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Winding Clamping Force Effect Due to Moisture and Insulation Aging Changes

Vinaya B. K[1], Manjunath S[2], Rajath Shankar P. S[3]

[1]*Professor, Department of EEE, Srinivas Institute of Technology, Mangalore, India*
[2,3]*Professor, Department of EEE, Don Bosco Institute of Technology, Bangalore, India*

Abstract*: Power transformer windings are designed to withstand high axial forces which results from short circuit events. To withstand these forces, the winding assembly is clamped to pre-determined pre-load pressure during manufacture. This paper discusses the important relationship between changes in moisture level versus clamping pressure for new transformers. It further relates laboratory investigations of changes in clamping pre-load versus changes in operating temperature, moisture content and insulation aging effect. The effect of temperature, moisture content is the Hot Spot Temperature (HOT) and Top Oil Temperature (TOT). The Hot Spot Temperature (HST) value depends on the ambient temperature, the rise in the Top Oil Temperature (TOT) over the ambient temperature, and the rise in the winding HST over the top oil temperature and thermal model under linear loads. The hot spot, top oil and loss life of power transformer under harmonic load are calculated. In this paper a new semi-physical model comprising of the environment variables for the estimation of HST in transformer is proposed and also MATLAB/Simulink-based valid model of hot spot temperature under variable environmental condition is proposed. The winding hotspot temperature can be calculated as a function of the top-oil temperature that can be estimated using the transformer loading data, top oil temperature value, ambient temperature, wind velocity and solar heat radiation effect. The estimated HST is compared with measured data of a power transformer in operation.

Keywords: winding clamping model, top oil temperature, hot spot temperature, Matlab

I. Introduction

An important criteria for prolonged transformer life is its ability to withstand short circuit events. A short circuit can result in severe radial and axial forces which can damage the insulation integrity. Axial forces which result from short circuits are controlled by the proper pre-loading of the transformer coils during manufacture. This discusses tests designed to measure the tendency of the insulation to expand or shrink during the manufacturing process and through the life of the transformer.

In most transformers designed today, a rigid clamping system is utilized to compress the windings to the specified pre-load value. The change in thickness on insulation on the winding will change the pressure on the winding and also expansion and contraction during load cycles. The insulation being organic, will change in thickness and elasticity over time resulting from effect of moisture, temperature and aging.

II. Effect of Moisture and Temperature

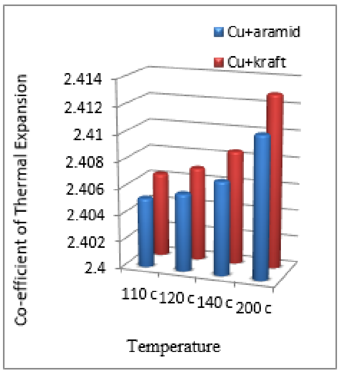
The explanation for this temperature effect can be identified in thermal expansion. It has to be taken into consideration that any aging causes dimensional expansion of the components of the test devices, due to different material expansion coefficients. Due to variation in the rate of thermal expansion of the respective materials there is an effect on the clamping over the operating range of a transformer.

Fig. 1. Clamping model with kraft and aramid paper

Fig. 2. Clamping model with kraft and aramid paper

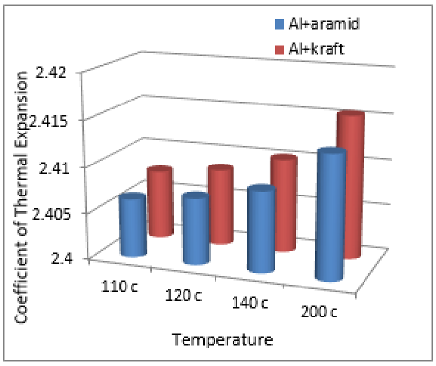
III. Comparison of Mathematical Analysis versus Experimental Analysis

A. *Mathematical Analysis*



Temperature	Copper+Aramid (cm)	Copper+Kraft (cm)
110 c	2.4052	2.4063
120 c	2.4058	2.407
140 c	2.407	2.4085
200 c	2,4106	2.4129

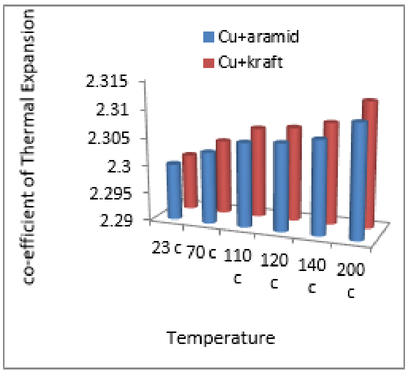
Fig. 3. Copper + Kraft and Copper + Aramid



