TRANSFORMER DESIGN OPTIMIZATION USING NESTED LOOP

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ABSTRACT

This paper presents Power Transformer design using Nested Loop by optimizing the important parameters but keeping in sight the guidelines of the International Electro Technical standards and fundamental Power Transformer specification in general. The result obtained by using the Nested Loop optimization have been compared with the result obtained using conventional calculation method (CCM). Using the same sets of parameters, it is evident that the parameters applying the Nested Loop have been optimized in comparison to the parameters in CCM. The result of CCM and Nested Loop have been obtained by coding in MATLAB which is the first effort thus far in the industries in Malaysia. The presented paper provides convenient, accurate, fast and reliable solution to overcome any issues related to the optimization of 132kV Transformer with several listed design options and it fulfills the criteria or compatible with any kinds of Transformer needs by the global grid power system. Hence, this paper demonstrates a better and efficient solution for Power Transformer design using the Nested Loop optimization techniques.

ABSTRAK

Penulisan ini mempersembahkan rekabentuk Alatubah Kuasa yang mengaplikasikan teknik Nested Loop dengan mengoptimumkan parameter-parameter penting kepada alatubah disamping mengekalkan keperluan standard IEC (International Electro Technical) dan spesifikasi asas alatubah kuasa secara umum. Perbandingan keputusan yang diperolehi menggunakan teknik pengoptimuman Nested Loop telah dibandingkan dengan kaedah kiraan konvensional (CCM). Menggunakan set parameter yang sama, ternyata bahawa pengaturcaraan yang mengaplikasikan Nested Loop adalah lebih optimum berbanding CCM. Perbandingan keputusan ini telah diperolehi dengan menggunakan kaedah pengaturcaraan didalam perisian MATLAB yang mana pertama kali diperkenalkan didalam industri Alatubah kuasa di Malaysia ini. Penulisan ini menawarkan solusi yang mudah, cepat, tepat dan terbukti dalam menyelesaikan isu pengoptimuman yang berkaitan dengan Alatubah 132kV dengan penyenaraian beberapa pilihan rekabentuk dan memenuhi kriteria atau sepadan dengan keperluan alatubah ynag berada di dalam system grid kuasa secara global. Secara keseluruhannya, penulisan ini mempamerkan solusi yang lebih baik dan effisyen dengan cara pengoptimuman Alatubah kuasa menggunakan teknik Nested Loop.

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E	Voltage applied to the primary
k	Factor (for rectangular waves)
B_M	Maximum flux density
N	Number of primary turns
A_c	The cross sectional area (cm^2)
f	Frequency of operation (Hz)
W_A	Core window area (Circular mils)
A_C	The effective cross sectional area, in cm^2
P_0	Output power (W)
ΔB	Flux density swings (Tesla)
f_{SW}	The switching frequency (Hz)
K	The winding factor
P_w	Total winding losses (W)
${I_p}^2 R_p$	The primary and secondary rms current (A)
${I_s}^2 R_s$	The primary and secondary dc resistance (Ω)
P_w	Copper conductor or winding losses (W)
K_r	AC resistance coefficient (R_{ac}/R_{dc})
ρ	The core permeability
A_C	The effective cross sectional area, in cm^2
$V_{Ø}$	The rated phase voltage, kV
V_{LL}	The rated line to line voltage, kV

S The rated apparent power, VA

$I_{\emptyset}$ The rated phase current, A

I_{LL} The rated line current, A

$V_{\emptyset}$ The phase voltage of the Low Voltage side.

LIST OF ABBREVIATIONS

CCM	Conventional Calculation Method
C.S.A	Core Cross Sectional Area
LV	Low Voltage
HV	High Voltage
TER	Tertiary Voltage
IEC	Electro-Technical Committee
BIL	Basic Insulation Level
DIL	Dielectric Insulation Level

CHAPTER 1

INTRODUCTION

1.1 Introduction

An optimum design of Transformer depends on combination of few important factors namely the minimization of active part cost, minimization of active part mass, minimization of total owning cost, and minimization of manufacturing cost as well as maximization of transformer apparent power. One of the challenges of such an objective function is that the transformer manufacturing cost depends on the cost of the material (copper, aluminum, steel, etc.) that are stock exchange commodities with fluctuating prices on the world market [1].

An early attempt was done which described a method for design optimization by computer. It utilizes a routine called "Monica", which is use to guide the choice of the independent variables in such way that the optimum, usually the lowest cost design, is reached. In essence, this routine does self-optimize its design. The paper shows none of the design interaction between the designer and the program [2].

The choices of the right core, winding and insulation materials and their subsequent sizing and geometry play a vital role in the final performance of these transformers. The objective is to use the best practices obtained from this study in order to help in the development of the computer aided design tools which in the end objective of the design process, in order to facilitate the user to try out combinations of the materials and the design methodology in the medium frequency high power design space and come out with optimal design [3].

1.2 Proposed Method

The nested for loop was developed in 1984 after other earlier programming environment. It was developed to execute a group of statements in a loop for a specified number of times. To iterate over the values of a single column vector, first transposed it to create a row vector.

To iterate over the values of a single column vector, first transposed it to create a row vector. With a high reputation, MATLAB program will be tested to perform engineering related task in order to test its performance.

1.3 Problem Statement

For Transformer rating up to 132kV voltage levels, it is essential to have a well optimized design. Many industrial design fatal error in the past were caused by the wrong decision making during the first design stage. The occurrence of such mistake have emphasized the importance of design and development process study. The tradition product design technique involves in trial-and-error design sheets and testing methodology to synthesize a set of promising Transformer design that attain the targeted results. However, this technique is time consuming and costly. An alternate way is the top-down reverse engineering and approach which couples with the proven Nested Loop (MATLAB) technique to identify the optimal structure of the Transformer design.

1.4 Objectives

The objective of this study are:

1. To design a 132kV Power Transformer
2. To optimize the design by using the Conventional Calculation Method (CCM) and the Nested Loop Algorithm
3. To compare the result obtained using CCM and Nested Loop

1.5 Scope of Works

This study was carried out by designing a 132kV Transformer for a designated TNB substation. An excel sheet with formulas was developed for the CCM while the MATLAB software was used for the programming of the transformer design. The initial transformer design was then optimized by using the Nested Loop to obtain the best Core parameter, number of Low Voltage turns, Impedance and Reactance value as specified by the customer. Hence the overall parameter is also computed and compared.

CHAPTER 2

POWER TRANSFORMER DESIGN

2.1 Introduction

It has been recorded in history as Power Transformer being the leading and essential to Power Grid system. With its primary power source conversion from primary to secondary stage utilizing few important principle of transforming voltage together with isolating electrical and noise decoupling. The main idea for Transformer to operate is by supplying energy to the load efficiently. The challenge whereby consistence as supplying bulk electrical machine with very low frequency can be very high staking risk. The concept of grasping a reduced size, lesser losses, greater efficiency and lesser volume solid state Transformer may be achieve in one or a mixture of this three criteria: (1) Modification of the structural core and winding, (2) Manipulating the flux density of the structural core or (3) Manipulating the temperature where the winding is operating [4].

2.2 Design Parameters and Electrical Performance of Power Transformer

A Power Transformer design is determined by few terms, which are Core Diameter, Low Voltage number of Turn (LV_{Turn}), Magnetic Flux density (B_{Final}), Voltage Per Turn, Core Weight, No Load Loss, Impedance and Load Losses. The terms are defined as follows:

A. The connection of the term equation comprising voltage (E), Flux Density (B_M), and Frequency (f) is defined by the experiments of the Faraday's Law [4]:

$$E = kB_M N A_c \, f \, x \, 10^{-8} \quad (1)$$

Where

E is primary voltage

k is 4.0 (for rectangular waves)

B_M is maximum flux density

N is number of primary turns

A_c is the cross sectional area (cm²)

f is the Frequency of operation (Hz)

B. Core Size Selection

Transformer Core solid and the thickness were determined. In Power Transformers, tally these losses to no-load losses, which occur when the Transformer is linked to a voltage source and give back substantially to growth cost of the Transformer [5]. Next, designers will look into the supplying output power and also the generated frequency in the system. The structure of the core considering the winding for it to be filled must be optimized in order to reduce leakage of flux. The selection of core and winding need to be balanced as core sectional area and winding diameter has to be suitable to avoid further difficulties during manufacturing. The power handling capability of a core can easily verify by this core area product (W_A x A_C). A rough indication of the required area product is given by [4]:

$$W_A A_C = \left[\frac{P_0}{(K \Delta B f_{SW})}\right]^{\frac{4}{3}} \quad (2)$$

Where

W_A is core window area (Circular mils)

A_C is the effective cross sectional area, in cm²

P_0 is output power (W)

ΔB is flux density swings (Tesla)

f_{SW} is the switching frequency (Hz)

K is the winding factor

C. Winding Losses

Winding losses of two Transformer carrying an AC current can be considered as

$$P_w = {I_p}^2 R_p \ x \ {I_s}^2 R_s \quad (3)$$

Where

P_w is total winding losses (W)

${I_p}^2 R_p$ is the primary and secondary rms current (A)

${I_s}^2 R_s$ is the primary and secondary dc resistance (Ω)

However, for a streamlined argument or study, designer can consider the succeeding calculation, which has been shown by Petkov [4]:

$$P_w = K_r \ x \ \rho \ x \frac{I^2{}_{rms}}{A_c} \quad (4)$$

Where

P_w is copper conductor or winding losses (W)

K_r is an AC resistance coefficient (R_{ac}/R_{dc})

ρ is the core permeability

A_C is the effective cross sectional area, in cm^2

2.3 Transformer Design Optimization Procedure

There has been a proposal to design Transformer applying the automatic optimization using shell Transformer. The design constraint is focused on the core lamination. When the area is decreasing, its dimension in lamination can be increased. The volume increase gradually until the set value of temperature is obtained. The Figure 2.1 shows the flowchart of designing the Transformer. Zooming in the design flowchart, another optimization criterion which chosen as subject for detailed were presented by another research. Focusing on the core type medium frequency and proposed an optimization flowchart which is indicated in Figure 2.2. In this automatic design optimization, the one turn voltage of primary winding is used as the key parameter to change the core and the winding design till the optimized result are obtained [3].

