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Enhancement Cooling System of Three-Phase Distribution Transformer (250 kVA) by using Thermosyphon

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Abstract: In this research, the enhancement cooling of the electrical distribution transformer 250 kVA has been studied experimentally by using thermosyphon method. Ten thermosyphon were proposed to enhance the cooling performance to the electrical transformer. Thermosyphon was made from cooper tube with outer diameter of 22.3 mm and thickness of 0.8 mm with evaporator and condenser length were 23 and 35 cm, respectively. The angle of inclination of the thermosyphon condenser section was 45°. A 40 aluminum fins were installed on the outer surface of the thermosyphon condenser section. The working fluid used was the distilled water with filling ratio of 50%. The comparing result for the electrical transformer with and without thermosyphon at partial load. The percentage improvement in the transformer efficiency, transformer insulation life, oil temperature, primary winding temperature secondary winding temperature and the oil heat power and primary and secondary resistance were 0.15, 82.7, 2.98, 4.376, 5.78 , 4.7, 34.9 and 41.2%, respectively. The enhancement percentage of heat transfer coefficient for high voltage top and below are 8, 6.66%, respectively and low voltage top and below are 10, 10.15, respectively and transformer tank top below and fin are 1.4, 2.9 and 1.49%, respectively.

Key words: Inclination thermosyphon, electrical transformercooling, efficiency, per unit life of insulation, primary temperature (HV), oil temperature, heat transfer coefficient, secondary temperature (LV), primary and secondary resistance, heat of oil (W)

INTRODUCTION

An electrical transformer is one of the most expensive components and play important role in an electricity system it is static machine it has two or more windings, electrical transforms transfer alternating voltage and current from system into another system of voltage and current usually of different values and at the same frequency (Susa, 2005).

According to research of electrical transformer, there are the losses of the electrical transformer which cause heat generation in the core and coils parts. The main problem in the electrical transformer is hot spot (Rashid, 2011), the most critical parameters in winding of the transformer is the hot spot which is determining the life of the insulation for the transformer for this reason this heat must be taken away from the electrical transformer. So, the high ageing occurs at the point of hot spot which experiences the maximum value of temperature. Hotspot temperature depends on ambient temperature and instantaneous load cooling model and also winding design (Dofan and Ali, 2011).

Many studies have been investigated to improve electrical transformer cooling system such as Rahimpour *et al*. (2007) built an experimental model to measure the temperature distribution inside a disk type winding cooled by natural convection which included block washers. They found that at using fewer numbers of disks in each section between two sequential block washers the maximum temperature of study decrease. Another researcher Patel *et al*. (2010) improved thermal conductivity of fluid via. added nanoparticles. Obtained results showed that the thermal conductivity was increased with decreasing the size of particle and with decreasing the volume fraction. Amoiralis *et al*. (2012) investigated a several benefactress designs for cooling system of electrical transformer (Onan). The objective of the present investigation is to study experimentally the cooling the electrical transformer oil by using thermosyphon.

MATERIALS AND METHODS

Experimental procedure: Figure 1 shows the electrical transformer with and without using thermosyphon which used in this investigation two thermal tests were performed on the electrical transformer the first test was without using thermosyphon and the second test was with using thermosyphon. In both tests the reading were taken from 8:30 am to 3:30 pm and the

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(a) (b)

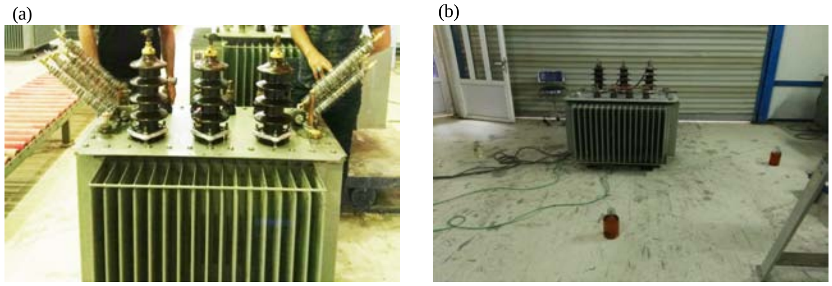

Fig. 1: The electrical transformer thermal test: a) Without thermosyphon and b) With thermosyphon

