ISBN: 978-1-4799-8903-4 2015 IEEE 11th International Conference on the Properties and Applications of Dielectric Materials (ICPADM)

Heat Distribution Pattern of Oil-filled Transformer At Different Hottest Spot Temperature Locations

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***Abstract*— Sustained high temperature on transformer insulation systems is one of the main causes of its accelerated degeneration. Continuous monitoring of transformer heat distribution could provide useful information on intensity and location estimation for hottest spot temperature (HST) development. Furthermore, faults will aggravate the formation of HST inside the transformer tank. However, there is difficulty in measuring and locating HST in many aged in-service transformer because there are no in-tank sensors installed. Thus HST can be monitored by observing the heat distribution pattern in the transformer. Therefore, this paper aims to investigate the effect of HST on the overall transformer temperature distribution and the heat distribution pattern associated with HST. The focus is on the effect of this heat distribution to the surface of transformer tank for condition monitoring purposes. Simulation of mineral oil-filled distribution transformer (ONAN type) was done by using Finite Element Method Magnetism (FEMM) 4.2 where particular interest was on the transformer cross section. Changes of heat dissipation at the inner and outer transformer body tank were analyzed. The results show that the continuous presence of HST increases oil temperatures as well as inner and outer tank surface temperatures. The existence of HST affects the whole temperature distribution pattern inside the transformer. Thus, the transformer HST can be used as indication of potential inside the transformer. The changes of surface heat near to the HST may also be useful in in-service monitoring the transformer condition.**

***Keywords*—oil-filled transformer; transformer hottest spot (HST); transformer faults; transformer heat distribution**

I. INTRODUCTION

Transformer temperature is an important indicator used in transformer monitoring [1]. Every internal transformer fault contributes to the irregularities that may be associated to transformer internal temperature [2]. In their study, [3] have written that because the internal temperature of the transformer affects the external surface temperature, it may be difficult to identify HST at its beginning. However, when transformer temperature profiles are developed, the trends can reveal how temperature changes occurring within and around specific locations can eliminate this difficulty.

Transformer heat distribution normally shows that the temperature at the top of the transformer is higher than temperature at the bottom of the transformer [4]. Therefore, when the temperature gradients transformer is plotted from top to bottom, it will have a gradually decrease. This makes it appropriate to use oil temperature at the top of the transformer as estimation for the HST reading inside the transformer [5].

Transformer HST intensity and estimated location can be determined by monitoring the heat distribution. In their publication, [6] has presented that HST in transformers will normally be caused by overloads or faults and thus occurs around the transformer winding and assembly [6]. Furthermore, [7] have presented that harmonic current can also cause overloads and temperature increase.

This paper uses Finite Element Method Magnetism (FEMM 4.2) software to analysis temperature rise caused by HST around the transformer winding. Furthermore, the paper investigates the effect of different HST locations on the overall transformer heat distribution pattern. The HST simulation was done on 100 kVA mineral oil filled ONAN. A cross section of the transformer is developed from [8] and shown in Fig.1. Thus it is worth mentioning that the study focuses on the effect of different HST locations on heat distribution around the outer surface of transformer tank for condition monitoring purposes.

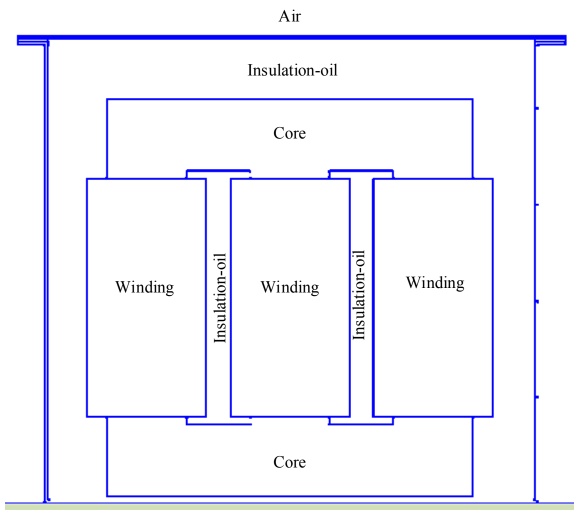


Fig. 1. Transformer cross-section [8]

II. SIMULATION

A. Properties

The materials ascribed to the transformer parts used in this simulation and their corresponding thermal conductivities are listed in Table I.

