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Design Criteria for Silicone Rubber Insulators (Composite Insulator)

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الملخص

تستخدم العوازل لأداء كلا من الوظائف الكهربائية والميكانيكية. وعلى هذا النحو يجب تصميم هذه العوازل بحيث يمكنها أداء وظائفها على النحو الأمثل دون الفشل أو الانهيار. تستخدم العوازل لتوفير الدعم الميكانيكي وكذلك منع التدفق الكهربي ذا الجهد العالي الغير مرغوب فيه اثناء النقل. تهدف هذه الورقة إلى مناقشة معايير التصميم لعوازل مطاط السيليكون.
تتضمن الطريقة المستخدمة في الدراسة مراجعة الدراسات السابقة من مصادر مختلفة تتعلق بمعايير التصميم لعوازل مطاط السيليكون. تشير النتائج إلى أن السلامة الكهربائية والميكانيكية تعد من أهم جوانب العوازل. وبالتالي يمكن أن تتأثر العوازل المركبة بعناصر مثل المواد الكيميائية ودرجة الحرارة وضوء الشمس والرطوبة. يمكن استخدام نتائج الدراسة لتصميم وبناء وتركيب عوازل مركبة موثوقة بنجاح لاستخدامها في خطوط نقل الكهربائية ذات الجهد العالي.

Abstract

Insulators are used to perform both the electrical and mechanical functions. As such the design of such materials should be made such that the insulators can perform the functions optimally without failing or break. Insulators are used to provide mechanical support as well as prevent the flow of electricity that is not required for the transmission of high voltage electricity. This research paper aims to discuss the design criteria for silicone rubber insulators. The method used in the study involved includes the review of literature from various sources regarding design standards for silicone rubber insulators. The results indicate the electrical and mechanical integrity are some of the most important aspects of insulators. The composite insulators can thus be affected by elements such as chemicals, temperature, sunlight and humidity. The results of the study can be used to design successfully, construct and install reliable composite insulators to be used in high voltage electricity transmission lines.

***Keywords**: design criteria, composite insulator, mechanical integrity, electrical integrity, degradation*.

1. Introduction

Almost all high voltage electric transmission is done using the overhead lines in which the insulators are used to provide mechanical support as well as prevent the flow of electricity that is not required. Electrical insulation is a very important element in the transmission of electricity. The hazardous nature of the electric power must be taken into consideration so as to prevent harmful effects. A composite insulator is a dielectric material that prevents the flow of electric current. The resistance to the flow of electric current is due to lack of free flow of internal charges. Composite insulators are therefore non-conductors that are used in parts of electrical equipment to separate or shore up the conductors without passing the power through itself. The Introduction should provide a clear background, a clear statement of the problem, the relevant literature on the subject, the proposed approach or solution, and the new value of research which it is innovation. It should be understandable to colleagues from a broad range of scientific disciplines.

Silicon rubber insulators are some of the widely used composite insulators for high voltage electric transmission. Silicone rubber is a synthetic polymer used as an electrical and thermal insulator due to the ability of the material to maintain useful properties over a broad range of temperatures [1]. This research paper aims to discuss the design criteria for silicone rubber insulators. The method used in the study involved includes the review of literature from various sources regarding design standards for silicone rubber insulators. The outcome of the current study can be used to design successfully, construct and install reliable composite insulators to be used in high voltage electricity transmission lines.

2. Design Criteria for or Silicone Rubber Insulators

Insulators are used to perform both the electrical and mechanical functions. As such the design of such materials should be made such that the insulators can perform the functions optimally without failing or breaking. The criteria used are then applied to assign the mechanical and electrical rates to a particular insulating material. The M and E rating are thus the point at which the insulator fails to perform its mechanical and electrical functions when there is a simultaneous application of stress and voltage. When designing a composite insulator one must, therefore, take into consideration the specified mechanical load. Silicone rubber insulators are made from hydrocarbons that have relatively weak electrostatic forces that are easily broken and hence the insulators are prone to mechanical deterioration. The composite insulators can thus be affected by elements such as chemicals, temperature, sunlight and humidity [2]. To ensure that the effect of these elements are reduced proper design considerations should be taken into place regarding electrical integrity, pollution performance, mechanical integrity, brittle fracture and others.

