Analysis and Prediction of Electric Field Intensity and Potential Distribution along Insulator Strings by using 3D models

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Abstract: - This The paper presents the development of three-dimensional models for the study of the electric field intensity and the potential distribution in insulators strings of an electrical system using the finite element method, and through a multiphysics platform is performed the resolution of physical systems, modelling and simulations. The design of models allows the calculation and simulation of the potential distribution and electric field intensity on insulators under different conditions of operation by enabling the analysis of the behavior against variations in conditions and factors involved in its functioning, as well as the evaluation of strategies for the mitigation of its consequences. In many high voltage applications corona discharge is seen as an unwanted side effect. Corona discharge from high voltage electric power transmission lines constitutes an economically significant waste of power for utilities. This analysis allows predicting possible future outputs of service of power lines due to failures of isolation and thus anticipating and scheduling preventive solutions.

Key-Words: - design, insulators, corona discharge, electric field, prediction.

1 Introduction

In transmission and electricity distribution systems insulators strings operate under mechanical, electrical efforts and environmental constants such as own ongoing efforts caused by voltage operation and weight of the elements associated with the chains (cables, brackets, accessories), transient efforts as lightning, operation switches, contamination in the chains, wind temperature changes, additional charge by presence of ice, rain, etc.

All of these factors affect the normal performance of the lines leading to the emergence of phenomena such as corona discharge and partial discharge. These phenomena produce consequences such as loss of power, generation of light, audible noise and interference, vibration, deterioration of materials, generation of ozone, nitrogen oxides and moisture between others and, if reaches certain importance, produces corrosion in drivers because of the formed acid [1].

Currently both the University and the professional scope of electrical engineering the study of these phenomena is carried out by analytical calculations based on empirical methods. These calculations allow us to determine the potential gradient for which appears ionization on the conductor surface called surface critical gradient under certain operating conditions from which it is possible to calculate the losses and other consequences due to corona discharge or verify the levels of tension and line conditions, but is not analyzed the behavior and distribution of the field and electric potential.

The electric field behavior and potential distribution has various options for its analysis which are: analytical methods through a simplified equivalent circuit, the pilot based on the measurement of fields and the numeric which approximate the solution of the problem through the implementation of numerical methods that solve the equations that define the behavior of the electric field. The first option does not allow an effective evaluation of the field and the distribution of the electrical potential, and the complexity of the model makes it difficult to obtain a solution. Experimental though effective involve high costs and sometimes the measurement methods can affect the natural behavior of the phenomenon. On the other hand, the application of numerical methods accompanied by progress in computational systems that use these techniques for solving allows complex studies of electromagnetic phenomena becoming a useful tool, flexible and less costly with respect to experimental methods.

One of the first researchers of the study of the discharge corona was F. W. Peek, who carried out his first experiments with a line of 275 m in length, powered by a 200 kV single-phase transformer since 1912. Diameters of wires analyzed by Peek experimentally were from several millimeters to an inch [2].

Subsequently, a large number of researchers is interested by this phenomenon, among them L. B. Loeb who headed one of them groups of research that more have contributed to the knowledge of the corona discharge. Loeb published in 1965 the book entitled "Electrical coronas" which is still considered a very important reference work [1].

The works and research oriented the analysis of the field electric in insulators of lines electric, are these of glass tempered, porcelain or synthetic through numerical methods due to [3], who define a method to determine an electrical field of low frequency in standard contaminated insulators, whereas models axisymmetric are considered and applying finite element method.

Rasolonjanahary analyzes the three-dimensional behavior of insulators contaminated using the numeric method of border elements establishing a theoretical formulation and comparing the results with obtained in analytical and experimental way [4].

Due to the continuous advancement in computer systems, can be currently studies extremely complex for electromagnetic phenomena using experimental and numerical techniques. The study and analysis of the electric behavior in insulators chains of glass tempered, porcelain and of others types as synthetic through the application of numerical methods allow the insulating design, as well as study the dimensioning of transmission structures (towers and posts) and the configuration of lines of transmission, influencing directly in the optimization of costs and improvements in the performance of transmission systems [5].

