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Estimation of optimum load and thermal response for Oil-Natural-Air-Natural cooling type power transformer

By

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Abstract:

This paper described the estimation of optimum load and thermal response for the Oil-natural Air-natural (ONAN) cooling type power transformer with installed load capacity of 30MVA in Sarawak, Malaysia. The estimation optimum load capacity is based on the nameplate rating, standard design of the existing transformer and factory acceptance test report (FAT). This involved loss of life and transformer thermal response such as hot-spot temperature, top-oil temperature, winding temperature and ambient temperature. By using the existing cyclic load of this transformer, the risk condition of the transformer could be prevented since capacity load could be estimated. The algorithms of this project were based on IEEE standard and IEC loading guide for oil-immersed power transformer.

Keywords:

Thermal response, optimum load capacity, hot spot temperature.

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1. Introduction:

The transformer's cyclic load profile could be used to estimate the transformer life and the maximum winding hot spot temperature rise occurred inside the insulator. Most of the power suppliers were interest in the transformer life expectancy and insulator temperature. The influence of hot spot temperature rise could affect the Degraded Polymerization (DP) of the oil insulator. Limitation of the load occurs in order to avoid the bubble generated and reduced the weakness of the dielectric. Stability and reliability of the performance in this transformer influences due to this tragedy. To obtain the optimum load without harm to the transformer's life, the rated value in nameplate used. IEEE and IEC loading guide for oil-immersed power transformer standard were used [1, 2, 3, 4, and 5].

2. Transformer Thermal response models:

In the analysis of the ONAN cooling type power transformer, the parameters obtained were shown in Table 1. These parameters are useful in order to obtain precise thermal response.

Besides, the load profile was needed in this case for the estimation of the optimum load capacity and transformer thermal response. Heat generated depends on the daily load profile which is the reactive power losses from the coil.

The time interval of the daily load profile and the top oil temperature rise in steady state condition must be determined in order to estimate real time maximum top oil temperature rise. The duration of the maximum top oil temperature rise which is the top oil time constant in hour is given by the following formula;

$$\tau_{TO,R} = \frac{C \times \Delta\Theta_{TO,R}}{p_{T,R}} \tag{1}$$

Where the thermal capacity for the ONAN cooling type transformer is determined as following formula;

$$\begin{aligned} C = {} & 0.1322(\text{Weight of core and coil assembly}) \\ & + 0.0882(\text{Weight of tank and fittings}) \\ & + 0.3513(\text{Liters of oil}) \end{aligned} \tag{2}$$

Table (1): *Transformer parameters*

Parameters	Value
No-load losses	10.98kW
Load losses	122.91kW
Ratio load losses to no-load losses at rated kVA ,R	11.1940
Top oil temperature at rated kVA,	60ºC
Winding temperature at rated kVA	25.09ºC
Weight of core and coil assembly	27750kg
Weight of tank and fittings	34250kg
Liters of oil	17.75ℓ
ONAN Exponent parameter, *m*	0.8
ONAN Exponent parameter, *n*	0.8
Interval time, *t*	0.5h
Total load losses	144.66kW

2.1. Top Oil Temperature Rise Over Ambient:

The ultimate top oil temperatures rise over ambient temperature is given as below;

$$\Delta\Theta ou = \Delta\Theta_{TO,R}\left(\frac{1+RK^2}{1+R}\right)^n \qquad (3)$$

Where the initial top oil temperatures rise over ambient temperature is given as following formula;

$$\Delta\Theta oi = \Delta\Theta_{TO,R}\left(\frac{1+RK^2}{1+R}\right)^n \qquad (4)$$

The top oil temperature rise is the differential of the ultimate and initial top oil temperature with the exponents factor which is given in the formula;

$$\Delta\Theta_{TO} = \Delta\Theta oi + (\Delta\Theta ou - \Delta\Theta oi)\left(1-\exp\left(\frac{-t}{\tau_{TO,R}}\right)\right) \qquad (5)$$

