OPEN ACCESS

International Journal Of Modern Engineering Research (IJMER)

Losses of Distribution Transformer under Load and Ambient Temperature

Mohamed Shaban[1], Adel Yahya[2]

*(Department of Electric and Electronic Engineering, High Electric Institute, Surman, Libya)

**(Department of Industrial Engineering, Regdalen, Al-Zawia University, and Zawiya, Libya)

ABSTRACT:- *Power transformer are important components in the distribution of electrical energy, and the loss of strategic unit can have an enormous impact on security and reliability of energy supply. The paper describes the algorithm for determining relative aging rate and loss on power transformer using the computer program, according to the thermal model of transformer given in (1). The simulation on the real transformer daily loading diagram and real ambient temperature is applied.*

Keywords:- *Power transformer, electrical energy, computer program, real temperature, real transformer.*

I. INTRODUCTION

Now much effort of power utilities and users are aimed to reduce the time of power failures and improve the power supply reliability. To achieve this aim, it is important to prevent power faults in distribution transformers resulted from deterioration of their insulation. One of the most important parameters is the operating temperature that has a major influence on the aging of the insulation and the lifetime of the unit. More specifics, the winding with the highest temperature, alias -hot spot will cause the degradation of the oil and insulation characteristics. The load ability of a transformer is limited by the allowable winding hot spot temperature and acceptable loss of life, owing to the heating effect from the conductor-carrying load current. Both the limiting factors are dependent on environmental conditions (ambient temperatures, solar heating, etc.) and load shapes (peak-load magnitudes, durations and frequencies). Many utilities are reviewing their transformer-loading guides by means of computer simulations of transformer thermal behavior under realistic operating conditions in attempt to make the best use of transformer capabilities [1].

II. THERMAL MODEL

It is known from the theory that the transformer is an apparatus with complex distribution of temperatures in certain functional parts. Their values change in each part of the transformer. Ageing of insulation is the most sensitive in the point with the highest temperature, hot-spot temperature of winding. The hot-spot temperature determines the transformer actual power and life duration. It occurs at top of windings, around radial area of winding, on the internal side of the insulation [1]. The exact calculation of the temperature distribution is a complex problem. It applies both to steady state and transient duties.

2.1. TEMPERATURE EQUATIONS

For distribution transformers with natural flows of oil and air (ONAN), the hot-spot temperature under any load K is equal to the sum of the ambient temperature, the top-oil temperature rise and the temperature difference between the hot spot and the top-oil:

$$\theta_a + \Delta\theta_{ok} + Hg_K = \theta_h \tag{1}$$

where:

$\Delta\theta oK$ - is top-oil temperature rise under load K [K]

Hg K - is temperature difference between the hotspot and the top-oil under load K [K] Top-oil temperature rise under any load K is determined by the following equation:

$$\Delta\theta_{or}.\left(\frac{1+R.K^2}{1+R}\right) = \Delta\theta_{oK} \tag{2}$$

Temperature difference between hot-spot temperature and top-oil temperature under any load K is:

$$Hg_r \cdot K^y = Hg_K \tag{3}$$

Where:
Hgr is temperature difference between hot-spot temperature and top-oil temperature under rated load [K].

2.2. RELATIVE THERMAL-AGEING RATE

Thermal ageing of the transformer insulation is a process of chemical nature, which primary depends on its temperature. Under the term thermal ageing is understood deterioration of its quality, i.e. deterioration of electrical and mechanical characteristics. Deterioration of these characteristics below specified limits may be considered that the design life duration of the transformer is over [2]. According to the Arrhenius law on chemical reaction rate, life duration is expressed as:

$$L_d = e^{\left(\alpha + \frac{\beta}{T}\right)} \tag{4}$$

Previous expression can be approximated by the simpler exponential expression of Mont singer life duration of the transformer is given by the expression:

$$L_d = e^{-p.\theta} \tag{5}$$

Where:
p is a coefficient of temperature variation for certain class of insulation,
θ is the temperature in degrees Celsius.

