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Design and Analysis of Extra High Voltage Non-Ceramic Insulator by Finite Element Method

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Abstract**—**High voltage insulator has to withstand sever electrical stresses. Higher electrical stresses lead to erosion of the insulator surface. Degradation of insulating properties leads to flashover and in some extreme cases it may cause to puncture. For analyzing these electrical stresses and implement necessary actions to diminish the electrical stresses, numerical methods are best. By minimizing the electrical stresses, reliability of the power system will improve. In this paper electric field intensity at critical regions of 400 kV silicone composite insulator is analyzed using finite element method. Insulator is designed using FEMM-2D software package. Electric Field Analysis (EFA) results are analyzed for five cases i.e., only insulator, insulator with two sides arcing horn, High Voltage (HV) end grading ring, grading ring-arcing horn arrangement and two sides grading ring. These EFA results recommended that two sides grading ring is better for minimization of electrical stresses and improving life span of insulator.

Keywords**—**Polymer insulator, electric field analysis, numerical methods, finite element method, FEMM-2D.

I. Introduction

INSULATORS play an imperative role in electrical transmission and distribution. At present polymer insulators are gaining importance due to their enhanced advantages. Silicone is having better temperature resistivity compared to Ethylene Propylene Diene Monomer (EPDM). Due to light weight and hydrophobic property, silicone composite insulators are superior compared porcelain and other polymer insulators. Due to continuous energy on insulators, insulators need to face higher electrical stresses mainly at HV end. In porcelain disc insulator string we can replace the disc whenever it was damaged. But in silicone composite insulators, sheds cannot be removed and replaced. Hence additional care needs to be taken in case of silicone composite insulators regarding electrical stresses. There are so many ways to recognize and diminish the electrical stresses. Numerical methods (like Finite Difference Method (FDM), Finite Element Method (FEM), Charge Simulation Method (CSM) and Boundary Element Method (BEM) etc.) are one of the best ways to analysis the electric field.

To improve the power system reliability, it is required to increase the life time by proper design and maintenance. Partial discharge is one of the problems that result from excessive high electric field stress at the insulator surface. The electric field norm is higher at the HV end side and null at earth side which will make the electric field distribution non uniform in the absence of grading ring. Grading ring will make the electric field distribution uniform by varying parameters [1]. Electric field is analyzed for sphere to plane gap arrangement with CSM and methods of moment. Results proved that CSM is better and accurate compared to methods of moment [2]. Electric fields of 11 kV and 33 kV silicone composite insulators are analyzed for various geometrical configurations as per International Electro-technical Commission (IEC) standards by FEM [3]-[6]. With the help of EFA results, best geometrical configurations are identified. EFA has been carried out for 400 kV Silicone Composite Insulator by BEM. Grading ring was designed and usage of microvarisor on the surface of the insulator was analyzed for 66 kV insulator with FEM [7], [8]. With the CSM, EFA results are analyzed for 500 kV High Voltage Direct Current (HVDC) and Alternating Current (AC) insulator and corona ring was optimized. EFA studies are carried out on both ceramic and non-ceramic insulators with respect to their ageing. Corona ring was recommended for some of the transmission insulators like 66 kV and 110 kV [9]-[14].

In this paper, 400 kV very heavy polluted silicone composite insulator was designed (i.e. 31 mm/kV) using FEMM-2D software package. This software package gives EFA results based on FEM.

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II. Design of Insulator

Geometrical configurations of the insulator like Creepage Distance (CD), length of the insulator, pitch etc., are required for designing the insulator. Geometrical configurations are given in Table I.

TABLE I
GEOMETRICAL CONFIGURATIONS

S.No	Parameters	Dimensions
1	Length of the Insulator (mm)	3900±100
2	CD (mm)	13000±100
3	Specific CD (mm/kV)	31
4	Dry Arcing Distance (mm)	3500±50
5	Pitch (mm)	60±3
6	Fiber Reinforced Plastic (FRP) Rod Length (mm)	3800±50

With respect to above configurations insulator was designed as shown in Fig. 1. Insulator has three main components they are end fittings (steel), weather sheds/housing (silicone rubber) and rod (FRP). Material properties are assigned to the model based on their permittivity values which are given in Table II. Surrounding medium of the insulator is assigned as air.

