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Improvement of Electric Field Stress Control on Polymeric Outdoor Insulator

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Abstract

The electric field stress control of polymeric outdoor insulators is crucial for ensuring their reliability and longevity in service. This study delves into the impact of insulator design managing electric field stress on outdoor polymeric insulators. Excessive electric stress, in conjunction with contaminants and moisture, can lead to surface arcing, potentially resulting in insulator flashover. By employing the Finite Element Method (FEM), the electric field and potential distributions along the insulator's surface leakage path were computed. The material selection and characterized boundary within the FEM framework. Comparative analyses of field and equipotential profiles for insulators with properties of weather shed and corona ring design under dry and uniformly contaminated surface conditions were conducted. The findings underscore the significance of utilizing innovative materials and computational methods to enhance stress control mechanisms for polymeric outdoor insulators, thereby mitigating the risks associated with electrical breakdown and flashover events.

1. Introduction

Insulators play an important role in high voltage distribution systems, outdoor insulators which are widely used in overhead transmission lines as suspension material high voltage insulators. Outdoor insulators play vital parts of the transmission and distribution networks to transfer electrical power to consumers [1]. There are many materials that are used to make insulators such as glass, ceramic and composite materials.

Nowadays, polymeric insulators have started to gain popularity amongst electric power utilities around the world. Polymeric insulator function well in contaminated environments because they are hydrophobic [2]. The advantages of polymeric insulators are also lightweight, require little maintenance, are easy to handle, and require less money for installation. Outdoor insulators are exposed to various environmental stresses such as humidity, erratic temperature, and pollution. Due to their lightweight and outstanding electrical performance in moderate to heavily polluted environments, polymeric insulators have been widely accepted till nowadays. To control electric field stress and enhance the performance of polymeric insulators under various environmental conditions, techniques like optimizing weather shed profile, using corona rings, and incorporating field grading materials like zinc oxide micro varistors have been investigated [3].

There are some factors that influence the electric field conditions at the insulator, it depends on the applied voltage, insulator design, corona ring, and space spacing. By choosing the optimum values of the insulator's parameter, it can increase reliability and reduce the electric filed stress within the insulator. A fundamental understanding of the electric field distribution and how it impacts the performance of insulators in various environments is necessary for their effective design and functionality [4],[5].

Lastly, in the industry there are many types and shapes of insulators used in power system transmission. They come with different densities, firmness and performing properties with the aim of withstanding the worst conditions such as during pollution, lightning and other breakdowns that may occur. The reliability of the insulator is the most important part that must take into consideration whether it is a polymeric insulator or other types of insulators. A good insulator should have very high dielectric strength to survive the voltage stresses in high voltage systems, as well as great mechanical strength to support the weight and tension of the conductors.

2. Methodology

Fig. 1 shows the flowchart of the project where the flow of the project is determined from the start to the end. This project will be using COMSOL Multiphysics as a simulation tool and to evaluate the electric field stress along the insulator. An analysis and comparison of the electric field will be carried out based on the result obtained.

