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DISC TYPE TRANSFORMER WINDINGS IN AN OD COOLING MODE WITH DIRECTED OIL FLOW

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ABSTRACT

In this paper, 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 main purpose of this study was to learn about the temperature distributions and oil velocity inside the 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. The study has shown that a geometrical detail approach provided for better design solutions in reasonable time and therefore it has shown its potential for practical use. Both the methods could be combined and used for further investigation.

Keywords: *power transformer, numerical methods, Matlab, oil cooling.*

INTRODUCTION

In transmission and distribution substations power transformer is a major portion of capital investment. 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. 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 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 of other transformer. The temperature affects the insulations. The structure of insulating materials using in transformer, mainly those based on cellulose, which 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 Mont singer 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. 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 in 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.

The benefits 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).

ALGORITHM

Step 1: Initialize the input variables of transformer on hourly basis. This includes load factor K, total losses q (W), ambient temperature $\Delta\theta A$ (^{o}C), OTI reading $\Delta\theta T_O(i)$ (^{o}C) and WTI reading $\Delta\theta HS(i)$ (oC) every hour in a given load cycle.
Step 2: The rated values of rated top oil rise over ambient temperature $\Delta\theta T_O(r)$ (^{o}C), rated hot spot rise over ambient temperature $\Delta\theta HS(r)$ (^{o}C), exponent n & m, weight of oil Moil (kg), current density S (A/mm^2), relative eddy current loss Pe (W), ratio of load loss at rated load to no-load loss R.
Step 3: The different values of final top oil temperature rise $\Delta\theta T_O(u)$ (oC) are determined by placing the values of K, R and n on hourly basis, using Equation (3).
Step 4: The different values of final hot spot temperature rise $\Delta\theta HS(u)$(^{o}C) are determined by placing the values of K and m on hourly basis
Step 5: The top oil time constant TT_O (mins) is determined
Step 6: The hot spot time constant THS (mins) is determined .
Step 7: The top oil temperature rise $\Delta\theta T_O$ (^{o}C) is obtained from the application of Equation (2).
Step 8: The hot spot temperature rise $\Delta\theta HS$ (^{o}C) is obtained from the application .
Step 9: The hot spot temperature θH during a day on hourly basis is calculated.
Step 10: The aging acceleration factor is obtained.
Step 11: The equivalent aging of the power transformer is calculated.
Step 12: The percentage loss of life is obtained from the application.
All the steps illustrated above, may be repeated for a load cycle that contains overload conditions during an hour for a day. The percentage loss of life thus calculated shows the amount of loss of life of transformer that can be used toestimate the reduced loss of life of the power transformer.

BLOCK DIAGRAM

Fig. 1 shows a simplified block diagram of the MATLAB/ Simulink thermal dynamic model of a power transformer.

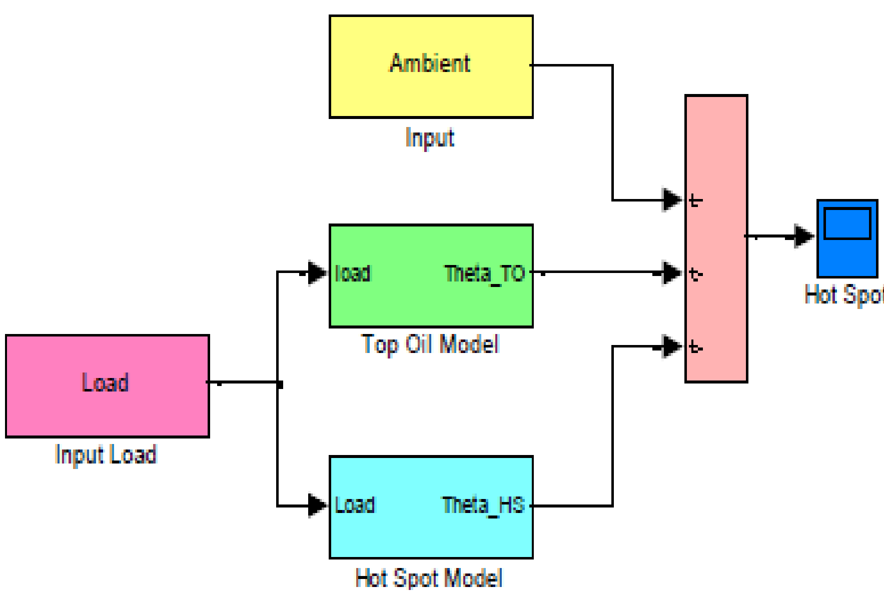
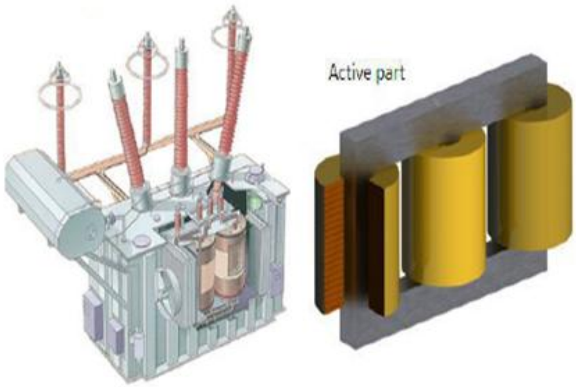


