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EXPERIMENTAL STUDY OF POLLUTION AND SIMULATION ON INSULATORS USING COMSOL® UNDER AC VOLTAGE

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Abstract

The flashover of pollution, observed on the insulators used in high voltage transmission, is one of the most important power transmission stakes. It is a very complex problem due to several factors including the modelling difficulties of complex shapes of insulators, different pollution densities at different regions, non-homogeneous pollution distribution on the insulator surface and unknown effect of humidity on the pollution. In the literature, some static and dynamic models have been developed by making some assumptions and omissions to predict the flashover voltages of polluted insulators.

This paper aims to experimentally analyse the flashover process and simulation of the distributions of the potential and the electric field under 50 Hz applied voltage on a real model simulating the 175CTV outdoor insulators largely used by the Algerian Company of Electricity and Gas (SONELGAZ). This real model is studied under non-polluted (distilled water), and polluted (distilled water and sand) environments. The simulations were carried out by using the COMSOL multiphysics software. This program uses the finite element method to solve the partial differential equations that describe the field. Experimental results made in the laboratory and simulation results are original and found to be congruent.

Keywords: insulator; flashover; pollution; high voltage; potential; electric field.

1. INTRODUCTION

Outdoor insulators can become heavily coated with dirt, chemicals, wet and environmental pollution [1].

The performance of insulator strings (cap and pin type) is considered as a key factor in the determination of power system reliability. The insulators requirements not only withstand normal operating voltage, but also avoid the occurrence of flashovers. The reduction of its performance is mainly due to the air-borne pollution deposits, which can form a conducting or partially conducting surface layer with fog or wet and enhances the risk of flashover.

In service, outdoor insulators are actuality subjected to various operating conditions and environments, such as humidity and pollution will contribute to reduction of their performance. [2]

In power systems, line insulators are often installed outdoors, which exposes them to adverse environmental and atmospheric factors, such as dust, fog, dew, rain, snow and industrial pollution. When the air humidity is low, the existence of these contaminations will not affect the normal functioning of the insulator. But when the air humidity is high, the contamination layers on the surface of the insulators get wet, and the soluble salt of the contaminations is dissolved in water. A conductive water film is thus formed, which leads to a higher conductance of the insulator surface. Then the leakage current increases sharply, and the flashover voltage of the insulators decreases greatly. Consequently, the flashover can occur in the operating voltage. This phenomenon may affect the security and stability of power system [3–7].

The flashover phenomenon is one of the most complex problems observed in high voltage outdoor insulators by numerous researchers,[7-11]. In particular, the final stage of the complex mechanism that occurs when an intermediate pollution band forms on the insulating surface has been highlighted [12-15].

The non-homogeneity is due to the presence of different polluting agents in the same region. Also, the non-uniformity of the distribution on the insulator surfaces stems the insulator profile, wind direction, and the position of the insulator strings in relation to the ground (vertical, horizontal, inclined).

The insulator position in the string, the site's pollution degree at the upper or lower insulator surface and the unknown effect of humidity on the pollution. [5, 15-17] are important factors. For the insulation of overhead power transmission l ines, resistance to moisture and mechanical strength areof paramount importance; therefore, porcelain a nd glass are most suitable.

The electric field distribution on the surface and within an insulators string depends on numerous parameters including applied voltage, insulator design, tower configuration, corona ring, hardware design and phase spacing. To determine the ideal conditions obtained for a linear potential distribution along an insulators string, corona rings are required. Unfortunately, manufacturers impose independent recommendations for the use of their corona rings as no specific design and placement standards are available, [18].

Focusing on the previous studies presented in the literature, it has been noted that the most developed models were investigated a simplified insulators models such as circular shape. However, not searchers studied the real model which presents the complexity of the geometry.

In the present work, an experimental and numerical studies were presented for analysing a real model of the insulators string.

In one hand, the laboratory experiments were carried out.

In other hand, the experimental findings are given to predict the influence of the problem of pollution, the potential distribution and electric field under normal operating conditions of the real model by using a 2D finite element model of the COMSOL multiphysics software.

2. METHODOLOGY

Figure 1displays a real model of the 175CTV insulator with a length p=0.11 m, a diameter d=0.175 m, a width of the pin n=0.011 m and weight=1.5 kg. It consists of an insulating block carrying to its upper part a cap sealed out of malleable pig iron and inside a steel stem with grooves. And the conical head is also sealed in glass.

