CORONA MODELING FOR POLYMER INSULATORS UNDER SERVICE CONDITIONS

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Abstract: The concerns about corona due to its harmful effects and its impact on the power system are well known. Among them, the exposure of polymer insulators, reducing service life and leading to possible failures, is particularly worrisome. A better understanding of corona for different arrangements is of interest for design and preventive maintenance purposes. Currently, this is done using empirical formulations or based on recommended levels of electric field. The electric field is affected by several factors, which influence in the corona establishment, such as the environmental conditions (moisture, temperature, pressure, etc.) and the service conditions (contamination, voltage level, arrangements, etc.). The objective of the present work is to propose a model for predicting corona. For this, it is necessary the knowledge of the electric field and its variations due to the mentioned factors. This paper investigates the corona formation in polymer insulator arrangements, observing the influence of some service conditions, such as moisture and contamination of the insulator surface, in corona process. Experiments were performed in 15kV-class polymer insulators and the corona activity was visually observed and photographed. The results indicate that space charge affect corona formation, changing the electric field. This is observed by changing the superficial conditions of the insulators. A good corona prediction model should be able to include the generation and concentration of these charges.

1 INTRODUCTION

Concerns related with corona and its harmful effects on the power system have been discussed extensively in recent years [1-4]. Particularly, the brittle fracture, corrosion and superficial degradation of polymer insulators are worrisome. These effects are caused by exposure of insulator to corona and may lead system to failures.

It is well known that the electric field plays a major role in corona formation. One way to avoid corona formation is by controlling the electric field along the insulator. To prevent corona, values for the maximum electric field, near or even inside the insulators, are recommended [5]. These limits are not fully consensual, as the electric field depends on the insulator shape, composition, environmental and superficial conditions. Based on field experience and on the suggested electric field, techniques are employed to prevent corona onset. Design of new insulators and use of corona rings in voltage levels not previously adopted are presented solutions [6-8]. Understanding corona activity and its formation is interesting as a criterion to design high voltage apparatus.

Recently, some works have been proposed to model the corona effect [9-11]. It is quite complex to consider all processes involved in corona formation. Each model performs considerations in order to simplify the computational implementation. Because of this, very often the surface conditions affecting the electric field distribution are not considered

The objective of this paper is to investigate the electric field and the influence of service conditions in the corona formation. For this, a model for corona prediction is proposed, in which the surface conditions may be incorporated. The model is intended for application in polymer insulators, avoiding the corona establishment, regardless of conditions submitted.

Experimental and computational simulations were performed. An experimental model, reproducing superficial conditions in a 15kV-class polymer insulator, was used. The influence of service conditions, as water droplets and pollution, in the corona formation, was investigated. Corona onset voltage was observed, and afterward, the electric field was estimated by simulations.

Preliminary results suggest that only maximum electric field is not sufficient to determinate corona inception. Corona model should consider the service conditions, evaluating the electric field and its changes, to predict the phenomenon in insulation arrangements.

2 CORONA MODELING

The chosen corona model to be implemented for corona simulation was the hydrodynamic model. At the present time, this model is not fully implemented yet. This section presents the initial study and analysis for its use.

The hydrodynamic model is derived from the continuity equation, considering different types of charge generated (electrons, negative ions and positive ions). The essential process for corona formation: ionization, attachment and recombination, are considered. Basically, the rate of increase of charges, in time and space, is provided by each charge carrier produced and removed, due to all mentioned processes.

