Effects of Environmental Factors in Transformer's Insulation Life

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Abstract: - 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. In this paper a new semi-physical model comprising of the environmental 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 hot-spot temperature can be calculated as a function of the top-oil temperature that can be estimated using the transformer loading data, top oil temperature lagged regressor value, ambient temperature, wind velocity and solar heat radiation effect. The estimated HST is compared with measured data of a power transformer in operation. The proposed model has been validated using real data gathered from a 100 MVA power transformer

Key-Words: - Top Oil Temperature - Hot Spot Temperature – Environmental variables

1 Introduction

Power transformers are the main components and constitute a large portion of capital investment. When a power transformer fails, an adverse effect occurs in the operation of transmission and distribution networks resulting in increase of the power system operation cost and decrease of reliability in electricity delivery.

A prospective the transformer designer employs detailed electrical models to develop reliable and cost effective transformer insulation. Transformer aging can be evaluated using the HST. The increase in TOT and there by increase in HST has the effect of reducing insulation life [1-4]. Abnormal conditions, such as overloading, supplying non-sinusoidal loads or exposure to higher ambient temperature than normal, can accelerate transformer aging and accordingly accelerate the time to end of life. The increase in TOT and HST accelerates the end of the transformer lifetime. The average lifetime of oil-immersed a transformer based on the lifetime of the solid insulation is well defined in [5], in which the average lifetimes based on different end of life criteria are summarized. The load on a transformer cannot be increased indefinitely without

causing premature aging of transformer's insulation. Aging or deterioration of insulation is a time-function of temperature, moisture content, and oxygen content. The moisture and oxygen contributions to insulation deterioration can be minimized with modern oil preservation systems, leaving insulation temperature as the primary parameter. The primary contributor to insulation temperature is the heat generated by load losses. Since the deterioration in the insulation is related to the insulation temperature and the temperature distribution due to load losses is not uniform in the windings in most cases, it is reasonable to believe that the greatest deterioration to the insulation will happen at the part of the winding operating under the highest temperature condition. Therefore, in aging studies it is usual to consider the aging effects caused by the HST.

The variation of power transformer loading beyond nameplate rating in both normal and emergency cases increases temperature inside the transformer tank and may causes the rapid thermal deterioration of the insulation [6]. This is a cause of transformer failure. In order to make the power transformers in terminal stations operate at their full

capacity without failures due to temperature increase at the same time, a careful study of their entire thermal behaviour is needed. The standard normal lifetime for oil-immersed power transformer for a continuous HST of 110°C based on [1] and other IEEE standards.

There are two approaches to deal with HST: to measure it or to calculate it. Measuring the HST imposes unwanted costs to the system. For this reason, several models for prediction of HST have been presented in the literature [7]. Since the thermal phenomena are quite complex, it is not easy to consider all the details in the thermal model precisely. There are some simplified thermal models in the appropriate standards such as IEEE which have limited accuracy. The commonly used model is described in clause 7 in the IEEE loading guide [1]. The top oil rise equation of clause 7 of the IEEE guide is modified to allow for continuously varying ambient temperature [8]. An alternative method is suggested in Annexure G. The method requires the use of bottom oil rise over ambient at rated conditions. The duct oil temperature is introduced which may be higher than the top oil temperature under certain conditions [3]. Also this model requires more test parameters for calculating HST.

The prediction of HST compared with measured HST, the error is most likely due to insufficient driving variable data rather than an inaccurate or insufficient model [9]. In this paper, we report on the results of several attempts to improve the model used for predicting transformer HST. The result of this research lends additional support to the hypothesis that accurate prediction of transformer HST is due to noise in the input data and the absence of measurements for significant driving variables. In this paper, introduce the additional environmental variation factors such as wind velocity and solar radiation. It is assess the loss of life of proposed model. This paper is organized as follows. Section 2 reviews the thermal model for power transformer. Section 3 discusses the transformer description, which is the collection of data and design values used to construct the different models. Section 4 discusses the assessing of transformer insulation life characteristics. Section 5 discusses the transformer loss of life evaluation. Section 6 discusses the results and discussions and section 7 discusses the conclusions.

2 Thermal Model For Power Transformer

When a transformer is energized and loaded at ambient temperature (θ_a), dissipation caused by core

losses, winding losses, stray losses in the tank and metal support structures are sources of heat which cause the transformer oil and winding temperature rise. The transformer oil is cooled by the radiator assembly and flows to the bottom of the cooling ducts to reach bottom oil temperature (θ_{bo}). The transformer oil flows vertically upward the winding ducts and exits the winding ducts at the top winding duct oil temperature. The transformer oil enters the radiators at the top oil temperature in the main tank (θ_{top}) [3].

