value=3**0.5, command=sel1)

radio_3.pack(side=LEFT)

radio_4 = Radiobutton(radio_frame_2, text="Delta", bg="white", variable=winding_type_lv, value=1, command=sel1)

radio_4.pack(side=RIGHT)


#entry boxes

e1 = Entry(root, bd=3)

e2 = Entry(root, bd=3)

e3 = Entry(root, bd=3, width= 10)

e4 = Entry(root, bd=3, width = 10)

e1.place(x=175, y=110)

e2.place(x=175, y=143)

e3.place(x=235, y=185)

e4.place(x=235, y=224)




#labels initials

t_p=IntVar()

t_p.set(0)

turns_per_phase = Label(root, textvariable=t_p , bg = "white", fg = "red")

turns_per_phase.place(x=140,y=346)

v_t=IntVar()

v_t.set(0)

volts_per_turn = Label(root, textvariable=v_t, bg = "white", fg = "red")

volts_per_turn.place(x=140, y=388)

c_d=IntVar()

c_d.set(0)
```

```
accepted_core_dia_lbl = Label(root, textvariable=c_d, bg = "white", fg = "red")
accepted_core_dia_lbl.place(x=190, y=431)
f_d=IntVar()
f_d.set(0)
flx_density_renewed_lbl = Label(root, textvariable=f_d, bg = "white", fg = "red")
flx_density_renewed_lbl.place(x=190, y=474)

#labels core design
L1 = IntVar()
L1.set(0)
L1_lbl = Label(root, textvariable=L1, bg = "white", fg = "red")
L1_lbl.place(x=190, y=603)
L2 = IntVar()
L2.set(0)
L2_lbl = Label(root, textvariable=L2, bg = "white", fg = "red")
L2_lbl.place(x=290, y=603)
L3 = IntVar()
L3.set(0)
L3_lbl = Label(root, textvariable=L3, bg = "white", fg = "red")
L3_lbl.place(x=390, y=603)
L4 = IntVar()
L4.set(0)
L4_lbl = Label(root, textvariable=L4, bg = "white", fg = "red")
L4_lbl.place(x=490, y=603)
L5 = IntVar()
L5.set(0)
L5_lbl = Label(root, textvariable=L5, bg = "white", fg = "red")
L5_lbl.place(x=590, y=603)
L6 = IntVar()
L6.set(0)
```

```
L6_lbl = Label(root, textvariable=L6, bg = "white", fg = "red")
L6_lbl.place(x=690, y=603)
L7 = IntVar()
L7.set(0)
L7_lbl = Label(root, textvariable=L7, bg = "white", fg = "red")
L7_lbl.place(x=780, y=603)

#phase current
p_c = IntVar()
p_c.set(0)
phase_current_lbl = Label(root, textvariable = p_c, bg = "white", fg = "red")
phase_current_lbl.place(x=750, y=118)



B1 = IntVar()
B1.set(0)
B1_lbl = Label(root, textvariable=B1, bg = "white", fg = "red")
B1_lbl.place(x=190, y=659)
B2 = IntVar()
B2.set(0)
B2_lbl = Label(root, textvariable=B2, bg = "white", fg = "red")
B2_lbl.place(x=290, y=659)
B3 = IntVar()
B3.set(0)
B3_lbl = Label(root, textvariable=B3, bg = "white", fg = "red")
B3_lbl.place(x=390, y=659)
B4 = IntVar()
B4.set(0)
B4_lbl = Label(root, textvariable=B4, bg = "white", fg = "red")
B4_lbl.place(x=490, y=659)
```

```
B5 = IntVar()
B5.set(0)
B5_lbl = Label(root, textvariable=B5, bg = "white", fg = "red")
B5_lbl.place(x=590, y=659)
B6 = IntVar()
B6.set(0)
B6_lbl = Label(root, textvariable=B6, bg = "white", fg = "red")
B6_lbl.place(x=690, y=659)
B7 = IntVar()
B7.set(0)
B7_lbl = Label(root, textvariable=B7, bg = "white", fg = "red")
B7_lbl.place(x=780, y=659)

