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Behaviour Of Paper Insulation In Different Conditions

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Abstract- Transformer is one of the main equipment in power transmission and distribution network. Thus, it is important to ensure optimal operation of power transformer for an efficient supply of energy to utilities. One of the main components of a power transformer is the transformer insulation system, namely, transformer insulation oil and transformer insulation paper. This review provides an in-depth discussion on the reactions that occur in the insulation system of the power transformer. These include, oxidation, hydrolysis, pyrolysis, partial discharge, and arcing. The reaction mechanisms, conditions and the relationship between these reactions are thoroughly analysed in this review. Apart from that, this review also provides an inclusive discussion on the state-of-the-art methods used to monitor the byproducts formed from the mentioned reactions. These methods were developed to overcome the limitation of conventional methods that are complex and costly. Moreover, it presents an impartial evaluation of the challenges and prospects in making the power transformer monitoring system more efficient in terms of cost and time. Information corroborated in this review is expected to provide an important roadmap for future research in monitoring the condition of power transformer.

Keywords -Transformer failure, insulation failure, harmonics, power quality (PQ), distribution transformers

I. INTRODUCTION

The study of insulating material selection, behavior and performance are important aspects to be considered for designing any electrical instrument, machine or device. Apart from conductors, insulator forms the backbone of any electrical system. Though insulators form the backbone, they are also the weakest link in the system. Hence, maximum care and attention is needed while choosing insulating materials for a given application so that it gives the desired performance under worst working conditions. This paper addresses the problem of selection criteria, test specifications and material treatment to justify the use of various dielectrics/insulating materials used for insulating high voltage instrument transformers i.e. CTs and PTs.

While in use, insulating materials are subjected to various electrical, mechanical, thermal stresses and partial discharges. Therefore, criteria for selection of these materials is, that, they must withstand these stresses without or with such rate of deterioration such that their performance is not affected throughout the life expectancy of the equipment, which is considered approximately 25- 30 years.[1] For instrument transformers, selection and tests for insulating materials are major considerations. The governing standards of the current transformer is IS: 2705, IEC:185 and for the voltage transformer is IS:3156, IEC: 186. The requirements of instrument transformer are specified in terms of service conditions, ratings and special features such as limiting dimensions etc.

II. RESEARCH MOTIVATION

There are many benefits of home insulation. Insulating will add the comfort to the building, create a healthier home environment, reduce the energy bills and have a positive environmental impact. Adding home insulation to an existing home will regulate the temperature, making the living environment more enjoyable, especially in places of extreme weather. With insulation the home will become more energy efficient. Insulation will keep the home cooler in the summer and warmer in the winter. This will reduce the amount of heating and cooling appliances that is needed to keep the house comfortable.

Because of this, home insulation will reduce the energy bills and the costs of cooling and heating. Adding acoustic insulation will also enhance the sound control. Insulation creates a sound barrier, keeping unwanted sounds out and protecting the privacy by keeping the sounds inside from being audible outside. Insulating the home also creates a moisture barrier, keeping undesirable moisture out and offers much comfortable living environment inside. Insulating the electrical outlets and the corresponding components will protect home against any electrical shock. The benefit of home insulation is not related to the occupants inside the house only but it is also extended to keep the environment out of pollutants. The insulated building will contribute to use less energy for airconditioning. This will reduce the carbon footprint, and also reduce the amount of chemicals released into the environment from air-conditioning units. Therefore, insulation is a key element in the so-called "green home policy".

III. TRANSFORMER FAILURE INVESTIGATION

To conduct failure analysis on distribution transformers IEEE standard C57.125 Guide for Failure Investigation, Documentation, and Analysis for Power Transformer and Shunt Reactors [9] is used. It provides a procedure to perform failure analysis on transformers to find out the most probable cause of transformer failure.

A failure investigation generally starts with no supply complaints from the affected area where the distribution transformer has failed. When failure is confirmed, then onsite investigation and testing is conducted to collect vital data from site. Before conducting the failure investigation all historical data related to transformer must be gathered. The failed transformer is inspected externally, internally and finally teardown is performed so that analysis to be done to find out the cause of failure of transformer.

1. Preparation for information gathering

Before conducting the onsite investigation, documents related to the history of the condition of the transformer must be collected which will stand very helpful during the onsite inspection, which may include:

- Routine inspection reports;
- Maintenance work records including reports on past problems;
- Historical DGA results;
- Historical oil test results;
- Transformer name plate ratings;
- Factory test data reports;
- Loading data at the time of failure;
- List of any faults or switching event in the system just prior to failure.

