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ORIGINAL ARTICLE

Risk assessment of desert pollution on composite high voltage insulators

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A B S T R A C T

Transmission lines located in the desert are subjected to desert climate, one of whose features is sandstorms. With long accumulation of sand and with the advent of moisture from rain, ambient humidity and dew, a conductive layer forms and the subsequent leakage current may lead to surface discharge, which may shorten the insulator life or lead to flashover thus interrupting the power supply. Strategically erected power lines in the Egyptian Sinai desert are typically subject to such a risk, where sandstorms are known to be common especially in the spring. In view of the very high cost of insulator cleaning operation, composite (silicon rubber) insulators are nominated to replace ceramic insulators on transmission lines in Sinai. This paper examines the flow of leakage current on sand-polluted composite insulators, which in turn enables a risk assessment of insulator failure. The study uses realistic data compiled and reported in an earlier research project about Sinai, which primarily included grain sizes of polluting sand as well as their salinity content. The paper also uses as a case study an ABB-designed composite insulator. A three-dimensional finite element technique is used to simulate the insulator and seek the potential and electric field distribution as well as the resulting leakage current flow on its polluted surface. A novel method is used to derive the probabilistic features of the insulator's leakage current, which in turn enables a risk assessment of insulator failure. This study is expected to help in critically assessing – and thus justifying – the use of this type of insulators in Sinai and similar critical areas.
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Introduction

Leakage current on polluted insulators' surface is a major cause of insulation failure in high voltage power lines. Maintenance of those lines thus necessitates the periodic cleaning the insulators' surfaces, which is known to be a costly operation. The magnitude of leakage current on a polluted insulator depends on pollution severity and the contamination salinity, which subsequently affects the conductivity of the contamination layer. With thousands of kilometers of transmission and sub-transmission lines in Sinai, rather than relying on the costly insulator washing, composite insulators are nominated to be used instead of ceramic insulators. Composite insulators are now widely used worldwide because of their lower weight, higher mechanical strength, higher design flexibility, and their reduced maintenance. They display lower leakage current due to their higher surface resistance [1,2]. Silicone rubber – used to fabricate insulators – can provide long-term and satisfactory service even under polluted and wet conditions. This is due to its long-term hydrophobic surface properties. The hydrophobic

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surface inhibits the formation of a continuous water film and the flow of leakage current along the surface. This blocks the initiation of dry band arcing that leads to flashover. In a study by Zhang and Hackam, the strong relation between hydrophobicity and high surface was established when high temperature vulcanized (HTV) silicone rubber rods were subjected – under high voltage – to accelerated wetting in salt-fog and immersion in a saline solution [3]. The surface resistance was measured and found to depend on the duration of the exposure to the salt-fog without electric stress, the duration of the exposure to combined salt-fog and electric stress, and the specimen length.

The pollution layer accumulated on the insulator surface during normal desert atmospheric weather has a thickness that depends on the type of soil in this region and on the polluting sand grain sizes. When sand is deposited on insulator surface and in the presence of a major source of wetting, such as dew in the early morning, leakage current would flow on the surface. Conductive sand areas are then heated, and dry bands are formed leading to possible surface flashover [4].

Relevant previous work in this area included estimating the current density distributions along polluted insulator surface, using surface charges simulation method [5]. Other studies simulated the leakage current while accounting for amount of salt in the contamination layer [6]. Other experimental studies were made on the effect of desert pollution on polymeric insulator [7,8]. In another study, leakage current was estimated using the FEMLAB software with different conductivities of contamination layer [9].

This paper aims to investigate the prime factor responsible for initiating insulator failure under power-frequency voltage, namely leakage current flowing through surface pollution.

Insulator simulation was carried out using an accurate 3-D ANSYS software program, which is based on the Finite Elements method. The program required higher performance computing and gave results with high accuracy. The ratings of transmission lines in Sinai are mainly 500 kV, 220 kV, and 66 kV. A typical two-shed insulator, which may be used on 220 kV power lines is used as a case study. Such leakage current distributions are determined with different sand grain thickness and with different sand conductivities. Realistic data are used, which are based on sand samples collected from Sinai desert near present and future transmission lines' corridors and were reported by an earlier study [10]. In that study, the statistical distributions of sand grains size in the desert soil were acquired from random samples, where their salinity and subsequent conductivity were measured. Based on the calculated influence of sand grain size and salinity on the resulting leakage current, statistical distribution mapping was carried out to produce the overall probability density distribution of leakage current. The cumulative statistical distribution of leakage current was then employed to assess the risk of insulator failure.

Methodology

Insulator computational model

This paper uses a 220 kV ABB silicone rubber insulator as shown in Fig. 1a; its dimensions are given in Table 1. The UNIGRAPHICS program was used to create the insulator model in 3-D and export it to the ANSYS program, where the material of the insulator was defined to be silicone rubber,

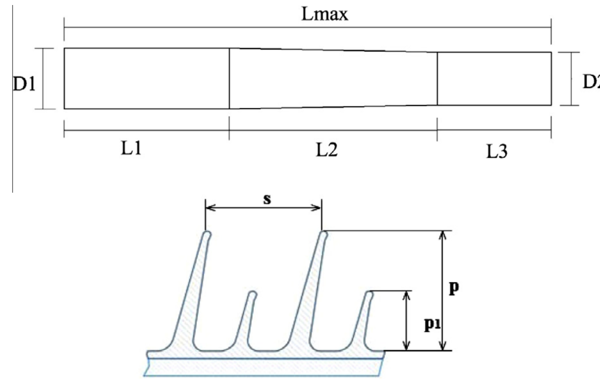

Fig. 1a Insulator shape with the shed as in ABB design guide.

Table 1 Composite insulator dimensions.

Dimension	Symbol	Value (mm)
Inner diameter 1	D1	250
Inner diameter 2	D2	219
Length 1	L1	680
Length 2	L2	855
Length 3	L3	470
Maximum length	L_{max}	2005
Distance between two sheds	S	55
Height of long shed	P	55
Height of small shed	P1	25

as shown in Fig. 1b. In ANSYS program, appropriate finite-element meshes were then used for analysis, where the potentials at the ends of the insulator were ground at one end and the peak phase voltage $\frac{220*\sqrt{2}}{\sqrt{3}} = 179.629$ kV at the other side.

Sample insulator sector

It is both a tedious task and unnecessary to micro-analyze the leakage current distribution along the entire insulator. Instead, a sample sector of the insulator was selected, where the boundary conditions (local potential and electric field) resulting from those conditions were placed around that sector. The insulator sector has two sheds; one shed is long and the other is short with a total creepage distance of 186.14 mm. The leakage current density materialized on the insulator surface as then sought by means of ANSYS. Unigraphics was used to simulate this sample insulator sector as shown in Fig 1c. The directional components x and y of leakage current density were obtained, from which the tangential (surface) current subsequently resulted.

Results and discussion

Effect of contamination layer thickness

The selected sample insulator simulation section of Fig. 1c was subjected to the boundary conditions, where the potentials on the two ends of the sample sector – as acquired from the global analysis – were 54.196 kV and 49.828 kV.

Based on the statistical distributions of sand grain sizes in Sinai – reported in an earlier study [10] – sand grains with diameters in the range of 1–2 mm prevailed. Therefore, this

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