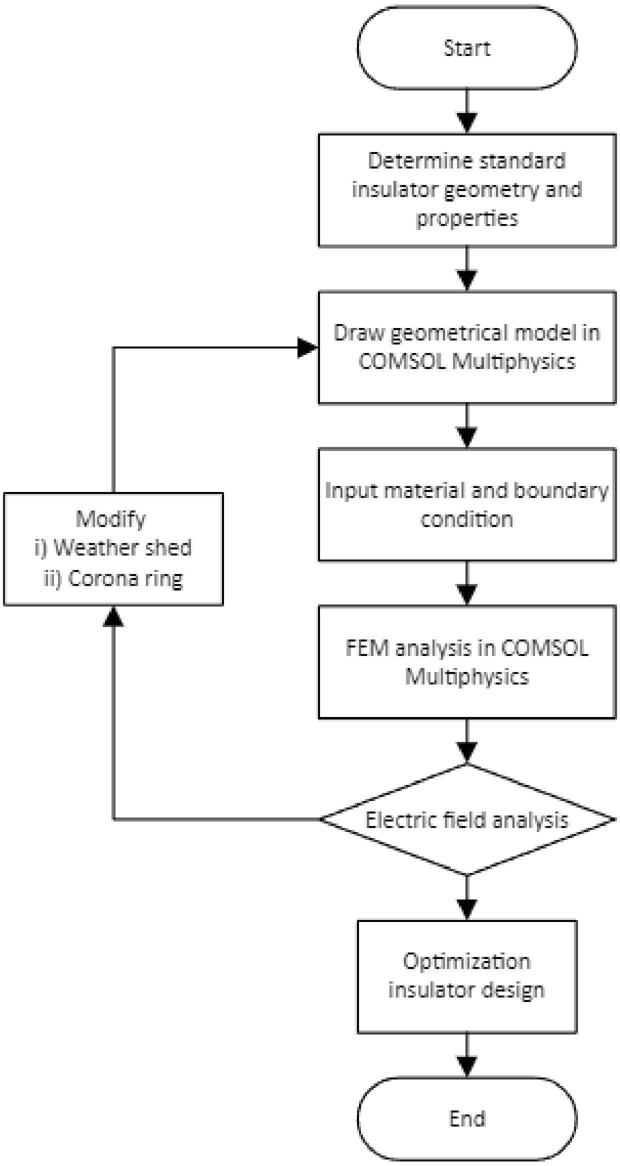


Fig. 1 *Flowchart of project*

2.1 Design of the polymeric outdoor insulator

Fig. 2 shows an initial design of polymeric outdoor insulator is used as a model for electric field investigation. The design and modelling are carried out using COMSOL Multiphysics software. To construct the insulator, there is some aspect need to consider such as geometry, and materials selection.

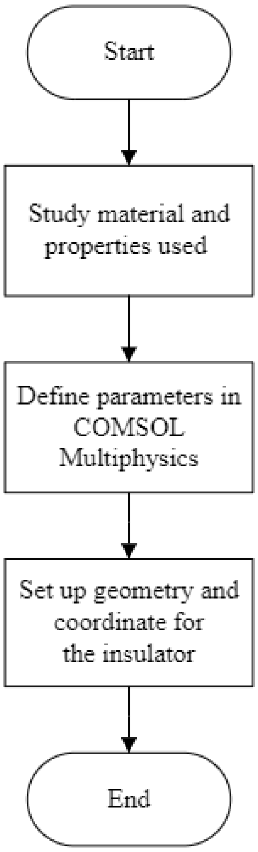


Fig. 2 *Flowchart of designing the insulator using COMSOL Multiphysics*

2.2 Electric field distribution around the insulator

COMSOL Multiphysics to simulate the electric field distribution around a polymeric outdoor insulator. By precisely modelling the insulator's shape, material properties, and boundary conditions, the simulation highlights areas where improvements can be made. This detailed analysis is essential for designing insulators that are more robust and reliable for high-voltage applications.

2.3 Comparison and analysis

To determine the electric field stress control on various design and parameter, the simulation result will be evaluated and compared. Comparing the electric field conditions across various designs of polymeric outdoor insulators involves simulating each design in COMSOL Multiphysics to analyse their performance under non polluted environments. By evaluating the electric field distribution in each design, we can identify differences in field strength and stress concentration areas. This comparison highlights which designs effectively minimize high electric field regions and distribute stress more evenly. The insights gained from this analysis inform design improvements, ensuring the selected insulator design offers optimal performance and reliability in high-voltage applications.

3. Result and discussion

This section aims to evaluate the electric field distribution around insulators with various design modifications, focusing on the addition of corona rings with different sizes, variations in weather shed dimensions, and changes to the core rod size.

