SENSITIVITY STUDY ON INFLUENCING PARAMETERS OF TRANSFORMER THERMAL MODEL WITH DIRECTED OIL FLOW

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ABSTRACT

The thermal design of a power transformer has to keep the temperature within limits according to international agreement standards. Two of the limits are a maximum temperature rise and a maximum oil temperature. The purpose of this study was to study the temperature distributions and oil velocity inside coil of the power transformer and to model and develop a program using MATLAB that can modulate the suitable parameter that not exceeds maximum temperature rise in disk coil transformer. Two methods have been used to study the velocity and temperature parameters affecting the oil flow through the transformer. The first approach focused on equation derived from previous worked about oil flow and temperature distribution. The second approach was to handle the problem as a global optimization problem solved by numerical methods. The optimization was done using predictions from a program used for velocity and temperature calculation. The numerical method result was successful; on all the designs tested it gave a lower temperature rise value according to international agreement standards. Test the program by using different value in the parameter have been tested on sensitivity of study. The study has shown that a geometrical detail approach provided for better design solutions in reasonable time and therefore has shown its potential for practical use. Both the methods could be combined and used for further investigation.

ABSTRAK

Reka bentuk haba pengubah kuasa perlu dikekalkan suhu mengikut had piawaian perjanjian antarabangsa. Dua daripada had adalah kenaikan suhu maksimum dan suhu minyak yang maksimum. Tujuan kajian ini adalah untuk menyiasat taburan suhu dan halaju minyak di dalam gegelung pengubah kuasa dan model dan dibangunkan program menggunakan perisian MATLAB yang boleh memodulasi parameter yang sesuai dimana tidak melebihi kenaikan suhu maksimum dalam cakera pengubah gegelung. Dua kaedah telah digunakan untuk menyiasat halaju dan suhu parameter yang mempengaruhi aliran minyak melalui pengubah. Pendekatan pertama memberi tumpuan kepada persamaan yang diperolehi daripada kajian sebelumnya berkaitan aliran minyak dan pengedaran suhu. Pendekatan kedua untuk menangani masalah tersebut diselesaikan dengan menggunakan kaedah berangka. Pengoptimuman menggunakan ramalan nilai daripada persamaan dilakukan untuk pengiraan halaju dan suhu. Hasil kaedah berangka berjaya pada semua reka bentuk yang diuji dan memberikan suhu yang lebih rendah daripada nilai kenaikan mengikut piawaian perjanjian antarabangsa. Program ini telah diuji dengan menggunakan parameter yang berbeza untuk pelbagai sensitiviti pengajian. Kajian ini telah menunjukkan bahawa pendekatan terperinci geometri yang disediakan bagi penyelesaian reka bentuk yang lebih baik dalam masa yang munasabah dan berpotensi untuk kegunaan praktikal. Kedua-dua kaedah ini boleh digabungkan dan digunakan untuk siasatan lanjut.

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LIST OF ABBREVIATIONS

IEC	-	International Electrotechnical Commission
IEEE	-	Instituted of Electrical and Electronic Engineer

CHAPTER 1

INTRODUCTION

1.1 Overview

Power transformers represent the largest portion of capital investment in transmission and distribution substations. In addition, power transformer outages have a considerable economic impact on the operation of an electrical network since the power transformers are one of the most expensive components in an electricity system [1].

In fact most of power transformers use paper and oil as the main form of insulation. There are three possible mechanisms that contribute to the insulation degradation are hydrolysis, oxidation and pyrolysis. The agents responsible for the respective mechanisms are water, oxygen and heat temperature indeed the temperature has been considered as the main parameter affecting the loss-of-life of insulation. Hence, the heat produced (internal temperature) in the transformers as a result of loading and the effect of ambient temperature is the important factor that affecting the life other transformer [2].

The temperature affects the insulations. The structure of insulating materials using in transformer, mainly those based cellulose, is subject to aging. Aging modifies the original electrical, mechanical and chemical properties of the insulating paper used.

There is an exponential relation between temperature, duration of thermal effect and the extent of aging of insulating material.

The thermal stress reduces the mechanical and dielectric performance of the insulation. The experiments, which were carried out by Montsinger indicate that when the transformer temperature has the values between 90-110^{o} C, 8^{o} C increments on these values results in having the life of the insulation [3]. Therefore, the temperature limits permitted in the active parts, influence on structure design, size, cost, load carrying capacity and operating conditions of the transformers have already been precisely defined.

There are two types of winding and ducts arrangement in power transformer; disk type winding and layer type winding. The case considered is a disc type of winding which is cooled sometimes by directed oil flow and sometimes by non-directed oil flow. Figure 1 shows a three phase power transformer. When higher voltage started to be transformed there was a need for a better insulation material than air. Mineral-oil was then used as insulation material in the transformers. A side effect of this was that the heat produced in the transformer was better transported away and the transformer cooled down. An interest for cooling equipment began.

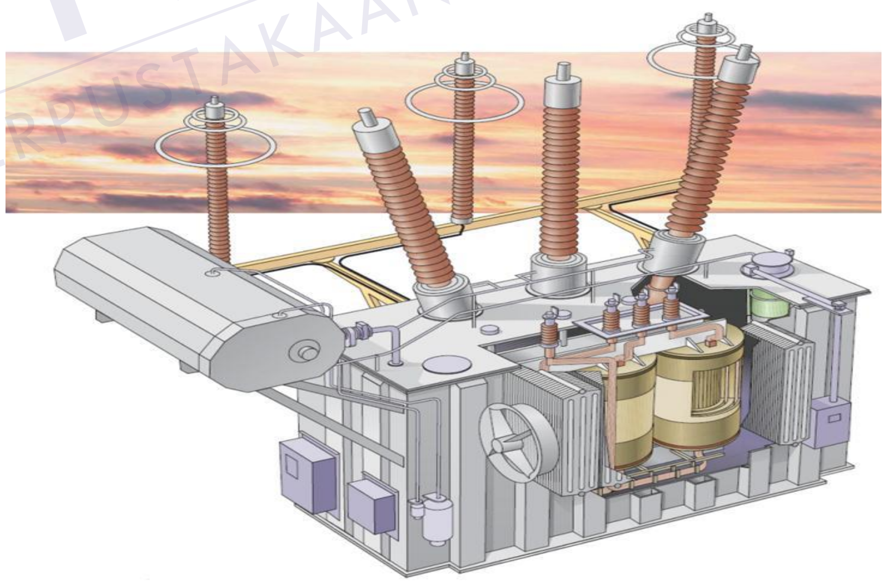

Figure 1.1: Three phase transformer

1.2 Problem Statement

The no load losses and the load loss consist of I^2R,all these losses cause heating in the corresponding parts of transformer and this heat must be taken away to avoid high temperature which will cause deterioration of insulation.

