Study of Hydrophobicity Effect on 220kV Double Tension Insulator String Surface Using Finite Element Method

M. Nageswara Rao, V. S. N. K. Chaitanya, P. Vijaya Haritha

Abstract**—**Insulators are one of the most significant equipment in power system. The insulators' operation may affect the power flow, line loss and reliability. The electrical parameters that influence the performance of insulator are surface leakage current, corona and dry band arcing. Electric field stresses on the insulator surface will degrade the insulating properties and lead to puncture. Electric filed stresses can be analyzed by numerical methods and experimental evaluation. As per economic aspects, evaluation by numerical methods are best. In outdoor insulation, a hydrophobic surface can facilitate to prevent water film formation on the insulation surface, which is decisive for diminishing leakage currents and partial discharge (PD) under heavy polluted environments and harsh weather conditions. Polymer materials like silicone rubber have an outstanding hydrophobic property among general insulation materials. In this paper, electrical field intensity of 220 kV porcelain and polymer double tension insulator strings at critical regions are analyzed and compared by using Finite Element Method. Hydrophobic conditions of polymer insulator with equal and unequal water molecule conditions are verified by using finite element method.

Keywords**—**Porcelain insulator, polymer insulator, electric field analysis, EFA, finite element method, FEM, hydrophobicity, FEMM-2D.

I. Introduction

ELECTRICAL insulators must be used in electrical systems for reliable power transmission. Higher electrical stresses on the insulator surface will lead to failure of insulator. Electrical stresses will increase due to heavy pollution and degradation insulating material. Porcelain is most commonly used material for overhead insulators. Porcelain is free from porosity since porosity is the main cause of deterioration of its dielectric property. It must be free from an impurity and air bubbles inside the material which may affect the insulators. Nowadays usage of polymer insulator is high compared to porcelain due to its best dielectric properties. Electric field stresses on the insulator surface will degrade the insulating properties and lead to puncture. Electric field stresses on the insulator surface will degrade the insulating properties and lead to puncture. Electric filed stresses can be analysed by numerical methods and experimental evaluation. For evaluation of insulators, Finite Element Method is the best method because the insulator requires the external boundary surroundings points for accurate results.

The field distributions along composite insulators are mainly influenced by the earth and high voltage (HV) capacitances. The real simulations are calculated numerically using FEM [1]-[4]. Electrical fields of 11 kV and 33 kV silicone composite insulators for various geometrical configurations are analyzed as per International Electrotechnical Commission (IEC) standards by FEM [5]. The difference of dielectric lost at different relative humidity leads to the temperature raise variation with the relative humidity [6]. Hydrophobicity of any materials is its resistance to flow of water on its surface. The hydrophobic surface is water repellent, in contrast with a hydrophilic surface that is easily wetted [7]-[11].

In this paper, 220 kV double tension porcelain and polymer insulator strings are designed using Finite Element Method Magnetics (FEMM) software. FEMM-2D software evaluates the results on the bases of Finite Element Method. Electric field intensity at critical regions of the insulator strings is evaluated. Hydrophobic condition on the polymer insulator surface is evaluated for two cases i.e., with equal and with unequal water molecules.

II. Geometrical Configuration

Geometrical configurations of the insulator like creepage distance, length of the insulator, pitch etc., are required for designing the insulator. Geometrical configurations are taken and tabulated in Table I. Insulator models are as per IEC and IS standards [12], [13].

TABLE I
GEOMETRICAL CONFIGURATIONS

S. No	Parameters	Dimensions (For Single Insulator)	
		Porcelain	Polymer
1	Length of the Insulator (mm)	2200+60	2200+60
2	Disc/Shed Diameter	260+12	Big:130+6 Small:100+5
3	No. of Discs/Sheds	14	Big:46 Small:45
4	Pitch (mm)	125+7	50+3
5	FRP Rod Length (mm)	------	2100+60
6	Core Diameter (mm)	------	26+2

III. Material Properties

For designing the insulators, with addition to geometrical

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configurations material properties of insulator are required. Various materials like ceramic, cement, silicon rubber, steel, FRP rod, aluminum and air are needed to assign to the model. These are assigned with the help of their respective permittivity values. Material properties are given in Table II.

TABLE II
MATERIAL PROPERTIES

S.No	Material/Medium	Component	Permittivity
1	Ceramic	Porcelain Disc	5.9
2	Cement	Porcelain	19.6
3	FRP	FRP Rod (Polymer insulator)	5
4	Silicone rubber	Polymer shed and housing	3
5	Steel (end fittings)	For both polymer and porcelain insulators	1
6	Air	Surrounding medium	1
7	Aluminium	Conductor	3
8	Water	For Polymer insulator	81

IV. DESIGN OF PORCELAIN INSULATOR STRING

220 kV double tension porcelain insulator string is designed with respective geometrical configurations. Insulator model is shown in Fig. 1.

