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Electric Field and Current Density Characteristic of Contaminated Solid Insulator

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Abstract: The performance of an insulator may degrade over a time period. One of the main factor is due to presence of contamination on the insulator which leads to flashover, corona and damages the insulator. This study focuses on overhead XLPE cables used in distribution system with voltage rated 33kV. The contaminants are varied in order to study the behaviour of electric field and current density of the XLPE insulator. Contaminant used in this study is sodium chloride, lead and rain water. Quickfield software was used to draw and simulate the contaminated cable. The electrical conductivity of cable and contamination was used to represent every layer of the drawing. From the result produce, analysis on the electric field and current density of a contaminated and non-contaminated insulator was made. Analysis shows that the contaminated insulator has higher electrical field and current density compared to non-contaminated insulator. When the electrical conductivity is high, the electric field is the lowest and the current density is the highest in an insulator. Whereas, the XLPE insulator with sodium chloride contamination has the highest current density followed by rain water and lead due to highest conductivity of sodium chloride. The electric field strength of lead is the highest followed by rain water and sodium chloride.

Keywords: Electric field, Current density, contamination, insulator

1. Introduction

In recent years, research investigating the factors that affects the life span of solid insulator has focused on XLPE cables. Medium voltage insulator is used extensively in power transmission and distribution industry. However, they are exposed to various types of contaminants. These contaminants can range from sea salt to cement dust and various type of fertilizers used for agriculture purpose [1]. The type and level of pollution have been widely investigated by researcher [2]. They have discussed on the severity of the pollution according to different weather and the sources that produce them. When the particles from contaminant settle on the surface of the insulator and combine with the fog, mist or rain, the insulator begins to degrade. In other words, the pollution degrades the insulators and affects severely to their electric characteristics.

Organic peroxides such as DCP (di cumyl peroxide) polyethylene builds XLPE cable. The combination of polyethylene at high temperature and inert gas atmosphere that produces a chemical action converts thermoplastic polyethylene into thermosetting (elastomer) polyethylene or XLPE. XLPE cable has excellent electric performance. The dielectric loss should be smaller than paper insulation and insulation of PVC [3]. HVDC XLPE possesses high volume resistivity, high dielectric strength, long DC lifetime and low space charge accumulation [4], and the permissible conductor temperature of XLPE cable is higher than the paper insulated cable [4]. The maximum operating temperature can be as high as 90°C [5].

Contamination on insulator surface such as water or mist leads to formation of a conductive layer. Electric field causes leakage current to be driven along the wet insulator surface. The flow of leakage current along the insulator surface leads to surface heating, dry band formation, partial arcs and under certain conditions leads to flashover [6]. The presence of contamination on the medium voltage cable causes the electric field intensity and current density to increase.

The objective of this study is to analyse the electric field and current density characteristic when there is a layer of contaminant on the XLPE cable. Different contaminant has a different value of electrical conductivity. In this study, we have used three different types of contaminant to investigate which contaminant has the highest current density and electric field. The electric field distribution is increased with the volume resistivity. However, the conductivity has a close relationship with electric field and temperature, whose change would cause a change of the conductivity distribution of XLPE insulation, as well as the electric field. The relationship mentioned above indicates the difficulties in the study of field distribution in XLPE insulation [7].

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The findings of this study help us understand that contamination layer on the insulator cable will lead to degradation of cable. Besides that, different contaminations possess different electrical conductivity which will lead to different value of electrical field and current density that affects the XLPE cable.

2. XLPE Cable and Contamination Model

Cable voltage can be as high as 600kV [8], and the power rating as high as 1500MW [9]. HVDC system is that it is more applicable in long-distance power transmission, it is with lower power loss than HVAC transmission for the same power capacity [10], and long distance transmission can possibly compensate the weakness that HVDC system with higher expenses due to the construction of converters and inverters [11], [8]. In this study, the voltage that a cable carries, type of insulation and number of core varies between the types of cables. In this paper, 33kV single core XLPE insulated cable is used. Professional software is adopted to simulate the distribution of current density and electric-field along the insulator surface with and without the presence of contaminants [12]. The drawing of 2D modelling for the contaminated XLPE insulated cable as shown in Figure 1 that is drafted using Quickfield 6.1 Student Version. DC conduction is selected to study on the characteristic of electric field and current density of contaminated solid insulator. Dc conduction problem type enables the model to simulate electric field and current density based on the type of contaminants.