IEEE Loading Guide [1] has been used to calculate hotspot temperature. The bottom and top oil temperature are measured during temperature-rise test in manufacturer's plant. In the same process the average oil temperature rise is calculated, and the average winding temperature is obtained by resistance variation [3]. These thermal parameters use to construct the thermal model of oil-immersed transformer, as shown in Fig.1. In this model, the hot-spot temperature is the sum of ambient temperature, top oil temperature rise ($\Delta\theta_{top}$), and hot-spot to top oil temperature gradient ($\Delta\theta_H = H.g$), where H is hot-spot factor and 'g' is thermal gradient between winding and oil average temperatures.
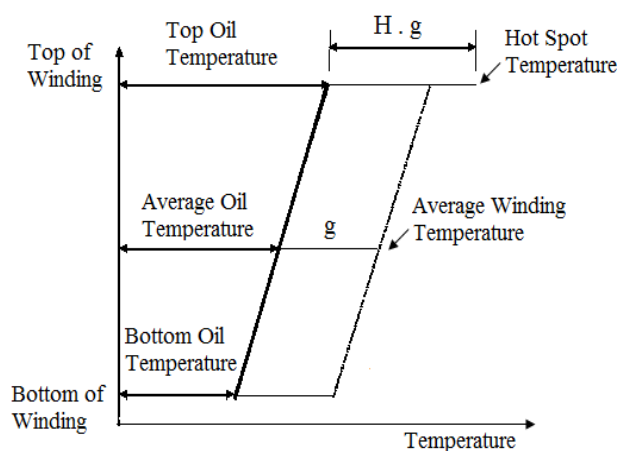

Fig. 1 Transformer Thermal Diagram

This diagram is based on the following assumptions:
- The change in the oil temperature inside and along the winding is linearly increasing from bottom to top.
- The increase in the winding temperature from bottom to top is linear with a constant temperature difference 'g'.

At the top of the winding HST is higher than the average temperature rise of the winding. The difference in the temperature between the hot spot and the oil at the top of the winding is defined as H.g, where H is a hot spot factor. It may be vary

from 1.1 to 1.5, depending on short circuit impedance, winding design and transformer size.

2.1 Top Oil Equation

The traditional IEEE top-oil-rise (Clause 7) model [1], is governed by the differential equation:

$$T_0 \frac{d\theta_0}{dt} = -\theta_0 + \theta_u \qquad (1)$$

Solution of above differential equation:

$$\theta_0 = (\theta_u - \theta_i)(1 - e^{-t/T_0}) + \theta_i \qquad (2)$$

Where

$$\theta_u = \theta_{fl} \left(\frac{K^2 R + 1}{R + 1} \right)^n \qquad (3)$$

$$T_0 = \frac{C \theta_{fl}}{P_{fl}} \qquad (4)$$

and

θ_o - top-oil rise over ambient temperature (°C);
θ_u - ultimate top-oil rise for load L (°C);
θ_i - initial top-oil rise for t=0 (°C);
θ_{fl} - top-oil rise over ambient temperature at rated load (°C);
T_o - time constant (h);
C - thermal capacity (MWh/°C);
P_{fl} - total loss at rated load (MW);
n - oil exponent
K - ratio of load L to rated load;
R - ratio of load loss to no-load loss at rated load.

However, this fundamental model has the limitation that it does not accurately account for the effect of variations in ambient temperature, and therefore is not applicable for an on-line monitoring system. Lesieutre.B.C [10] has proposed a modified top-oil temperature model developed from the IEEE top-oil rise temperature model by considering the ambient temperature at the first-order characterization. Moreover, in place of mention in top-oil rise over ambient temperature, the final temperature state is considered in the model. To correct this for ambient temperature variation, recognize that the time-rate-of-change in top-oil temperature is driven by the difference between existing top-oil temperature and ultimate top-oil temperature ($\theta_u+\theta_{amb}$):

$$T_0 \frac{d\theta_{top}}{dt} = -\theta_{top} + \theta_u + \theta_{amb} \qquad (5)$$

Where

θ_{amb} - ambient air temperature (°C);

Discretizing this model using the backward Euler rule because of its stability properties, rearranging the above equation yields,

$$\theta_{top}(k) = \frac{T_0}{T_0 + \Delta t} \theta_0 [k-1]$$
$$+ \frac{\Delta t \theta_{fl} R}{(T_0 + \Delta t)(R+1)} \left(\frac{I[k]}{I_{rated}} \right)^{2n} \frac{\Delta t \theta_{fl}}{(T_0 + \Delta t)(R+1)} + \theta_{amb}(t)$$

$$(6)$$

Where

n = 0.8 for Oil Natural Air Natural (ONAN)
 = 0.9 for Oil Natural Air Forced (ONAF) or Oil Forced Air Forced (OFAF) Non Directed
 = 1.0 for Oil Forced Air Forced Directed (OFAFD)

For forced cooling systems using the value n = 1, the above model is simplified to,

$$\theta_{top}[k] = \frac{T_0}{T_0 + \Delta t} \theta_{top}[k-1] + \frac{\Delta t}{(T_0 + \Delta t)} \theta_{amb}[k]$$
$$+ \frac{\Delta t \theta_{fl} R}{(T_0 + \Delta t)(R+1)} \left(\frac{I[k]}{I_{rated}} \right)^2 + \frac{\Delta t \theta_{fl}}{(T_0 + \Delta t)(R+1)}$$

$$(7)$$

Rewriting the above equation in a discretized form, substituting K's for the constant coefficients,

$$\theta_{top}[k] = K_1 \theta_{top}[k-1] + (1 - K_1)\theta_{amb}[k]$$
$$+ K_2 I[k]^2 + K_3 \qquad (8)$$

Where $K_1 - K_3$ are complex functions of the respective differential equation coefficients, and is the per-unit transformer current (based on the rated value of the transformer) at time-step index k.

