iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 **Issue:** IV **Month of publication:** April 2019

DOI: https://doi.org/10.22214/ijraset.2019.4041

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 7 Issue IV, Apr 2019- Available at www.ijraset.com

Defining a Transformers Aging Factors in the Future

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Abstract: Environmental factors used to have a major contribution to a transformer's aging process. Heat and humidity were the main reasons for the degradation of the insulation layer and caused corrosion to the oil tank. With power electronics being introduced into the grid, repetitive transients are becoming an influential player in shortening of the transformer's life span. This paper will discuss the major aging factors affecting the transformer and it will also propose how a predictive health model can be applied to judge the state of this very important component.

I. INTRODUCTION

Transformers are an important asset that ensures transmission and distribution capabilities to the electric grid. These components have been in use for a very long time and many of them are starting to reach the end of their designed life time. Naturally, the amount of load at which they operate most of the time has great influence on how long they can remain in operation
However, other forms of aging are also present. Environmental factors such as temperature and humidity cause degradation of the transformer's insulation. Power quality is also becoming an issue. Lightning surges and especially very fast transients (VFT) produced by DC/AC converters are becoming an issue. VFT are mostly present at power generation plants where electricity generated in DC needs to be converted to AC and also in substations at both ends of an HVDC line.

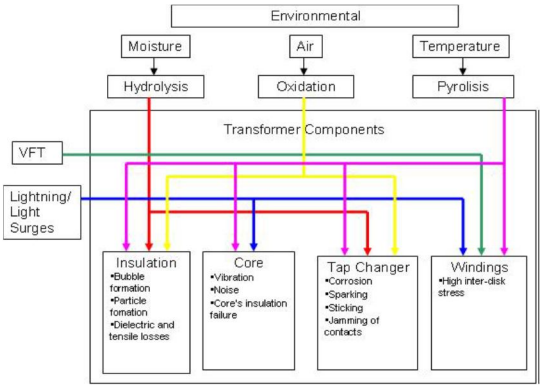


Fig.1 – Aging factors

All these aging factors have to be known in order to produce an accurate model of a transformer in terms of aging. Such model is required so that a centralised system, such as e.g. a smart grid, can use the information as a reference point against online data coming from the device and produce a predictive health model (PHM) to assess its state.

A. Aging Factors

To assess the state of a transformer, each component would have to be analysed separately. However, the main question remains whether a transformer can perform normally if one of the components is faulty. It is reasonable to assume that this would depend on the state of the individual part. To assess the state of the whole component, it would be beneficial to go with the odds of which part tends to fail most often.

B. Environmental Agents

For cooling purposes, transformers are usually left outside the substation. This makes them vulnerable to heat, cold, rain and wind. Humidity is especially hazardous as it will deposit itself on the tank of the transformer and slowly turn into rust and causing leakages. All external parts are affected. The tap changer will corrode leading to corrosion of the contacts which causes jamming. It can also penetrate into the insulation layer adding moisture to the oil paper insulation. To maintain good dielectric properties required for operation, the oil's moisture levels need to be maintained within certain limits as even a 1% change can be dangerous.

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Table 1 shows the values of the moisture levels at which the oil should be kept.

Table 1 – Dangerous moisture levels [1]. Av. Moisture level	Condition
4%	Entering risk zone
5%-6%	Considerable failure risk
7%	Failure imminent

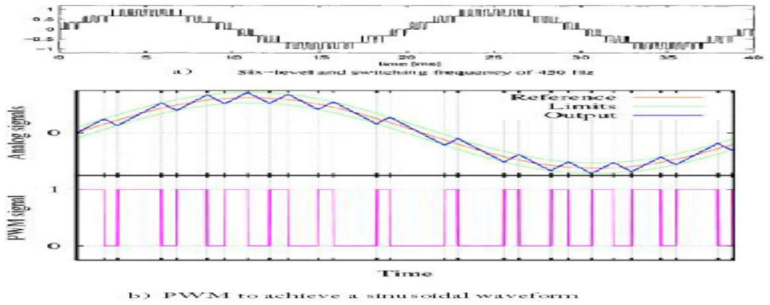


Fig.3 shows some examples of a simple converter switching waveform.

Fig. 3) on the other hand uses Pulse Width Modulation (PWM) to obtain the output which is indicated by the blue line. The average waveform is a sinusoid which means that power can flow into the grid as the two are compatible.
Even though the two sinusoids are different, there are some common features, namely fast rise pulses and high frequencies. It is known that the frequency of the converters in these locations can vary from 0.5 kHz to 10 kHz and the rise time of these pulses is very fast in the vicinity of 1 μs.

