International Journal of Electronic and Electrical Engineering.
ISSN 0974-2174 Volume 10, Number 1 (2017), pp. 31-38

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Determination of Hot Spot Temperature using IEEE Thermal Model

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Abstract

Failure of transformer in grid is one of the major concerns. In India the failure of distribution transformer is around 25% per annum, which is higher compared to developed nations. It is necessary to keep transformer in service for uninterrupted power supply. For uninterrupted operation of the Transformer it is necessary for effective Monitoring of the transformers health. The major factor that affects the transformers health is the thermal loading. The most important parameter in determining the transformer loading capability is winding Hot spot temperature. This paper presents two different Thermal models to determine the winding hot spot temperature. Simulation of the thermal models done in MATLAB. It compares the simulation results of both the thermal models. Both the thermal model uses Load current, different Temperatures, and Ambient temperature as an inputs and calculate the hot spot Temperature. The winding hot spot temperature can be used to find insulation ageing.

Keywords: Hot spot Temperature, Thermal models, Transformers

I. INTRODUCTION

The Hot spot temperature is the essential parameter for deciding the health and loading capability of transformer. Operating time of transformer is mainly depends upon conditions of insulation of the transformer winding. The main cause of failure in distribution transformer is prolonged overloading and loss of life due to thermal degradation of insulation. So, it is necessary to know about hot spot temperature at each movement of the transformer performance at different loading condition and different ambient temperature.

II. THERMAL MODEL I

In this model the top fluid temperature, load current, rated hot spot temperature rise and other constant parameters are as input to calculate the winding hot spot temperature.

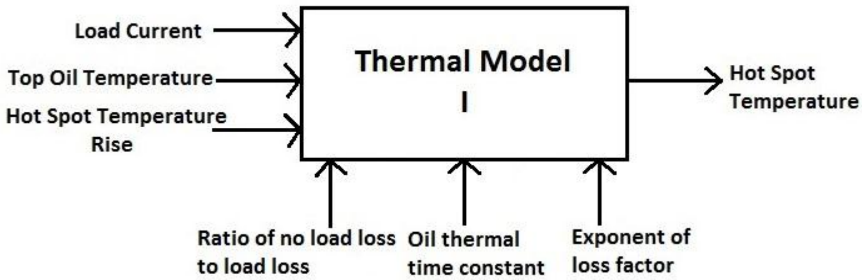


Fig.1 Block Diagram

The hot spot temperature is given by,

$$\frac{I^2{}_{pu}\,[K_\theta + \frac{P_{EC-R}}{K_\theta}]}{1 + P_{EC-R}}\,[\Delta\theta_{H-R}]^{\frac{1}{m}} = \tau_H \frac{d\theta_H}{dt} + [\theta_H + \theta_{TO}]^{\frac{1}{m}}$$

Where,

I_{pu} = Load current in pu

K_θ = Resistance correction due to temperature change

P_{EC-R} = Rated pu eddy current losses at hot spot location

$\Delta\theta_{H-R}$ = Hot spot temperature rise over top oil, °C

τ_H = Hot spot time constant, min

θ_H = Hot spot temperature, °C

θ_{TO} = Top oil temperature, °C

m = Winding hot spot exponent

A. Simulation model

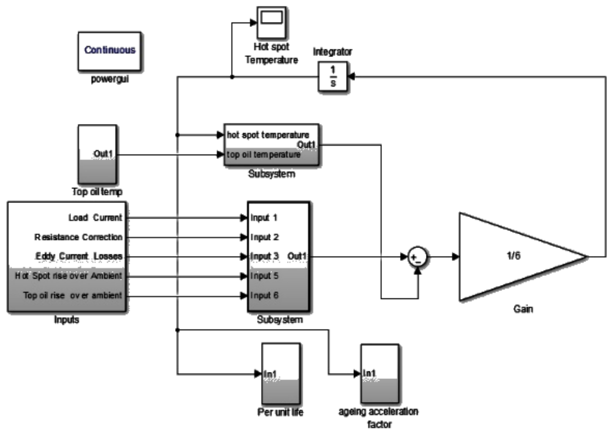
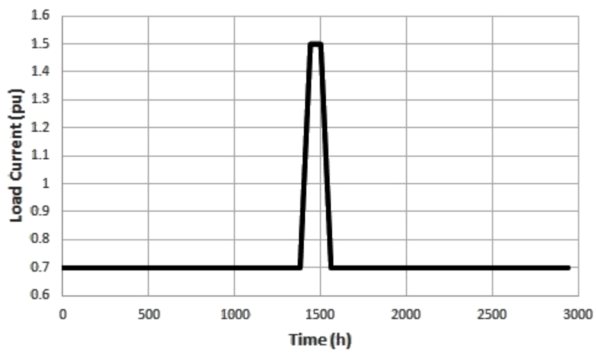