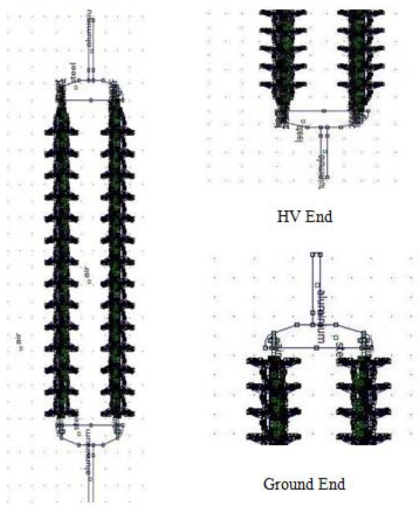

Fig. 1 220 kV porcelain double tension string model

Material properties are assigned to the model. They are shown in Table II. Boundary conditions are given to the model by applying line to ground voltage (i.e., 245/√3 = 142 kV) to the HV side of the insulator model and ground end is given as zero volts. 2D triangular elements are assigned to the model. These elements are distributed throughout the model and its boundary. By running the model, contours will form throughout and surrounding area of the model. Fig. 2 shows the 2D triangular elements of the model and Fig. 3 shows the contours of the model.

Electric field intensity is evaluated at all critical regions of the insulator string. Here electric field intensity is evaluated in two cases (i.e., without corona ring and with corona ring).

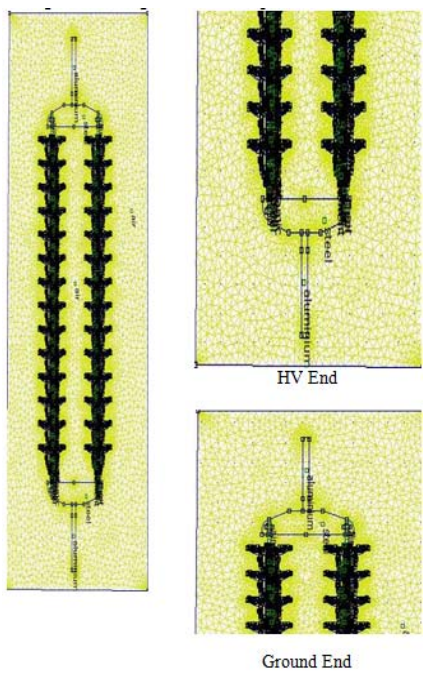

Fig. 2 Insulator model with 2D triangular elements

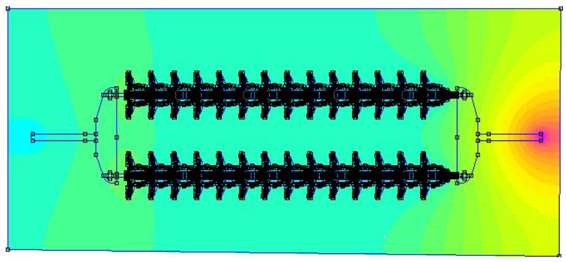

Fig. 3 Insulator model with contours

A. Without Corona Ring

For the model shown in Fig. 3, maximum electric field intensity is evaluated at all critical regions of the insulator. Results are given in Table III.

TABLE III
EFA RESULTS FOR PORCELAIN STRING-WITHOUT CORONA RING

S.No	Critical Regions	Max. Electrical field intensity (kV/mm)	
		Insulator1	Insulator2
1	First disc/shed (HV side)	0.26	0.28
2	Creepage distance	0.26	0.28
3	Triple point	0.77	0.79

B. With Corona Ring

Corona ring at HV end is attached to the model and results are given in Table IV. Model with corona ring is shown in Fig. 4.

By comparing two cases, insulator with grading ring got less electrical stresses.

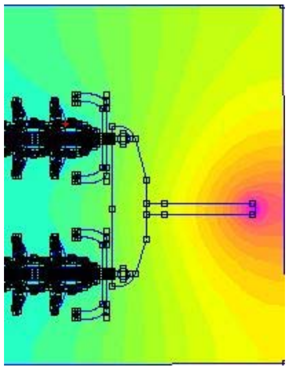

Fig. 4 Insulator model with grading ring at HV end

TABLE IV
EFA RESULTS FOR PORCELAIN STRING-WITH CORONA RING

S.No	Critical Regions	Max. Electrical field intensity (kV/mm)	
		Insulator1	Insulator2
1	First disc/shed (HV side)	0.22	0.24
2	Creepage distance	0.22	0.24
3	Triple point	0.76	0.71

V. DESIGN OF POLYMER INSULATOR STRING

220 kV double tension polymer insulator string is designed with respective geometrical configurations. Insulator model is shown in Fig. 5.

