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Effect of Hot Spot Temperature to the Temperature and Current Distribution in Transformer-Oil Based Nanofluids

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Abstract: Heat transfer coefficient must be in adequate level to ensure the transformer oil is in good condition. The presence of power losses in the core and windings in the form of heat may cause the transformer oil to deteriorate easily. Continuous monitoring of transformer heat distribution could provide useful information on the hot spot temperature (HST) development. Therefore, this paper simulates a 30MVA Oil Natural Air Natural (ONAN) transformer temperature distribution pattern with and without HST. This study aims to observe the effect of three different HST values located at the top of HV winding on the temperature distribution. Next, the correlation between temperature and current distribution with the presence of HST was also included. Mineral oil and transformer oil-based Al_2O_3 nanofluid was used in this study to determine transformer oil with better heat transfer coefficient in convection process. Results show that the presence of HST causes an increased in temperature distribution at the top of the transformer. It is also evident that the usage of transformer oil-based Al_2O_3 nanofluid improves overall heat transfer characteristics of the base fluid. Also, it is found that the temperature and current distribution pattern was similar that indicates a correlation between both parameters.

Keywords: Nanofluids, Hot Spot Temperature, Current Distribution, Temperature Distribution

1. Introduction

Transformers can be considered as the most useful static device that works on the principles of electromagnetic induction. A transformer is an electrical device that transfers electrical power from one electric circuit to another without changing its frequency. In simple words, transformers serve to increase or decrease alternating current (AC) voltage. The transformer core is used to provide a controlled path for the magnetic flux generated in the transformer. The magnetic flux is generated by the current that flows through the windings or also referred to as coils. Historically, the apparatus of

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electromagnetic-induction constructed by Michael Faraday in the year 1831 contained all basic elements of transformers particularly two independent coils and a closed iron core [1]. In the year 1886, William Stanley introduced the first transformer for commercial used. The efficiency of this machine is generally higher than 95% since there is no moving part in the transformer [2].

Large transformers are then introduced with transformer oil-filled that cools and insulates the windings. The transformer oil-filled was introduced to overcome the heat dissipation problem in high rated transformer. This is because the failure of transformer to dissipate heat may reduce the lifespan of transformer [2]. George Westinghouse is the person who immerse the entire transformer in a tank of oil and spaced the laminations in the core so that the oil could circulate by convection among them [1]. Convection process is important in cooling the transformer along with conduction process. Almost all oil immersed type of transformer will undergoe convection process especially for Oil Natural Air Natural (ONAN) and Oil Natural Air Forced (ONAF) transformer.

Nowadays, transformer oil is generally made of highly refined mineral oil. Mineral oil has good electrical and cooling properties that able to cool the windings and insulation of the transformer tank. The mineral oil circulates inside the transformer and absorb heat from the transformer interior via conduction process. Although the convection process occurs inside the transformer, there may be some areas inside the transformer that fail to dissipate heat which causes the heat to be accumulated in the transformer. Hence, if this condition continues for some period of time, it may eventually reduce the lifespan of the transformer radically. Therefore, this paper simulates the heat distribution pattern produced by working transformer in the absence and presence of HST using finite element software.

2. Materials and Methods

2.1 Transformer model

A 30MVA ONAN transformer was modelled in QuickField software to determine the thermal properties of the transformer. A two dimensional (2D) model of transformer is developed based on a transformer cross-sectional shown in Figure 1. It is important to note that the transformer temperature distribution in this work is measured only at the top part of the transformer tank. This is due to the movement of hot oil at the top part of the transformer tank while cool oil moves to the bottom part of the transformer tank as the movement of oil circulating inside the transformer.