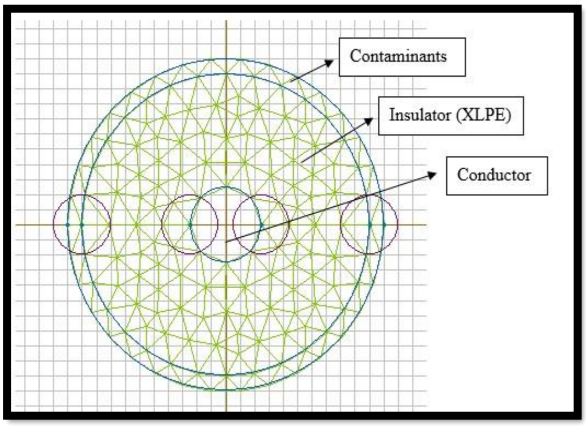

Fig. 1 Cross-sectional area of XLPE cable.

2.1 Simulation Parameters and Method

In this study, the model has been design based on the given dimension of the XLPE insulated cable that is being used for 33kV medium voltage overhead lines. The model was built using Quickfield software. Quickfield Software is a finite element analysis software package running on Windows platforms [13]. It is later simulated to obtain the electric field and current density performance of different type of contaminants. A complete design of a contaminated XLPE insulated cable are divided into several layers which is the contaminant layer, insulation layer and the conductor layer. Each layer has their own specification and dimension which is summarized in Figure 2.

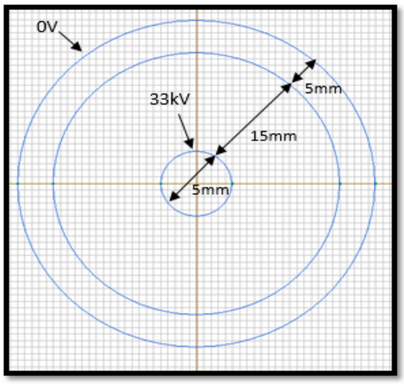

Fig. 2 Size and dimension of XLPE insulator.

The pollution can be caused by a great variety of sources [14]. The presence of contaminants on the surface of the insulator causes a formation of layer. The leakage current is said to be high through the insulator when the resistance diminishes as the contaminated layer is dampened [15]. Thus, the temperature of the contaminant layer is increased which leads to damaging left over resistance. The resistance diminishes completely when the temperature reaches boiling point which begins to lose humidity [16]. From this point the layer of resistance begins to enlarge until it’s totally dried. It will then reach the maximum value of resistance. This phenomenon is a lot more feasible in narrow parts of the insulator where the density of current is higher. The increase in resistance causes the current to decrease, but its formation implies that most tensions applied to the insulator appear through the resistance by being humid at the remainder layer. An increase of contaminants produces the increase in the leakage current which increases the flashover of the insulator [2][17]. The materials and conductivity used for the simulation is summarized in Table 1. In this study, rain water, lead and sodium chloride is used as contaminant.

Table 1 Materials and conductivity for electric field and current density computation

Part	Material	Conductivity (S/m)
Conductor	Copper	5.98×10^{7}
Insulator	XLPE	4×10^{-8}
Contaminants	Rain water	0.01
	Lead	4.87×10^{-6}
	Sodium Chloride (Salt)	22.2

The concept of current density should play an important role in electrical insulation studies as the insulation problem of HV system is due to the contamination of insulator [18]. The surface conductivity of an insulator is usually strong influenced by the local environment on the insulator [19], [20]. Equation (1) has been used to calculate the electric field and current density in the cable insulation and in the cavity by using finite element method. The electric field and current density of the contaminated insulator that is obtained from the simulation can be studied from the equation as the electric field and current density value differs as the electric conductivity of the contaminant varies. When the electric conductivity of the contaminant is high, the current density of the insulator will be high and the electric field is low. The equation governing the electric field computation [21]:

$$J = \sigma E \tag{1}$$

J: is the current density (A/m2).
σ: is the electric conductivity of dielectric material.
E: is the electric field strength (V/m).