The lower end of this stem is round and has appropriate dimensions to penetrate in the cap of the subsequent element and to be maintained by a pin.

The assembly is performed by sealing the cap and the dielectric insulator by cement, then the stem and the dielectric.

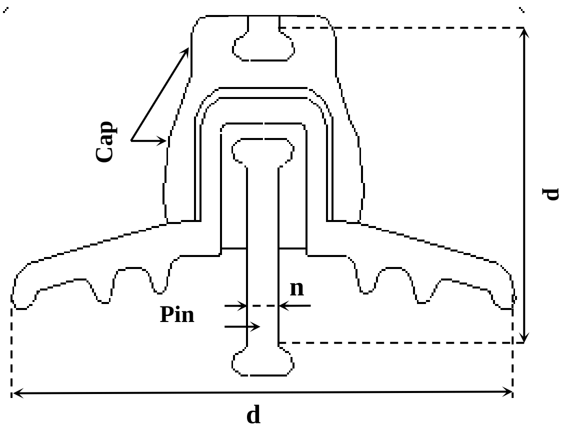


Fig. 1. Real model of the insulator 175CTV.

2.1. Experiment

Experimental studies were carried out using the experimental test bench as shown in fig.2, at High Voltage Laboratory (University of Biskra, Algeria).

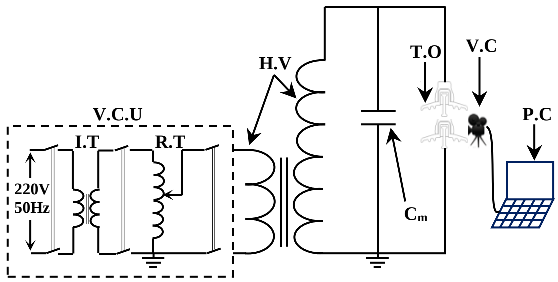


Fig. 2. Schematic diagram of the experimental setup: V.G.U: Voltage control unit, I.T: Isolating transformer, T.O: Test object (175 CTV insulator), R.T: Regulating transformer, H.V: High voltage transformer, V.C: Video camera, C_m: A capacitive for measuring the applied voltage, P.C: Personal computer.

The devices listed below were used:

- a high voltage transformer, 140kV/5kVA/50Hz,
- a regulating transformer, U_1=220V, U_2=0 to 250V, 5500 VA,
- an isolating transformer,U1=220V, U2=220V,
- a capacitor to measure the applied voltage C_m=100 pF.
- a digital scope meter, (25 Mhz, 250M Sa/s)
- a control panel unit, powered by 220V, presented in fig. 3.
- a P.C used for data acquisition, and a video camera to record the evolution of electrical discharge behaviour.

Figure. 2 correspond to the assembly.

Fig. 3. Control panel unit. (Laboratory of high voltage from Biskra University).

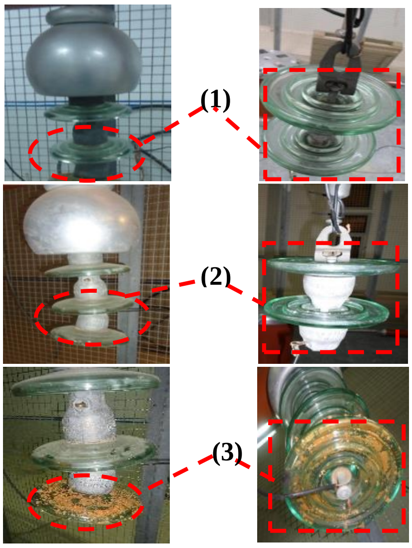


Fig. 4. Real insulator in the laboratory;
(1) Clean insulator,(2) Wet (distilled water),
(3) Polluted (distilled water and sand).

For an element of an insulator, the three tensions represent the stages of skirting are measured and checked the influence of pollution on the behavior of insulators string 175CTV, for the following cases:

– Dry: clean insulator,
– Polluted insulator: for two cases: with only distilled water and with distilled water+ sand, on the surface of the insulator and inside the insulator. fig.4.
– Two cases of the surface of insulators string, to see the influence of pollution on the behavior of the insulator for one and two elements by measuring the flashover voltage.

