EFFECT OF POLLUTION ON PIN-TYPE POLYMERIC INSULATORS BY THE FINITE ELEMENT METHOD

EFEITO DA POLUIÇÃO EM ISOLADORES POLIMÉRICOS TIPO PINO POR MEIO DO MÉTODO DOS ELEMENTOS FINITOS

EFECTO DE LA CONTAMINACIÓN EN AISLADORES POLIMÉRICOS TIPO PIN MEDIANTE EL MÉTODO DE ELEMENTOS FINITOS

https://doi.org/10.56238/sevened2025.029-101

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ABSTRACT

The climatic conditions of an environment and its unpredictable changes can be a major problem in the sizing of long transmission lines, due to the constant exposure of its components to the various types of weather present in the environment. The accumulation of pollutants on the surface of insulators is one of the main factors contributing to insulation failures in transmission lines. This wear occurs because when it comes into contact with moisture, a thin conductive layer forms, changing the distribution of the electric potential and increasing the concentration of the electric field. Thus, it is relevant to analyze insulators in operation when they are subjected to adverse conditions imposed by the environment, which can lead to failures, damaging equipment, causing inconvenience and losses due to eventual shutdowns in the electrical power system. This work analyzes two topologies of pin-type polymeric insulators, voltage class of 15 kV, with the objective of analyzing the electrical behavior when the insulator is subjected to pollution. The analysis of the electric potential, electric field and current density in polymeric insulators is performed using computer simulation. A pollution layer is modeled on the surface of the insulators in order to investigate the influence of pollution on the operation of the insulators, with the variation of the conductivity and permittivity parameters it is possible to simulate pollution at different levels of criticality. From the results obtained, it was possible to observe the electrical characteristics of the two different topologies of polymeric insulators and to verify which is the best topology for the different levels of pollution.

Keywords: Electric Field. Insulators. Transmission Lines. Pollution.

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RESUMO
As condições climáticas de um ambiente e suas mudanças imprevisíveis podem ser um grande problema no dimensionamento de longas linhas de transmissão, devido à exposição constante dos seus componentes aos diversos tipos de intempéries presentes no ambiente. O acúmulo de poluentes na superfície dos isoladores é um dos principais fatores que contribuem para falhas de isolamento nas linhas de transmissão. Esse desgaste ocorre porque ao entrar em contato com a umidade, uma fina camada condutora se forma, alterando a distribuição do potencial elétrico e elevando a concentração de campo elétrico. Desse modo, é relevante a análise de isoladores em operação quando estes estão submetidos sob condições adversas impostas pelo meio, que podem levar a ocorrências de falhas, danificando equipamentos, causando transtornos e prejuízos devido a eventuais desligamentos no sistema elétrico de potência. Este trabalho analisa duas topologias de isoladores poliméricos tipo pino, classe de tensão de 15 kV, com o objetivo de analisar o comportamento elétrico quando o isolador está submetido à poluição. A análise do potencial elétrico, do campo elétrico e da densidade de corrente nos isoladores poliméricos é realizada utilizando simulação computacional. Uma camada de poluição é modelada na superfície dos isoladores a fim de investigar a influência da poluição na operação dos isoladores, com a variação dos parâmetros de condutividade e permissividade é possível simular a poluição em diferentes níveis de criticidade. A partir dos resultados obtidos foi possível observar as características elétricas das duas topologias diferentes de isoladores poliméricos e verificar qual a melhor topologia para os diferentes níveis de poluição.

Palavras-chave: Campo Elétrico. Isoladores. Linhas de Transmissão. Poluição.

RESUMEN
Las condiciones climáticas ambientales y sus cambios impredecibles pueden representar un gran desafío al diseñar líneas de transmisión de gran longitud, debido a la constante exposición de sus componentes a diversas condiciones climáticas. La acumulación de contaminantes en la superficie de los aisladores es uno de los principales factores que contribuyen a las fallas de aislamiento en las líneas de transmisión. Este desgaste se produce porque, al entrar en contacto con la humedad, se forma una fina capa conductora que altera la distribución del potencial eléctrico y aumenta la concentración del campo eléctrico. Por lo tanto, analizar los aisladores en funcionamiento es importante cuando están sometidos a condiciones ambientales adversas, que pueden provocar fallas, dañar equipos y causar interrupciones y pérdidas debido a posibles interrupciones en el sistema eléctrico. Este trabajo analiza dos topologías de aisladores poliméricos tipo pin, con una clase de tensión de 15 kV, para analizar su comportamiento eléctrico ante la contaminación. El análisis del potencial eléctrico, el campo eléctrico y la densidad de corriente en los aisladores poliméricos se realiza mediante simulación por computadora. Se modela una capa de contaminación en la superficie de los aisladores para investigar la influencia de la contaminación en su funcionamiento. Variando los parámetros de conductividad y permitividad, es posible simular la contaminación a diferentes niveles de criticidad. Los resultados permiten observar las características eléctricas de las dos topologías de aislantes poliméricos y determinar cuál es la más adecuada para los distintos niveles de contaminación.