The electric strength of the high voltage cable is affected by the presence of contaminants in the insulating part [22]. The contaminant is introduced into the model cable insulation to investigate the effect of contaminant presence on the XLPE electrical field insulation system. The electric field intensity is obtained from the negative gradient scalar potential. The relationship equation of E and V is as follows [23]:

$$E = -\nabla V$$

3. Results and Discussion

The simulation results of medium voltage XLPE insulated cable displays the concentration of current density and electric field at each layer of the cable. The colour map displays the level of concentration of current density and electric field which can be referred from the legend right next to the colour map. Simulation is conducted with three different contaminants. From result obtained, the electric field and current density strength is the highest at the conductor and it slowly reduce as it reaches the contamination layer. The legend that display colours shows that the red colour indicates high electric field and current density. Figure 3 and Figure 4 shows the simulation of XLPE insulated cable without any contaminants on it. In Figure 3, the red colour displays highest current density in the cable which is nearest to the conductor. Whereas, the blue colour shows the lowest current density which is closer to ground. The maximum value of current density, J is 0.2830A/m2. Figure 4 shows the electric field strength when it is not contaminated.

The electric field strength is the strongest at the middle which is nearest to the conductor. The blue colour represent the lowest electric field strength which is nearest to the outer layer of the cable. The maximum value of electric field, E is 7.080MV/m.

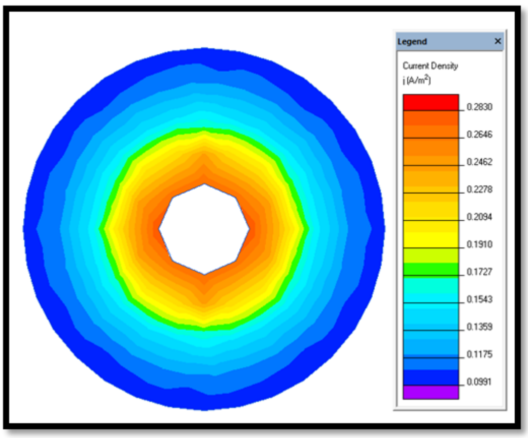

Fig. 3 Colour map and legend of current density without any contaminant.

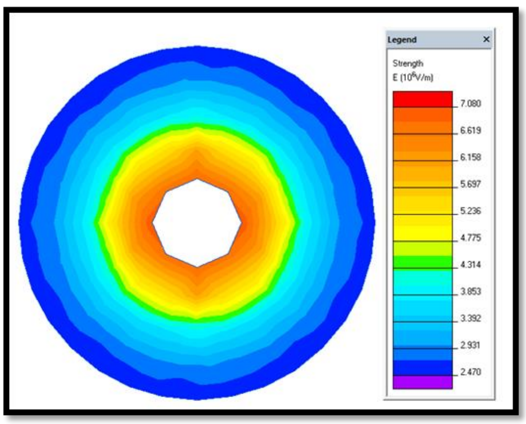

Fig. 4 Colour map and legend of electric field without any contaminant.

Figure 5 and Figure 6 shows the colour map and legend for both electric field and current density with presence of rain water contaminant. Figure 5 shows the current density when the XLPE cable is contaminated with rain water. The current density is the highest in the middle and reduces along the cable. Purple colour shows that there is zero current density which is on the contaminated layer. The maximum value of current density, J is 0.2830A/m2. Figure 6 shows the electric field strength when rain water is presence on it. The electric field strength is the highest near the conductor and the lowest at the outer most layer. The maximum value of electric field, E is 7.070MV/m.

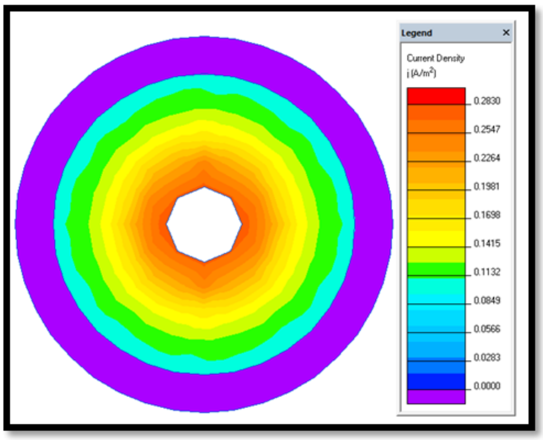

Fig. 5 Colour map and legend of current density with presence of rain water.

