Effect on Distribution Transformer Life in Smart Grid Environment

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***Abstract* -** This report presents a detailed study of effect on distribution transformer life in smart grid environment. The main idea is to present the effect on LOL(Loss of life) rate of transformer in different scenarios like change in DG penetration, different types of DG units like wind, solar etc., plug-in-vehicles (PEV) and their penetration levels. The factors like variation of atmospheric temperature, consumer load variation have also been taken into account while calculating LOL rate. Regarding DG technologies, it should be noted that remarkable reduction is achieved in loss-of-life rates of the examined transformers. However, the extent of the reduction largely depends on the penetration and production pattern of the DG unit. On the other hand, due to increase in PEV vehicles, it is obvious that local distribution transformer as a likely part of the chain to be adversely affected by unregulated PEV (Plug-in Electric Vehicle) charging.

Index Terms *- Distribution Transformer, Hot point, Cooling methods, Loss of life Transfarmer in solar & wind power scenario.*

I. INTRODUCTION

Since transformer is one of the most costly devices in power system, its life is an important factor to be studied. Smart grid environment includes distributed generation (DG) units and their types like wind, solar, micro-turbines, combined heat and power plants etc. and increasing plug-in-electric (PEV) vehicles chargers. It also includes load side management techniques at the consumer end. In the smart grid environment, the distribution transformer life gets affected either in positive or negative way.

During the last decade, the instalment of distributed generation (DG) units has been increasing steadily with low-voltage (LV) customers. The main reason for the LV customers to adopt DG technology is the objective to cut their own electricity bill, whereas it is recognised that the customer-owned DG units may also bring about important benefits to distribution companies (DISCOMs)[1].

Regardless of the technical challenges in appropriately accepting distributed generation (DG) units, one of the foremost benefits is the capability of DG units to lengthen life time of distribution transformers [1].

Enumerating the benefits is one of the main priorities of DISCOMs in the improvement of incentives that inspire consumers to choose DG technologies which increase DISCOMs' benefits. It is obvious that by operation of consumer owned DG units, load currents flowing through distribution transformers are reduced. This can lead to a decrease in the timely growth of the transformers' hot spot temperature (HST), and so in the transformers' loss-of-life (LOL) rate, the frequency by which they lose their anticipated life. About DG technologies, it should be noted that extraordinary reduction is attained in loss-of-life rates of the inspected transformers for all of the proposed scenarios.

Distribution transformer life also depends upon the amount of penetration of DG units in the power system. Therefore, the life should be studied with different penetration level of DG units.

Different types of DG units like wind, solar, micro-turbines, combined heat and power plants etc. affect the transformer life in different ways. So, each of them should be analysed separately in relation to distribution transformer life.

Society's increased concern over green-house gas production and the reduction in price of electric vehicle technologies has augmented the figure of electric vehicles (EV) and plug-in hybrid vehicles on the road. These vehicles can upsurge mileage by 60% given the same amount of conventional energy. The number of electric vehicles will continue to increase over the coming 20 years, at which time EVs may embrace as much as 50% of new vehicle purchases [2].Thus, this factor also becomes an important one to be related with transformer life. Different penetration levels should also be an important factor while analysing the life.

It is known that PEV will have adverse effect on life of transformer, as they will increase the peak load on the transformer and thus will increase the hot-spot temperature.

II. TRANSFARMER LIFE

Factors affecting life:

Transformer life mainly depends upon its insulating material. The dielectric strength of an insulating material decreases with increasing temperature. The chief source of heat generation in transformer is its copper loss or I^2R loss. Though there are other aspects, that increase heat in transformer such as hysteresis & eddy current losses but influence of I^2R loss dominate them. If this heat is not dissipated appropriately, the temperature of the transformer will increase incessantly, which may harm paper insulation and liquid insulation medium of transformer.

Transformer temperatures:

Top oil temperature: Transformer top oil temperature is measured using a thermometer at the top of the tank as shown in figure below.