In liquid-immersed power transformers, the temperature of the winding is very important in order to prolong the service life of the transformer. Knowing the temperature distribution especially hot spot temperature at each point of transformer is vital [6, 7, 8, 9, 10] to ensure safe operation during the period of service. The winding made of copper can hold mechanical strength up to several hundred degrees Celsius without deterioration and the transformer oil does not significantly degrade blow 140 C ^{o}, however this is not case for the paper insulation. The paper insulation deterioration rapidly if its temperature is more than 90 C^o [11].

Most of the transformers are using mineral oil as transformer insulating oil. The insulating oil temperature depends on the winding temperature and is usually used to indicate the operating conditions of the transformer [9]. The increase in temperature will influence the insulating material and may cause aging. Depends to the insulating material type, the transformer has a maximum limit of temperature rise [12].

There are several types of numerical protection relay designed to provide protection for transformers. They are also used to calculate losses due to high temperature generated inside the transformer. In this project, Matlab software is used to predict the heat distribution in liquid-immersed transformers.

1.2 Objectives

The objectives of this project are as the following:

(i) To study the distribution of both the oil velocity flow and temperature inside coil of transformer.

(ii) To develop a program using MATLAB, that can modulate the suitable parameter that not exceeds maximum temperature rise in disk coil transformer.

(iii) To analyze the result of sensitivity study.

1.3 Project Scope

The scope of this study is designed base on the following considerations:

(i) Transformer parameter

- The project will consider only three transformer parameters which are different location of block washer for five disks, vertical duct size and horizontal duct size.
- This study focus on pressure drop, oil velocity and temperature value for five disks.
- Transformer cooling type for this study is oil directed air flow (ODAF).

(ii) Software

- Develop a program to model and perform numerical calculation using Matlab Software

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents literature reviews that focus on both fundamental theories and modeling of transformer. This includes specification of power transformer, cooling system, oil flow, and also MATLAB software.

2.2 Power Transformer

A power transformer is the electrical device which is used to change the voltage of AC in power transmission system. Modern large and medium power transformers consist of oil tank with oil filling in it, the cooling equipment on the tank wall and the active part inside the tank. As the key part of a transformer, the active part consists of 2 main components: the set of coils or windings (at least comprising a low voltage, high voltage and a regulating winding) and the iron core, as figure 2.1 shows. For a step-up transformer, the primary coil is low voltage (LV) input and the secondary coil is high voltage (LV) output. The situation is opposite for a step-down transformer. The iron core is the part inducing the varying magnitude flux. Nowadays, transformers play key roles in long distance high-voltage power transmission.

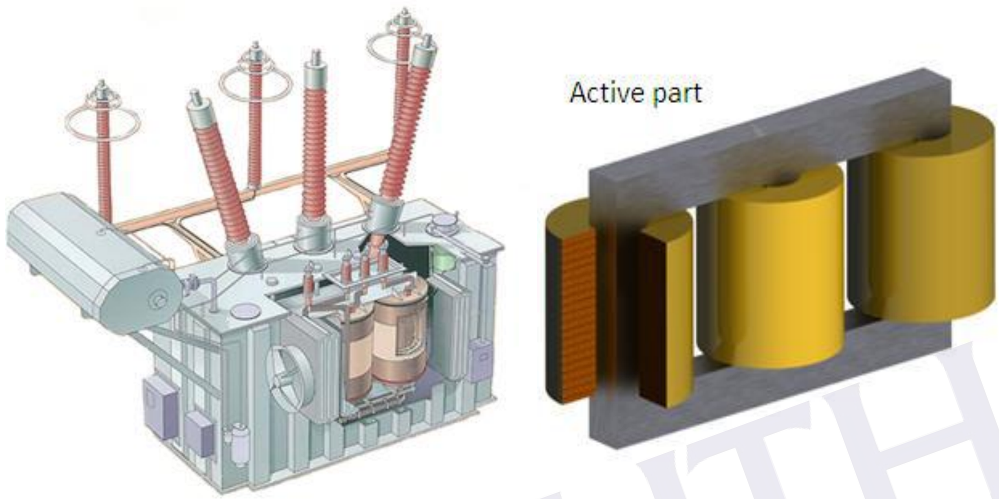

Figure 2.1: Structures of disk winding transformer

The term power transformers used to refer to those transformers used between the generator and the distribution circuits and these are usually rated at 500 kVA and above. Power systems typically consist of a large number of generation locations, distribution points, and interconnections within the system or with nearby systems, such as a neighboring utility. The complexity of the system leads to a variety of transmission and distribution voltages. Power transformers must be used at each of these points where there is a transition between voltage levels.

Power transformers are selected based on the application, with the emphasis toward custom design being more apparent the larger the unit. Power transformers are available for step-up operation, primarily used at the generator and referred to as generator step-up (GSU) transformers, and for step-down operation, mainly used to feed distribution circuits. Power transformers are available as single-phase or three-phase apparatus. The construction of a transformer depends upon the application. Transformers intended for indoor use are primarily of the dry type but can also be liquid immersed. For outdoor use, transformers are usually liquid immersed.

The normal life expectancy of a power transformer is generally assumed to be about 30 years of service when operated within its rating. However, under certain conditions, it may be overloaded and operated beyond its rating, with moderately predictable "loss of life." Situations that might involve operation beyond rating include emergency rerouting of load or through-faults prior to clearing of the fault condition. Power transformers have been loosely grouped into three market segments based on size ranges [10, 13, 14]. These three segments are:

a) Small power transformers: 500 to 7500 kVA
b) Medium power transformers: 7500 to 100 MVA
c) Large power transformers: 100 MVA and above.