TABLE I. TRANSFORMER SIMULATION PROPERTIES

Transformer Parts	***Material***	***Thermal Conductivity (W/m*K)***
Air	Air	0.0181
Insulation-oil	Mineral oil	0.162
Core	Silicon steel	31
Windings	Aluminum	171
Transformer body	Steel	43
Ground	Concrete	1

B. Measurements

Four HST locations were chosen in this study identified as HST1, HST2, HST3 and HST4 which located at 22 cm, 35 cm, 48 cm, and 60 cm respectively. The HSTs, measured from top to bottom of transformer, are shown in Fig.2. The size and temperature for each HST are fixed at 1cm and 100 °C respectively.

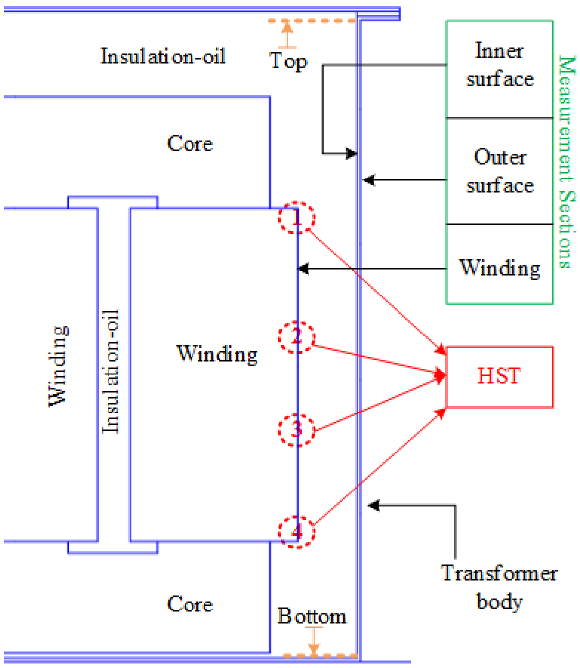


Fig. 2. Transformer cross-section

To verify any changes in temperature that occurs due to existence of HST in the simulated 100 kVA transformer, initial simulation was done at zero HST condition. Under this initial condition, the top-oil temperature obtained was 60.58 °C; which is similar to the top-oil temperature of 60 °C given on the data plate of the transformer. Fig.3 shows the result of temperature density plot in normal condition.

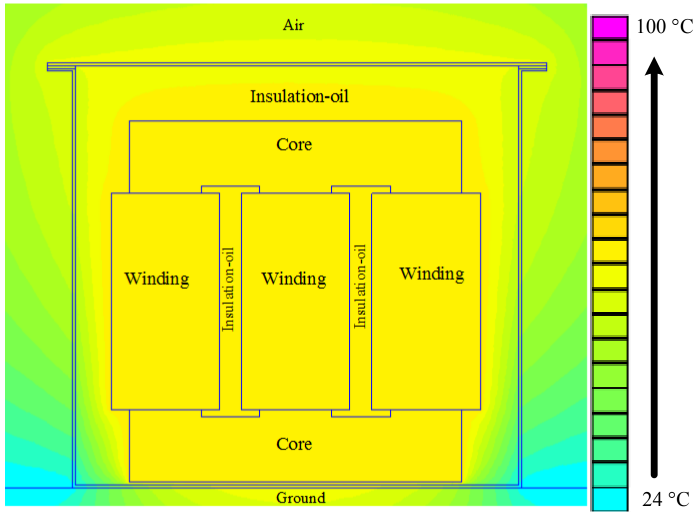
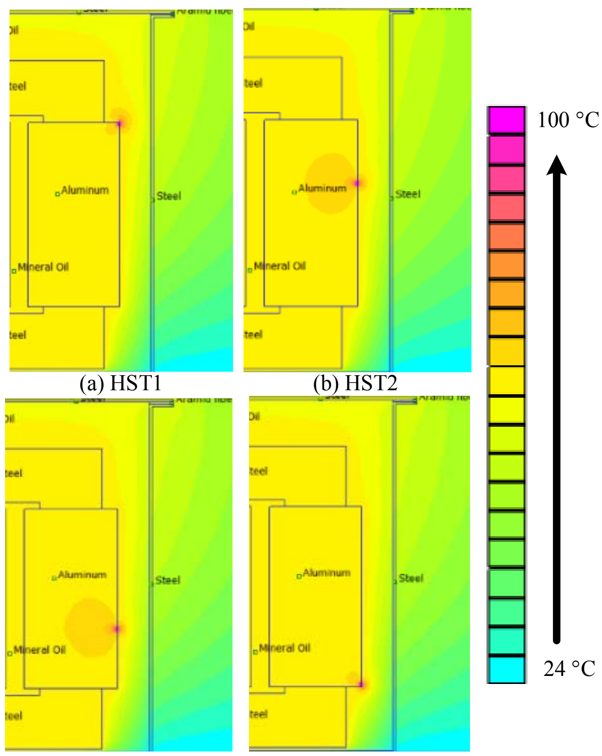


Fig. 3. Normal condition temperature density plot for validation

III. HEAT DISTRIBUTION RESULTS

When HST was introduced in the four locations identified earlier, the simulation results give the temperature density plots that are shown in Fig.4. From the color bar range shown, it is apparent that the heat distribution pattern for each HST is different.