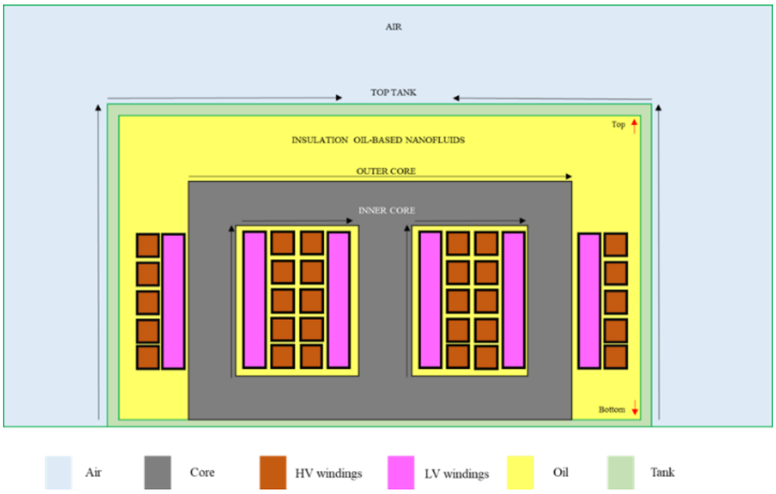


Figure 1: Transformer cross-sectional model

2.2 Simulation Parameters

The material properties of the transformer and their corresponding thermal conductivities listed in Table 1 were inserted manually to the model drawn in QuikField software for simulation as shown in

Figure 2. To evaluate the thermal behavior of nanofluids as cooling mechanism in a transformer, Al_2O_3 nanofluid was chosen as the insulation oil in this study.

Table 1: Transformer simulation parameters

Transformer Parts	Material	Thermal conductivity (W/m*K)
Air	Air	0.0181
Insulation oil	Mineral oil	0.162
Insulation oil	Al_2O_3 nanofluid	0.22109
Core	Silicon Steel	31
Windings	Aluminium 2024-T6	110
Transformer Tank	Steel	43

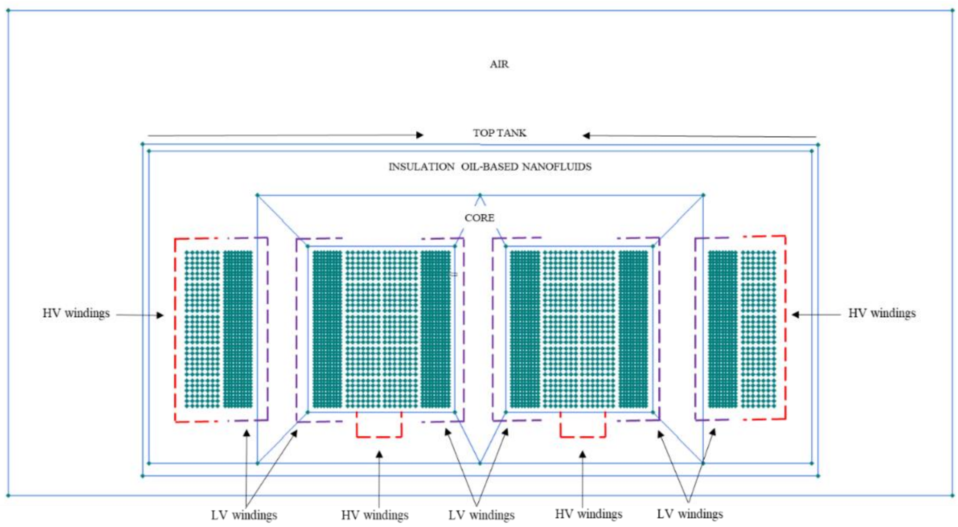


Figure 2: Transformer model with winding using quickfield software

Table 2 tabulates the value of hot spot temperature (HST) that had been used in this works. Different value of HST is used on the HV winding in order to indicate the effect of HST on temperature distribution at the top tank of the transformer.

