Investigation of the Influence of Hydrophobicity and Dry Band on the Electric Field and Potential Distributions in Silicon Rubber Insulator

Seyed Mohammad Hassan Hosseini, Mohammad Mahdi Manzari Tavakoli

Abstract— **This paper presents the effect of hydrophobicity and dry bands on electric field distributions calculations by using finite element method based computational software (Maxwell-Comsol) along a 10-unit silicon rubber insulator string that is used in polluted and clean area. In hydrophilic insulators the applied voltage will mostly drop along the dry band. If the voltage is high enough, partial arc will appear across it. If the applied voltage is high enough, the partial arc will extend and causes a total flashover. In general, the composite long rod insulator set field distribution is more non-linear than of a set with conventional insulators. The main causes of this are missing intermediate metal parts and the dielectric material features of the polymeric materials in composite insulators. Hence, study the effect of dry bands and surface hydrophobicity degree on electric and potential field distribution of polymeric insulators is necessary.**

Index Terms— **Polymeric insulator, hydrophobicity, FEM, Dry band**

I. Introduction

DUE to various advantages of polymeric insulators to non- polymeric ones they attracted much more attention.

Hydrophobic surface, light weight, resistivity to human destruction are the examples of the advantages of polymeric insulators [1], [2].

Resistance of any material to flow of water on its surface is called hydrophobicity. The hydrophobic property is reduced as the insulator's surface ages due to environmental effects and the electric activity caused by wetting and pollution. The hydrophobicity classification of polymeric insulators guide is demonstrated in Fig. 1 [3].

The electric field strength on polymeric insulators needs to be calculated to satisfy four objectives [4]:

- Preventing the significant discharge on the surface material.
- Avoiding the internal discharge activity inside the fiberglass rod and the sheath rubber material.
- Preventing corona phenomenon.
- Optimization of insulator design.

Manuscript received December 22, 2016; revised January 25, 2017.

S. M. Hassan Hosseini is with the Electrical Engineering Department, South of Tehran Branch, Islamic Azad University, Tehran, Iran (e-mail: smhh110@azad.ac.ir).

M. M. ManzariTavakoli is the Msc student of the Electrical Engineering Department, South of Tehran Branch, Islamic Azad University, Tehran, Iran (e-mail: mmm.tavakoli@yahoo.com).

Hence, the study of the effect of dry bands and surface hydrophobicity degree on electric and potential field distribution of polymeric insulators, simulations was carried out using Maxwell and Comsol software at 5 states:

1. Dry and without pollution contamination insulator
2. Hydrophobic surface insulator.
3. Hydrophilic surface insulator.
4. Without dry band insulator.
5. With dry bands insulator.

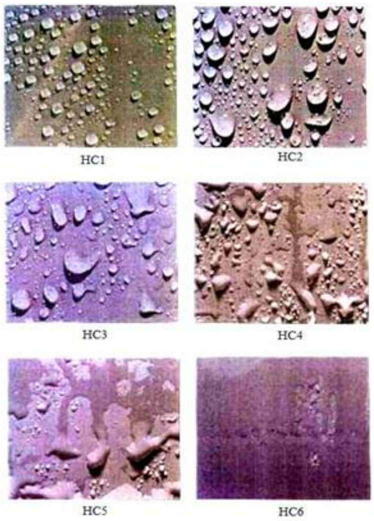


Fig. 1 Hydrophobicity Classification Guide

II. Method Analysis

A. Electric Field and Potential Distributions

An easy way to evaluate the electric field distribution is to calculate electric potential distribution initially and then calculate field distribution by subtracting gradient of electric potential distribution from it. This can be written as follows:

$$E = -\nabla V \qquad (1)$$

From Maxwell's equation:

$$\nabla E = \nabla.\varepsilon\nabla V = -\rho \qquad (2)$$

Where ρ is volume charge density Ω/m, ε is material dielectric constant. Without space charge ρ =0, Poisson's equation becomes Laplace's equation.

$$\varepsilon.\nabla(\nabla V) = 0 \quad (3)$$

B. Equations for FEM Analysis of Electric Field

The two dimensional function F(v) in the Cartesian system of coordinates can be written as follows:

$$F(u) = \frac{1}{2}\int_D \left[\varepsilon_x \left(\frac{du}{dx}\right)^2 + \varepsilon_y \left(\frac{du}{dy}\right)^2 \right] .dxdy \quad (4)$$