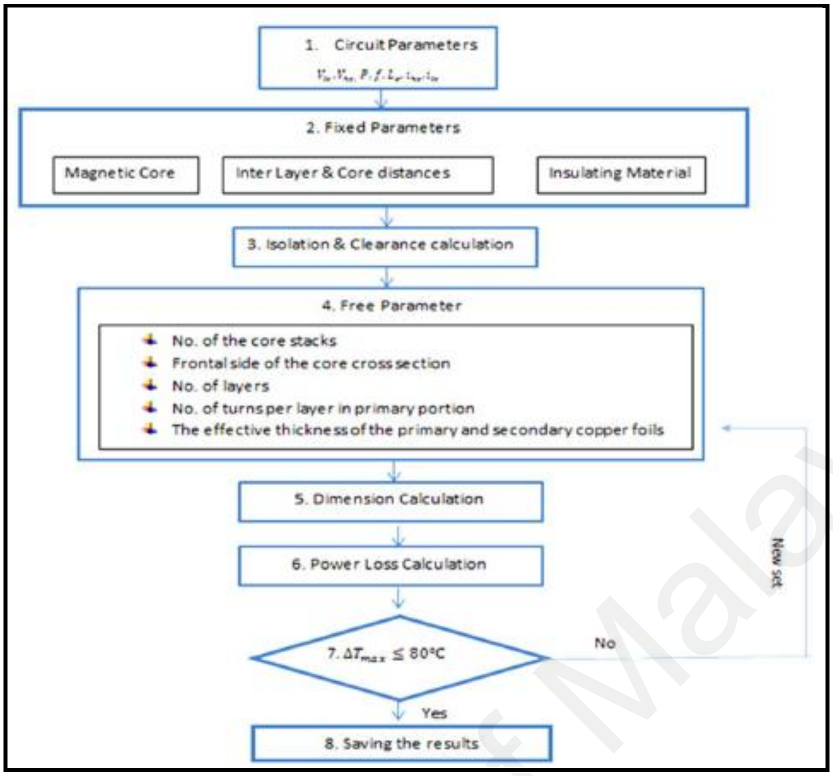

Figure 2.1: Design Flow Chart for Transformer Design Optimization

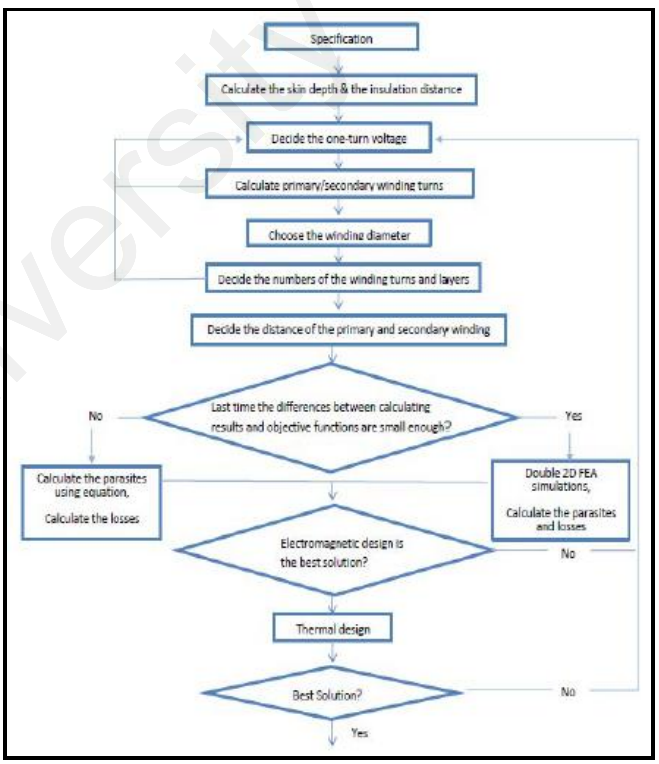

Figure 2.2: Automatic Design Optimization

2.4 Nested Loop (MATLAB)

Cleve Moler invented the program in the year of 1970. The program invented were rendered from the FOTRAN with it sub program identified as LINPAK and EISPACK utilizing linear and eigenvalue method. It was re-written in C in the 1980's with more functionality, which includes plotting routines [6].

The statement inside of a nested loop can be any valid statement, including any selection statement. For example, there could be an 'if' or 'if-else' statement as the action, or part of the action in a loop. For example if the data for any type of analysis loaded into a matrix variable. The script will find the size of the matrix and then loops through all the elements in the matrix using by using the nested loop. The outer loop iterates through the rows and the inner loop iterates through the columns [7].

Loops and conditional statement can be nested within other loops or conditional statements. This means that loops and/or conditional statement can start (and end) within another loop or conditional statement. There is no limit to the number of loops and conditional statement that can be nested. Figure 2.3 show the structure of a nested for-end loop within another for-end loop. In the loops shown in this figure, if for example n=3 and k=4, then first k=1.Next, k =2, and the nested loop executes 4 times with h =1, 2, 3, 4. Finally k=3, and the nested loop executes 4 times again. Every time a nested loop is typed, MATLAB automatically indents the new loop relative to the outside loop. Nested loop and conditional statement are demonstrated in the following chapter [8].

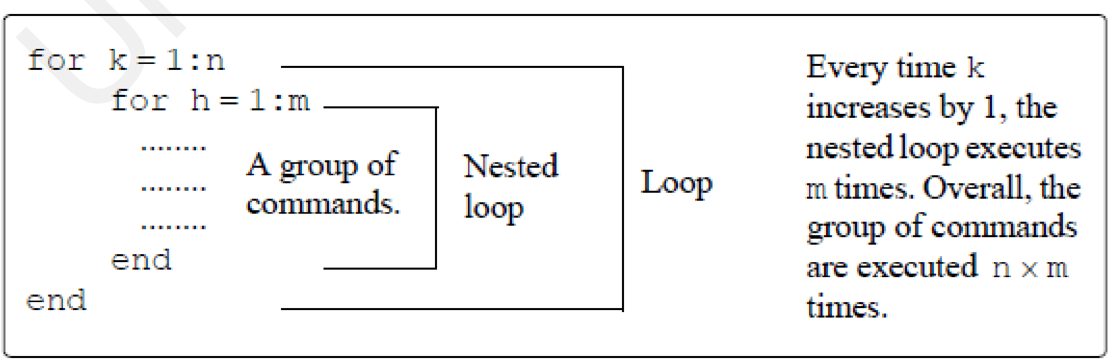

Figure 2.3: Structure of Nested Loop

CHAPTER 3

RESEACRH METHODOLOGY

3.1 Introduction

The transformer is an electromagnetic conversion device in which electrical energy received by the primary winding is first converted into magnetic energy which is reconverted back into a useful electrical energy in other circuit (secondary winding, tertiary winding, etc.) Thus, the primary and secondary winding are not connected electrically, but coupled magnetically. A Transformer is termed as either a step down or a step up transformer depending on whether the secondary voltage is higher or lower than the primary voltage, respectively. Transformer can be used as either step-up or step-down voltage depending upon the need and application. Hence, their windings are referred as high-voltage/low-voltage or high tension/low tension winding in place of primary or secondary windings [9].

From a maker's perspective, it is useful to design and produce a set range of Transformer sizes. Usually, the terminal voltages, VA rating and frequency are specified. In the conventional method of Transformer design, these specification decide the materials to be used and their dimension. The methodology has been used as a strategy tools for teaching in engineering school. However, by designing to rated specification, consideration is not openly given to what materials and sizes what are actually available. It is possible that an engineer having designed a Transformer, maybe then find the material sizes not exist. The engineer may then be forced to use available materials. Therefore, the performance of the actual Transformer built is likely to be different from that of the design calculations. Thus, the optimized design of the magnetic component is not based on selection of the right magnetic core but on the definition of its best dimensions [10].

In the reverse design approach, the physical characteristics and the specification are determined by evaluating the dimensions of the windings and core. By manipulating the amount and type of material actually to be used in the transformer construction, its performance can be determined. This is essentially the opposite of the conventional Transformer design method. It allows for the customized design, as there is considerable flexibility in meeting the performance required for a particular application. [11].

In this chapter, Transformer design terminology, Transformer design steps and review of the optimization technique are explained.

3.2 Transformer Design Mathematical Model

The Transformer performance is determined by few terminologies, which are Voltage requirement and calculation, etc. The terminologies are defined as follows:-

1. Voltage Requirement and Calculation

Determine the HV and LV Winding, Line Voltage and Phase Voltage. Phase Voltage is required for winding turn calculation. For Star connection of three phase Transformer, phase voltage is equal to $\frac{1}{\sqrt{3}}$ line voltage. For delta connection, phase voltage is equal to line voltage. The formula is as follow:

(Y- Vector Group)

$$V_{\emptyset} = \frac{1}{\sqrt{3}} V_{LL} \tag{1}$$

(Δ- Vector Group)

$$V_{\emptyset} = V_{LL} \tag{2}$$

where $V_{\emptyset}$ is the rated phase voltage, kV and V_{LL} is the rated line to line voltage.

