

**ANALYSIS OF THE PRESENCE OF INTERNAL CAVITIES IN PIN-TYPE
POLYMERIC INSULATORS UNDER POLLUTION**

**ANÁLISE DA PRESENÇA DE CAVIDADES INTERNAS EM ISOLADORES
POLIMÉRICOS TIPO PINO SOB POLUIÇÃO**

**ANÁLISIS DE LA PRESENCIA DE CAVIDADES INTERNAS EN AISLADORES
POLIMÉRICOS TIPO PIN BAJO CONTAMINACIÓN**

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ABSTRAT

This paper presents a study of the electric field in pin type insulators under the influence of an internal cavity. Polymeric insulators 15 kV were modeled with the aid of technical design software. Computational simulations to obtain the electric field were performed using COMSOL Multiphysics. The simulated cavity inside the insulator has spherical and elliptical geometry, with different values for its diameter. The position of the internal defect was varied from a region near the cable to a region near the hardware. For each simulated case, three levels of pollution were applied to the surface of the insulator, also considering the case in which it is intact. The results obtained for the case in which the insulator is intact does not present large variations in the electric field in the internal region. With the presence of a cavity, the electric field distortions in the cavity region assumed high values, surpassing in some cases the value of the dielectric strength of atmospheric air. The most critical defect detected was for elliptical geometry, whose electric field values were higher than the spherical case.

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

RESUMO

Este trabalho apresenta um estudo do campo elétrico em isoladores poliméricos tipo pino sob a influência de uma cavidade interna. Isoladores poliméricos de 15 kV foram modelados com o auxílio de um software de desenho técnico. Simulações computacionais para se obter o campo elétrico foram realizadas utilizando o COMSOL Multiphysics. A cavidade simulada no interior do isolador possui geometria esférica e elíptica, com diferentes valores para o seu diâmetro. A posição do defeito interno foi variada desde uma região próxima ao cabo até uma região próxima a ferragem. Para cada caso simulado foram aplicados três níveis de poluição na superfície do isolador, considerando também o caso em que ele se encontra íntegro. Os resultados obtidos para o caso em que o isolador se encontra íntegro não apresenta grandes variações no campo elétrico na região interna do equipamento. Já com a

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presença de uma cavidade, as distorções do campo elétrico na região defeituosa assumiram valores elevados, chegando a ultrapassar o valor da rigidez dielétrica do ar atmosférico. O defeito mais crítico detectado foi para a geometria elíptica, cujos valores de campo elétrico foram superiores ao caso esférico.

Palavras-chave: Campo Elétrico. Isoladores Poliméricos. Cavidades Internas. Poluição.

RESUMEN

Este artículo presenta un estudio del campo eléctrico en aisladores poliméricos tipo pin bajo la influencia de una cavidad interna. Los aisladores poliméricos de 15 kV se modelaron utilizando un software de dibujo técnico. Las simulaciones por computadora para obtener el campo eléctrico se realizaron utilizando COMSOL Multiphysics. La cavidad simulada dentro del aislador presenta geometrías esféricas y elípticas, con diferentes valores de diámetro. La posición del defecto interno varió desde una región cercana al cable hasta una región cercana al hardware. Para cada caso simulado, se aplicaron tres niveles de contaminación a la superficie del aislador, considerando también el caso intacto. Los resultados obtenidos para el caso intacto del aislador no muestran variaciones significativas en el campo eléctrico dentro del equipo. Sin embargo, con la presencia de una cavidad, las distorsiones del campo eléctrico en la región defectuosa asumieron valores altos, incluso superando la rigidez dieléctrica del aire atmosférico. El defecto más crítico detectado fue para la geometría elíptica, cuyos valores de campo eléctrico fueron mayores que en el caso esférico.

Palabras clave: Campo Elétrico. Aislantes Poliméricos. Cavidades Internas. Contaminación.