Where: ε_x and ε_y are x- and y- components of dielectric constant in the Cartesian system of coordinates. In case of isotropic permittivity distribution $\varepsilon_x = \varepsilon_y = \varepsilon$ equation (4) can be reformed as:

$$F(u) = \frac{1}{2}\int_D \left[\varepsilon\left(\frac{du}{dx}\right)^2 + \left(\frac{du}{dy}\right)^2 \right] .dxdy \quad (5)$$

If the effect of dielectric loss on the electric field distribution is considered, the complex functional $F(u)$ should be taken as:

$$F(u)^* = \frac{1}{2}\int_D w\,\varepsilon_0(\varepsilon - j\,\varepsilon tg\,\delta)\left[\left(\frac{du}{dx}\right)^{*2} + \left(\frac{du}{dy}\right)^{*2} \right] .dxdy \quad (6)$$

Where ω is angular frequency, ε_0 is the permittivity of free space ($8.85\times10^{-12}\frac{F}{m}$), $tg\,\delta$ is tangent of the dielectric loss Angle, and u^* is the complex potential [5].

The calculation of the electric potential at every knot in the total network composed of many triangle elements was carried out by minimizing the function F(u), that is [6]:

$$\frac{\partial F_{u\,j}}{\partial V_i} = \frac{\varepsilon_0 \varepsilon_r}{2}\int_i \frac{\partial}{\partial V_i}\left(\frac{\partial^2 V}{\partial r^2} + \frac{1}{r}\frac{\partial V}{\partial r} + \frac{\partial^2 V}{\partial z^2}\right) drdz \quad (7)$$

III. INSULATOR MODELING

Generally a composite insulator is comprised of a core material, end fitting, and a rubber insulating housing. The core is of FRP to distribute the tensile load. The reinforcing fibers used in FRP are glass (E or ECR) and epoxy resin is used for the matrix. Supplying electrical insulation and protecting the FRP from the elements are the main functions of rubber housing [7]. The structure of a composite insulator and reference lines and dry bands location are demonstrated in figure 2. For modeling a String insulator employed on the 20 kV network is used. Table I demonstrates relative permittivity and conductivity and in table II insulator condition have been shown. Insulator simulation is done in 2D and cylindrical conditions. In Fig. 2 dry bands location (1,5) and reference lines(2,3,4) are shown. The second reference line is in accordance with the creepage distance path, and the reference line 4 places into insulator core.

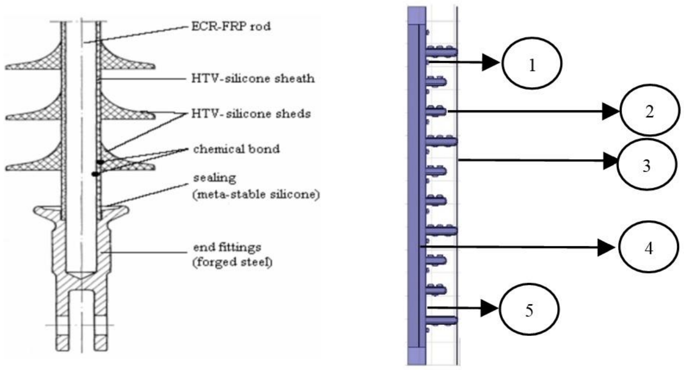


Fig. 2 Structure of composite insulator with reference lines and dry bands location

TABLE I
Relative Permittivity and Conductivity considered

Material	Water droplets	Pollution layer	Film water mixed to pollution	FRP	Silicon Rubber	Air
Permittivity	83	15	20	7	3.45	1
Conductivity (S/m)	0.01	0	0.01	0	0	0

TABLE II
Insulator assume condition

Creepage distance (mm)	Sheds Diameter s(mm)	Dry Band Length (mm)	Hydrophilic surface water mixed to pollution film thickness(mm)	Pollution layer thickness (mm)
680	27-17	20	1	1

IV. FLASHOVER OF WET POLLUTED INSULATOR

Generally, the surface of insulators is covered with a layer of pollutants, which is accumulated since installation or the last cleaning operation. In some zones, the deposited layer will decrease dramatically the insulating strength of insulators and, under certain environmental conditions; result in flashover faults. These zones include either areas of high industrial density or the suburbs of large cities, installations near the sea, or exposed to strong winds coming from the sea, or close to deserts where the insulators are exposed to the strong winds transporting sand and salt. Normally, the dry contamination layer does not endanger the power system operation. However, when the contamination layer is wetted due to condensation, frost, drizzle, fog, or onshore gales, etc., its conductivity will decease dramatically. Sometimes this will cause flashover faults. Generally, the flashover process on polluted insulators includes several necessary steps as shown in Fig. 3 [8]:

ISBN: 978-988-14047-7-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

1. When the contamination layer is wetted, a leakage current flows through it, due to its high conductivity. The value of leakage current depends on conductivity.
2. The leakage current will heat the insulator surface and cause the surface temperature to increase. Due to the shape of insulators, the current density on the surface is generally non uniform. In the areas of high current density, the heating effect of current is greater and a local dry zone will appear in these areas.
3. The local dry zone will lead to the constriction of current. Then, the dry zone has a tendency to extend laterally until a complete dry band is formed and the current is interrupted.
4. The resistivity of the dry band is much higher than that of the wet contamination layer. The applied voltage will mostly drop along the dry band. If the voltage is high enough, the air around the dry band will be broken down and a partial arc will appear across it.
5. Depending on the conditions, the partial arc can evolve in two different ways: it may die out, or move laterally to find a more stable position corresponding to a shorter arcing distance, and if the apply voltage is high enough, flashover will occur.

The major point in flashover insulator is that partial arc occurs when dry band electric field of insulator exceed its wet surface. It happens when injected power to the arc from the source be more than its loss power. If the power of the source decreases, the resistance of the arc rises, and as a result, the arc extinguishes.

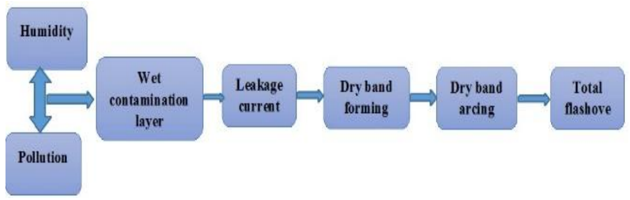


Fig. 3 Flashover steps

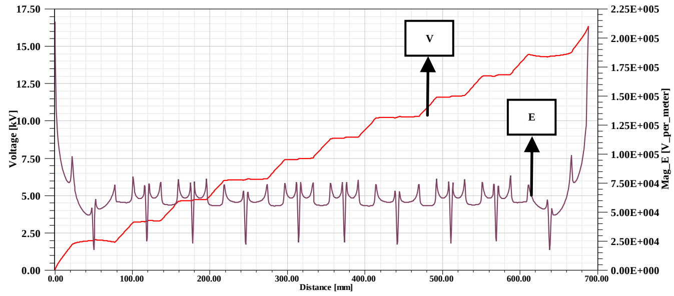
V. SIMULATION RESULTS

In this part the simulation results for clean and polluted condition is presented. The results illustrate the effect of pollution and hydrophobicity degree and the location of dry bands on silicon rubber insulator's electric field and potential distributions. These results are achieved by 2D cylindrical simulation with applying v_x to lower electrode ($v_x = \left(20/\sqrt{3} \times \sqrt{2} \right) = 16.33kv$), using Maxwell and Comsol software. The States of A, B, C were simulated with Maxwell software and state D is simulated with Comsol software.

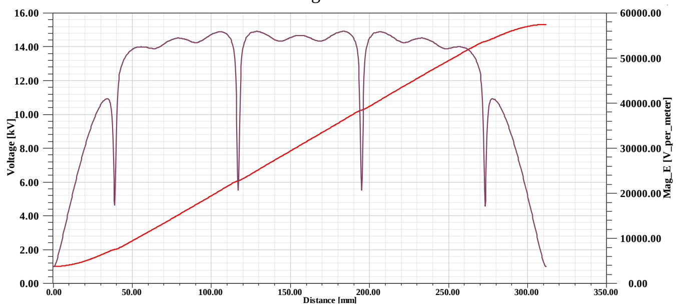
In the following figures the results have been displayed in two graphs the red graph shows potential distribution and the violet graph shows electric field distribution.

A. Clean and dry insulator

In this part the simulation is carried out in clean and dry condition. Figure 4 illustrates the electrical field intensity distribution and electrical potential on surface of insulator on clean and dry condition.



a. Along reference line 2



b. Along reference line 3

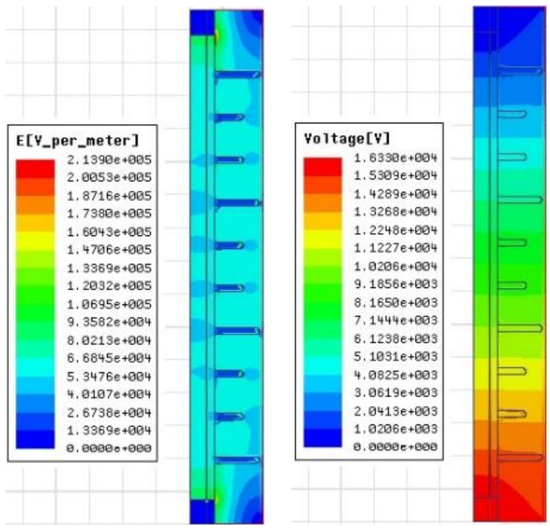


Fig. 4 Electric field and potential Distributions along reference lines on clean and dry insulator condition

B. Hydrophobic and polluted surface insulator

In this step, hydrophobic surface insulator is covered with 1mm thickness of contamination layer. This step is similar to HC1 state of hydrophobicity classification.