2. Current Calculation

Determine the HV and LV Winding, Line Current and Phase Current. Phase Voltage is required for winding type and its carrying capacity. For Star connection of three phase Transformer, phase current is equal to line current. For delta connection, phase current is equal to $\frac{1}{\sqrt{3}}$ line current. The formula is as follow:

(Y- Vector Group)

$$I_{\emptyset} = I_{LL} = \frac{S}{\sqrt{3V_{LL}}} \tag{3}$$

(Δ- Vector Group)

$$I_{\emptyset} = \frac{I_{LL}}{\sqrt{3}} = \frac{S}{3V_{\emptyset}} \tag{4}$$

where S is the rated apparent power , VA and $I_{\emptyset}$ is the rated phase current and I_{LL} is the rated line current.

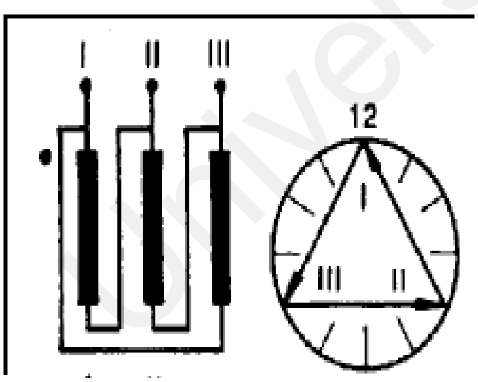

Figure 3.1: Delta Connection

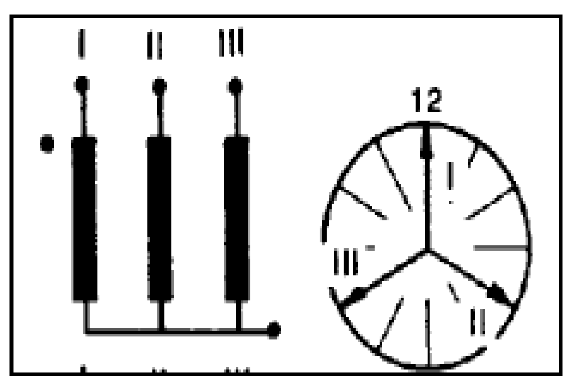

Figure 3.2: Star Connection

3. Core Diameter Estimation and Induced Voltage Constraint

3.1 Core Diameter Estimation

Usually core are made of silicon steel or CRGO (Cold Rolled Grain Oriented) steel that is used to create alternating magnetic circuit for Transformer. The calculation is as follow:-

Diameter of the Transformer Core, D (5)

$$= (Thickness\ of\ CRGO\ Plates\ Width_1 x\ Number\ of\ Blades\ Width_1)$$
$$+\ (Thickness\ of\ CRGO\ Plates\ Width_2 x\ Number\ of\ Blades\ Width_2)$$
$$+\ (Thickness\ of\ CRGO\ Plates\ Width_3 x\ Number\ of\ Blades\ Width_3)$$
$$+\ (Thickness\ of\ CRGO\ Plates\ Width(n)\ x\ Number\ of\ Blades\ Width(n))$$

OR to select the Core Diameter value based on experience or some empirical formula [9].

3.2 Core Cross Sectional Area (Core C.S.A)

In design, effective section is determined by the Core Cross Sectional area. At certain condition of the core diameter, the more stacks the bigger the effective section area is. Stacked factor selection related to the thickness, flatness of silicon steel and varnish film thickness. Space actual factor reduces as coating of the non-magnetic insulation were measured together as thickness. Usually with the value of 0.97.

$$Core\ (C.S.A) = \frac{\pi(D^2)}{4} x\ Stacked\ Factor\ x\ Utilization\ Factor \qquad (6)$$

where D is the diameter of the Transformer core.

3.3 Induced Voltage Constraint

For a sinusoidal waveform, the rms value of the induced voltage in the primary winding is given by

$$E_p = \sqrt{2\pi}\ x\ Freq(Hz)\ x\ N_{LV}\ x\ B\ x\ Core\ C.S.A \qquad (7)$$

where $Freq(Hz)$ is the operating frequency , N_{LV} is the number of Turn in the LV Winding, and B is the maximum value of flux density. Rated frequency for Malaysia is 50 Hz whereas for the Maximum Flux Density is around 1.7 Tesla. For developing large Transformer and Reactors, it is necessary to know the distribution of the magnetic leakage field to calculate the electro-dynamic forces and the stray losses due to eddy currents in the winding conductors and in steel part such as core, tanks, pressing beams and others [12].

Cold Rolled Grain Oriented (CRGO) has a unique saturation flux density value up to a value of 2.0T whereas 1.9T are the value of saturation of the knee point to begin appearing. The severity of the over-excitation conditions as stated by the user will determine the operating points (the mutual flux density, B indicated by the peak value).

3.4 Preliminary Calculation of the Low Voltage Winding Turn (N_{LV})

$$N_{LV} = \frac{V_{\emptyset}}{E_p} \tag{8}$$

where $V_{\emptyset}$ is the phase voltage of the Low Voltage side.

According to the formula of the Low Voltage Winding Turn N_{LV} , it is not necessarily an integer. If rounding down to an integer, magnetic flux density, B will be bigger than preliminary calculation. If rounding up to an integer, magnetic flux B, will be smaller than the preliminary calculation.

3.4 Calculation of the High Voltage Winding Turn (N_{HV})

Usually HV winding has tap. Calculate the number of Turn according to the tapping phase voltage. Calculate the biggest number of tapping turn at first:-

$$N_{HV\ MAX} = \frac{V_{\emptyset\ MAX}}{E_p} \tag{9}$$

Consequently for the Nominal Tap Voltage and Minimum Tap Voltage

$$N_{HV\ NORM} = \frac{V_{\emptyset\ NORM}}{E_p} \quad (10)$$

$$N_{HV\ MIN} = \frac{V_{\emptyset\ MIN}}{E_p} \quad (11)$$

where, $N_{HV\ NORM}$ is the number of Turn in the HV for Nominal Voltage and $N_{HV\ MIN}$ is the number of Turn in the HV for Minimum Voltage.

4. Main Insulation Distance

4.1 Clearance of Inner Winding to the Core Distance, A1

Voltage Class, (kV)	11
Dielectric Level (AC/LI,(kV))	95/28
Insulation Distance (mm)	17
Thickness of Cylinder (mm)	3 and 5
Quantity of Cylinder	3

Table 3.1: Insulation Distance

4.2 Winding End to Upper Yoke Distance, A2

Voltage Class, (kV)	132	33	11
Dielectric Level (AC/LI,(kV))	650/275	200/72	95/28
Insulation Distance (mm)	100	100	100

Table 3.2: Winding End to Upper and Lower Yoke Distance

4.3 Winding End to BottomYoke Distance, A3

Voltage Class, (kV)	132	33	11
Dielectric Level (AC/LI,(kV))	650/275	200/72	95/28
Insulation Distance (mm)	100	100	100

Table 3.3: Winding End to Upper and Lower Yoke Distance

4.4 Winding Top End Insulation Distance, A4

Voltage Class, (kV)	132	33	11
Dielectric Level (AC/LI,(kV))	650/275	200/72	95/28
Insulation Distance (mm)	220	220	220

Table 3.4: Winding Top End Insulation Distance

4.5 Winding Bottom End Insulation Distance, A5

Voltage Class, (kV)	132	33	11
Dielectric Level (AC/LI,(kV))	650/275	200/72	95/28
Insulation Distance (mm)	150	150	150

Table 3.5: Winding Bottom End Insulation Distance

4.6 Main Duct Insulation Distance, A6

Voltage Class, (kV)	132	33
Dielectric Level (AC/LI,(kV))	650/275	200/72

Insulation Distance (mm)	50	16
Thickness of Cylinder (mm)	2 and 3	3
Quantity of Cylinder	4	1