Palabras clave: Campo Eléctrico. Aisladores. Líneas de Transmisión. Contaminación.

1 INTRODUCTION

Society's energy need has been growing proportionally with its industrialization. The industrial poles are in the process of expansion and energy processing becomes fundamental for the development and continuity of operation of the means of production. To this end, the efficiency of electricity transmission, from the generation sites to the consumption centers, is indispensable.

One of the main factors that lead to failures in electrical systems is related to the degradation of the materials that make up the insulators, the main elements that make up the transmission lines. These, in turn, are subject to deterioration due to the consequence of the constant exposure of such components to environmental agents, aggravated by unexpected climatic variations. The presence of certain chemical elements in polluted air, associated with humidity, form a conductive layer that is deposited on the surface of the insulator. The conductive layer can cause distortions in the distribution of the potential and electric field, inciting the appearance of partial discharges.

The electric field in an insulator is uniformly concentrated over its ends, but the degradation of the material that composes it and its exposure to adverse conditions can distort its modulus and compromise uniformity. This distortion is, in short, a result of the surface rupture of insulation, which is motivated to arise due to the difference in permittivity between certain regions on the surface of the insulator. The formation of electric arcs, the increase in the leakage current and the distortions of the electric field of the insulator, in addition to accelerating the deterioration of the component, are parameters that can be used to evaluate its degree of degradation, consequently its applicability, and it is possible to evaluate the efficiency of the transmission line that composes it.

To evaluate the electric field, the electric potential, the current density and, consequently, the efficiency of the insulator, computer simulations were used. These simulations were carried out with the COMSOL Multiphysics software, in which it uses the Finite Element Method, a mathematical procedure that determines, from differential equations, the variables of interest. The 3D modeling of the two topologies was based on the AutoCAD software. The incidence of pollution was modeled by inserting a conductive layer under the surface of the insulators, varying conductivity and permittivity parameters, which emulate three levels of pollution.

The verification of the type of insulator topology that stands out from the different pollution conditions becomes relevant due to the lapses in operation that these components can cause. Therefore, this work aims to evaluate two topologies of pin-type polymeric insulators, of the 15 kV voltage class, verifying which one presents the best performance for three levels of pollution: low, medium and high.

2 THEORETICAL FOUNDATION

A. Pollution in insulators

Environmental pollution compromises the efficiency and performance of transmission line components. On the surface of the insulators, even if intact, pollution causes a reduction in the insulation capacity. For polymeric insulators, the hydrophobic surface can also be impacted [1-3].

In fact, pollution particles in contact with water form electrolytes capable of degrading the polymeric material. In practice, the combination of pollution with fog, rain or dew produces a layer of conductive moisture, minimizing electrical bearability [4-6]. The succession of these events results in an excessive flow of leakage current along the surface of the insulator, promoting the formation of dry bands and possible disruptive discharges.

Pollution provides or intensifies the non-uniformity of the electric field, whose action of the electric field in the insulating medium favors the occurrence of phenomena such as: internal partial discharges, superficial partial discharges and electrical trailing. Thus, the occurrence of these phenomena due to pollution causes momentary or permanent degradation of the electrical characteristics of the insulators, which significantly affect the operation of the electrical system and cause failures [4, 7].

Insulators contaminated by biological pollution and the places where this type of pollution usually occurs can be seen in Fig. 1.

Figure 1

(a) Polluted polymeric insulator and (b) transmission line near the region of abundant vegetation

(a)

(b)

Pollution problems are often found near industrial areas, sea coasts, agricultural land, bird habitats, deserts, snowy regions, areas with close proximity to abundant vegetation. With the rapid advance of industrialization, pollution levels tend to increase more and more in the very near future. For these reasons, it is necessary to select or replace insulators for those that perform satisfactorily under pollution [6].