#Conductor specifications placement

c_b = IntVar()
c_b.set(0)
conductor_b_lbl = Label(root, textvariable = c_b, bg = "white", fg = "red")
conductor_b_lbl.place(x=633,y=241)

c_h = IntVar()
c_h.set(0)
conductor_h_lbl = Label(root, textvariable = c_h, bg = "white", fg = "red")
conductor_h_lbl.place(x=752,y=241)

n_rad_v = IntVar()
n_rad_v.set(0)
n_radial_parallel_lbl = Label(root, textvariable = n_rad_v, bg = "white", fg = "red")
n_radial_parallel_lbl.place(x=940, y=125)
```

```
n_axi_v = IntVar()
n_axi_v.set(0)
n_axial_parallel_lbl = Label(root, textvariable = n_axi_v, bg = "white", fg = "red")
n_axial_parallel_lbl.place(x=940, y=155)

c_d_v = IntVar()
c_d_v.set(0)
current_density_lbl = Label(root, textvariable=c_d_v, bg = "white", fg = "red")
current_density_lbl.place(x=717,y=306)

lv_l = IntVar()
lv_l.set(0)
lv_conductor_layers_lbl = Label(root, textvariable=lv_l, bg = "white", fg = "red")
lv_conductor_layers_lbl.place(x=940, y=186)

lv_rad_t = IntVar()
lv_rad_t.set(0)
lv_radial_thickness_lbl = Label(root, textvariable=lv_rad_t, bg = "white", fg = "red")
lv_radial_thickness_lbl.place(x=980,y=245)

lv_id = IntVar()
lv_id.set(0)
LVID_lbl = Label(root, textvariable=lv_id, bg = "white", fg = "red")
LVID_lbl.place(x=630,y=336)

lv_od = IntVar()
lv_od.set(0)
LVOD_lbl = Label(root, textvariable=lv_od, bg = "white", fg = "red")
LVOD_lbl.place(x=740,y=336)
```

```
res_pp = IntVar()
res_pp.set(0)
resistance_per_phase_lbl = Label(root, textvariable=res_pp, bg = "white", fg = "red")
resistance_per_phase_lbl.place(x=730,y=368)

turn_l = IntVar()
turn_l.set(0)
turn_length_lbl = Label(root, textvariable=turn_l, bg = "white", fg = "red")
turn_length_lbl.place(x=730,y=396)

wire_l = IntVar()
wire_l.set(0)
wire_length_lbl = Label(root, textvariable=wire_l, bg = "white", fg = "red")
wire_length_lbl.place(x=730,y=422)

lv_w_b = IntVar()
lv_w_b.set(0)
lv_weight_bare_lbl = Label(root, textvariable=lv_w_b, bg = "white", fg = "red")
lv_weight_bare_lbl.place(x=970,y=336)

lv_w_i = IntVar()
lv_w_i.set(0)
lv_weight_with_insulation_lbl = Label(root,textvariable=lv_w_i, bg = "white", fg = "red")
lv_weight_with_insulation_lbl.place(x=970,y=381)

s_l = IntVar()
s_l.set(0)
stray_loss_lbl = Label(root, textvariable=s_l, bg = "white", fg = "red")
stray_loss_lbl.place(x=730,y=447)
```

```
l_l = IntVar()
l_l.set(0)
load_loss_lbl = Label(root, textvariable=l_l, bg = "white", fg = "red")
load_loss_lbl.place(x=730,y=474)

grd = IntVar()
grd.set(0)
gradient_lbl = Label(root, textvariable=grd, bg = "white", fg = "red")
gradient_lbl.place(x=990,y=464)

#button
iterate = Button(root, text ="ITERATE", command = calculate)
iterate.place(x=430,y=430)
root.mainloop()
```