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Modelling and analysis of electrical performance outdoor glass insulator under various services and lightning impulse

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Abstract. This paper is focus on modelling of glass type insulator with voltage rating of 275 kV. The glass insulators are still widely served in overhead transmission line because of its high dielectric strength capability. However, their outdoor application has resulted in the exposure to the various service conditions such as weather, pollution and lightning conditions. Further, the inclination effect of the insulator under the nominal voltage and lightning impulse is modelling through Finite Elementary Method (FEM). Then, the model of glass insulator is constructed in three different inclination angles by using the Ansys Maxwell 3D for simulation purpose. The results show the inclined insulator due to the wind load effect has the lowest breakdown voltage at most 53.33% compared with the vertical insulator. Under the outdoor environment factors such as humid, wet and contamination, the localized electric field and current density had increased significantly. Consequently, this situation may cause the power losses, localized heating effect also reduces the electrical performance of the insulators.

1. Introduction

Insulators play an important role in the safety of high voltage transmission. In distribution system, its functioning by providing the mechanical support for the cable and it is also designed to insulate the energized cable from tower [1]. It also reduces the chances of flashover current and breakdown voltage in distribution system. Any failure of insulator may lead to short circuit and damage of high voltage equipment. There are several factors affect the performance of insulator in high voltage transmission. Inclination effect of the insulator is one of the factors will significantly bring down the performance of insulator respect to the cross arm [2]. The effect of inclination is mainly caused by the wind load action on transmission system or improper installation. The wind swings the glass insulator at different inclination angle with respect to the cross arm especially in heavy rain weather. Another problem unproper installation method which will cause the inclination to the insulator[3]. Then, the lifespan of insulation will be reduced greatly due to this effect. Figure 1 shows the inclination of the insulator respect to the cross arm[4].

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Figure 1: Inclination of insulation due to wind load

The outer insulators are exposed to the environment stresses, different weather may have different level of humidity depended on water molecules present in the air. It may affect the electrical conductivity of the air and the insulation properties of the glass insulator [5]. Moreover, the air consists of dirt, salt and chemical particles that may vary at several places. The glass insulators where nearby the sea may be suffering from salt contamination due to sea breeze. Typically, the pollution is deposited on the surface of the glass discs whereby the glass disc plays the important role in flashover protection by increasing the creepage length. Whilst, the higher contamination levels of insulator may increase the surface conductivity of glass disc and consequently reduce the creepage distance of the insulator. Therefore, this will reduce the lifespan of the glass insulator [6].
Malaysia has reported as a country which has high lightning density in the world. Many research had focused on high power transmission system to improve their safety and the performance in Malaysia [7]. The lightning may strike on insulators and causes failure in distribution line in term of direct effect and non-direct effect [8]. This failure is due to the electromagnetic effects between the lighting electromagnetic field and line conductor. Moreover, this failure is getting worst whenever the lightning strike on the inclined insulator [9]. This is because the angle of insulator might affect the distribution of electric field. Previous researcher had highlighted the significant impact of angle for outdoor insulator under the lightning impulse. Because of the electrical performance attenuation, the chance of flashover for outdoor insulators increases [2].

2. Services environment of outdoor transmission insulator

Outdoor overhead insulator is exposed to external services environment. Unlike indoor insulator, outdoor insulator is difficult to carry out inspection. Performance of outdoor insulator is also highly depended on climate and the environment.

2.1. Lightning impulse

Lightning is an electrostatic discharge produced by imbalance potential difference between clouds and the ground, or between the clouds themselves. It occurs typically during a thunderstorm. During a thunderstorm, particles inside storm clouds collide to each other. Then, the potential difference between storm clouds and the ground increases. Consequently, the accumulated negatively charge from the clouds discharge to the ground [10]. Objects on the ground, likes tree become positively charged to balance two charges in nature. In transmission system, wherever lightning strikes a point on the tower or line will cause the current and potential difference between lightning strike point and ground rise significantly. Consequently, voltage from lightning impulse which discharge in line insulator will cause the flashover or breakdown on the insulation air gap occurred [11]. In addition, the performance of a system's lightning protection is depending on lightning withstand level and the tripping rate. Generally, it refers to maximum magnitude of lightning impulse voltage (kV) that the line can resist without leading to insulation flashover under direct lightning strike. In addition, the lightning strike distance is depended on the return stroke current of the lightning. According to IEEE (1985) standard, the strike distance is:

$$S = 8 \times I\ 0.65 \tag{1}$$

S = strike distance (m)

I = return stroke current (kA)

As per IEC Standard 61000, the impulse voltage wave shape is 1.2/50 microseconds[1]. The 1.2/50 microseconds impulse wave represents a unidirectional wave which rises to its peak value from zero at 1.2 microseconds and then reduced to 50% of peak value at 50 microseconds. Figure 2 illustrates the lightning impulse waveform 1.2/50 microsecond[1].