The figures 5 to 7 show electric and potential distributions in three below states:

- Without dry band wet polluted insulator
- With lower dry band wet polluted insulator
- With upper dry band wet polluted insulator
- With lower-upper dry bands wet polluted insulator

C. Hydrophilic and polluted surface insulator

In this part the hydrophobic property is reduced as the insulator's surface ages due to environmental effects and the electric activity caused by wetting and pollution. This step is similar to HC6 state of hydrophobicity classification. Due to high conductivity of water, a leakage current flows through the wetted insulator surface. The value of leakage current depends on conductivity. The thickness of pollution film mixed with water is assumed 1 mm. The figures 8 to 10 will show electric and potential distributions in four below states:

- Without dry band wet polluted insulator
- With lower dry band wet polluted insulator
- With upper dry band wet polluted insulator
- With lower-upper dry bands wet polluted insulator

D. Hydrophilic and polluted surface insulator simulated

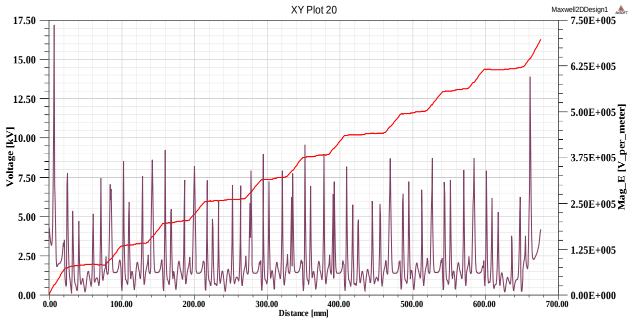
In this step, the insulator is simulated in the Comsol software to validation the results from Maxwell software. (Figures 13 to 15)

The results show the similar trend in the electrical and potential field in any dry bands positions. It shows electric field and potential distributions has similar value at any location of dry bands in hydrophilic surface.

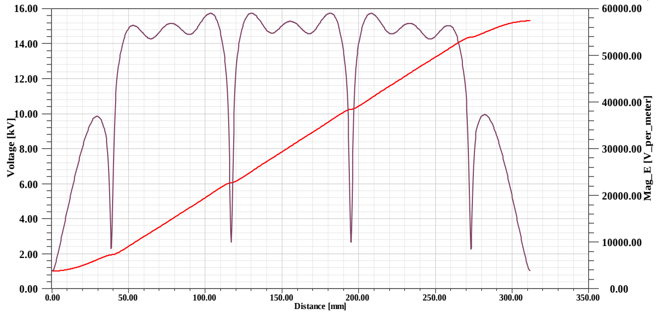
The small mismatch between the output results achieved from Maxwell and Comsol (about 5%) is mainly due to little difference in their simulated insulator profiles.

VI. Conclusion

In the presented work, the effect of hydrophobicity and dry bands on electric field distribution was simulated and analyzed. The simulation was done by Maxwell and results were presented. At the clean and dry surface insulator state, electric and potential intensity had less fluctuation and value. At wet hydrophobic surface insulator state, electric and potential distributions had higher value and more non-uniform distributions compared to the dry and clean state. However, the insulator operated normally. In the wet hydrophilic surface insulator state, electric and potential intensity did not change considerably, but after dry band forming, its value saw a sharp increase and therefore, partial discharge may happens. If the applied voltage be high enough, the partial discharge extended along surface, and the total flashover may occurred. It can be seen that in the hydrophilic state resulted from lower and upper dry bands, the electric field and potential distributions have similar values regardless of dry bands location. For more accuracy, the final state was evaluated with Comsol software as well, and same results were obtained from each software.