2.2. Computational approach

COMSOL Multiphysics is a computer program used the finite element method to solve the partial differential equations (PDEs) which is defined the studied problem. To prepare a full simulation, numerous steps must be followed. A simple schematic presented these steps is shown in figure 5.

– **Step 1.** Creation of the geometry (Physical model). By using an interface, an insulator element (chain of insulators Elements) is defined. The inputs for this interface are x and y coordinates of all the points that defined the geometry of the insulator.
– **Step 2.** Incorporation of the different parameters for the physics interface of the geometry. In fact, material properties (cap and pin, glass, cement, Portland and air) are defined. These properties include the permittivity and conductivity of each material. In addition, boundary conditions and applied voltages (HV and 0V) are performed.
– **Step 3.** Creation of the mesh grid. A user-controlled mesh is built automatically. Indeed, the element size parameters and free quad settings are applied.
– **Step 4.** A default solver sequence is defined for a stationary analysis to compute the distribution of the field and electrical potential.

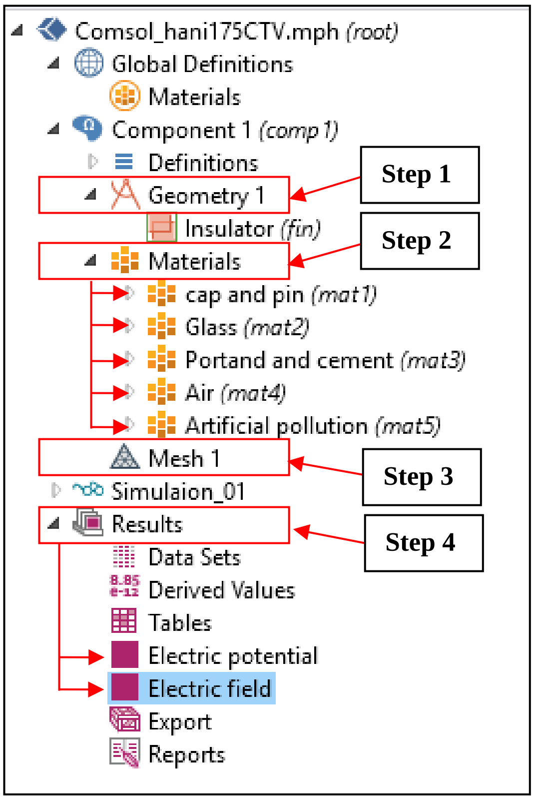


Fig. 5. The structure identifying the main steps for the COMSOL model creation

To simplify the calculation of the electric field which satisfies these conditions, COMSOL uses the derivative of the potential (V) which is defined by the following relation field-potential:

$$\vec{E} = -\,grad\,\vec{V} \tag{1}$$

Obtaining Poisson's equation is exceedingly simple, for from the point form of Gauss's law:

$$\nabla.D = \rho \tag{2}$$

The dentition of D

$$D = \varepsilon\, E \tag{3}$$

and the gradient relation, (equation 1) or:

$$E = \nabla V \tag{4}$$

By substitution equ.2, 3 and 4) we have:

$$\nabla.\, D = \rho = \nabla.(\varepsilon\, E) = -\nabla.(\varepsilon \nabla V) = \rho \tag{5}$$

or:

$$\varepsilon\nabla.(\nabla V) = -\rho \tag{6}$$

without charge $\rho = 0$, Poisson's equation becomes Laplace's equation:

$$\varepsilon\nabla.(\nabla V) = 0 \tag{7}$$

finally:

$$\nabla^2 V = 0 \tag{8}$$

COMSOL solves the equation for the potential V on a field programmed by the user and also defines the source and the boundary conditions. In this case we used two low conductivity values, 1200 µS/cm and 3000 µS/cm, [18].

3. EXPERIMENTAL RESULTS

The flashover development process under 50Hz alternative current voltage was examined with non-uniform pollution distribution.

The influence of the insulation surface pollution on the behaviour of the insulator (one and two elements) was investigated.

For one element, a digital video setup was used to monitor the glass surface discharge activity. Careful analysis of these video recordings allowed visual examination of the electric discharge development with the increase of the applied voltage magnitude. (fig.6).