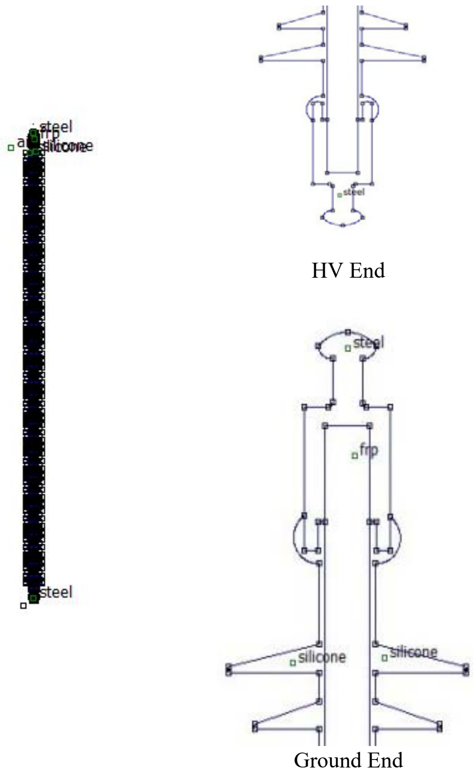

Fig. 1 Insulator Model

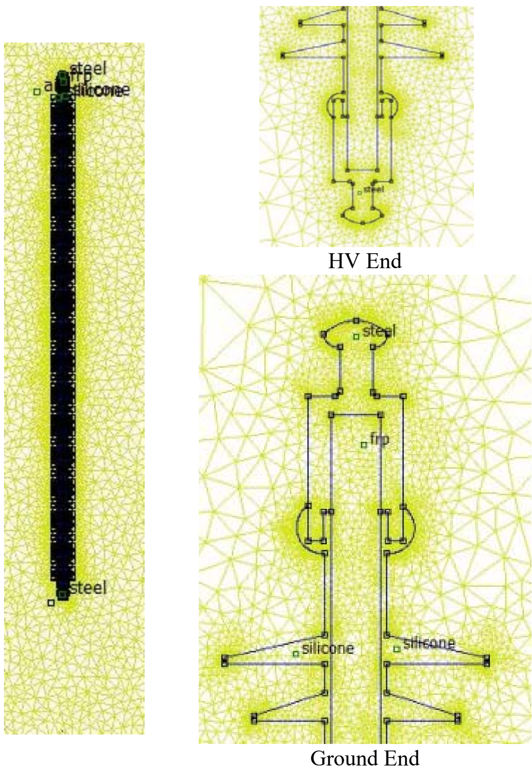

Fig. 2 2D Traingualar elements

TABLE II
MATERIAL PROPERTIES

S.No	Material/Medium	Permittivity
1	FRP	5
2	Silicone Rubber	3
3	Steel	1
4	Air	1
5	Aluminium	3

After assigning the material properties to the model, boundary conditions are given. Line to ground voltage (i.e. 420/√3=242 kV) is applied 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. Figs. 2 and 3 show 2D-triangular elements and contours of the model. Fig. 4 shows voltage distribution of the insulator.