Table 3.6: Main Duct Insulation Distance

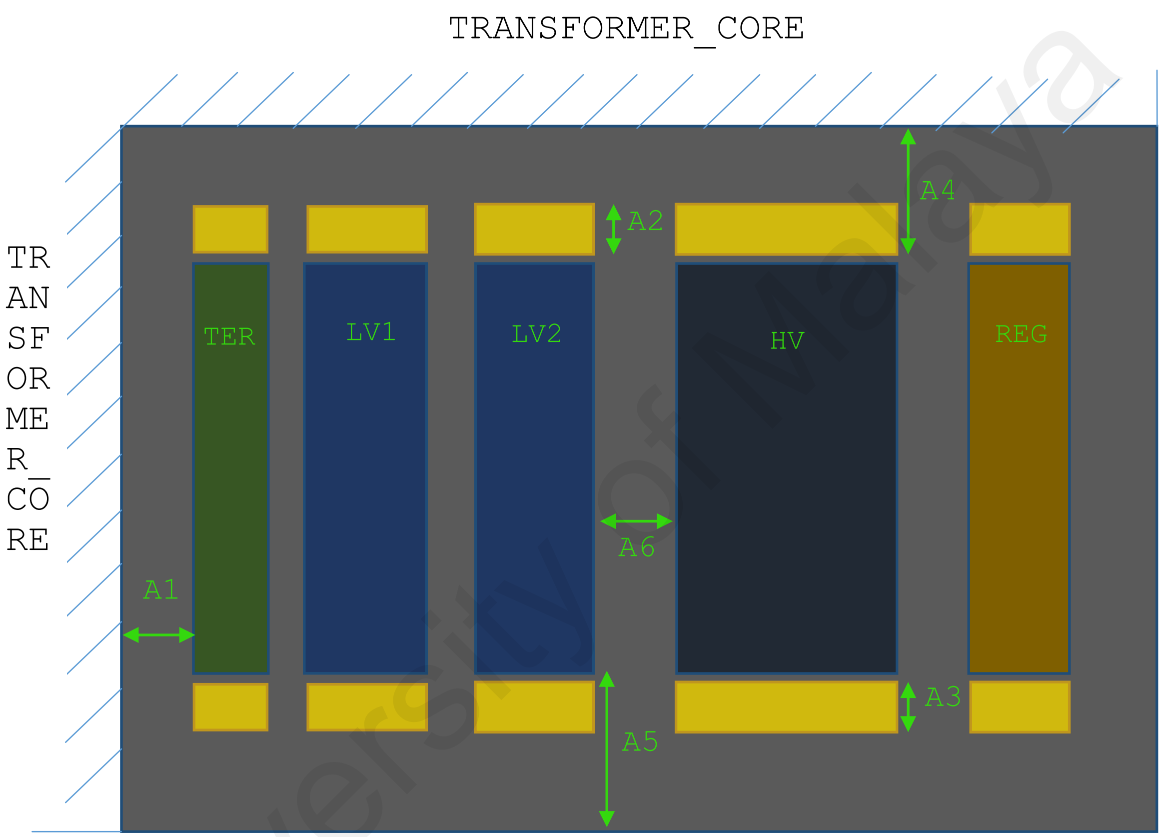

Figure 3.3: Insulation Distance

4.7 Phase to Phase Distance

Voltage Class, (kV)	33
Dielectric Level (AC/LI,(kV))	200/72
Insulation Distance (mm)	36

Table 3.7: Main Duct Insulation Distance

5. Winding Calculation

5.1 Low Voltage Winding Design

Usually, when copper type conductor section area is smaller than 2mm², use round enameled wire. However if the conductor width is up to and including 15mm and the thickness is up to and including 4.3mm, use either paper wrapped flat wire or glass fiber wrapped flat wire. The same case for Aluminum type, when it is smaller than the 8mm², use enameled round wire. Nevertheless, if the conductor width is up to and including 17mm and the thickness is up to and including 5.3mm, use either paper wrapped flat wire or glass fiber wrapped flat wire. The complicated shape of the insulation system is such that it has to relieve the electric stress at the end of the winding and it does this by distributing the potential and hence stress around a labyrinth of duct and barriers [13].

5.1.1 Current Density Selection

Current density of the conductor is determined by the load loss, winding temperature rise and dynamic stability and thermal stability when short circuited the second winding. Usually the current density of the copper conductor is up to and including 3.5A/mm² without exceeding the temperature rise limits, while current density of copper conductor is up to and including 2.0mm². One consequential problem is that short-circuit forces and stresses in the windings have increased also [14].

5.1.2 Current Density Calculation

$$I_{(LV\ CURRENT\ DENSITY)} = \frac{I\text{Ø}_{LV}}{A_{(LV\ CONDUCTOR)}} \tag{12}$$

The edges of the conductor appears due to manufacturing casting copper curvy radius of 0.6 – 1.2mm which in turn elude high-pitched corners possibly damaged the insulation layer and to lessen the high electric stress levels, and as calculated above eventually requires a smaller area of the conductor.

5.1.3 Paper Cover Insulation on the Conductor

An upper dimension of the insulation wrapping tend to upgrade the withstand pressure but deteriorates heating values compared to the copper and the nearby liquid insulated area. A firm layer of wrapping are necessary from existing structure strength point of views. Convection process is one of the way of natural heat transfer through the oil channel provided the gap in between is properly prepared. Mid-depth area of the windings should have a bigger gap in between the conductor called the ducts for effective cooling. Axial ducts reacts as the cooling agent from internal side of the winding as well as the outer of the windings.

Important factor of thermal and dielectric rules in Transformer manufacturing will decide for the insulation in between the winding disc. Thermal condition normally are the deciding factor for the Low Voltage winding side. Convection process is one of the way of natural heat transfer through the oil channel provided the gap in between is properly prepared. Mid-depth area of the windings should have a bigger gap in between the conductor called the ducts for effective cooling. Axial ducts reacts as the cooling agent from internal side of the winding as well as the outer of the windings.

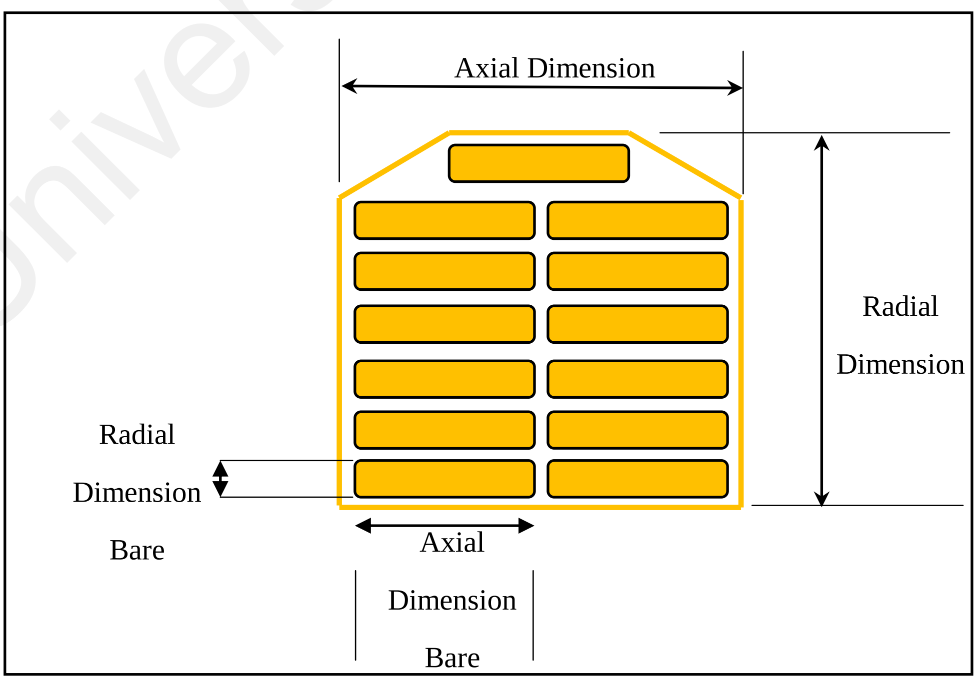

Figure 3.4: CTC Copper Conductor Dimension

5.2 High Voltage Winding Design

The section number and layer field strength of High Voltage winding is determined by voltage level. The Basic Insulation Level (BIL) of 230kVrms/550kVp normally the value required for 132kV Transformers. The designer will optimize the value to somewhere around 20% based on details scheming or analysis involving the impact on the inter-turn disc. Rated voltage and impulse stresses as one of the indication. The selection of the discs size need to be selected in order for a proper copper width is determined as designing stage of the Low Voltage Winding. Under few circumstances, if the dimension chosen is optimum, the winding height need to be indirectly proportional to the number of turns.

The primary side voltage winding has been proposed to perform as a disc winding with continuous arrangement. Disc winding with shielding arrangements and interleaved disc are selected normally for 132kV class transformers. For 220kV voltage level, this arrangements has been proven to stabilize the stresses appearing along the winding.

5.2.1 Paper Cover Insulation on the Conductor

As stated earlier, the insulation required for any copper conductor on the winding will be based on the impulse test voltage and the strain in between the conductor turn. Next the cooling part need to be considered as the ducts will be placed along the disc. Designers have the flexibility in modifying the gaps in between the two direct continuous disc. Line end and neutral end tends to have difference in the dimension of the space as it will undergo testing with overvoltage conditions and will witness a sharp ramp in the waveform.

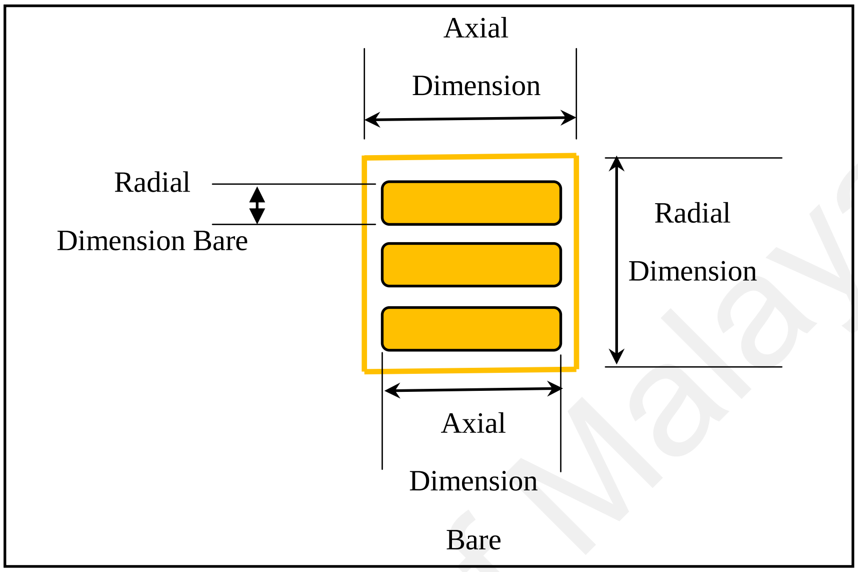

Figure 3.5: Bunch Copper Conductor Dimension

5.3 Height of the Low Voltage and High Voltage Winding

The rule of thumb in order to maintain the dimension are to make sure that the height of LV and HV are the same. However, there are sample cases which the LV windings are resize in order to reduce the strain of over-voltages and voltage impulse. In some design, the same identical dimension of windings are located in middle level line to reduce axial pressure. The electric field leakage is less at the dominant dimension area with less number of pressure acting on it. Such short circuit pressure acting on typical secondary level winding or Low Voltage in a helical and layer shape.

