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Surface Tracking on Polymeric Insulators Used in Electrical Transmission Lines

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Abstract

Polymeric insulators need proper management and maintenance. Without proper management, the electric devices can be affected by factors such as leakages in the electricity system. In outdoor insulation, the environment subjects the material to a variety of stresses simultaneously that can lead to rapid degradation and loss of the insulation properties. Contamination of the surface of the insulating material, aging, electrical and mechanical stress are some of the forces that will result in the failure of the insulating material. To improve their reliability, research into the formulation of the material and the development of standards to eliminate creepage are being done. This work looks at the phenomenon of surface tracking. It investigates the actual process and looks at the possible types of surface tracking on polymeric insulators used under different environments. This also gives a short description of the emergence of polymeric insulators into the market.

Keywords: *polymeric insulator, surface tracking, current leakages, electricity conductor.*

1. Introduction

For many years research has been done on the types of materials that are used for electrical insulation. The research has revealed that the best material for electrical insulation is the polymeric material. Over the past many years, insulators were made of porcelain and glass. These were the best before the invention of the polymeric insulating materials since they had very little effects on the environment and were also stable. However, these insulating materials proved to be so heavy in weight hence their installation was so hard and involving. They were also so expensive and brittle and so were so liable to breakages under small stress and pressure. As a solution to all these, the polymeric insulators came to the market with the advantages of being so light, affordable and very flexible to breakages. It also has the advantage of resistance to vandalism and poses better dielectric properties. Polymeric insulators are made by the process of polymerization that involves the combination of different monomer in the presence of a catalyst under controlled temperatures and pressure.

Despite the many advantages that are attached to the polymeric insulators, they have disadvantages. These insulators are subject to surface tracking. Surface tracking is the formation of carbon tracks on the surface of the polymeric insulators. When this happens, the polymeric insulators lose the dielectric properties and hence become good electric transmitters.

Electrical surface tracking occurs on the surface of the solid polymeric insulators when the carbon tracks form on the surface of the insulators [1]. This stands to be the most severe breakdown mechanism that is linked to the polymeric electric insulators. Surface tracking leads to a breakdown in electric transmission. It also leads to the wastage of the electric power due to the resultant electric spillages. It also endangers the lives of the users of the electricity because it leads to severe exposure of the individuals to the electric shocks [2].

The main cause of surface tracking is the deposition of the carbon traces on the surface of the insulators over a period of time. When dust deposits on the surface of the insulators, a film is formed. When this film stays on the surface for a longer time, it becomes a good conductor and hence able to conduct electricity on the surface of the insulator. In most case, this happens under the very humid conditions. The dust is from the environmental air and contains traces of electrons that give it the electric transmission ability [3].

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Surface tracking also occurs as electric treeing. This is a situation where the polymeric insulating material makes some tree-like cracks when subjected to high and divergent electrical field stress over a long period of time. These cracks become conducting paths and hence makes the insulator loses its dielectric ability [4].

Surface tracking and electric treeing can be prevented by the use of ATH fillers. It involves the formulation of different compounds of the polymeric insulators that can handle the electric stress without failure [1]. Filling the polymeric insulators using the ATH fillers gives them the ability to allow endothermic reactions that result in the release of water vapor when heated. The released water vapor cools on the surface of the insulator. When this happens, thermal degradation is limited and hence the formation of continuous carbon tracks is prevented. The ATH fillers and the insulating polymeric materials are blended in the monitored proportions to ensure perfect compatibility that gives out the best dielectric properties [4].

Surface maintenance and regular monitoring of the insulating surfaces is also another way of preventing the surface tracking from occurring on the surface of the polymeric insulators [5]. In the case where the tracking is as a result of the deposition of the film of dust, cleaning of the surface can be the solution. Regular inspection of the insulators can be done to ensure that any deposit of the dust particles are cleaned away and the surfaces of the insulators are kept clean.

2. Polymeric Insulators

Polymeric insulators are made by the process of polymerization in large reactors in industries. The monomers are placed in the reactor with the necessary catalyst, and the reaction happens at room temperature. After polymerization, the material is then compounded further to produce specific polymer compounds that have different uses. Examples of a conventional polymeric insulator in use today are the Ethylene-Propylene Rubber (EPR) and silicon rubber [6].