For all the states of the real insulator (clean, wet and polluted), the activity of discharge follows three stages. In the polluted and wet cases, the insulator becomes less rigid, and with the concentration of pollution, we notice:

- The appearance of a large number of partial arcs characterized by a low intensity. Also, the discharges disappear and reappear quickly along the clean strip in a continuous way. fig.6 (Initiation of arcs).
- The intensifications and multiplication of arcs through the clean strip. Weak discharges located at the ground electrode side were also noticed probably due to the high field (high applied voltage) at the interface between the electrode and the glass surface. fig.6 (Evolution of arcs).
- Following the increase in the applied voltage, shortly after the connection, the final jump begins, and an electric partial arc is formed between the two electrodes. fig.6 (Total flashover.).

Fig. 6. The process of flashover, (a)Initiation of arcs, (b)Evolution of arcs, (c)Total flashover.

This test is intended to determine the 175CTV insulator skirting potential of severity of pollution, (clean/dry, wet and polluted). To reach this objective, we increased voltage until obtaining a flashover of the insulator. With the first place we must determine the tension of flashover in a clean state (dry) and for the continuation introduce pollution.

3.1. Influence of pollution

In this section, we present the three cases which thus represent the steps of flashover for one element of 175CTV insulator.

Figure.7 shows the variation of the applied voltage for different states of the surface of the cap and pin 175 CTV insulators. For all surface conditions the insulator, the discharge activity goes through three stages. Initialization of the arcs, evolution of the arcs and final flashover of the insulator. In the polluted and humid case, the insulation becomes less rigid, and the insulator becomes more resistive.

The most unfavourable case is where the voltage is very low (polluted case) or the insulator is less rigid. The voltage decreases when the surface of the insulator is polluted (wet or polluted).

During the experiment, the evolution of the skirting potential was revealed as follows:

- Appearance of the effect crowns in the surroundings of 4-17 kV for all cases. (fig.7).
- Appearance of the electric arcs which represent the second stages of flashover, then the final stages with the total flashover of the insulator.

We notice that the flashover voltage decreases in an almost linear way according to the severity of pollution. Then the equivalent impedance of the insulator decreased and the insulator became more conductive.(fig.7).

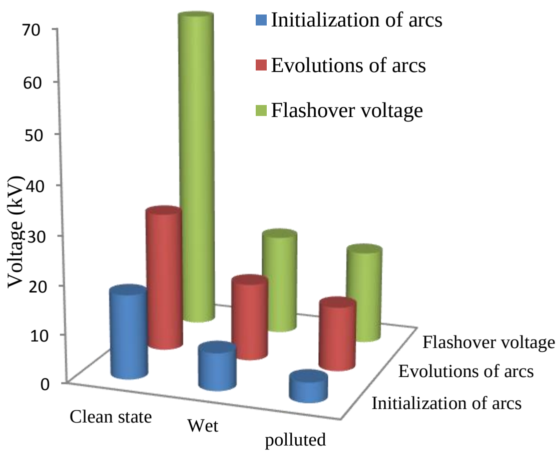


Fig. 7. Voltage for different state of the surface, clean state, Wet (water distilled) and polluted,(water distilled+sand). For one element.

3.2. Influence of the number of elements (insulators)

Figure 8depicts the effect of the conductivity on the flashover voltage for both one and two insulator elements. The results are carried out at a constant level of pollution. From these results, it has been observed that the flashover voltage increases with increasing in the number of elements for a given level of pollution. This fact is because the number of items directly affects the dielectric strength system. Then the surface conductivity increase causes a reduction of flashover voltage.

Furthermore, a decrease in impedance equivalent of the insulators string was observed. The latter becomes less rigid.

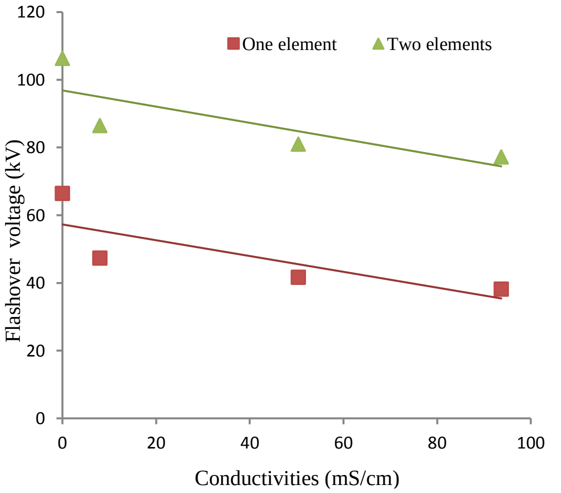


Fig. 8. Flashover voltage (U_c)-Conductivities (δ), for one & two elements of the insulator).

