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Electric Field Mitigation for String Insulators using Corona Ring and Zinc-Oxide (ZnO)

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Abstract: The simulation results of the electric field distribution along cap and pin insulators on various mitigation techniques under dry-clean and polluted conditions are presented in this paper. The behavior of the electric field along the insulator string is examined using the finite element method (FEM). For this study, the modeling and execution of the electric field analysis are done using COMSOL Multiphysics version 6.0. In this study, the effectiveness of corona rings and Zinc-Oxide (ZnO) micro-varistors as tools for reducing the increase in electric field intensity was investigated. To investigate the impact of pollution and mitigation strategies on the distribution of the electric field on the surface of the insulator, reference data from dry-clean conditions were used as the benchmark. It was found that the application of combined methods of corona rings and ZnO is the best scheme for stress control as it reduced the electric field intensity up to almost 3% for both dry-clean and polluted conditions.

Keywords: Finite Element Method (FEM), Zinc-Oxide (ZnO)

1. Introduction

The insulator or insulator string is one of the important parts of the transmission line. The purpose of the insulator is to prevent the flow of an electric current. The function of the insulator string in a transmission line is to provide the necessary clearance between line conductors, conductors to ground, and between conductors to tower [1]. The transmission line in Peninsula Malaysia operates from as low as 132 kV up to as high as 500 kV system. The engineers must ensure that the system operates and delivers the best quality to the consumer [2].

At the High Voltage string insulator, the top of the string insulator will be connected to the cross arm of the tower (Low Voltage terminal), while the bottom of the insulator is connected to the conductor line (High Voltage terminal) [1]. The conductor will carry a High Voltage which will create a high electric field around the conductor. Hence, there will be a variation of the electric field between the HV terminal and the LV terminal. So, this can lead to partial breakdown or tracking breakdown if the electric field intensity is higher than the insulation properties of the string insulator [3]. Knowing that the electric field control had to be done to avoid the breakdown. The electric field control can be done by reducing

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or mitigating the electric field intensity along the string insulator. Corona ring or ZnO can be used to mitigate the electric field [1]. To use the corona ring or ZnO, the ideal size, thickness, and location to put the things need to be designed to make sure it is suitable to the system. There is also a possibility where the combination of both the corona ring and ZnO can be added to the string insulator to reduce the electric field better than each of them separately.

2. Materials and Methods

This section described the method and technique used in this study to mitigate the electric field intensity along string insulators using corona rings and Zinc-Oxide (ZnO) in COMSOL Multiphysics 6.0.

2.1 Materials

Table 1 shows the material properties used in this study. The insulator model uses seven different types of materials: glass, concrete, steel, sodium chloride, zinc oxide, aluminum, and air. Glass is used as the dielectric material to create isolation between the lines and the ground terminal. The relative permittivity and electric conductivity of each material vary. NaCl was selected for the analysis of the polluted condition and has a relative permittivity of 60. One of the typical contaminants that can be found on the surface of an insulator is NaCl. ZnO's relative permittivity in this study is 12.

Table 1: Material properties

Material	Relative Permittivity, (ε_r)	Electric Conductivity, (σ)
Glass	4.2	0
Concrete	15	1.0×10^{-4}
Steel	2	10.1×10^{6}
Air	1	0
NaCl	60	5.5×10^{-6}
ZnO	12	0
(Aluminum)	N/A (conductor)	35.5×10^{-6}

2.2 Methods

This section explains the proposed methodology for designing and analyzing the electric field mitigation along string insulators for dry-clean and polluted conditions using corona ring and Zinc-Oxide (ZnO). COMSOL Multiphysics 6.0 software was used to design each part of the string insulator which used Finite Element Analysis (FEA) to analyze the electric field distribution around the area of interest. The cap and pin glass insulator of 8 units was modeled with a voltage rating of 132 kV. Each of the cap and pin height is 146 mm. The glass insulators consist of two main components; the metal end fittings and dielectric material. The insulator was modeled according to the technical data of the standard insulator [4]. The configuration height, H of the insulator is 1168 mm for a total of 8 units of disc insulator, the disc radius, r is 126 mm and the creepage length of the insulator is 216 mm. These parameters are still in the range of the standard insulator.