3.1 Design of polymeric outdoor insulator

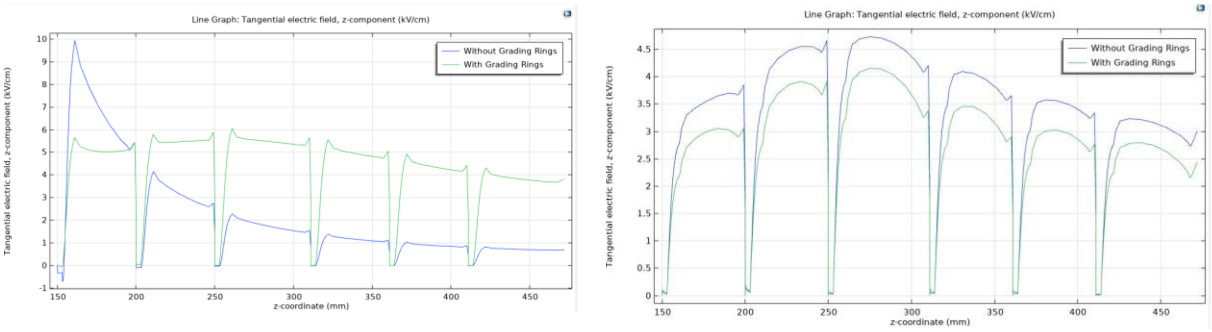
Table 1 shown these dimensions were constructed and analyzed using COMSOL Multiphysics to evaluate the electric field performance and ensure reliability in high-voltage outdoor applications.

Table 1 *Parameter of insulator*

Description	Parameter (mm)
Length of insulator	1150
Diameter of end fitting	24
Diameter of core rod	12
Thickness of shed	3
Diameter of shed	48
Distance of each shed	50
Diameter of the grading ring	30
Distance of the grading ring from the end	150

3.2 Tangential electric field with and without grading ring

Fig. 3 shows the electric field without the grading ring exhibits higher peaks, reaching up to 10 kV/cm, and shows more significant fluctuations along the z-coordinate. In contrast, the addition of the grading ring markedly reduces these peaks to lower values and stabilizes the electric field distribution, resulting in a smoother and more uniform field. While for Fig. 3(b), under polluted environments the electric field exhibits higher peaks, reaching up to approximately 4.5 kV/cm and the presence of the grading ring significantly reduces these peaks to around 4 kV/cm. This outcome stabilizes the electric field distribution, resulting in a smoother and more uniform field.



(a) **(b)**

Fig. 3 *Tangential electric field along insulator (a) dry-clean insulator; (b) polluted insulator*

3.3 Tangential electric field with grading ring distance from core rod

Fig. 4 shows the graph of tangential electric field, z-component (kV/cm) for difference grading ring distance from core rod. As the Fig. 4 shows the line graph with a 100mm distance exhibits the highest peak electric field values. The field intensities reaching up near to 10.0 kV/cm, which may suggest a stronger electric field stress in this configuration. While the initial design of 175mm radius of grading ring shows a more moderate peak electric field of about 6.0 kV/cm, with a smoother and more uniform distribution along the insulator length. The 250mm configuration, exhibits the lowest overall electric field intensities, with a maximum peak of about 5.80 kV/cm. It can be concluded as the grading ring is closer from the core rod, the more localized the electric field becomes that may leads to higher peak values and by increasing the distance it may allow the electric field to spread more uniformly.

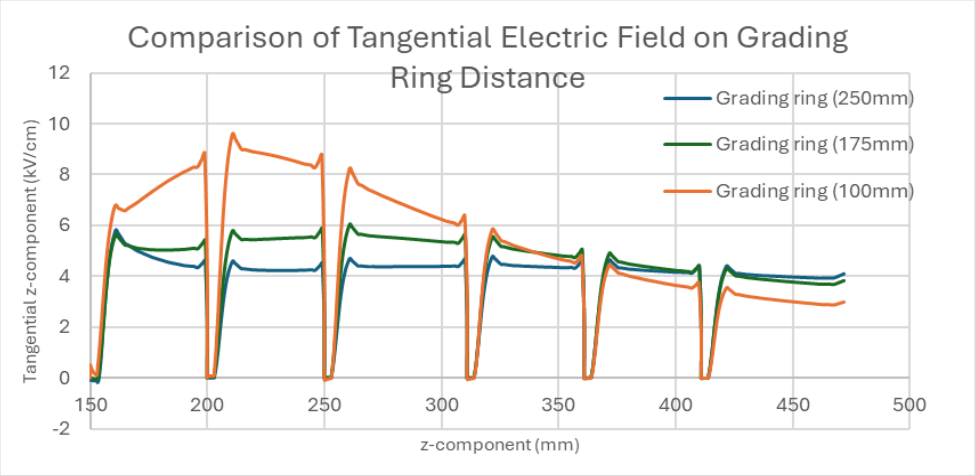


Fig. 4 *Comparison graph of tangential electric field, z-component (kV/cm) for difference grading ring distance from core rod*