5.4 Core and Windings Total Dimension

As designer establish the core dimension as well as the winding size which is derived from the conductor size and copper area, now is where the core winding combination begin. The important mean diameter and whole radius of windings layer are given below:-

ITEMS	CLEARANCE (mm)	GAP (mm)	DIAMETER (mm)
1			684
2	21	Tertiary Winding	705
3			726
4	16	Tertiary to Low Voltage Winding	742
5			758
6	38	Low Voltage 1	796
7			834
8	16	Low Voltage 1 to Low Voltage 2	850
9			866
10	38	Low Voltage 2 Winding	904
11			942
12	50	Low Voltage to High Voltage	992
13			1042
14	110	High Voltage Main Winding	1152
15			1262
16	40	HV to Regulating Winding	1302
17			1342
18	11	Regulating Winding	1353
19			1364
20		Phase to Phase Distance	36

Table 3.8: Core and Windings Total Dimension

The examples shown in the calculation consider the gap dimension of both HV and LV based on their respective radial dimension. It should be noted that the distance required in between core to tertiary winding for 33kV class is specified as 21mm with 70kV rms/10kVp insulation level. It is different cases for a less voltage level since the value of gap and mechanical consideration will be observed to decide the distance in between winding and core. It should be noted that the Basic Insulation Level can be slightly higher than the specified level due to consideration of surge voltage in between windings thus deciding the gap of inner core towards innermost winding. For example, looking on the distance between phases in HV winding as static and the other distance from the HV static in comparison to other winding should be made larger in any adjacent direction.

Lightning impulse of the HV winding is important and as deciding factor to determine the dimension of the HV to LV gaps. Based on the testing procedure, when lightning impulse is conducted on HV side, other terminal will be grounded. To be on the save side, the dimension gap in between phases are kept larger compared to the LV gap. In some design, Basic Insulation Level are specified as one way for the maker to tell the phase to phase distance. As the existing electric field calculation software could only take maximum electric field strength as the insulation criterion, which is redundant and with low economic feasibility [15].

The insulation height in between winding and core is a strict requirements adhering to the dielectric insulation level, winding compact clamping as well as thermal consideration. This will in turn decide the highest or maximum dimension of the end insulation that can be made through early designing process. The specified Basic Insulation Level of the 132kV side are 550kVp and 230kV rms. From this value, the insulation from the upper top yoke up to the distance between phases can be computed. Another important criteria in deciding the specification of the insulation are the 3 phase top leads of HV winding. Winding support will be put to ensure all the winding is clamped all together to avoid any movements to the winding. Winding support which is made out of insulation pressboard is suit for the design since it has a good mechanical structure strength. However, due to the dimension or size, it may cause a problem during design stage because it will affect the height and affecting clearances. The whole transformer body also was design in a way that the oil will flow through in between the windings and directed in a direction of top to the bottom for efficient cooling.

Upper and lower lead voltages are of 33kV voltage of 70 kVrms/170 kVp Basic Insulation Level should sides of delta connection is linked. 70 kV rms/170 kVp Basic Insulation Level is intended for Neutral connection. Any increase during any over current or fault condition will be covered under the gap or clearance requirement of 38kVrms/95kVp Basic Insulation Level. The assembled winding need to be strong at the bottom part. Some area are required for the winding to place perfectly. There are very little option on selection of space in the bottom. The Neutral terminal will be on the higher side in order to maintain a line voltage at the winding. There will be specific test to be performed to test such condition. Designer will have to think with end in mind when dealing with this condition during designing stage.

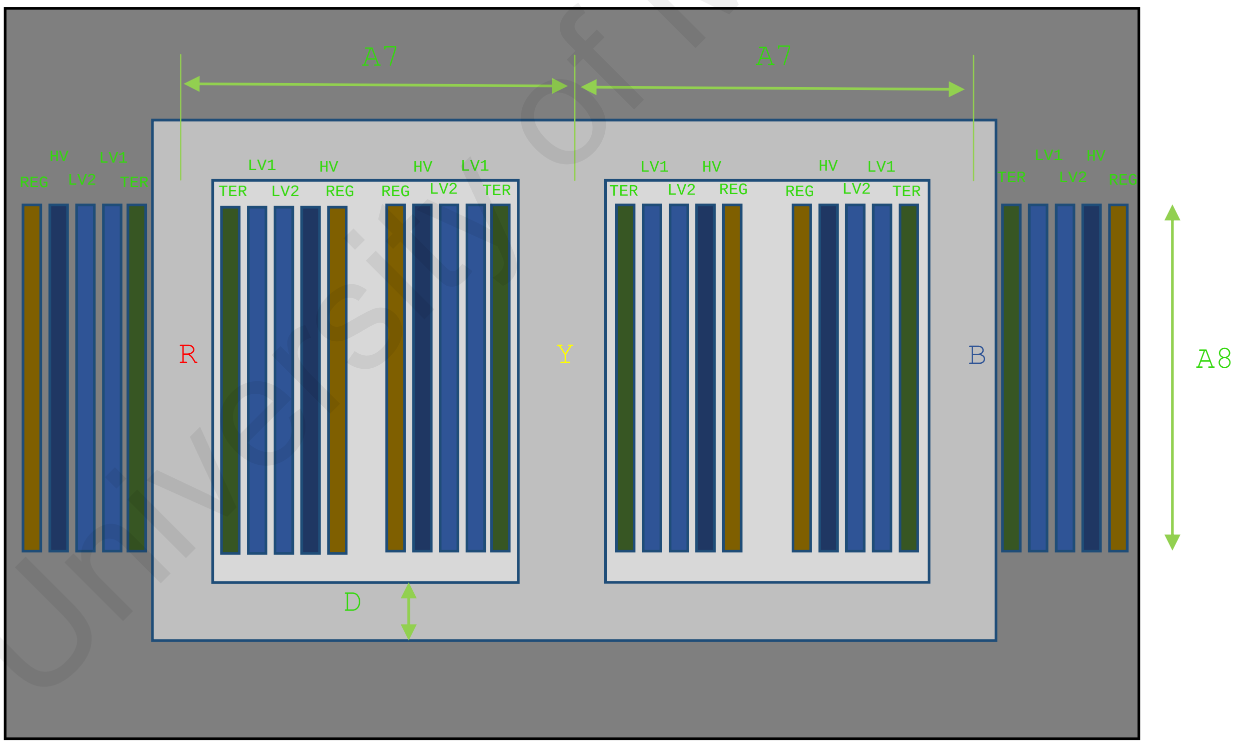

Figure 3.6: Dimension of the Core and Windings

5.4.1 Dimension of the Core and Windings

No	Location	Distance (mm)

1	Centre to Centre Distance of the Core Structure , A7	1400
2	Core Leg Length, A8	1530
3	Core Diameter, D	650

Table 3.9: Dimension of the Core and Windings

6.0 Core Weight and Loss Calculation

$$Core\ Length = 4\ x\ \left(\frac{1}{2}\ x\ Core\ Diameter\right) + (3\ x\ Core\ Leg\ Length) + (4\ x\ Centre\ to\ Centre\ Distance\ of\ the\ Core\ Structure) \quad (13)$$

This calculation demonstrates the equation in order to determine the Core Volume utilizing the given values at initial stage.

$$Core\ Volume = Core\ Length\ x\ Core\ Cross\ Sectional\ Area \quad (14)$$

$$Core\ Weight = Core\ Volume\ x\ Core\ Density \quad (15)$$

Where the density of the Core Lamination = 7.65 x 10^{-6} kg/mm³

In obtaining the No Load Losses, two modules will be considered, the eddy loss and hysteresis loss. The losses are calculated using the curves as manufacturer provides it which take into account few modules. For example, Watt/kg (losses of core lamination) from the contractor curvature at peak effective flux densities of 1.7 Tesla = 1.2.

Limb and yokes are identified to be the greater contributor of the flux loss densities considering area of flux cross, saturation and others. Hence, a penalty has to be executed for these area while computing the losses. As a simpler measure, the known factor are marked as 2.0. Based on the drawing weight of parts can be computed. From an assumption, the joints add 30% from all the calculation. The core loss be able to be determined.

$$Weight\ of\ the\ Joints = 0.3\ x\ Core\ Weight \tag{16}$$

$$Total\ Core\ Loss = Core\ Weight - Weight\ of\ the\ Joints \tag{17}$$

The value that is known to most of the manufacturer are in the area of 1.7 Tesla flux density that can be define based on constructing factor. The measurement on the Epstein's Test will indicate the flux density when it is built at manufacturer premise. Here all identified factor during the building of the core will be examined and tested with the outcome of the values. The building factor need to be considered as 1.3. Therefore the calculated core loss can be identified.

$$Calculated\ Core\ Loss = Total\ Core\ Loss\ x\ 1.2\ x\ 1.3 \tag{18}$$

7.0 Equivalent Circuit: Shunt Branch

The corresponding circuit has per-phase amounts. The shunt branch has few components in parallel: R_c symbolizes the total core loss and X_m denotes the magnetizing reactance.

$$R_c = \frac{(Rated\ Voltage)^2}{Calculated\ Core\ Loss} \tag{19}$$

$$I_c = \frac{(Rated\ Voltage)^2}{R_c} \tag{20}$$

The amounts are being designed as stated to the HV side. A higher value of R_c shows increased steel characteristic degradation of the reluctance linkages from example over current withstand pressure between the core building will further overcome the resistance and increased loss. For a simpler measure, designers refer to a schedule data on the losses information to establish core losses. There are tendency of higher losses from the single plate due to jointing. The example of the built core at 1.7 with given flux density as below

$$No\ Load\ Current = I_o = \frac{\frac{VA}{kg}\ x\ Core\ Weight}{\left(\sqrt{3}\ x\ Rated\ Voltage\right)}$$

$$Magnetizing\ Currents = I_m = \sqrt{{I_o}^2 - {I_c}^2} \quad (22)$$

The no-load power factor is as follow

$$Cos\ \theta_0 = \frac{I_c}{I_o} \quad (23)$$

When material grades are optimized, the lowering in I_m can be still be bigger than the decrease in I_c. It will be computed as the given equation

$$X_m = \frac{Rated\ Voltage}{I_m} \quad (24)$$

The single plate has higher effective permeability than the core being built due to jointing effect from one another. Magnetizing reactance provides for higher effective permeability based on the equivalent circuit. Both characteristic of magnetic reactance and reluctance of magnetic circuit are in inversely proportional with regards of the winding.