Material properties are assigned to the model. They are shown in Table II. Boundary conditions are given to the model by applying Line to ground voltage (i.e., 245/√3 = 142 kv) to the HV side of the insulator model and ground end is given as zero volts.

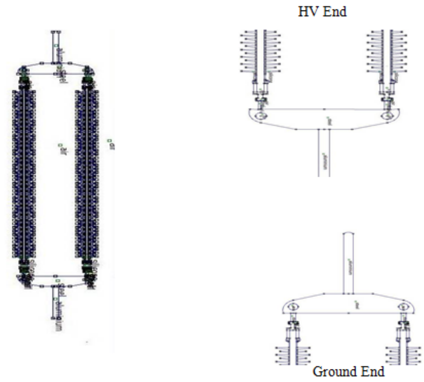

Fig. 5 220 kV Polymer Double tension string model

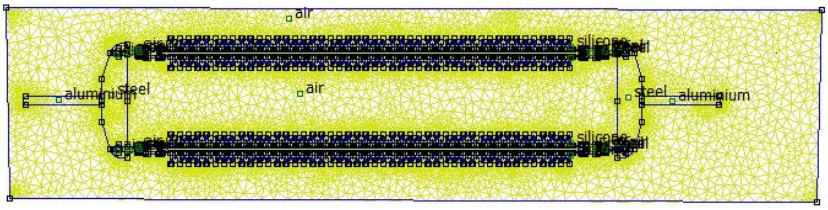

Fig. 6 Insulator model with 2D triangular elements

2D triangular elements are assigned to the model. These elements are distributed throughout the model and its boundary. By running the model, contours will form throughout and surrounding area of the model. Fig. 6 shows the 2D triangular elements of the model and Fig. 7 shows the contours of the model.

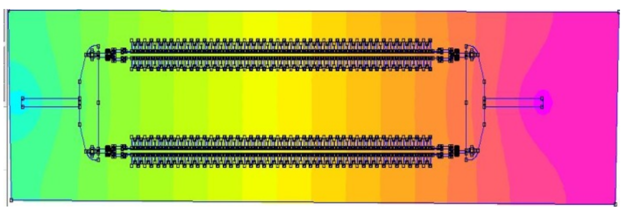

Fig. 7 Insulator model with Contours

Electric field intensity is evaluated at all critical regions of the insulator string. Here electric field intensity is evaluated in two cases (i.e., without corona ring and with corona ring).

i. Without Corona Ring

For the model shown in Fig. 3, maximum electric field intensity is evaluated at all critical regions of the insulator. Results are given in Table V.

TABLE V
EFA RESULTS FOR POLYMER STRING-WITHOUT CORONA RING

S.No	Critical Regions	Max. Electrical field intensity (kV/mm)	
		Insulator1	Insulator2
1	Inside FRP	0.031	0.031
2	Inside silicone rubber	0.035	0.035
3	Creepage distance	0.044	0.044
4	First shed (HV)	0.032	0.031
5	Triple point	0.037	0.036

ii. With Corona Ring

Corona ring at HV end is attached to the model and results are given in Table VI. Model with corona ring is shown in Fig. 8.

By comparing two cases, insulator with grading ring got less electrical stresses.

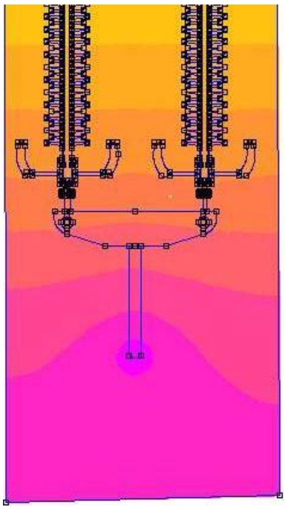

Fig.8 Insulator model with Grading ring at HV end

TABLE VI
EFA RESULTS FOR POLYMER STRING-WITH CORONA RING

S.No	Critical Regions	Max. Electrical field intensity (kV/mm)	
		Insulator1	Insulator2
1	Inside FRP	0.031	0.031
2	Inside silicone rubber	0.035	0.033
3	Creepage distance	0.043	0.043
4	First shed (HV)	0.030	0.030
5	Triple point	0.036	0.036

VI. STUDY OF HYDROPHOBICITY ON POLYMER INSULATOR

Study of hydrophobicity on polymer insulator is done in two cases.