Table 2: Difference value of HST at the top of HV winding

Transformer condition	Hot spot temperature
Hot spot A (HST A)	100°C [2]
Hot spot B (HST B)	110°C [3]
Hot spot C (HST C)	140°C [4]

3. Results and Discussion

The simulation results for heat distribution of 30MVA transformer at normal working condition (without HST) is illustrated in Figure 3. From the figure, it is proven that the hottest part is found in the winding area compared to other part of the transformer. The heat is believed to be transferred in different ways in order to cool the transformer via conduction, radiation and convection. Conduction process occurs when the heat is transferred to the oil that surrounds the core and windings and it was conducted at the walls of the transformer tank. Meanwhile, convection and radiation process occurs when the heat is transferred to the surrounding [5].

Figure 4 depicts the comparison of temperature distribution between transformer oil-based Al_2O_3 nanofluid and mineral oil under normal working conditions. Based on the observation from Figure 4, there are clear differences in temperature distribution approximately 3.8% between these two types of insulating oils. The highest temperature for both oils recorded was in the middle of the tank. This results supports the theory that the temperature pattern is downward due to the heat being accumulated in the middle of the tank as stated in [6]. Mineral oil recorded the maximum reading of temperature at 58.3°C while transformer oil-based Al_2O_3 nanofluid is at 60.5°C. Worth to mention that the curve graph also shows the minimum temperature distribution for both insulating oil. The minimum temperature for mineral oil is at 56.1°C while 58.3°C for transformer oil-based Al_2O_3 nanofluid. According to [5], the heat is accumulated in the middle of tank thus proving that the middle of the tank recorded the maximum temperature while both sides of the transformer tank recorded the minimum temperature.