8.0 Leakage Reactance Scheming

A procedure for the determining the reactance is explained here. The inductance in the design winding taking N turns which flux linkages Ø can be designed based from this expression.

$$L = \frac{N_{\emptyset}}{i} \tag{25}$$

$$L = \frac{NBA}{i} = \frac{N\mu HA}{i} = \frac{N\mu(Ni/l)A}{i} = \frac{\mu N^2 A}{l} \tag{26}$$

$$L = \frac{\mu N^2 A}{l} = \frac{N^2}{l/(\mu A)} = \frac{N^2}{\Re} \tag{27}$$

The relationship $\emptyset = BA$ and $H = (Ni/l)$ will be utilized, $\Re$ is the reluctance of the directive direction of flux and the other marking in the equation. It is a recognized effects that in the formula, the magnetic densities Ø is connected through whatever number of (N) turns, and (l) turning into overall winding axial dimension. Form the given formula, (l) comprising flux $\emptyset$ through the flux circular shape which connected throughout the turns. LV and HV windings will be the center point of the field presence of flux. The relation between LV and HV turns are that half of LV field will be residual to the HV winding turn. From the observation, this phenomenon can be assume to be calculated from axial height. Hence the flux lines in the clearance area depending to the amperes turn will be same. For instance, the magnetizing amperes-turns are neglected if the LV and the HV ampere-turns which are of same values. In this case the calculation of the leakage reactance will be solely based on the axial length (heights) which are equal in terms of flux.

Using the Maxwell's ampere-circuital law, are whole sets of connotation assumed to be equal in the flux lines towards the gap area. It is the same for any direction in the windings of HV and LV flux lines. As the ampere turn lowered, and the distance is far away from winding, lower H and Bwill be recorded. Therefore, having the Current and Number of turn (Ampere-Turn) and the vector shaping in a trapezoidal form. To establish a calculation of leakage inductor value, magnetic flux value has to be seen as variable due to winding dimension across the line. Accordingly, when inductor value is measured as

$\frac{\mu N^2 A}{l}$, the cross sectional area of the flux circular shape area, consisting the secondary side winding, the clearance and the primary side winding have 1/3 as the calculation factor.

Also, the formula l value in the equation considered to be efficient dimension of the circular, to be designed by height known as Rogowski factor. Height of the winding will relate to the factor calculated and the circular flux shape. This also will consider the linkages between nearby windings and the total manufacturing length.

To compute the effective area as per below formula

$$A = \pi \; x \; mean \; diameter \; x \; radial \; depth \tag{28}$$

The terms conforming to the secondary and primary windings are grew by A equal π times ΣEATD by equation below

$$K_R = \frac{1 - e^{-H_w/(T_1+T_{g+T_2})}}{\pi H_w/(T_1 + T_{g+T_2})} \tag{29}$$

And the equivalent axial dimension of the magnetic circular is l . The leakage inductor on going to the primary side will be established (on the primary side).

$$L = \frac{\mu N^2 A}{l} \tag{30}$$

The intended circuitry will be seen to the secondary side, the value needs to be multiplied by

$$\frac{[(Rated \; kV_{L-L})_{LV}]^2}{[(Rated \; kV_{L-L})_{HV}]^2} \tag{31}$$

For example the ration of squares of the line-line voltage of the HV and LV Windings. The leakage reactance is (referred to the HV side).

(32)

$$X = 2\pi f L$$

The per-unit overall impedance and reactance value is depended to the true value seen on the primary side as

$$\frac{[(Rated\ kV_{L-L})_{LV}]^2}{[(MVA)_{3\emptyset}]} \tag{33}$$

9.0 Load Loss Calculations

9.1 Copper Loss in LV Winding

$$Mean\ Turn\ Length, LV = \pi\ x\ mean\ diameter\ x\ 3\ Phases \tag{34}$$

$$Resistance = Copper\ Resistivity\ x\ \frac{LV\ Length}{Area} \tag{35}$$

Where resistivity = 0.0211 Ω-mm²/m at 75°C.

$$\text{Copper Loss (I}^2\text{R Losses)in LV} = (I_{\emptyset\ \text{LV}})^2 x\ Resistance \tag{36}$$

9.2 Copper Loss in HV Winding

$$Mean\ Turn\ Length, HV = \pi\ x\ mean\ diameter\ x\ 3\ Phases$$

$$Resistance = Copper\ Resistivity\ x\ \frac{HV\ Length}{Area} \tag{37}$$

Where resistivity = 0.0211 Ω-mm²/m at 75°C.

(38)

$$\text{Copper Loss } (\mathrm{I}^2\mathrm{R} \text{ Losses}) \text{in HV} = (I_{\emptyset \text{ HV}})^2 x \; Resistance$$

$$\text{Total Copper Loss in Windings} =$$
$$(\text{Copper Loss } (\mathrm{I}^2\mathrm{R} \text{ Losses}) \text{in LV} + \text{ Copper Loss } (\mathrm{I}^2\mathrm{R} \text{ Losses}) \text{in HV}) \tag{39}$$

10. Calculation of Copper Weight

$$\text{LV Winding Volume} = Total\ Length\ of\ the\ conductors\ x\ Area\ of\ one\ Turn \tag{40}$$

$$\text{LV Winding Weight} = \text{LV Winding Volume}\ x\ Copper\ Density \tag{41}$$

Where the copper density = 8.89 g/cm³

$$\text{HV Winding Volume} = Total\ Length\ of\ the\ conductors\ x\ Area\ of\ one\ T \tag{42}$$

$$\text{HV Winding Weight} = \text{HV Winding Volume}\ x\ Copper\ Density \tag{43}$$

Where the copper density = 8.89 g/cm³

3.3 Power Transformer Design Process

The flow chart of the Power Transformer Design is specified below [16].

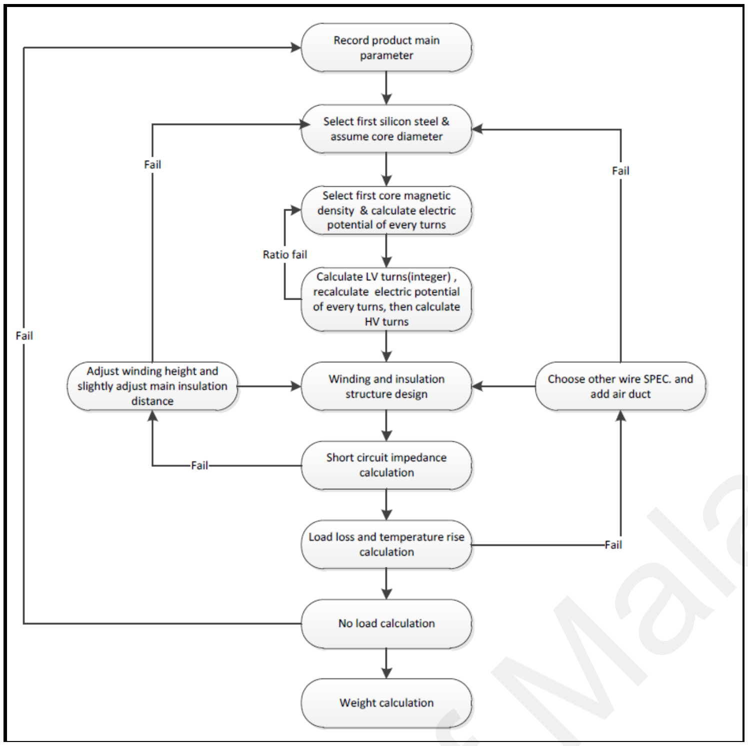

Figure 3.7: Power Transformer Design Process

3.4 Optimization Relation For Magnetic Flux Density and Low Voltage Turn

```
 for LV_Turn_=zzz:yyy
  for Diameter_=xxx:www
    LV_No_Of_Turn_=LV_Turn_*1;
    Core_Sectional_Area=(((pi*(Diameter_^2))/4)*Stacking_Factor*Utilization_Factor);
    Voltage_Per_Turn =((4.44*B_Initial*Frequency*Core_Sectional_Area)/1000000);
    New_Voltage_Per_Turn = (LV_PHASE_VOLTAGE/LV_Turn_)
    B_Final(LV_Turn_,Diameter_) =
(((New_Voltage_Per_Turn/Voltage_Per_Turn)*B_Initial));

  end
end
```

Figure 3.8: Optimization code for the Magnetic Flux Density and Low Voltage Number of Turn

This program lines perform nested loops based on the prompted values by the Transformer designer. The function check first to make sure that the Core Diameter loops based on the range prompted by the designer. It is followed by the parentheses containing the column assigned to it. The values computed will be stored in matrices array and indexed according to its row and column element.