3.4 Tangential electric field with different grading ring radius

Fig. 5 shows th***e*** graph of tangential electric field, z-component (kV/cm) for difference grading ring radius. Fig. 5 shows the smallest grading ring radius which is 5mm produces the highest peak electric field values approximately 6.5kV/cm. Indicates that it is less effective at controlling field stress leading to higher stress concentrations near the terminal that could increase the risk of insulation failure. While for 15 mm radius demonstrates better performance by lowering the peak field values by 5.4kV/cm. The 25 mm radius grading ring achieves the best results among the others grading ring, significantly reducing the peak electric field intensity to the 4.8kV/cm. Based on the comparison result of the findings highlight, increasing the grading ring radius leads to better electric field management, with the 25 mm radius offering the most optimal performance.

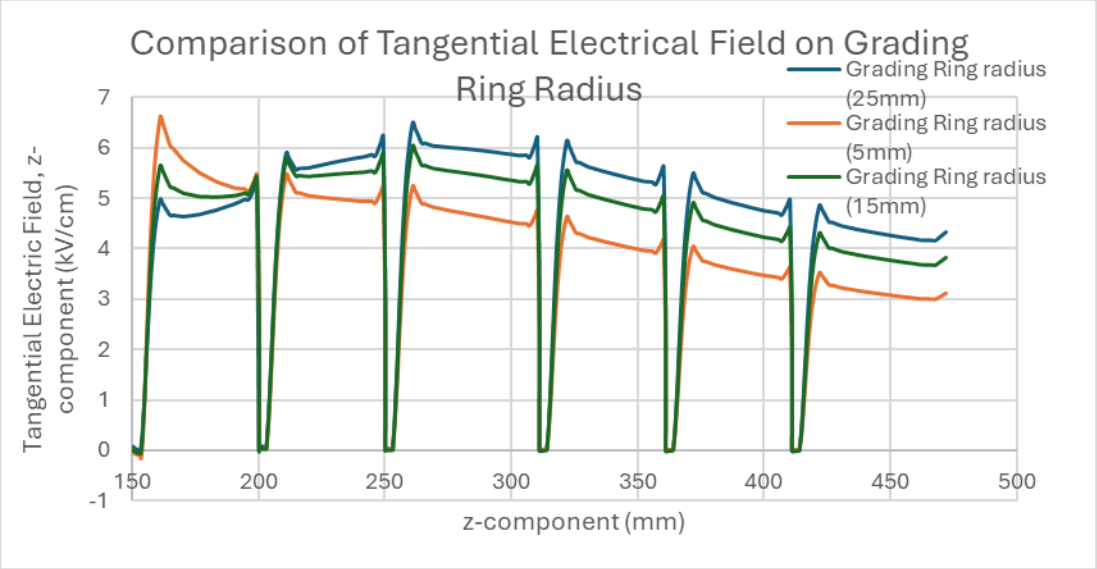


Fig. 5 *Comparison graph of tangential electric field, z-component (kV/cm) for difference grading ring radius*

3.5 Analysis on optimized grading ring design

Fig. 6 shows a graph of tangential electric field, z-component (kV/cm) for difference grading ring radius and distance from core rod. Fig. 6 shows comparison graph for two grading ring configurations which is with a 25 mm radius and 250 mm distance from the core rod and another with a 15 mm radius and 175 mm. The grading ring with a smaller radius and shorter distance (15 mm radius and 175 mm distance) produces higher peak electric field values and sharper variations along the insulator. In contrast, the grading ring with a larger radius and greater distance (25 mm radius and 250 mm distance) significantly reduces the peak electric field values and achieves a smoother, more uniform field distribution. The larger radius helps cover a broader area, while the increased distance allows for better field redistribution along the insulator, minimizing stress concentrations and improving performance.