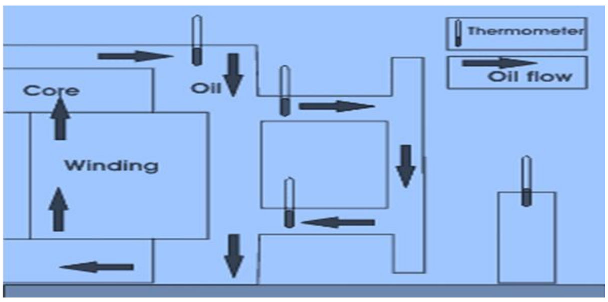

Fig. 1 Demonstration of top oil temperature measurement

Hot spot temperature:

Though, the resulting temperature increase is averaged over the entire winding, the inner side of a winding is hotter than its outer side, in reality. The hot spot is at certain point inside the coil containing the lengthiest thermal routes. This hot spot temperature differential is obtained by the manufacturer on prototype units; it's generally articulated as a temperature rise above the average temperature.

Average rise = 105 [degrees]C (hot spot) -10 [degrees]C- 40 [degrees]C (ambient) = 55 [degrees] C

Different transformer cooling methods: In electrical power transformer , we also use peripheral transformer cooling system apart from in-built cooling system, to increase the dissipation rate of heat of transformer. There are different cooling methods for transformers depending upon their size and ratings. These are given below:

1. ONAN (Oil Natural Air Natural)
2. ONAF (Oil Natural Air Forced)
3. OFAF (Oil Forced Air Forced)
4. OFWF (Oil Forced Water Forced)
5. ODAF (Oil Directed Air Forced)
6. ODWF (Oil Directed Water Forced)

III. TRANSFORMER MODEL

A. Transformer thermal model

The thermal model [1], which is used to obtain the thermal response of sample transformers, is given below. The calculation process is given in steps, which are as follows.

Step-1 For every time interval; obtain the ultimate top-oil temperature rise and the ultimate HST rise using the load level at that interval, by using equations (1) and (2), respectively as given below.

$$\Delta\Theta_{TO,U} = \Delta\Theta_{TO,R} \times \left(\frac{K^2R+1}{R+1}\right)^n \quad (1)$$

$$\Delta\Theta_{H,U} = \Delta\Theta_{H,R} \times K^{2m} \quad (2)$$

Step-2Using the ultimate top-oil temperature rise and the ambient temperature at each time interval, obtain the rise in the top-oil temperature over ambient temperature, using equation (3).

$$\Gamma_{TO}\frac{d\Theta_{TO}}{dt} = (\Delta\Theta_{TO,U} + \Theta_A) - \Theta_{TO} \quad (3)$$

Step-3Calculate the rise in the HST over top oil temperature, using equation (4).

$$\Gamma_H\frac{d\Delta\Theta_H}{dt} = \Delta\Theta_{H,U} - \Delta\Theta_H \quad (4)$$

Step- 4 To calculate the actual hot spot temperature, add the top-oil temperature to the HST rise obtained by using equation (4), by using equation (5).

$$\Theta_H = \Theta_{TO} + \Delta\Theta_H \quad (5)$$

B. Transformer LOL Model

After calculating the hot spot temperature for each instant, the following equation [1] can be used to calculate the LOL rate of oil-immersed transformers for that instant.

$$F_{aa} = \exp\left(\frac{15000}{383} - \frac{15000}{\Theta_H + 273}\right)$$

The equivalent LOL rate for given interval can be obtained as follows. The equation is modified to allow for the determination of the LOL rate in given time.

$$F_{EQ,A} = \frac{\sum_{n=1}^{N} F_{aa_n}\Delta t_n}{\sum_{n=1}^{N}\Delta t_n}$$

IV. PROPOSED SCEANRIOS

A. Scenario 1:

In this scenario, An IEEE 33-Bus system (as shown below) is used to calculate LOL rate of distribution transformer connected at substation in different cases as shown in the table below. The active and reactive power data of IEEE 33-bus system at each bus is given in Appendix A. Distribution transformer rating is taken as 4550 KVA to maintain reference loading at K=1.