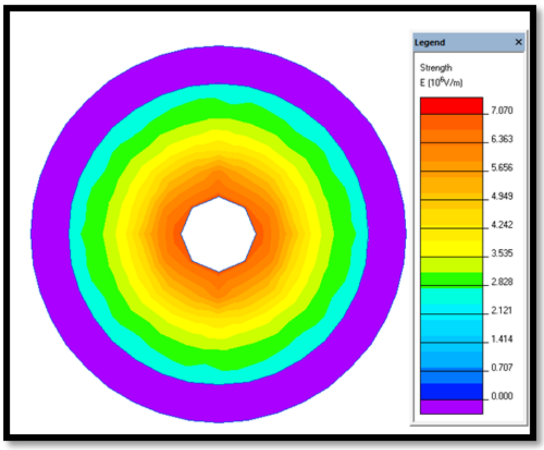

Fig. 6 Colour map and legend of electric field strength with presence of rain water.

Figure 7 and Figure 8 shows the result display in graph form for the electric field and current density of the non-contaminated XLPE cable. The electric field and current density decreases gradually. The measurement is obtained from the starting point of conductor and ending point of XLPE insulated layer.

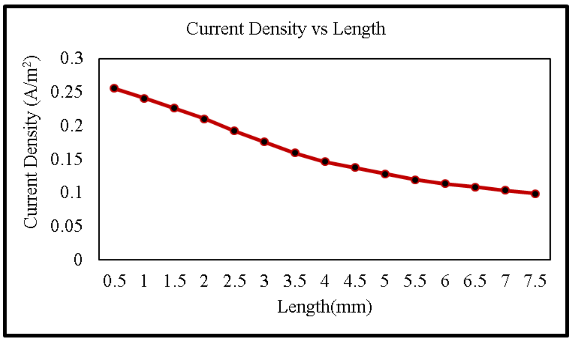

Fig. 7 Current density without contaminant

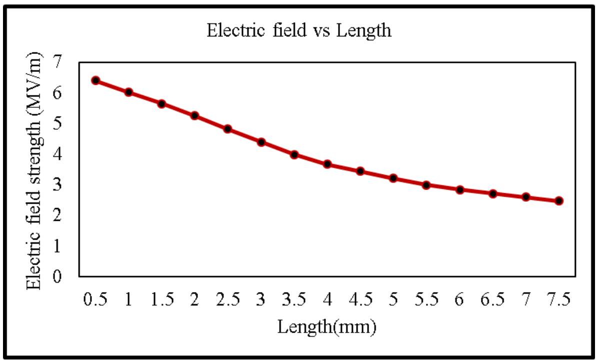

Fig.8 Electric field without contaminant.

Based on Figure 9, the graph shows the current density decrease gradually from the starting point which is conductor to end point contamination which is rain water. From the graph, the current density is the highest at the layer which is closest to the conductor. Whereas, the current density in the insulation layer is moderate and followed by the contamination layer. It shows that, the current density is zero at the layer of contamination. So as the behaviour of electric field. Figure 10 shows the graph for electric field characteristic with presence of rain water as contamination.

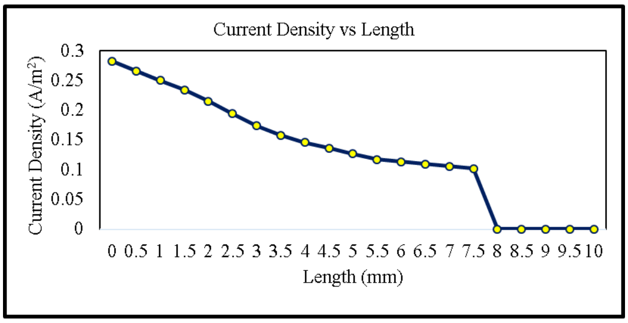

Fig.9 Current density with presence of rain water.