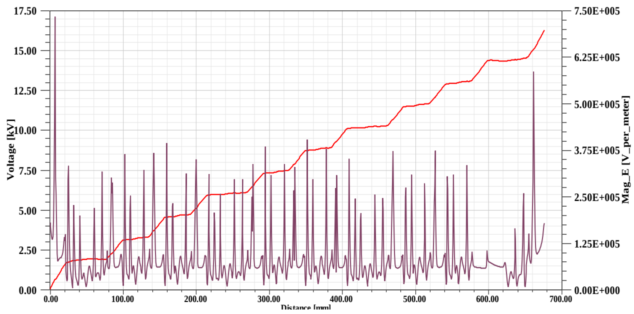


a. Along reference line 2

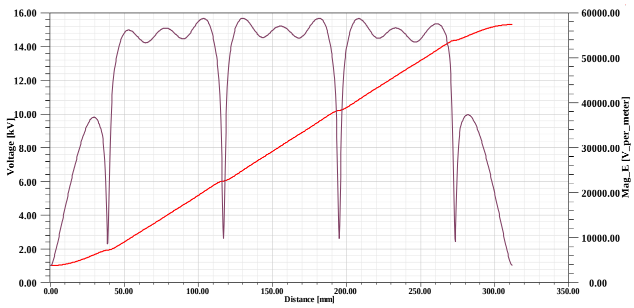


b. Along reference line 3

Fig. 5 Electric field and potential Distributions along reference lines on hydrophobic and polluted surface insulator condition, and without air gap.



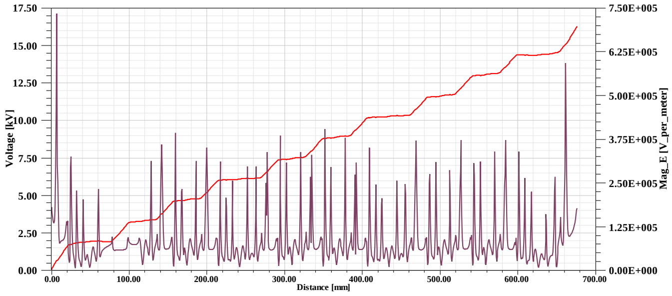
a. Along reference line 2



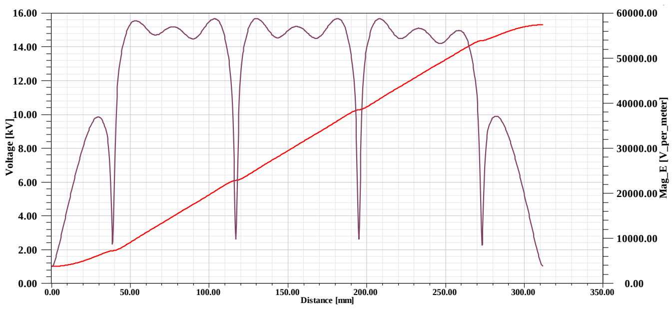
b. Along reference line 3

Fig. 6 Electric field and potential Distributions along reference lines on hydrophobic and polluted surface insulator condition with lower air gap.

ISBN: 978-988-14047-7-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

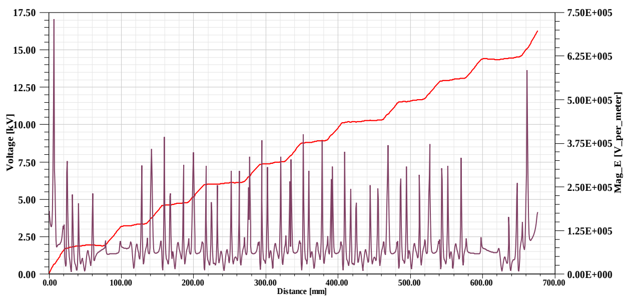


a. Along reference line 2

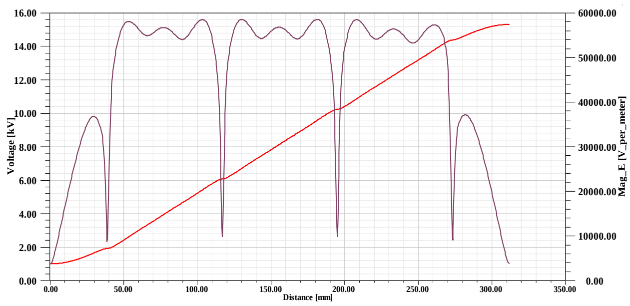


b. Along reference line 3

Fig. 7 Electric field and potential Distributions along reference lines on hydrophobic and polluted surface insulator condition, with upper air gap.

