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Research Article

Design of Thermoelectric Cooler Transducer based Transformer Heat Exchanger System

Gurpreet Kaur†* and Neha Gupta†

†Dept. of Electrical Engineering, Sri SAI College of Engineering, Pathankot, India

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Abstract

Heat dissipation is a pronounced problem in transformers as transformers are enclosed devices and due to no rotating part in transformers. Any solid body with losses taking place in it generates heat inherently, as, any form of energy loss in a body is dissipated in the form of heat. The loss can be either magnetic loss, due to contact of fluxes or hysteresis loss, or ohmic loss, due to the current passing through a conductor and the resistance being given by it or mechanical loss, due to moving parts and the friction between the surfaces in contact. The heat generated in any body is dissipated to the surrounding media and ultimately to the ambient. As the transformer start heating up, the winding insulation may start weakening and the value of the dielectric constant of the mineral oil reduces from the standard value. Investigations are carried out to analyze the amount of temperature raise during the transformer functioning and designing auto cooling system.

Keywords: *TEC, Heat Exchanger, Power System, Transformer, Auto cooling.*

1. Introduction

Power transformers are one of the most costly apparatus in an electricity system. Knowing their condition is necessary to meet the goals of maximizing return on investment and lowering the total price related with transformer operation. The transformer winding hot-spot temperature is one of the most significant parameters when defining the power transformer thermal conditions and overloading capability beyond the nameplate rating. Hence, in order to increase transformer operational efficiency and minimize the chance of an unexpected outage, several on-line and off-line monitoring systems have been developed (Adejumobi *et. al*. 201).

An ideal two winding transformer has the power equals the input power while having two different voltage levels on its input and output terminals, namely,

$$\bar{S}_1 = \bar{S}_2 \tag{1}$$

An ideal transformer has the equivalent circuit as shown in Figure 3.4. This is supposed to be a generator step-up transformer (GSU) that will step-up the voltage at the primary side (or low side) from a lower level to a higher voltage at the secondary side (high side). It is normally believed that power flows from the primary side to the secondary side of transformers (Berg and Fritze 2011). The primary/secondary voltages and currents have the following relationship:

$$\bar{E}_1 \bar{I}_1 = \bar{E}_2 \bar{I}_2 \tag{2}$$

$$\frac{\bar{E}_1}{N_1} = \frac{\bar{E}_2}{N_2} \tag{3}$$

$$N_1 \bar{I}_1 = N_2 \bar{I}_2 \tag{4}$$

where, $\bar{E}_1$ = primary voltage, $\bar{I}_1$ = primary current, N_2 = number of primary turns, $\bar{E}_2$ = secondary voltage, $\bar{I}_2$ = secondary current, and N_2 = number of secondary turns.

2. Losses in the transformer

Transformer manufacturers generally attempt to design transformers in a way that minimum losses occur in rated voltage, rated frequency and sinusoidal current. Though, by increasing the number of non-linear loads in recent years, the load current is no longer sinusoidal. Due to this non-sinusoidal current, there is extra loss and temperature in transformer. Transformer loss is divided into two main groups: no load and load loss as given in following equations

$$P_T = P_{NL} + P_{LL} \tag{5}$$

where, P_{NL} is No load loss, P_{LL} is Load loss, and P_T is total loss.

*Corresponding author **Gurpreet Kaur** is M.Tech Student and **Neha Gupta** is working as Assistant Professor

No load loss or core loss occurs due to time variable nature of electromagnetic flux passing through the core and its arrangement is affected by the amount of this loss. As distribution transformers are forever under service, in view of the number of this type of transformer in network, the amount of no load loss is high but constant this type of loss is caused by hysteresis phenomenon and eddy currents within the core (Perez 2010). Frequency and maximum flux density of the core are proportional to these losses and are separated from load currents. Many experiments have shown that core temperature increase is not a restrictive parameter in determination of transformers permissible current in the non-sinusoidal currents. In addition, considering that the value of voltage harmonic component is less than 5%, only the chief component of the voltage is considered to calculate no load loss, the error of ignoring the harmonic component is negligible. Therefore, IEEE C57 .110 standards has not considered the core loss increase due to non-linear loads and has supposed this loss constant, under non-sinusoidal currents (Abanihi *et. al*. 2014).