2 Applied Methodology

Through three-dimensional models is evaluate and computationally analyzed different operation conditions of insulators strings that constitute lines of transmission and distribution of electric energy. Insulators are used as support and drivers, at the same time holding them isolated from earth [6]. The most common material used for insulators is the porcelain shown in Fig. 1, and glass and synthetic materials such as epoxy resins.

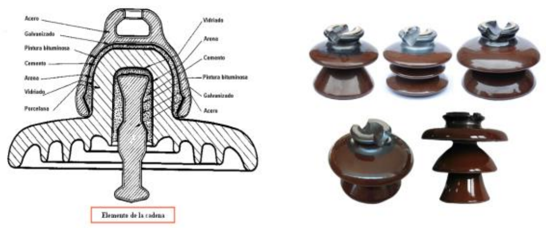

Fig. 1: Porcelain electric insulator

Strings made of insulators are used in high and medium voltage by a variables number of them dependent from voltage operating (Fig.2).

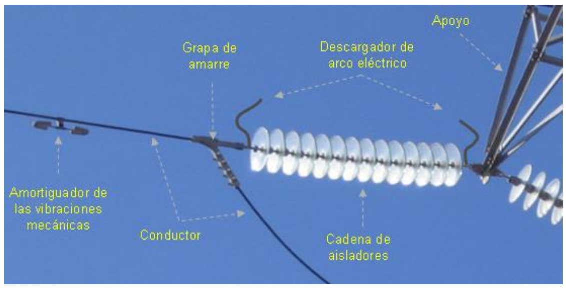

Fig. 2: Insulator strings

When the electric field or potential gradient reaches the "dielectric strength of air" (approximately 30 kV/cm at normal atmospheric pressure), the air is ionized, becomes conductive and produced a local discharge. This phenomenon is accompanied by a luminous glow which comes from the name of corona discharge. In addition, produced losses of energy, an easily perceptible hum and noise on radio and television in the vicinity of the area where the phenomenon is located. Ozone is also produced in the presence of moisture, nitrous acid, which brings as a consequence the corrosion of conductors if the phenomenon is intense. The surface gradient necessary to achieve the threshold corona in the gas surrounding a smooth cylindrical conductor, is called visual critical gradient or gradient of initiation, Ev. The level Ev on the surface of the conductor means that at a certain distance from that surface breakdown level required activate the download process and the beginning of the luminous manifestations has been reached [7].

The calculation of the critical or initiation gradient, from which there are downloads of the type corona is of great importance to evaluate the consequences of this phenomenon. The critical gradient is a function of the conductor diameter , the condition of its surface and the relative density of the air which in turn depends on the pressure and temperature . Peek, obtained empirically formula that is the most used for the calculation of the critical gradient in cylindrical conductors. The critical gradient "Ec", kV tip/cm, is expressed as:

$$E_c = g_o\,\delta_m \left(1 + \frac{0.301}{\sqrt{\delta\,R}}\right) \quad (1)$$

Where

g_o : disruptive critical gradient of air ≈ 29.8 kVpunta / cm.

R : conductor radio, en cm.

δ: relative air density

m: state superficial coefficient

$$\delta = \frac{0.393}{273+T} \qquad (2)$$

Where P air pressure, en mm Hg, and T air temperature, in ° C.

The analysis and evaluation of the models was conducted using the computational tool Comsol Multiphysics. This is a package of software analysis and resolution by $e.m.f.$ for various physical applications and engineering, especially coupled phenomena, or Multiphysics.

3 Modelling a 3D Insulator String

3.1 Protothype in CAD and geometry

The equipment design is developed in CAD (Fig. 3.a), this design is imported to COMSOL (Fig.3.b). Multiphysics platform modules have the option of correcting any inconvenience in the contours of the imported part.

