

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

M. Nageswara Rao, V. S. N. K. Chaitanya, P. Pratyusha

Abstract—High voltage insulator has to withstand severe 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.

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.

Dr.M.Nageswara Rao, Associate Professor, V.S.N.K. Chaitanya, Assistant Professor (C), and P.Pratyusha, PG student, are with the Department of Electrical and Electronics Engineering, University College of Engineering, JNTU Kakinada, Andhra Pradesh., India (e-mail: nagjntuk@gmail.com, chaitu824@gmail.com, prathyupalavalasa@gmail.com).

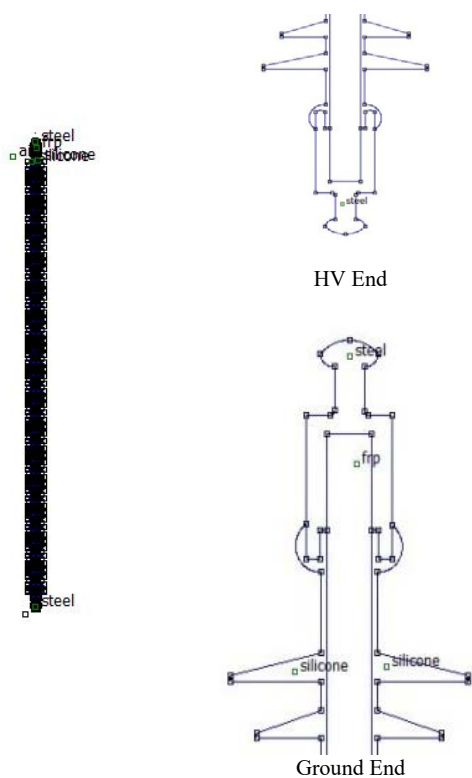


Fig. 1 Insulator Model

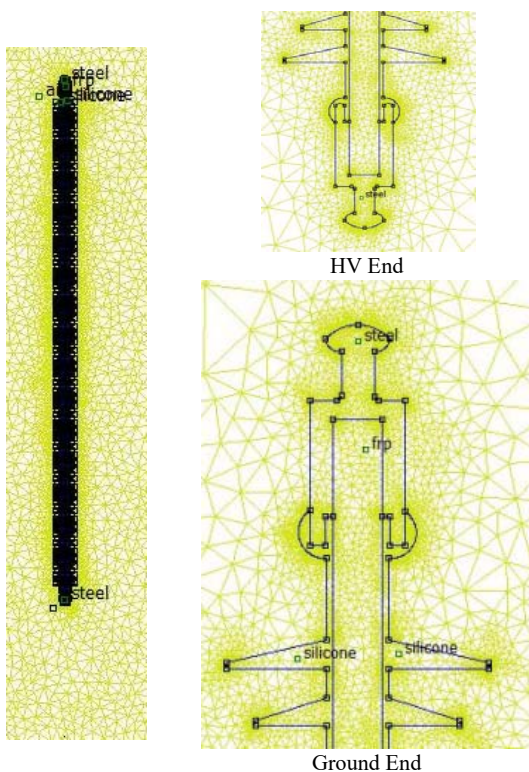


Fig. 2 2D Traingular elements

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. $420/\sqrt{3}=242$ 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.

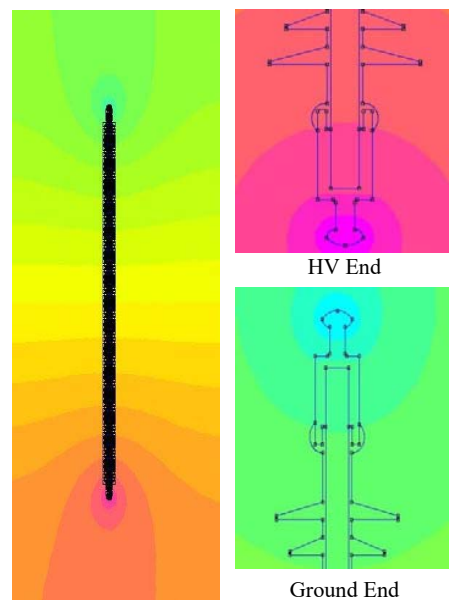


Fig. 3 Contours

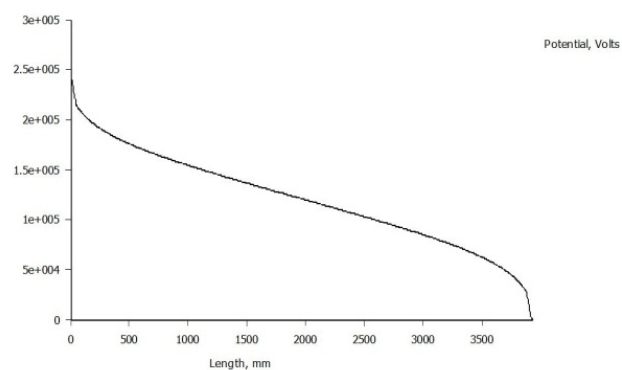


Fig. 4 Voltage Distribution

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 field 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.