Load loss includes dc or Ohmic loss, eddy loss in windings and other stray loss and it can be obtained from short circuit test. The coil losses, generally called as load losses, are connected to the feeding power to the connected load. For linear loads, load losses are mostly I^2R losses, it means that load losses are directly proportional to the square of current from no- load to full- load, driven by coil resistance (White *et. al*. 2004).

The load losses in a power transformer are because of the electric resistance of windings and stray losses. The Resistive action of the winding conductor to the current flow will be missing in the form of heat and will be degenerate in the surrounding area within the transformer. The magnitude of that loss increases as the square of the current. Stray losses take place due to the leakage field of winding and because of high currents seen in internal structural parts such as bus bars. Stray losses can influence the overall rating of the transformer as they can create hot spots when the current leads become extremely high, affecting the overall life of the transformer (Philip 2001).

3. Temperature Effect in Transformer

When a current is passed throughout a conductor, heating losses are formed in the form of I^2R losses, where I is the amount of current passing through the conductor having resistance R. An equilibrium conductor temperature is reached if the heat is removed at the same rate as that at which it is produced. Physical and chemical effects leading the interaction between materials are normally temperature dependent and chemical reaction rates classically increase with increasing temperature (Berube *et. al*. 2005, Bhat, and Javhar (2014).

Monitoring the transformers through temperature sensors is one of the simplest and most efficient condition monitoring techniques for the benefit management in smart distribution grid. Nonstandard temperature readings approximately always indicate some type of insulation failure in a transformer. Therefore, it has become frequent practice to monitor the hot spot, main tank, and bottom tank temperatures on the shell of a transformer. As the transformer start heating up, the winding insulation may start weakening and the value of the dielectric constant of the mineral oil reduces from the standard value (Areny and Webster 1991, Bhushan and Tekade 2014, Stefan and Mihai 2010).

In order to analyse the temperature conditions inside a transformer, the analogy between thermal and electrical processes is briefly discussed. A thermal process can be given by the energy balance equation:

$$q \times dt = c_{th} \times d\theta + \frac{\theta - \theta_{amb}}{R_{th}} \times dt \tag{3.6}$$

where: q is the heat generation, C_{th} is the thermal capacitance, θ is temperature, R_{th} is the thermal resistance, q_{amb} is the ambient temperature (Betta 2001). The equation may be again written as follows:

$$q = c_{th} \times \frac{d\theta}{dt} + \frac{\theta - \theta_{amb}}{R_{th}} \tag{3.7}$$

4. Methodology

The research work is carried out with different combinations of load (R, L, and C) at a particular interval of time are considered and corresponding temperature rise is analysed in our system (transformer). Then at different load and corresponding heat generation, the voltage variations are also considered in TEG. Since we know the saturated voltage value of TEG, hence maximum temperature rise in transformer at different load for a particular interval of time can be measured. Once maximum temperature is measured then cooling can be done automatically by using particular control which will be shown in experiment 3. Block diagram for experiment II is shown in Fig 1.

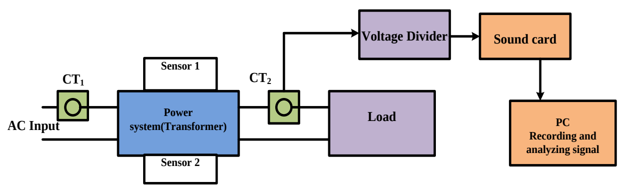

Fig.1 Block diagram for obtaining maximum heat generation

Procedural Steps

- AC input is given to power system (transformer) via CT_1 for controlled signal.
- Output of power system is given to CT_2 for controlled signal given to load which is connected to CT_2. Output leads of CT_2 is connected to voltage divider, then to sound card, and to PC.