3.5 Pseudo Code for the Overall Optimization Algorithm

```
data = B_Final;
[minNumCol, minIndexCol] = (min(abs(data-B_Initial)));
[maxNum, Core_Diameter] = min(minNumCol);
LV_Turn_Optimized = minIndexCol(Core_Diameter);
```

Figure 3.9: Simplified Pseudo Code for Overall Optimization Algorithm

The data will be based on the value of the final flux density calculated from the formula below:

$$BFinal = \frac{E_p{}'}{E_p} x\ BInitial \tag{44}$$

Next, the constraint were set for the algorithm to search for the optimized value. Here, the value required is as below condition:

$$BFinal \ \approx BInitial \tag{45}$$

Where the value of the $BFinal$ is set to be as close to as the $BInitial$ values in this design case is at 1.7 Tesla.

This function sorts the structure based on the $BFinal$ values. The function check first to make sure that the Core Diameter loops based on the range prompted by the designer. It is followed by the parentheses containing the column assigned to it and at the same time identifying the optimized Low Voltage number of turn committed to it. In order to achieve the minimum power loss, the Medium Frequency Transformer should operate at the optimum flux density which can be calculated by the equation [17].Using this combined function, the elements of the row and column are compared to determine the optimized value [18].

CHAPTER 4

RESULT OF POWER TRANSFORMER DESIGN OPTIMIZATION

4.1 Introduction

In this chapter, the results of this study are explained and going to be discussed. For this purpose, the results are focused on the Core Diameter values, Number of Low Voltage Turns, Percentage of Resistance, Reactance and Impedance as well as the No Load Losses. In order to determine the optimized design of the Power Transformer based on the mentioned important and high performance parameters, section 4.2 shows the results of a preliminary result of a Conventional Calculation Method (CCM) Power Transformer design. Section 4.3 shows the result of the Power Transformer after optimization. There are few curves obtained in giving justification ot the optimized design using Nested Loop. In Section 4.4, both the results from Conventional Calculation Method (CCM) and Nested Loop are compared to determine which method is able to give better optimized Power Transformer design.

4.2 Conventional Calculation Method (CCM) of Power Transformer Design

The Conventional Calculation Method (CCM) Power Transformer Design is designing through trial and error method. The typical medium rating Power Transformer specification are as Table 4.1. The important design Parameters are tabulated in Table 4.2. The method given is used for the design calculation of Transformer which in the opinion based on the experience in the Transformer industry, is the most realistic and complete conventional design method available in the literature to the best of our knowledge [19].

Rating	3-Phase, 45MVA, 132/33/11kV
Vector Group	YNyn0d11
Frequency	50 Hz
Magnetic Flux Density, $B_{INITIAL}$	1.7 Tesla
Impedance	10% – 20%
No Load Loss	20,000 – 25,000 Watt

Load Loss	200,000 – 250,000 Watt

Table 4.1: Conventional Calculation Method (CCM) Design Parameters

Core Diameter, D	650mm
Number of Low Voltage Turn, LV_{Turn}	166 Turn
Induced Voltage, E_p	114.774
Voltage Per Turn, $E_p{}'$	115.383
Magnetic Flux Density, B_{FINAL}	1.69104

Table 4.2: Conventional Calculation Method (CCM) Design Parameters

Design Variable	**Result**		
	MINIMUM	NOMINAL	MAXIMUM
Core Weight, (kg)	26581.7		
Reactance Percentage, % X	13.0894	13.7125	14.2932
Resistance Percentage, % R	0.48936	0.39801	0.396184
Impedance Percentage, % Z	13.0985	13.7183	14.2987
No Load Loss, NLL (Watt)	23817.2		
Load Loss, LL (Watt)	220212	179106	178283

Table 4.3: Conventional Calculation Method (CCM) Electrical Performance

By using the design parameters and the assumptions made in section 3.2, the Electrical Performance as shown in Table 4.2 can be achieved. The data shows that with current core diameter of 650mm as per Table 4.1, the weight of core is 26581.7 kg. The cost is assumed to be directly proportional to the weight of the core. It is also found that the

Impedance value were kept at 13% to 14% value. The total Losses were calculated between 178kW to 220kW.

Based on the computed result, the Power Transformer is fit for production and manufacturing process. The electrical performance were considered standard as per current market, However, from the eye of a Sales and Marketing executives and potential customer, the costing is considered high, there is always a way to fulfill the cost saving while keeping the electrical performance optimization on par. This is where the research and development begin and the conventional calculation method (CCM) will be transform to optimized design.

4.3 Nested Loop Optimization of Power Transformer Design

In Nested Loop optimization, the initial dimension of the Core Diameter, (D), Magnetic Flux Density (B_{FINAL}), Induced Voltage (Ep), Voltage per Turn (Ep') and the number of Turn (LV_{Turn}) are determined by the algorithm instead of trial and error mode. The initial values of optimization were prompted by the Transformer Designer during the optimization process.