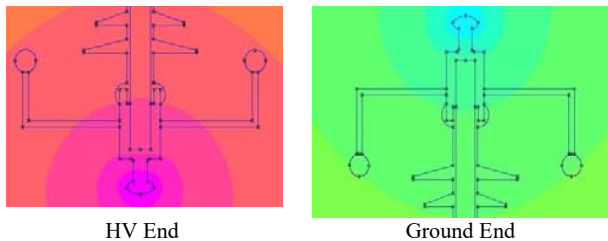


Fig. 5 Insulator model with arcing horns

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.

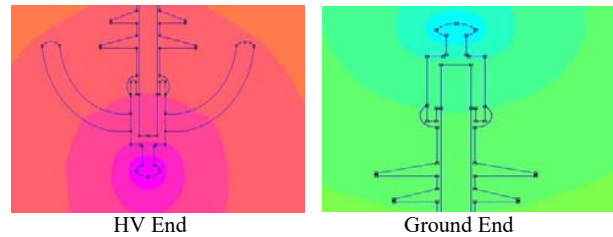


Fig. 6 Insulator model with grading ring at HV end

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.

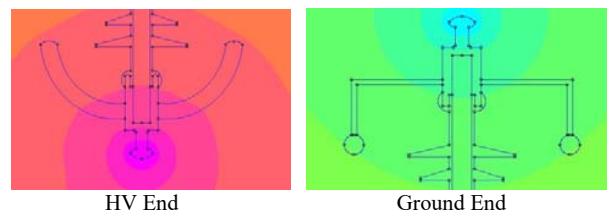


Fig. 7 Insulator model with grading ring and arcing horn

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

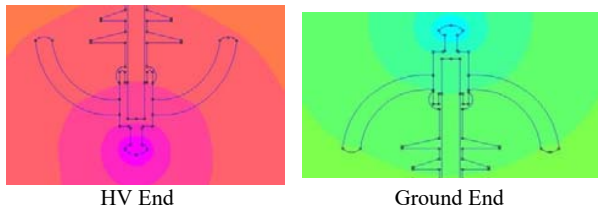


Fig. 8 Insulator model with both sides grading ring

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 arcing 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 field intensity of the insulator is diminished by the application of grading ring.