Fig. 1: Block diagram showing the thermal dynamic model of a power transformer

Thermal dynamic model of a power transformer is solved using MATLAB program for determination of the top oil temperature rise $\Delta\theta T_O(t)$ and hot spot temperature rise $\Delta\theta HS(t)$ respectively. At each discrete time interval of 60 minutes, the top oil temperature rise and the hot spot winding temperature rise are calculated. The hot spot temperature θH is the sum of ambient temperature, top oil temperature rise and hot spot temperature rise. The measured hot spot temperature θH results for a 315MVA, 400/33 kV transformer during the given load cycle are then used to determine the residual life of the transformer.

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. For a step-up transformer, the primary coil is low voltage (LV) input and the secondary coil is high voltage (HV) 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.



LIQUID-FILLED 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.

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. 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.

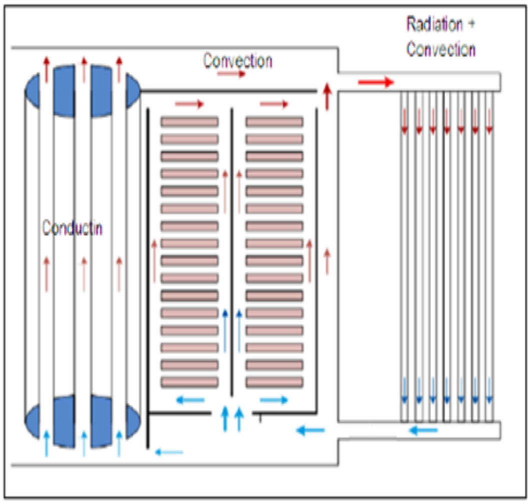
TRANSFORMER COOLING SYSTEM

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 involves three different heat transfer mechanisms which are conduction, convection and radiation. 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.

COOLING ARRANGEMENT

OIL NATURAL AIR NATURAL (ONAN)

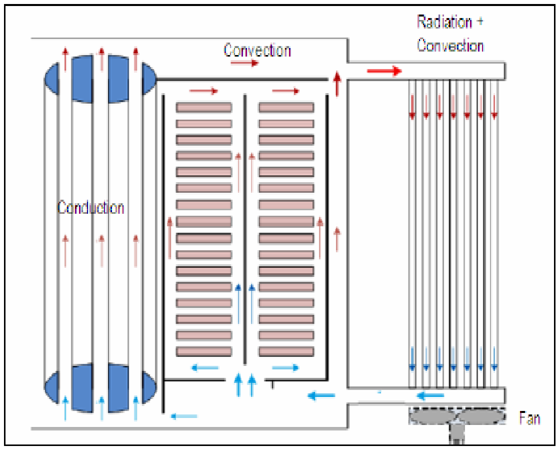
The simple and most common cooling type used in the practice is ONAN. ONAN refers to Oil Natural Air Natural. The ONAN cooling is achieved when the oil flow through the transformer winding is driven by pressure difference between the tank oil and the cooler oil. This pressure difference is due to a temperature 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 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.



ONAN cooling diagram

OIL NATURAL AIR FORCE (ONAF)

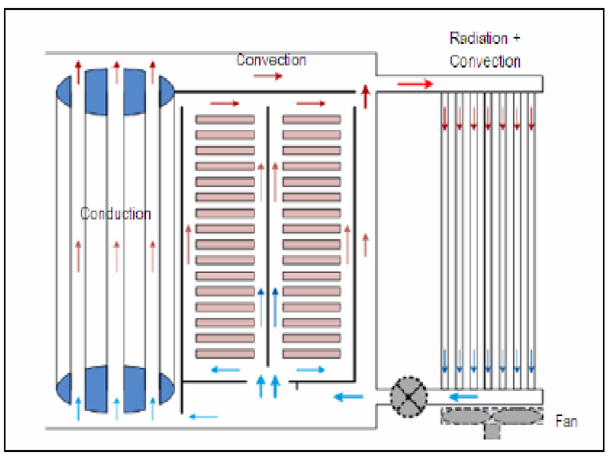
One way to increase the oil circulation rate is by improving the efficiency of the external heat dissipation. This can be done by using the fans to blow air onto the cooling surfaces of radiators. The forced air from the fans takes away the heat from the radiators (cooling) at a faster rate than natural 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.