3. Mechanical and Electrical Integrity of Silicone Rubber Insulators

Personal safety and power reliability are important in the designing of an insulator. The reliability of the insulation regarding electrical and mechanical standards must be considered so as to meet the lifetime of the insulators. The lifetime of power lines is estimated to be over 50 years a period that requires that the both the electrical and mechanical reliability of the insulators are maintained, something that must be taken into design consideration. Given that the UHV and EHV transmitted along the line have a potential power capacity of thousands of MW, design insulation that takes into consideration the electrical stresses and mechanical loads should be developed [3]. Aging of the insulators starts to occur as soon as the installation is completed. Aging presents permanent and irreversible changes that affect the insulating materials. Composite insulators are highly susceptible to aging as the material made of hydrocarbons whose bonds easily break leaving causing deterioration. The deterioration causes the reduction in performance [4]. It is necessary to identify the deterioration as soon as possible so as to reduce the detrimental effects associated with the low performing insulators.

One important way of determining the integrity of an insulator is by carrying tests aimed at evaluating the physical and mechanical condition of the insulator as well as their ability to perform their functions. The testing of insulating material is conducted through the insulation resistance testing. Aging should be considered when selecting the

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insulation material as the process of aging not only affects the electrical characteristics of the materials but mechanical integrity as well. The measurement involves applying a voltage across the dielectric material and the current flowing the material measured from which resistances is measured as a subject of ohms law. An integrity test is necessary to ensure that an appropriate maintenance programme can be put in place to prevent the chances of low performance and electric current seepage [5].

Electrical integrity of the silicon rubber insulator should be dependable for use in transmission of high voltage electricity. As such the design of such materials should be made in such that reflects enhanced electrical properties. The transmission voltage is high thus the insulation must be able to handle such high voltage as well. Some aspects of the electrical integrity that are essential for consideration include partial discharge, dielectric breakdown strength and voltage endurance. The improvement of the above aspects may lead to better and reliable insulation materials with low maintenance costs. The aspects must be tested in the design process of the insulators so as to verify the suitability for use [6].

The importance mechanical integrity of transmission line insulators can never be overstated. Mechanical failure can see conductors dropping out of service something that can also lead to serious environment hazard and electricity loss. The transmission lines are bound to hang loosely as a result of lack of mechanical support provided by the insulators. In as much as polymeric insulators possess the favorable mechanical strength to weight ratio, it is necessary to consider the mechanical deterioration that results from the mechanical load during the lifetime of the line. The insulators must be able to withstand stresses associated with the conductor weight. Other factors that may lead to overstressing may include wind load, icing and broken conductor conditions [7].

4.Pollution Performance

One of the most significant problems in power transmission is the pollution flashover. The problem caused by pollution flashover is complicated due to the many aspects involved in the modeling and designing of insulator and density of pollution in different regions [8]. Some of the environments that have been documented to possess high rates of pollution include areas close to industrial areas, near sea coast and in the desert. Stages that characterize the pollution flashover include a buildup of the contamination layer, insulator wetting, and leakage of current surge, dry-band arc formation and a final extension of the arcs over a wider area. Getting to understand the above stages is necessary for designers in formulating solutions to pollution and enhancing the pollution performance of the insulator [9].

Flashover pollution characteristics of different insulating materials are essential to help the designer to select the most suitable materials to be used in the insulation of transmission lines [10]. Silicon rubber insulators are the commonly used insulating materials and are thus used in the highly polluted environment. Studies indicate that polymeric insulators such as silicon rubber perform better than ceramic-based insulators when they are new, as such the designer needs to consider the suitability of the materials in a particular environment. Performance properties in relation in hydrophobicity should, therefore, be considered when designing an insulator. The silicon rubber insulators are prone to occasional loss and are known to regain hydrophobicity [11]. The methods that have been documented to cause uniform pollution on the surface of the insulators include abrasion, spraying with various chemicals such as kaolin and use of wetting agents. Low molecular weight (LMW) elements present on the surface of the insulator are known to bring about the hydrophobic nature of the materials improving their pollution performance as well. A criterion for selecting LMW should be present in a design process to help optimize the pollution performance of a particular material [12].

