ELECTRIC FIELD MAPPING AND PARTIAL DISCHARGE ESTIMATION IN POLYMERIC INSULATORS USING FINITE ELEMENT METHOD

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Abstract: This study correlates the electric field distribution, obtained by using computational simulations based on the finite element method, with the results of partial discharges measurements, in a polymeric insulator. The material employed in the tests was a 15 kV class pin type insulator, widely used in Brazilian distribution power systems. Artificial imperfections were inserted on the simulated insulator, making it possible to analyze its effect on the electric field distribution and on the partial discharges occurrences. Computer aided design software was used to build the perfect and imperfect insulator graphical models. These models were imported to the finite element method simulation software (Comsol Multiphysics®), allowing the estimation of electrical quantities. The partial discharge intensities in the superficial cavities of the pin type insulator were quantified by an arrangement for partial discharge measurement. The tests took place in the High Voltage Laboratory of the Federal University of Campina Grande. The simulation method used was proved to be efficient, and results of this work show that it is possible to estimate the occurrence of the discharges by using the developed method.

1 INTRODUCTION

All electrical systems need efficient insulation. In distribution and transmission systems this task is mostly performed by insulators, which also handle the mechanical efforts.

Traditionally the insulators were made of ceramic materials, but due to advantages such as reduced weight, lower installation costs, good performance under pollution and higher hydrophobicity, which grants a smaller leakage current, polymeric insulators are growing in use [1].

Despite the above cited advantages, the knowledge regarding the aging of polymeric insulators is still restricted, which implies in few useful tools to predict failures in this kind of equipments [2]. It should also be pointed out that the polymers used in these insulators are highly susceptible to arcs, this increases the importance of predictive maintenance [3], therefore many studies nowadays aim to create techniques that enable the analyses of polymeric insulators. The most notable of these techniques are radiography, thermography, ultraviolet detection and electrical field mapping, which was used in this work.

A second order partial differential equation describes the electrical field distribution. Analytically solving this kind of problem is impossible in most practical cases, so it is imperative to solve this kind of problem with a numerical method. One method of proved efficiency is the finite element method (FEM).

The electrical field mapping generally aims to determine areas that are submitted to high electrical fields, because this would increase the probability of failures and accelerate the aging of the insulator. This acceleration is mostly due to the formation of partial discharges.

Partial discharges (PD) are electrical discharges that occur in a region of space submitted to an electrical field but do not link the two electrodes [4]. Partial discharges happen in regions with lower dielectric strength, usually internal voids in the polymer or in the interface between the polymer and the electrode.

Any equipment submitted to elevated voltages is susceptible to suffer PD. In polymeric insulators this effect can be particularly harmful. Because the evolution of this phenomenon is slow, the insulator may operate years until it is possible to detect it, and by this time it probably would be too late. In some situations PD even pierce the insulator.

Determining the electrical field distribution of equipment will denote regions submitted to an electrical field which is high enough to provoke PD, and estimate its intensity, but this estimation is only possible if there is a database of electrical field distributions correlated to PD measurements.

This work used computational simulations, based on the finite element method to calculate the electrical field distribution on polymeric pin-type insulators, class 15 kV, to correlate its results with field measurements of PD, in order to establish a method to construct a database that will enable the estimation of partial discharges.

2 METODOLOGY

The developed work can be divided in two stages. Initially, polymeric insulators were tested to measure their partial discharges, and then those situations were simulated by using the software COMSOL Multiphysics* to determine the electrical field distribution using FEM.

2.1 PD measurements

To measure PD, the circuit represented in figure 1 was used. This circuit was built according to standards NBR 6940 [5] and IEC 60270 [6].

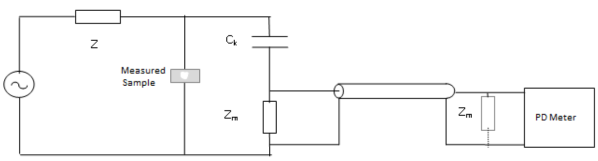

Figure 1: Circuit used to Measure PD.

In figure 1, the impedance Z is a resistor used to limit currents, C_k is a coupling capacitor and Z_M is an impedor. The precision of the results obtained with this circuit depends on the ratio of C_k and the capacitance of the sample.

The primary objective of the measurements is to determine the PD in an artificially inserted hole in the surface of the insulator, in order to correlate it with the electrical field that will be determined with the simulation.