1 INTRODUCTION

The proper functioning of electrical insulators is one of the main factors in the quality and reliability of the transmission and distribution of electrical energy, so that the condition of these equipment is the focus of several studies in the area of electrical systems, especially with regard to polymeric insulators [1-3]. Since the 80's, polymeric insulators have been gradually replacing ceramic insulators due to several advantages, such as lower weight and cost. However, disadvantages such as the difficult

The detection of flaws within it and the lack of information regarding the aging process of polymeric materials foster the need for in-depth investigations to reduce the possibility of component failure [4], [5].

Failures in polymeric insulators can have several origins, one of the most common being the presence of cavities inside the insulating material [6]. Cavities can occur during the process of manufacturing, transporting, installing and operating the equipment, and their presence alters the behavior of the insulator when subjected to an electric field, which can generate internal partial discharges, which act by degrading the insulating material, increasing the internal cavity slowly until the dielectric loses its insulating properties, causing a disruptive discharge and consequently the failure of the electrical system [7].

In order to reduce the risks of internal partial discharges and consequently failures, the study of the electric field and potential distribution in polymeric insulators with cavities or cracks is of great importance [6]. Several authors have evaluated the influences of cavities on the distribution of electric field in insulators [8 – 12], however the electric field is also a function of the geometry of the equipment, the cavity and the severity and distribution of external contamination, so that such aspects must be taken into account during the analyses.

A common approach to electric field analysis in equipment is the use of computer simulations based on the finite element method (FEM). The finite element method (FEM) is a numerical method used to find approximate solutions to complex problems by subdividing them into several smaller, discrete, and correlated problems [13]. From computer simulations and the use of FEM, it is possible to analyze the influences on the electric field of internal cavities, their geometric shape and location, as well as external contamination simultaneously.

Thus, the present work aims to evaluate the impacts of the location and geometric shape of the cavity in polymeric distribution insulators, simultaneously at different levels of external contamination. Knowledge of the electric field in a polymeric insulator that has

internal defects can be useful in determining the defect in advance, as well as the actual chances of insulator failure.

Therefore, the objective of the research is the analysis of electric fields applied to pin-type polymeric insulators under the influence of internal defects and pollution. To this end, computer simulations of electric field calculation must be performed analyzing the behavior of the electric field when cavities are inserted into the insulator body. The variation of the diameter and dimensions of the axes of spherical and elliptical cavities are also studied.

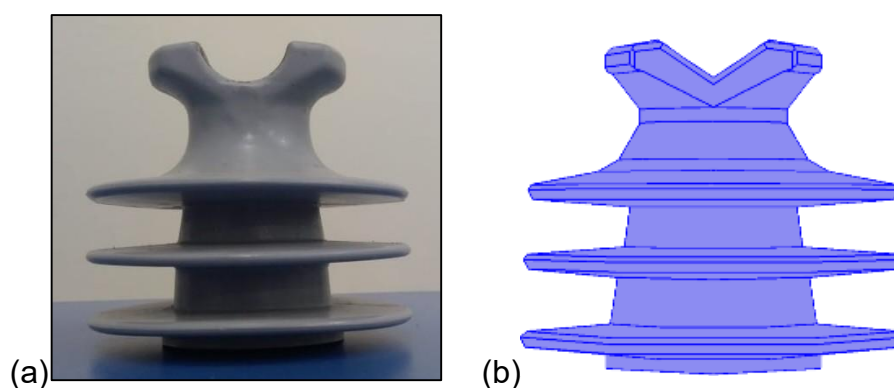
2 MATERIAL AND METHODS

2.1 MATERIAL

For the development of the computer simulations, a 15 kV class pin-type polymeric insulator was considered, which has three fins of the same size and does not have a fiberglass core. The insulator was graphically modeled in three dimensions using a computer-aided design program. The electric field analyses were performed using the finite element method, with the COMSOL Multiphysics® program. The modeled insulator and its three-dimensional representation, used in the simulations, can be observed in Figure 1 (a) and (b), respectively.

