# DEVELOPMENT OF A NEW PORCELAIN INSULATOR DESIGN APPLIED TO DISTRIBUTION NETWORKS IN BRAZIL

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## ABSTRACT

*This paper presents some results of a new porcelain insulator design applied to distribution networks in Brazil. The mechanical modeling allows the analysis of the flexural strength. In the electrical modeling an axi-symmetric electrostatic formulation is applied to study the porcelain insulator performances. This analysis allows to examine if the electric field values are above of the dielectric strength values of the material, which would result in the rupture of the dielectric. After this, the prototypes are manufactured based on the simulations and tested electrically according to Brazilian standard. The use of this new porcelain system in replacement of the current system presented the following characteristics: higher insulation weather resistance, higher safety, lower maintaining, the same installation cost, and the advantage of being more aesthetically pleasant.*

## INTRODUCTION

Distribution networks in Brazil are predominantly overhead lines and built with bared conductors, requiring a constructive pattern that uses reliable insulators and a variety of accessories for mechanical fastening, as crossarms and hardware. The need to increase the reliability of distribution networks as well as reduction of construction cost and mainly for its operation and maintenance motivated the development of a new design for mounting and insulation of medium voltage networks [1].

The current system of insulation for distribution networks of medium voltage consists of crosshead, metal fittings and electrical insulator (Fig. 1). This system has a low weather resistance, difficulty in installation and maintenance and in some cases low levels of electrical insulation. This paper presents the development of a new porcelain insulator design applied to distribution networks in Brazil. The use of this new porcelain system (Fig. 2) in replacement of the current system presented the following characteristics: higher insulation weather resistance, higher safety, lower maintaining, the same installation cost, and the advantage of being more aesthetically pleasant.

The product development and the results validation were carried by implementing the following steps:

**1. Evaluation of technical requirements:** through the consultation of the standards it was verified the mechanical and electrical requirements for the development of the new porcelain system;

Fig. 1. Current porcelain system.

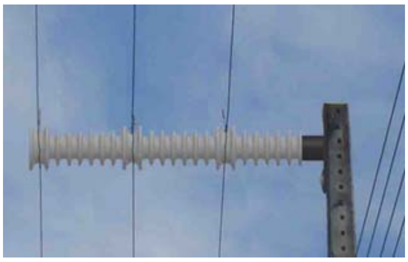

Fig. 2. New porcelain system.

**2. Development of geometry and electrical and mechanical simulations using the finite element method**: The mechanical modeling allowed the analysis of the flexural strength. In the electrical modeling an axi-symmetric electrostatic formulation was applied to study the porcelain insulator performances. This analysis allowed to examine if the electric field values are above of the dielectric strength values of the material, which would result in the rupture of the dielectric [2];

**3. Manufacturing prototypes:** the prototypes were manufactured based on projects defined in step 2. The porcelain system was obtained by plastic forming with subsequent machining, glazing and firing of quartz porcelain;

**4. Electrical testing:** the prototypes were tested electrically according to Brazilian standard NBR 12459;

**5. Field testing:** the prototypes results will be validated through application of the insulating porcelain systems in a distribution network located in a region of great severity of use.

This paper presents some results of the new insulator development. These results were obtained through a research and development project funded by Brazilian Electricity Regulatory Agency (ANEEL).

## DEVELOPMENT OF INSULATOR GEOMETRY

The new porcelain system is designed to replace the current system in distribution line until 25 kV of the CELESC. Fig. 3 shows the initial basic geometry. In this geometry the mechanical and electrical simulations were performed.

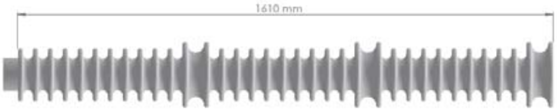

Fig. 3. Initial basic geometry.

The definition of dimensions and materials that form the insulator was obtained by mechanical simulation of the assembly. These simulations were performed using the Solid Edge ST and the solver NX Nastran. For this, one insulator extremity was setting and in other extremity was applied loads of 5000 N, 8000 N and 10000 N (Fig. 4).

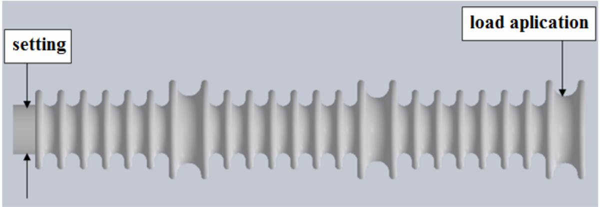

Fig. 4. Scheme of load application.

The mechanical simulations indicated the need of the use of strengthening core to improve the mechanical behavior and ease of assembly.

