Thermal Modelling and Fiber-Optic based Temperature Measurement of Power Transformer

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Abstract: The present study provides an overview of thermal modeling of transformer and fiber optic based measurement system for temperature measurement of power transformer. Detailed analysis of different parts of power transformer and fiber optic based sensor and instrumentation analysis has been carried out in this paper.

Keywords: Power transformer, Measurement, thermal modelling

Introduction

Power transformer is one of the indispensable part of electrical power system which is used either to step-up or step-down power. Transformer are static device which provides very high efficiency up to 99.8%. For proper functionality of transformer, different measurement needs to be carried out. Due to the dynamic nature of loading of transformer and requirement of 24x7 monitoring, standard sensors can't be employed in transformer.

Presence of water and impurity in transformer oil degrades the performance of transformer to a certain extent. Optical fiber based measurement of water quantity in oil is explained in [1]. Transformer oil breakdown using optical fiber has been explained in [2]. A review of transformer condition monitoring using fiber optic sensors has been explained in [3,4]. Continuous monitoring of multi-point hot-spot detection has been discussed in [5]. Partial discharge detection in power transformer using optical fiber has been discussed in [6]. Temperature evaluation for power transformer in overload conditions has been evaluated in [7]. Thermal modeling of transformer has been discussed in [8].

In this paper, thermal modeling of power transformer and measurement of temperature using fiber-optic measurement technique has been discussed.

This paper is organized as follows. Section II provides the detailed thermal modeling of power transformer. Section III provides fiber optic measurement concept has been discussed.

Thermal Modelling of Power Transformer

Equivalent circuit diagram of transformer is illustrated in Figure 1.

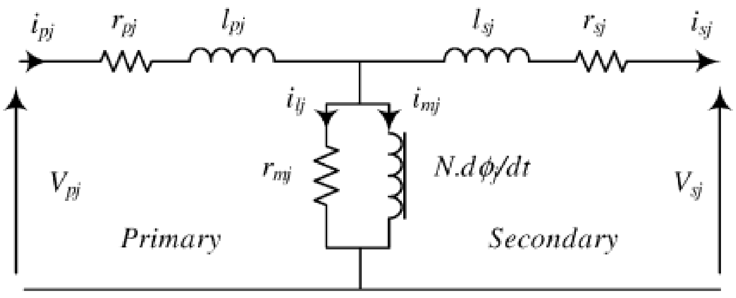

Figure 1: Equivalent circuit diagram of transformer

In a transformer, there are different modes of heat dissipation such as conduction, convection and radiation.

Conduction, $Q_{con} = \frac{\theta_1 - \theta_2}{R_\theta}$ (1)

Convection, $Q_{conv} = K_c(\theta_1 - \theta_2)^n$ (2)

Radiation, $Q_{rad} = 5.7 \times 10^{-8} e^{(T_1^4 - T_0^4)}$ (3)

Newton's law of cooling $Q_{rad} = \lambda_{rad}\theta S$ (4)

The equation of temperature rise with time of any body is given by $\theta = \theta_m\left(1 - e^{\frac{-t}{T_h}}\right) + \theta_i\left(e^{\frac{-t}{T_h}}\right)$

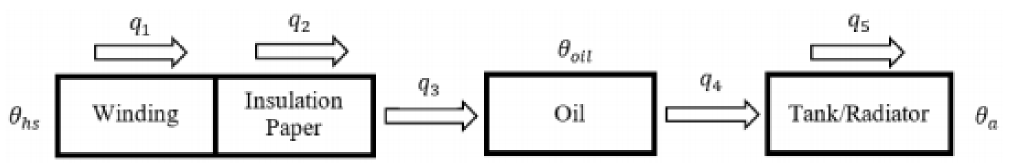

Figure 2: Flow of heat in power transformer

Figure 2 and Figure 3 shows the flow of heat in power transformer and electrical equivalent model. where q_1 represents the conduction through copper of the winding, $q2$ is the conduction through the insulation paper, $q3$ is the convection from insulation paper to the oil, $q4$ is the convection from the oil to the tank, $q5$ is the conduction through the tank/radiator of transformers, θhs is the HST, θoil is the TOT. Equivalent circuit diagram of thermal model of transformer is illustrated in Figure 3.