The coefficient (1-k) is replaced by another coefficient k_4,

$$\theta_{top}[k] = K_1 \theta_{top}[k-1] + K_4 \theta_{amb}[k] +$$
$$K_2 I[k]^2 + K_3 \qquad (9)$$

The linearized models in (8) and (9) are both physical models; they are based on physical principles.

2.2 Hot Spot Equation

Main aim of this paper is to determine the acceptability of HST model by fitting with measured data and to examine the method can be used for the fitting process. We made several changes to the top-oil model in hopes of improving its performance. This is to be expected since, by adding another coefficient, we have added an extra degree of freedom that the linear optimization routine can use to find a better model. The resulting model is known as a semi-physically based model because it is not entirely based on physical principles.

It is made to the model was to account for solar radiation and wind velocity ref. in [11-12]. Solar radiation and wind velocity is a significant

source of environmental variation factors when transformer placed in outdoor. The equations (10) and (11) are used to predict the HST via top oil temperature rise model.

$$T_0 \frac{d\theta_{top}}{dt} = -\theta_{top} + \theta_u + \theta_{amb} + \theta_R + \theta_{wx} + \theta_{wy} \qquad (10)$$

Discretizing (10) using the backward Euler discretization rule gives the linear form,

$$\theta_{top}[k] = K_3\theta_{top}[k-1] + K_2\theta_{amb}[k] + K_1 I[k]^2 \\ + K_4 + K_5 S_{rad}[k] + K_6 V_x[k] + K_7 V_y[k] \qquad (11)$$

Where, coefficients $K_1 - K_7$ can be calculated from measured data using standard linear least squares technique, since all of them appear linearly in the model.

Using TOT predicted by the model (11), we can calculate the HST from the following equation:

$$\theta_h = \theta_{top} + \theta_{hm}\left(\frac{I(k)}{I_{rated}}\right)^{2m} \qquad (12)$$

Where θ_{hm} is the maximum HST over TOT in the rating load that provided by manufacturer. In this case study θ_{hm} is 36℃. Also, m is the cooling coefficient and can vary in the range of 0.8–1. In this study forced cooling system is considered in which m is 1.

3 Transformer Description

To validate the proposed model, data gathered under various load conditions from a real power transformer (100 MVA and 230/110 kV) which are recorded in the month of may , have been used. In this study, work has been carried out in a power transformer situated at Perundurai, Tamilnadu, with the specifications as shown in Table 1.

Table 1 Rating of Substation Transformer

Parameter		Value
Rating		100 MVA
Rated Voltage	HV	230 kV
	LV	110 kV
Rated Line Current	HV	251 A
	LV	525 A
Weight of core & Coil		74,000 kgs.
Weight of Tank and Fittings		35,000 kgs.
Oil mass		41,800 kgs.
Total Weight		1,50,800 kgs.
Volume of Oil		4,700 lit.
Top Oil Temperature Rise		50 °C
Hottest Spot Conductor rise over Top Oil temp. rise at rated load		36 °C
Ratio of Load loss at rated load to no-load loss (R)		5.0
Oil time constant (Watt-hour/ ℃)		3.0

TOT, Load, and ambient temperature were sampled every 30 minutes for 24 hours . Similarly, wind velocity and solar radiation measured and missed data were received from metrological department. The data were filtered to eliminate bad data and divided into separate data files. The models built in this work use only the highest cooling mode: NOFA or FOFA.

4 Transformer Insulation Life Characteristics

Insulation aging is a function of temperature and other environmental factors. Today with modern cooling systems, the effect of solar heat flux can be reduced, but the temperature is a limiting factor that should not exceeded from a predetermined value. Since, in most apparatus, the temperature distribution is not uniform, that part which is operating at the highest temperature will ordinarily undergo the greatest deterioration. Therefore, in aging studies, it is usual to consider the aging effects produced by hottest spot temperature.