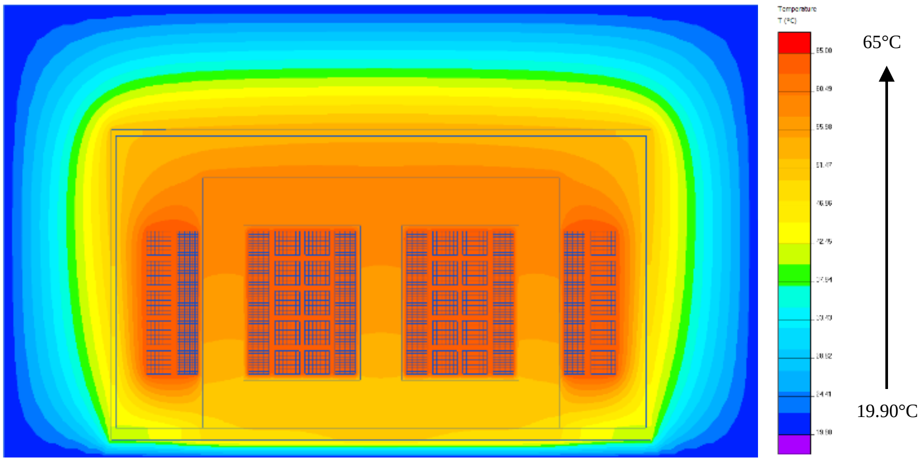


Figure 3: Temperature distribution for 30MVA transformer without HST

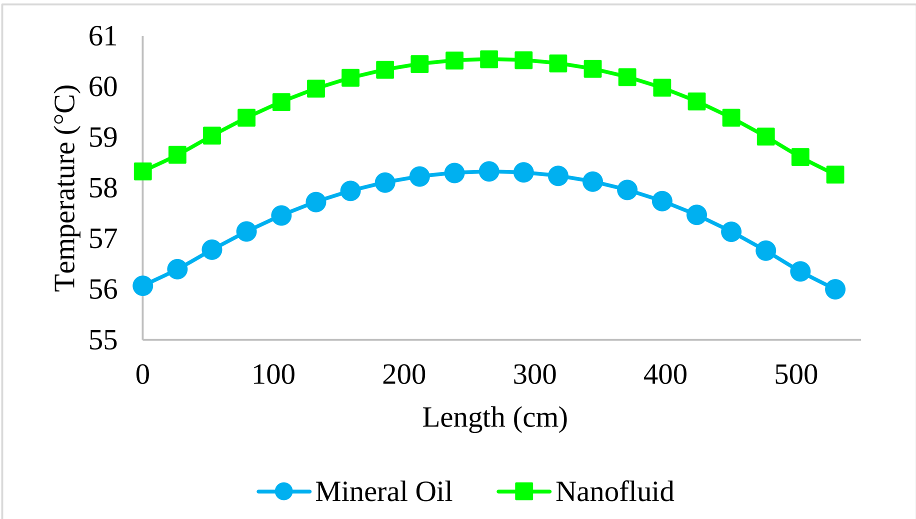


Figure 4: Comparison of temperature distribution between mineral oil and transformer oil-based Al_2O_3 nanofluid under normal working condition

3.1 Temperature distribution for 30MVA ONAN transformer with the presence of hot spot temperature (HST)

With the growing capacity of transformer, losses and heat dissipation was also increased. According to researcher [7], the increment of losses and heat dissipation may be worsened with the presence of HST as it can cause degradation of the winding insulation material. Thus, in order to characterize the thermal behavior of the transformer in full capacity, the simulation is conducted with the presence of three different values of HST which are 100°C, 110°C and 140°C. All of these three HST values had been located only at 1cm from the top of HV winding. Figure 5-7 shows the working of 30MVA ONAN transformer with the presence of HST A, HST B and HST C respectively at the top of HV winding. The reason why all HST value is located at top of HV winding is because there is a significant increase when HST is located at the top of HV winding compared to the bottom of HV winding [2, 6-9].

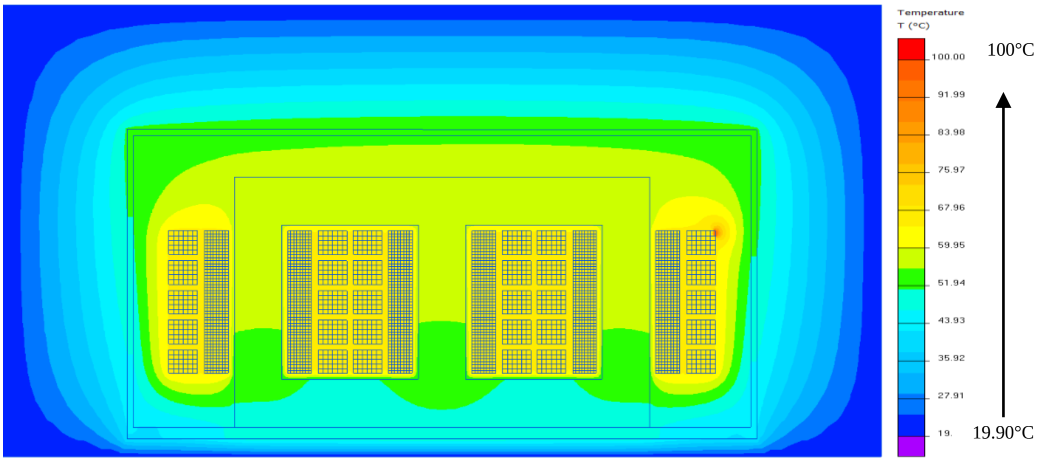


Figure 5: Temperature distribution of transformer with the presence of HST A at the top of HV winding