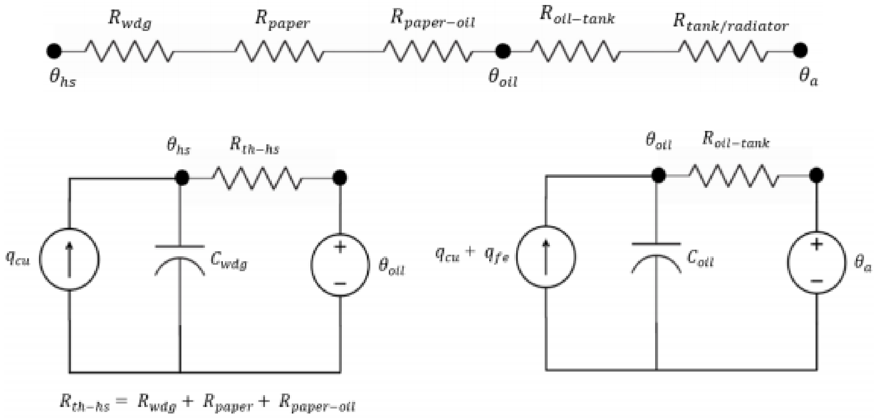

Figure 3: Equivalent circuit diagram of thermal model of transformer

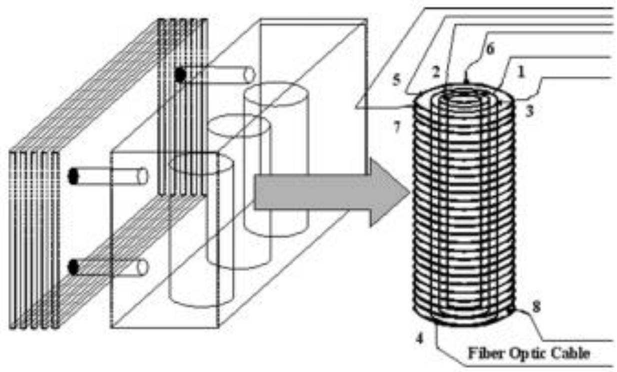

Figure 4: Location of temperature sensor

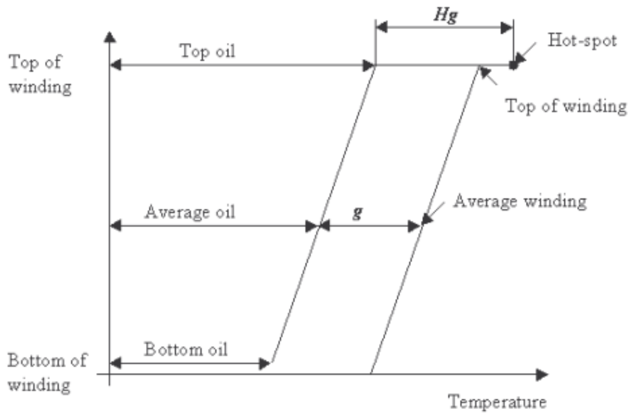

Figure 5: Relationship between temperature and type of winding in power transformer

Figure 4 shows the location of temperature sensor in a power transformer. Figure 5 shows the relationship between temperature and type pf winding in power transformer.