The Figure below shows advancement in the developments of polymeric insulators.

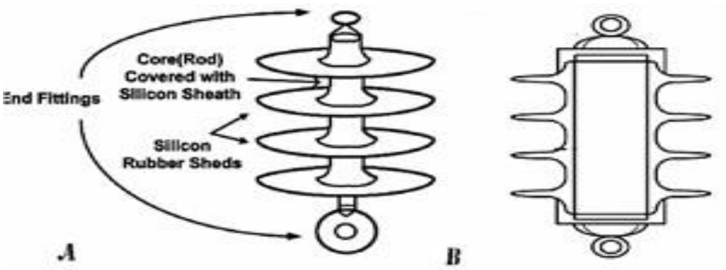

Figure 1. A) Old Style Polymeric Insulator, B) New Style Polymeric Insulator [7]

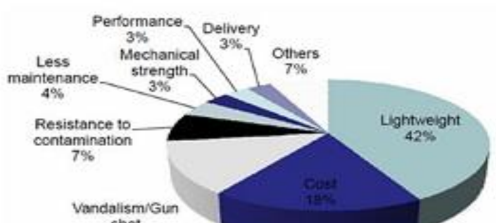

Figure 2. Reasons for the wide usage of polymeric Insulators for outdoor applications [8]

The main advantages of this type of insulators are related to the weight and performance in adverse weather. The polymers, when used as insulators, give a reduction in weight by up to 90%. This reduction in weight improves the installation process and handling of shock loads. The Figure 2 below demonstrates the importance of using the polymeric insulators over porcelain and glass insulators.

Despite these many benefits of the polymeric insulators, there are still mechanical, electrical and environmental conditions that affect the polymeric insulators. Environmental factors such as Ultraviolet light, wind, fog, ozone, high-temperature humidity and inorganic pollution as illustrated in the Figure 3, still affect the polymeric insulators. These factors either lead to surface tracking or aid the aging of the polymeric insulators. The process of surface tracking is discussed below.

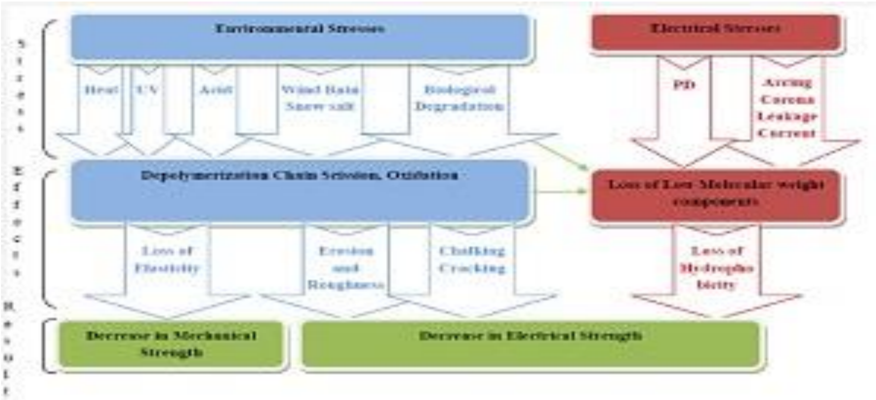

Figure 3. Effects of Degradation on Polymeric Insulators

3. Surface Tracking

Surface tracking that occurs on solid insulators stands out to be one of the severe breakdown mechanisms that are linked to the polymeric materials. This is primarily undertaken under the long-term service conditions. Several relays and activities can be used to detect the failure in a transmission that occurs in an electricity transmission line. A breakdown of an electricity transmission line is a serious issue that can lead to prevention to a total breakdown of the systems as a result of non-healing characteristics associated with solid insulators. It is worth noting that some situations can be so severe that it becomes so late to save the insulator especially after the occurrence of tracking initiation and growth as illustrated in the Figure 4. Surface tracking is a vital component in polymeric insulators. Its central importance arises from the fact that it can be used in detecting several conditions associated with insulators, such as leakage of current, discharges, tracking initiation, dry state, and severe damage. Two of the most used procedures and processes to help in surface tracking are back propagation network type and neutral network. This increases the amplitude frequency components as opposed to the fundamental frequency in regards to the condition of the surface.