Case.i: Equal distribution of water molecules on the insulator surface (with contact angle of 135^0).

Case.ii: Unequal distribution of water molecules on the insulator surface (with contact angle of 135^0).

i. Equal Distribution of Water Molecules

Water molecules are equally distributed along the surface of the insulator and EFA results are tabulated at critical regions. Model with equal water molecules are given in Fig. 9 and EFA results are given in Table VII.

TABLE VII
EFA RESULTS-WITH EQUAL WATER MOLECULES

S.No	Critical Regions	Max. Electrical field intensity (kV/mm)	
		Insulator1	Insulator2
1	Inside FRP	0.031	0.031
2	Inside silicone rubber	0.033	0.033
3	Creepage distance	0.052	0.052
4	First shed (HV)	0.047	0.032
5	Triple point	0.032	0.032

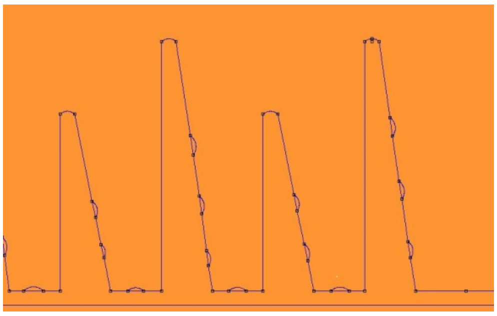

Fig. 9 Insulator model with equal water molecules

ii. Unequal Distribution of Water Molecules

Water molecules are unequally distributed along the surface of the insulator and EFA results are tabulated at critical regions. Model with equal water molecules are given in Fig. 10 and EFA results are given in Table VIII.

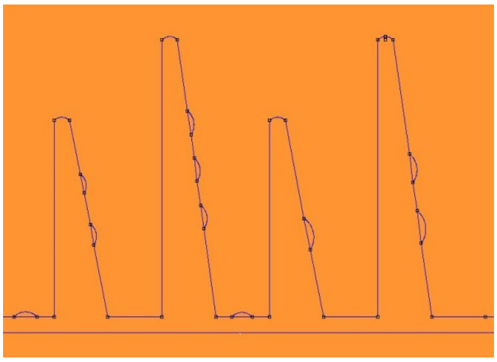

Fig. 10 Insulator model with unequal water molecules

TABLE VIII
EFA RESULTS-WITH UNEQUAL WATER MOLECULES

S.No	Critical Regions	Max. Electrical field intensity (kV/mm)	
		Insulator1	Insulator2
1	Inside FRP	0.031	0.031
2	Inside silicone rubber	0.033	0.033
3	Creepage distance	0.053	0.053
4	First shed (HV)	0.049	0.035
5	Triple point	0.038	0.038

VII. RESULTS COMPARISON

By comparing EFA results of porcelain insulator with and without grading ring, by placing grading ring electric field intensity decreased by 14-15% at first shed and 2-10% at triple point. Comparative bar graph is shown in Fig. 11.

As we can see by comparing EFA results of polymer insulator with and without grading ring cases, grading ring minimized the electric field intensity by 0-5% at inside FRP, 2% at creepage distance, 3-6% at first shed and 0-3% at triple point. Comparative bar graph is shown in Fig. 12.

By comparing EFA results of porcelain insulator with grading ring and polymer insulator with grading ring, electric field intensity of polymer insulator with grading ring decreased by 86-88% at first shed/disc, 80-82% at creepage distance and 95% at triple point. Comparative bar graph is shown in Fig. 13.