Figure 1

Sample and Model Drawing of 15kV Integral Insulator



2.2 METHODS

To investigate the influences of cavities inside the insulator under study under pollution, different shapes and locations of the fault were considered, as well as different levels of pollution. The simulation procedure is described below.

Initially, the geometric domain of the problem was determined as 3D. Later, the physical domain of the problem (Electric Currents, in the case of the program used) was defined. For the complete definition of the problem, a limited space was defined, containing the arrangement and other modeled elements.

To simulate internal cavities in the insulator, two geometries were defined: spherical and elliptical. The position of the cavity was varied from the cable to the hardware, being centered at distances of 4 mm, 12 mm and 20 mm from the cable, representing, respectively, the case close to the cable, an intermediate case and a case close to the hardware. Regarding the spherical cavity, the radii were varied in 1, 2 and 3 mm. The same occurred with the elliptical cavity, however, two simulations were performed, in which one dimension at a time was varied in the axis of the transverse plane of the insulator, with radial dimensions of 2, 2.5 and 3 mm.

The pollution was represented by a 2.0 mm layer on the surface of the insulator. Considering that the pollution of a region varies according to the location, time of exposure and 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 the electric field parameters under different pollution levels. Three different levels of pollution were simulated: light, medium and heavy. After modeling, it was necessary to insert 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 program and from references in the literature, as shown in Table 1.

Table 1

Constants assigned to the materials present in the simulation

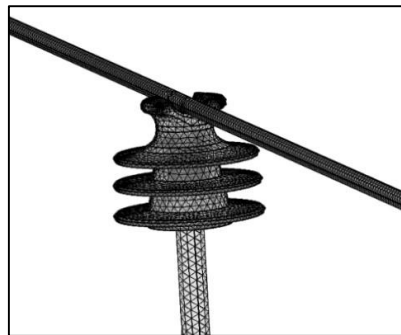
<i>Materials</i>	<i>Electrical Permittivity</i>	<i>Electrical Conductivity (S/m)</i>	<i>Materials</i>	<i>Electrical Permittivity</i>	<i>Electrical Conductivity (S/m)</i>
Polymer	4,5	1.00×10^{-5}	Medium Pollution $\epsilon^{(B)}$	15	1.00×10^{-5}
Galvanized Iron ^(A)	1.00×10^5 107	5.98×10^6	Heavy Pollution ^(B)	15	1.50×10^{-4}
Aluminium	1.00×10^5	35.5×10^6			

Source: (A) [14], (B) [15]. Others found in the COMSOL Multiphysics® libraries

Boundary conditions were then applied, such as the operating voltage on the cable and the ground potential on the fastening hardware. Subsequently, all the elements that make up the domain were divided into regions composing the mesh, as shown in Figure 2. This process is known as discretization.

Figure 2

Discretized isolator in COMSOL Multiphysics®



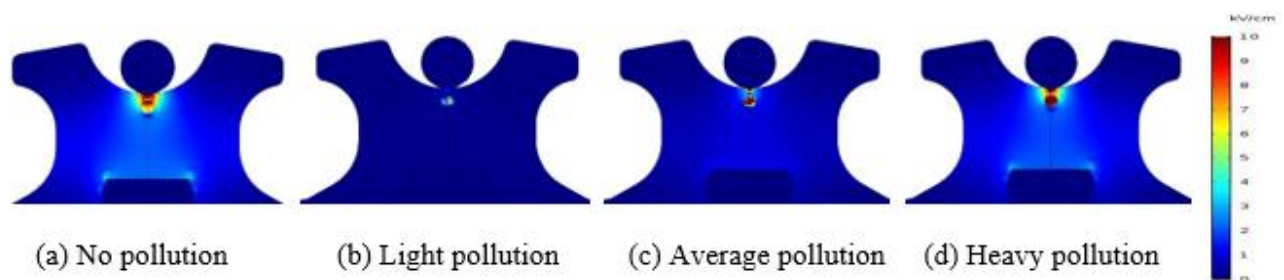
From the results, the analysis necessary for the interests of the study is carried out. Planes transversal to the insulator were observed, in order to allow the evaluation of the distribution of the electric field in the cavity region.