(a) HST1 (b) HST2

(c) HST3 (d) HST4

Fig. 4. Transformer temperature density plot results for each HSTs

For example, Fig.4 (a) and Fig.4 (d) shows that HST heat distributions has little effect to the winding; thus heat distribution of HST1 in Fig.4 (a) has more influence to the insulation-oil compared to HST4 in Fig.4 (d). In contrast, HST2 and HST3 in Fig.4 (b) and Fig.4 (c) heat distribution clearly shows higher influence on the winding than the insulation-oil.

Fig.5 shows the temperature difference with and without the existence of HST at the winding, inner surface and outer surface of transformer body tank. HST1 to HST4 plot whether at the winding, inner surface or outer surface of transformer are uniquely different from each other. From the plot, HST1 has the highest temperature difference compared to other HSTs. Meanwhile, temperature differences for the inner and outer surface of transformer body tank are almost the same.

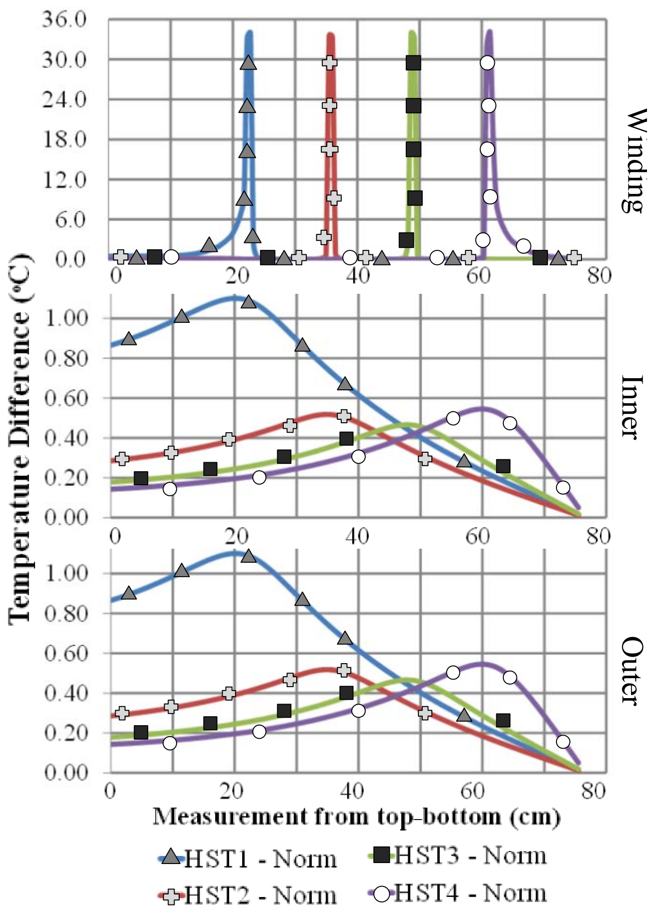


Fig. 5. Transformer temperature difference at each HSTs location seen from winding, inner and outer surface

Fig 6 shows the temperature plots of the inner and outer surfaces of the transformer tank and the result shows that the temperatures at HST locations on the winding are significantly different from those at the inner and outer surfaces of the transformer. Although, the temperature (100 °C) and size (1 cm) of all HSTs are same, the distribution pattern of the HST located at the upper part of transformer winding have greater impact on temperature of top transformer compared to other HSTs located below. This shows that outer and inner surface tank temperatures can be used to estimate the location of HSTs; especially when the HST exists around the upper windings.

Table II shows the percentage temperature increase of the outer surface temperature for HST1 to HST4 measured from top to bottom of transformer as in Fig.2. It also shows the estimated HST locations and pattern seen at the outer surface compared to the exact location of HST at the transformer winding.