2. Onsite Inspection

A quick onsite inspection of a failed transformer is necessary to collect the vital data which may be destroyed during restoration of supply. Onsite inspection consists of examining the external conditions around the failed transformer and thorough examination of transformer.
External Conditions: On arriving at site before starting the visual inspection the conditions all around the transformer, first examine, interview the peoples in the vicinity at site about any abnormality they saw during normal operation or during the time of failure. Investigator has to look for any unusual sounds, odors, debris expelled from transformer or accessories, foreign objects in area, any evidence of vandalism, load on transformer, system disturbances and any dead animal in area.
Transformer conditions: Investigator to look for following visible abnormalities in the transformer main tank for bulging, cracks, leaks, sign of overheating, oil spill or fire, oil level in main tank, oil level in conservator, damage to radiators, damage to conservator and bushings for leaks, broken porcelain, holes in caps and tracking. If no visible damage is found externally, then next step is to conduct diagnostic testing of transformer.

3. Diagnostic Testing

When there is no visible damage is found in external examination of transformer. Then diagnostic tests are conducted to find out fault and to give indication of repair. Test data should be recorded carefully and several tests may be interpreted together to diagnose a problem. Samples of insulating oil for testing must be taken prior to opening the transformer for inspection. Following tests can be conducted on transformer.
Insulation Resistance: Winding to winding, winding to ground, core to ground, dielectric absorption (Polarization Index).
Other tests: Transformer Turn ratio; Winding DC Resistance; Oil dielectric breakdown; Excitation (low voltage) Before performing field tests, safety precautions should be taken to ensure that the transformer is disconnected from all power and auxiliary sources and has been properly earthed.

IV. THERMAL INSULATORS

Those materials that prevent or reduce various modes of heat transfer (conduction, convection and radiation) from the outside to the inside or vice versa, whether the environment temperature is high or low.
The Advantages of Thermal Insulation

1. Reduce the amount of heat transmitted through the parts of the house.
2. Reduce the energy required for heating or cooling the house.
3. Make the internal temperature of the building stable, non-volatile.
4. Keep the temperature of the building elements stable thus long time life.
5. Reduce energy bills.
6. Reduce the burning of fuel in power plants.
7. Reduce the emission of greenhouse gases.

V. COMMERCIAL INSULATORS

The thermal insulation refers to all isolators systems and processes that reduce the heat exchange between inside and outside. Thermal insulation in buildings in hot climates is designed to prevent the entry of heat to the building. Thus, the using of thermal insulation materials reduces the heat transfer. The most important thermal insulators are glass wool, cork, polyurethane and other polymeric materials as well as evacuated panels. It should refer here that air is one of the best thermal insulators due to its low coefficient of thermal conductivity (0.025 W/m.K) and availability everywhere.

The most common insulators:

1. Cellulose: which is made from wood or recycled paper and is characterized by its susceptibility to water and dust absorption.

2. Cork: This is taken from cork tree. It could be made industrial from petroleum product which is called the Expanded Polystyrene (EPS). It is found in the form of panels and used as thermal and acoustic insulators.

3. Glass wool: are widely used to insulate buildings, as well as boilers and reservoirs.

4. Rock wool: This material is used to isolate the buildings and storages.

5. Polyurethane: usually uses as insulated panel or foam to fill the cracks.

6. Polystyrene cork: both types, EPS and XPS

7. Astrofoil (XPE) layers: consist of two aluminum foils and including air bubbles which are made of polyethylene materials. The aluminum layers reflect the solar radiations in the summer while the air bubbles reduce the heat transfer through the walls because of high air isolation. This material is a good insulator against the water and air leaks.

8. Polycarbonate panels: These sheets are lightweight panels, and are composed of several layers to be able to withstand the shocks with the presence of air cavities for the purposes of thermal insulation.

9. Reflective materials: such as aluminum panels, alu-cobond and reflective paints. These materials are used to reflect solar radiation on the exterior walls.

10. Fire retardant sheets: are wooden panels characterized by their ability to delay the fire growth in addition to the thermal insulation ability.