4.1 Aging calculation
IEEE Loading guide shows that insulation life is an exponential function of HST [1]:

$$\% \text{ of Insulation life} = A.e^{\left(\frac{B}{\theta_h + 273}\right)} \qquad (13)$$

Where θ_h is the HST (℃), A and B are constants that are determined according to insulation material and HST reference defined for normal insulation life. Equation (13) can be used for both distribution and power transformers because both are manufactured using the same cellulose insulation. For instance, suppose HST reference for insulation life to be 110℃. It means that if the transformer works continuously with this HST, its life will be 1 per unit (life in hour can be determined according to the used insulation). Using above assumptions, equation (13) would be:

$$\text{Per Unit Life} = 9.8 \times 10^{-18} e^{\left(\frac{15000}{\theta_h + 273}\right)} \qquad (14)$$

Equation (14) yields a value of 1 per unit life for the reference HST of 110 ºC and it is the basis for calculating the aging accelerating factor (F_{AA}). The F_{AA} is the rate at which a transformer insulation aging is accelerated compared with the aging rate at 110 ºC. F_{AA} is given as

Aging Accerlation Factor ,

$$F_{AA} = e^{\left(\dfrac{15000}{383} - \dfrac{15000}{\theta_h + 273} \right)} \qquad (15)$$

F_{AA} is greater than 1 when the HST is over 110 ºC and less than 1 when the HST is below 110 ºC. A curve of F_{AA} vs. HST is shown in Fig. 2 and some F_{AA} values at different temperatures are presented in Table 2. The conclusion from Fig. 2 and Table 2 is that the loss of life of transformer insulation is related to the HST exponentially.

Table 2   Aging Acceleration Factor at Different HST Values

HST (ºC)	F_{AA}	HST (ºC)	F_{AA}
60	0.0028	130	6.9842
70	0.0104	140	17.1995
80	0.0358	150	40.5890
90	0.1156	160	92.0617
100	0.3499	170	201.2294
110	1.0	180	424.9200
120	2.7089	190	868.7719
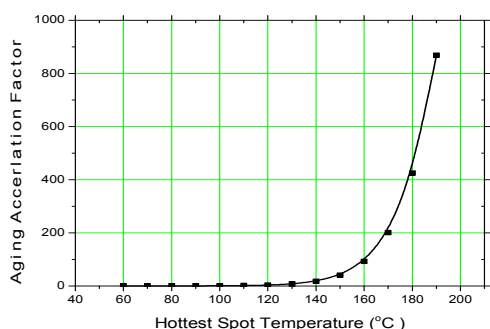
Fig. 2. F_{AA} Vs HST Plot

The HST is varying according to load and ambient temperature. For this reason, (15) may be used to calculate equivalent aging acceleration factor of the transformer. The equivalent aging acceleration factor at the reference temperature in a given time period for the given temperature cycle is defined as:

$$F_{EAA} = \frac{\sum_{n=1}^{N} F_{AA,n} \Delta t_n}{\sum_{n=1}^{N} \Delta t_n} \qquad (16)$$

Where F_{EAA}, is equivalent aging acceleration factor for the total time period. N is total number of time intervals. Δt_n is n^{th} time interval and $F_{EAA,n}$ is aging acceleration factor for the temperature which exists during the time interval Δt_n.

4.2   Percentage Loss of Life

The equivalent loss of life in the total time period is determined by multiplying the equivalent aging by the time period (t) in hours. In this case total time period used is 24 hours. Therefore, the equation of percent loss of life equation is as follows [1] :

$$\% \text{ Loss of Life } = \frac{F_{EAA} \times t \times 100}{\text{Normal Insulation Life}} \qquad (17)$$

5   Transformer Loss of Life Evaluation

The evaluation based on the climatic parameters included in the TOT and HST calculations. It is to construct four different models using equation (12), according to the inclusion of environmental variables solar radiation heat flux and wind velocity as follows:

Model   1: Derived from Amoda model
Model   2: Semi-physically based model with
          solar   radiation and wind velocity effects

Using linear regression analysis and least square estimation method estimate the top oil temperature and hot spot temperature by equations (11) and (12)

5.1   Constructing of X and Y Matrix

Using matrices allows for a more compact frame work in terms of vectors representing the observations, levels of regressor variables, regression coefficients, and random errors.

For the linear model, the X matrix contains measured values of I^2, θ_{amb}, solar radiation S_{rad}, wind velocity components V_x, V_y and as a lagged regressor, $\theta_{top.}$

Regression models involve the following variables:

- The unknown parameters denoted as β; this may be a scalar or a vector.
- The independent variables, X.
- The dependent variable, Y.

In various fields of application, different terminologies are used in place of dependent and independent variables.

A regression model relates Y to a function of **X** and **β**.

The approximation is usually formalized as $E(Y \mid \mathbf{X}) = f(\mathbf{X}, \boldsymbol{\beta})$. To carry out regression analysis, the form of the function f must be specified. Sometimes the form of this function is based on knowledge about the relationship between Y and **X** that does not rely on the data. If no such knowledge is available, a flexible or convenient form for f is chosen.

Assume now that the vector of unknown parameters **β** is of length k. In order to perform a regression analysis the user must provide information about the dependent variable Y:

- If N data points of the form $(Y,\mathbf{X})$ are observed, where $N < k$, most classical approaches to regression analysis cannot be performed: since the system of equations defining the regression model is underdetermined, there is not enough data to recover $\boldsymbol{\beta}$.
- If exactly $N = k$ data points are observed, and the function f is linear, the equations $Y = f(\mathbf{X}, \boldsymbol{\beta})$ can be solved exactly rather than approximately. This reduces to solving a set of N equations with N unknowns (the elements of $\boldsymbol{\beta}$), which has a unique solution as long as the $\mathbf{X}$ are linearly independent. If f is nonlinear, a solution may not exist, or many solutions may exist.
- The most common situation is where $N > k$ data points are observed. In this case, there is enough information in the data to estimate a unique value for $\boldsymbol{\beta}$ that best fits the data in some sense, and the regression model when applied to the data can be viewed as an over determined system in $\boldsymbol{\beta}$.