In these conditions, the correlated equations for each flashover voltage are expressed as follows:

For one element, $U_c = -0{,}233\ \delta + 57{,}27$ (9)

For two elements, $U_c = -0{,}239\ \delta + 96{,}86$ (10)

4. SIMULATION RESULTS

In this paper, the numerical input of the proposed model is taken from the measured data of the flashover voltage. Thus, realistic results are predicted by the numerical model present a good agreement comparing to the anterior works.

Figure 9 shows the physical model of the insulators string in the clean state. All configurations of the model yielded a relatively difficult representation as we used the COMSOL multiphysics (Finite Element Method) then we called up on the model.

The voltage applied to the electrode was fixed that activates (pin) with voltage 30kVat the lower part of the glass.

As results, the electric potential and the electric field are conducted. The latter is a continuation of the programs making it possible to give the distribution of the electric potential and electric field in two dimensions. For that, we introduced, in this software, our model with all its specifications (forms and nature of the electrodes and the various mediums, applied voltage, boundary conditions,).

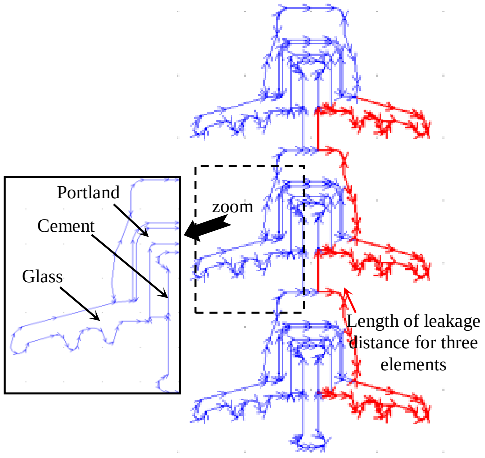


Fig. 9. Presentation of the insulators string in the COMSOL.

A boundary condition is required anywhere the system exits and can be set as an applied voltage in the first pin and ground voltage in the third cap of the insulators string. General interpretation was given on the basis of numerical simulation of the effect of the pollution on the surface of the insulator. A physical model was simulated using Comsol, based on the real geometrical dimensions of the insulators string 175 CTV.

The profile of the insulators string is introduced in the software. The meshing is an important step in the simulation procedure which affects directly the accuracy of the computational findings. Then a meshing analysis is required to minimize the error calculation.

The mesh density is higher in the critical regions of the insulators where higher accuracy is required. The number of meshes for insulators string is 31919 elements, after the refining 127676 elements with calculation time 16,583s. (Fig.10).

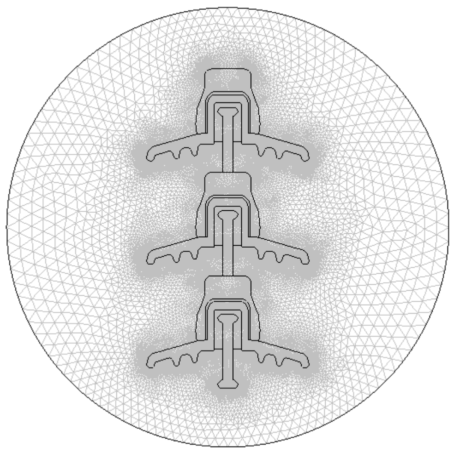
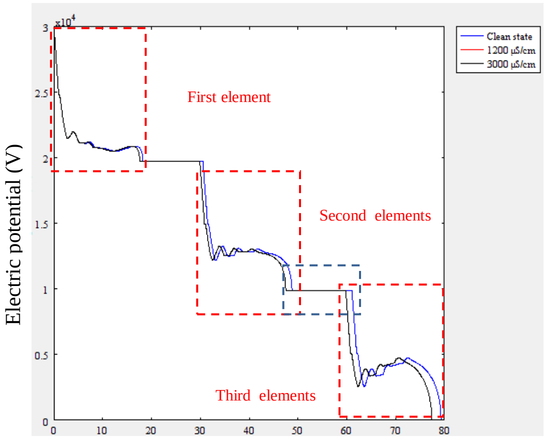


Fig. 10. Discretization and determination in finite elements of mush elements of the insulators string 175 CTV.