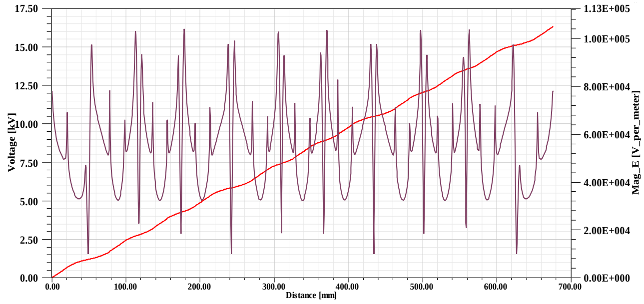


a. Along reference line 2

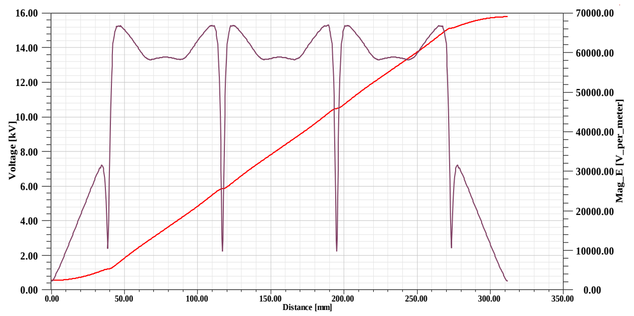


b. Along reference line 3

Fig. 8 Electric field and potential Distributions along reference lines on hydrophobic and polluted surface insulator condition with lower-upper air gap.

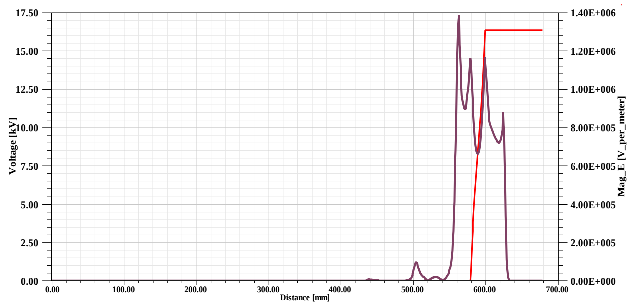


a. Along reference line 2

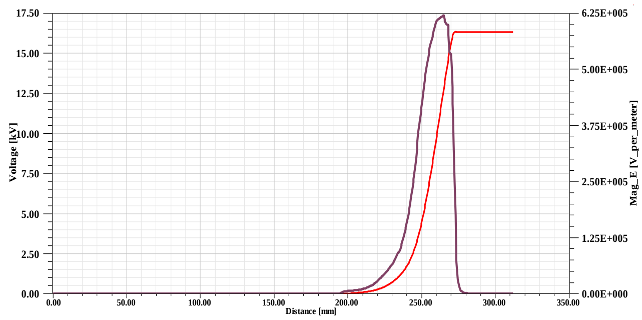


b. Along reference line 3

Fig. 9 Electric field and potential Distributions along reference lines on hydrophilic and polluted surface insulator condition without air gap.



a. Along reference line 2



b. Along reference line 3

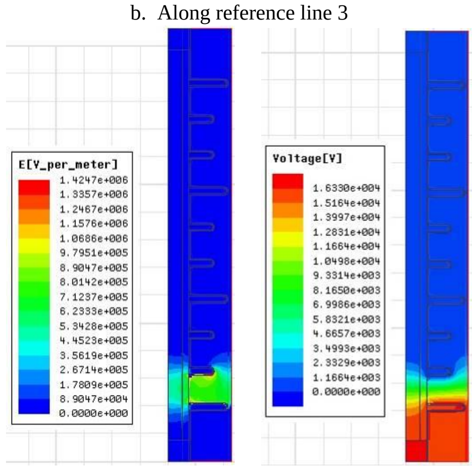
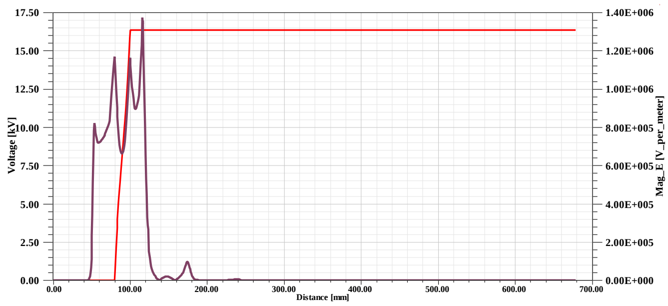
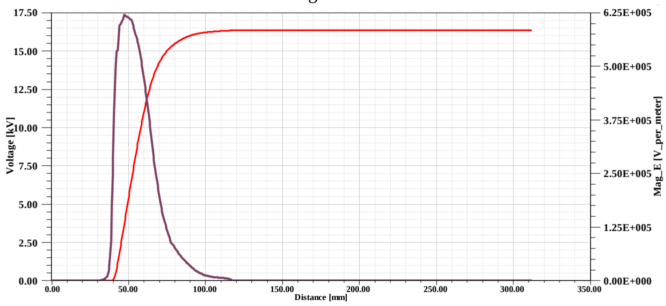


Fig. 10 Electric field and potential Distributions along reference lines on hydrophilic and polluted surface insulator condition with lower air gap.