3 FINDINGS

The behavior of the electric field for a spherical cavity with a radius of 2 mm, whose center is 4 mm from the cable, can be observed in Figure 3 for the different levels of pollution analyzed.

Figure 3

Distribution of the electric field in the insulator with a spherical cavity close to the cable



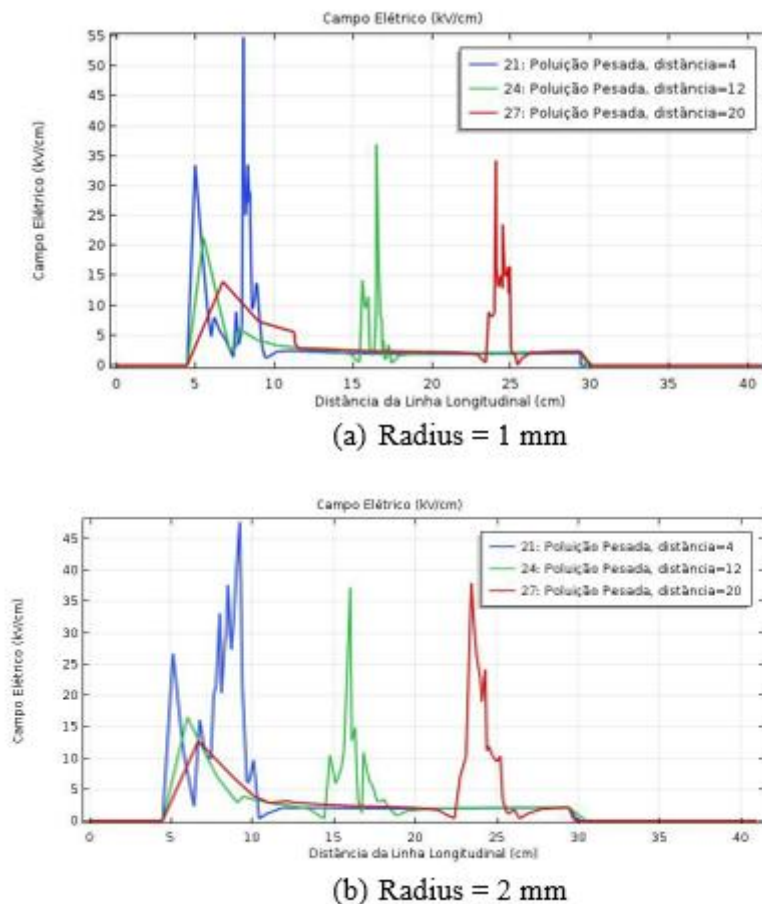
It is possible to observe that the presence of pollution will not necessarily increase the values of the electric field in the region of the cavity, verifying that for light pollution the field

reaches a lower value when compared to the case without pollution. The result is in agreement with what was addressed by [7], who in turn found that for a spherical cavity close to the cable, the electric field values are lower as the level of pollution increased. However, the results of the present work are divergent as pollution is high. For cases of medium and heavy pollution, unlike light pollution, the electric field values intensify and surpass the case without pollution. This divergence of results is due to the difference in the geometric approach, because [7] it obtained results in 2D and the present work obtained the results from a 3D geometry, which in turn is more consistent with reality.

In addition, the results are analyzed by means of graphs that correspond to the electric field distributions calculated under a longitudinal line drawn from the phase to the grounded hardware and can be seen in Figure 4.