4.1. Distribution of the electric potential

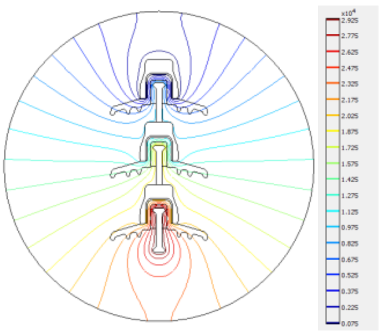
Figure 11 shows the variation of the applied voltage as a function of the leakage distance for different cases of the insulators string surface. The

distribution and the equipotential lines of the electric potential for the clean state of the three elements are shown in figure 12.
For this, we introduced the different conductivities values. (1200 µS/cm and 3000 µS/cm).

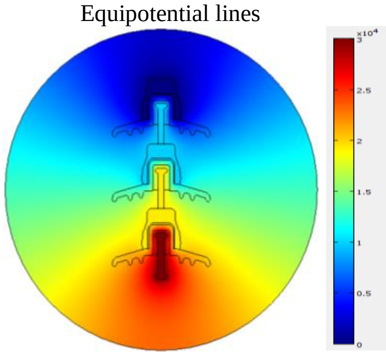


Leakage distance (cm)

Fig. 11. Electric potential-leakage distance for different conductivities in the case three elements.



Equipotential lines



Distribution of electric voltage

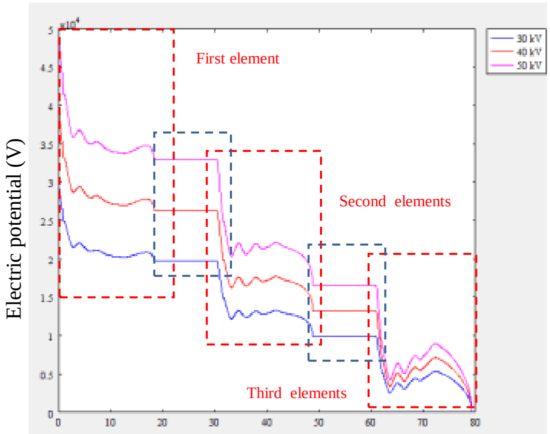
Fig. 12. Distribution of the potential on the real model for insulators string in the clean state.

According to these results, it has been observed that the variation of the conductivity of the polluting layer has practically not affect the potential along the leakage distance of the insulators string. By comparison between the clean and polluted cases, a slight variation was observed. In these conditions, it can be concluded that the decrease in the leakage distance was caused by the appearance of the polluting layer in the surface of insulators string.

The potential is very important at the level of the high voltage electrode and then decreases at a higher distance from the active electrode.

Figure 13 shows the variation of the potential as a function of the leakage distance, for different applied voltages. In this way, three levels of applied voltage were considered, 30 kV, 40 kV and 50 kV. From these results, it has been observed that depending on this applied voltage, the potential is distributed equitably, along the leakage distance, on the three elements (almost a third of the applied voltage to each element).

The three curves also pass through two regions where the potential remains constant. These are the metal parts of the insulators string (cap and pin).
Cap and pin being metallic elements, the tension at their levels remains constant; these are the equipotential parts.



Leakage distance (cm)

Fig. 13. Electric potential-leakage distance for different level of applied voltage in the clean state in the case three elements.

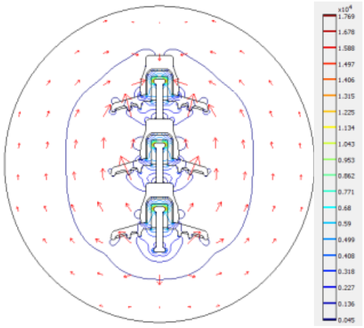
4.2. Distribution of the electric field on the real model

Figure 14 shows the distribution of the electric field, equipotential lines and vectors lines for the clean state case of the real insulators string under service voltage 30kV.

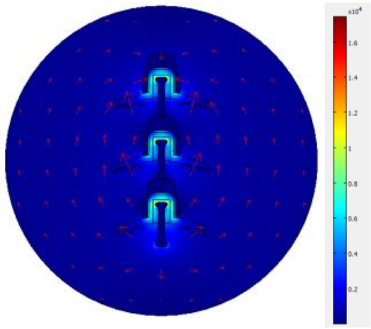
It can be seen an obvious divergence of the vectors of the electric field from the pin of the first elements (active electrode) to the cap of the third elements (ground electrode) (fig. 14). These vectors are oriented from the high voltage electrode to the ends of the insulators string and converge towards the ground electrode.