In the last case, the regression analysis provides the tools for:

1. Finding a solution for unknown parameters $\boldsymbol{\beta}$ that will, for example, minimize the distance between the measured and predicted values of the dependent variable Y (also known as method of least squares).
2. Under certain statistical assumptions, the regression analysis uses the surplus of information to provide statistical information about the unknown parameters $\boldsymbol{\beta}$ and predicted values of the dependent variable Y.

5.2 MATLAB Program

Using equation (13), the coefficients to run the MATLAB programme were found, There are several options in MATLAB to perform multiple linear regression analysis (MLR). One option is Generalized Linear Models in MATLAB (glmlab) which is available in either Windows, or Unix. Variables and data can be loaded through the main.glmlab window screen. Another option is the Statistical Toolbox, which allows the user to program with functions. MATLAB programs can also be written with m-files. These files are text files created with either functions or script. A function requires an input or output argument. While the function method simplifies writing a program, using script better illustrates the process of obtaining the least squares estimator using matrix commands.

6   Results and Discussions
6.1   Normal and Emergency Load Profile

Fig. 3 shows the typical load, ambient temperature and hottest spot temperature profile for 24 hour normal load cycle in summer season (mid of may) of a 230/110 kV, 100 MVA power transformer..
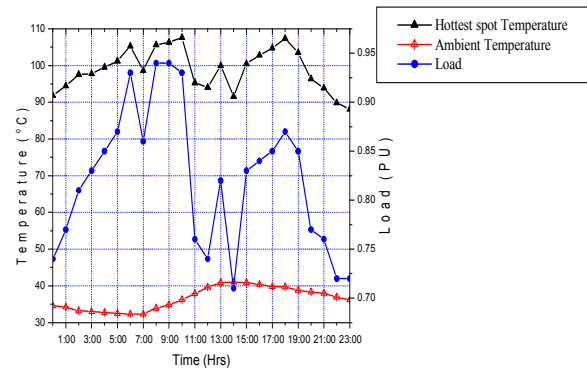

Fig. 3 Typical Load, Ambient and Hotspot Temperature curve for 24 hrs normal load cycle

Also Fig. 4 shows that the estimated results of corresponding aging accerlation factor for normal load cycle. Fig. 5 shows the typical load, ambient temperature and hottest spot temperature profile for 24 hour load cycle with 2 hours emergency load between 11 am to 1 pm. Fig. 6 shows the corresponding 2 hours emergency load cycle aging accerlation factor. The results obtained using IEEE loss of life equations, at normal load cycle accumulated aging is 8.830 hours of 1,80,000 hours with the hot spot temperature is not exceed to 110 ℃. The thermal age characteristics comparison for a normal load and emergency load profiles are shown in Fig. 7.
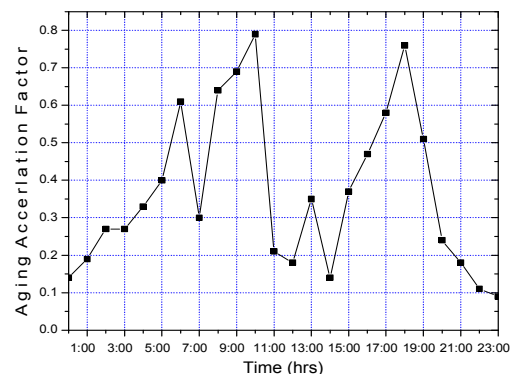

Fig. 4 Aging Accerlation Factor for 24 hrs normal load cycle

The Fig. 6 and Fig.7 shows that the aging acceleration factor increases appropriately due to the load variation. Similarly loss of life for emergency load in percentage for a 24 hours load cycle with 2

hours emergency load is 0.61. The above value is increased due to short overloading of 2 hrs between 11 am to 1 pm, resulting in the hot spot temperature and aging accerlation factor exceeded the acceptable limit. The equivalent aging accerlation factor for normal hourly load profile is 0.37 and the equivalent aging accerlation factor for emergency load profile is 4.54. The result shows that the overloaded transformer has spent 109 hours or 4.5 days of its life.
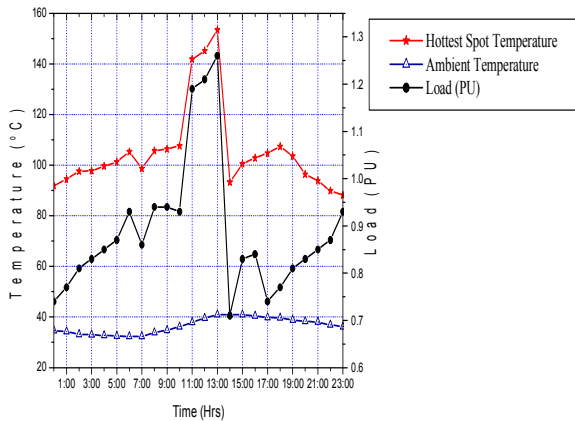