Due to imperfections in the fabrication process of the insulator, small irregularities are formed on the surface of the insulator and become potential sources of PD.

To reduce the effect of these imperfections, the region where the hole would be inserted was painted with conductive ink. This ink should put the whole surface in the same electric potential.

The measurements can be divided in three groups listed on Table 1.

Table 1: Characteristics of the insulators in each group of measurement.

Measurement group	Description
I	Insulators before applying ink
II	Painted insulators
III	Painted insulators with the artificial hole.

This work will present results from two different insulators. They represent two opposed situations: the first one is the optimal case, where the results denote only the pattern of discharges in the roughness and the inserted hole, the other insulator has at least one extra source of discharges that makes the analyses more complicated.

Measurements of partial discharges are highly sensible to noise, so before each one of the nine measurements the noise was measured by using the circuit in figure 1, but with no sample. Then the level of measured noise was used as a threshold to filter the actual PD measurement.

During the measurements, the first PD were noticed when the voltage was in 15 kV. Therefore, this value was used in all measurements.

It is not possible to guarantee that all the measured partial discharges are actually happening in the region being analyzed, because it is possible that internal voids exist in the insulator, but it is reasonable to assume that any variation on the intensity or amount of PD is due to the inserted modifications.

The results of PD measurements are the magnitude and phase of all discharges that happened during the measurement, which took one minute each. These results will be presented here as graphics of intensity versus phase.

2.2 Simulations

To perform the simulations, first a graphical model of the insulator was built by using the software AutoCad**, and then exported to the software implemented by the FEM. The model took advantage of the axial symmetry of the insulator, so that the simulation process would be faster. All physical constants needed to characterize the materials are available in COMSOL Multiphysics, the software used for the simulations.

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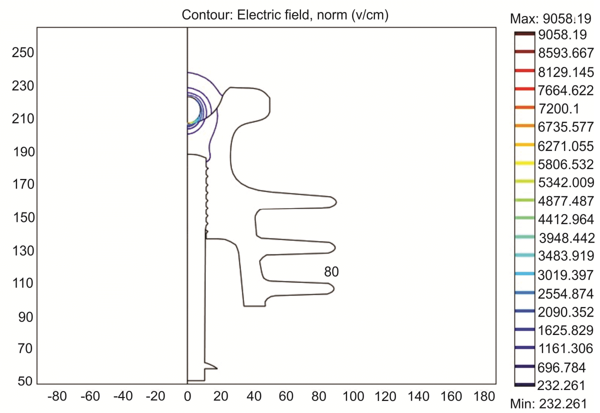
* COMSOL Multiphysics is a registered trademark of COMSOL AB.
** AutoCAD is a registered Trademark of Autdodesk, inc

The imperfections in the surface of the insulator were only represented in the region of interest i.e. near the source of potential. They were represented as chamfers of about 0.3 mm, The width of conductive ink was 0.1 mm. The same process used to simulate the conductive ink might be used to represent pollution in further developments of this work.

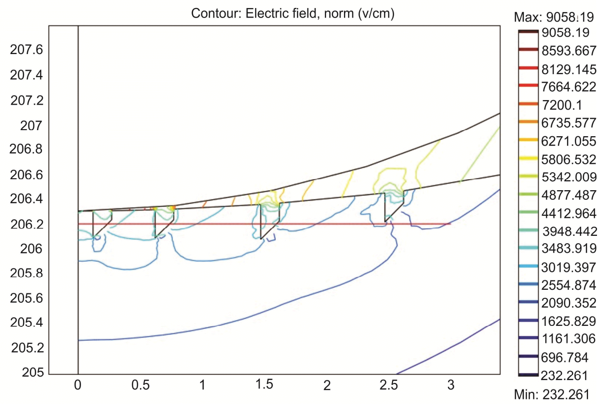
3 RESULTS

If the only source of discharges were the discharges happening in the roughness near the high voltage source, the expected pattern of PD would be discharges in the first and third quarters of the voltage wave, with the discharges in the first quarter up to ten times greater than in the third [7].

The results of the simulation for the group of tests I are presented in Figure 2.



(a)



(b)

Figure 2: (a) Results of the simulation for the group of tests I; (b) Details of area where the insulator is in contact with the voltage source.

The Graph shown in Figure 3 represents the electrical field across the red line presented in figure 2 (b).