In the actual temperature range, this expression is sufficiently accurate and it gives conservative results, it means that calculation error results in estimated loss of life. There is, however, no simple and unique end-of life criterion that can be used for quantitative statements about the remaining life of transformer insulation, but it is possible to make meaningful comparisons based on rate of ageing instead. This is the inverse of the lifetime of transformer insulation, which is call rate of ageing (E):

$$E = C.e^{p.\theta} \tag{6}$$

The constant in the (6) is dependent on characteristics of insulation and cooling medium. According to IEC 354, the coefficient for temperature variation p may be taken as a constant over the actual range of temperature between 80 c^0 and 140 c^0 for thermal class of insulation "A" value of the coefficient p is such that the rate of ageing doubles for every temperature rises of 6 K. The rate of ageing refers to the winding hot-spot temperature. For transformers designed in accordance with IEC 76, hot-spot temperature at which ageing rate is normal, at rated load and ambient temperature of $20C^0$ is 980C. Relative ageing rate at other operating conditions is defined as ratio of ageing rate at and normal ageing rate and is expressed as [3]:

$$V = \frac{E(\theta_h)}{E(98^0C)} \tag{7}$$

Given the value of the coefficient p, relative rate of thermal ageing can be expressed as follow:

$$V = 2^{\frac{\theta_h - 98}{6}} \tag{8}$$

This function implies that the relative ageing rate is very sensitive to the hot-spot temperature.

2.3. LOSS-OF LIFE

The evaluation of power transformer loss of life is, of course highly dependent of deterioration conditions of the materials (oil, insulated paper, etc.) from which a transformer is built. The main reasons for the deterioration of these substances, along the lifetime of transformer are:
1- Abnormal heating due to overload operations.
2-Mechanical stresses.
3- over voltages.
4- High humidity of the oil.

Loss-of-life which is caused by overload of the transformer is expressed in months, days or hours. If the load and ambient temperature are constant during a period, the relative loss of life is equal to V. t, t being the period under consideration [4]. The same applies to constant operating condition and a variable ambient temperature. Generally, when operating conditions and ambient temperature are changing, the relative ageing rate varies with time .In the literature, to determine the loss-of-life over a cert in period of time from t1 to t2 the (9) in integral form, or (10) in discrete form are used, depending on the available weighted data:

$$L = \frac{1}{t}\int_{t_1}^{t_2} V.dt \qquad (9)$$

$$L = \frac{1}{N}\sum_{n=1}^{N} V_n \qquad (10)$$

Where:
n -is the number of each time interval,
N -is the total number of equal time intervals,
Vn -is relative ageing rate at time interval n.

III. SIMULATION DIAGRAM

On the basis of the temperature model presented in the previous section, using the program, simulation is made for determining the life duration of the transformer, loaded according to the actual daily load diagram and sinusoidal variation of ambient temperature. The procedure for determination of ageing of the transformer by means of simulation is as follows: Equitation (8) is used to determine relative ageing rate in certain time interval where the hot spot temperature is constant. Because temperature is continuously changing, on account of load and ambient temperature variations, it is necessary to define the modality for determination of the ageing in this particular case.