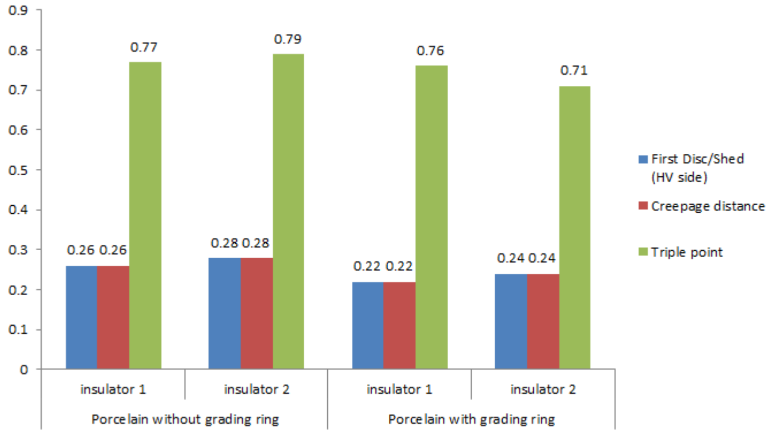

Fig. 11 Comparison between porcelain insulator with and without grading ring

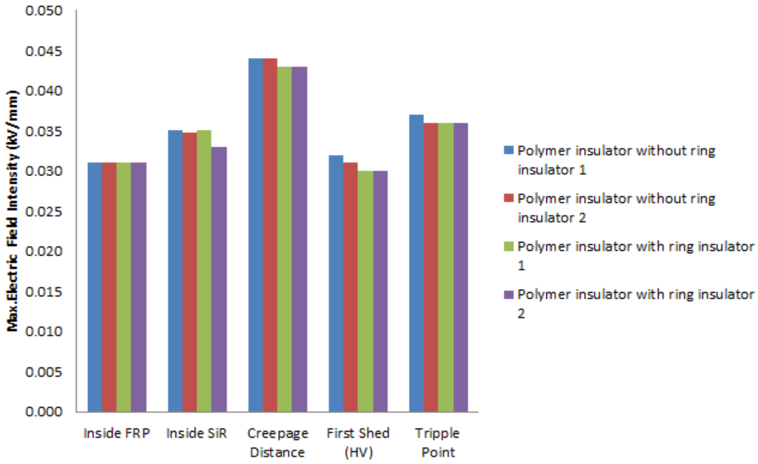

Fig. 12 Comparison between polymer insulator with and without grading ring

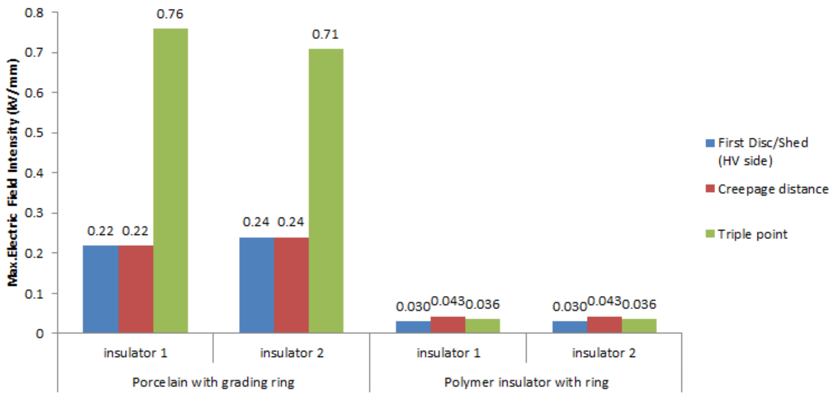

Fig.13 Comparison between porcelain insulator with grading ring and polymer insulator with grading ring

By comparing hydrophobic condition of polymer insulator with equal and with unequal distribution of water molecules, electric field intensity increases in creepage distance by 2%, first shed by 4-9%, and 19% at triple point in case of unequal distribution of water molecules. Comparative bar graph is shown in Fig. 14.

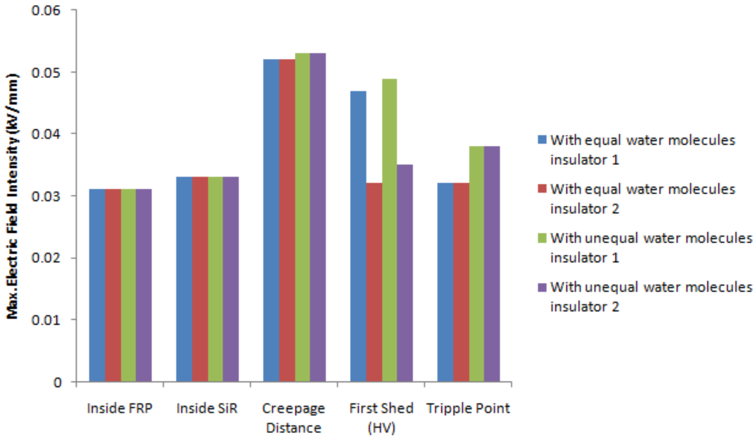

Fig. 14 Comparison between polymer insulator with equal and unequal water molecules

VIII. Conclusion

Electric field intensity at all critical regions of the porcelain and polymer insulator strings are analyzed. Compared to porcelain, polymer insulator has very less electrical stresses. Hydrophobicity condition on polymer insulator surface is studied in two cases (i.e., with equal water molecules and with unequal water molecules). Electric filed intensity is high in case of unequal water molecules on the surface of the insulator.

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