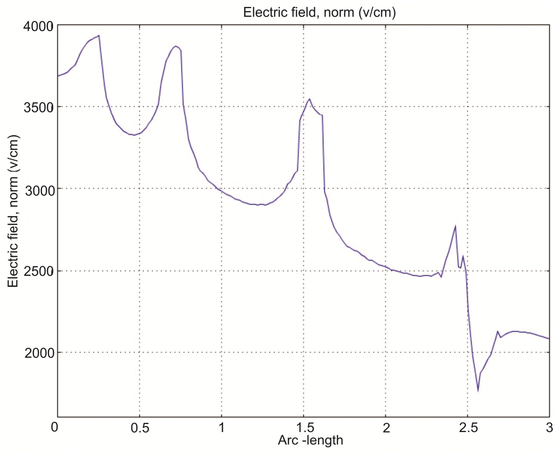


Figure 3: Electrical field across the region with roughness in the first simulation.

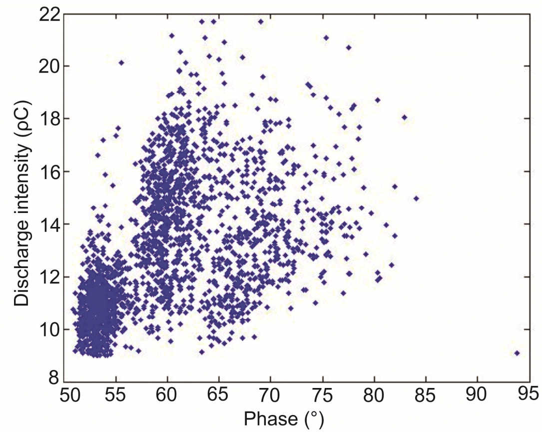
The results of simulations show regions with low dielectric strength, the air gaps formed by the roughness, submitted to peaks of electrical field.

Figure 4 shows the results of measurements of PD in the tests of group I.

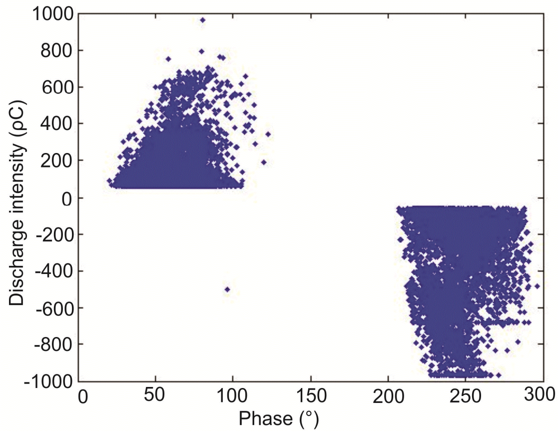
The result presented by the first sample, figure 4(a), represents the situation expected. No discharges are presented in the third quarter because they are in the same magnitude of noise.

The second sample, Figure 4(b), presents discharges with higher magnitude, especially near 90 and 270 degrees of phase, typical corona phases. Since the magnitude in the second half is greater than in the first half, it is possible to affirm that the corona is caused near the high voltage electrode [7]. No possible source of corona was used in the simulation. Therefore, the results presented in Figure 3 cannot be directly related to this case.

Figure 5 shows the result of the simulator of the insulator after it was painted, and figure 6 shows the graph of the electrical field across the red line of figure 5.



(a)



(b)

Figure 4: Results of measurements in group I for both samples: (a) the first sample and (b) the second sample.

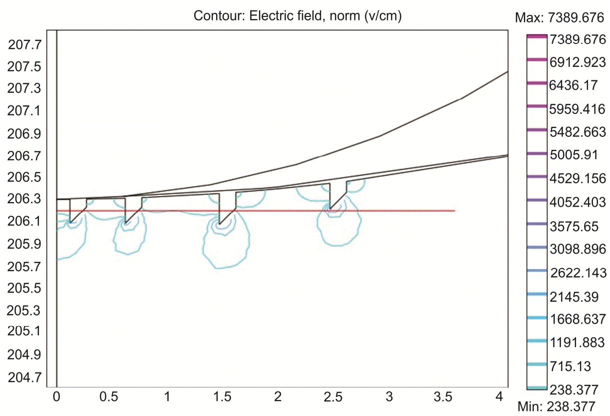


Figure 5: results of the simulation for group of tests II.