VI. LITERATURE REVIEW

Peter Brncal et al [1] The first part of paper deals with the base information about diagnostics of power transformers. The second part of paper deals use of method of frequency domain spectroscopy (FDS) for traction transformer. This method is used in analysis insulating condition and its solution has scientific importance for analysis of power transformer with system of oil-paper. It was found, that the results of these tests are highly impacted by the operating temperature during the experimental measurement. Finally, the paper presents experimental results of this diagnostic measurement for a real traction transformer at different operating temperatures and states (with oil and without). It has been found, that moisture and conductivity between paper and oil in an insulating system are highly dependent from temperature.

Sorokhaibam NilakantaMeitei et al [2] Power transformers are critical components of power system networks. Failure of this equipment risks the entire system, resulting in power outages and income losses. The reliability of this device is generally determined by its insulating quality. Hence, it is essential to check the transformer's insulation oil condition regularly. Traditional test techniques for assessing the condition of power transformers insulation oil have several drawbacks. Optical fiber-based sensors for monitoring transformer oil conditions have been designed to address such issues.

Fugen Song et al [3]The accurate identification of the oil-paper insulation state of a transformer is crucial for most maintenance strategies. This paper presents a multi-feature comprehensive evaluation model based on combination weighting and an improved technique for order of preference by similarity to ideal solution (TOPSIS) method to perform an objective and scientific evaluation of the transformer oil-paper insulation state.

Zhaoliang Gu et al [4] The 1000 kV transformer is one of the most important equipment in ultra high voltage (UHV) power grid, and its service life largely depends on the state of its oil paper insulation system. Especially when micro-bubbles appear in oil paper insulation, the insulation performance of oil paper insulation will be greatly reduced. In this paper, the oil paper insulation micro-bubbles generation platform has been built in the laboratory for 1000 kV transformers. Based on the platform, the influence of temperature rate on oil paper insulation micro-bubbles was studied firstly. By setting the heating power, the micro-bubbles generation experiment of oil paper insulation samples with 3.0% water content was carried out. It is found that with the increase of heating rate, the initial temperature of micro-bubbles generation will increase and the time interval of micro-bubbles escape will be shorten.

Jilani Rouabeh et al [5] This article presents the hypothetical steps leading to the damage of power transformers in order to examine whether there is a correlation between the electrostatic properties (ECT) and the electro-hydrodynamic properties (EHD) of insulating oils. Vegetable oils such as, olive oil (OO) and sunflower oil (SO) have been tested as alternative oils for the insulation and cooling of transformers and their blends with naphthenic mineral oil (MO) on the basis of well-defined ratios and for a remarkable aging time, which is an original contribution and insight offered by this paper.

Vimal Angela Thiviyanathan et al [6]Power transformers are able to provide more than 30 years of operation and a big percentage of power transformer failure occurs when they are more than 20 years old due to worn-out parts or faults within the transformer [1].

Carmela Oria et al [7] The solid insulation in the windings of power transformers, which generally consists of oil-impregnated thin paper, is one of the key elements for the performance and durability of these electrical machines. Insulation paper is subjected to static and dynamic forces of electromagnetic origin, in combination with high temperatures and chemical reactions, during the operating life of a power transformer. The mechanical properties of the cellulosic insulation are relevant parameters because its breakage could result in the electric failure of the transformer. Indeed, paper manufacturers usually provide values of the tensile strength and elongation at breakage of the insulating paper in its two principal material directions, the MD (machine direction) and CD (cross-direction). However, paper is a highly anisotropic material and its material properties evolve as the paper insulation ages. The paper insulation in an operating transformer is subjected to a multiaxial stress state field including compressive and shear stresses.

Paul Jusner et al [8] Cellulosic pulp has been processed into insulation paper since the earliest days of electrical engineering. This polymer synthetized by nature has proved to be competitive to man-made plastics throughout the last century and is still widely used in electrical power transformers. The high working temperatures prevailing in such apparatuses and the desired lifespans of up to 40 years shifted the thermal stability of cellulose to the center of attention of many researchers.

Juana Abenojar et al [9] The main aim of this study is the thermal characterization of an organic insulation. This insulation is a compound of two mono-component epoxy resins: Epoxylite® primer and Elmotherm® varnish. A mono-component epoxy resin usually needs a high temperature to cure; through differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA), non-isothermal curves are obtained, allowing the estimation of activation energies of curing and decomposition processes respectively.