Fig. 2: Thermosyphon with 40 fins at 45° angle of inclination

Fig. 3: Manufacture steeps of fins

maximum temperature of the electrical transformer oil was recorded at the end of the test. In case of the enhancement cooling to the electrical transformer oil by using ten thermosyphon. The thermosyphon fabricated from a cooper pipe with the outer diameter of 22.3 mm and thickness of 0.8 mm. The experiments were carried out by using ten thermosyphon with evaporator and condenser lengths of 23 and 35 cm, respectively with an inclination angle of 45° shows in Fig. 2 and 3. Manufacture steeps

Fig. 4: Drill the top plate of the transformer

of fins the fined thermosyphon which used in this investigation and 40 aluminum fins was used in this research with inner and outer diameters of 22.2 and 45 mm, respectively and a thickness of 0.3 mm. The lip for the fin was extended to increase and enhance the contact area between the fin and pipe of the thermosyphon. Figure 4 shows drill the top plate transformer. Figure 5 shows fixing thermosyphon on top cover. All the parts of the electrical transformer were placed in the oven for 16 h and at temperature of 120°C to remove the humidity as shown in Fig. 6. The last shape of transformer after using thermosyphon as shown in Fig. 7. All the test measurements were taken in the Al-Waziriya company for electrical industries on the 3 phase distribution electrical transformer (250 kVA, core type and oil immersed) at partial load.

Fig. 5: Fixing thermosyphon on top cover

Fig. 6: The active part in oven

Fig. 7: The last shape for transformer with thermosyphon

Calculations: The efficiency of electrical transformer will be calculated to evaluate the transformer performance by the following equations. From the primary and secondary winding Resistance (R_1 and R_2) that found from experimental work can be calculated copper loses. Copper losses primary winding for three phases (Azeez, 2016):

$$Pc_1 = 3*I_1^{2*}R_1\ (W) \quad (1)$$

Copper losses secondary winding for three phases:

$$Pc_2 = 3*I_2^{2*}R_2\ (W) \quad (2)$$

Total copper loss is:

$$Pc_T = (Pc_1+Pc_2)*1.05\ (W) \quad (3)$$

Where added 5% to account for stray losses:

$$\text{Iron losses} = \text{Weight of transformer}^* \text{ specific power}^*1.07 \quad (4)$$

Specific power for this transformer = 1.1 W/kg. Where added 7% to account for stray losses. Total transformer losses = (copper loses+iron loses):

$$P_T = Pc_T+Pi_T\ (W) \quad (5)$$

The efficiency of transformer at unity power factor (Jabbar, 2013):

$$n = \frac{s}{s+P_t} \quad (6)$$

the s, capacity of transformer = 250 (kVA). The thermal performance tests of thermosyphon were performed and the rate of heat transfer (Q_{oil}) for the oil was calculated by the following Eq. 7 (Ozsoy and Corumlu, 2018):

$$Q_{oil} = mc_p\Delta \quad (7)$$

Where:
m, c_p = The mass and specific heat of oil
ΔT = Temperature difference

Oil specific heat can be calculated by following Eq. 8 (Roberto, 2018):

$$C_p = 807.163+3.58*T \quad (8)$$

T is the oil temperature (K). Percentage decrease in the heat of oil equal to:

$$\text{Percentage decrease in the heat of oil} = \left(Q_{\text{without thermosyphon}}-Q_{\text{with thermosyphon}}\right)/Q_{\text{without thermosyphon}} \quad (9)$$

To calculate the heat transfer coefficient of transformer (coils and tank) it has been calculated by the following Eq. 10 (Azizi *et al*., 2011). The Rayleigh number based on the constant heat flux is formulated as follows:

$$Ra_{hf} = \frac{g.\beta.\rho^2.q_w.c_p.\delta^4}{k^2_{oil}.\mu} \quad (10)$$

Where, δ is:

$$\delta = \frac{b-a}{2}\,(m) \quad (11)$$

b = Outer diameter of coils
a = Inner diameter of coils

The equation of Nusselt number for the upper annular of coils (flow laminar) is:

$$Nu_m = 0.61Ra_{hf}^{0.2} \quad (12)$$

And for the lower annular of coils (laminar flow) is:

$$Nu_m = 0.35Ra_{hf}^{0.2} \quad (13)$$

The mean film coefficient for each case is:

$$h_m = \frac{Nu_m.k_{oil}}{\delta}\,\left(W/m^2.K\right) \quad (14)$$

The heat transfer convection at the outer surfaces of the tank of transformer is classified at three sections. At the top cover of the tank of the transformer tank, the equation Nusselt number is (Gastelurrutia *et al*., 2011):

$$Nu_{Lid} = 0.865Ra_L^{0.25} \quad (15)$$

At the bottom of transformer tank:

$$Nu_{base} = 0.27Ra_L^{0.25} \quad (16)$$

And at the vertical fin:

$$Nu_v = 1.22\left(0.6108Ra_y^{0.2364}\right) \quad (17)$$

$$Ra_L = \frac{g\beta\left(T_s-T_a\right)L^3}{\alpha\nu} \quad (18)$$

$$Ra_y = \frac{g\beta\left(T_s-T_a\right)y^3}{\alpha\nu} \quad (19)$$

L is the length of base and lid = 0.89 m (from the design sheet from Alwazyria), Y is the height of fins = 0.5 m (from the design sheet from Alwazyria).

RESULTS AND DISCUSSION

Figure 8-15 show the results of the laboratory tests of the electrical transformer 250 kVA with and without use enhancement cooling by thermosyphon from 7:30 am to 3:30 pm at partial load.

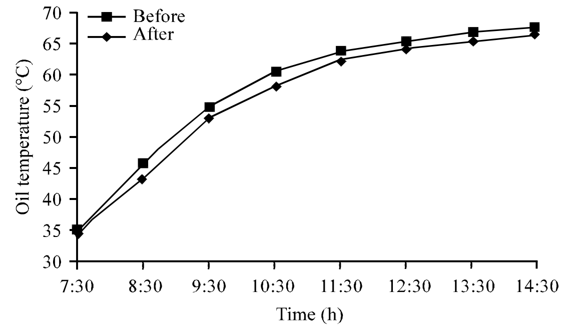

Fig. 8: Oil temperature with time with and without thermosiphon

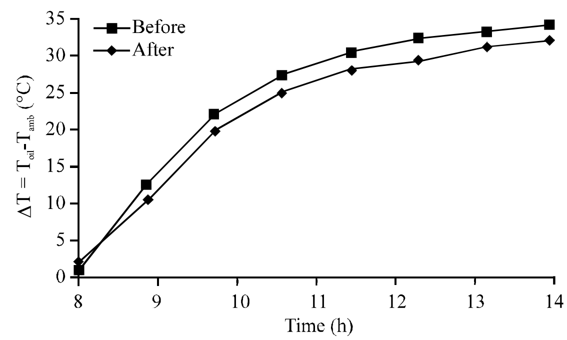

Fig. 9: Oil temperature rise with time with and without thermosiphon

Figure 8 shows the average electrical transformer oil temperature at ambient temperature distribution with respect to test time and the average oil temperature in the case of using thermosyphon increased more than that without using thermosyphon. This was due to more heat dissipation from the electrical transformer to the surrounding in the case of using thermosyphon.

Figure 9 shows the average oil temperature rise which equal to the temperature difference between the top oil temperature inside the electrical transformer and the outside average oil temperature at ambient temperature with respect to test time and shows that the temperature rise in the case of use enhancement cooling by thermosyphon was lower than that without use thermosyphon. This was due to additional heat dissipation by using the thermosyphon. Figure 10 and 11 show that the oil temperature at the top and below high voltage winding side with respect to the test time for both cases with and without using thermosyphon. Figure shows that the oil temperature in case of using thermosyphon was lower than that without using the thermosyphon due to increasing the heat dissipation by the thermosyphon. Figure 12 and 13 show that the oil temperature at the top and below low voltage winding side with respect to the test time for both cases with and without using thermosyphon. Figure shows that the oil

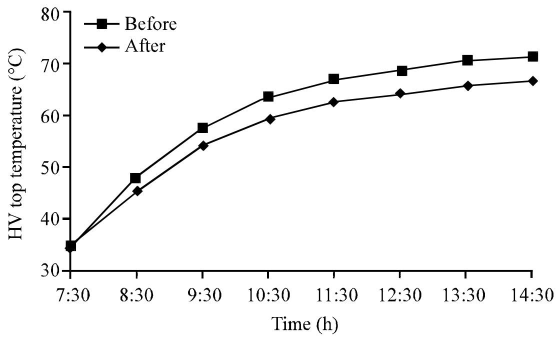

Fig. 10: High voltage side top oil temperature with time with and without thermosyphon