5. Degradation of the Insulator

The designer must bear in mind that surface degradation depends on the insulator material. It is, therefore, necessary to consider some of the factors that cause faster degradation of the polymeric insulating materials [13]. The silicone rubber insulators are known for their excellent pollution performance however the materials are affected by surface degradation. Some of the processes that lead to degradation aging include chemical, electrical, mechanical, water ingress and UV radiation processes [14].

Electrical processes affect the degradation of the composite insulators since the distribution of the electric charge along the high voltage insulator is not uniform. The lack of uniformity in the distribution of charges, therefore, causes pollution as a result of discharges. Mechanical processes occur as a result of direct mechanical stresses such as tensile and cantilever loading on the insulator. Indirect stresses occur due to the tears on the surface that have been caused by the release of stresses that were trapped during the manufacturing processes. Considering such stresses in the design of an insulator eliminates future and potential degradation that may affect the insulator as a result of the aging process [15].

Brittle fracturing in combination with the water of ingress is also known causes of indirect mechanical stress. Chemical processes that cause degradation are those that results from chemical attack of the insulation material. Studies conducted on surfaces of field-aged insulators show uniform layers of pollution. Examination of the sea pollution indicated salts while inland pollution majorly agricultural fertilizers, dust particles and industrial particles. Wetting of the above particles resulted in the reaction of the products with the polymer in the applied field [16].

Tropical climate encourages the growth of microorganisms on the surface of the surface of the insulation. The biological particles are destroyed by the electric arc however the particles as slimy materials that cause further degradation of the insulator [17]. Processes by water ingress should also be considered as possible sources of degradation of the polymeric insulators. Taking place in three major ways, water ingress carries ionizable contaminants and corrosive chemicals that affect the mechanical properties of the polymer. The three ways in which water ingress occur in polymeric insulators include absorption of water into the material, through poor sealing at the ends of the insulator and ingress through the surface defects and damages.

6. Brittle Fracture

The composite insulators are known to perform much better than the ceramic insulators. Some advantages that the non-ceramic insulators possess over the conventional insulators include ease of installation, improved damage tolerance, excellent impact resistance and high strength-to-weight ratio. However, a mechanical failure can result in service due to the fracture of the rod [18]. One factor that causes mechanical failures of composite insulators is the brittle fracture of the fiberglass

reinforced polymer (FRP). The mechanical failures have been shown to occur even at lowest mechanical loads during the operational service of the insulator. The effect of fracture has been known for over two decades; however, the problem still affects some modern composite insulator designs. Designing a polymeric insulator, therefore, entails formulating a material composition of the FRP rod that can resist the brittle fracture. The rods that can resist brittle fracture can be thus be used to design composite insulators. Such a rod was introduced into the market in the year 1983 and resulted into insulators that led into 15 years of operational service [15]. It is necessary to include the FRP rods in composite insulators so as to promote the load bearing ability of the insulators. The rods are majorly made by the protrusion. The major constituents of the rods include epoxy resins, vinyl esters and polyesters having reinforcement of E-glass or ERC-glass that is also known as the boron-free E-glass [14].
Design criteria of composite insulators entail a description of the brittle fracture formation as well as the instances of failures that can result due to the fracture process. The characteristics of failures caused by brittle fracture include: the failures are catastrophic and unpredictable; lack of reliable measure to monitor the composite insulators that are in service that is likely to suffer from brittle fracture and uncertain causes of failures. One of the primary characteristics of the attributes of the brittle fracture is a large crack formed inside the FRP rod running perpendicularly to the long axis of the insulator. Design consideration of the brittle entails various analyses to establish the extent of the fracture and as part of failure investigation. The three analyses that are conducted include microscopic, macroscopic and chemical analyses. The above analyses give results that depict the nature of the crack [15].

7. Conclusion

Composite insulators are known to outperform the ceramic insulators. The Mechanical and reliability of polymeric insulators are critical for the high-performance voltage transmission lines and since most high voltage electricity transformation is done using overhead lines safety and performance of the composite insulators used must be considered. The composite insulators can be affected by elements such as chemicals, temperature, sunlight and humidity. The reliability of the insulator regarding electrical and mechanical standards must be considered so as to meet the lifetime of the insulators. When designing an insulator, one must bear in mind that the degradation of the insulator surface depends on the type of the insulator. Processes that lead to degradation of composite insulators include chemical, electrical, mechanical, water ingress and UV radiation processes.

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