Figure 4

Electric field along the longitudinal line for a spherical cavity

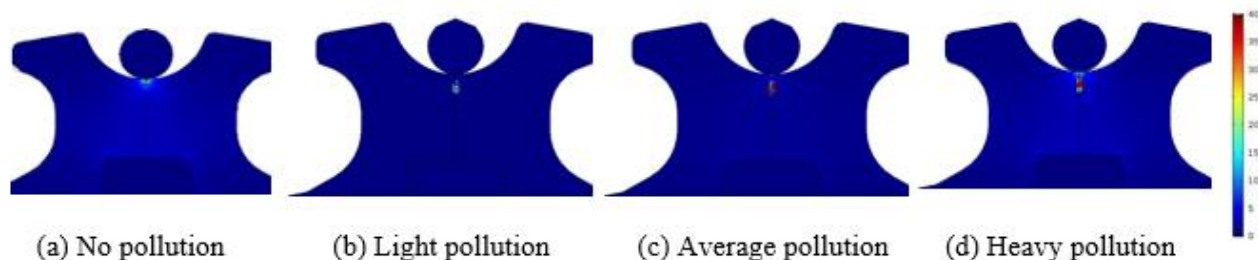


As can be seen in Figure 4, when the longitudinal line is present in the phase and in the hardware, the electric field is null because it is a conductive material. The intensity of the electric field increases when there is a transition from the conductive material to the dielectric. In the cavity region, there is distortion of the electric field with higher intensities in the regions close to the cable. In addition, the greater the distance from the cavity to the phase terminal, the lower the values of the electric field, with the exception of the radius of 2 mm, which presents an increase in the electric field in the variation from 12 to 20 mm. The highest field value is obtained for the radius of 3 mm, when the cavity is 4 mm from the phase conductor, in which case the end of the defect is closest to the conductor.

When it is considered that the geometry of the internal cavity has an elliptical shape, the results obtained have a higher electric field strength at the ends when compared to the spherical shape. Figure 5 shows the electric field distribution in which the minor axis has a value of 2.5 mm.

Figure 5

Electric field distribution in the insulator with elliptical cavity with minor shaft equal to 2.5 mm



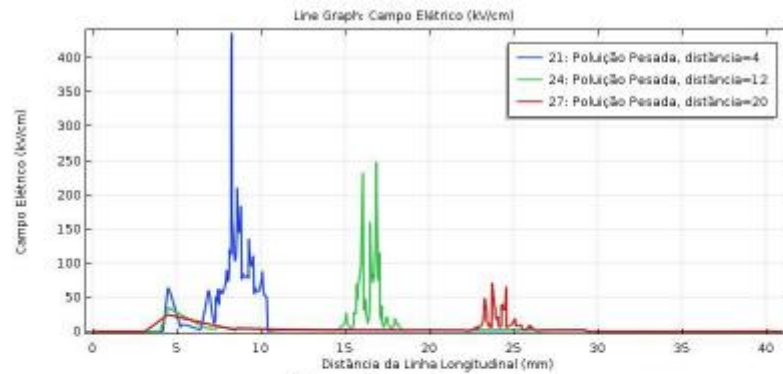
Differently from what was observed for the spherical cavity case, the elliptical cavity presented lower electric field values for the intact case. However, for medium and heavy pollution, the electric field values showed intensification of the electric field, reaching levels that exceed the dielectric strength of atmospheric air.

Figure 6 shows the electric field values in the longitudinal line drawn from the phase to the hardware, varying the position of the defect, as was done in the spherical case. It is relevant to mention that the electric field peaks occur in approximately the same regions along the longitudinal line, varying only their intensity, whose maximum amplitude is located in the defects close to the phase conductor. However, considering that the electric field is highly non-uniform in the region, the

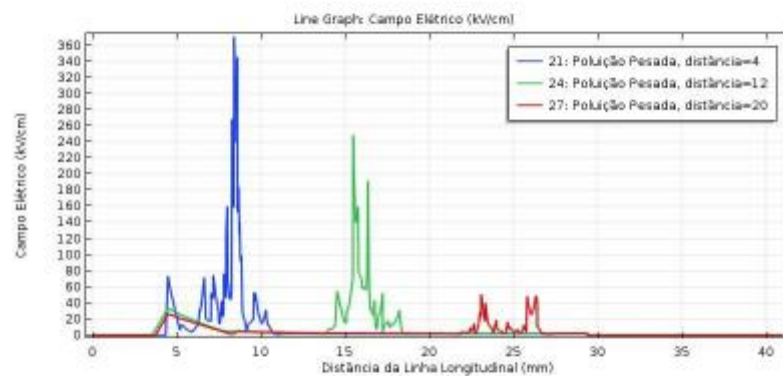
probability of bombardment of the polymeric material by the action of the electric field, which may cause localized electrical rupture.