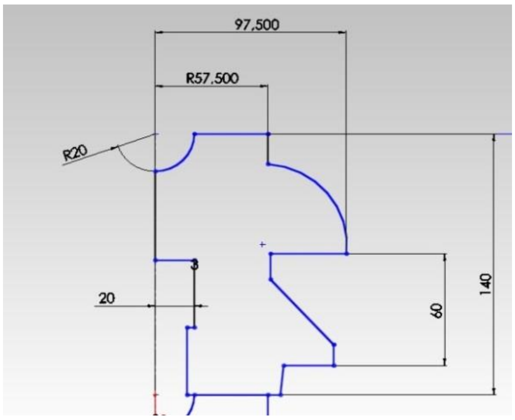

Fig. 3: a) Geometric design in CAD

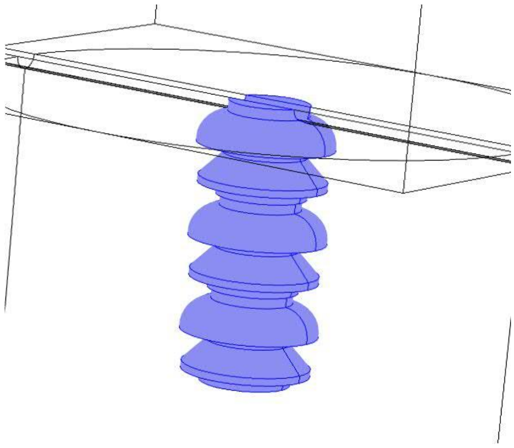

Fig. 3: b) Geometry imported in COMSOL.

3.2 Using AC/DC Technology

The module AC/DC allow the possibility to built a computacional model that represent a ssytem under study by specifying the physical conditions of the virtual prototype and software delivery prediction of electric, magnetic and electromagnetic fields, so it is a design and analysis technique implemented in a computer. [8]. The main advantages that brings the use of this technology are: the electric field prediction, the design and protothype system avoiding experiments of high cost, the visualization and the animated system in the variables terms modifying the components properties and the environment.

3.3 Meshing Sequences

To solve the proposed moddels we must make a mesh geometry. The meshing of Fig. 4 is achieved with the function "mesh" CFD simulation software, this part of the process is of utmost importance and it is always done after adding and defining multifisics conditions, it is here in which defines the type of mesh necessary for the analysis by finite element.

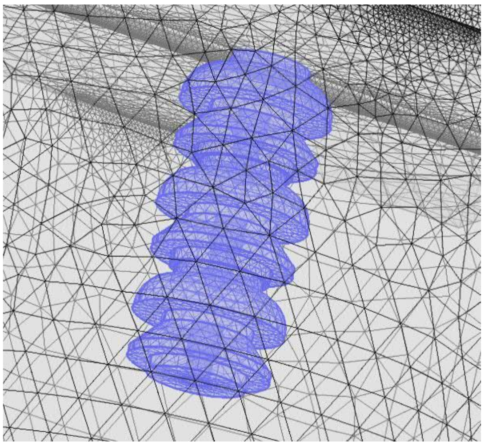

Fig. 4: Model meshed

3.4 Simulations sequences

After design the chain of insulators model to study, is possible carry out a without number of simulations of the same facing under different conditions of operation, modifying parameters of interest e involved in the training of the phenomena in study. Below are some of the conditions simulated in the chain of insulators on a line of 33kV corresponding to those used for the distribution of energy in medium voltage in Argentina.