A laminated steel core with copper or aluminum windings are used in power transformer in which the windings have a solid insulation of refined paper, and highly refined mineral oil is the insulating and cooling medium for the entire transformer. The core, windings and insulation all have specific thermal capabilities. Losses in the winding and core cause temperature rises in the transformer, which are transferred to the insulating oil. Failure to limit these temperature rises to the thermal capability of the insulation and core materials can cause premature failure of the transformer.

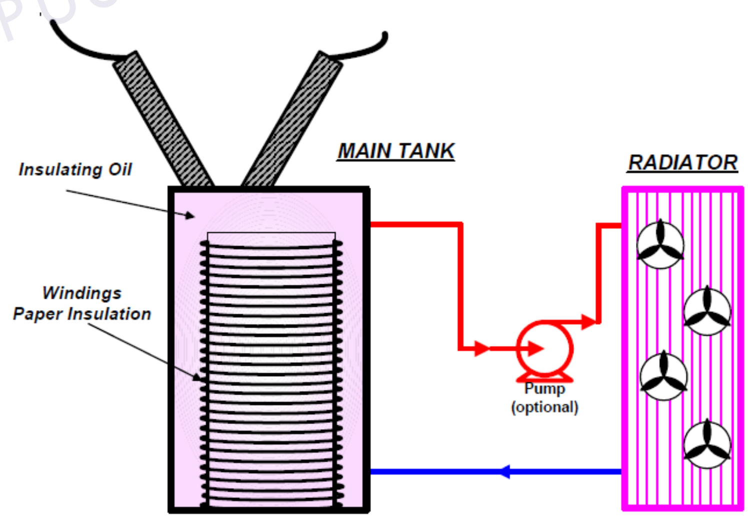

Figure 2.2: A simple transformer representation [9]

2.2.1 Liquid-Filled of Transformer

Each of the transformers is constructed according to its application. Indoor transformer intended to use dry type transformer but sometimes can be liquid-filled. But for outdoor use, usually liquid-filled transformer will be chosen. Some of the dry type transformer are not suitable for outdoor because the method of cooling system is by circulating air through the coil and core assembly which is use either by force air flow (fan) or natural convection.

This cooling method is suitable for low voltage – indoor transformer. At higher voltage, oil is needed to insulate the winding due to the losses which are high through the process of conduction, convection and radiation for effective winding cooling, the moving oil must be able to contact with every conductor for maximum convection and conduction of the conductor heat from the winding to the oil. In the other hand, direct oil cooling is not effective for outdoor environment where it can make the windings dirt and moisture.

A Comparison of Liquid-Filled and Dry Type Transformer Technologies written by Tommy Nunn [7] of IEEE-IAS Cement Industry Committee evaluated the comparison both types of the transformer. He stated that both type have pro and cont in terms of loads, environment, purchase cost, safety, availability to operate, materials and manufacturing process. In recent years, transformers technologies have improved the insulation system, core material and computer design programs.

Another research has been done by Jerrery Wimmer, M. R. Tanner, Tommy Nunn and Joel Kern on the specification Installation and operational impact of both types in a marine environment [8]. They found that fiber glass winding will have maximum operating size through 25000kVA and also application of vacuum technologies increased the reliability on tap changing reduced the maintenance. Table 2.1 list some advantage and disadvantage of liquid-immersed transformer.

Table 2.1: Liquid-immersed transformer [9]

Advantage	Disadvantage
Transformer oil is combustible	Needs oil regular checking filtration and replacement of oil
Smaller size	Costly and need high recurring expense
Lower cost	Produce a little bit of danger
Greater overload capability	Located away from the main building

2.2.2 Transformer Heating

In thermal modeling of power transformer, two significant sources of heating are considered; no-load losses and load losses. Whenever the transformer is energized, no-load losses will present which is made up of hysteresis and eddy loss in the transformer core. Hysteresis loss is caused by the elementary magnets in the material aligning with the alternating magnetic field. Eddy currents are induced in the core by the alternating magnetic field.

Load losses consist of copper loss due to the winding resistance and stray load loss due to eddy currents in other structural parts of the transformer. The copper loss consists of both DC resistance loss, and winding eddy current loss. The amount of loss is dependent on transformer load current, as well as oil temperature. DC resistance loss will increase the increasing temperature but other load losses decrease with increasing oil temperature [9].

Temperature in liquid-filled transformer can be decreased by transferring heat from the core and windings to the insulating oil. Nature circulation of the coil will transfer heat to the external radiators. The radiators are used to increase the cooling surface area of the transformer. Sometimes, pumps are used to increase the oil flow and at the same time radiators efficiency also increasing. For some large transformer (at substation and power plan) required active cooling to remove the heat from the core and windings and usually through circulating oil. Sometimes have two stage of cooling.

There are various cooling modes of transformer that established by IEEE and IEC. IEEE has adopted the IEC designation [9]. The designations totally describe the cooling method for the transformer and the cooling method impact the response of insulating oil to overload condition. Table 2.2 lists the common transformer cooling designations.

Table 2.2: Transformer cooling designations [9]

Old IEEE Cooling Designations		**IEC Equivalent**
Self-cooled	OA	ONAN
Forced air cooled	FA	ONAF
Directed-flow forced liquid cooled	FOA	ODAF
Water cooled	OW	OFWF
Forced liquid and water cooled	FOW	OFWF

2.2.3 Impact Oil Temperature of Transformer

The temperature of insulating oil will increase if the transformer load is increases, so loading the transformer above the nameplate rating can cause a risk to transformers life [5]. According to the IEEE standard, temperature rise of the oil near to the top main tank should not exceed 65º C.

These risks include reduced dielectric integrity due to gassing, reduced mechanical strength and permanent deformation of structural components such as the core and windings, or possible to damage auxiliary equipment such as tap changers, bushings, or current transformers. If the insulation system follow the IEEE STD C57.100 [52], it will get the acceptable thermal aging performance and at least can be used up to 20.5 years (180 000 h). Standard temperature limits are defined in the IEEE standard - Guide for Loading Mineral Oil-Immersed Power Transformers and list in the Table 2.3.