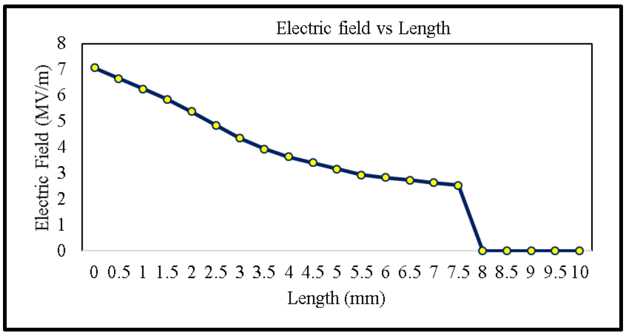

Fig.10 Electric field strength with presence of rain water

Figure 11 shows the graph for current density with presence of lead as contamination. The concentration of current density decreases from conductor to layer of contamination. It shows that, the current density is zero at the layer of contamination. Figure 12 shows the electric field strength behaviour with presence of lead as contamination. The electric field strength is zero at the contamination layer.

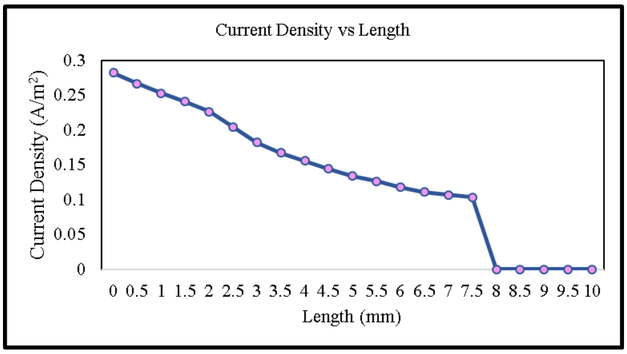

Fig.11 Current density with presence of lead.

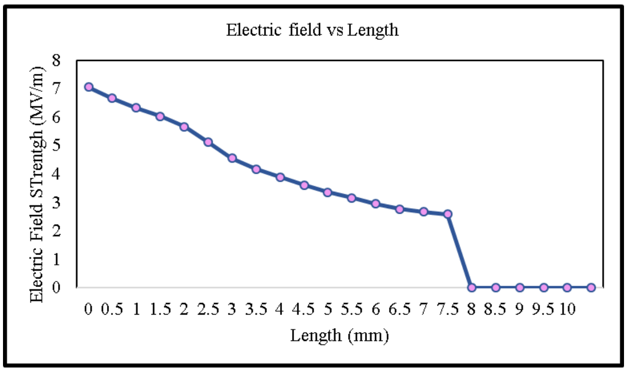

Fig.12 Electric field strength with presence of lead.

Figure 13 shows the graph for current density with presence of sodium chloride as contamination. The concentration of current density decreases from conductor to layer of contamination. It shows that, the current density is zero at the layer of contamination. Figure 14 shows the electric field strength behaviour with presence of sodium chloride as contamination. The electric field strength is zero at the contamination layer.

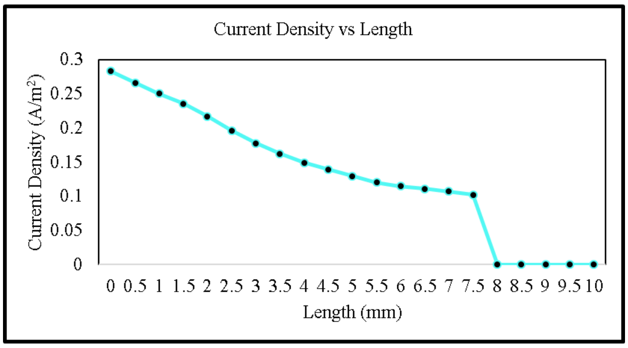

Fig.13 Current density with presence of sodium chloride.

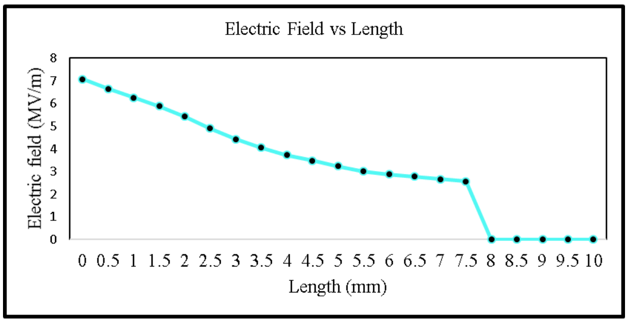

Fig. 14 Electric field strength with presence of sodium chloride.