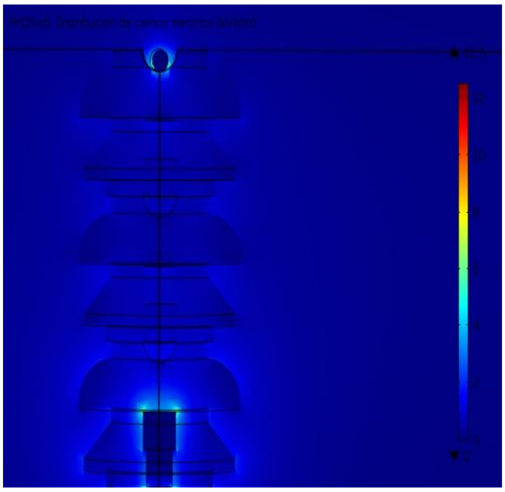

Fig. 5 Electric field distribution in porcelain insulator

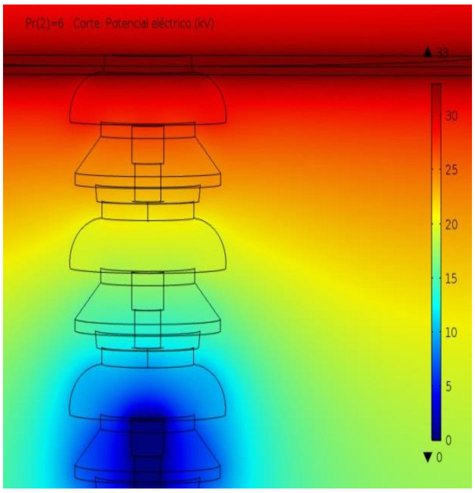

Fig. 6 Potencial Electric

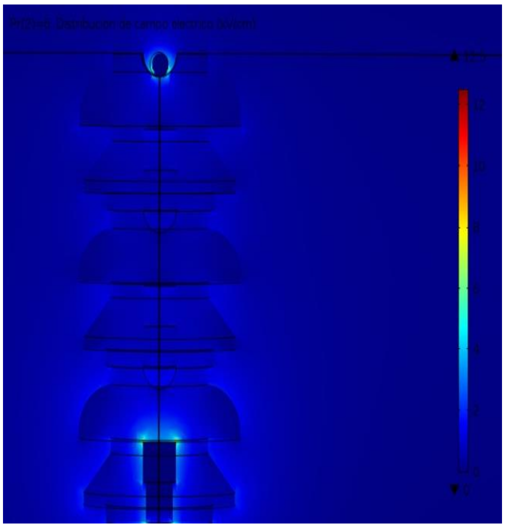

Fig. 7 Distribution of electric field in insulator of ethyl propylene.

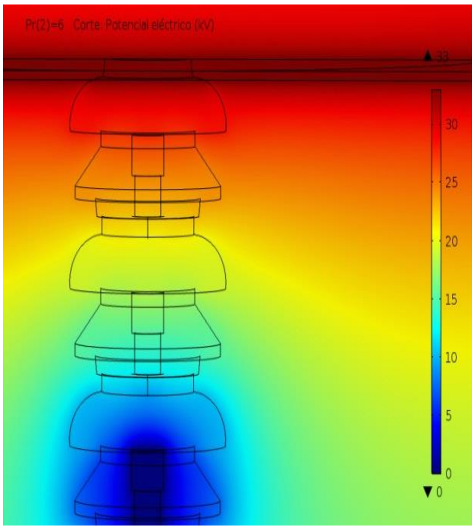

Fig. 8 Potential electric.

The Fig. 5, 6, 7 and 8 show respectively the distribution of field and potential electric of the chain of insulators when this is composed of insulators of porcelain and ethyl-propylene.