2.2. Winding Hottest Spot Temperature rise:

Transient winding hottest spot temperature rise over top oil temperature is given by;

$$\Delta\Theta_H = \Delta\Theta_{H,R} K^{2m} \tag{6}$$

2.3. Hot Spot Temperature:

The hot spot temperature could be obtained from the summation of top oil temperature rise, winding hottest spot temperature rise and ambient temperature. This equation is shown below;

$$\Theta h = \Theta a + \Delta\Theta_{TO} + \Delta\Theta_H \tag{7}$$

2.4. Aging Acceleration Factor:

For the equation of an aging acceleration factor (F_{AA}) for a given load and temperature or for a varying load and temperature profile over a 24 hours period as follows;

$$F_{AA} = \exp\left(\frac{15000}{383} - \frac{15000}{\Theta h + 273}\right) \tag{8}$$

2.5. Loss of Life:

Percent loss of insulation life in the time period is equivalent hours life consumed divided by the definition of total normal insulation life (hours) and multiplied by 100. The equation is given as follows;

$$\%LOL = \frac{F_{EQA} \times 24}{Normal \quad Insulation \quad Life} \times 100 \tag{9}$$

Where normal insulation life is 219000h (25 years) and F_{EQA} is equivalent aging factor for the total time period is given by equation below;

$$F_{EQA} = \frac{\sum_{n=1}^{24} F_{AAn} \Delta t_n}{\sum_{n=1}^{24} \Delta t_n} \tag{10}$$

3.0. Results:

Thermal response of the ONAN cooling type with 30MVA, 33/11kV transformer where tested by using the parameters and the methodology above. Daily equivalent load of this transformer where taken as shown in Figure 1. From the experiment, the peak load obtained is 0.403928p.u fall between 8.04 to 9.01 hours. Table 2 shows the daily equivalent load. Therefore the optimum load for this daily load is 0.403928 which is equal to 12.11784MVA. The optimum capacity load could be overloaded below the 1.20p.u.

Table (2):*The duration of the daily equivalent load*

Time /hour	Load/per unit
0 to 8	0.183095
8.04 to 9.01	0.403928
9.02 to 24	0.183095

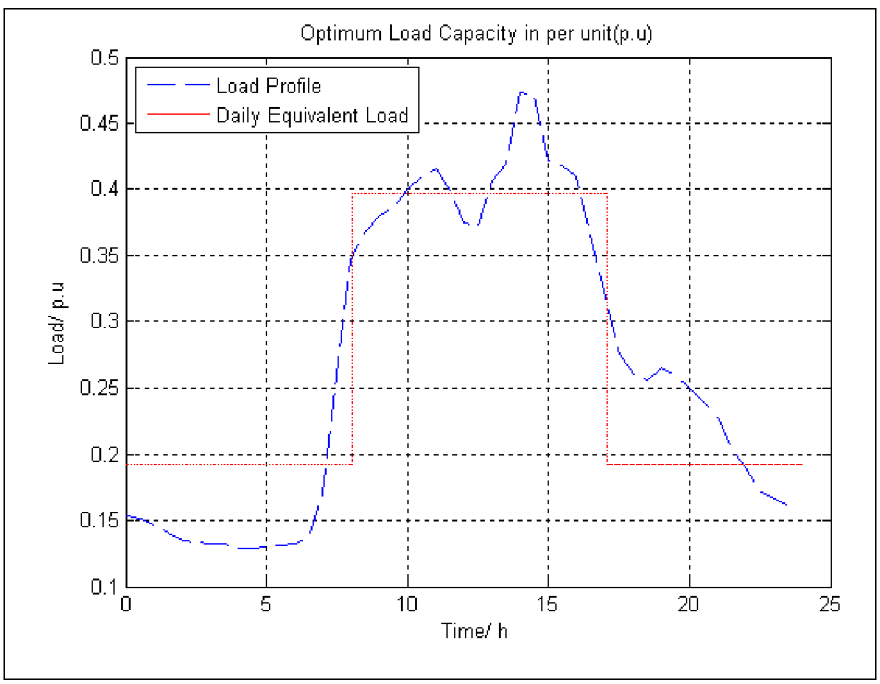

Figure (1): *Load profile with the one cycle Daily Equivalent Load*

Average ambient where taken by measured 1m length from the back side, rear side, left and right side of the transformer. Although the range of the temperature is in the range of 23ºC to 34ºC, the average ambient temperature obtain is 30 ºC for duration of 24 hour.