ISBN: 978-988-14047-7-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)



a. Along reference line 2



b. Along reference line 3

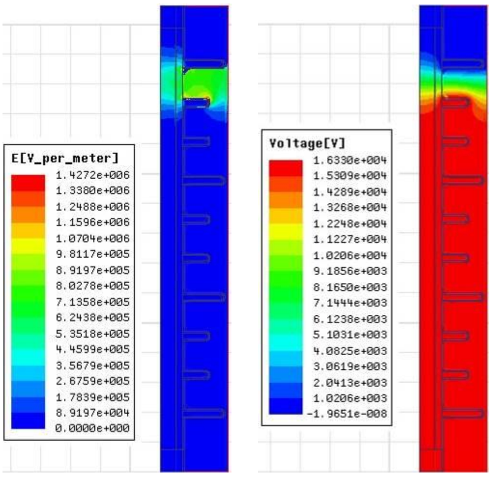
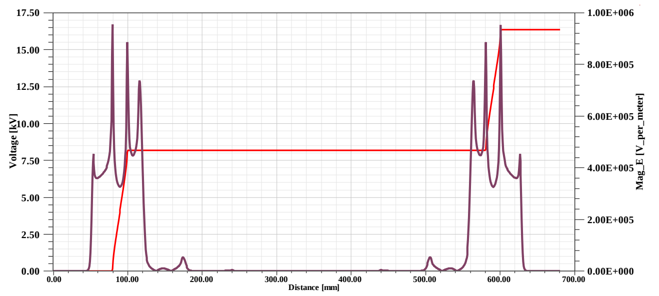
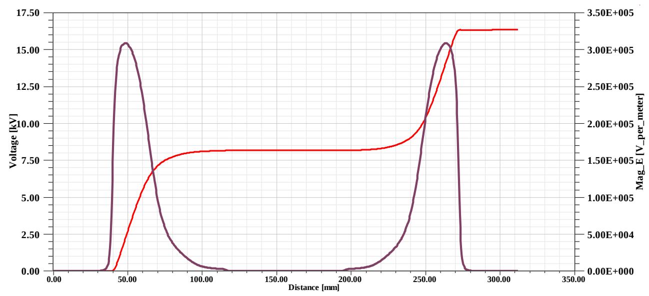


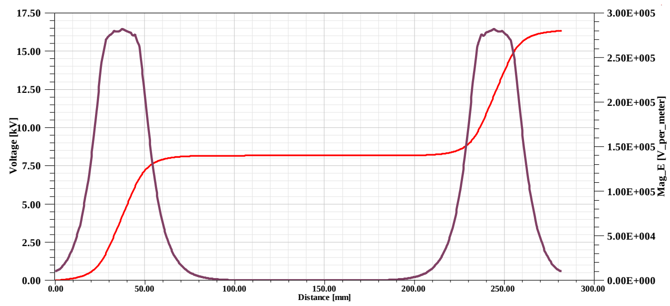
Fig. 11 Electric field and potential Distributions along reference lines on hydrophilic and polluted surface insulator condition, with upper air gap.



a. Along reference line 2



b. Along reference line 3



c. Along reference line 4

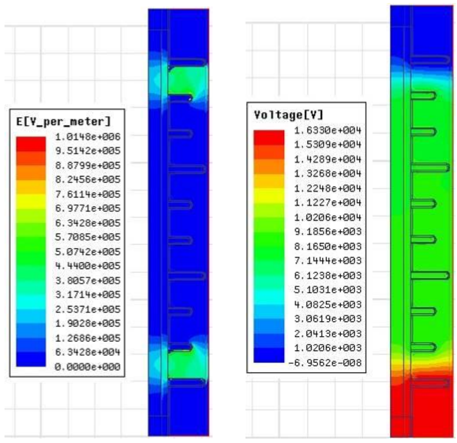


Fig. 12 Electric field and potential Distributions on hydrophilic and polluted surface insulator condition with lower-upper air gaps.