Table 2.3: IEEE standard temperature rise

Standard temperature limits		
Average windings temperature rise	65º C	Above ambient
Hot-spot temperature rise	80º C	Above ambient
Top liquid temperature rise	65º C	Above ambient
Maximum temperature limit	110º C	Absolute

The insulating transformer’s fluid must meet the same criteria similar to those other high voltage equipment such as circuit breaker and capacitors. The criteria are:

i. The fluid must conduct heat but not electricity
ii. Must not be chemical reactive
iii. Must not be easily ionize that can allow are.

2.3 Review of Previous Research

Robert M. Del Vecchio and Pierre Feghali (1999) have modeled a thermal model of a disk coil with directed oil flow. In this model each path segment, oil velocities and temperature rises are computed. The oil Flow is assumed to be thermally driven. The model includes temperature dependent oil viscosity, resistivity, oil density, and temperature and velocity dependent heat transfer and friction coefficients a computer code based on the analysis The code calculates temperatures of the coil disks and of the oil in all the ducts as well as duct oil velocities[15].

GüvenKömürgöz İbrahim ÖzkolNurdanGüzelbeyoğlu (2001) in this study the temperature distribution in the disk coil of transformer winding, there are series of numerical experiments are conducted so as to develop a new thermal model for oil immersed transformer windings. A line of eight-disc-coil has been modeled as a series of heat producing sources in a vertical channel. The heat transfer equations for the model in hand were solved by a semi numerical-analytical method to obtain temperature distribution. Also, the results obtained are verified by ANSYS packet program [4].

Zoran R. Radakovic and Marko S. Sorgic (2010) they have introduced basics of detailed thermal hydraulic model for thermal design of oil power transformers .The paper presents the method for the calculation of temperatures inside oil power transformers, and the transformer in more detail starting from the construction of a transformer, physical parameters of applied materials, temperature of the outer cooling medium, and distribution of power losses, and the calculation temperature distribution of the winding, in each conductor of the oil, temperature in each cooling channel and in each characteristic point, and in the core, on the surfaces and the hottest spots[16].

Table 2.4: Summary of technology development that done by other researcher

Author	**Findings**						
	Oil Velocity	**Pressure**	**Flow Rate**	**Temperature**			
				Disk	**Oil**	**Path**	**Nodal**
A.J. Oliver [5]	√	√		√	√		
A.Weinlader [17]	√	√	√	√	√	√	
E.P. Childs [18]		√		√			
F. Torriano [8]			√	√	√		
DelVecchio[HYPERLINK \l "RMD991" 12]	√	√		√	√	√	√
J.Zhang [19]		√		√			√
J.Zhang [20]			√	√		√	√
L. W. Pierce [21]				√	√	√	

2.4 Oil Guided and Non-Oil Guided Disk Windings

Oil guided and non-oil guided windings are proposed in disc windings transformers. In the active part, as shown in Figure 2.1, between winding and core, LV windings and HV windings, windings and outer casing, there are insulation board layers. Then, a closed space can be formed for each layer of windings. Figure 2.3 shows the 2D cross sectional area of one layer of disc windings. As Figure 2.3 at the left side shows, the guides are set in vertical ducts every 6 disks are oil guides. The purpose of setting oil guides is to improve the natural convection capability of the oil flow by avoiding the stagnation of the oil inside ducts. Cold oil come in the windings from the bottom and go through the vertical and horizontal ducts, the oil guides would change the oil flow direction and make the global oil distribution even.

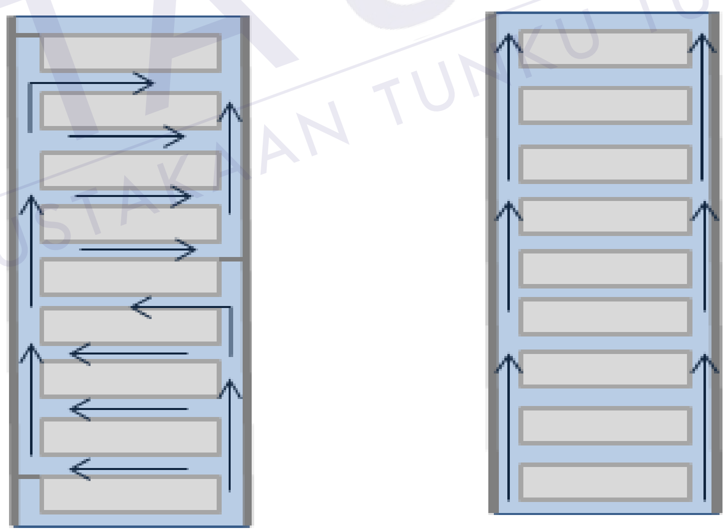

Figure 2.3: 2D cross-sectional images of disk windings

In reality and the real manufacturing process, considering some situation with quite small windings radius as well as cost effective consideration, the non-guided disk windings may be applied. Figure 2.3 at the right side shows the 2D cross-sectional image of non-oil guided winding. It can be seen that the construction of non-oil guide winding looks like a longer section of winding with oil guides. For non-oil guided model, due to its large scale in the vertical length, the oil flow distribution as well as the temperature distribution is expected to become complex [4, 5, 17].

2.5 Transformer Cooling System

The heat produced in a transformer must be dissipated to an external cooling medium in order to keep the temperature in a specified limit. If transformer insulation is experienced higher temperature than the allowed value for a long time, it will cause rapid degradation of insulation and hence severely affect the transformer life.

In oil immersed transformer, the heat is transferred from the active parts (core, winding and structural components) to the external cooling medium by the oil. The heat from the active parts is transferred by the process of oil circulation. The process of transferring heat from involves three different heat transfer mechanisms which are conduction, convection and radiation [12]. The conduction process involves the heat transfer between the solid parts, whereas the convection process involves the heat transfer between a solid surface to a liquid or vice versa. The heat transfer by radiation is between solid or liquid to the surrounding ambient temperature.