Fig. 2 Simulation diagram of thermal model-I

B. Results: Inputs



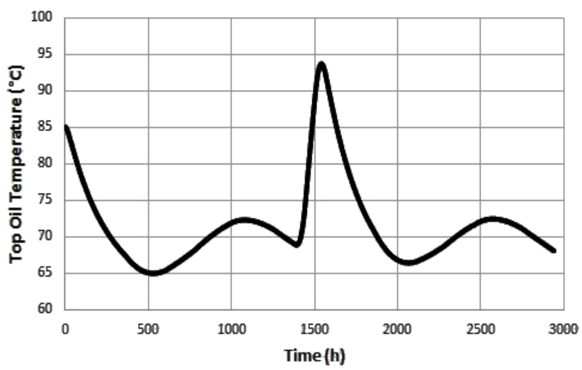


Fig. 3 Waveforms of load current & top oil temparature

C. Results: Output

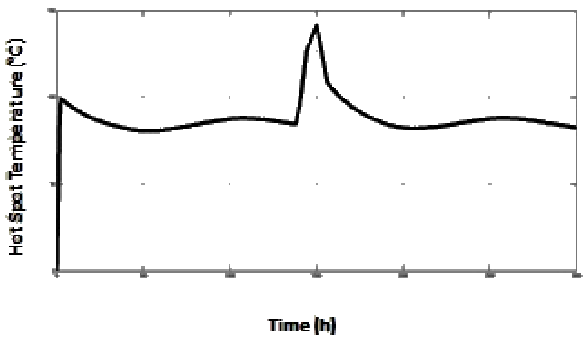


Fig. 4 Hot spot temparature waveform

III. THERMAL MODEL II

The hot spot temperature and oil temperature are obtained from equations for the conservation of energy during a small instant of time Δt.

For temperature acquire from the calculation at the prior time t1 are used to calculate the temperatures at the next instant of time t1+Δt or t2. The time is incremented again by Δt and the last calculated temperatures are used to calculate the temperature for the next time step.

The hot spot temperature made up of the following components

$$\theta_H = \theta_A + \theta_{BO} + \theta_{WO-BO} + \theta_{H-WO}$$

Where,

θ_H = The hot spot temperature, °C

θ_A = Ambient temperature, °C

θ_{BO} = Bottom oil temperature, °C

θ_{WO-BO} = Temperature rise of oil at winding hot spot location over bottom oil, °C

θ_{H-WO} = Winding hot spot temperature rise over oil next to the hot spot location,°C

The simplified block diagram to determine the hot spot temperature is shown below,

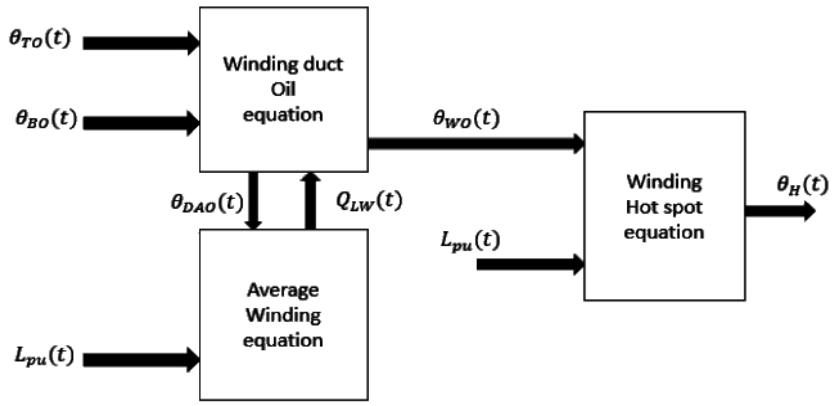


Fig. 5 Block Diagram of theraml model to estimate hot spot temperature

In order to determine the hot spot temperature this model make use of three equations namely.