C. Reference to AC motors

The design of an AC motor's stator and a transformer's winding is very similar as they both behave as capacitive objects. The main difference is in the insulation layer between the windings. Being fed by adjustable speed drives (ASD), they also experience high frequencies similar to the values mentioned before and rise times faster than 1 μs.

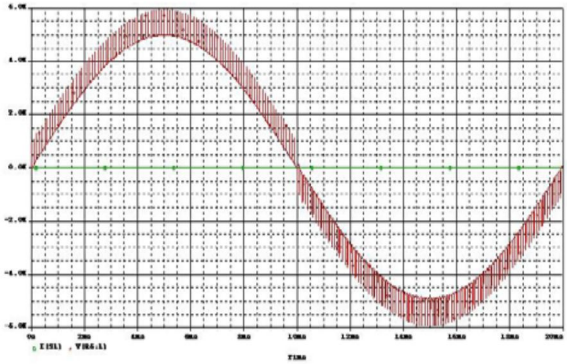


Fig4 The aging "polluted" waveform simulated in PSpice.

Research is being conducted on transformer paper samples immersed in oil stressed with the waveform in Fig. 4. The frequency of the pulses is 2 kHz and the amplitude is 1 kV. The amplitude of the sinusoidal waveform is 5 kV, 50 Hz. The results will be compared with another batch of samples stressed with only the sinusoid at 5 kV, 50 Hz. The expected results are that the time to failure with the above waveform will be shorter than with the 50 Hz one.

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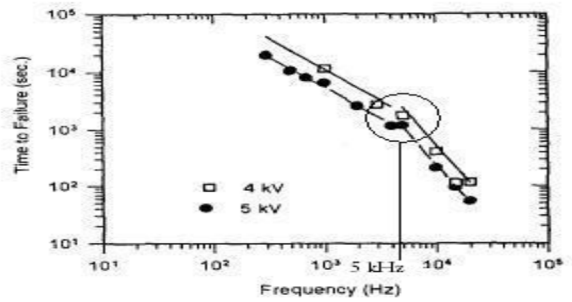


Fig 5Time to failure at different frequencies between two magnet wires

The high frequency has a major impact on the time to failure. In Fig. 5, two square waveforms of amplitude 4 kV and 5 kV were applied to two wires with a layer of insulation. It is clear from this figure that the rate of frequency is inversely proportional to the time to failure. It is interesting to observe that at 5 kHz the constant of proportionality changes. The time to failure can be loosely calculated as $Tf=B/f$below 5 kHz and $Tf=C/f2$ above 5 kHz, where $Tf$is the time to failure and B.

II. PREDICTIVE HEALTH MODEL (PHM)

In order to maintain the transformers effectively, knowledge of the health state of transformer is essential. Therefore, a health state prediction model is proposed that contains all essential information for prediction of the health state of the transformer [6].

The health state of a transformer depends upon various electrical and environmental factors, which can be assessed by various monitoring techniques. The health state prediction model predicts the future health state of the transformer, considering the historical and present condition data.

The condition data incorporates the operating condition such as load, voltage, temperature as well as the monitoring data such as results partial discharges. The operational condition gives usage of the transformer and rate of aging of the transformer. The monitoring system gives an indication of the present health state of the transformer. Any previously implemented or future management actions to improve the health state such as maintenance schemes are also considered in the model. Expected future trends such as load growths and fault forecasts should also be considered to predict accurate health state. Based on the inputs, the health state of transformer in the future can be predicted by using the predictive health model

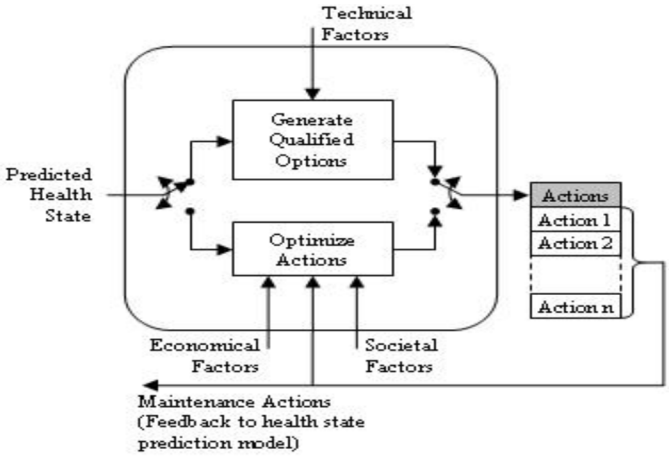


Fig 6 Optimisation model of a component.