Temperature	Aluminium+Aramid (cm)	Aluminium+Kraft
110 c	2.4064	2.4076
120c	2.4072	2.4084
140 c	2.4087	2.4102
200 c	2.4132	2.4155

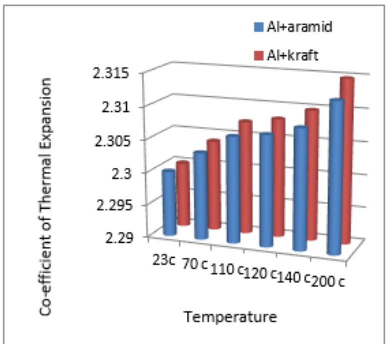
Fig. 4. Aluminium + Kraft and Aluminium + Aramid

B. *Experimental Analysis*



Temperature	Copper+Aramid	Copper+Kraft
23 c	2.3	2.3
70 c	2.3027	2.3032
110 c	2.305	2.306
120 c	2.3055	2.3067
140 c	2.3067	2.3081
200 c	2.3101	2.3123

Fig. 5. Copper + Kraft and Copper + Aramid



Temperature	Aluminium+Aramid	Aluminium+Kraft
23 c	2.3	2.3
70 c	2.3033	2.3039
110 c	2.3062	2.3073
120 c	2.3069	2.3081
140 c	2.3083	2.3098
200 c	2.3126	2.3148

Fig. 6. Aluminium + Kraft and Aluminium + Aramid

The Fig. 5 and Fig. 6, shows the experimental analysis results as compared with mathematical analysis and with the help of these results we can see the moisture effect changes in the winding clamping pressure effect.

Tabular columns and the graphs show the coefficient of thermal expansions for mathematical and experimental analysis

IV. Effect of Insulation Aging

The effect of insulation aging is done by hotspot and top oil temperature models. The models used for top oil and hot spot temperature calculations are described in IEC and IEEE loading guides. According to the IEC 354 loading guide for oil immersed power transformers, the hotspot temperature in a transformer winding is the sum of three components: the ambient temperature rise, the top oil temperature rise, and the hot spot temperature rise over the top oil temperature. During a transient period, the hot spot temperature rise over the top oil temperature varies instantaneously with transformer loading, independently of time. The variation of the top oil temperature is described by an exponential equation based on a time constant (oil time constant). Aging or deterioration of insulation is a time-function of temperature, moisture content, and oxygen content.

V. Simulation Model

A. *The Thermal model by MATLAB Simulink*

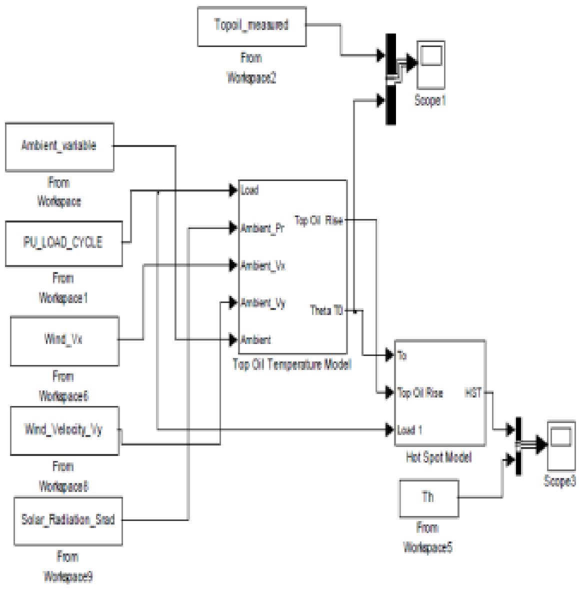


Fig. 7. MATLAB/Simulink model of proposed system

B. *Top Oil Power Transformer Temperature Model*

The model for top oil temperature rise over ambient temperature captures that an increase in the load current of the transformer will result in an increase in the losses within the device and thus an increase in the overall temperature. This temperature change depends upon the overall thermal time constant of the transformer, which in turn depends upon the heat capacity of the transformer, i.e. the mass of the core, coils, and oil, and the rate of heat transfer out of the transformer.