- Now the load is varied for particular interval , and then temperature rise in power system for that time period is calculated. Corresponding to that temperature rise, voltage variation is also noted in TEG.
- Now the load is increased for same interval of time, and temperature is again raised and corresponding voltage variation is noted down.
- Load is increased till saturated voltage value of TEG is reached and then corresponding maximum temperature raised is obtained and now auto cooling can be done using a particular control.
- At each load, output of CT_2 is given to voltage divider for further processing and then that processed signal is given to sound card for obtaining audio signal and resulting waveforms are recorded in PC. Table 1 and 4.2 shows different load combinations for X_c= 50 μF and 25 μF respectively.

Table 1 Calculation of Impedance

Resistance (R), Ω	Capacitance(C), μF	Inductance (L), mH	Impedance(Z)
124	50	300	127.73
		400	138.60
		500	155.31
		600	176.04
		700	199.60
		1000	279.60
		1200	337.16
		1800	517.19

Table 1 Variations in generated voltage of two array sensor due to different load

S.No	Load, Z1, Ω (Xc= 50μF)	Voltage (V) sensor array
1	127.73	0.32
2	138.60	0.81
3	155.31	0.93
4	176.04	1.1
5	199.60	1.32
6	279.60	1.54
7	337.16	1.61
8	517.19	1.97

5. Results

Maximum heat generation in transformer and consequent voltage variation in TEC sensor was obtained, by considering load combinations (*R, L, C*). Table 2 shows various combinations of load (*R, L, C*) for X_c =50 μF and corresponding voltage variations in TEG. Figure 2 shows the graphical representation of sensor voltage having various load connected to the system for regular interval of time. Also the output from the load is recorded using CT which is further connected to the voltage divider circuit and sound card of the PC shown in Fig 3 and Fig 4. Auto cooling of the power system (transformer) was done, by using microcontroller (PIC controller, 16F877A).

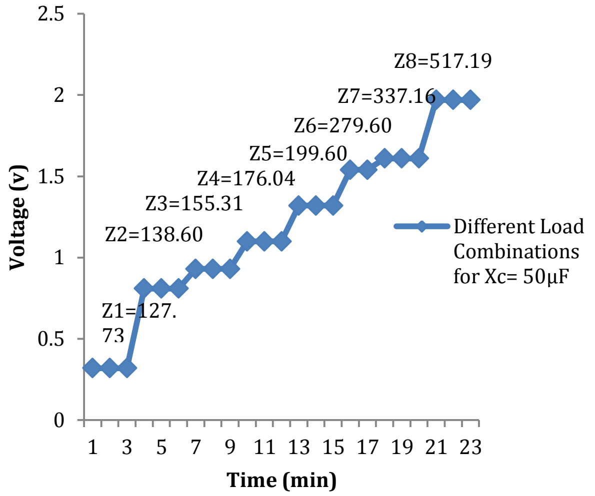

Fig.2 Output waveform for different load combination at particular interval of time for XC= 50 μF.

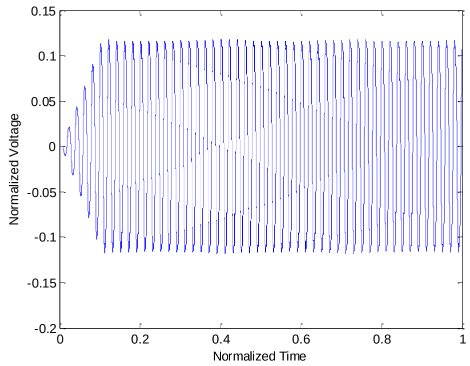

Fig.3 Output waveform for XC=50 μF and XL=300 mH.