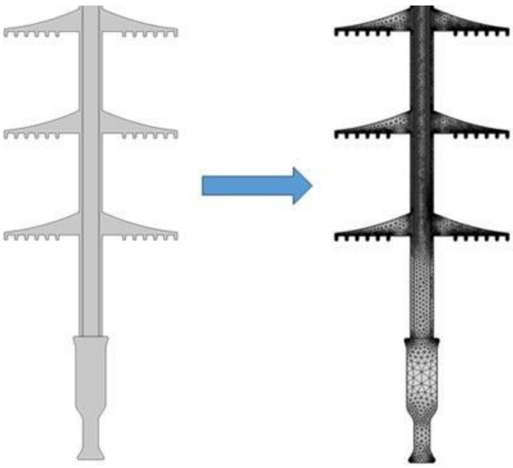
B. Finite Element Method

In order to evaluate variables of interest that can identify the efficiency of insulators in operation, computer simulations were used in this study. These simulations were performed with the COMSOL Multiphysics software, which uses the Finite Element Method (FEM).

Numerical methods are particularly useful when the analytical solution is very complicated. FEM is a numerical method for solving problems involving complex geometries based on partial differential equations [8]. An example of insulator analysis using FEM can be seen in Fig. 2.

Figure 2

Discretization of polymeric insulator



According to [8, 9] the application of FEM in a problem involves five steps:

1. Discretization of the domain (object of study) into finite elements, these sub-regions are simple geometries whose common points are called nodes.
2. Definition of a model that best describes the physical phenomenon involved and definition of the equations, based on the so-called interpolation functions calculated at each node;
3. Construction of a global matrix representing a system of equations, connecting all the elements in a domain. The boundary conditions must be delimited in this step.
4. Solution of the system of equations obtained using numerical calculus.
5. Visualization and consultation of the numerical values of the results of the analyzed case through the application of FEM in software

The advancement of computational tools and consequently the reduction of costs has popularized FEM not only in the sphere of designers, responsible for programming and developing software based on the method, but also by users who seek to understand the concept behind programs such as FEMM, FEMLAB and COMSOL Multiphysics.

3 MATERIAL AND METHODS

A. Material

The simulations are carried out using two geometries of pin-type insulators, made of polymeric material and voltage class of 15 kV. The isolators are graphically modeled in 3D using AutoCAD® software, the analyses are carried out using the COMSOL Multiphysics® software. The insulators that will be modeled for use in the computer simulations can be seen in Fig. 3.

Figure 3

Shaped insulators for analysis

(a)

(b)

The insulators, despite having the same voltage class, have different shapes, insulator 3 (a) has three fins of the same size and insulator 3 (b) has 4 fins, two larger and two smaller interspersed.

B. Methods

In this section, the methodologies used for the computer simulations are presented, carried out by means of the COMSOL Multiphysics® software based on the Finite Element Method.

1) Computer Simulations

The simulations aim to allow the analysis of the electric potential, the electric field and the current density, determining, in the end, the influence of pollution on the operation of the insulators and what is the best option for use. In the simulation procedure, the geometric domain of the problem is initially determined as 3D. Subsequently, the physical domain of the problem (Electric Currents, in the case of the software used) is defined. For the complete definition of the problem, a limited space is defined, containing the arrangement and other modeled elements

Pollution is represented by a 2.0 mm layer on the surface of the entire insulator, considering that the pollution of a region varies according to the location, the time of exposure and the ambient humidity, the values of permittivity and electrical conductivity of the pollutant layer were varied. This variation was carried out with the objective of evaluating from a light level of pollution to a high level. After modeling, it is necessary to enter the physical constants that characterize each material of the simulated system. The constants that characterize the materials were obtained from the libraries of the simulation software itself, and some others from references in the literature, as shown in Table I.