The expressions for the increase of electrons, positive ions and negative ions, are presented in Equations 1, 2 and 3, respectively.

$$\frac{\partial N_e}{\partial t}+\frac{\partial N_e W_e}{\partial x}=N_e\alpha W_e-N_e\eta W_e-N_e N_p\beta_{pe}+S_{PH}+S_D \quad (1)$$

$$\frac{\partial N_p}{\partial t}+\frac{\partial N_p W_p}{\partial x}=N_p\alpha W_p-N_e N_p\beta_{pe}-N_n N_p\beta_{pn} \quad (2)$$

$$\frac{\partial N_n}{\partial t}+\frac{\partial N_n W_n}{\partial x}=N_n\eta W_n-N_n N_p\beta_{pn} \quad (3)$$

In these equations, subscripts *e*, *p* and *n*, refer to electrons, positive ions and negative ions, respectively. The velocities of charges are described by W_e, W_p and W_n, while the number of them are N_e, N_p and N_n. The contributions of ionization, attachment and recombination processes are considered through their respective coefficients (α, η and β). The portion of electrons generated by photoionization (S_{PH}) and by diffusion (S_D) is also incorporate. The values to be used for calculation will be based on [12, 13]. Although presented in one dimension, these formulations can be easily extended to more dimensions.

Through these expressions, it is possible to estimate the effect of a charge in the electric field due to its position, at any moment. If this field is known, it is possible to predict corona formation.

For computational implementation of this model, it is necessary to establish the conditions for corona formation. These conditions are experimentally investigated.

Basically, the visual corona onset voltage was identified in the experiments. From them, the electrostatic field was calculated by numerical simulations. Then, the space charge is incorporated and the electric field is recalculated. After that, it is checked whether the changes in the field are sufficient to initiate corona.

3 EXPERIMENTAL

The corona onset voltage on a polymer insulator sample was observed. The experiments aimed to investigate the corona formation along the insulators surface, due to water drops and pollution on their sheds.

3.1 Procedure

The setup used in the experiments was arranged to ensure that the first corona discharges were located on the surface of the insulator. Therefore, voltage was brought to the arrangement through smooth copper tubes. An overview of the experimental set up is shown in Figure 1.

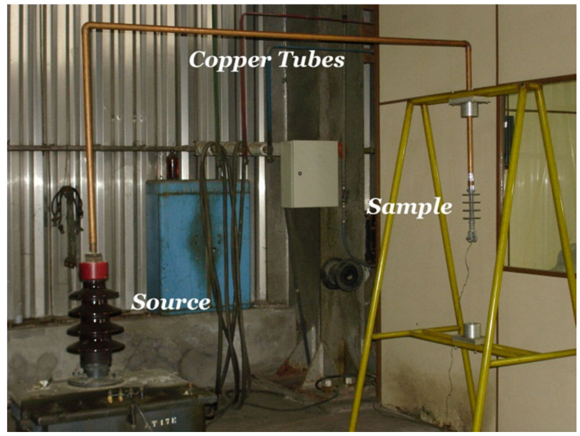


Figure 1: Overview of experimental setup.

The tests consisted of energizing a polymer insulator in a completely dark environment, applying a sinusoidal 60 Hz voltage, whose magnitude could be varied in the range of 1kV to 50 kV. From a low voltage level, at which corona activity was not detected, the voltage was increased in steps of 500 V. The arrangement was photographed, for each applied voltage. After the end of each experiment, the photographs were analyzed, and corona onset voltage was identified for each configuration.

In order to maintain the same light sensitivity, a digital camera was used to record the pictures with the same exposure time and sensitivity in all situations. The camera was set to ISO 3200, exposure time of 30 seconds and f/4.5 aperture. The camera was kept at a fixed distance of one meter from the arrangement.

The sample used in experiments was a 15kV-class polymer insulator. To simulate contamination and moisture of the insulator surface, two models were used. One model consisted of placing two metallic semi-spheres, simulating water droplets, in the first shed of the insulator, near of energized end. In the second model, water droplets, with conductivity and volume determined, were placed in the same shed. By varying the water conductivity, the severity of contamination was simulated. The conductivity was controlled by adding salt to achieve severe pollution.

Corona formation was evaluated for five cases named C_1, C_2, C_3, for metallic semi-spheres and S_1, S_2, for water droplets. In these cases, the following parameters were modified: the distance between the semi-spheres and the insulator shank (D_I), the distance between the semi-spheres (D_S), and conductivity of water droplets. Figure 2 shows the basic arrangement, highlighting the distances used as parameters. The diameter of the semi-spheres was fixed in 1.2 cm. The volume used in each water droplet was 80 µl, controlled by use of micro-pipet. In cases C_1 and C_2 corona inception between the semi-spheres was observed. When comparing C_2 and C_3, corona is assessed by the distance between the semi-sphere and the insulator shank.