From the graph obtained, the pattern of the graph for contaminated and non-contaminated shows almost the same result. The electric field strength and current density behaviour is slightly different in all four conditions. The multiple line graph in figure 15 displays the current density of contaminated and non-contaminated cables. The legend jr indicates the current density for rain water whereas jl indicates the current density for lead followed by js which is sodium chloride and jc is without contaminant. Figure 16 shows the electric field strength for contaminated and non-contaminated XLPE cable. The legend displays the same as current density. ES indicates the electric field for sodium chloride, EL is for lead, ER is for rain water and EC is without contamination.

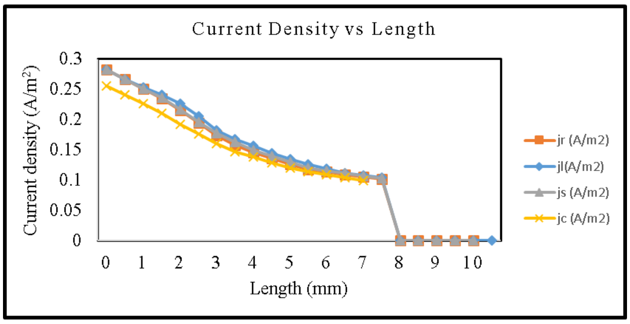

Fig.15 Comparison of current density of all conditions.

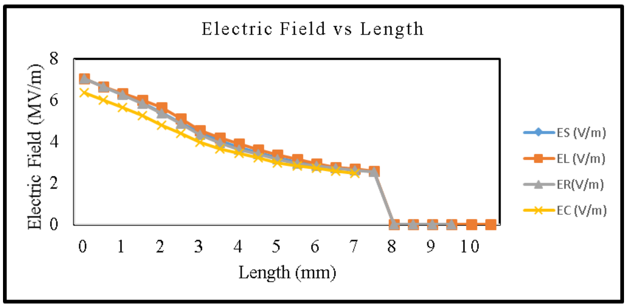

Fig. 16 Comparison of electric field of all conditions

From the data obtained, it shows that the electric field and current density decreases. Whereas, the electric field in contaminated condition is higher compare to the non-contaminated layer. Effect of pollution severity on electric field distribution was studied in [24], and it was shown that electric field intensity increases with increase in pollution severity. Besides that, it was found that the current density is also higher in contaminated condition compared to the non-contaminated condition as reported earlier by Arshad (2015) [25]. When the electric conductivity of the contamination is higher, the current density is high and the electric field is low. Based on the result obtained, sodium chloride has the highest current density compared to rain water followed by lead and vice versa for electric field. This is because the electric conductivity of sodium chloride is higher than rain water followed by lead. Table 2 shows the comparison of maximum and minimum electric field strength and current density between contaminated and non-contaminated XLPE insulated cable.

Table 2 Comparison between electric field and current densities at contaminated and non- contaminated Medium Voltage XLPE insulated cable

Condition of Medium Voltage XLPE Insulated cable	Electric Field, E(V/m)		Current Density, J(A/m^2)	
	Minimum (E_{min})	Maximum (E_{max})	Minimum (J_{min})	Maximum (J_{max})
Clean	2479100	6396840	0.099164	0.255874
Rain water	2553150	7073060	0.101726	0.282922
Lead	2588910	7074040	0.101557	0.282912
Sodium Chloride (Salt)	2551950	7073060	0.102478	0.282922

4. Conclusion

An attempt to simulate the distribution of current density and electric field strength for contaminated insulator using Quickfield Student Version is conducted in this paper. Medium voltage cable with rating of 33kV with XLPE insulation which is used in distribution system is taken as main research object with contaminant layer are modelled on the surface of the insulator. The type of contaminants used is sodium chloride, lead and rain water.

The simulation results show that the contaminants on the XLPE insulator affects the electric field strength and current density. The electric field and current density of contaminated XLPE insulator is higher compared to non-contaminated insulator. The contaminants varied in this research shows the difference in electric field and current density. Sodium chloride has the highest conductivity followed by rain water and lead. The current density is the highest when electrical conductivity is highest. Whereas, the electric field is the highest when the electrical conductivity is lowest. Thus, the electric field strength is the strongest in lead followed by rain water and sodium chloride. The current density is the highest in sodium chloride followed by rain water and lead.

Increasing in electric field and current density will expedite the premature aging process that may lead to flashover and result in calculated field would help in improving the insulator design especially for contaminated areas.

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