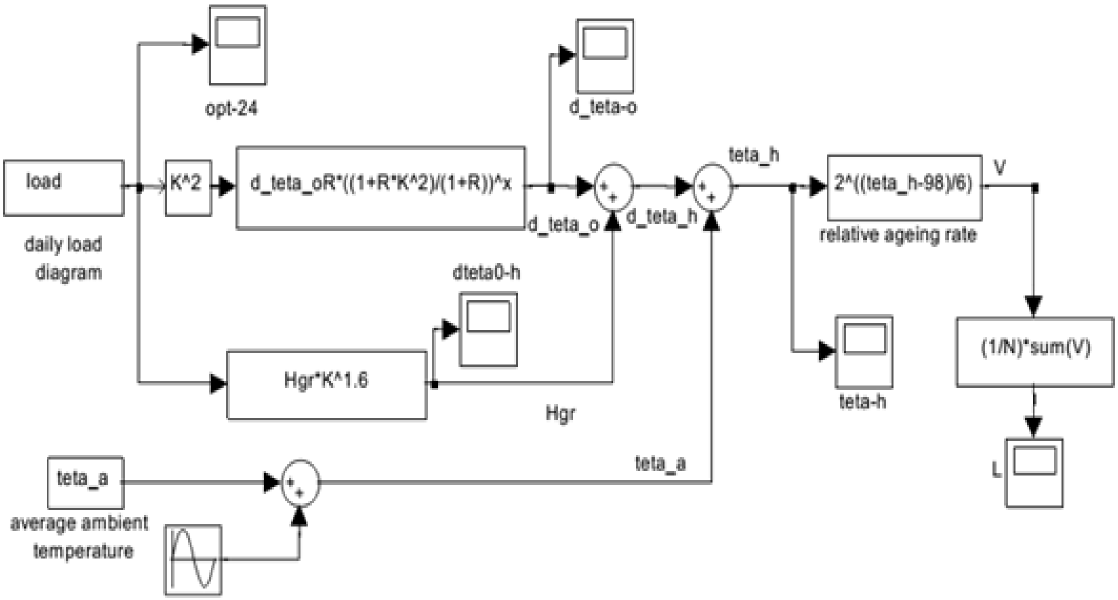

Fig. 1.Simulation diagram

Temperature variation can be solved by assumption that it is constant in small time intervals. In the taken time intervals according to temperature model, hot spot temperature is determined, and then the relative ageing rate. All the values obtained for the relative ageing rate in the observation period, are summed, and loss of life duration can be obtained by dividing this sum with the number of the time intervals, (9) and (10).

3.1. L0AD AND AMBIENT TEMPERATUREB PROFIL

For temperature calculations, the time constant of the windings is neglected, because its value usually is small and it is about 5 to 20 minutes. It has only limited effect on the hot spot temperature, even at large fast load changes [4].