Table I

Constants assigned to the materials present in the simulation

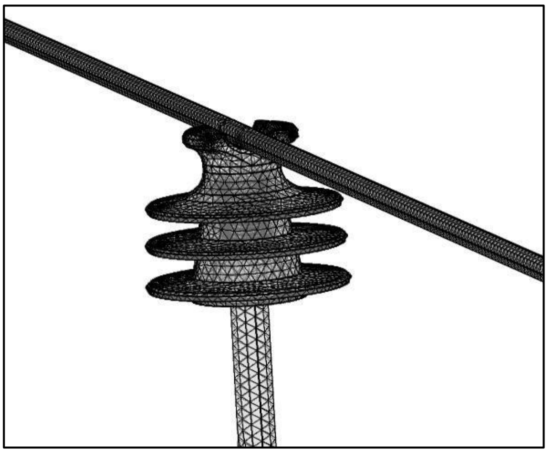
Material	εr – Relative Permissivenes s	σ - Electrical Conductivity (S/m)
Air	1,00	1.00 x $^{10-15}$
Iron Galvanized	1.00 x 105	5.98 x 107
Aluminium	1.00 x 105	35.5 x 106
Polymer	4,5	1.00 x 10-5
Light Pollution(B)	15	1.00 x 10-6
Average Pollution(B)	15	1.00 x 10-5
High pollution(B)	15	1.50 x 10-4

(A)[10], (B)[11]. Others found in the COMSOL Multiphysics® libraries.

Boundary conditions such as the operating voltage on the cable and the ground potential on the fastening hardware are then applied. Subsequently, all the elements that make up the domain are divided into regions composing what is called a mesh, as shown in Fig. 4, the process is known as discretization. From the results, the analysis necessary for the interests of the study is carried out.

Figure 4

Discretized isolator in COMSOL Multiphysics®



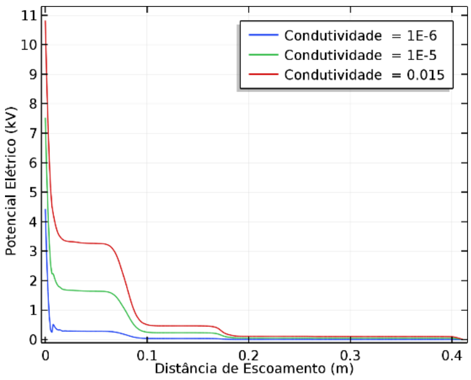
A. Insulator 1

4 FINDINGS

It can be seen that with the increase in the level of pollution, the electric field becomes more intense along the insulator. In addition to the distribution of potential and electric field, the potential distribution for the three proposed pollution levels along the runoff distance of isolator 1, which has three fins of the same size, is illustrated in Fig. 5.

Figure 5

Electric potential over runoff distance for three pollution levels

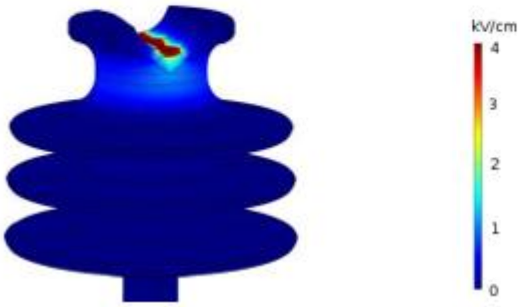


It is verified that the higher the level of pollution, the higher the values of the electric potential along the insulator. The variation in the electric field distribution in insulator it can be visualized, as shown in Fig. 6 behavior of the current density on the surface of the insulator, as illustrated in Fig. 7.

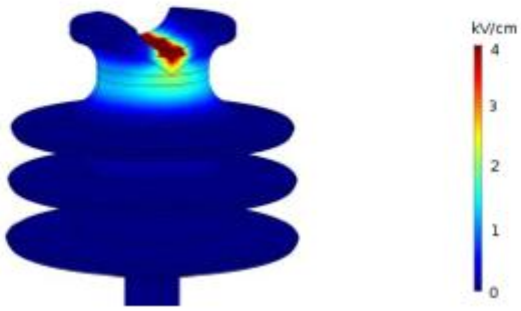
Figure 6

Electric potential over runoff distance for three pollution levels.

(a)



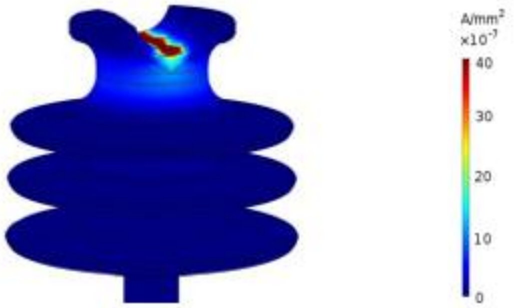
(b)