## ELECTROSTATIC FORMULATION

The electrostatic model applied to study domain Ω, of boundary Γ, is characterized by the following differential equations, behaviour law and boundary conditions [3]:

$$\mathit{curl}\,\boldsymbol{e}=0\,,\quad \mathit{div}\,\boldsymbol{d}=\rho\,,\ \text{in}\ \Omega, \qquad \text{(1a-b)}$$

$$\boldsymbol{d}=\varepsilon\,\boldsymbol{e}\,, \qquad \text{(1c)}$$

$$\boldsymbol{n}\times\boldsymbol{e}\big|_{\Gamma_e}=0\,,\ \boldsymbol{n}\cdot\boldsymbol{d}\big|_{\Gamma_d}=0\,,\ \text{with}\ \Gamma=\Gamma_e\cup\Gamma_d \qquad \text{(1d-e)}$$

where $\boldsymbol{e}$ is the electric field (V/m), $\boldsymbol{d}$ is the electric flux density (C/m$^2$), $\rho$ is the electric charge volume density (C/m$^3$) of electric charge, $\varepsilon$ is the electric permittivity (F/m), and $\boldsymbol{n}$ is the outgoing normal vector from domain Ω. The global constraints that can be defined are related to total charge and potential difference, whose ratio defines a capacitance. Based on (1a), we can introduce an electric scalar potential $v$ such that:

$$\boldsymbol{e}=-\mathit{grad}\ v\,. \qquad (2)$$

By grouping (1b) and (1c), we obtain the equation [3]:

$$\mathit{div}\ (\varepsilon\ \mathit{grad}\ v)=-\rho\,, \qquad (3)$$

which, taking into account the boundary conditions, should be solved on the whole domain. Condition (1d), for the electric field, is written for the formulation in scalar potential.

$$v\big|_{\Gamma_e}=v_o=\text{constant}\,. \qquad (4)$$

For the electric flux density, relation (1e) is stated in the form:

$$\boldsymbol{n}\cdot\mathit{grad}\ v\big|_{\Gamma_d}=0\,. \qquad (5)$$

The weak formulation of electrostatic formulation, considering ρ = 0, is given by [3]:

$$\iiint_{\Omega}\varepsilon\ \mathit{grad}\ v\cdot\mathit{grad}\ v'\,d\Omega=0 \qquad (6)$$

where $v'$ symbolizes the test function for the scalar potential, and Ω represents the computation domain. The uniqueness condition of the electric scalar potential requires that the value of this potential must be known at least in a point of the computation domain.

## RESULTS USING THE ELECTROSTATIC FORMULATION

In this paper, the tridimensional computation domain of the insulator is represented by an axi-symmetric domain. Fig. 5(*left*) indicates the cross-sectional plane and the axis of symmetry used to define the problem. The red line in Fig. 5(*left*) represents the Dirichlet boundary condition ($V_{out}$). The Air_Inf region is applied to consider the $V_{out}$ = 0 in the red line. Fig. 5(*middle*) shows a zoom of the insulator where $V_1$, $V_2$, $V_3$ are the three-phase voltages applied in the insulator. Fig. 5(*right*) presents the mesh of computation domain.

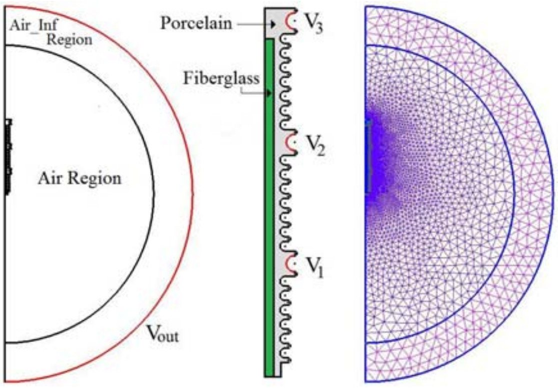

Fig. 5. Computation domain (*left*); zoom of insulator (*middle*); and mesh of computation domain (*right*).

Table I: Data used in the simulations for the line voltage of 25kV.

| Case A | Case B |
|---|---|
| $V_1$ = 0 $V_m$ = 0 V | $V_1$ = 1 $V_m$ = 14,45 kV |
| $V_2$ = – 0.866 $V_m$ = – 12.51 kV | $V_2$ = – 0.5 $V_m$ = – 7.23 kV |
| $V_3$ = + 0.866 $V_m$ = +12.51 kV | $V_3$ = – 0.5 $V_m$ = – 7.23 kV |
| $V_{out}$ = 0 V | $V_{out}$ = 0 V |

Table I shows the data in the simulations for the line voltage of 25 kV. Therefore, $V_m$ = 25 kV/1.73 = 14.45 kV. For this study, two isolator prototypes are simulated, one with height of 1110 mm (prototype 1) and other with height of 1610 mm (prototype 2). Fig. 6 and Fig. 7 show the electric potential distribution (*left*) and the electric field vectors (*right*) for the prototype 1 of height 1110 mm considering the cases A and B (Table II), respectively. The maximum electric field values for the case A and for the case B were, respectively, $2.88.10^5$ V/m and $2.61.10^5$ V/m, both smaller than the dielectric strength of porcelain which is $2.10^7$ V/m.

