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Failure analysis of transformer liquid — solid insulation system under selective environmental conditions using Weibull statistics method

R. Madavan [a,*], Sujatha Balaraman [b]

[a] Liquid Dielectrics Lab, Department of EEE, National Engineering College, Kovilpatti, India
[b] Department of EEE, Government College Engineering, Tirunelveli, India

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ABSTRACT

The failure free operation of transformers is a main factor on economic and safety aspects as per the industrial consumer's point of view. Basically, the transformer is one of the prime equipment in power system network because of its unkind operating condition at different circumstances like higher operating temperature, overloading and continuous operation under uneven outdoor environmental conditions. Above said operating conditions lead to unpredicted failure in the transformer and this directly has an effect on reliability of the power system network. This work aims to investigate the failure rate of transformer liquid insulation (LI)–solid insulation (SI) system at various selective environmental conditions, by considering relative humidity of the air as a frequently variable environmental factor. For investigation, mineral oil (MO) and natural ester like sunflower oil (SFO) and rapeseed oil (RSO) are chosen as the LI system and Kraft paper is chosen as the SI system. The humidified samples are aged at 140 °C up to 1000 h at closed condition. Critical parameters of both LI and SI are periodically measured at an interval of 200 h. Weibull distribution statistics method is used to predict the failure rate of the insulation system with respect to time and relative humidity of the air. From the analysis, it is inferred that the degradation rate of the transformer LI–SI increases with an increase in relative humidity of the air. It is also noted that the LI-MO degrades rapidly when compared with other natural esters.

1. Introduction

Electricity is one of the most crucial infrastructural contributions for economic growth of a country. Demand for the electricity was increased over the last decades and in future also. Efficient utilization of generated power is the most economical way to reduce the demand. One of the awkward realities of the Indian power sector is high failure rate of distribution transformer (DT), mainly those deployed by the state power utilities. Going by accepted technical standards, DTs are meant to have an operational lifetime of 30 years [1]. However, transformers are going for repair works within three years. The DT's per annum failure rate in all the states of India is very high and it is estimated up to 15–25% as against 1–2%, even in the developing countries [2].

Number of DTs currently installed in India was around 4.3 million [3]. For Tamilnadu having 2,31,224 DTs, the failure rate was around 20%; out of this, around 5% of the failure was due to moisture [4]. In order to minimize the heat loss produced from windings and to provide insulation, oil-filled transformers were used more than a century and transformer oil also reduces stress from

* Corresponding author.
E-mail address: srmadavan@gmail.com (R. Madavan).

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changes in voltages and it indicates the condition of the transformer [5,6]. The major causes for failure of DTs are poor operating conditions, loose connections, contamination, aging, excessive load, moisture, poor maintenance and weather conditions (lightning, snow, ice outdoor temperature and air humidity) particularly in the rural and remote areas [7,8].

DTs installed in rural and remote places are suffered due to vulnerable weather conditions predominantly due to relative humidity of the air. Generally in India, the average annual relative humidity of the air is between 40%–80% and it is very high during rainy seasons. Due to poor maintenance, there may be a chance for failure of breather and this allows moisture to get enter into the tank. The possible other ways for moisture to have contact with the oil are via bad gasketing, cracked insulation, a loose manhole cover, a ruptured explosion diaphragm, paper degradation and oil degradation [9]. If the presence of moisture in oil gets increased, it leads to rapid deterioration of the insulation system. The harmful effect of moisture on transformer insulation (MO-SI) system was demonstrated in various theoretical and experimental studies. Moisture rapidly increases the degradation rate of the transformer (mineral) oil. Also, it degrades the characteristic performance and life of the transformer rapidly [10–15].

Petroleum based MO was used in India as DT's liquid insulation system because of its cheapness, having good physical, and dielectric and thermal properties. However there are some drawbacks, such as, MO poses fire hazards as byproduct which is not environmental friendly, and has limited resources [16,17]. In recent years mineral oil is replaced by biodegradable, environmental friendly ester oils. Biodegradable oils have good electrical strength, high flash point, high fire point and it will not produce any hazardous byproducts during fire [18,19]. If biodegradable, eco-friendly ester oils replace MO, then there is a need to study the effect of moisture on ester oils before it is used as a LI system in DTs.

Weibull distribution statistics method is the commonly accepted and successful method used for mathematical modeling to predict the failure rate of any equipment using bathtub curve as shown in Fig.1 [20]. Engineering product failure rate is not stable with regard to time. A bathtub curve is a universally applicable method to analyze the product failure probability and it's classified into three stages [21]. Early failure is the first stage in this curve; it is mainly caused by defects in the apparatus due to fabrication and installation errors or defects in the materials. It is usually known as infant failure.

The failure during the normal operating stage is known as random failure period and the failure rate of this period is low and constant. As a product gets aged, the failure rate increases as pointed out in wear-out stage of Fig.1. This stage indicates the products' end of life and hence precautionary replacement is essential [22].

In this work, the failure rate of transformer LI (MO and NEO)–SI is analyzed using Weibull distribution parameters under various selective outdoor (humidity) conditions. The relative humidity of the air is varied to simulate various climatic conditions. After that, LI–SI samples are aged at constant temperature and the results are observed as per the standards as shown in Table 1.

2. Sample preparation process

2.1. Relative humidity

Present scenario shows that climatic conditions make an impact in day to day atmospheric temperature and relative humidity of the air is unstable. Temperature and relative humidity of the air are the primary aspects of comfortable environment [26]. Relative humidity (RH) is a very commonly used term to measure humidity of the air and it is expressed in percentage. It is the ratio of partial pressure of water vapor (pw) to the saturation pressure of water vapor (ps) at the prevailing ambient temperature or it is the measure of the amount of water vapor holding capacity of the air [27].

$$\%RH = pw/ps \times 100. \tag{1}$$

Generally in India, the average annual relative humidity of air is between 40%–80%. Some parts of India (desert) have less than 40% and hill stations have higher than 80%. When the relative humidity of air reaches 100%, air is saturated and it will make foggy and perhaps drizzle. Conducting experiments above 80% is like directly adding some troops of water in oil samples. Hence, the samples are prepared in the proposed work by considering 20%–80% of relative humidity of the air.

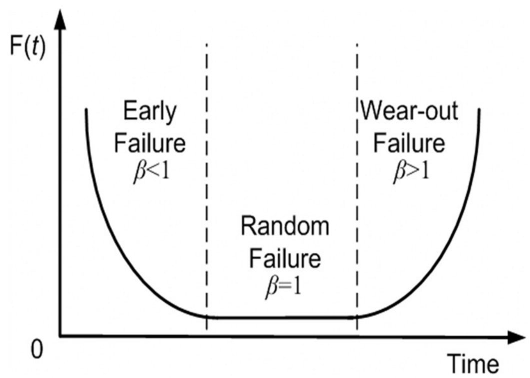

Fig. 1. Bathtub curve for different values of β [20].