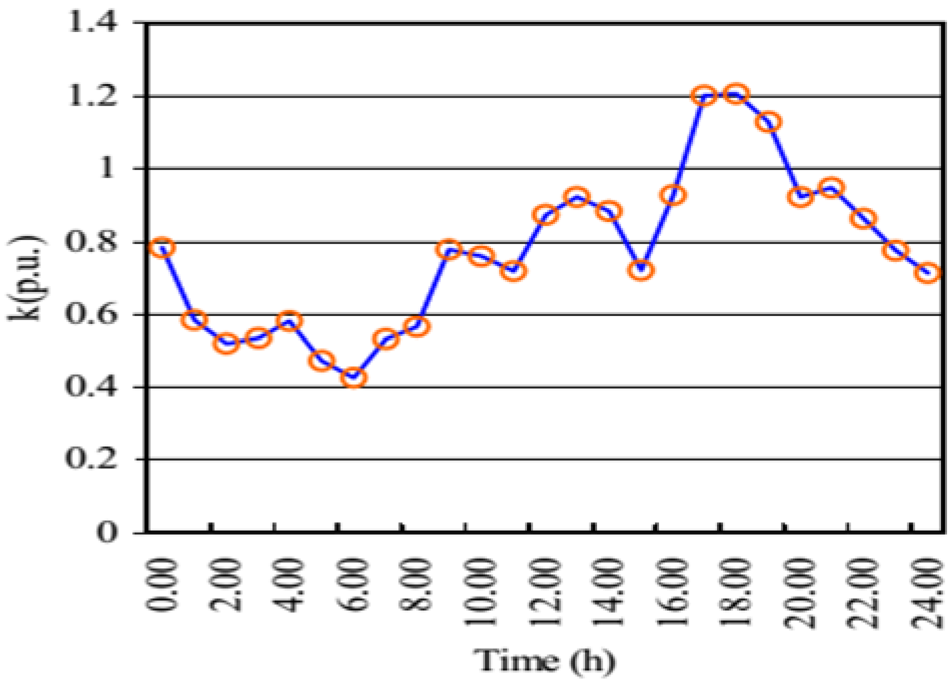

Fig. 2. Daily load diagram

Daily load profiles for transformer, was recorded in a field investigation using electronic storage equipment. Because load changes are taken every 15 minutes, the time constant is neglected in the simulation algorithm. Due to these reasons, it is assumed that the last article in the equation (1) changes its value momentarily by the change of the load. Simulation program uses an actual daily load diagram of distribution transformer, shown in figure 2. The maximum value of load factor is 1.231 p.u. at 18.15h, and the minimal value is 0.337 p.u. at 05.30h. In this paper, for calculation of the ageing of transformer, are used thermal characteristics for distribution transformers of the standard IEC 354, which are presented in table 1 bellow.

Distribution transformer	ONAN		
Oil exponent	x		0.8
Winding exponent	y		1.6
Loss ratio	R		5
Hot-spot factor	H		1.1
Oil time constant	τ_o	(h)	3.0
Hot-spot rise	$\Delta\theta_{hr}$	(K)	78
Average winding rise	$\Delta\theta_{Wr}$	(K)	65
Hot-spot to top-oil gradient	Hg_r	(K)	23
Top-of-winding oil rise	$\Delta\theta_{or}$	(K)	55
Ambient temperature	θ_a	(°C)	20

TABLE 1.Thermal characteristic for transformer

IV. SIMULATION RESULTS

The results presented in this paper refer to distribution transformer with the following data: 630 kVA, 10 kV/400 V, windings made of copper and other data given in table 1.For the load diagram shown previously, and sinusoidal variation of ambient temperature, the results from the analysis are shown in the figures bellow.

The presented results indicate high degree of influence on the load and ambient temperature, on hot-spot temperature and accordingly influence on life duration of the transformer.

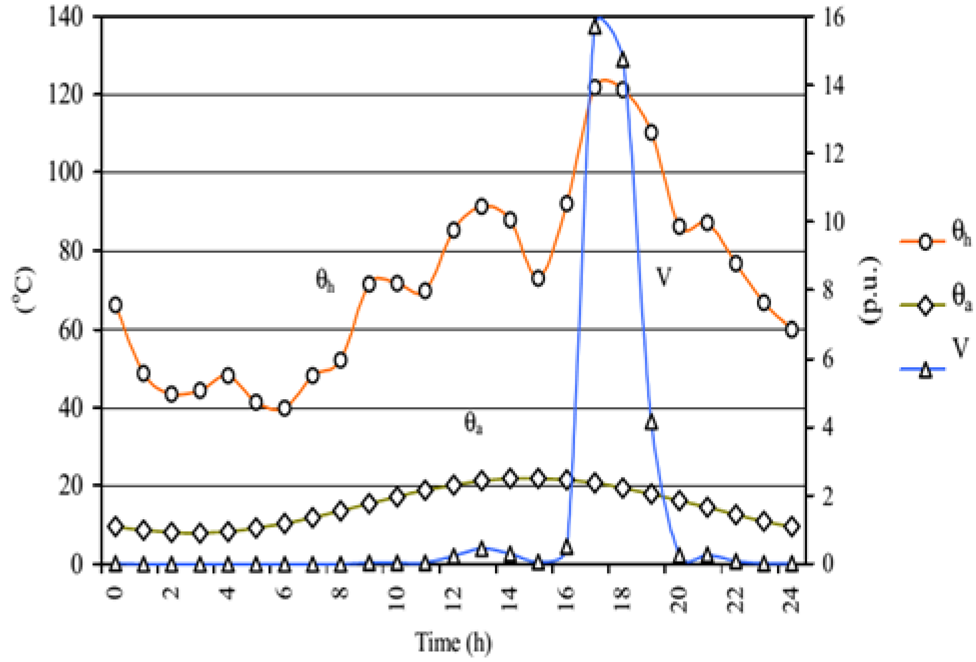

Fig. 3 Daily variation of: ambient temperature, hot-spot temperature and relative ageing rate