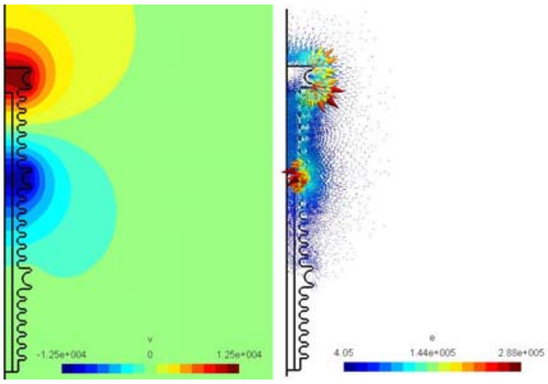

Fig. 6. Electric potential distribution (*left*) and the electrical field vectors (*right*) for the insulator with height of 1110 mm: Case A.

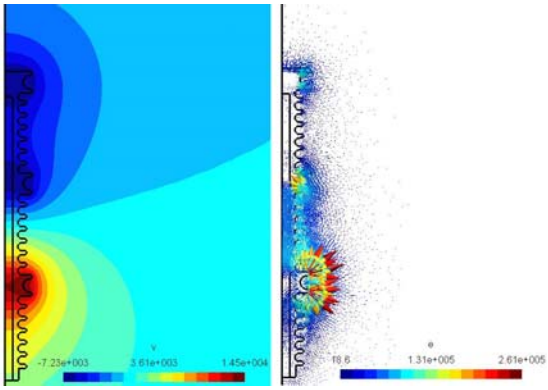

Fig. 7. Electric potential distribution (*left*) and the electrical field vectors (*right*) for the insulator with height of 1110 mm: Case B.

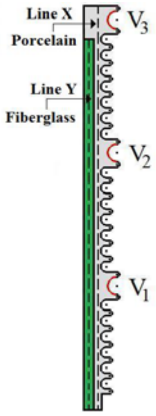

Fig. 8. Dashed line X cutting the porcelain region and dashed line Y cutting the fibreglass region.

Fig. 8 presents two dashed lines (line X and line Y) where the electric field module is analyzed. Fig. 9 and Fig. 10 show the electric field modules on line Y and on line X, respectively, for the insulator with height of 1110 mm: Case A and Case B. Again, the electric field values are smaller than the dielectric strengths of fiberglass ($3.10^7$ V/m) and of porcelain ($2.10^7$ V/m).

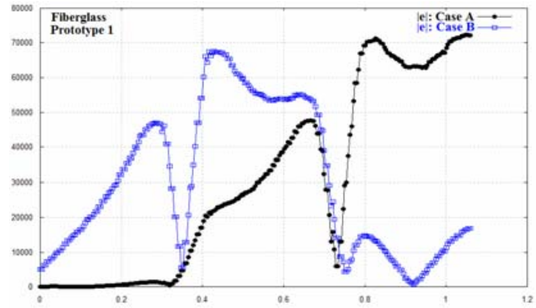

Fig. 9. Electric field module on line Y for the insulator with height of 1110 mm: Case A and Case B.

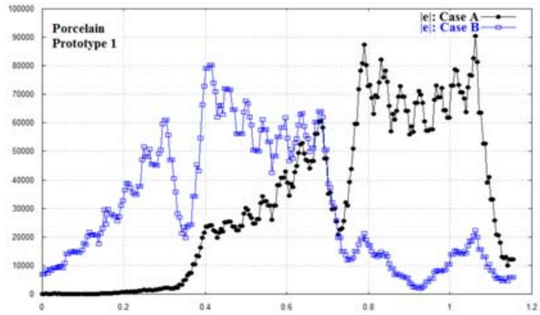

Fig. 10. Electric field module on line X for the insulator with height of 1110 mm: Case A and Case B.

According to the Brazilian standard, the insulator must withstand 150 kV which represents the dry lightning impulse withstand test. Table III shows the data in the simulations for the line voltage of 150 kV. Therefore, $V_m$ = 150 kV/1.73 = 86.70 kV.