Figure 15 depicts the variation of the electric field as a function of the leakage distance, for different conductivity values. Two states of the surface of the insulators string were considered. (Clean and polluted state).

The electric field is very intense, which explains the appearance of the electric arcs during the experimental tests. This fact is also highlighted in our anterior work [19].

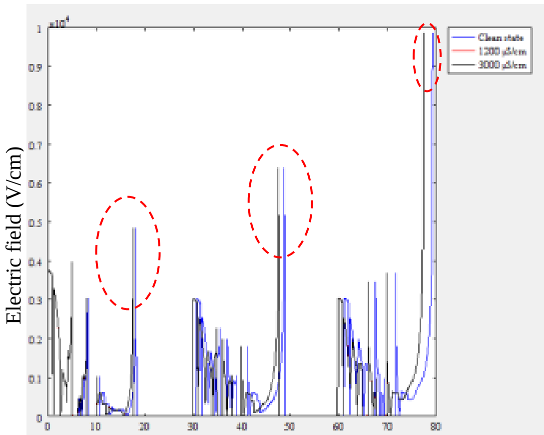


Equipotential lines



Distribution of electric filed

Fig. 14. Electric field and equipotential lines distribution on the insulators string. In the clean state case.



Leakage distance (cm)

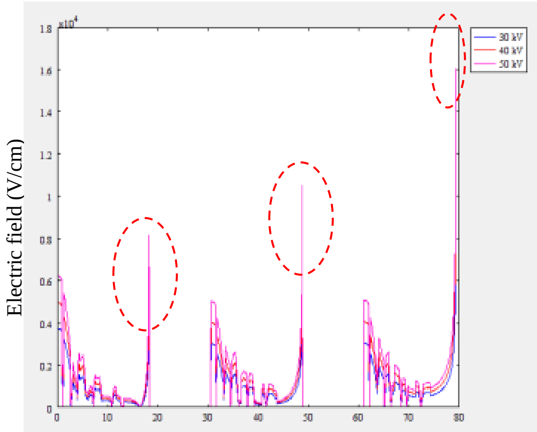
Fig. 15. Electric field-leakage distance for different Conductivity in the clean and polluted case.

The electric field is practically affected by the surface condition (polluted or clean) of the insulators string. In addition, the result shows that conductivity has a slight variation on the distribution of the electric field. Therefore, it can be noted that the decrease in the leakage distance was caused by the appearance of the polluting layer in the surface of insulators string.

It comes out from these characteristics that the electric field is practically null inside the two electrodes, because the two electrodes are conductive.

Figure 16 illustrates the variation of the electric field as a function of the leakage distance, for different applied voltages. Three levels of applied voltage were considered. (30, 40 and 50 kV) in the clean state.

From these results, it has been noted that the increase of the applied voltage of the active of the first element causes the increase of the electric field intensity along the leakage distance of the insulators string in the clean state condition. Furthermore, the results show that the electric field reaches its maximum values at the end of the insulators string. In fact, the electric field intensifies with the increase of the applied voltage.



Leakage distance (cm)

Fig. 16. Electric field-leakage distance for different applied voltage.

3. CONCLUSION

In the present work, we presented the main results of the various tests carried out in High Voltage Laboratory (University of Biskra, Algeria). Otherwise, numerical simulations were carried out to analyze the behavior on the175CTV outdoor insulator largely used by the Algerian Company of Electricity and Gas (SONELGAZ) to understand the correlation between pollution severity and partial arcs activity.

The flashover voltage decreases according to the conductivity of the polluted environment. Furthermore, the insulators string is less rigid when the surface conductivity increases.

As main results, the conductivity of the polluting layer has practically a slight effect on the distributions of the potential and the electric field.

On the other hand, the surface state of the insulator influences the distribution of the electric field.

Also, the distribution of potential along insulators string is almost identical to each element of the string. Moreover, the parts near the active electrode are the most exposed to electrical constraints, namely the potential difference and the electric field. The metal parts of an insulator (cap and pin), are the centres for equipotential, representing regions with fixed potential.

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