a) Winding duct oil equation
b) Average winding equation
c) Winding hot spot equation

A. Winding duct oil temperature

Winding duct oil temperature rise over bottom fluid is given by,

$$\Delta\theta_{DO/BO} = [\frac{Q_{LOST,W}}{(P_W + P_E)}]^x (\theta_{TDO,R} - \theta_{BO,R})$$

Where,

$\Delta\theta_{DO/BO}$ = Winding duct oil temperature rise over bottom fluid, °C

$Q_{LOST,W}$ = Heat lost by windings, W-min

$\theta_{TDO,R}$ = Winding duct oil temperature at rated load, °C

$\theta_{BO,R}$ = Bottom oil temperature at rated load, °C

x = Exponent for duct oil rise over bottom oil

P_W = Winding I2R losses, W

P_E = Eddy current losses, W

B. Average winding temperature

The average winding temperature is given by,

$$\theta_{W,2} = \frac{Q_{GEN,W} - Q_{LOST,W} + M_W C_{P_W} \theta_{W,1}}{M_W C_{P_W}}$$

Where,

$\theta_{W,2}$ = Average winding temperature at next instant of time, °C

$\theta_{W,1}$ = Average winding temperature at prior time, °C

$Q_{GEN,W}$ = Heat generated by the windings, W-min

$Q_{LOST,W}$ = Heat lost by the windings, W-min

$M_W C_{P_W}$ = Winding mass time specific heat, W-min/°C

C. Winding hot spot temperature

The winding hot spot temperature is given by,

$$\theta_{H,2} = \frac{Q_{GEN,HS} - Q_{LOST,HS} + M_W C_{P_W} \theta_{H,1}}{M_W C_{P_W}}$$