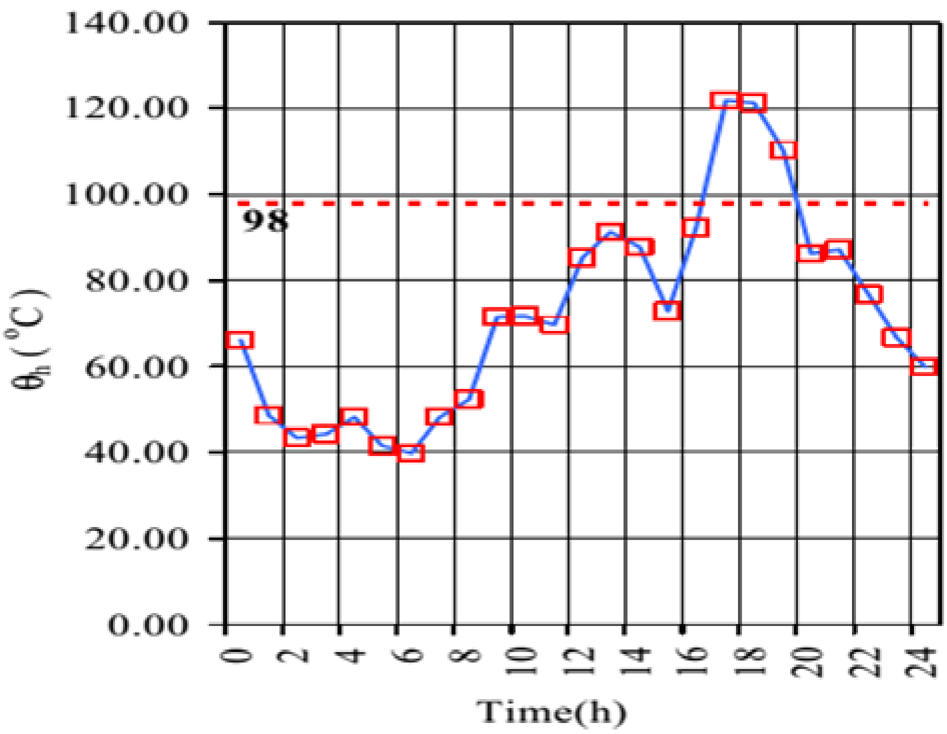

Fig. 4 Hot spot temperature

Decreasing, i.e. in this case increasing of life duration is 1.72 p.u., i.e. 1.72 days, calculated to expression (10). It means that loading over a single day and ambient temperature, for one day, the transformer lost only 13 hours and 50 minutes of its life duration.

V. CONCLUSION

Both manufacturers and customers are interested in an accurate prediction of hot-spot temperature: the manufacturer for an optimal design and a good quality product, the customer can use this knowledge to conduct realistic on-line monitoring, to execute safe overloading of the power transformer. The loading guides base their considerations of transformer loading on both short-time and long-time aspects. The short time aspects consider the risk of immediate failure at high temperature due to gassing and relate it to a hot-spot temperature. The long-term aspect describes material ageing and deals with deterioration of the mechanical properties of the insulation after heating. The presented results indicate high degree of influence on the load and ambient temperature, on hot-spot temperature and accordingly influence on life duration of the transformer and loss of life. Concerning the thermal model of the transformer i.e. algorithm used for determination of ageing of the transformer in this paper, can be considered as satisfactory, because it results from the relevant international standards.

REFERENCES

[1]. IEC 354, "Loading guide for oil-immersed power transformersî, second edition, 1991-09.
[2]. L.W.Pierce, "An investigation of the thermal performance of an oil filled transformer winding, IEEE Transactions on Power Delivery, Vol.7, No.3, pp.1347-1358, 1992
[3]. W.J.McNutt, "Insulation Thermal Life Consideration for Transformer Loading Guidesî, IEEE Transactions on Power Delivery, Vol.7 No.1, pp.392-401, 1992.
[4]. C.C.Wong, "Substation power-transformer-loading analysis and computer simulations of loadability under realistic operating conditions, IEE Proc.-Gener. Transm.Distrib, Vol.141, No.5, pp.413-421, 1994.