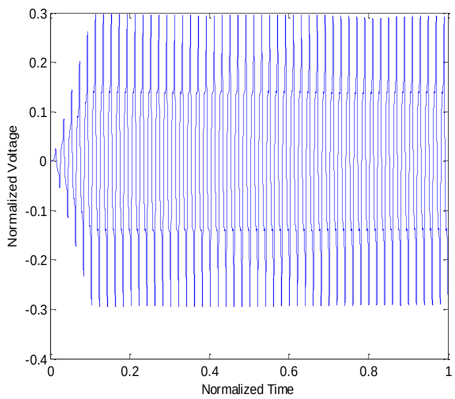

Fig.4 Output waveform for XC=50 μF and XL=1800 mH.

Figure 5 shows flow chart for ADC program in PIC 16F877A for auto-cooling of transformer. DC supply is given to microcontroller and heat exchanger system. Microcontroller is connected to heat exchanger system and power system through interface circuit. Thermocouple sensors S1 and S2 are connected to power system for sensing maximum temperature in power system, and heat exchanger system with power system is used for cooling purpose. As from experiment 1&2, we have preset value of temperature, and when this preset value of t temperature reaches, it will be sensed by sensor S1 and S2 and command will be given to microcontroller to start the heat exchanger system for cooling of the system.

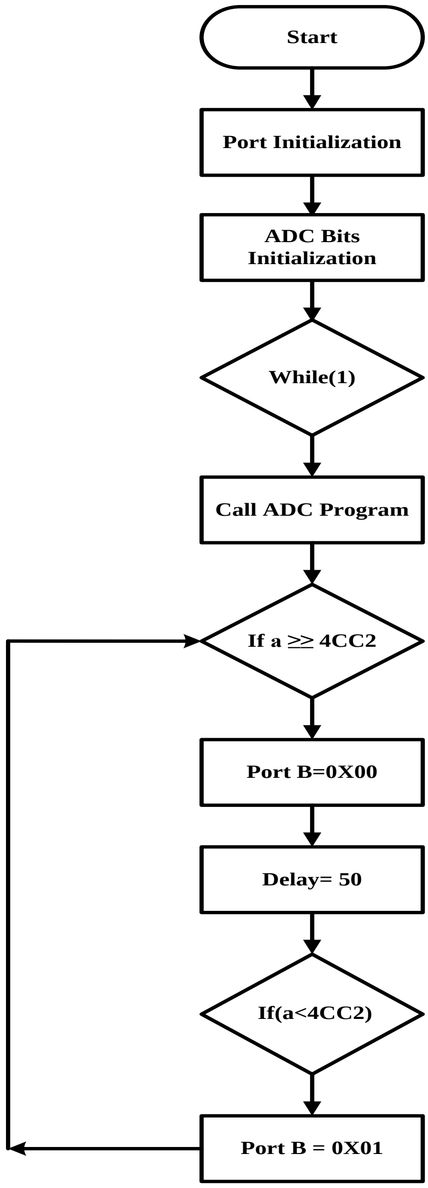

Fig.5 Flow chart for ADC program in microcontroller (auto-cooling of transformer)

Conclusions

Research work is carried out for auto-cooling of power system (transformer) has been design. For that purpose two experiments were performed. First experiment is carried out to estimate the temperature rise in transformer with varying load connected to it. Different load combinations were considered and at different load, temperature rise corresponding to voltage variation is estimated. Maximum temperature rise estimated for R= 124Ω, X_C= 50μF, impedance, Z_{max}=517.19Ω and voltage V_{max}=1.97 volts is about 44^0C Also minimum temperature rise R= 124Ω, X_C= 50μF, impedance, Z_{min}=127.73Ω and voltage V_{min}=0.32 volts is about 32 ^{0}C. Finally experiment is done using microcontroller for designing auto-cooling system for transformer. Auto-cooling of transformer is done by using microcontroller PIC 16F877A and heat exchange system, in which PIC after sensing high temperature rise gives command to heat exchange system for cooling.

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