Fig. 5 Load, Ambient and Hotspot Temperature curve for 24 hrs load cycle 2 hrs emergency load
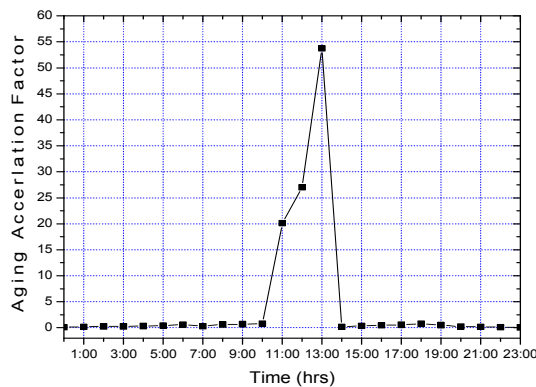
Fig. 6 Aging Accerlation Factor for 24 hrs load cycle with 2 hrs emergency load

6.2   Normal and Emergency Load Profile for semi physical model

It is derived from the two models, the changes of load would be greater comparing to thermal changes which result appropriate effect of temperature on the models.
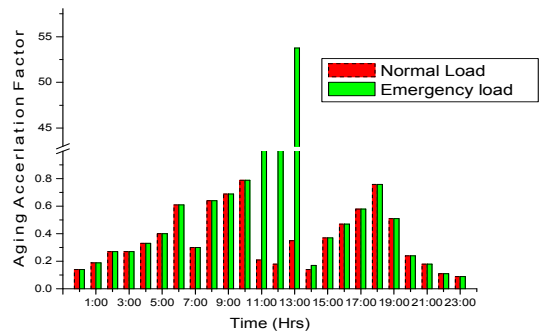
Fig. 7. Comparison of Aging Accerlation Factor (Faa) for normal and Emergency Load

It is to investigate the effect of environmental variables and ambient temperature on transformer's insulation life. To do this, first it is to calculate the θ_{top} using (11) for the given load and ambient temperature and then with substituting it in (12) then calculate the HST. The results of final predicted proposed HST (model 2) and amoda method (model 1) compared with measured value and results in percentage of error is shown in Fig. 8.
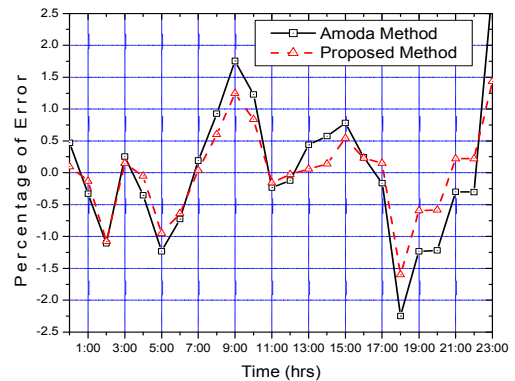

Fig. 8. Hot Spot Temperature: Error Comparison for normal load profile

Calculation derived from two models cumulative insulation age for normal load profile   using equation (15) and the results compared with actual are shown in Fig. 9, also it should use to calculate equivalent aging acceleration factor (Equation (16)). Accumulation of age for actual (HST Measured using optical fibre measurement) is more compared with two models and model 2 closer than Model 1.

The equivalent aging acceleration factor in two cases are added for each hour and divided by the time cycle of total time period (24 hours). The transformer is overload (emergency) temporarily with the same climatic situation the results are shown in Fig. 10 and Fig 11.
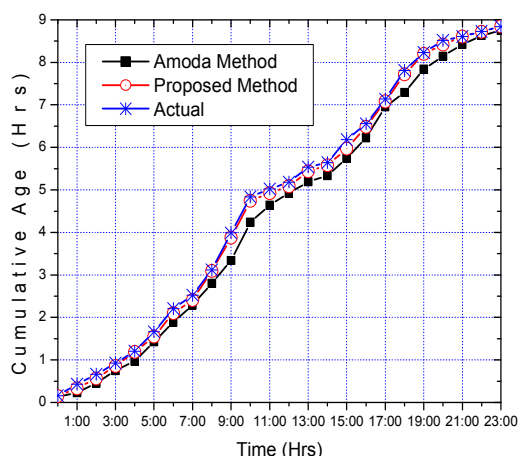
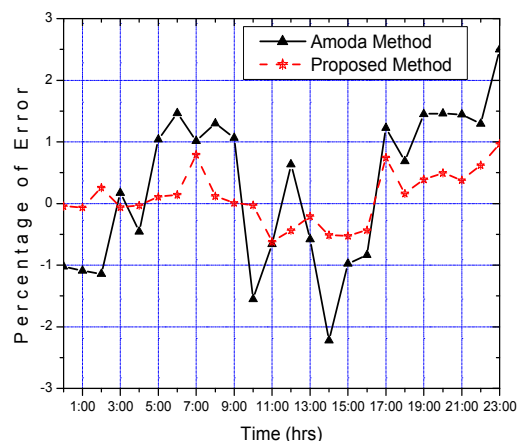Fig. 9 Cumulative insulation age Comparison for normal load profile