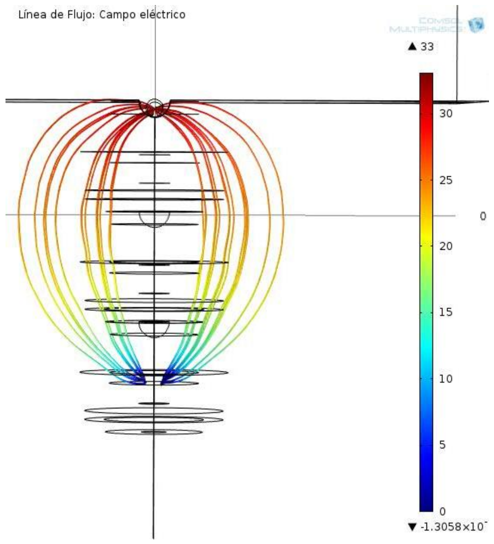

Fig. 9 Flow lines of electric field in porcelain insulator.

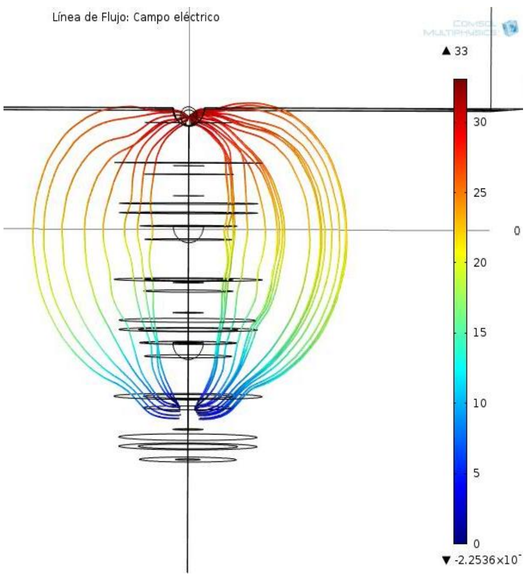

Fig. 10 Lines of flux of electric field in ethyl propylene insulator

Fig. 9 and 10 shows the distribution of the flow lines of the electric field in both cases.

The electric field through the length of arc of the insulator where supports the driver for different materials, which differ in the electric permittivity: synthetic material ($\varepsilon r = 2$), ceramic ($\varepsilon r = 6$), glass ($\varepsilon r = 10$) are analyzed, Fig. 11 and 12.

One of the alternatives to reduce the electric field in this area is to add a semi-conducting screen between conductor and insulator. The Fig. 13 and 14 shows the evaluation of such alternative.

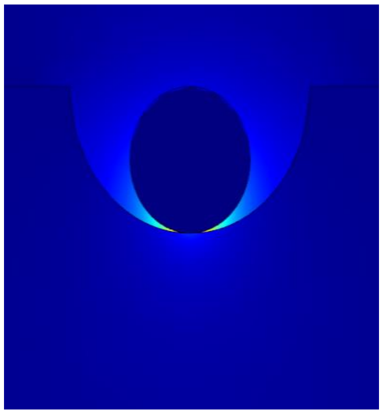

Fig. 11 Level surface of Electrical field in length of arc for different materials