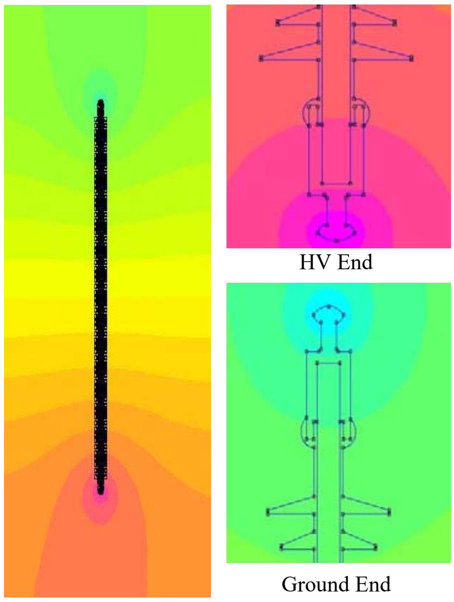

Fig. 3 Contours

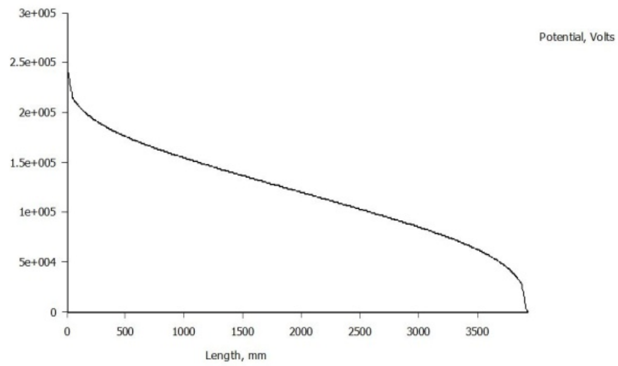

Fig. 4 Voltage Distribution

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III. EFA Results

EFA results are taken for the following cases:

Case i: Only Insulator -without grading ring and arcing horn

Case ii: Insulator –with both sides arcing horn.

Case iii: Insulator -with grading ring at HV end

Case iv: Insulator-with grading ring at HV end and arcing horn at ground end.

Case v: Insulator –with both sides grading ring.

For all the above cases, EFA results are taken and tabulated for critical regions (i.e. inside FRP, inside silicone rubber, first shed, CD, dry arcing distance and triple point) of the insulator.

i. Only Insulator-Without Grading Ring and Arcing Horn

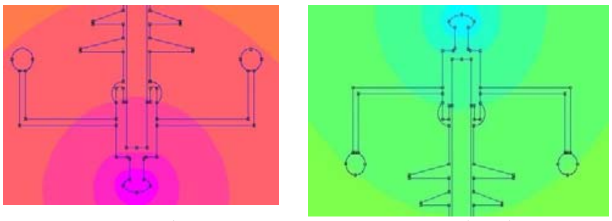
For the insulator model given in Fig. 1, EFA results are noted and given in Table III. Compared to all the results, at triple point electric filed intensity is more.

TABLE III
EFA Results-I

S.No	Critical Regions	Max. Electric Field Intensity (kV/mm)
1	Inside FRP	0.158
2	Inside Silicone rubber	0.125
3	CD	0.133
4	First Shed	0.127
5	Triple Point	0.190
6	Dry Arcing Distance	0.128

ii. Insulator-With Two Sides Arcing Horn

Arcing horns are used to protect of insulators from damages like flashovers. Arcing horns are added to the model both HV and LV side with 25 mm diameter. Fig. 5 shows the insulator model with arcing horns. EFA results are given in Table IV.



HV End Ground End

Fig. 5 Insulator model with arcing horns

TABLE IV
EFA Results-II

S.No	Critical Regions	Max. Electric Field Intensity (kV/mm)
1	Inside FRP	0.160
2	Inside Silicone rubber	0.125
3	CD	0.133
4	First Shed	0.127
5	Triple Point	0.190
6	Dry Arcing Distance	0.084

iii. Insulator-With Grading Ring at HV End

Mostly electric field will be higher at the HV end side and null at earth side, which will make the electric field distribution non uniform in the absence of grading ring. Grading ring will make the electric field distribution uniform by varying parameters. A grading ring (radius: 300 mm, height: 110 mm) is attached at the HV end of the insulator model. Material is assigned to the ring as per Table II. EFA results are given in Table V. Insulator model with grading ring at HV end is shown in Fig. 6.