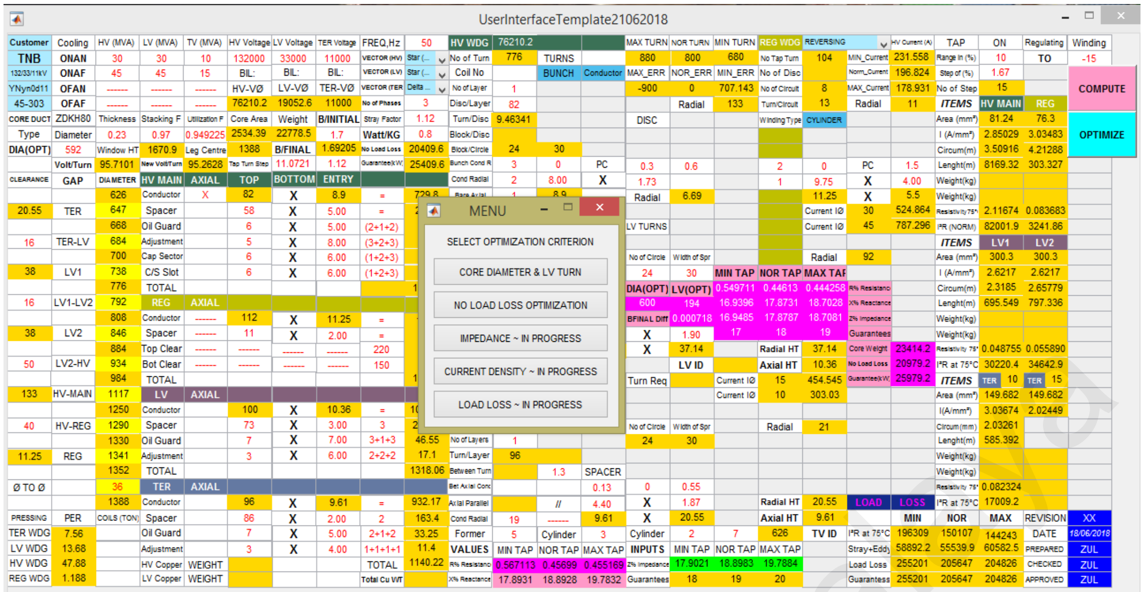

Figure 4.1: Prompt Data Pop-Up for Optimization Criterion

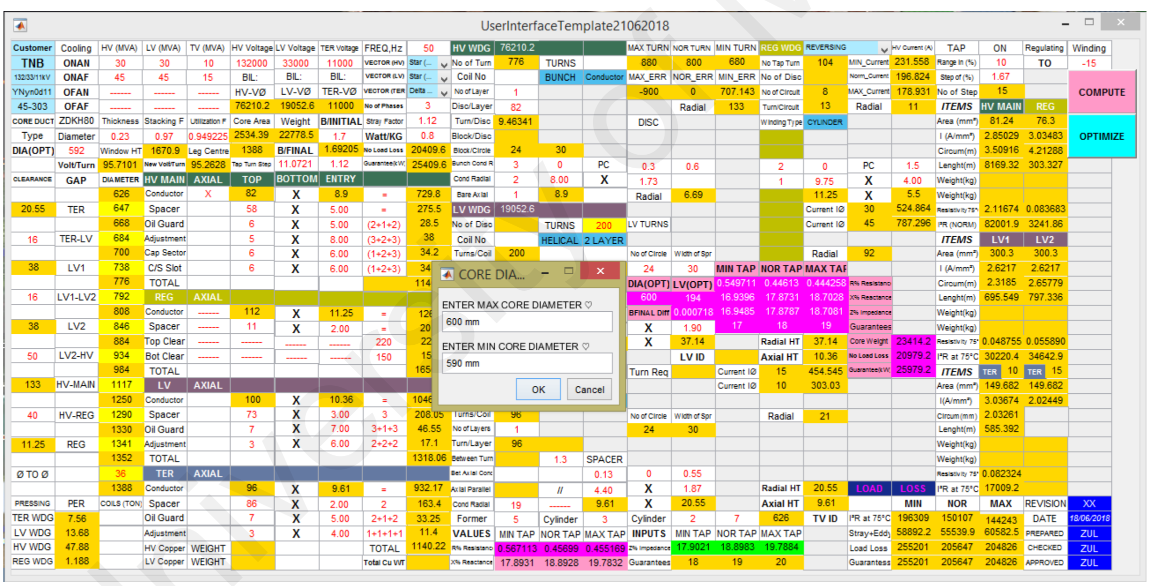

Figure 4.2: Prompt Data Acquisition for Optimization Criterion of Core Diameter

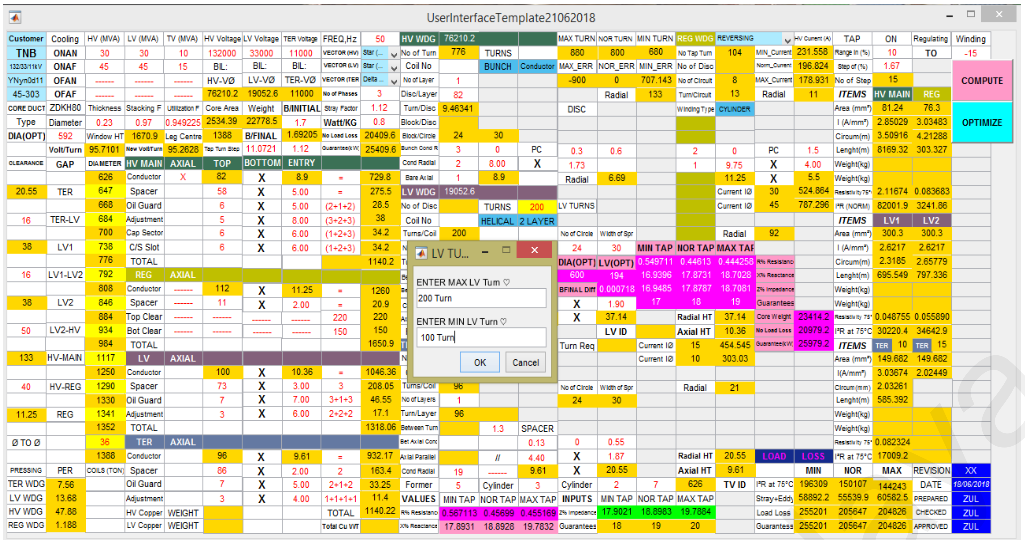

Figure 4.3: Prompt Data Acquisition for Optimization Criterion of LV Turn

Number of Simulation	1	2	3	4	n	10
Core Diameter, D, mm	590	591	592	593	.	600
Number of Low Voltage Turn, LV_{Turn}	200	200	200	200	.	194
Induced Voltage, E_p, V	95.263	95.263	95.263	95.263	.	98.209
Voltage Per Turn, $E_p{'}$,V	95.0646	95.387	95.710	96.034	.	98.314
Magnetic Flux Density, B_{FINAL} , T	1.70355	1.6978	1.6921	1.6864	.	1.69928

Table 4.4: Result of Nested Loop Optimization (Matlab) Design Parameters

Design Variable	Result		
	MINIMUM	NOMINAL	MAXIMUM
Core Weight, (kg)	23414.2		
Reactance Percentage, % X	16.9396	17.8731	18.7028
Resistance Percentage, % R	0.549711	0.44613	0.444258
Impedance Percentage, % Z	16.9485	17.8787	18.7081
No Load Loss, NLL (Watt)	20979.2		
Load Loss, LL (Watt)	247370	200758	199916

Table 4.5: Result of Nested Loop Optimization Electrical Performance (Ø = 600mm)

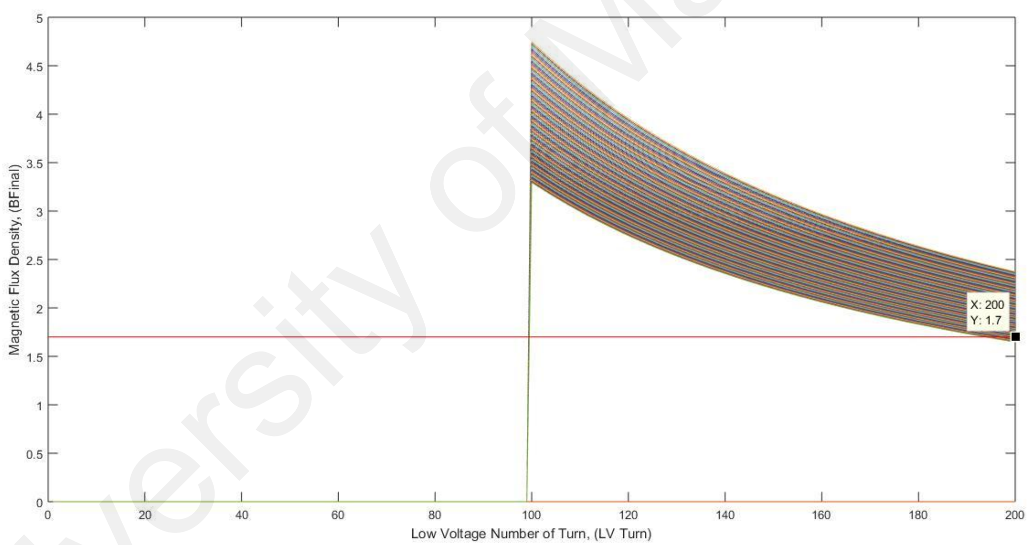

Figure 4.4: Convergence Characteristic of Nested Loop Optimization

The optimization will commenced with acquisition of input from designer. A range of Core Diameter dimension will be prompted as well as the Low Voltage number of turn range. For this example the range of the Core dimension is between 590mm to 600mm while for Low Voltage number of turn in between 200 to 100 turn. In this study, the optimized criterion chosen was the Core Diameter in order to reduce the dimension of the Core. The data shows that the optimized core diameter can be reduce up to 600mm as per Table 4.3, and the weight of core is reduced to 23414.2 kg respectively. The cost will be shrinking as a result of the optimization. On the other side of the electrical performances, it is also found that the Impedance value were increasing from 16% to 18%. The total Losses were calculated between 204kW to 255kW.

4.4 Result Comparison between CCM (Conventional Calculation Method) and Nested Loop Optimization

In this section, both of the result from Conventional Calculation Method (CCM) and Nested Loop Optimization are compared. The comparison is made by comparing the dimension of the Core Diameter, Number of Low Voltage Turn (LV_{Turn}), Magnetic Flux Density (B_{FiTal}), Electrical performance and also the Transformer Core Weight. The comparison result is tabulated in Table 4.5.

Design Parameters	**Designing Method**	
	Conventional Calculation Method (CCM)	**Nested Loop Optimization (Matlab)**
Core Diameter, D	650mm	600mm
Number of Low Voltage Turn, LV_{Turn}	166 Turn	194 Turn
Induced Voltage, E_p	114.774	98.209
Voltage Per Turn, $E_p{}'$	115.383	98.314
Magnetic Flux Density, B_{FINAL}	1.69104	1.69928

Table 4.6: Result of Comparison between CCM and Nested Loop Optimization

Design Variable	Conventional Calculation Method (CCM)			Nested Loop Optimization (Matlab)		
	MINIMUM	NOMINAL	MAXIMUM	MINIMUM	NOMINAL	MAXIMUM
Core Weight, (kg)	26581.7			23414.2		
Reactance Percentage, % X	13.0894	13.7125	14.2932	16.9396	17.8731	18.7028
Resistance Percentage, % R	0.48936	0.39801	0.396184	0.549711	0.44613	0.444258
Impedance Percentage, % Z	13.0985	13.7183	14.2987	16.9485	17.8787	18.7081
No Load Loss, NLL (Watt)	23817.2			20979.2		
Load Loss, LL (Watt)	220212	179106	178283	247370	200758	199916

Table 4.7: Result of Comparison between CCM and Nested Loop Optimization Electrical Performance

From the result in the table 4.5 and 4.6, the optimized Core Diameter, 600mm and Low Voltage number of turn, 194 turn were presented respectively. The voltage per turn and Magnetic Flux density were 98.314 and 1.69928 respectively. It is observed that the Core Diameter can be reduced up to 7% as a result of the optimization technique of the Nested Loop. Consequently, with the 7% reduction of the Core Diameter, the weight of the core will follow through with reduction up to 11.9%. The No-Load Loss also will see further reduction also up to 11.9%. From a manufacturing side of view, the reduction in the Core Weight is significant due to the amount of raw materials and handling involved. The positive reduction also will give back to the spoilage during manufacturing process if considered the total mass production events. To the Sales and Marketing executives, this will be a positives sales margin keeping the same selling price tag but with a lower overhead cost. However, for every manufacturing design, there are always a trade-off. The optimization using nested loop will yield a higher total Load Loss. This is due to for every inches of dimension reduction on the Core Diameter, the number of Low Voltage Turn will be increased. Hence, the length of Copper will be increased and resulting for a higher Impedance value and I^2R Load Loss. In this case, a potential customer will be advised on the specification and tolerable values of the Transformer to be installed to the Grid system with agreement on both parties involved.

CHAPTER 5

CONSLUSION AND FUTURE WORKS

5.1 Conclusion

In this work, optimization of the Conventional Calculation Method (CCM) of the Power Transformer design has been successfully performed. One main algorithms were used in this study namely Nested Loop Optimization (MATLAB). The conventional calculation method still uses the Excel sheet as part of trial and error method in designing Power Transformer whereas the Nested Loop Optimization were using sophisticated user GUI technique developed in the MATLAB software environment. The electrical performance was evaluated based on the Core Diameter dimension, number of Low Voltage turn (LV_{Turn}), No-Load Loss, Core Weight and also the total Load Losses.

From the result that has been obtained, Nested Loop Optimization yield the optimum result in terms of cost saving and practicality over the Conventional Calculation Method (CCM). Furthermore, the time consuming when using the Conventional Calculation Method (CCM) in excel sheets can be phase out with the application style of the Designer GUI at the fingertip just to give broad ideas and consideration on the designing parameters and optimization.

5.2 Future Work

Future work that can be performed are as follows:-

1. A hybrid algorithm can be proposed. Few other function optimization algorithm can be used namely Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Back Search Algorithm (BSA) for the Power Transformer Design Optimization.
2. Use more parameters as variable for optimization of the Power Transformer
3. Develop an application tools of designing and optimization coupled together for android environment. This to be in line with the upcoming revolution of Industrial 4.0.

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