Figure 6

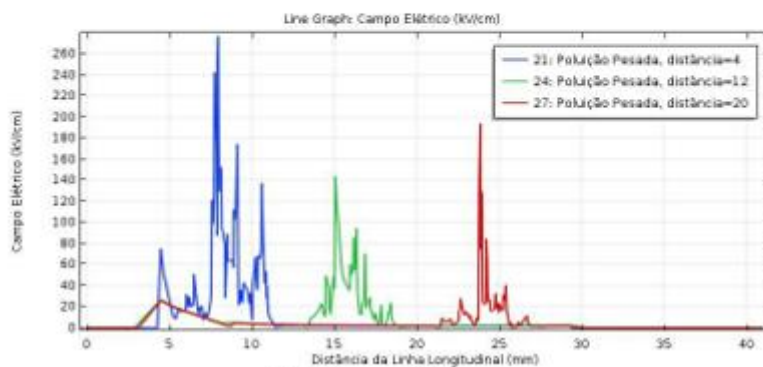
Electric field along the longitudinal line for an elliptical cavity



(a) Minor shaft = 2 mm



(b) Minor shaft = 2.5 mm

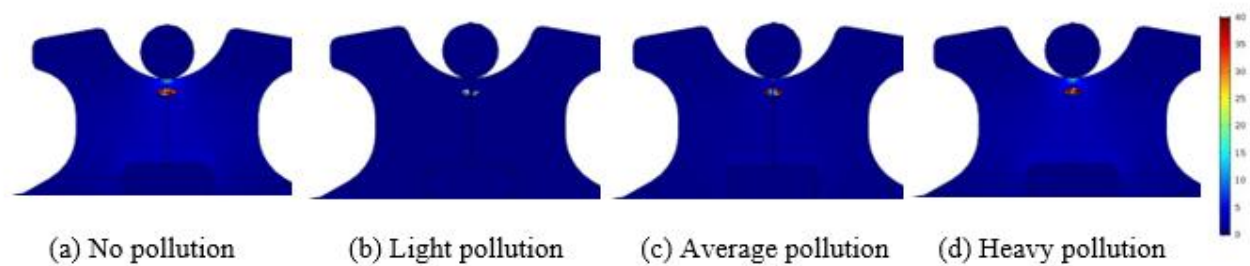


(c) Minor shaft = 3 mm

Even so, in Figure 7 the distributions for the electric field can be verified in the case where the variation in the dimension of the ellipse is made by the major axis, whose value corresponds to 2.5 mm.