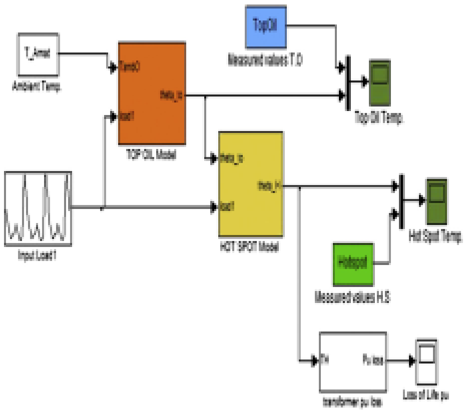


Fig. 8. MATLAB/Simulink of proposed thermal model

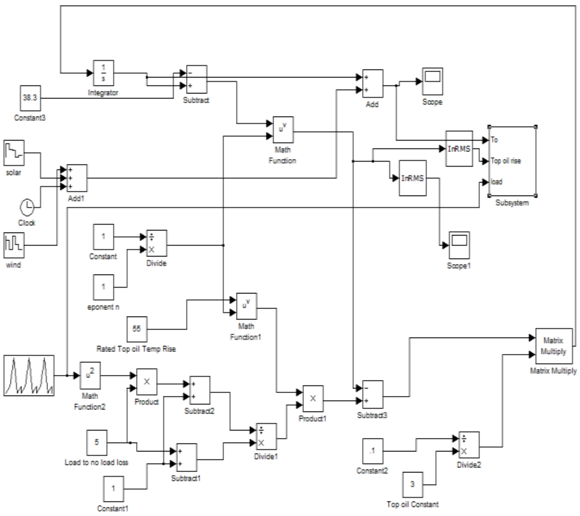


Fig. 9. Simulink model of top oil power transformer temperature model

C. Simulation Results

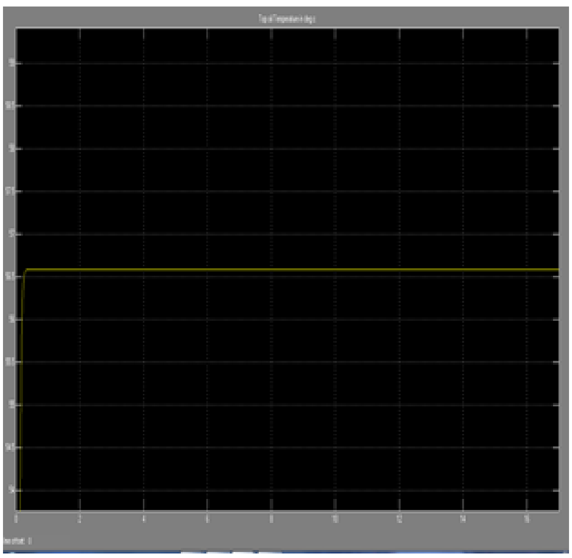


Fig. 10. Simulation result for proposed model

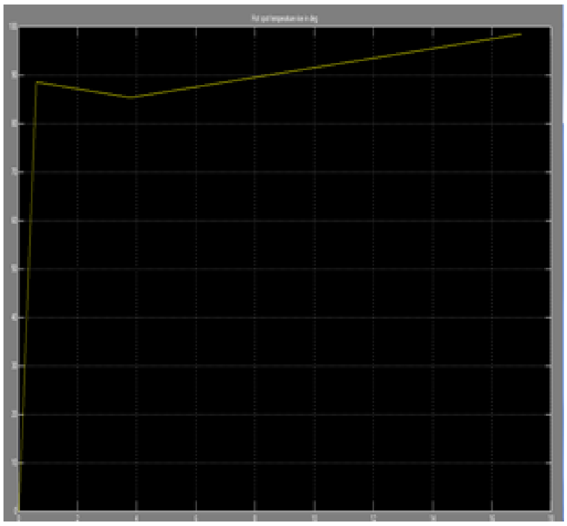


Fig. 11. Simulation result for top oil power transformer temperature model

VI. Conclusion

From the above results, the co-efficient of thermal expansions of the clamping material due to the effect of moisture and temperature is slightly more than the clamping material that is being used before it is kept in the heat treatment furnace. Then from the effect of insulation aging i.e., top oil temperature and hot spot temperature, top oil temperature are nearly greater than the ambient temperature of about 19oCand the hot spot temperature is about 53oC. From the above results the hot spot temperature is more accurate than the top oil temperature.

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