HV End Ground End

Fig. 6 Insulator model with grading ring at HV end

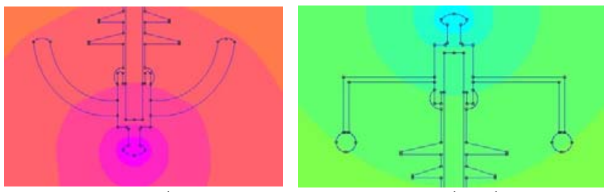
TABLE V
EFA Results-III

S.No	Critical Regions	Max. Electric Field Intensity (kV/mm)
1	Inside FRP	0.156
2	Inside Silicone rubber	0.119
3	CD	0.125
4	First Shed	0.123
5	Triple Point	0.176
6	Dry Arcing Distance	0.079

Comparing EFA results with previous cases (i.e. insulator without grading ring, with both sides arcing horn) field intensity is minimized at all critical regions of the insulators.

iv. Insulator-With Grading Ring at HV End and Arcing Horn at Ground End

In this case both grading ring and arcing horn are added to the model. Grading ring is attached at HV end and arcing horn is attached at ground end. EFA results and insulator model are given in Table VI and Fig. 7. Comparing with previous case (i.e. insulator with only grading ring at HV end) field intensity is minimized at first shed. Field intensity at all the remaining regions is same.

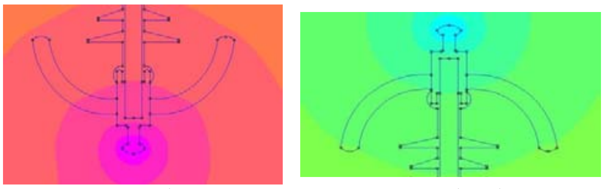


HV End Ground End

Fig. 7 Insulator model with grading ring and arcing horn

TABLE VI
EFA Results-IV

S.No	Critical Regions	Max. Electric Field Intensity (kV/mm)
1	Inside FRP	0.156
2	Inside Silicone rubber	0.119
3	CD	0.126
4	First Shed	0.121
5	Triple Point	0.178
6	Dry Arcing Distance	0.079



HV End Ground End

Fig. 8 Insulator model with both sides grading ring

v. Insulator-With Both Sides Grading Ring

In this case grading rings are added on both sides (i.e. HV and ground ends) of the model. EFA results and insulator model are given in Table VII and Fig. 8. By comparing with insulator with grading ring at HV end and arcing horn at ground end case, field intensity is minimized at all the regions of the insulator except inside FRP and dry acing distance.

TABLE VII
EFA RESULTS-V

S.No	Critical Regions	Max. Electric Field Intensity (kV/mm)
1	Inside FRP	0.156
2	Inside Silicone rubber	0.116
3	CD	0.125
4	First Shed	0.118
5	Triple Point	0.176
6	Dry Arcing Distance	0.080

IV. RESULTS COMPARISON

Comparing EFA results for all the above cases, electric filed intensity of the insulator is diminished by the application of grading ring.