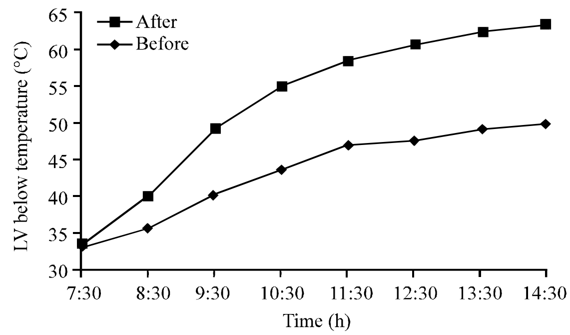

Fig. 13: Low voltage side below oil temperature with time with and without thermosyphon

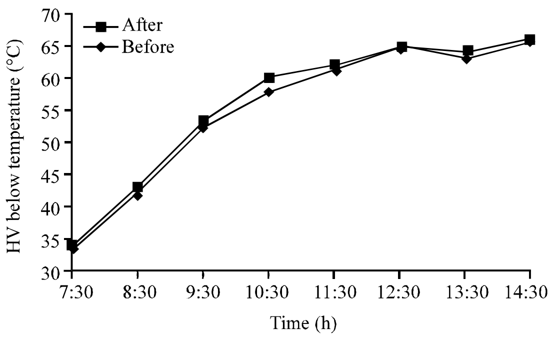

Fig. 11: High voltage side below oil temperature with time with and without thermosyphon

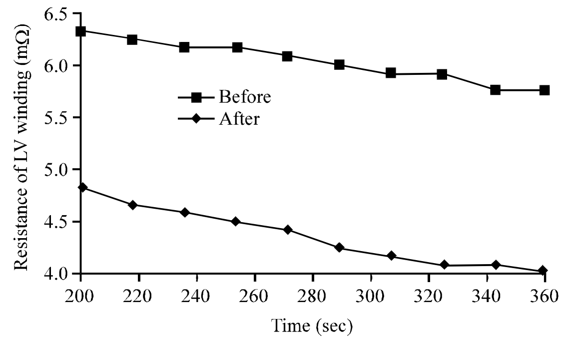

Fig. 14: Resistance of low voltage with time with and without thermosyphon

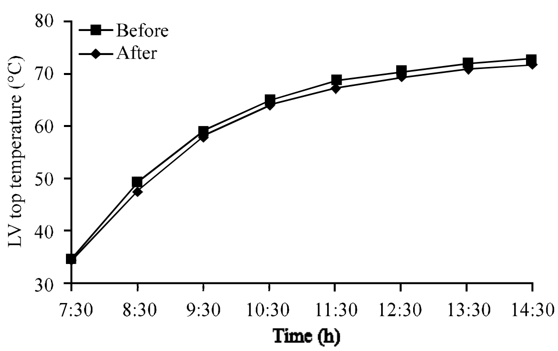

Fig. 12: Low voltage side top oil temperature with time with and without thermosyphon

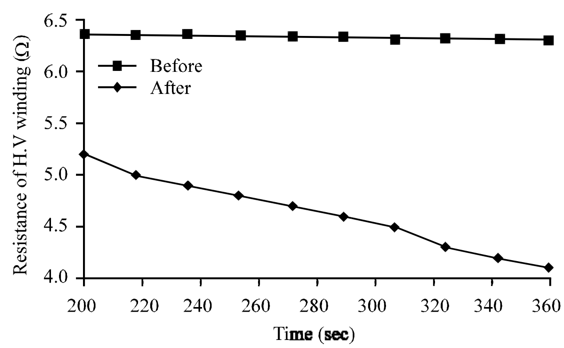

Fig. 15: Resistance of high voltage with time with and without thermosyphon

temperature in case of using thermosyphon was lower than that without using the thermosyphon due to increasing the heat dissipation by the thermosyphon. Figure 14, 15 show primary and secondary winding resistance before and after modification the primary winding the maximum difference before and after use thermosyphon was 2.2 mΩ while in secondary winding resistance was 2.1 Ω. Also, the figures show that the oil temperature difference increase. This because the thermosyphon was design to working at operation temperature between 80 and 85°C which it gives a better thermal performance at this temperature.