Top oil temperature rise over ambient is represented as

$$\Delta\theta_{TO,U} = \Delta\theta_{TO,R}\left(\frac{K^2R+1}{R+1}\right)^n \quad (5)$$

$$\Delta\theta_{TO} = \left(\Delta\theta_{TO,U} - \Delta\theta_{TO,i}\right)\left(1-\exp\left(\frac{-t}{\tau_{TO}}\right)\right) + \Delta\theta_{TO,i} \quad (6)$$

$$\tau_{TO} = \tau_{TO,R}\, f \quad (7)$$

Where $\Delta\theta_{TO}$ is top oil rise over ambient temperature, U is the ultimate index, R stands for rated, K is the ratio between actual and rated load, n is the empirical exponent

Winding hottest temperature rise over top oil can be represented as

$$\Delta\theta_{H,U} = \Delta\theta_{H,R}K^{2m} \quad (8)$$

$$\Delta\theta_{H} = \left(\Delta\theta_{H,U} - \Delta\theta_{H,i}\right)\left(1-\exp\left(\frac{-t}{\tau_{w}}\right)\right) + \Delta\theta_{H,i} \quad (9)$$

Where $\Delta\theta_{H}$ is the hottest spot rise over top oil temperature , m is the empirical exponent and τ_w is the winding temperature time constant.

The hottest spot and top oil temperature can be represented as

$$\Delta\theta_{H} = \theta_A + \Delta\theta_{TO} + \Delta\theta_{H}$$
$$\theta_{TO} = \theta_A + \Delta\theta_{TO} \quad (10)$$

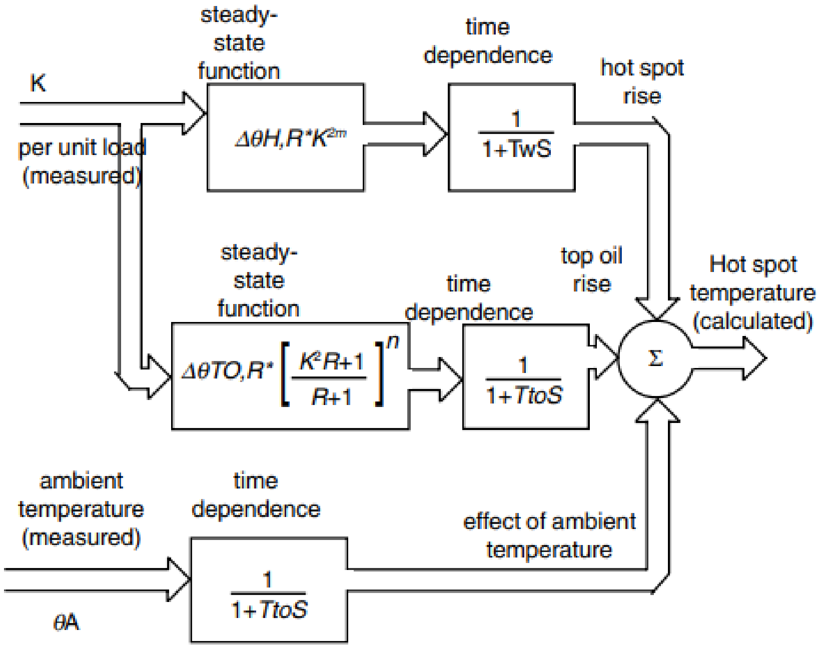

Figure 6: Hot spot temperature as a function of per unit load and ambient temperature

Table 1 illustrates the different parameters of power transformer.

Table 1: Different maintenance for transformer

1	Hourly Basis	Ambient temperature
2		Oil Temperature
3		Winding Temperature
4		Load Voltage
5		Load Current
6		Noise emission
7	Weekly basis	Dehydrating Breather
8		Oil level in tank/conservator
9		Buchholz relay
10		Gasket joint and radiator
11		Explosion vent
12	Quarterly	Dielectric strength
13		Cable and bushing
14	Half-yearly	Earthing terminal
15		Dissolved gas analysis
16	Yearly	Surge relay, pressure relief valve (PRV)
17		Core and winding

Fiber Optic Based Measurement

Figure 7 shows the PC based fiber optic based data acquisition system comprising of multiple fiber optic sensor, multiplexer, optical signal processing unit and narrow band light source.