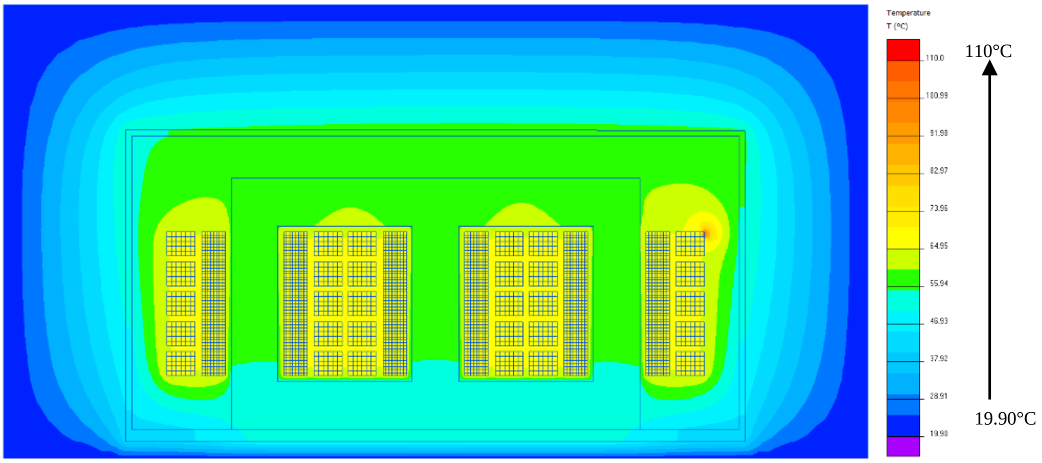


Figure 6: Temperature distribution of transformer with the presence of HST B at the top of HV winding

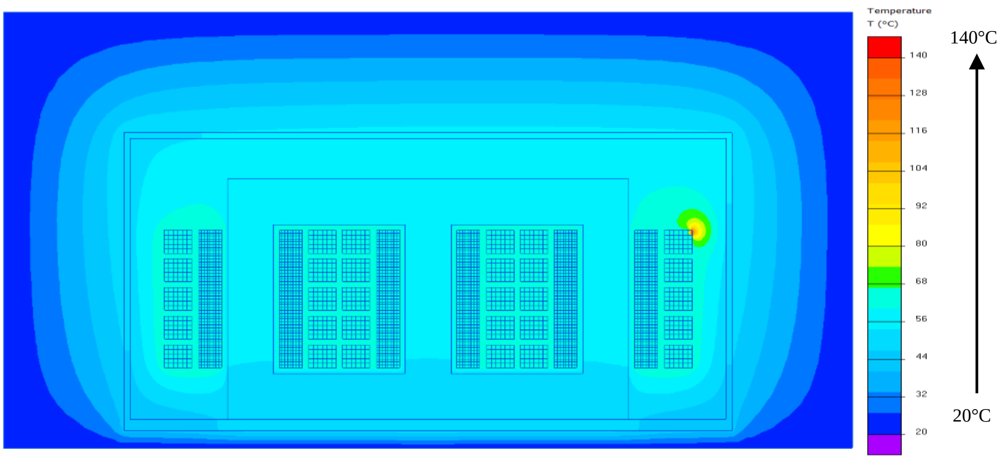


Figure 7: Temperature distribution of transformer with the presence of HST C at the top of HV winding

Figure 8 illustrates the comparison of temperature distribution at the top part of the transformer tank using mineral oil and transformer oil-based Al_2O_3 nanofluid with the presence of all HST. From Figure 8, it can be seen that HST causes an increment in the temperature distribution of the transformer either using mineral oil or transformer oil-based Al_2O_3 nanofluid. It also can be concluded from the current finding that the temperature distribution increases with the increase of HST value. Since the HST C is the highest value in this work compared to HST A and HST B which is at 140°C, the temperature distribution with the presence of HST C had a considerable increase for both insulating oil.