One end of the string insulator is connected to the transmission line (high voltage) at the bottom of the insulator, and the other end is connected to the tower at the top of the insulator. (ground). Glass is used as a dielectric material to isolate the line terminal from the ground terminal. At the high voltage terminal, 132 kV was applied. A model insulator with labels for each boundary is shown in Figure 1. Since there is no initial voltage or 0V, the LV terminal can be regarded as being at ground zero. Steel, which is used to make the core rod, is a conductor of electricity

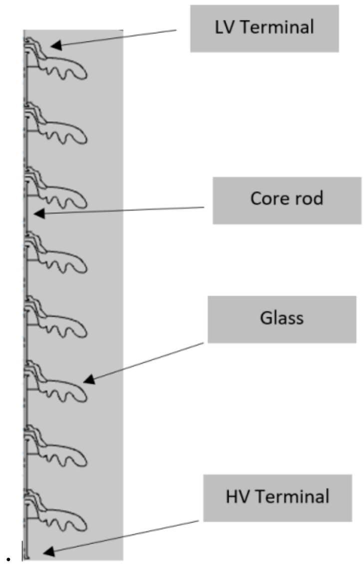

Figure 1: Boundary condition of the model

To simulate the worst-case scenario of pollution accumulation, the pollution model shown in Figure 2 is placed on top of each surface of an insulator disc. The relative permittivity of the material chosen for the pollution analysis was 60 for NaCl. COMSOL Multiphysics 6.0 was used to simulate this condition for the study. When the pollution level is higher, the layer might be thicker.

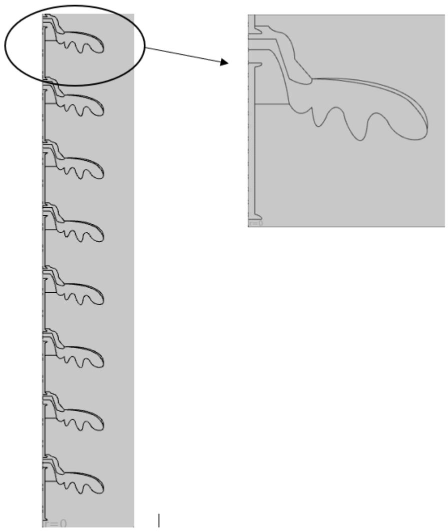

Figure 2: Pollution layer modeling

Corona ring and Zinc-Oxide micro-varistor are the methods that have been used to reduce electric field intensity at critical points. ZnO micro-varistors are applied at both ends of the insulator since they are the places where the electric field is at the highest [1], [5]. The same goes for the design of the corona ring, it is usually applied at high voltage terminal and low voltage terminal (ground). The material recommended for use in the corona ring is aluminum [6]. The model of Zinc-Oxide and corona rings is shown in Figure 3 and Figure 4. The visual combination of ZnO micro-varistor and corona rings is depicted in Figure 5. This method used the same installation of corona rings and the ZnO layer as the previous model to distribute the electric field along the string insulator better.