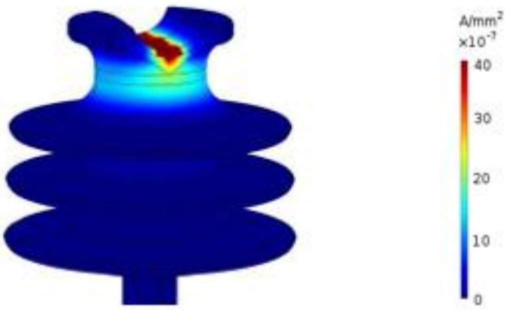
(c)

Figure 7

Current density in the insulator with (a) light, (b) intermediate, and (c) high pollution



(a)



(b)

(b)

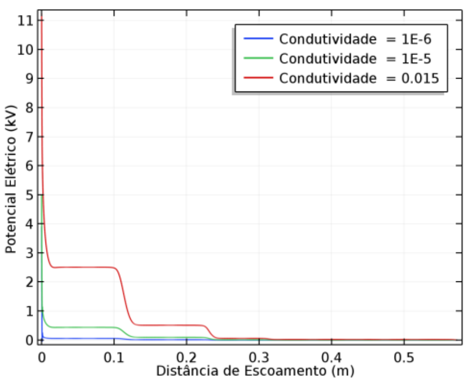
It is observed that the current density behaves in a similar way to the potential and electric field, in the sense of increasing the number of regions in which it is more intense. Next, the analysis of isolator 2 is presented.

B. Insulator 2

The distribution of potential along the flow of isolator 2 for the three proposed pollution levels is illustrated in Fig.8.

Figure 8

Electric potential over runoff distance for three pollution levels

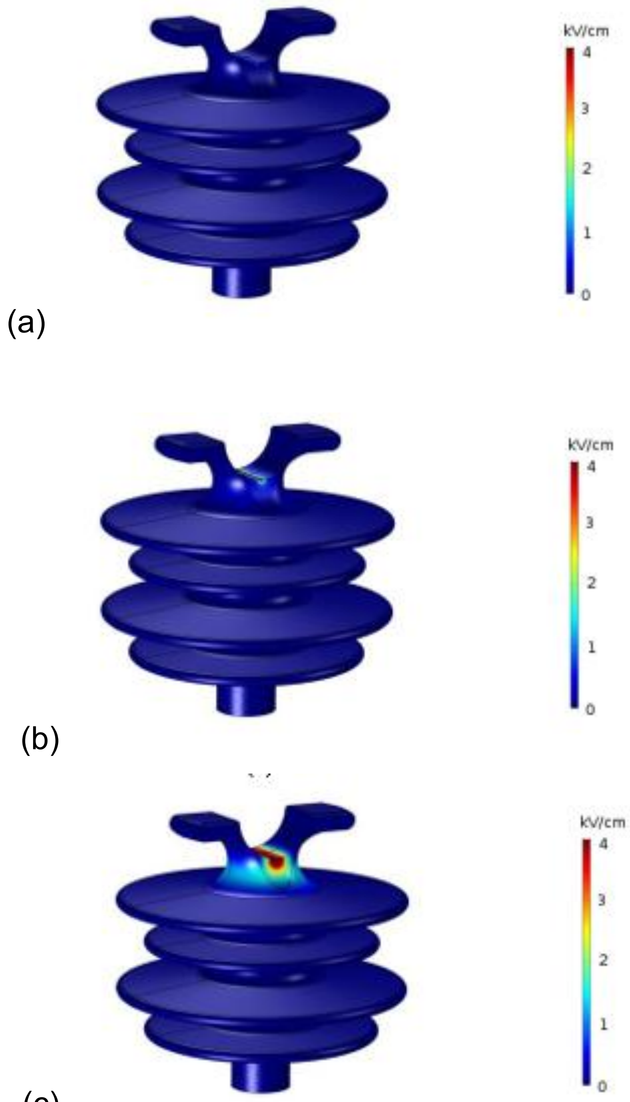


It is verified that the higher the level of pollution, the higher the values of the electric potential along the insulator. This behavior is observed because as the pollution increases, the greater the conductivity on the surface of the pollution.

The variation of the electric field distribution in insulator 2 can be visualized, as shown in Fig. 9.