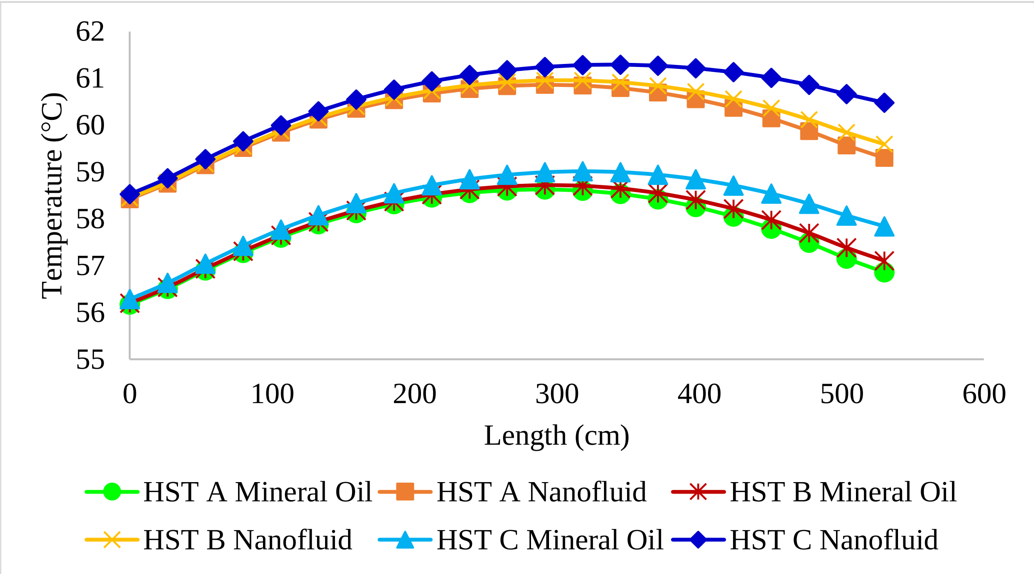
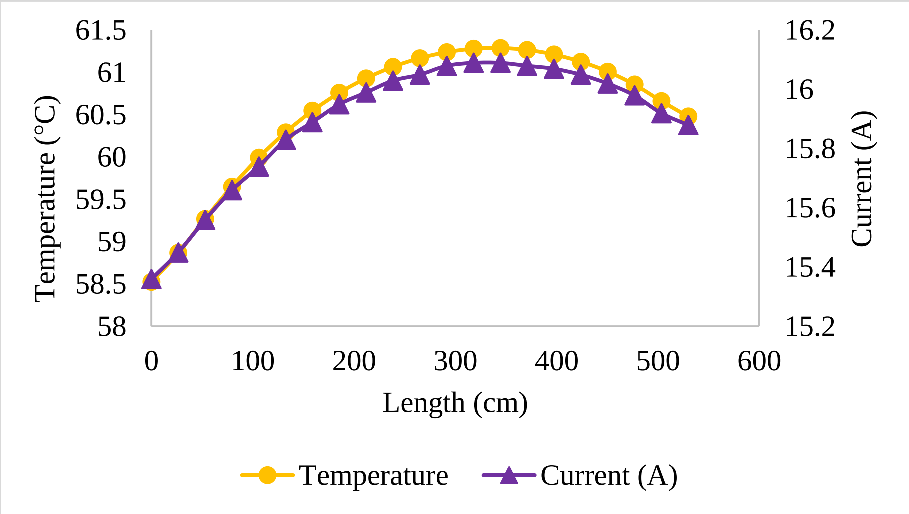