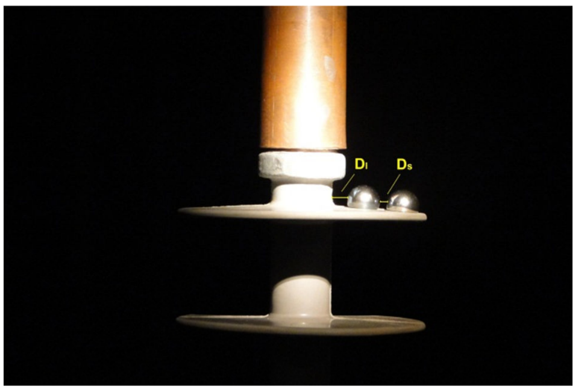


Figure 2: Detail of the arrangements.

Table 1 describes the evaluated cases and the parameters used for each case.

Table 1: Parameters were used in the experiments.

Cases	Type	Conductivity	D_I(cm)	D_S(cm)
C1	Semi-spheres	∞	0.26	0.56
C2			0.14	0.29
C3			0.53	0.26
S1	Water droplets	40 µS	0.86	0.52
S2		200 mS	0.82	0.42

The atmospheric conditions registered during the experiments were: relative humidity 40 %, temperature 25°C and pressure 698 mmHg.

3.2 Results and discussion

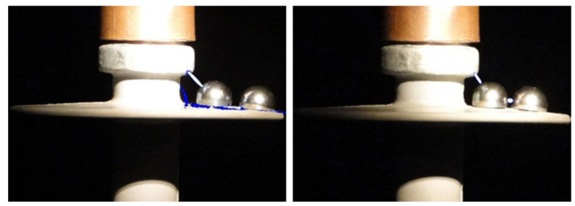
The observed corona onset voltages are presented in Table 2. The voltages applied for corona onset near the insulator shank (V_I), between the hardware end fitting and the semi-sphere (V_F) and between semi-spheres (V_S) are showed.

Table 2: Corona onset voltage (semi-spheres).

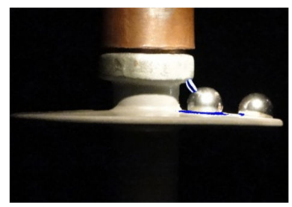
Cases	V_I(kV)	V_F(kV)	V_S(kV)
C1	34.5	38.5	39.0
C2	---	27.5	27.5
C3	30.0	25.5	---

Values not shown in Table 2, correspond to high levels of corona onset voltage which were not achieved in these cases. Based on the results, it is observed that corona onset voltage for each gap and each case is dependent on the distance. In any case, the semi-spheres reduce the corona onset voltage to a level where it did not occur without them. In all cases, the closer distance between the semi-spheres and from them to the hardware, the lower the corona onset voltage.

To illustrate the corona activity observed during the experiments, Figures 3 and 4 show photographs superposing corona activity and the insulator.



a) case C_1 – 39.0 kV b) case C_2 – 27.5 kV



c) case C_3 – 25.5 kV

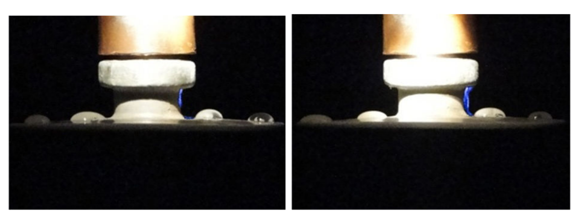
Figure 3: Corona in the semi-spheres.

For the water droplets, corona onset voltages are presented in Table 3. In this case, corona was observed only near the insulator shank.

Table 3: Corona onset voltage (water droplets).