The hottest-spot temperatures were 55.48ºC and 54.13ºC for the IEEE method and IEC method correspondingly. Figure 2 and Figure 3 shows the thermal response based on IEEE and IEC. Mean square error (MSE) of the top oil temperature measurement and method is acceptable with 3.8079. In other meaning that, this is very accurate and precise. However, the MSE of the IEC method is still acceptable with value of 7.9615.

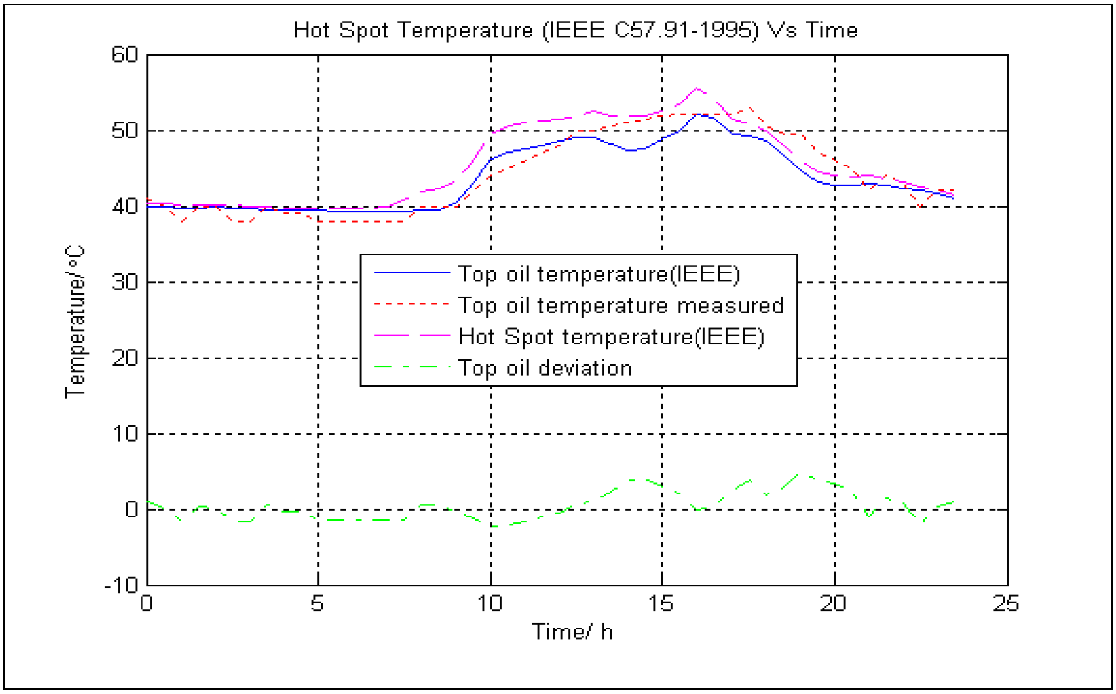

Figure (2): *Thermal response based on IEEE*

Table 3 show the maximum and minimum deviation of the top oil temperature. The deviation patterns were shows in the Figure 2 and Figure 3.

Aging acceleration factor for both standard were shown in Figure 4 and Figure 5. Non losses of life occur in this type of load.

Table (3): *Deviation of the top oil temperature*

	Temperature	
	(IEEE)	(IEC)
Hottest Spot temperature	55.4831ºC	54.1302ºC
Maximum Deviation	4.8836 ºC	6.8362ºC
Minimum Deviation	-2.2319ºC	-2.9364ºC
Mean Square Error (MSE)	3.8079	7.9615