ONAF cooling diagram

OIL FORCE AIR FORCE (OFAF)

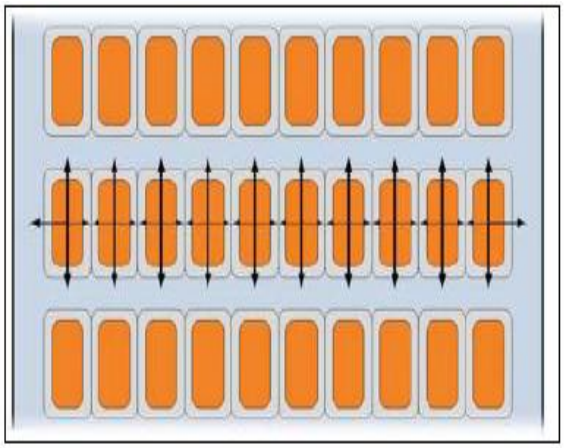
One way to improve the heat dissipation capability is to increase the value of mass flow rate; m and this can be done by using a pump to circulate the oil. Moreover to increase heat transfer rate, fans have to be always operating at the radiators. This improves the heat transfer to the radiators (cooling) 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)



OFAF cooling diagram

OIL DIRECT AIR FORCE (ODAF)

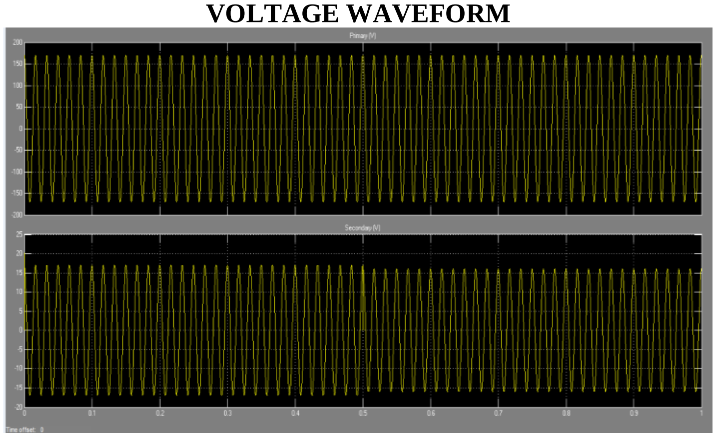
A group of conductors surrounded by vertical and horizontal cooling ducts. The heat generated in each conductor must be transferred to the oil to keep the temperature within the limits. The heat flow in the horizontal direction from a central conductor is limited by the similar temperature conductors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



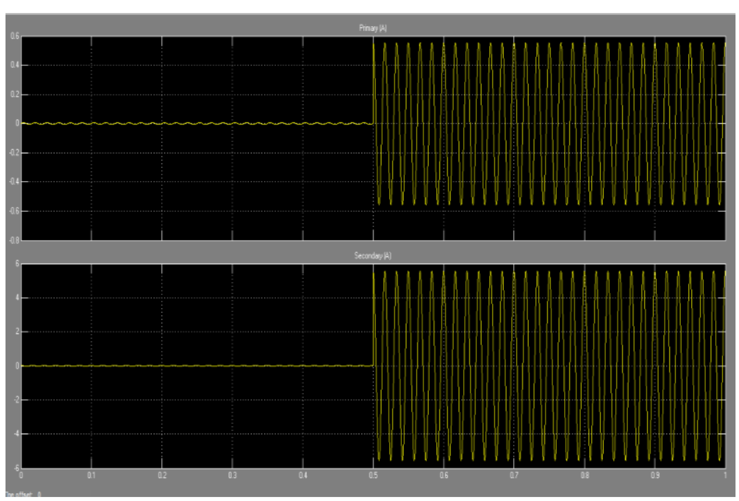
Cross section of a disc or helical winding showing heat flow paths

OUTPUT

VOLTAGE WAVEFORM



CURRENT WAVEFORM



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.

CONCLUSION

Two methods have been used in this study. 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 numerical method result was successful; on all the designs tested. In this methodology, the Transformer oil used in power transformer is combustible. The device used in this transformer is small in size so it reduces the complexity and area occupied by the power transformer. It has greater overload capability. The cost is low compared to other methodologies. Proper guidance will help to monitor and troubleshoot any problem occurred in the middle of the process and also to make sure the project successfully.

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