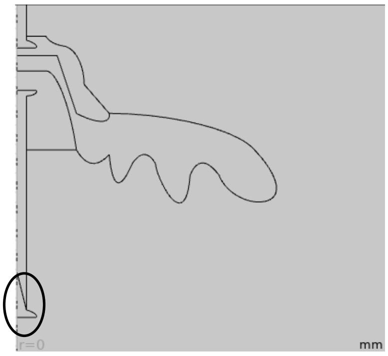

Figure 3: Zinc oxide model

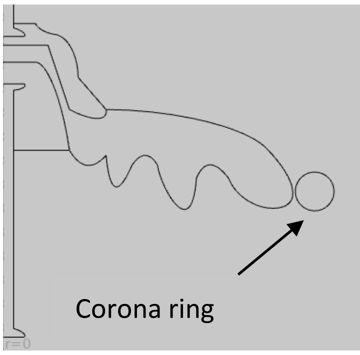

Figure 4: Corona ring model

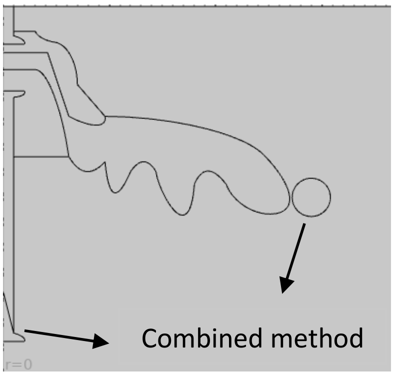

Figure 5: Combined method model

3. Results and Discussion

The computational results of the dry-cleaned and polluted conditions with and without stress reduction techniques are shown in this section. The dry-clean condition must be analyzed first because it will be a source of reference information. It will also determine the impact of pollution on the distribution of the electric field and the efficiency of stress reduction techniques used on the insulator. Additionally, this section will compare and discuss the analysis of the dry-cleaned and polluted conditions, both with and without stress management techniques.

3.1 Results

The analysis of dry-clean conditions, polluted conditions, and mitigation methods on 132 kV-rated insulators is discussed in this section. The computation results of electric field intensity were divided into (10) sections; near LV, shank 1, shank 2, shank 3, shank 4, shank 5, shank 6, shank 7, shank 8, and near HV. The separation was created to observe how the electric field behaves along the insulator surface in the absence of pollution and stress reduction techniques. It is also to identify which shank will have the highest maximum electric field intensity so that the data can be used for the application of stress control later.

Table 1: Results of electric field intensity with and without ZnO

Surface region	Dry-clean condition (kV/m)	Dry-clean condition with ZnO (kV/m)	Polluted condition (kV/m)	Polluted condition with ZnO (kV/m)
Near LV	1928.1	1926.5	4165.1	4174.1
Shank 1	1263.2	1262.4	1102.5	1105.5
Shank 2	497.3	497.2	494.4	494.4
Shank 3	206.9	207.3	215.1	215.1
Shank 4	141.2	141.1	149.7	149.7
Shank 5	128.3	128.7	136.9	137.5
Shank 6	154.1	154.4	161.8	161.9
Shank 7	273.8	273.8	275.1	275.4
Shank 8	2083.5	2083.7	2164.6	2165.4
Near HV	9651.8	9421.6	9709.8	9520.2

Table 2: Results of electric field intensity with and without corona ring

Surface region	Dry-clean condition (kV/m)	Dry-clean condition with corona ring (kV/m)	Polluted condition (kV/m)	Polluted condition with corona ring (kV/m)
Near LV	1928.1	1926.4	4165.1	4166.1
Shank 1	1263.2	1265.4	1102.5	1109.8
Shank 2	497.3	497.4	494.4	494.5
Shank 3	206.9	207.1	215.1	214.9
Shank 4	141.2	140.9	149.7	149.7
Shank 5	128.3	128.7	136.9	137.3
Shank 6	154.1	154.5	161.8	161.9
Shank 7	273.8	273.9	275.1	275.4
Shank 8	2083.5	2082.8	2164.6	2165.5
Near HV	9651.8	9417.6	9709.8	9574.6

Table 3: Results of electric field intensity with and without combined method

Surface region	Dry-clean condition (kV/m)	Dry-clean condition with combined method (kV/m)	Polluted condition (kV/m)	Polluted condition with combined method (kV/m)
Near LV	1928.1	1925.1	4165.1	4174.2
Shank 1	1263.2	1236.5	1102.5	1082.4
Shank 2	497.3	497.6	494.4	494.4
Shank 3	206.9	206.9	215.1	215.4
Shank 4	141.2	141.6	149.7	149.8
Shank 5	128.3	128.7	136.9	137.1
Shank 6	154.1	154.4	161.8	161.9
Shank 7	273.8	273.9	275.1	275.4
Shank 8	2083.5	2083.2	2164.6	2165.3
Near HV	9651.8	9385.7	9709.8	9515.6