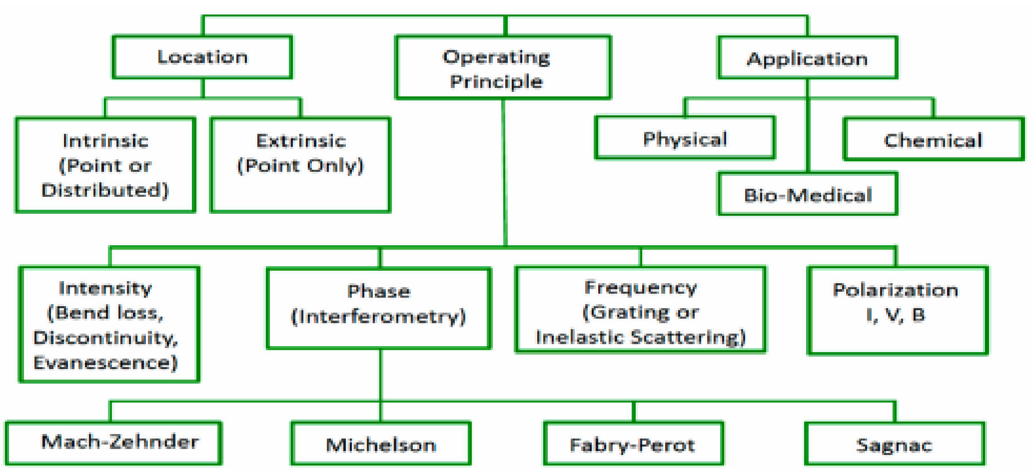

Figure 7: Classification of optical-fiber system

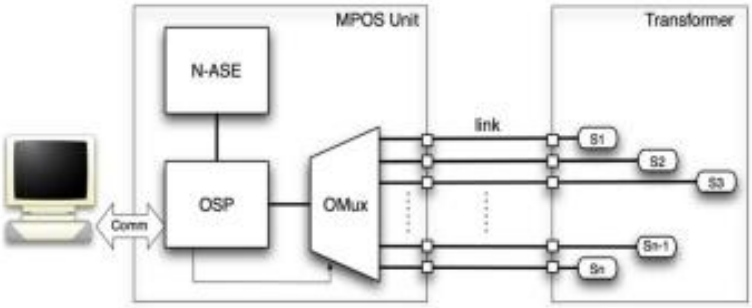

Figure 8: Fiber optic based data acquisition system

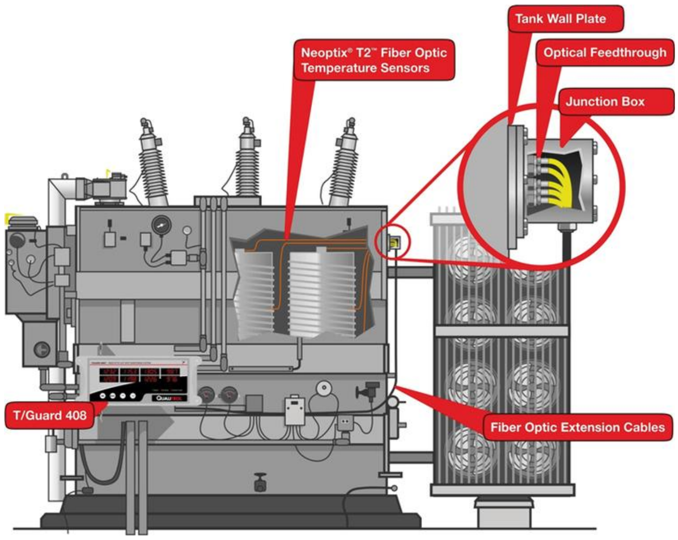

Figure 9: Illustrative example

Figure 8 shows the Fiber optic data acquisition system and Figure 9 shows the illustrative example.