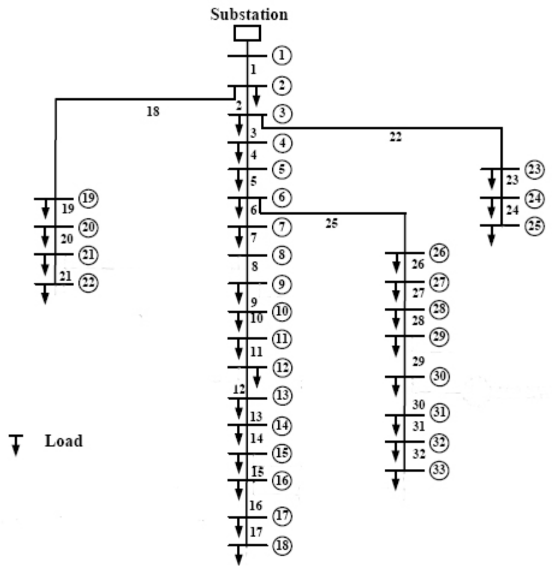

Fig. 2 IEEE 33-bus System

Table 2: Bus connection for scenario 1

Case No.	Bus No.	DG /PEV
1	0	0
2	4	DG1
3	4	DG2
4	4,30	DG1,DG2
5	4,19,30	DG1, DG3, DG2
6	4	PEV1
7	4	PEV2
8	4,30	PEV1,PEV2
9	4,19,30	PEV1,PEV2,PEV3

DGs and PEVs ratings are as given in the table below.

Table 3: DG/PEV ratings for scenario 1

DG1	50+4i kVA
DG2	100+10i kVA
DG3	500+100i kVA
PEV1	20 kW
PEV2	40 kW
PEV3	60 kW

In this scenario, LOL rate is calculated at constant temperature as well as with variable temperature. The variable temperature for a day is as shown in the figure below, for which data are given in Appendix B. The data has been recorded at Jaipur , Rajasthan , India on a particular summer day.

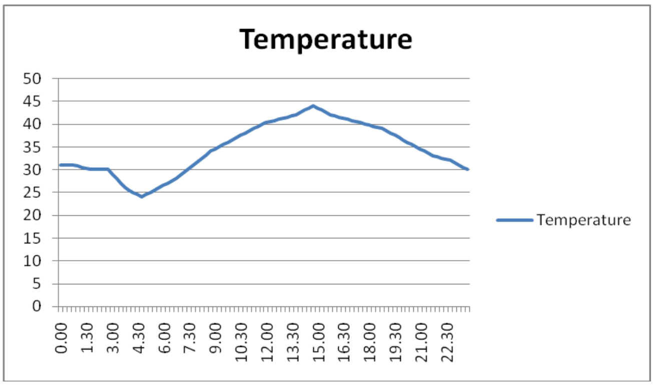

Fig. 3 Temperature vs time of the day

For each case a LOL rate is calculated as per the following algorithm:

Step1: Get the rated top oil temperature and hot spot temperature.
Step2: Get the values of R, m, n, time constants of top oil and winding.
Step3: Do load flow calculation on IEEE 33 bus system.
Step4: Calculate total load on transformer.
Step5: Calculate the value of K.
Step6:Using the thermal model calculate the transformer LOL rate.

Scenario 2:

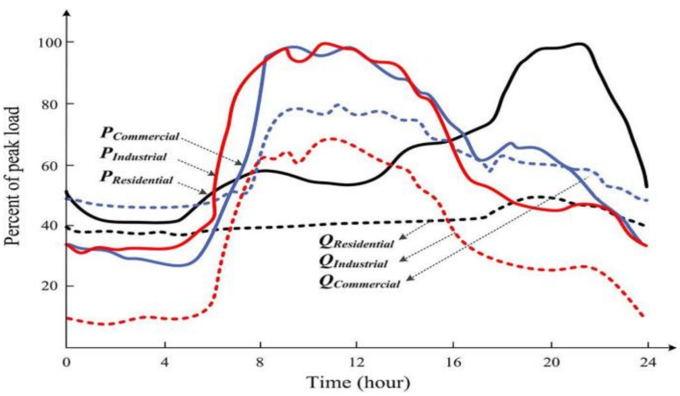

Fig. 4: Consumer load variation during a day

P_Wind	0-100kW	UPF
Q_Wind	0-100kW	UPF

There are four cases of constant power source as given below and fifth case being without any connected DG/PEV, for which LOL rate was obtained.