3.2 Discussions

Table 1 summarizes the dry-clean insulator analysis and the plotted distribution of the electric field in each section. The maximum electric field, for each section, were obtained as 1928.1 kV/m in LV terminal, 1263.2 kV/m in shank 1, 497.3 kV/m in shank 2, 206.9 kV/m in shank 3, 141.2 kV/m in shank 4, 128.3 kV/m in shank 5, 154.1 kV/m in shank 6, 273.8 kV/m in shank 7, 2083.5 kV/m in shank 8 and 9651.8 kV/m in near HV. This analysis demonstrates that near HV is the most important component because, as predicted, it generated the highest electric field intensity (9651.8 kV/m).

Outdoor insulators in real life are constantly exposed to pollution and are negatively impacted by it. The natural environment's wet pollution of the surface will also have an impact on the distribution of the electric field. When the pollution dried, the dry bands significantly altered the distribution of the electric field, which could result in partial discharge, also known as premature breakdown. [1], [7]. This typically occurs at vulnerable locations with strong electric fields. The increase in electric field strength on the insulator surface was caused by the pollution effects that NaCl is used to simulate. Except for shank 8, near the HV, and much more near the LV, as shown in Table 1, there is not much increment in other sections.

The results of the electric field from the ZnO micro-varistor's effect on dry-cleaning and polluted conditions are also shown in Table 1. The outcomes unequivocally demonstrate ZnO's efficacy in both situations. The HV terminal's voltage was lowered to 9421.6 kV/m for dry-cleaning conditions from 9651.8 kV/m previously. ZnO application reduced the HV terminal's voltage from 9709.8 kV/m to 9574.6 kV/m for polluted conditions. This study demonstrates that ZnO can be used to reduce stress in both dry-clean and polluted environments. The electrical stress along the string insulator can be reduced and redistributed by ZnO.

Corona ring's impact on dry-cleaning and polluted conditions is shown in Table 2. In the dry-clean condition and the polluted condition, it was observed that the electric field distribution had improved by 1.02% and 1.01%, respectively. The corona rings increased the electric field intensity at shank 1 while decreasing the electric field at HV terminals in dry-clean and polluted conditions. Electric field strength increased for the dry-clean condition from 1263.2 kV/m to 1265.4 kV/m and for the polluted condition from 1102.5 kV/m to 1109.8 kV/m. It has been demonstrated that corona rings can reduce the electric field's intensity while also appropriately redistributing stress along the insulator's surface.

Table 3 shows the effect of the combination of ZnO micro-varistor and corona ring towards electric field intensity along the string insulator. It seems that combined methods are working extremely well under dry-clean and polluted conditions since this model reduced the most electric field intensity at the HV terminal compared to other models. For dry-clean conditions, the HV terminal was reduced from 9651.8 kV/m to 9385.7 kV/m. While for polluted conditions, the HV terminal was reduced from 9709.8 kV/m to 9515.6 kV/m.

4. Conclusion

The effectiveness of the techniques used to control the stress caused by the electric field intensity along the string insulator has been demonstrated. Two techniques had been simulated, and the distribution of the electric field had improved as expected. This study also provides information on the area with the highest electric field stress, which will be the area where the breakdown will most likely occur. The simulation illustrates how pollution, such as salt formation, affects the intensity of the electric field along a string insulator. In light of the findings of this study, it is advised to combine the use of corona rings and Zinc-Oxide (ZnO) micro-varistor to improve the distribution of the electric field along the string insulator, as this combination has the greatest success in reducing the intensity of the electric field at critical locations.

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