Yannaphol Kittikhuntharadol et al [10]Because of its low cost and suitable qualities, mineral oil (MO) has been commonly employed in transformers. Alternative liquid insulations with great characteristics have recently been presented. Natural ester (NE) and palm oil (PO) are considered alternative liquid insulations. This paper aims to study the physical and chemical properties of NE and PO which were used in a transformer for 21 months.
Shuangrui Jia et al [11] The detection of partial discharge (PD) in transformers is of great significance for preventing insulation defects from developing into insulation failures. Transformer partial discharge detection technology includes pulse current method, radio frequency measurement method, UHF method, ultrasonic detection method, gas chromatography, and optical detection method. Among them, the optical detection method has the characteristics of strong anti-electromagnetic interference ability, and the signal can be transmitted and received without loss.

A. Meysam Nazari et al [12]This research reports on an experimental investigation into the alternating insulation breakdown voltage (AC) and convective heat transfer behavior of nano-oil for application in electrical transformers. The base fluid of the examined nano-oil is nitro libra type transformer oil, one of the common mineral oils used in transformers. It contains iron oxide magnetic colloidal nanoparticles.
Muhammad Rafiq et al [13] This century is undergoing a wave of knowledge and inventions making use of exceptional properties of nanofluids (NFs) in applications such as manufacturing and process heating, air conditioning and refrigeration systems, solar energy, heat pipes, electrical cooling systems and many others. Research investigations about NFs are on the increase due to growing attention and demand for NFs as heat transfer fluids. This can be observed from the number of articles published.

Xuan Meng et al [14]As the essential equipment in ultra-high voltage direct current transmission systems, converter transformers provide an important role in the stable operation of the power grid. During the long-term operation of converter transformers, the aging and decomposition of the oil-paper insulation cause a great quantity of metal and non-metal solid particles in the transformer oil, which is one of the important reasons for the equipment failure. The solid particles are affected by various forces in transformer oil, among which the Coulomb force dominates their motion characteristics. The charging process of solid particles contacting the electrode is very important. There are many discussions on the charge carried by metal particles after colliding with the electrode, but less research on the Coulomb force of non-metallic particles in the oil.

Zhaoliang Guet al [15] Frequency domain spectroscopy (FDS) technology has been widely used to evaluate the insulation state of electrical equipment. However, there are still many in-adaptability when using FDS technology to evaluate the insulation state of transformer bushings. Especially, the result will be affected by temperature in the quantitative diagnosis of moisture degree. The influence of different temperatures on FDS detection data of transformer bushings has been studied to solve this problem in this paper.

VII. BREAKDOWN IN SOLID AND LIQUID DIELECTRICS

- The breakdown mechanisms is similar to those described for gaseous dielectrics.
- The phenomenon of partial breakdown takes place only in extremely nonuniform fields before the complete breakdown.
- The PB leads to the treeing process and ultimately complete breakdown.

- The breakdown strength also depends strongly upon the type of voltage, ac, dc, impulse; li or si with which it is measured.
- The breakdown strength of these dielectrics is distinguished into two broad categories known as the ‘intrinsic’ and the ‘practical’ breakdown strengths measured in uniform or near uniform fields.

Intrinsic strength of liquid dielectrics Breakdown in Liquids In highly purified liquid dielectrics, breakdown is controlled by phenomena similar to those for gasses and the electric strength is high (of the order of 1 MV/cm). Unfortunately, liquids are easily contaminated, and may contain solids, other liquids in suspension and dissolved gasses. The effect of these impurities is relatively small for short duration pulses (10 s).

However, if the voltage is applied continuously, the solid impurities line up at right angles to equipotentials, and distort the field so that breakdown occurs at relatively low voltage. The line up of particles is a fairly slow process, and is unlikely to affect the strength on voltages lasting for less than 1 ms. Under the action of the electric field, dissolved gasses may come out of solution, forming a bubble. The gas in the bubble has a lower strength than the liquid, so that more gas is produced and the bubble grows, ultimately causing breakdown. Because, of the tendency to become contaminated, liquids are not usually used alone above 100 kV/cm in continuously energised equipment, however, they are used at much higher tresses (up to 1 MV/cm) in conjunction with solids, which can be made to act as barriers, preventing the line-up of solid impurities and localising of any bubbles which may form. The main function of the liquid in such arrangements is to fill up the voids.