Figure 4. Severe tracking on EPDM sheathed arrester in Oman. Insulator Performance Resolving

Surface tracking is the formation of carbon tracks on the surface of polymeric insulators that makes the insulators lose their dielectric property [9]. One the tracks are formed, the material loses their ability to insulate the power cables, and the process is irreversible. A common cause of surface tracking can be a series of small localized sparks on the surface of the insulators. These sparks are often caused by the interruption of the flow of leakage current through the film of conducting contaminant on the surface of the insulator.

In moist or humid environments, dust particles from the environment will form a thin film that can conduct electricity on the surface of the insulator. When this happens over a longer period, the insulator will have a continuous strip of a thin film on its surface connecting the two terminals at different potential [10]. The leakage current from the transmission line will then flow over this thin film that is formed on the surface of the insulator. In some cases, the leakage current can produce heat that will force the film of conducting contaminant to break away. The breakage is because the thin film can only carry a considerably little amount of energy and thus an overcapacity will lead to the breakage in the connection [11]. At the point where the interruption occurs, small localized sparks are created due to the sudden interruption in the flow of current. The sparks can cause carbonization in the organic insulators, and this may lead to a carbon track on the surface of the insulators. In some treatise, this carbon track is often referred to as a bridge since it forms at a location between points at different potentials [12].

In this scenario, the cause of tracking is majorly the contamination on the surface of the insulator caused environmental factors such as dust and conducting particles. In environments with much rain, the tracking process is usually initiated when the surface of the insulator begins to dry. As noted earlier, the interruption of the leakage current will cause small localized sparks on the surface of the insulator. The drying process will create alternate wet and dry regions on the surface of the insulator. Since the dry and moist areas have a different level of resistivity, the flow of leakage current is likely to be interrupted leading to a buildup of electrical potential. The built electrical potential occurs at the wet regions on both sides of the dry bands. The sparks produced by this electric potential will melt the surface of the insulator leading to constant degradation and formation of carbon tracks that can conduct electricity. This process is referred to some treatise as wet tracking [10]. The ability of water to conduct electricity, in this case, is enhanced by the presence of ions and other contaminants like salts in the water.

3.1. Andrinov Mechanism

The Andrei Nov mechanism is another process by which polymeric insulators get degraded. This process occurs at low temperatures below 149^{o}C. The thermal oxidation process initiates a cutting of the Si-C bond. The result of this oxidation process leads to the formation of both a free radical and a peroxide. The decomposition of the peroxide results in formaldehyde and hydroxide. Subsequently, the two compounds produce volatile components that are carbon oxides, hydrogen, and water. Further reaction of the free radical and the hydroxide with the methyl groups produces an inert silica residue. The result of this chain of reactions will eventually lead to the degradation of the silicon rubber in the insulators [13].

The oxidation of the silicone rubber requires an aerobic environment. The rate of the generation of the formaldehyde is also dependent on the temperatures of the environment. At higher temperatures, it has been noted by some studies that silicone rubber has a greater rate of formaldehyde generation. This explains the high rate of surface tracking that has been observed in silicone rubber in environments with high temperature. A sustained deposit of salts and other conductive material like dust in the eroded regions will lead to the formation of activity that will bridge the gap between electrodes.

3.2. Degradation in Inert Atmospheres

Thermal degradation occurs in both oxidative and inert atmospheres. Oxidative degradation initiated at lower temperatures, whereas in inert environments, the process, starts at considerably higher temperatures; usually above 400^{o}C. Siloxane Oligomers are the principal products of the inert degradation as compared to the oxidative degradation that produces silica, carbon dioxide and water [14]. Despite erosion being the core method of degradation, it is also possible that the heat causes the development of carbon tracks on the surface of the insulators. The fact that electric cables are somewhat connected with a pole to the ground, degradation will affect them through heat and carbonization.

To mitigate the problem of heat and carbonization, inorganic fillers have been suggested as the possible remedy. The role of the fillers, when used in polymeric insulators, is to retard the effect of the flames at instances of flashovers. The fillers have also been found to be helpful in the thermal stability of the polymers leading to protection from erosion of the insulators. In outdoor application insulators are filled with either silica or alumina tri-hydrate [15].