Where,

$\theta_{H,2}$ = Hot spot temperature at next instant of time, °C

$\theta_{H,1}$ = Hot spot temperature at prior time, °C

$Q_{GEN,HS}$ = Heat generated at hot spot temperature, W-min

$Q_{LOST,HS}$ = Heat lost for hot spot calculation, W-min

$M_W C_{P_W}$ = Winding mass time specific heat, W-min/°C

D. Simulation Model

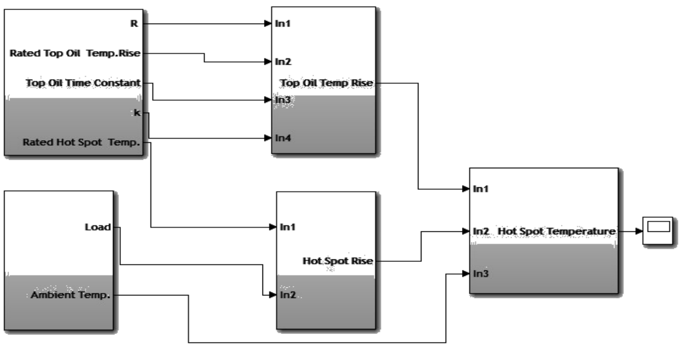


Fig. 6 Block Diagram of thermal model-II

E. Results: Inputs

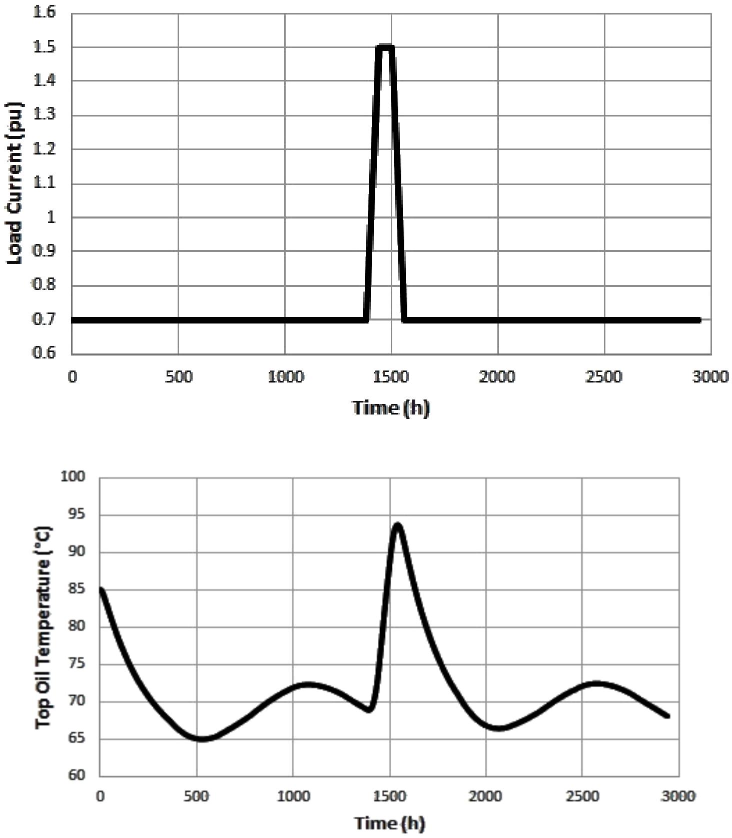


Fig. 7 Waveforms of load current & top oil temparature

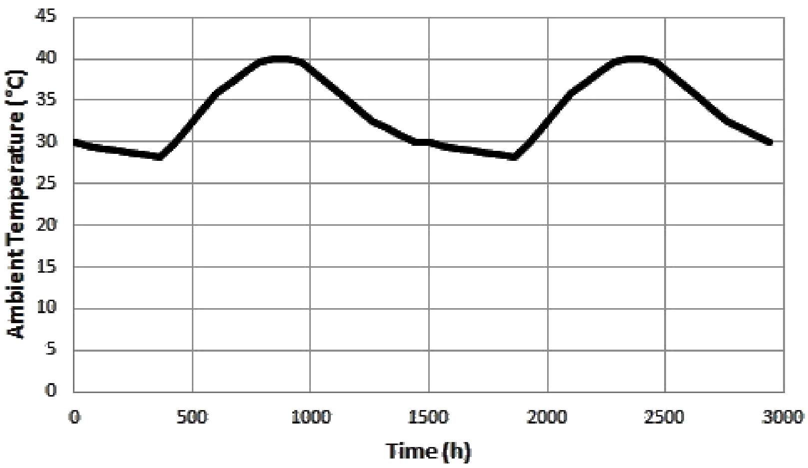


Fig.7 Abmient temparature waveform

F. Results: Output

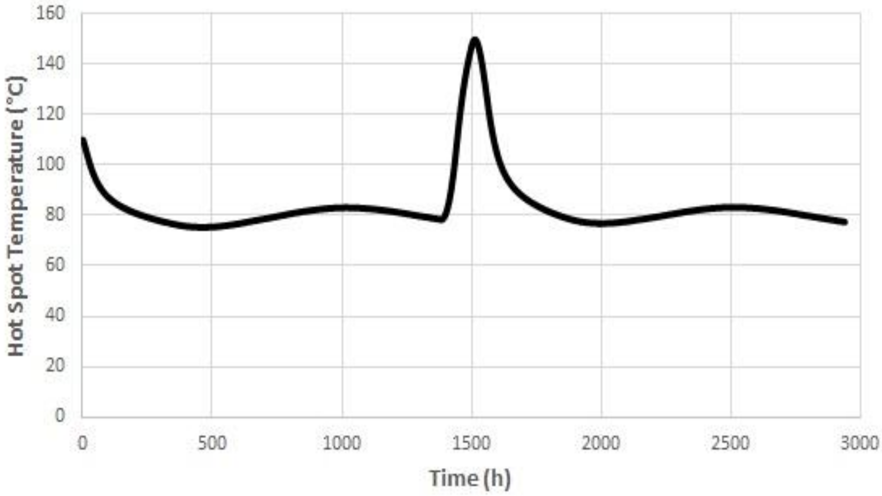


Fig. 8 Hot spot temparature waveform

IV. CONCLUSION

This paper presents simplified models to determine the hot spot temperature of the transformer winding. Simulations of thermal model I and II are made using MTLAB software. The results of the simulations clearly states that the hot spot temperature of the transformer winding obtained using both thermal models are found to be almost similar.

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