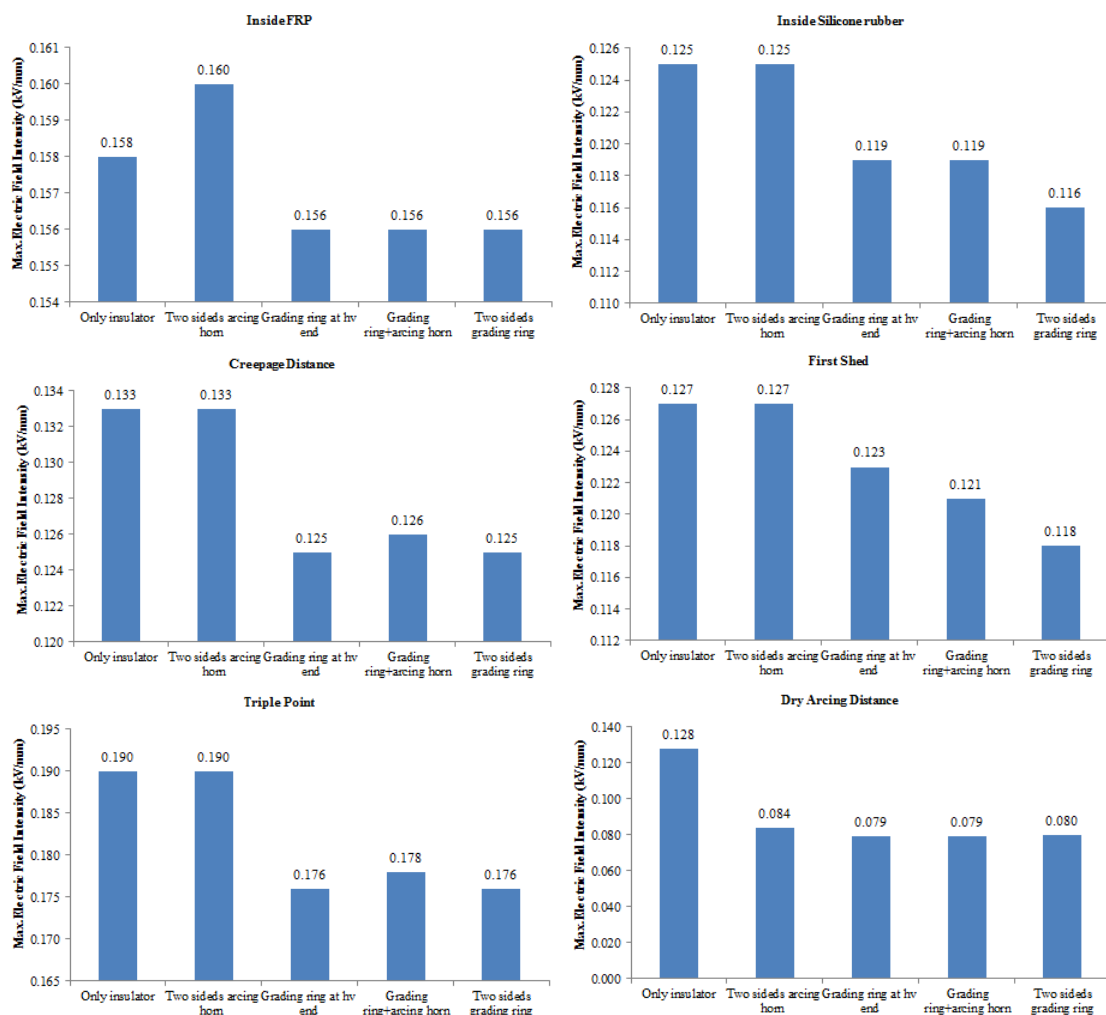


Fig. 9 EFA Results Comparison

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.

ACKNOWLEDGMENT

We acknowledge our gratitude to University College of Engineering, JNTU Kakinada for their support in completion of this work.

REFERENCES

- [1] B. M'hamedi, "Optimal design of corona ring on HV composite insulator using PSO approach with dynamic population size," *IEEE Transactions on Dielectrics and Electrical Insulation* Vol. 23, No. 2, pp.1048-1057, April 2016
- [2] D Harimurugan, "A comparative study of field computation methods: Charge simulation method and method of moments," 2018 International Conference on Power, Signals, Control and Computation (EPSCICON), ISBN: 978-1-5386-4208-5, Jan 2018.
- [3] M. Nageswara Rao, "Electric Field Analysis of Polymer Insulators for Various Geometrical Configurations," *IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI-2017)*, ISBN: 978-1-5386-0814-2, pp.1722-1727, Sep 2017.
- [4] IEC -61109 "Insulators for Overhead Lines Composite Suspension and Tension Insulators for A.C. Overhead Lines with a Nominal Voltage Greater Than 1 000 V Definitions, Test Methods and Acceptance Criteria," 2008.
- [5] IS -731 "Specification for Porcelain Insulators for Overhead Power Lines With A Nominal Voltage Greater Than 1000 V," 2001.
- [6] IEC -60383-2 "Insulators for Overhead Lines with a Nominal Voltage Greater Than 1000 V Definitions, Insulator string and Insulator sets for A.C system test Methods and acceptance criteria," 1993.
- [7] M. Nageswara Rao, "Design of corona mitigation device and application of ZnO microvaristor on 66kV insulators by finite element method," *IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI-2017)*, ISBN: 978-1-5386-0814-2, pp.1047-1051, Sep 2017.
- [8] V.S.N.K. Chaitanya, "Electric field analysis and experimental evaluation of 400kV Silicone composite insulator", *International Journal Electrical computer Energetic Electronic and Computer Engineering*, vol. 10, no. 7, pp. 484-487, 2016.
- [9] Ravi S. Gorur "Charge Simulation Based Electric Field Analysis of Composite Insulators for HVDC Lines," *IEEE Transactions on Dielectrics and Electrical Insulation.*, vol. 21, no. 6, pp.2541- 2548, Dec. 2014.
- [10] Zongren Peng, "Electric Field Calculation and Grading Ring Optimization of Composite Insulator for 500kV AC Transmission Lines," *International Conference on Solid Dielectrics*, Potsdam, Germany, pp.1-4, July. 2010.
- [11] Rahul Krishnan "Electric Field Analysis of High Voltage Insulators," *International Journal of Computer Science and Informatics*. ISSN:2231-5292, vol. 1, Iss.4, pp.31-35, 2012.
- [12] Xingliang Jiang, "AC Flashover Performance of Porcelain, Glass and Polymeric Insulators at High Altitudes," *IEEE 11th International Conference on the Properties and Applications of Dielectric Materials*, pp. 376-385, 2015.
- [13] G. Haddad, "Evaluation of the aging process of composite insulator based on surface characterization techniques an die electrical method," *IEEE Transaction on Dielectrics and electrical Insulation*, vol. 23, no.1, pp. 732-737, Feb 2016.
- [14] R. Add-Rahman, "Stress Control on polymeric outdoor insulators using zinc oxide microvaristor composites," *IEEE Transaction on Dielectrics and electrical Insulation*, vol. 19, no.2, pp. 705-713, April 2012.