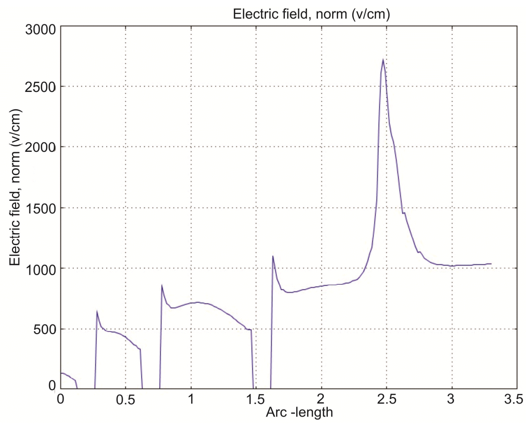
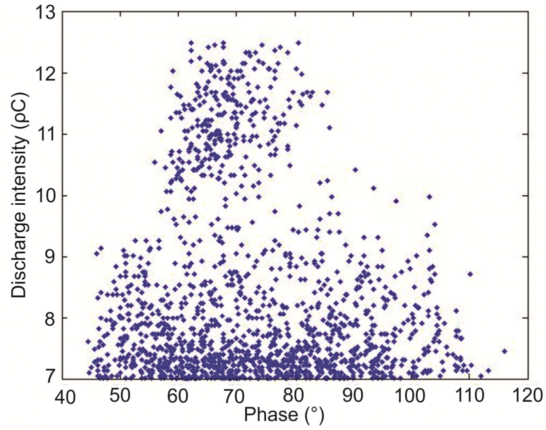
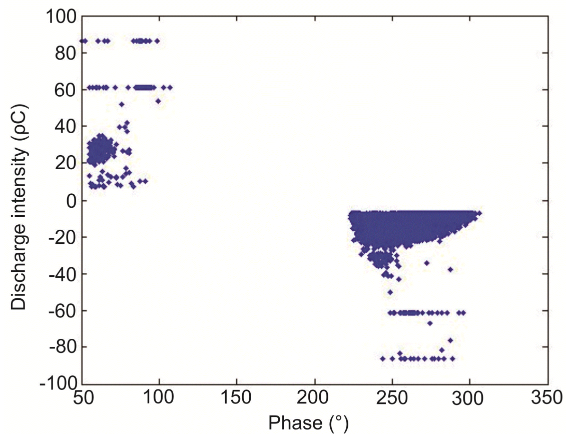


Figure 6: Electrical field across the region with roughness in the second simulation.



(a)



(b)

Figure 7: Results of measurements in group II for both samples, (a) the first sample and (b) the second sample.

The conductive ink promoted a severe reduction of the electrical field level, especially considering that this electrical field is no longer applied to a region with low dielectric strength. So it is expected that the level of PD is also reduced. The results of PD measurements for the group of tests corresponding to this situation are shown on Figure 7.

As expected, the amount and intensity of partial discharges were reduced. In the case of the second insulators, the reduction of corona may or may not be linked to the changes in electrical field, since many other factors may alter this phenomenon, such as changes in the environment conditions and unnoticed changes in the geometry of the measurement circuit. The reduction in the magnitude of corona enables a better estimation of PD.

The last simulation result represents the electrical field perturbation by the insertion of a hole in the insulator after it was painted, this result is presented in Figure 8, and the graph of the electrical field across the red line is presented in Figure 9.

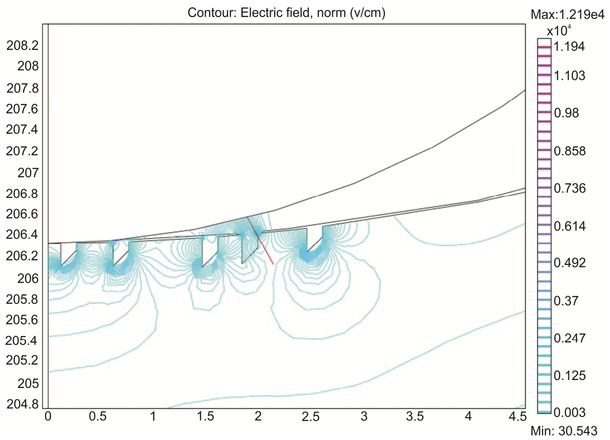


Figure 8: Results of the simulation for group of tests III.