Figure 9

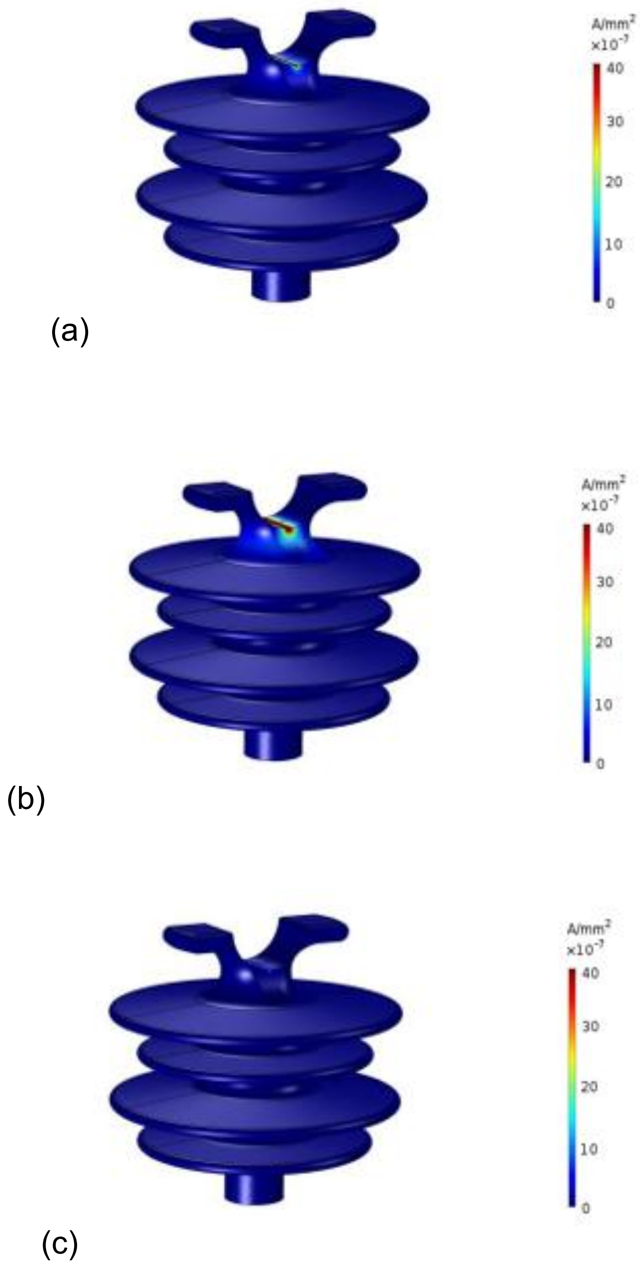
Distribution of the electric field in the insulator with (a) light, (b) intermediate, and (c) high pollution



It is clear that with the increase in the level of pollution, the becomes more intense along the insulator. In addition to the potential distribution and electric field, the behavior of the current density on the surface of insulator 2 was also simulated, as illustrated in Fig. 10.

Figure 10

Current density in the Insulator with (a) light, (b) intermediate, and (c) high pollution



It is observed that the current density behaves in a similar way to the potential and electric field, in the sense of increasing the number of regions in which it is more intense.

5 CONCLUSION

In this article, the electric field, the electric potential, the current density and, consequently, the efficiency of the insulator with different levels of pollution were evaluated. The simulations were carried out with the COMSOL Multiphysics software, in which it uses the Finite Element Method. The 3D modeling of the two topologies was based on the AutoCAD software. The incidence of pollution was modeled by inserting a conductive layer under the surface of the insulators, varying conductivity and permittivity parameters, which emulate three levels of pollution.

Comparing the results of the insulators under different pollution conditions, it was noticed that the behavior of the distribution of the insulating potential once became resistive, compromising the insulator's insulation capacity.

This occurred because as the level of pollution increased, the conductivity on the surface of the pollution increased. In the analysis of the electric field, the increase in the electric field was also noticed with the increase in pollution, which can lead to premature wear of the insulator. In terms of current density, it was also observed that there was an increase with the increase in pollution, which also implies an increase in the leakage current and consequent increase in losses.

Comparing the performance between the two types of insulators, it was found that insulator 2 is the best option, as it has lower values of potential distribution, electric field and current density. The advantage of insulator 2 can be attributed to the greater yield distance consisting of 58 cm, 38% greater than the yield distance of insulator 1, which consists of 42 cm.

ACKNOWLEDGMENTS

The authors would like to thank the support of the Coordination of Graduate Studies in Electrical Engineering (Copele) of the Federal University of Campina Grande (UFCG), the Coordination for the Improvement of Higher Education Personnel (Capes) and the National Council for Scientific and Technological Development (CNPQ) that enabled the contribution of the necessary resources to the Research, whose results are recorded in this technical article.

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