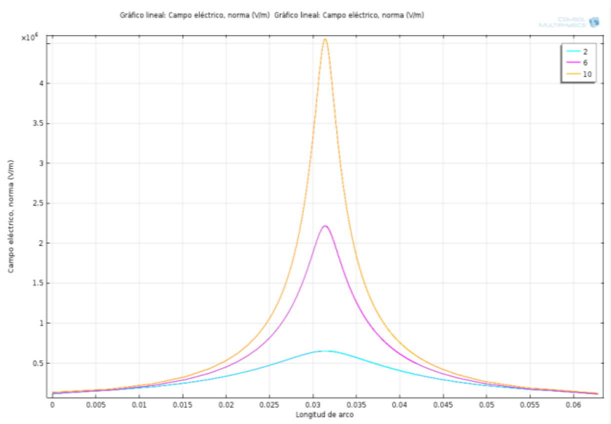

Fig. 12 Electrical field in length of arc for different materials

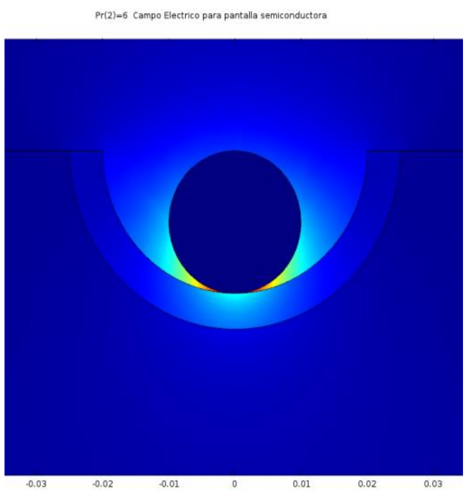

Fig. 13 Level surface of Electrical field in length of arc for different materials with semiconductor plate.

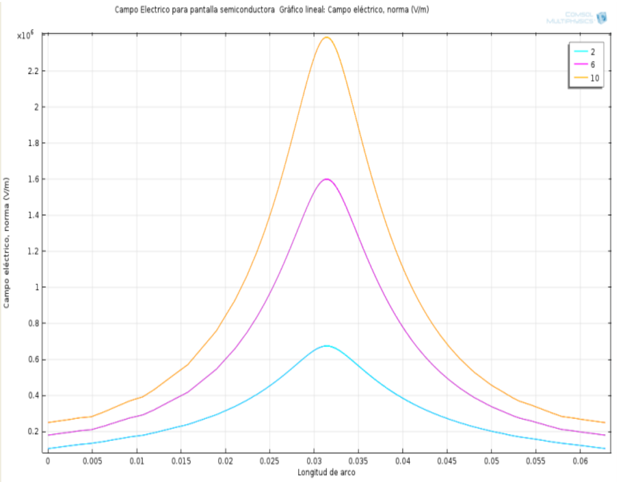

Fig. 14 Electrical field in length of arc for different materials with semiconductor plate.

The distribution of electric field in the case of an insulator damaged within the chain is simulated in Fig. 15 and 16.

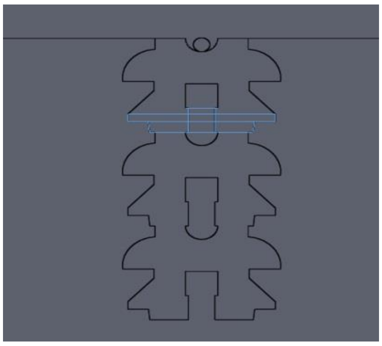

Fig. 15 Level surface of Electric field distribution for damaged string insulator

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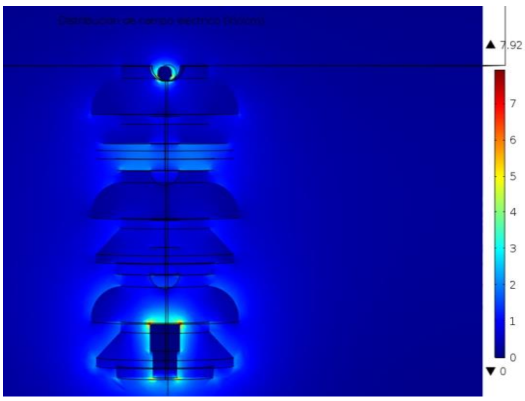

Fig. 16 Electric field distribution for damaged string insulator

Through a contour area, whose material properties can be configured easily, in the upper part of the elements that make up chain could be analyzed the effect of them front of deposited pollution or face the effect of water product of rain. This last case is presented in Fig. 17 and 18.