3.3. Tracking caused by a Corona

For electrical conductors that carry over 3500 volts, the ionization of air around the conductor is a common phenomenon. The ionization process produces a faint glow around the conductor as the nitrogen component in the air is broken down. When this process occurs, the production of ozone, ultraviolet light, heat and electromagnetic emissions occur [16]. In some instances, when the environment is humid, nitric acid is produced. Ozone is a gas that weakens rubber based insulation material and is an odorless gas.

Even without the presence of leakage current, the occurrence of a corona is still possible. The ionized air around the area where the corona occurs is very conductive. Between two faces, a flashover can occur once the conducting path is completed. The flashover can also occur between the phase and the ground if the conductive ionized air reaches in contact with the ground. A flashover will cause carbonization on the surface of the insulator. The heat produced will leave a conductive track on the insulator leading to the loss of the insulating properties of the material [17].

Most common cause of Coronas are the little air space left between conductors [18]. The initial onset of a corona is hard to detect as the only by-product that is produced at this time is the ozone. However, after a longer period of existence, a white fibrous powder or dust residue can be seen on the rubber based insulators [19]. This dust or residue is the physical sign of the breakdown of the insulation. Cables that are tie-wrapped together often experience a corona, and the results are as illustrated in the Figure 5 below.

Figure 5. Dust Deposit on Tie-Wrapped Cables [18]

Figure 6. Treeing in Underground Cable Insulators

It has been proven that the dust left behind by a corona is conductive in nature. This nature of the dust will support arcing conditions that can lead to the deterioration of the rubber based insulators in the long run.

3.4. Electrical Trees

The electrical trees are usually larger and visible with naked eyes. In some cases, the development of the electrical trees starts as water trees but the resultant injection of electrical current transforms them to electrical trees [20]. The big tracks of electrical trees are then filled with conducting material from the environment that will in the long-run result in the loss of the insulating properties of the dielectric material. This kind of degradation forms at regions with surface defects. The surface defects create a condition of high electrical stress on the dielectric material leading to cracks or a network of electrical trees. Their development is also accelerated by the rapid changes in the electrical fields of the conductors that are covered. In seasonal events like switching operations, the electrical trees are advanced by the changes in the electrical field that causes stress in the dielectric material.

The Figure 6 (image retrieved from (https://en.wikipedia.org/wiki/Electrical_treeing)) shows an advanced stage of formation of the electrical trees. The tracks have been carbonized as they appear dark in color. At this stage, the tracks can conduct electricity and thus the insulating properties of this dielectric material cannot be recovered.

The most commonly observed electrical trees are either the bow-tie trees or the vented trees [21]. The bow-tie trees typically start from within the dielectric material due to partial discharges and grow outwards to the electrodes. These types of electrical trees do not end up bridging the gap between the electrodes as the supply of oxygen is minimal, and their growth is prohibited.

Vented trees, on the other hand, grow from the electrode insulation interface. They normally progress from the first electrode to the other and are the leading cause of insulation failures. Their growth and carbonization of the tracks are aided by the availability of free air [22]. Detection of the electrical trees in the insulation material can be done through partial discharge measurements.

4. Conclusion

The demand for electricity in various location and the needs to safely transmit power from the sources to users has seen several improvements in the insulation technology. Initially, porcelain and glass insulators were the common type of insulators used. The glass and porcelain insulators were relatively stable under high temperatures and other environmental conditions. The problem of these insulators, however, remained the weight of the insulators and the brittleness of the material. To overcome such problems, polymeric insulators were introduced in the industry at the beginning of the 1970s. Despite all the advantages of the polymeric insulators, surface tracking is the major shortcoming of this type of insulators.

As revealed by the research, polymeric insulators play a vital role in ensuring s stable electricity supply system. Polymeric insulators need proper management and maintenance. Without proper management, the electric devices can be affected by factors such as leakages in the electricity system. The solution to this problem of surface tracking is the use of the filler technology. This is the technology that involves the use of other dielectric materials to fill the tracks on the surface of the damaged polymeric insulators. Another solution is then monitoring of the insulators to maintain a clear surface that is free from the carbon deposits. For the case of the electric trees, fillers can still be used as the uttermost solution.

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