Cases	V_I (kV)
S1	30.0
S2	25.0

As the results show, the water conductivity affects the corona voltage. For a high conductivity, a lower voltage is required for the formation of this phenomenon. These results suggest that insulators, when exposed to polluted environments, become more susceptible to corona formation.



a) case S_1 – 30.0 kV b) case S_2 – 25.0 kV

Figure 4: Corona in the water droplets.

The preliminary experimental results show that the insulator surface conditions play a role in the corona onset.

For further analysis, an investigation of the electric field distribution was performed.

4 SIMULATIONS

4.1 Procedure

From the observed corona onset voltages, the electric field distribution was calculated for each situation. A computational package, named FEMM, based on the Finite Element Method was used [14].

The objective was to investigate the maximum field value and its distribution at the corona formation area.

A computational model was used, and the electric field was calculated along the sensors, showed in the Figure 4. Sensor 1 (from A to C) evaluates the electric field near the insulator shank, sensor 2 (from A to B) is located between the hardware end fitting and the semi-sphere and sensor 3 (from C to D) between semi-spheres along the shed surface. For the 3 sensors, the field was named E_I, E_F e E_S respectively.

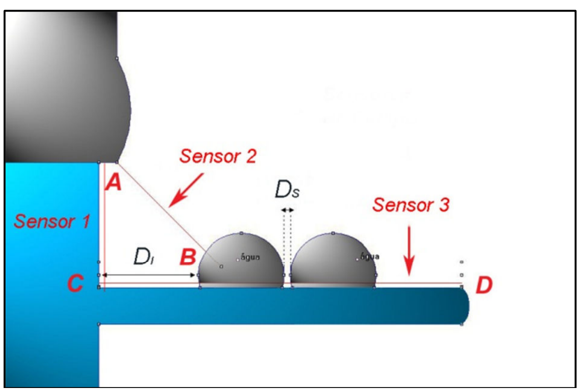


Figure 4: Sensors for electric field evaluated.

4.2 Results and discussion

The maximum electric field was investigated along the 3 sensors. Table 5 shows these values for the semi-spheres.

Table 5: Maximum electric field for corona onset (semi-spheres).

Cases	E_I(kV/cm)	E_F(kV/cm)	E_S(kV/cm)
C1	10.2	31.5	6.0
C2	---	21.6	6.0
C3	9.1	22.3	---

As seen, the maximum electric field values are similar for the same gap. For case C1, a higher field value E_F can be explained by the electric field distribution. This indicates that there is a region of local electric field responsible for the corona onset. Therefore, only the maximum electric field value is not sufficient to predict the corona formation.

The electric field distributions in each region due to the semi-spheres are shown in Figs. 5, 6 and 7. As seen, the electric field distributions are similar along each sensor. This can be explained by the electrostatic model used in these cases.

For Figure 5 the difference between the electric field distributions may be due to the closer distance between the semi-sphere and the insulator shank in Case C3. This causes a field enhancement in the middle of the gap and its reduction at the junction with the shed. This reduction depends on the contact angle which, for the semi-spheres was greater than 90°.

In smaller gaps, as those between the semi-spheres (Figure 7), the electric field for corona establishment was practically the same and constant for both cases. For greater distances, as shown in Figure 6, the higher the gap, the higher the electric field needed for corona onset.

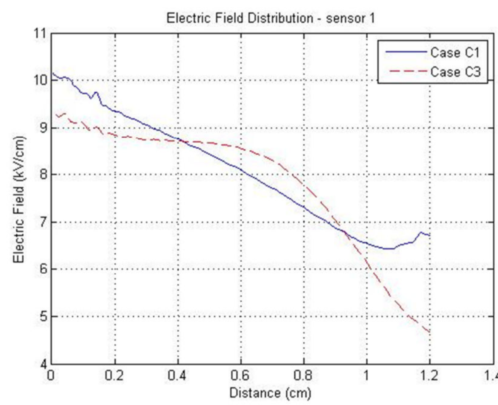


Figure 5: Distribution of the electric field (E_I) along sensor 1.