The most important heat transfer mechanism in an oil immersed transformer is through the convection. The convection process occurs between transformer winding and oil. It is always neglected in thermal calculation because of low surface temperature and small area available on a transformer for radiation process to occur. Four common types of cooling arrangement have been used in the industry and they will be explained in more details. There are four common types of cooling arrangement have been used.

2.6 Cooling Arrangement

2.6.1 Oil Natural Air Natural (ONAN)

The simple and most common cooling type used in the practice is ONAN. ONAN refers to Oil Natural Air Natural. The ONAN cooling is achieved when the oil flow through the transformer winding is driven by pressure difference between the tank oil and the cooler oil. This pressure difference is due to a temperature difference between the oil temperature in the tank and the oil temperature in the radiators. This natural circulation of oil sometimes has been referred as a “thermo siphon” effect. The ONAN design is shown in Figure 2.4.and arrows in the figure show the oil flow direction in the transformer.

The term siphon effect occurs when the heat generated in transformer core and winding are dissipated to surrounding oil mainly through the convection process. The density of the oil is inversely proportional to the temperature and is proportional to the pressure and height. As the oil temperature increases, its density reduces. The oil becomes light and due to buoyancy effect it moves upwards towards the top of the tank. Its place is taken by the cool oil from bottom which has a higher density. As the oil enters the cooler, the heat is dissipated along colder surfaces of the cooler, at the same time oil increases its density. The oil then flows downwards through the cooler and enters the bottom of transformer tank from the inlet thus the continuous oil circulation occurs.

The oil velocity in this natural circulation is relatively slow throughout the transformer and radiators. For this reason, ONAN transformers have large temperature difference between top oil and the bottom oil. They also have relatively large temperature difference between the winding temperature and the oil temperature.

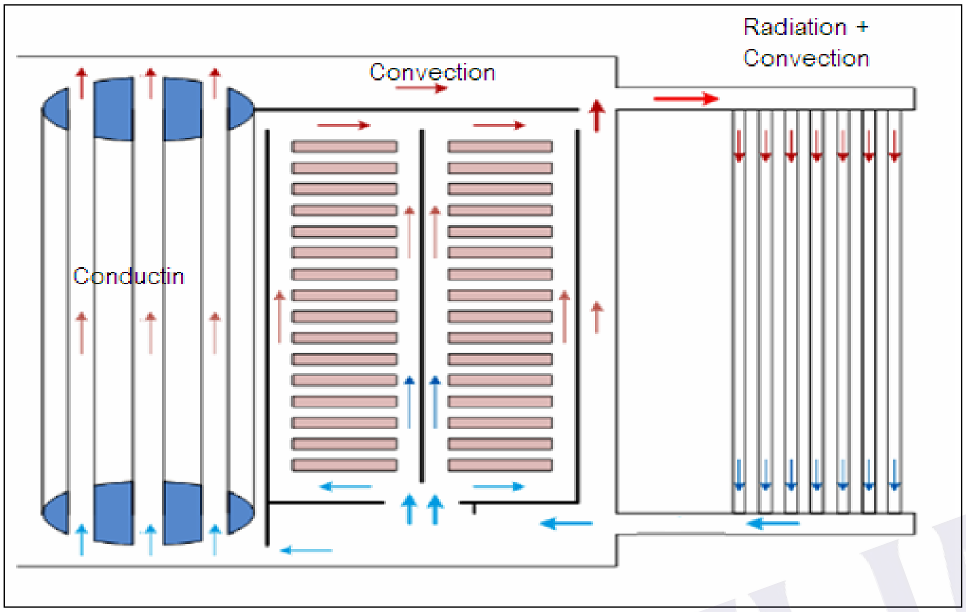

Figure 2.4: ONAN cooling diagram

This ONAN cooling mode is normally used for smaller rating transformer (distribution transformer). The ONAN cooling mode has a few advantages. They are:

- It requires less maintenance and more reliable as no cooler controls are involved.
- It is useful when low noise transformers are needed. The low noise level is easier achieve when the transformer are without the fans.
- No cooler loss due to malfunction of the fans and pumps.

2.6.2 Oil Natural Air Force (ONAF)

One way to increase the oil circulation rate is by improving the efficiency of the external heat dissipation. This can be done by using the fans to blow air onto the cooling surfaces of radiators. The forced air from the fans takes away the heat from the radiators (cooling) at a faster rate than natural air hence gives a better cooling rate. This leads to a lower average oil temperature (MO) hence increases the capability of the transformer to operate at a higher load. This type of cooling is termed as ONAF (Oil Natural and Air

Forced) as shown in figure 2.5. The introduction of the fans to the radiators improves the cooling characteristics of the radiators thereby reducing the number of radiators required to achieve the same amount of cooling. This also leads to smaller overall dimensions of the transformer/cooling design.

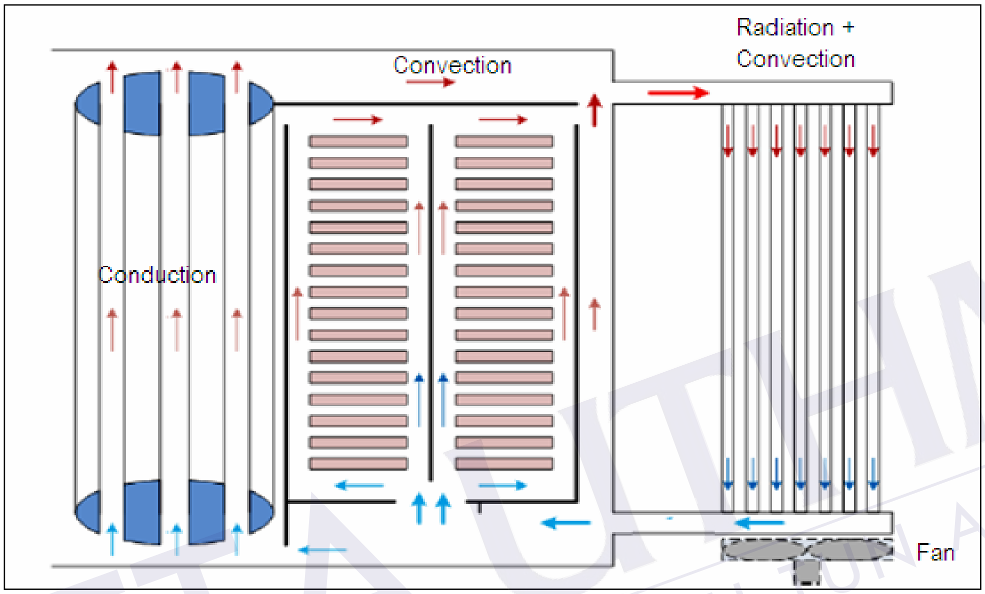

Figure 2.5: ONAF cooling diagram

In the ONAF cooling mode the oil circulates through the core and winding as the same as in the ONAN cooling mode. The flow rate inside the winding under ONAN and ONAF cooling arrangement is controlled by the themosiphon effect. Normally this flow rate is relatively low. Because of this, the heat dissipating of oil is low. The heat capacity can be expressed as