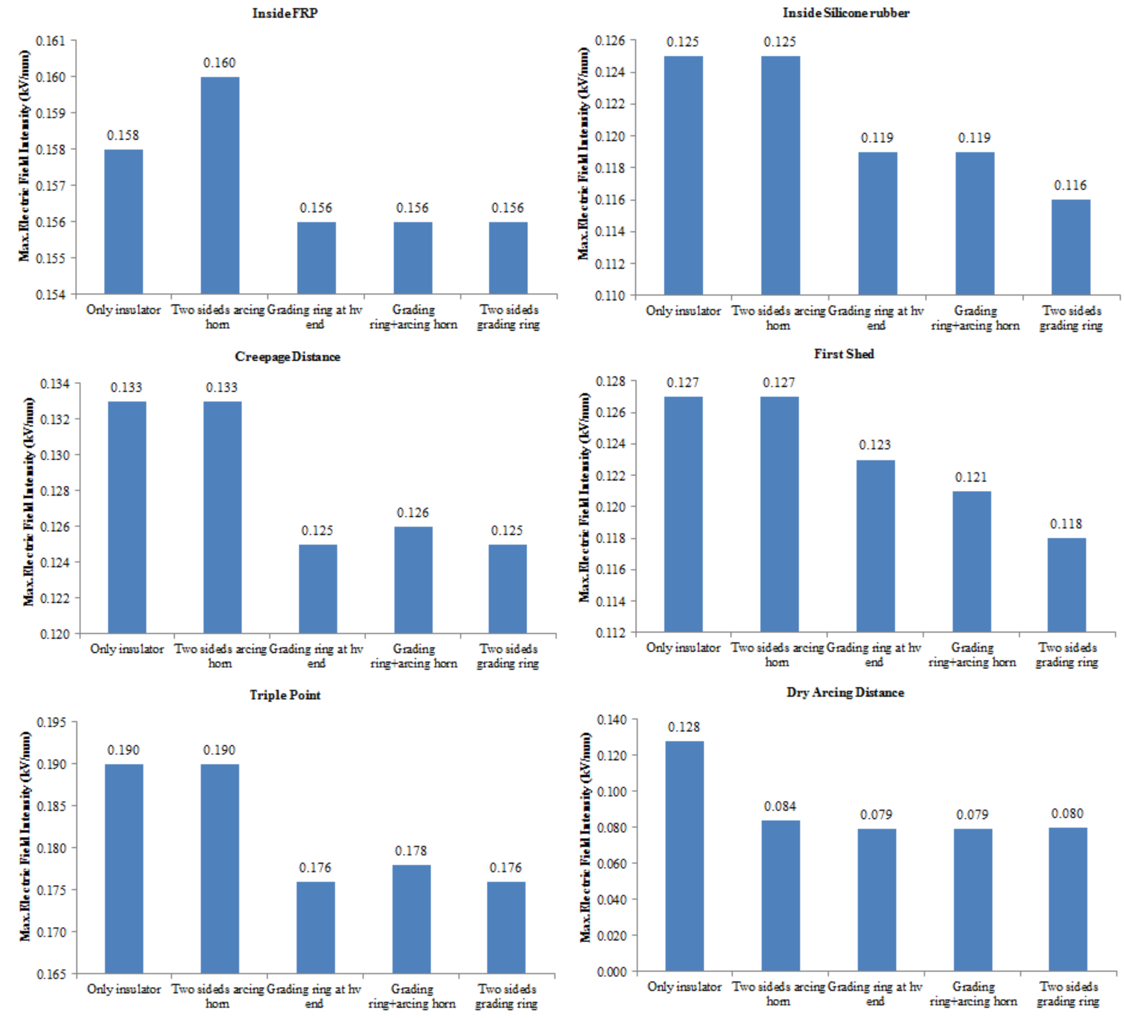


Fig. 9 EFA Results Comparison

By comparing EFA results, electric field intensity is diminished in case of two sides grading ring. Table VIII shows the % reduction of electric field intensity compared to two sides grading ring.

By comparing only grading ring at HV end and both sides grading ring case, EFA results at all the critical regions of the insulator are almost similar except inside silicone rubber and first shed. For better reliability of the system two sides grading ring is preferred for 400 kV polymer insulator.

TABLE VIII
COMPARISON WITH TWO SIDES GRADING RING RESULTS

Critical Regions	% Reduction of Electric Field Intensity compared to two sides grading ring results			
	Only insulator	Two sides arcing horn	Grading ring at HV end	Grading ring +arcing horn
Inside FRP	1.3	2.5	No Change	No Change
Inside Silicone rubber	7.2	7.2	2.5	2.5
CD	6.0	6.0	No Change	0.8
First Shed	7.1	7.1	4.1	2.5
Triple Point	7.4	7.4	No Change	1.1
Dry Arcing Distance	37.5	4.8	No Change	No Change

V. CONCLUSION

In this paper electric field intensity is analyzed for all the critical regions (i.e. inside FRP, inside silicone rubber, CD, first shed, triple point and arcing distance) of 400 kV silicone composite insulator by FEM. EFA is carried out for five cases i.e. only insulator, insulator with two sides arcing horn, HV end grading ring, grading ring-arcing horn arrangement and two sides grading ring. By comparing EFA results of all cases with two sides grading ring results, field intensity is diminished at all critical regions. EFA results of HV end grading ring and two sides grading ring are almost similar except inside silicone rubber and first shed regions. Hence it is recommended to provide two sides grading ring for better safety and to improve life span of insulator.

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