TABLE II. ESTIMATED LOCATION AND DISTRIBUTION PATTERN OF TRANSFORMER OUTER SURFACE BODY TANK

HST exact location (cm)	**Percentage Increase of outer surface temperature**				
	Length measured from top-bottom (cm)	***HST1 (%)***	***HST2 (%)***	***HST3 (%)***	***HST4 (%)***
	0	1.53	0.50	0.31	0.25
	18	1.98	0.68	0.43	0.34
	19	1.99	0.70	0.44	0.35
	20	2.00	0.72	0.45	0.36
	21	2.00	0.73	0.46	0.37
HST1	***22***	**1.99**	0.75	0.47	0.38
	23	**1.97**	0.77	0.48	0.38
	24	1. 94	0.79	0.49	0.39
	25	1.90	0.81	0.51	0.41
	26	1.86	0.83	0.52	0.42
	32	1.56	0.97	0.62	0.50
	33	1.51	0.98	0.64	0.51
	34	1.46	0.99	0.66	0.53
HST2	***35***	1.41	**1.00**	0.68	0.55
	36	1.37	**1.00**	0.71	0.57
	37	1.32	0.99	0.73	0.59
	38	1.30	0.98	0.75	0.60
	39	1.26	0.96	0.77	0.62
	45	1.03	0.81	0.94	0.77
	46	1.00	0.79	0.96	0.81
	47	0.96	0.76	0.98	0.84
HST3	***48***	0.93	0.74	**0.99**	0.87
	49	0.90	0.71	**0.99**	0.91
	50	0.87	0.68	0.99	0.95
	51	0.84	0.66	0.98	0.99
	52	0.81	0.64	0.96	1.03
	58	0.63	0.50	0.78	1.31
	59	0.62	0.49	0.76	1.32
	60	0.59	0.47	0.72	1.36
HST4	***61***	0.56	0.44	0.69	**1.37**
	62	0.53	0.42	0.66	**1.38**
	63	0.50	0.40	0.62	1.37
	64	0.48	0.38	0.59	1.34
	65	0.45	0.35	0.55	1.30
	76	0.06	0.05	0.07	0.19

Table II has shown that the highest percentage temperature increase of 2 % was recorded at HST1. It was further observed that the location of HST1 identified from the transformer outer surface was displaced from 21 – 23 cm (as was initial anticipated) to 22 – 23 cm (an apparent location). Therefore it can be said that the heat projected at HST1 will be located above the transformer winding; which is against the initial projection.

The temperature distribution pattern of HST2 differ from that of HST1 as shown in the Table II and the projection of the heat distribution for HST2 was equal to the upper and lower sections of the HST exact location. Thus the estimated location of HST2 at approximately 35-36 cm was accurate.

HST3 heat distribution pattern was noticed to be decreasing to that at the bottom of the transformer. It was therefore no wonder that the percentage increase of HST3 was the lowest at 0.99 % rises above the normal condition. However the estimated location of HST3 was slightly different from the apparent location; estimated location was between 48 and 50 cm while the exact location was between 48 and 49 cm.

Meanwhile, the heat distribution pattern of HST4 was in contrast to that of HST1 because the percentage increase in temperature difference was half of HST1. The percentage increase of temperature at HST4 was 1.38 % above normal condition. This temperature rise was the second highest percentage increase in the transformer. The estimated location of HST4 from the outer surface was also slightly different from the apparent location observed; estimated location was between 61 cm and 62 cm while the observed was 62 cm.

IV. CONCLUSION

This article presents the heat distribution pattern of oil-filled transformer at different HST locations and the increment of temperature at the outer wall tank. It also shows that there is no effect on top-oil temperature when HST is located at the bottom part of winding compared to when HST is at the top of the winding. From the temperature density plot, it can be concluded that HSTs located at the upper section of the winding have heat distribution profile that increases towards the temperature of the upper section of the transformer. Contrarily, the HST located at the bottom of the winding has heat distribution profile that decreases towards the low temperature of the bottom of the transformer.

It has also been shown that the estimation of HST location differs from the exact location when the HST exists at the upper part of winding. This study also noted that when HSTs occurs, there is increasing temperature on the outer wall tank of the transformer. Thus the percentage heat on the outer surface will increase by 1 to 2 % above normal condition. Accurate and precise sensors can be used to detect these changes. This study finally concludes that HST does contribute to the overall increase of transformer temperature and the heat distribution around the HST location and this can give a better view of HST formation.

ACKNOWLEDGMENT

This work was financially supported by Universiti Teknologi Malaysia (UTM), with the use of its facilities and by awarded a research university grants (GUP) under vote number 08H65, Ministry of Science, Technology and Innovation (MOSTI) under eScienceFund grant vote number 4S101, and Ministry of Education (MOE) under FRGS grant vote number 4F515.

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