QUOTE $Q = mC_p(T_{out} - T_{in})$ (2.1)

Where Q is heat flow in W, m is mass flow rate in Kg/s, Cp is specific heat in J/(Kg C^o), and temperature T_{out} (top oil temperature) and T_{in} (bottom oil temperature) are in C^o.

2.6.3 Oil Force Air Force (OFAF)

One way to improve the heat dissipation capability is to increase the value of mass flow rate; m and this can be done by using a pump to circulate the oil. Moreover to increase heat transfer rate, fans have to be always operating at the radiators. This improves the heat transfer to the radiators (cooling) and reduces considerably the temperature difference between the top and bottom of the radiators hence lower the oil temperature rise in the top parts of the transformer. This type of cooling is called OFAF (Oil Forced and Air Forced) as shown in Figure 2.6.

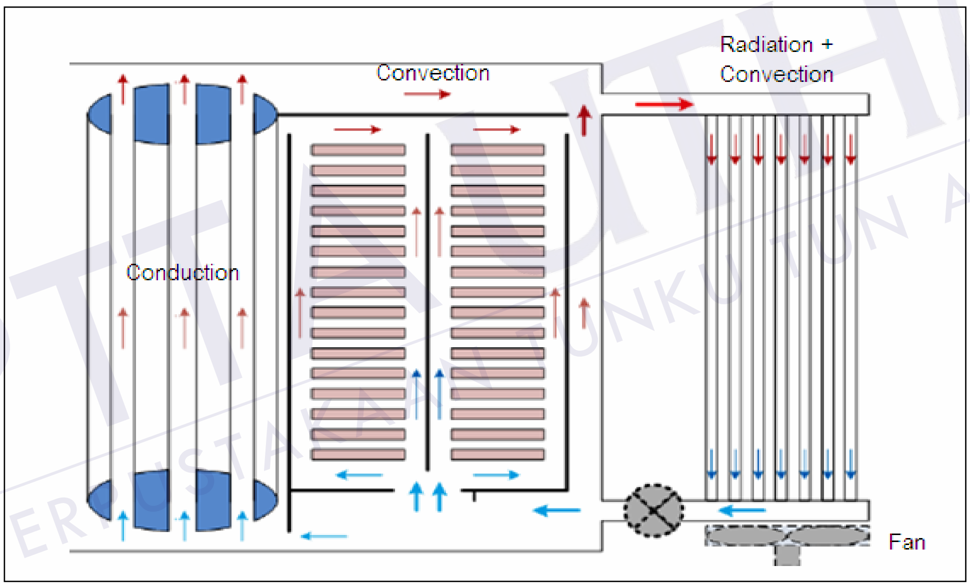

Figure 2.6: OFAF cooling diagram

Even through the oil is pumped from the radiators to the transformer tank, the oil in the winding tends to circulate at a velocity closer to the natural oil circulation modes, since most of the oil circulation by the pumps flows in the tank outside of the winding, due to the fact that oil tends to flow in the least resistance path which is the bulk oil space between the winding barriers and to the tank. Therefore the oil temperature rise at the top of the winding may be higher than the measured top oil temperature.

2.6.4 Oil Direct Air Force (ODAF)

Figure 2.7 shows a group of conductors surrounded by vertical and horizontal cooling ducts. The heat generated in each conductor must be transferred to the oil to keep the temperature within the limits. The heat flow in the horizontal direction from a central conductor is limited by the similar temperature conductors on either side of it. Therefore the heat can transferred via vertical directions.

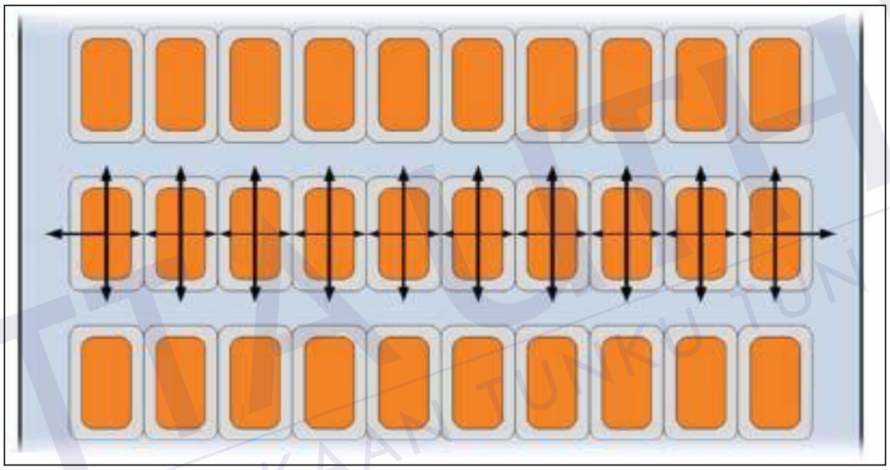

Figure 2.7: Cross section of a disc or helical winding showing heat flow paths

Naturally the oil tends to rise when it become hot. The vertical ducts provide a natural circulation path for this hot oil. This causes the oil flow through the horizontal ducts is much less than that in the vertical ducts and hence poor heat transfer between the conductors and the oil in the horizontal ducts. However the disks depend on the horizontal oil ducts for their cooling. This is the reason why directing the oil through the winding using block washer to occasionally block the vertical ducts is so important in achieving effective heat transfers from the conductors. The oil flow between the discs for a typical directed oil design is shown in Figure 2.8.