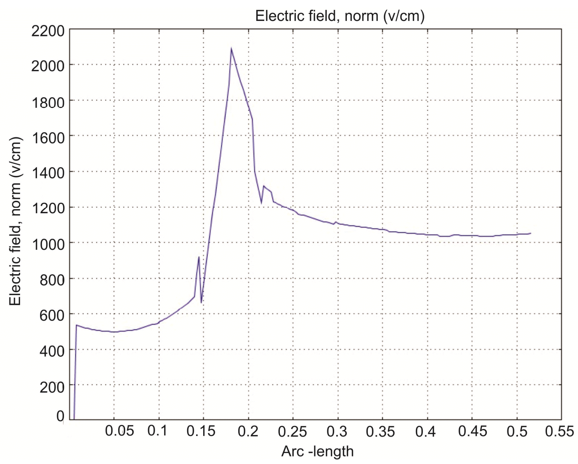
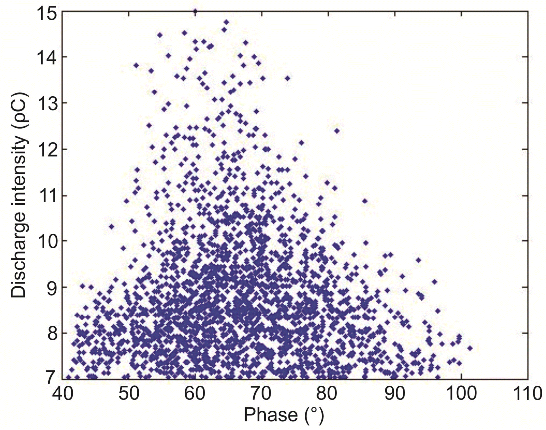
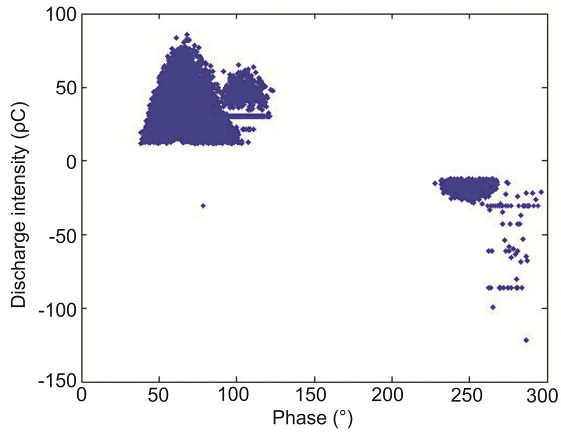


Figure 9: Electrical field in the region of interest on the third simulation, the values are measured across the red line.

The results of the simulation show that the maximum value of the electrical field is slightly lower than in the first simulation. Considering that the discharges are now confined to one cavity other than in various imperfections, it is expected that the magnitude and amount of discharges be lower than in the first case analyzed. The results of test group III are presented in Figures 10.



(a)



(b)

Figures 10: Results of measurements in group III for both samples, (a) the first sample and (b) the second sample.

As expected from the simulation results, the first sample had a smaller magnitude and smaller amount than in the first case. As for the second sample, the analysis was more complicated since the first measurement had a high level of corona.

Comparing the result of the simulations of group II and III for the second sample, it is possible to notice the increase in the amount and magnitude of PD, which are the discharges happening near the fifty degrees and two hundred and thirty degrees of phase, with the discharges in the first quarter of voltage wave being greater than in the third, which is expected, considering the increase of electrical field inside a cavity near the electric field source [7].

4 CONCLUSIONS

The results of the simulations were enough to estimate the variations on PD levels corresponding to variations on physical characteristics of the test, but this was only completely achieved in one of the presented cases. In the second case, the presence of corona made the results of the simulations less conclusive.

To overcome this fact, new simulations with possible sources of corona should be made. Extending this idea, the construction of a large database of simulations could be used to estimate the evolution of PD. The simulations database would also generate a database of electrical field levels that could be numerically related to the level of PD, but in order to make such estimations, more measurements need to be made.

Clearly, it is difficult to create a database that covers all the possible aspects that could interfere in real cases, but the analysis of the second sample shows that even in cases where not all aspects are analyzed it is still possible to perform a limited estimation. Therefore, the database idealized in this work would become a useful tool of analyses in any situation.

More efforts are currently being made in order to build such a database and results are promising.

5 REFERENCES

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