Simulation Results

Let us consider a power transformer of 10 kVA rating with HV voltage of 5000 V and LV voltage of 400 V. The iron loss is 468 W and copper loss is 1312 W. The power transformer has Oil Natural Air Natural (ONAN). Figure 10 and Figure 11 shows the experimental setup and results.

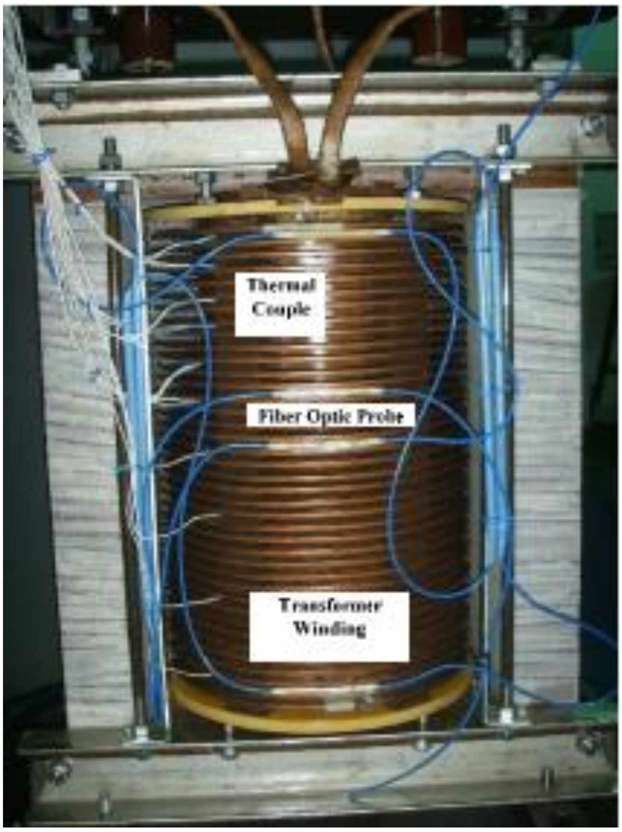

Figure 10: Exprimental setup of transformer with sensor and fiber optic core

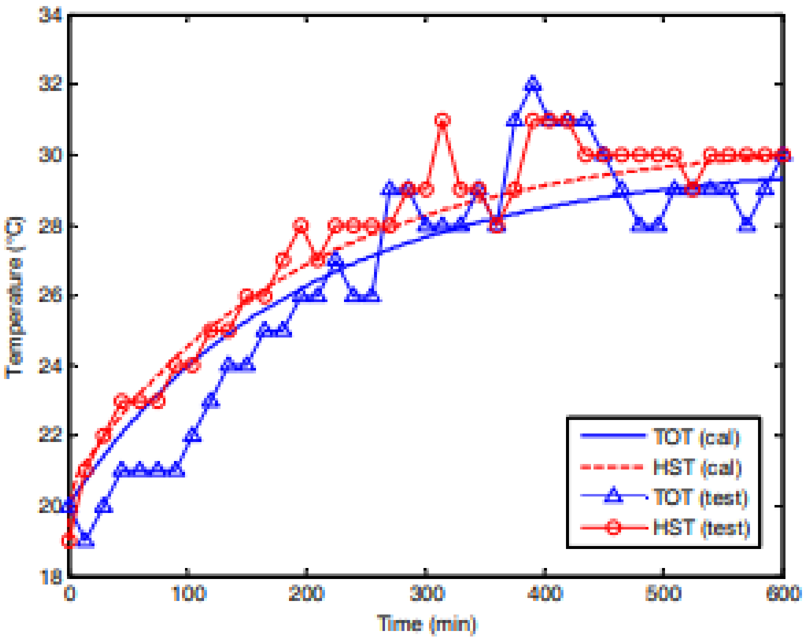

Figure 11:Temperature variation of transformer

Conclusion

This paper provides a basic idea about thermal modeling of power transformer and different techniques to measure different temperature parameters of transformer. Fiber optic measurement of transformer has been illustrated in this paper. Experimental results have been provided.

Acknowledgement

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