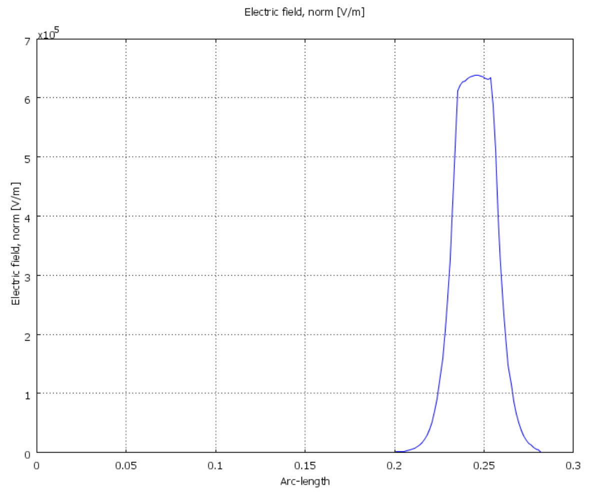


Fig. 13 Electric field and potential Distributions along reference line 4 on hydrophilic and polluted surface insulator condition with lower air gap.

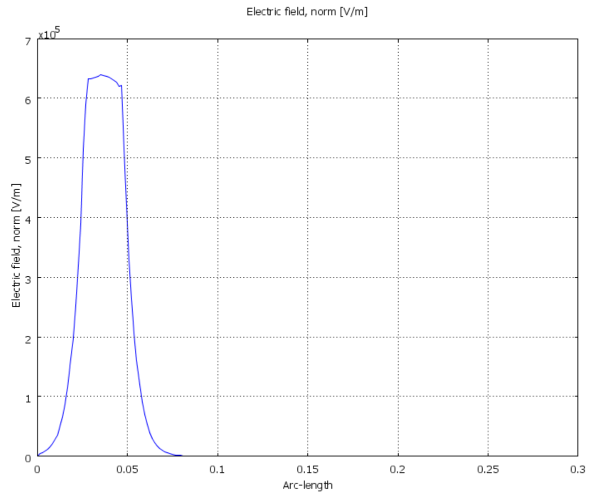


Fig. 14 Electric field and potential Distributions along reference line 4 on hydrophilic and polluted surface insulator condition with upper air gap.

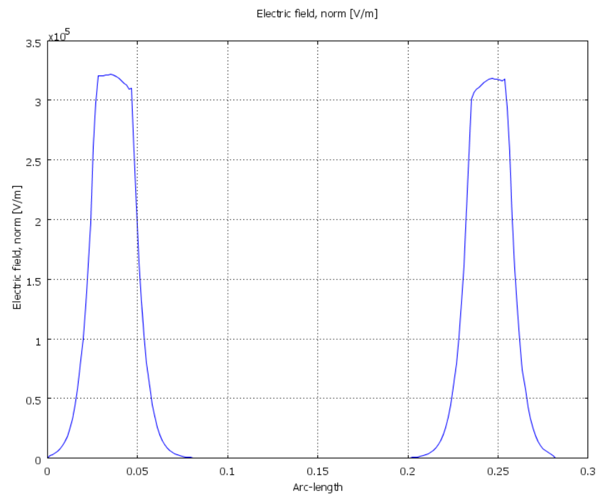


Fig. 15 Electric field and potential Distributions along reference line 3 on hydrophilic and polluted surface insulator condition with lower-upper air gaps.

REFERENCES

[1] S.M. Gubanski, "Modern outdoor insulation-concerns and challenges"IEEE Electr. Insul. Mag, Vol. 21, No. 6, pp. 5-11, 2005.

[2] R.Btehamdan, "Electric field study of Silicon Rubber insulator using finite element method (slim)". A project report submitted in partial fulfillments of the requirements for the award of the degree of Master of Engineering (Electrical – Power), 2006.

[3] Hydrophobicity Classification Guide. Guide 1, 92/1. Ludvika: STRI; 1992.

[4] Weiguo Que, M.S., "Electrical field and voltage distribution along non- cream insulators", PhD.Thesis 2002.

[5] B. Marungsri, W. Onchantuek, and A. Oonsivilai, "Electric Field and Potential Distributions along Surface of Silicone Rubber Polymer Insulators Using Finite Element Method", World Academy of Science, Engineering and Technology, 2008.

[6] S.Z. mousavi, B. Sheikhdoragh, A.A. Shayegani-Akmal "Investigation on pollution factors on electric field and potential distribution of polymeric insulator", World Academy of Science, Engineering and Technology, 2009.

[7] "The comparison of ceramic and non-ceramic insulators", E-Journal of New World Sciences Academy 2007, Volume: 2, Number: 4 Article Number: A0038.

[8] J.Farzaneh-Dehkordi, "Experimental study and mathematical modeling of flashover of EHV insulators covered with ice", M.S.Thesis July 2004.

ISBN: 978-988-14047-7-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)