Table III: Data used in the simulations for line voltage of 150kV.

| Case A |
|---|
| $V_1 = 0\ V_m = 0$ V |
| $V_2 = -0{,}866\ V_m = -75{,}08$ kV |
| $V_3 = +0{,}866\ V_m = +75{,}08$ kV |
| $V_{out} = 0$ V |

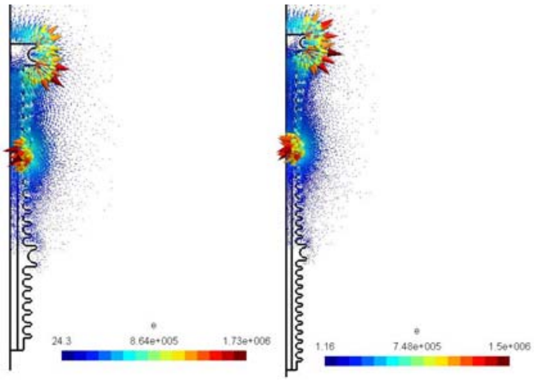

Fig. 11. Electrical field vectors for the insulator with heights of 1110 (*left*) and 1610 mm (*right*): line voltage of 150 kV.

Fig. 11 presents the electrical field vectors for the insulator with heights of 1110 (*left*) and 1610 mm (*right*). Fig. 12 and Fig. 13 present the electric field modules on line Y and on line X, respectively, for the two insulator prototypes. Again, the electric field values are smaller than the dielectric strengths of the fiberglass and of the porcelain.

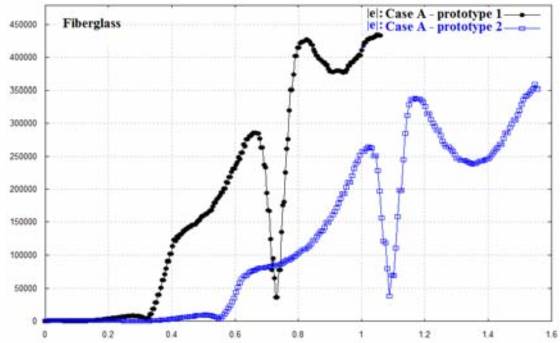

Fig. 12. Electric field module on line Y (fibreglass) for the insulator: height of 1110 mm (prototype 1) and height of 1610 mm (prototype 2).

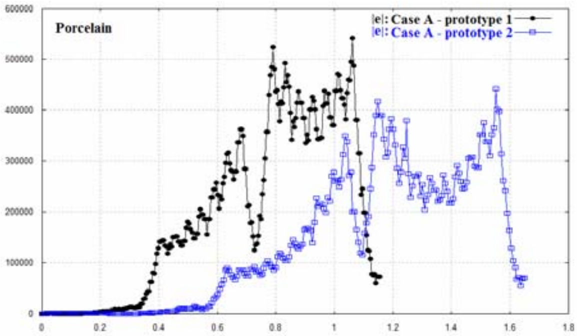

Fig. 13. Electric field module on line X (porcelain) for the insulator: height of 1110 mm (prototype 1) and height of 1610 mm (prototype 2).

## MANUFACTURING OF PROTOTYPES AND ELECTRICAL TESTING

Fig. 14 and Fig. 15 show the photos of the prototype and of dry lightning impulse withstand test assemblage, respectively.

Fig. 14. Photography of the prototype.

This test is performed to ensure that the insulators withstand the specified impulse voltage level, which is dependent on the dry arcing or strike distance. The intent is to make sure that the insulators do not flashover for impulse voltage values bellow the basic lightning impulse insulation level for which they are designed, and that there is no puncture due to the lightning impulses [1]. The test is performed under dry conditions, as rain has negligible influence on the lightning impulse flashover voltage. The prototypes 1 and 2 were approved in this test.

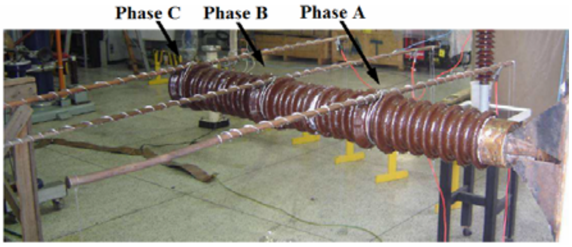

Fig. 15. Photography of dry lightning impulse withstand test.

## CONCLUSIONS

This paper presented some results of a new porcelain insulator design applied to distribution networks in Brazil. Firstly, a basic geometry was proposed and using mechanical and electrical simulations it was possible to determine the new insulator geometry. With the electrical simulation was noted that the electric field module values are smaller than the dielectric strengths of the fiberglass and of the porcelain. Thus, the prototypes were manufactured and tested electrically according to Brazilian standard NBR 12459. The two prototypes manufactured were approved in the tests. Now, the prototypes will be tested through application of the insulating porcelain systems in a distribution network located in a region of great severity of use. The results with the field tests will be presented in a future paper.

## REFERENCES

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[3] G. Meunier, 2008, *The Finite Element Method for Electromagnetic Modeling*, ISTE Ltd, London, UK.