Table 4: DG/PEV ratings for Scenario 2

DG1	50+10i kVA
DG2	100+20i kVA
PEV1	20 kW
PEV2	40 kW

For each case a LOL rate is calculated corresponding to each 15-minute interval as per the following algorithm:

Step1: Get the rated top oil temperature and hot spot temperature.
Step2: Get the values of R, m, n, time constants of top oil and winding.
Step3: Calculate total load on transformer for each 15-min interval.
Step4: Calculate the value of K for each 15-min interval.
Step5:Using the thermal model calculate the transformer LOL rate for each interval.

Scenario 3:

In this scenario, a single bus system with distribution transformer, a variable load (residential load has been taken for study) and a variable power source connected to it, is taken. The variable load is same as described in scenario 2. A wind and solar power source with following characteristic is taken for study. The data for the same is given in Appendix D. The transformer rating is 400KVA.The study has been done with variable temperature as given in Appendix B.

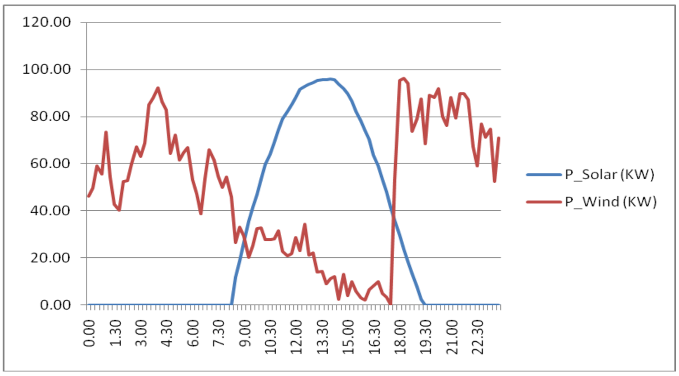

Fig. 5 Wind and solar power variation during a day

CONCLUSION & FUTURE SCOPE

By increasing the penetration of DG units, reduction would be achieved in the LOL rate of distribution transformer . Analyzing transformer loading factor along with transformer physical and locational characteristics highlights the role of load management to improve grid efficiency and maintaining assets.

Temperature and consumer load have the nearly proportional relation with the life of the transformer. Mixing the penetration level of different DG technologies can improve life in a tremendous way. For example, as shown in the presented work, wind power and solar power functioning together are having better effect on life as compared to their individual functioning.

Other DG technologies like micro-turbine, CHP (combined heat and thermal power) plant, V2G (Vehicle to grid) characteristics can be included in the calculation of LOL rate. These technologies can be mixed at different penetration levels to achieve least LOL rate. PEV charging can be modelled according to time of charging (mostly night-time), their specification and use.

Acknowledgement

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References

[1] S. M. Mousavi Agah and H. A. Abyaneh, "Distribution transformer loss-of-life reduction by increasing penetration of distributed generation," *IEEE Trans. Power Delivery*, vol. 26, no. 2, April 2011

[2] Jason M. Sexauer, Kerry D. Mc Bee and Kelly A. Bloch, "Applications of Probability Model to Analyze the Effects of Electric Vehicle Chargers on Distribution Transformers," *IEEEtrans system. power* s, vol. 28, no. 2, May 2013

[3] Qiuming Gong, Shawn Midlam-Mohler, Vincenzo Marano , and Giorgio Rizzoni, "Study of PEV charging on residential distribution transformer life," *IEEEtrans. smart grid,* vol. 3, no. 1, March 2012

[4] C.-S. Chen, T.-T. Ku1, C.-H. LIN, "Implementation of a systematic distribution transformer load management in Taipower", Published in *IETGeneration, Transmission & Distribution*, received on 21st August 2008, revised on 24th November 2008

[5] Themistoklis D. Kefalas and Antonios G. Kladas, "Harmonic Impact on Distribution Transformer No-Load Loss," *IEEEtrans. industrial electronics,* vol. 57, no. 1, January 2010

[6] Kerry D. McBee and Marcelo G. Simões, "General Smart Meter Guidelines to Accurately Assess the Aging of Distribution Transformers," IEEE *Trans. smart grid,* July 2012