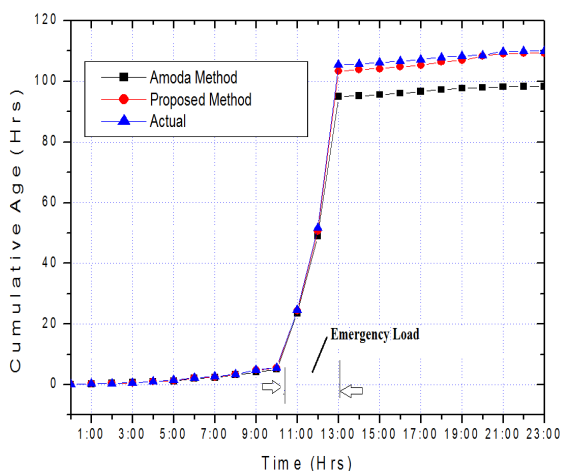Fig. 10. Hot Spot Temperature: Error Comparison for emergency load profile

Fig. 11. Cumulative insulation age for emergency load profile

6.3 Environmental variable effects

Fig. 8 and 9 shows that HST and cumulative age calculations are made for semi physical model with normal load profile. Fig. 10 and 11 shows that HST and cumulative age calculations are made for two models with emergency load profile. The loss of life (using Equation (17)) in percentage and in hours is shown in Table 3 for 24 hours load cycle.

In normal load profile model 2 shows better result which is closer to the actual HST and cumulative age. But a the models compared with actual HST and cumulative age, resulting as model 2 is closer to actual and model 1 is away from actual as shown in Fig.8 and Fig.9. The comparison in emergency load the difference is larger than in normal load as shown in Fig. 10 and Fig.11.

Table 3 Percentage Loss of life

24 hrs. Load Cycle	% Loss of Life		
	Model 1	Model 2	Actual
Normal Load	0.004914	0.00493	0.00495
Emergency Load	0.05464	0.05784	0.06058

In order to show the performance of the model as well as its precision and accuracy in HST modelling, 24 hours data's are used to predict TOT in all ranges. Fig.9 shows that addition of wind velocity and solar radiation of model 2. It is able to produce better result. The error between measured and predicted values is minimum.

6.4 Description of MATLAB/Simulink Model

The top oil temperature and hot spot temperature model has been calculated based on IEEE clause 7 and semi physical model equations (1) and (11).

Load and ambient temperature data's are saved in workspace and it is fed to an input of TOT model and the output of top oil temperature rise as a input of hot spot temperature model. Fig. 12. shows the Simulink model of proposed systems which allows additional input of solar radiation and wind velocity to the existing model inputs of load and ambient temperature. The wind velocity component divided in to two orthogonal components and it is fed it separately. Fig.13. shows the subsystem of proposed system which is top oil temperature rise model. Fig. 14. shows the subsytem1 of proposed system which is hot spot temperature model comprising the function of equation (12) and its output is hot spot temperature. Fig. 4 and 5 shows that MATLAB/Simulink simulation output of TOT

and HST of waveform for semi physical model with normal load profile. Simulation of TOT and HST are closer to measured value.
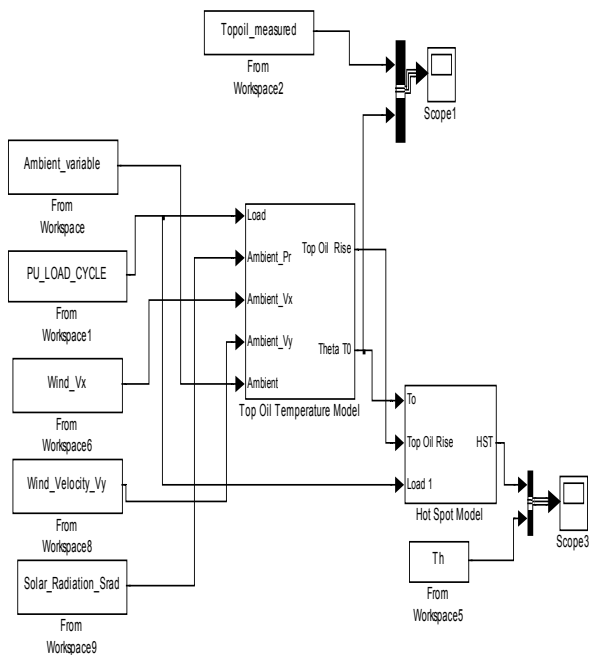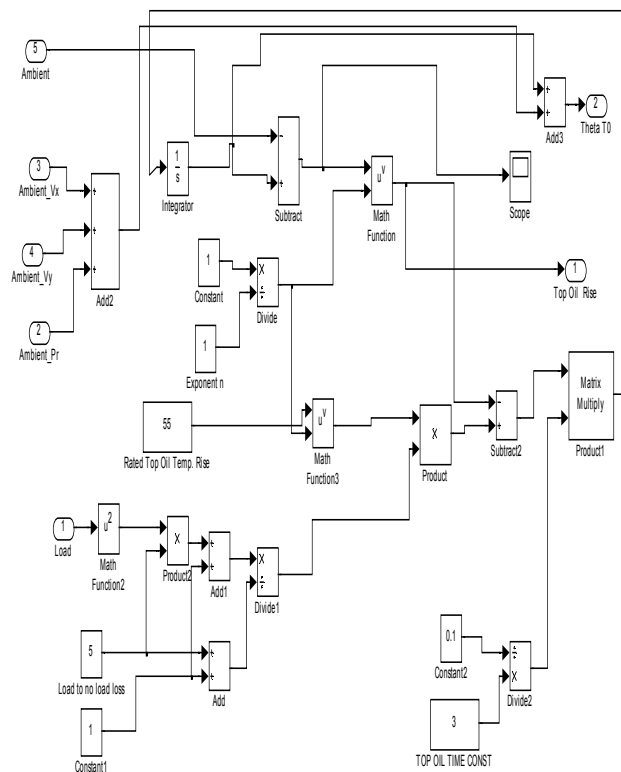