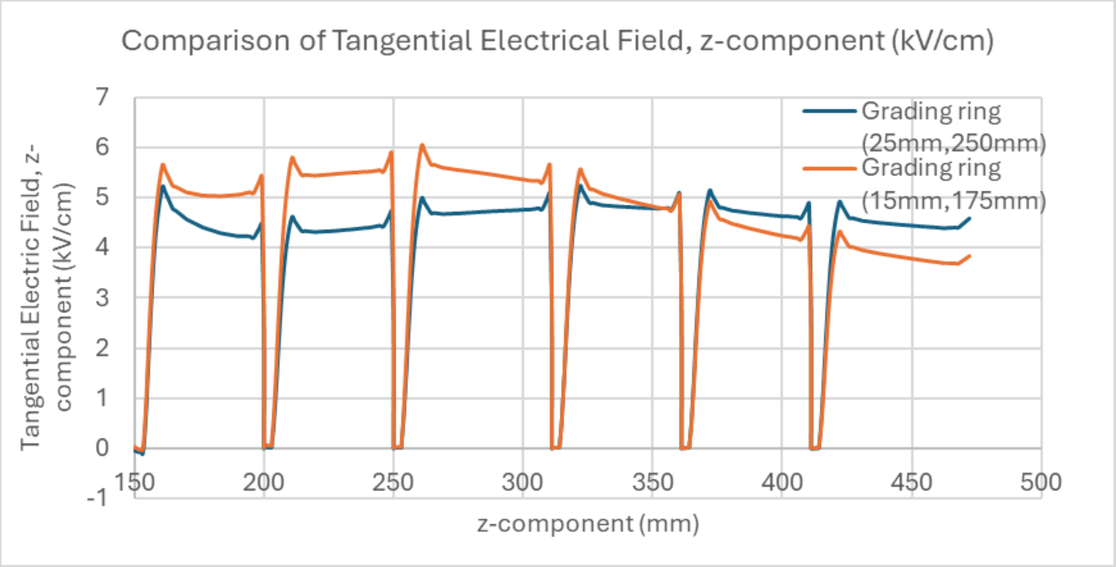
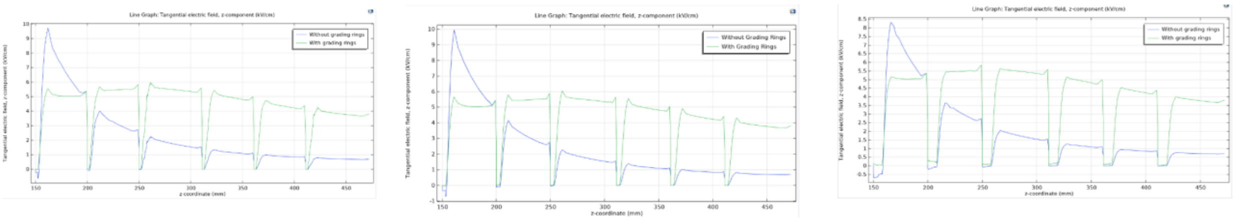


Fig. 6 *Comparison graph of tangential electric field, z-component (kV/cm) for difference grading ring radius and distance from core rod*

3.6 Tangential electric field with different thickness of weather shed

Fig. 7 shows a Tangential electric field along insulator with different thickness of weather shed (a) 2mm, (b) 3mm, (c) 8mm. As the 2mm weather shed it indicate significant stress concentrations of electric field without grading rings reaches high peaks of approximately 10 kV/cm. Addition of grading rings reduces these peaks to about 5.5 kV/cm and smoothens the field distribution that shows their effectiveness in controlling field stress. While for initial design of 3mm weather shed, the peak field values without grading rings are slightly lower around 9.8 kV/cm that demonstrating some improvement with increased thickness. The 8mm weather shed exhibits the lowest peak values among the configurations, with approximately 8.5 kV/cm without grading rings. By addition of grading rings reduces these peaks to around 5 kV/cm, achieving the most uniform field distribution.