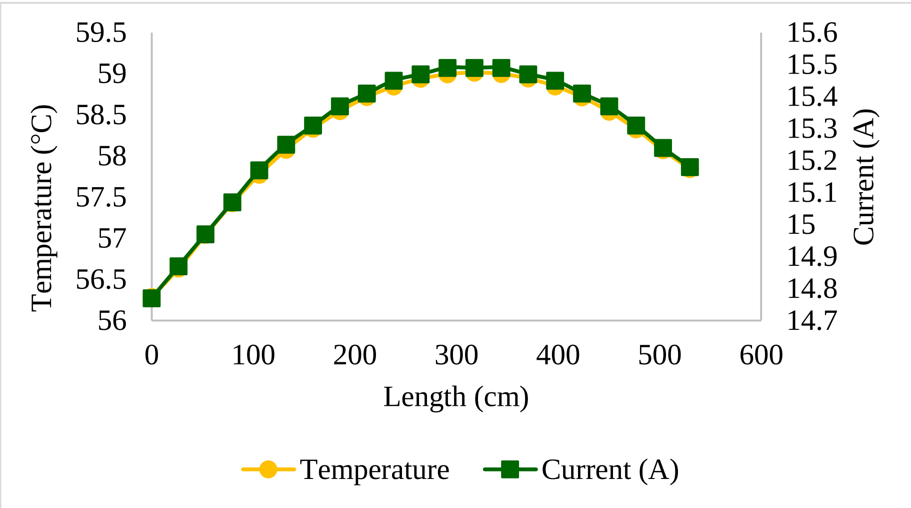
Figure 8: Comparison of temperature distribution at top of transformer tank with the presence of all HST using mineral oil and transformer oil-based Al_2O_3 nanofluid

3.2 Correlation between temperature and current distribution

Since HST C shows the most significant increase in temperature, the correlation between temperature and current distribution was analyzed only with the presence of HST C. Figure 9 represents the correlation between temperature distribution and current distribution at the top of transformer tank with the presence of HST C using mineral oil and transformer oil-based Al_2O_3 nanofluid as insulating oil. As can be seen from Figure 9, the current distribution curve graph can be considered as similar to the temperature distribution at the top of transformer tank. From the presented result, it is observed that current distribution of the transformer is much related with temperature distribution. Thus, it can be concluded that the presence of HST at the HV winding has led to an increase in temperature distribution and also current distribution.



(a)



(b)

Figure 9: Correlation between temperature and current distribution with the presence of HST C using (a) mineral oil and (b) transformer oil-based Al_2O_3 nanofluid as insulating oil.

According to the nameplate rating of transformer in Table 3, it is generally accepted that the full load current normally at 15.75 A for mineral oil transformer. But with the presence of HST at the HV winding in transformer oil-based Al_2O_3 nanofluid, the value of current seems much higher. Table 4 tabulates the reading of current distribution of transformer with the presence of HST A, HST B and HST C at the top of HV winding using mineral oil and transformer oil-based Al_2O_3 nanofluid as insulating oil. It is interesting to note that, when the value of HST exceeds 100°C temperature, the current can reach the maximum value of 16.09 A for transformer oil-based Al_2O_3 nanofluid. Meanwhile, the current distribution in mineral oil transformer still below the full load current level.

Table 3: Nameplate rating of the 30MVA ONAN transformer

Parameter	Value	Unit
Std. specification	IEC 60076-1	-
kVA	300	kVA
Phase	3	-
Frequency	50	Hz
Volts HV	11000	V
(No load) LV	433	V

Amps HV	**15.75**	A
Amps LV	400	A
No Load Loss	0.529	kW
Load Loss	3.024	kW
Temp. rise Oil/Winding	60/65	°C

Table 4: The reading of current distribution of transformer with the presence of all HST at the top of HV winding using mineral oil and transformer oil-based Al_2O_3 nanofluid as insulating oil

Transformer Condition	Hot Spot Temperature (°C)	Current (A) (Mineral oil)	Current (A) (Al_2O_3 nanofluid)
HST A	100°C	15.39	15.97
HST B	110°C	15.41	16.00
HST C	140°C	15.49	16.09

4. Conclusion

This paper presents the simulation of the temperature and current distribution pattern of 30MVA ONAN transformer with three different values of hot spot temperature (HST). Based on the presented results, it can be concluded that the presence of HST at the top of HV winding contributes to the increment of temperature distribution at the top of the transformer tank. As the value of HST become higher, the temperature distribution increases. Moreover, both temperature and current distribution are in an excellent agreement indicating a strong relationship between both parameters with the presence of HST. This study finally concludes that HST does contribute to the overall increase in transformer temperature distribution in both types of insulation oil.

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