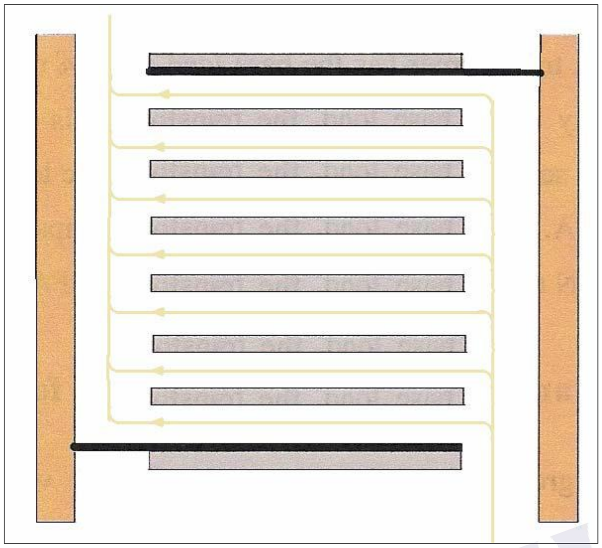

Figure 2.8: Oil flow in a directed flow winding

The transformer with directed forced cooling is called ODAF (Oil Directed Air Forced). A typical arrangement is detailed in Figure 2.8. Where the pumps are used to move the oil into the transformer and block washer are used to direct the oil flows inside the winding. The OD design will result in lower winding gradients than the ON and OF. It also reduces the top oil temperature rise of the winding and therefore the hotspot rise is much reduced compared to the ON and OF cooling mode.

As seen in Figure 2.9, block washer are often added alternately on the inner and outer diameters of the winding. The block washer will direct the oil to flow in horizontal ducts between the discs in order to improve conductor-oil heat transfer.

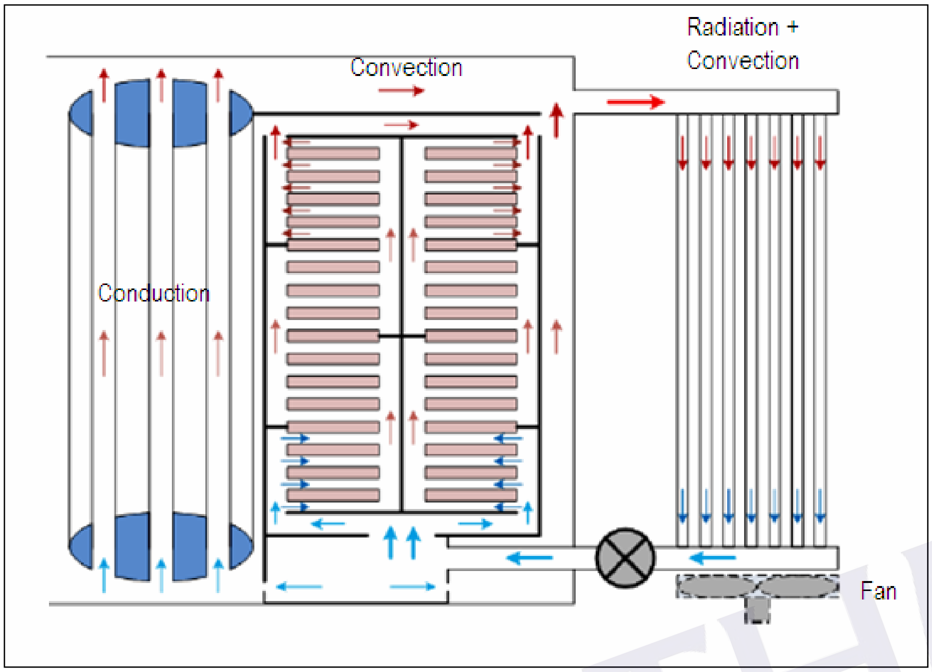

Figure 2.9: ODAF cooling diagram

CHAPTER 3

METHODOLOGY

3.1 Introduction

Methodology includes the following concepts as they relate to a particular discipline of field of inquiry: collection of theories, concept or ideas; comparative study of different approached; and critique of the individual methods. Methodology refers to more than a simple set of methods; rather it refers to the rationale and the philosophical assumptions that underlie a particular study. Proper process guidance will help to monitor and troubleshoot any problem occurred in the middle of the process and also to make sure the project is successfully.

3.2 Project Methodology

This project begins with collecting information regarding the technical issue in order to develop a thermal model of a disk coil using MATLAB. Figure 3.1 illustrate the flow chart that will be used in modeling thermal model of a disk coil.