1. The most likely elementary process of ionisation in hydrocarbon liquids is by excitation or molecular vibration, which is equivalent to thermal vibrations.
2. The process of dissociation of molecules in neutral, low molecular, gaseous particles takes place due to severe molecular vibrations, which requires energy levels in the range 1.5 to 7 eV.
3. Excitation of metastables, which may lead to ionization in a few stages, requires energy levels of the order of 1.5 to 10 eV.
4. Scintillation of electrons accompanied with weak luminescence, indicating high energy quanta of several eV; which is greater than 10 eV in some liquids leads to ionization process.

Breakdown of Commercial liquids

When a difference of potential is applied to a pair of electrodes immersed in an insulating liquid, a small conduction current is first observed. If the voltage is raised continuously, at a critical voltage a spark passes between the electrodes. The passage of a spark through a liquid involves the following.

(a) Flow of a relatively large quantity of electricity, determined by the characteristics of the circuit,

(b) A bright luminous path from electrode to electrode,

(c) The evolution of bubbles of gas and the formation of solid products of decomposition (if the liquid is of requisite chemical nature)

(d) Formation of small pits on the electrodes,

(e) An impulsive pressure through the liquid with an accompanying explosive sound.

Tests on highly purified transformer oil show that

(a) Breakdown strength has a small but definite dependence on electrode material,

(b) Breakdown strength decreases with increase in electrode spacing,

(c) Breakdown strength is independent of hydrostatic pressure for degassed oil, but increases with pressure if oil contains gases like nitrogen or oxygen in solution.

In the case of commercial insulating liquid, which may not be subjected to very elaborate purifying treatment, the breakdown strength will depend more upon the nature of impurities it contains than upon the nature of the liquid itself. These impurities which lead to the breakdown of commercial liquids below their intrinsic strength, can be divided into the following 3 categories.

(a) Impurities which have a breakdown strength lower than that of the liquid itself (ex: bubbles of gas). Breakdown of the impurities may trigger off the total breakdown of the liquid.

(b) Impurities which are unstable in the electric field (ex: globules of water). Instability of the impurity can result in a low resistance bridge across the electrodes and in total breakdown.

(c) Impurities which result in local enhancement of electric field in a liquid (ex: conducting particles). The enhanced field may cause local breakdown and therefore initiate complete breakdown.

Breakdown of Solid Insulating Materials

In solid dielectrics, highly purified and free of imperfections, the breakdown strength is high, of the order of 10 MV/cm. The highest breakdown strength obtained under carefully controlled conditions is known as the "intrinsic strength" of the dielectric. Dielectrics usually fail at stresses well below the intrinsic strength due usually to one of the following causes.

(a) electro-mechanical breakdown

(b) Breakdown due to internal discharges

(c) Surface breakdown (tracking and erosion)

(d) Thermal breakdown

(e) electro-chemical breakdown

(f) Chemical deterioration

Deterioration due to internal discharges

In organic liquid-solid dielectrics, internal discharges produce gradual deterioration because of

(a) Disintegration of the solid dielectric under the bombardment of electrons set free by the discharges (b) chemical action on the dielectric of the products of ionization of the gas

(c) High temperatures in the region of the discharges. All voids in the dielectric can be removed by careful impregnation and this results in an increase in the discharge inception stress Ei. The final value Ei then depends on electrical processes which lead to gas formation. In oil impregnated paper these are
(a) Decomposition of moisture in paper
(b) Local electrical breakdown of the oil.

The stress at which gas is evolved from paper containing appreciable quantities of moisture can be less than 10 V/µm, but increases continuously with increasing dryness and can be higher than 100 V/ µ m when the paper is thoroughly dry. Except in very dry conditions, the gas first formed arises from electrochemical decomposition of water held in the paper. When a gas bubble is formed in an oil-paper dielectric at the discharge inception stress Ei, discharges in the bubble decompose the molecules of the oil, resulting in further gas formation and a rapid growth of the bubble. As long as the bubble remains in the dielectric, the inception stress Ei is low, often lower than the rated stress, but resting the dielectric long enough for the gas to dissolve in the oil restores the initial high discharge inception stress. Although on resting Ei improves, permanent damage has been caused by the discharges and this manifests itself in an increase of loss angle and is due to the formation of ions by the discharges. Also, due to the discharges, widespread carbonization occur.

VIII. CONCLUSION

Degradation ofReview cellulosic insulation depends up on loading, operating temperatures, water level in oil and in insulation. Skillful maintenance of insulation under dry conditions will help preserving the insulation in dry conditions. It has been widely accepted factors like operating temperature, moisture in winding and loading patters will have important weightages in degradation of insulation.

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