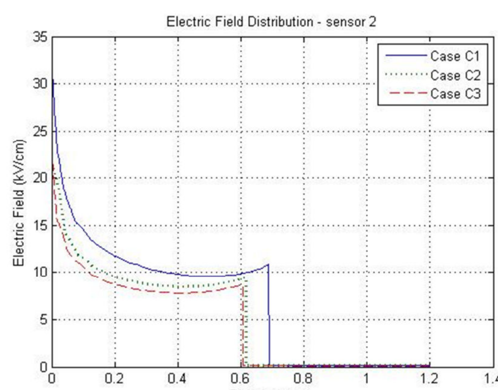


Figure 6: Distribution of the electric field (E_F) along sensor 2.

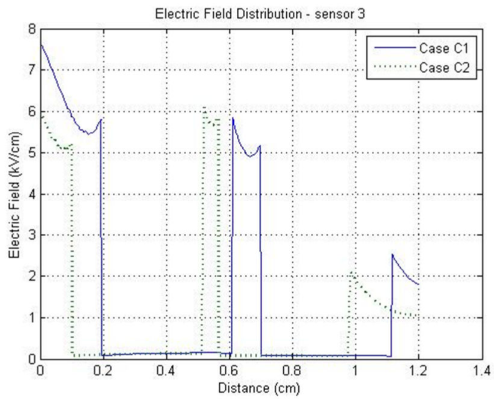


Figure 7: Distribution of the electric field (E_S) along sensor 3.

The results for water droplets experiments are shown in Table 6. The maximum electric field, for different water conductivity samples along sensor 1 are presented.

Table 6: Maximum electric field for corona onset (water droplets)

Cases	E_I (kV/cm)
S1	8.1
S2	6.8

From these results, it is observed that the corona onset electric field is lower for the higher water conductivity case (S_2). Since the gap distance is nearly the same, a possible reason for the difference is the generation and concentration of space charge, due to a larger number of ions in the water. These results suggest that an insulator exposed to environment with severe pollution would be easily prone to corona formation.

Figure 8 shows the electric field distribution for cases S_1 and S_2.

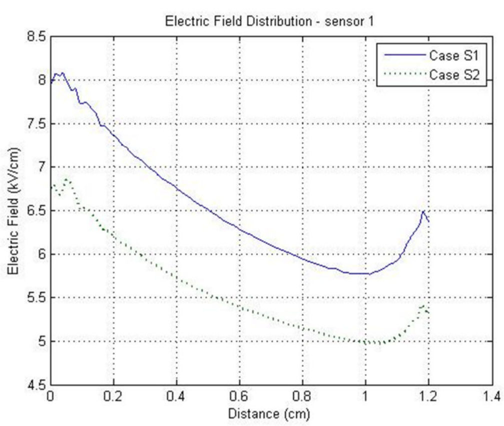


Figure 8: Sensors for electric field evaluated.

Once again, only the electrostatic field model is not sufficient to explain the corona formation. Probably, there are changes in magnitude and distribution of the electric field due to space charges.

5 CONCLUSIONS

Corona onset voltage was experimentally obtained for different polymer insulator surface conditions. The presence of water droplets and its influence in the corona formation was investigated. The onset voltage depends on the distance between the droplets and on the insulator surface conditions.

Additionally, numerical simulation analysis using an electrostatic model for corona onset was performed. The maximum electric field value is commonly used as a design criterion to avoid corona. The results indicate changes in the insulator surface conditions affecting the maximum electric field for corona onset. Particularly, conductivity and water droplets reduce this field value.

In summary, the results suggest that only the maximum value and the electric field distribution are not sufficient for identifying the corona onset. A more complete model, including the space charge and its influence in the electric field distribution is needed for a better prediction of the corona onset. A hydrodynamic model is under analysis to investigate the influence of such charge. The authors are now working on the computational implementation of this model, which is expected to be able to include the changes in the insulator surface conditions.

6 ACKNOWLEDGMENTS

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