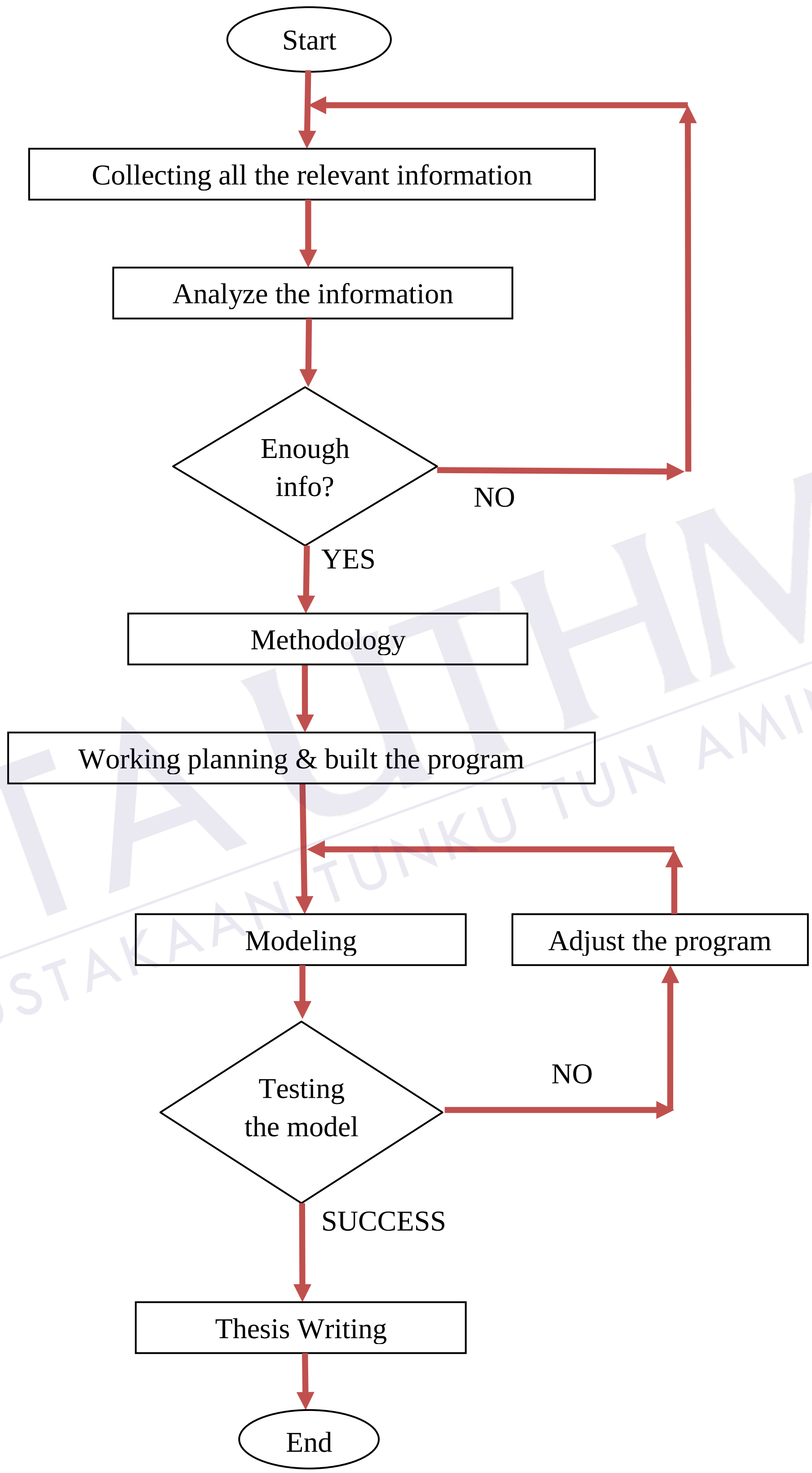

Figure 3.1: Flow chart in modeling thermal disk oil

Figure 3.1 shows the main flow chart in modeling the disk coil from collecting the information until writing thesis. From all the steps, it can be summarize into three main phases, see Figure 3.2 below. Phase I will be done in PS 1 meanwhile Phase II and III planning to be done in PS 2.

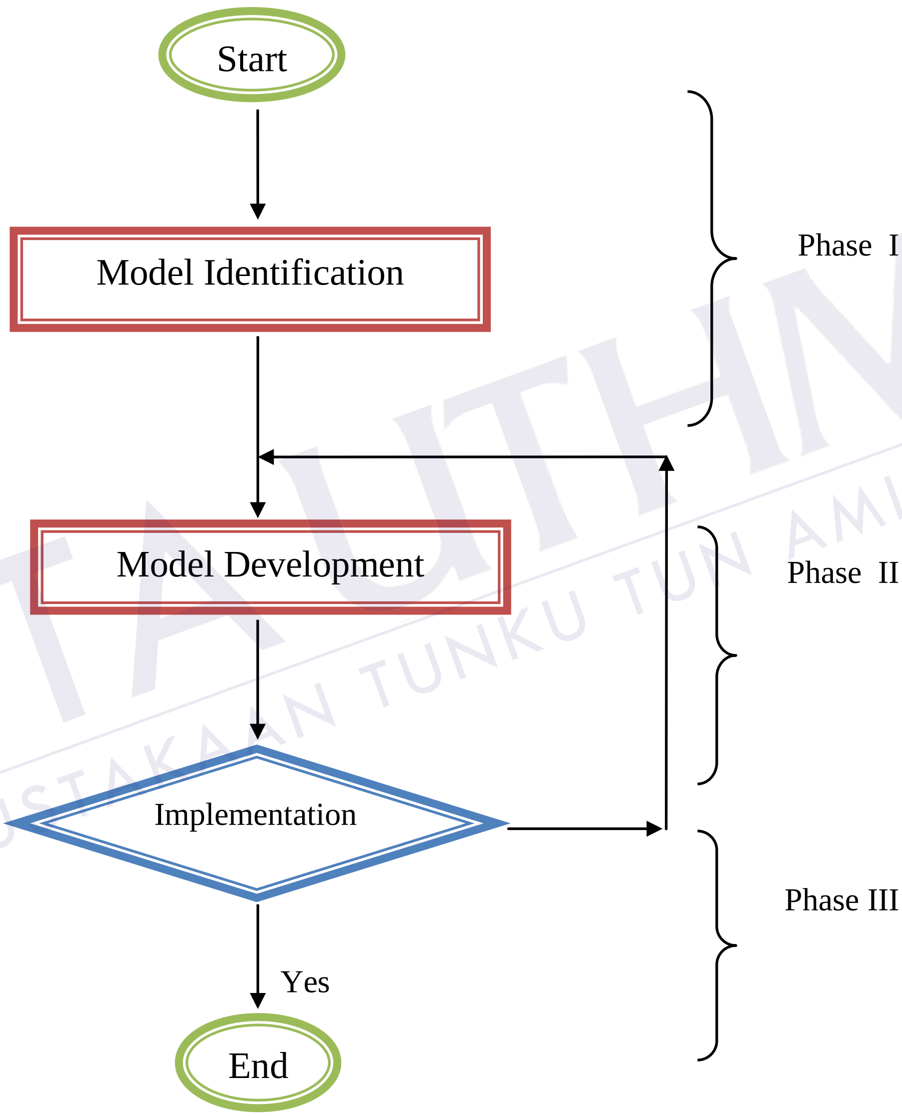

Figure 3.2: Summarized flowchart of modeling thermal model

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