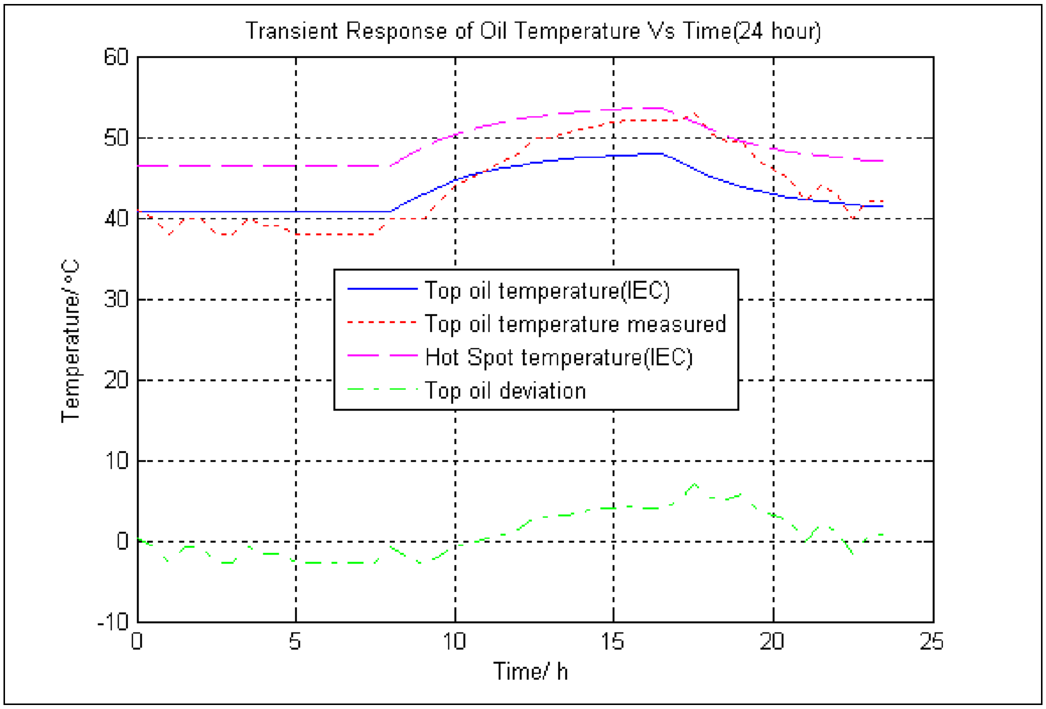

Figure (3): *Thermal response based on IEC*

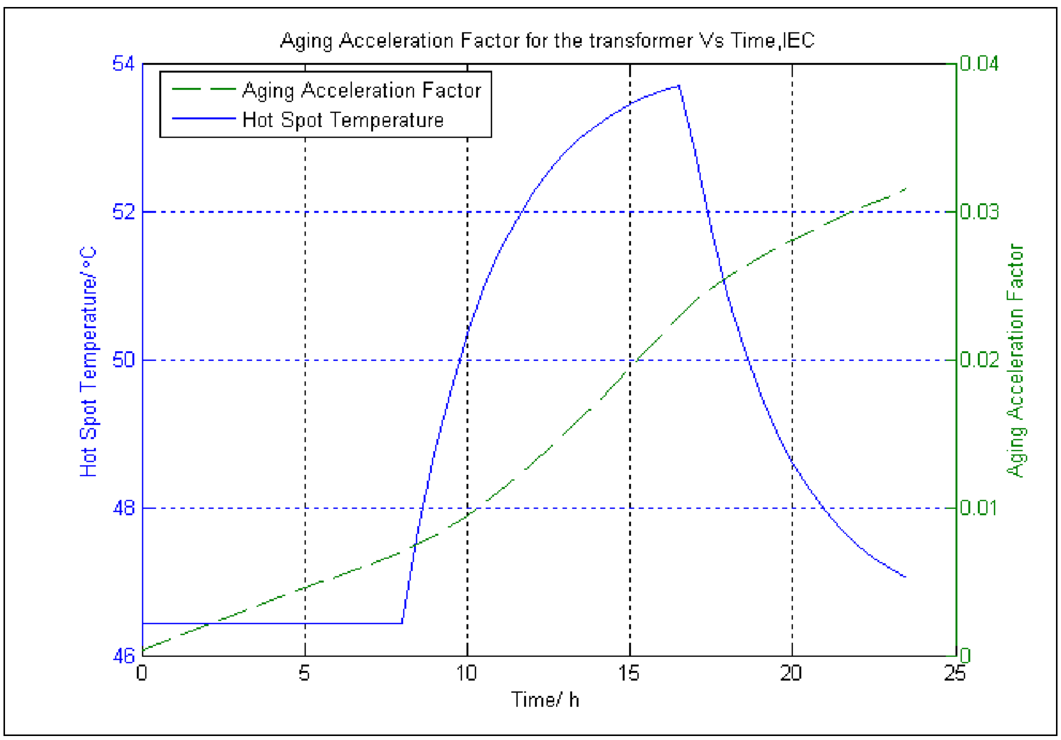

Figure (4): Aging acceleration factor based on IEC

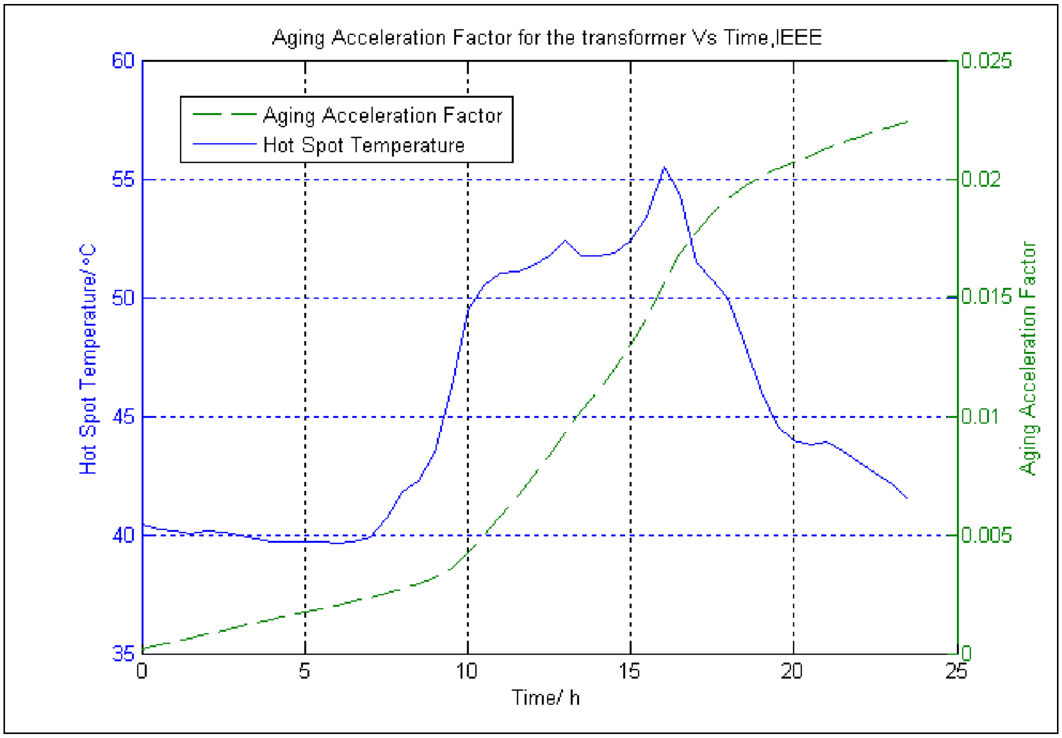

Figure (5): *Aging acceleration factor based on IEEE*

4.0. Conclusion:

As a conclusion, the mean square errors for both standards are acceptable. In other words, the estimation of the optimum load capacity and thermal response model is accurate and precise with the ambient temperature of 30ºC. There are non losses of life in this type of load due to the under load with below than 0.5p.u.

This model could be used in the thermal response notification and could use for the prediction for the planned load beyond nameplate (PBLN), short term emergency load (STE) and long term emergency load (LTE). The development of the prediction for the PBLN, STE and LTE will be carried out in future.

References:

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Nomenclatures:

R … Ratio load losses to no-load losses at rated kVA

K … Load profile per unit

$\Delta\Theta_{TO,R}$ … Top oil temperature at rated kVA in ºC

$\Delta\Theta_{H,R}$ … Winding temperature at rated kVA in ºC

$\Delta\Theta ou$ … Ultimate top oil temperature rise in ºC

$\Delta\Theta oi$ … Initial top oil temperature rise in ºC

Θa … Ambient temperature in ºC

$\Delta\Theta_{TO}$ … Top oil temperature in ºC

$\Delta\Theta_{H}$ … Winding hottest-spot temperature rise in ºC

Θh … Hot-Spot temperature in ºC

$p_{T,R}$ … Total power losses in KW

C … Thermal Capacity in W-h/ ºC

$\tau_{TO,R}$ … Top oil time constant in hour

t … Time interval of the load in hour

m … Exponent parameter

n … Exponent parameter

F_{AA} … Aging Acceleration Factor

F_{EQA} … Equivalent Aging Factor

$\%LOL$ … Loss of Life in percentage