III. CONCLUSION

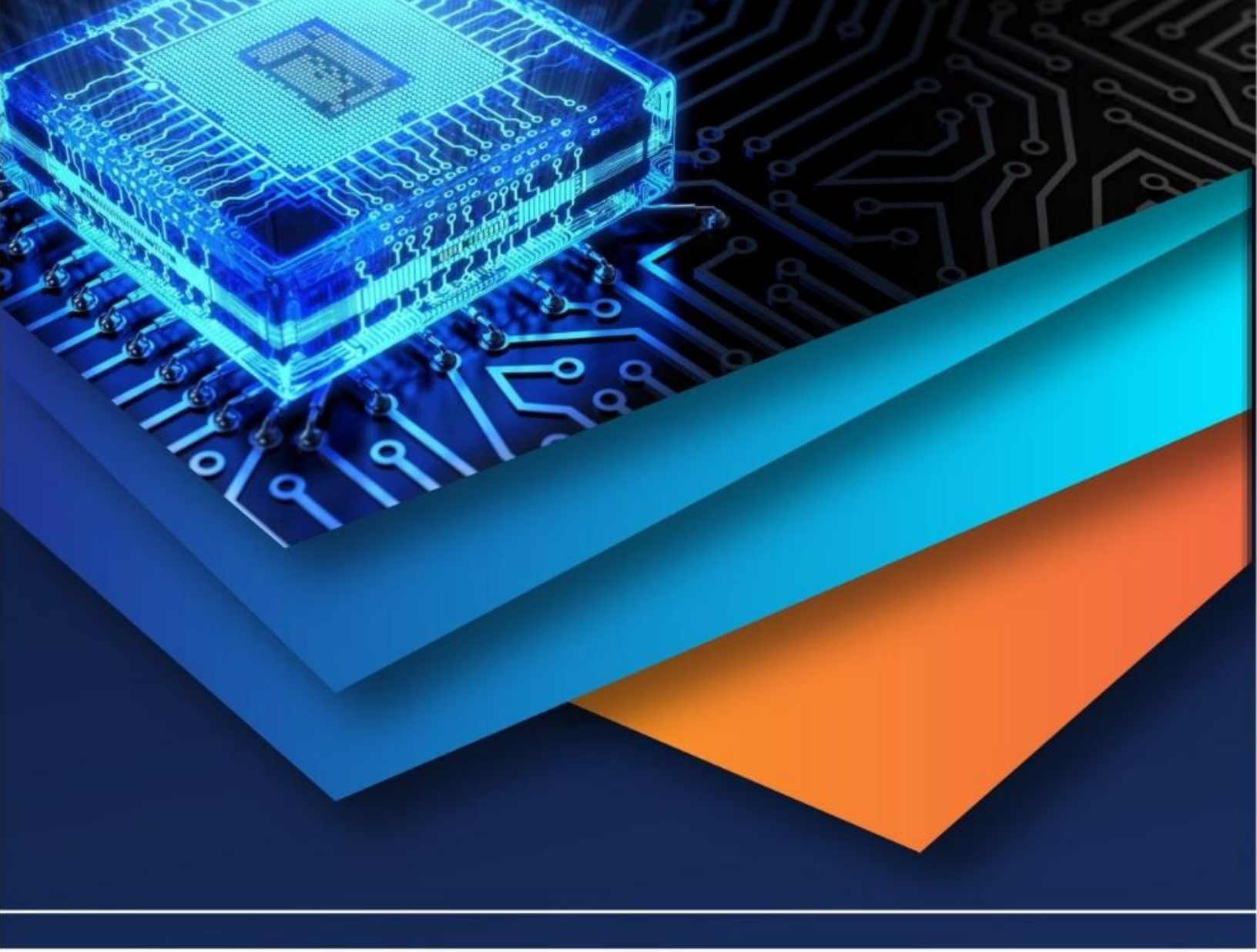
Creating an accurate aging model is vital for the creation of an intelligent system. The system should be able to monitor the state of a component, either transformer, cable or anything else, and schedule maintenance or replacement actions. Several aging models that rely on degree of polymerization, furanic compound or even moisture level already exist, but nowadays the electric grid is changing very rapidly and, as outlined earlier, new factors need to be considered. For this reason a study on the effects of repetitive transient is very important. Further work will be carried out and a study on the time to failure and partial discharges in correlation with frequency will be proposed.

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