Fig.12. MATLAB/Simulink Model of proposed system
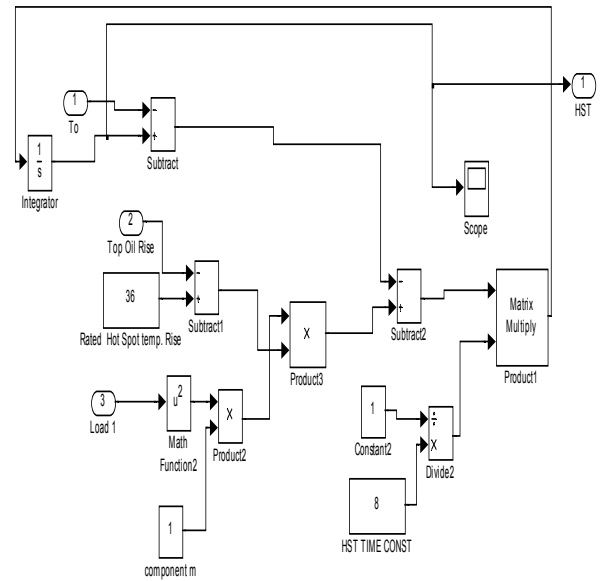

Fig. 13. Top Oil Temperature rise simulink model

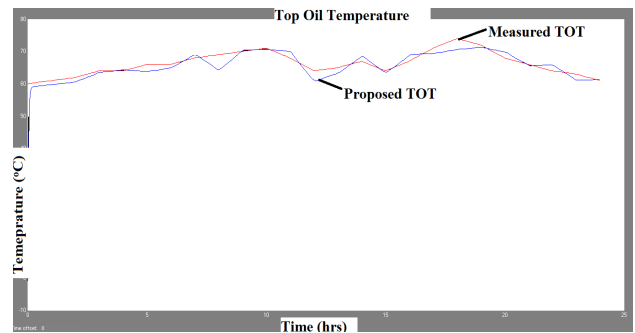

Fig.14. Hot Spot Temperature model
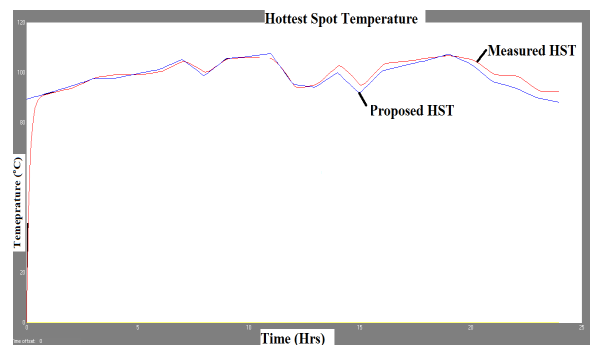

Fig. 15. Top Oil Temperature waveform

Fig. 16. Hot Spot Temperature waveform

7. Conclusion

In this paper an improved model for the estimation of TOT in transformers was proposed. The authors have used two models to attempt to accurately predict transformer temperature and loss of life for both normal and

emergency loads. The actual 24 hours data's of ambient temperature, solar heat flux, and wind velocity in summer season are the base parameters for proposed method. The semi-physically based model leading to the conclusion that any of several models are satisfactory for predicting transformer Hot-Spot-Temperature (HST). The preferred model for predicting HST is the linear semi-physically based model because it permits the use of simple and robust linear regression techniques. In this method, we expected the addition of solar radiation and wind velocity to significantly reduce the gap between actual and predicted. In this paper was shown that model 2 is a good model. Using the proposed semi physical model, the effect of ambient temperature and environmental variables on transformer insulation aging was investigated. Although in this study the proposed model was used to study the effect of environmental variables on insulation life, it is an exact model and used to predict the percentage loss of life the transformer.

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