Figure 7

Electric field by type of pollution

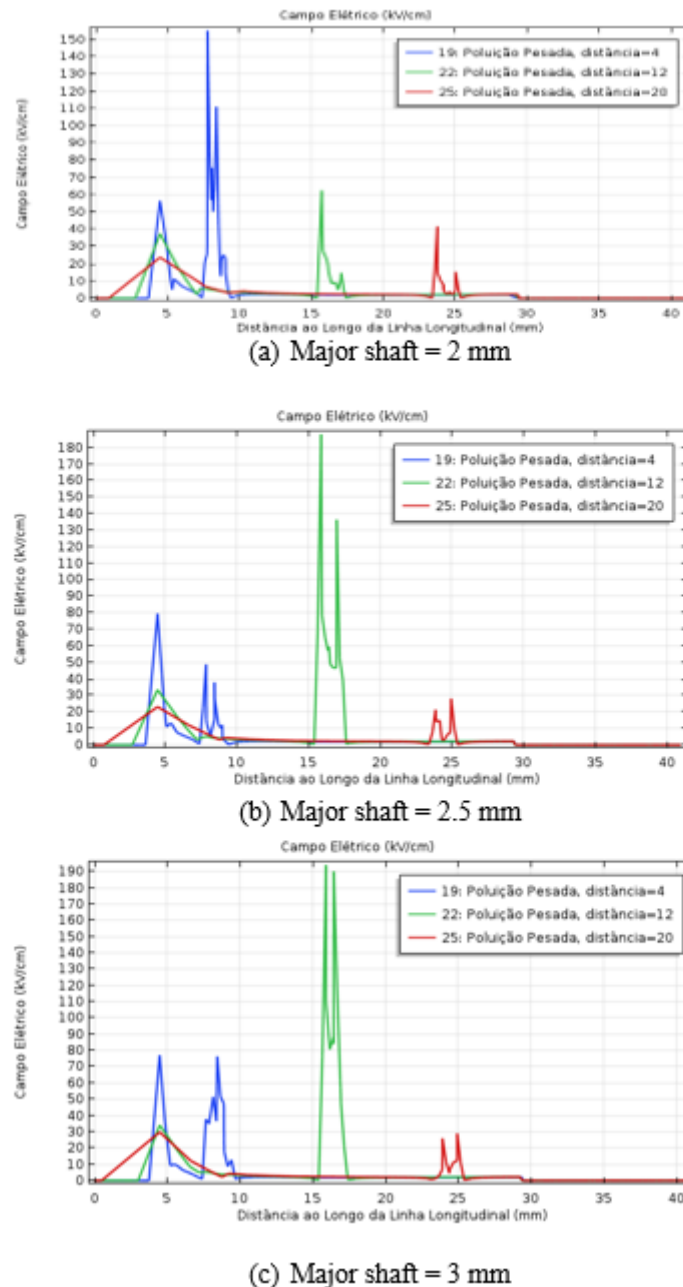


In the results obtained from Figure 7, the isolator with light and medium pollution present lower values of electric field along the cavity when compared to the intact case, with heavy pollution being the worst case analyzed, as measured in the previous analyses.

When considering the variation in the position of the cavity with a variable major axis, it is detected that when the major axis presents a value of 2.5, a result similar to that obtained for the value of 3 mm, with a peak electric field at the position of 12 mm, in the intermediate case. In the case where the cavity has a value of 2 mm, the peak values of the electric field decrease as the cavity approaches the hardware. These results are different from the previous case because the extremities of the ellipse, where there is a greater concentration of field, are farther from the conductor.

Figure 8

Electric field plot on central axis by pollution and internal cavity diameter



4 CONCLUSION

In this work, computer simulations of electric field calculation were performed in pin-type polymeric insulators under the influence of internal defects and pollution. The behavior of the electric field was analyzed according to the variation of the diameter and dimensions

of the axes of spherical and elliptical cavities, respectively, inserted in insulators. The results were compared with similar works found in the literature and it was detected that the computer simulation for the 3D geometric case differs from the works carried out with 2D geometry, because the isolator presents geometry of revolution, in which the 3D environment is more consistent with reality.

The analysis of the behavior of the electric field found that the presence of an internal defect, cavity, causes distortion in the distribution of the electric field, reaching high levels of intensity that exceed those of the dielectric strength of the atmospheric air. The worst case detected was for heavy pollution with an elliptical cavity located 4 mm from the phase conductor, which presented a value above 400 kV/cm. These high field values provide the necessary means for the degradation of the insulator, aggravating the defect, as well as compromising the correct functioning of the insulator.

The results show that the presence of cavities concomitantly with pollution, regardless of the distance from the conductor, is a problem for the correct functioning of the insulator, which can lead to internal discharges and localized electrical rupture, compromising the system as a whole.

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