These lower temperatures were gave a better performance for the electrical transformer with using the enhancement cooling by using thermosyphon. Where the percentages improvement in the transformer efficiency, transformer insulation, oil temperature, primary winding temperature, secondary winding temperature, primary winding resistance, secondary winding resistance and

Table 1: Primary and secondary winding resistance

Parameters	Without thermosyphon	With thermosyphon	Improvement (%)
Efficiency	98.39	98.54	0.15
Per unit life of insulation	$2.8*10^{19}$	$5.12*10^{19}$	82.7
Oil temperature	68.3	66.3	2.98
Primary temperature (HV)	74.27	71.02	4.376
Secondary temperature (LV)	79.6	75	5.78
Primary winding resistance	6.3	4.1	34.9
Secondary winding resistance	5.1	3	40.0
Heat of oil (W)	571.68	538.97	5.7

Table 2: The heat transfer coefficient of coils and tank before and after improvement

Parameters	Heat transfer coefficient for top	Heat transfer coefficient for below	Heat transfer coefficient for fin
HV (before)	69.0000	39.0000	-
HV (after)	63.4489	36.4000	-
LV (before)	94.7900	54.5400	-
LV (after)	85.2440	49.0434	-
Tank (before)	4.20000	34.8900	6.7
Tank (after)	4.14000	34.0000	6.6

Table 3: The enhancement percentage of heat transfer coefficient for coils and tank before and after improvement

Parameters	Heat transfer coefficient for top (%)	Heat transfer coefficient for below (%)	Heat transfer coefficient for fin (%)
HV	8	6.66	-
LV	10	10.15	-
Tank	1.4	2.90	1.49

heat power of the oil (difference temperature rise of the oil) are 0.15, 82.7, 2.98, 4.376, 5.78, 34.9, 40 and 5.7%, respectively. These percentage improvements for the electrical transformer increased if the load of the electrical transformer increased as mentioned above.

The efficiency of transformer, per unit life of insulation, oil temperature, primary and secondary winding temperature, primary and secondary winding resistance and the heat of oil before and after improvement are summarized in Table 1. The heat transfer coefficient of coils and tank before and after improvement are summarized in Table 2. The enhancement percentage of heat transfer coefficient for coils and tank before and after improvement are summarized in Table 3.

CONCLUSION

The following conclusions are obtained from this research. The average electrical transformer oil temperature rises lower in the case of using thermosyphon than that without thermosyphon. The difference of average electrical transformer oil temperature rise increased as the test time increased between both tests with and without thermosyphon.

The percentages improvement in the transformer efficiency, transformer insulation, oil temperature, primary winding temperature, secondary winding temperature, primary winding resistance, secondary winding resistance and heat power of the oil (difference temperature rise of the oil) are 0.15, 82.7, 2.98, 4.376, 5.78, 34.9, 40 and 5.7%, respectively.

The enhancement percentage of heat transfer coefficient for high voltage top and below were 8, 6.66%, respectively and low voltage top and below were 10, 10.15%, respectively and transformer tank top, below and fin were 1.4, 2.9 and 1.49%, respective.

Abbreviation:

Symbol	Definitions/Units
R_1, R_2	Primary and secondary resistance (Ω)
I_1, I_2	Current primary and secondary (A)
Pc_1, Pc_2	Primary and secondary copper losses (W)
P_{ct}	Total copper losses (W)
P_{it}	Total core (iron) losses (W)
P_t	Total losses (W)
Q	Heat of oil (W)
m	Mass (kg)
cp	Specific heat (J/K.kg)
T	Temperature (K)
Ra_{hf}	Rayleigh number (-)
Nu	Nusselt number (-)
h	Heat transfer coefficient (W//m^2C)
g	Gravity (N/m^2)
T_s	Surface Temperature (K)
T_a	Ambient Temperature (K)
k	Thermal conductivity (W/m.C)
μ	Dynamic viscosity (kg/s.m)
ρ	Density (kg/m^3)
β	Bulk temperature (K)
q_w	Heat flux (W/m^2)
δ	Average diameter (m)
T_{oil}	Temperature of oil (°C)
T_a	Temperature ambient (°C)
ΔT	Difference of Temperature (°C)

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