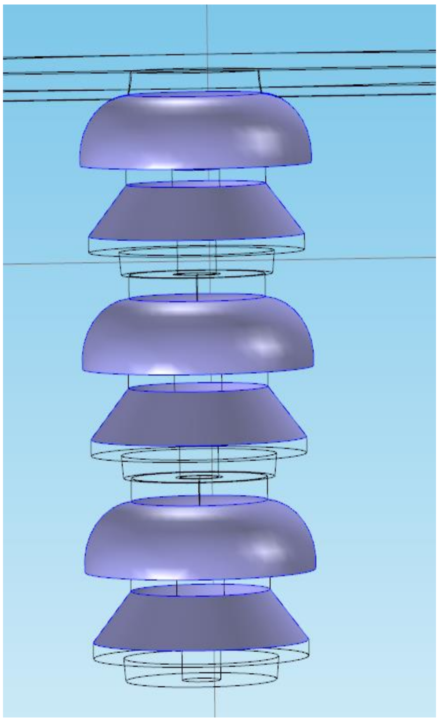

Fig. 17 Distribution of Electric field for the chain of insulators with wet surface.

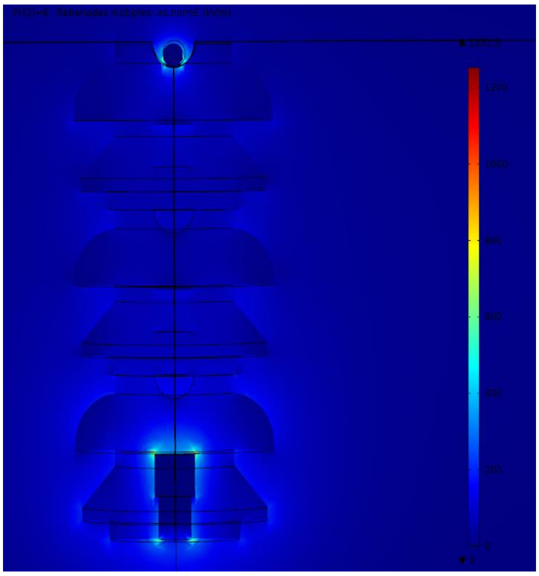

Fig. 18 Distribution of electric field for the chain of insulators with wet surface.

5 Modeling Results and Discussion

Use materials of low permittivity, ethyl-propylene case with respect to the ceramic or glass, involves a considerable decrease in the electric field; made desirable to mitigate the consequences of the corona effect and the partial downloads , Fig. 5 and 6.

An insulator damaged in the chain involves the loss of dielectric uniformity of the same generating a sudden change in the nature of the insulation and consequently an increase in the field in a relatively small region, presenting conditions favourable for the occurrence of partial discharges, Fig. 10.

Using a semi-conducting screen between the insulator and the driver allows us not only reduce the electric field, but it becomes more uniform around the point of contact between the insulator and conductor, Fig. 9.

All cases show that insulating contact point - driver is the increased intensity of field so this area is the greater issue of corona discharge.

Edges located at the ends of the insulator have the highest values of field because they are areas where high potential gradients are generated. This fact is important to analyze now that it is a propitious area for the initiation of surface discharges that can have outcome on the dielectric breakdown of the insulator, which is known as flutter and has the consequence of the outputs of services from electrical power lines.

The presence of water on the surface of the insulator generates a reduction of the dielectric strength of the same with an electric field more intense in a damp insulator that being dry as shown in Fig. 11. On the other hand, the products of rain moisture favors the appearance of disruptive discharges through the air due to the ionization of the same reason of humidity.

A layer of humidity on the insulator implies an increase in the conductivity of the same favoring the emergence of currents that outlined the outside of it.

4 Conclusion

The corona and partial discharges occur in non-uniform fields, in areas with large field intensities and is favored by the presence of humidity or contamination in the insulators, so these should be issues to take into account in the design of the chains according to the conditions in which it will operate the same.

These discharges in an insulating material usually begin in hollow filled with gas within the dielectric. After a partial discharges occurs a progressive deterioration of insulating materials, causing the rear insulation fault and subsequent exit of the line service.

The implementation of computational tools as CDF, for the analysis and simulation allows great versatility in the study of different conditions of operation in order to predict the behavior of the system under different conditions and so to program preventive actions for avoid consequences.

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