(a) **(b)** **(c)**

Fig. 7 *Tangential electric field along insulator with different thickness of weather shed (a) 2mm, (b) 3mm, (c) 8mm*

3.7 Analysis and Comparison on Initial Design of Insulator and Optimized Weather Shed with Grading Ring

Fig. 8 shows a graph of tangential electric field, z-component (kV/cm) for difference design of shed and corona ring. Based on Fig. 8 analysis of the tangential electric field for the three different insulator configurations highlights the impact of shed thickness and grading ring design on electric field stress control. For the first configurations, the shed thickness of 3 mm and a grading ring of 15 mm radius positioned 175 mm from the core rod. These peaks reach a maximum intensity of approximately 6 kV/cm, indicating areas of high electric field stress, which could increase the risk of partial discharge or surface degradation. This configuration shows the least uniform field distribution among the three designs, primarily due to the smaller radius and closer placement of the grading ring, which limits its ability to distribute the field effectively. As the second configuration, with shed 3mm, grading ring radius of 25mm, and 250mm distance from core rod. It improves the electric field distribution and reducing the maximum tangential field intensity to about 5 kV/cm. The larger grading ring radius and increased distance allow for better distribution of the electric field, enhancing uniformity along the insulator surface. As the last configuration, it achieves the maximum tangential electric field approximately 5 kV/cm that almost same as the second configuration.

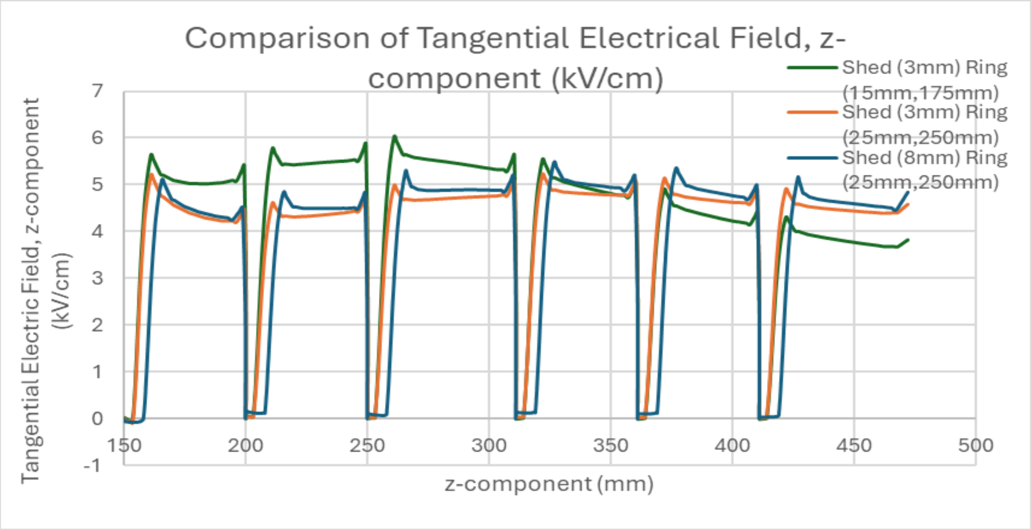


Fig. 8 *Comparison graph of tangential electric field, z-component (kV/cm) for difference design of shed and corona ring*

As the conclusion, the comparison between each design reveals that increasing both the shed thickness and the grading ring radius, while positioning the grading ring further from the core rod, significantly improves electric field stress control. The second configuration is recommended as the optimal design due to its superior performance in reducing field peaks and achieving a more uniform field distribution. This design is particularly suitable for minimizing stress under high-voltage conditions, ensuring the reliability and longevity of polymeric outdoor insulators.

4. Conclusion

Finally, the initial design of the polymeric outdoor insulator was analysed and optimized using finite element software, specifically COMSOL Multiphysics, as the simulation platform. The project focused on modifying the corona ring and shed parameters to enhance electric field stress control. The primary goal was to analyse and compare various insulator designs to identify the one with superior electric field management. Through the optimization process, it was proven that the final design effectively reduces electric field stress along the insulator, demonstrating a decrease in peak stress to 5.5 kV/cm with grading ring. This improvement was achieved by increasing the shed thickness and the grading ring radius, as well as positioning the grading ring further from the core rod.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: study conception and design: Muhammad Shazwan Haslan, Rahisham Abd Rahman; data collection: Muhammad Shazwan Haslan; analysis and interpretation of results: Muhammad Shazwan Haslan, Rahisham Abd Rahman; draft manuscript preparation: Muhammad Shazwan Haslan, Rahisham Abd Rahman. All authors reviewed the results and approved the final version of the manuscript.

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