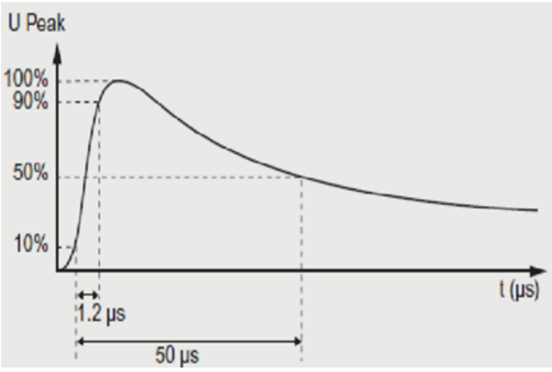


Figure 2: The 1.2/50 microsecond lightning impulse waveform[12]

2.2. Wind load and swing angle

Wind load exerted on the insulators are highly fluctuating and dynamic. According to the Malaysia standard, the maximum wind velocity value (Vs) stated is between the range of 32.5 m/s to 33.5 m/s in Peninsular Malaysia, this standard wind speed was recorded at 10m of height. However, the wind velocity at desired height is expected to increase. The maximum windspeed recorded in Malaysia is 41.7 m/s in Kuching, Sawarak while the highest daily mean speed recorded is 3.8m/s in Mersing, Johor referred to the Malaysia Meteorological Department[13]. Overhead Line tower and outdoor insulator usually subjected to the strong wind because of tall structure. Under the high wind speed, the insulator will swing away from and closer to tower body. Therefore, the inclination effect of the insulator respect to the cross arm is occurred. Notably, the windspeed is increasing with the altitude. When the insulators move towards the tower body, the clearances distance is reduced and the possibility of electrical arching and flashover is increases[14]. Several methods had been studied by previous researcher on possible swing angle for the outdoor transmission insulator under the wind load [15,16]. Figure 3 shows the inclination of the insulator in different angle.

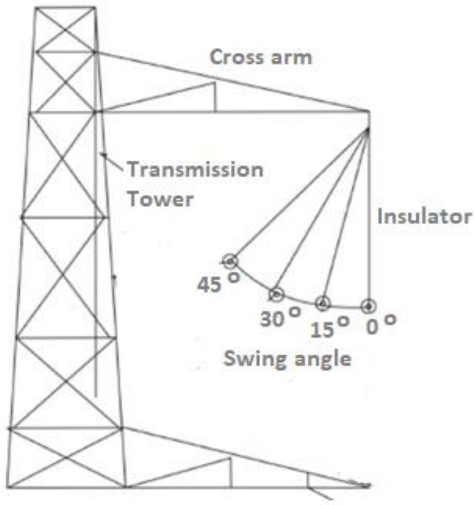


Figure 3: Swing angle of insulator

2.3. *Environment pollution*

For outdoor insulators, the contaminations effects is one of the greatest challenges. Peninsular Malaysia is surrounded by the sea. High voltage transmission system in Malaysia must pass through the area nearby the sea. Salty Wind from the sea will blow the insulator hence cause the salt precipitation on the surface high voltage insulator. This precipitate may reduce the creepage length of the insulator and lead to flashover of insulator. As a result, the flashover of polluted insulator is higher in the coastal area. The pollution effects will even be worse in humid condition [17]. According to previous research by using Finite Elementary Modelling (FEM), the contamination effect able to initiate the arching and flashover of the insulator. [18]. In fact, the type of pollution for outdoor insulator is depended on surrounding environment. Table 1 shows the common categories of insulator pollution.

Table 1: Type of insulator pollution

Type of contamination	Effects
Industrial pollution	Factory from industrial area releases the contaminants consists of smoke, dust, cement, chemical substances or conductive particles to the atmosphere. These particles spread into transmission zone by wind action. It forms a contaminant layer on glass insulator surface.
Marine pollution	The insulators exposed to coastal area will form a conductive layer on the surface. After the certain time, this thick layer is adequate to create conductive path. The level of contamination can be determined by using Equivalent Salt Deposit Density (ESDD)
Desert pollution	In desert zones, transmission system exposed to sand and dust deposition, it causes the flashover or aching. The sand moving in high speed also strike the insulator surface may cause the materials erosion. In fact, this condition is getting worst when the sand accompanied with rainy weather.
Biological pollution	The contaminants of the living organisms such as bacteria, algae are degraded on the surface of the insulator or can create a conductive layer. The oxalic acid released by algae are going to damage the insulator

	surface. This contaminant is strictly depended on the temperature and humidity

3. Model of 275kV high voltage glass insulator

Ansys Maxwell was selected to model and simulate the glass insulator by using finite elementary method. Figure 4 shows the 3D model for outdoor 275kV glass insulator.

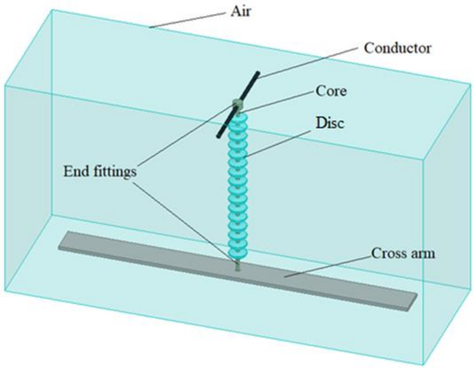


Figure 4: Model of 275kV glass insulator

In modelling part, three set of insulators were draw in different inclination condition. There were 45º, 60º and 90º of inclination angle with respect to cross arm. These angles are selected according to the possible swing angle in position of insulator with respect to cross arm of transmission line under the wind load. Besides that, the pollution effect is considered in this paper. Based on the IEC 50507, the four-standard level of the salinity are 10 g/L, 20 g/L, 30 g/L and 40 g/L. Table 2 shows the salinity level by referring to contamination of insulator.

Table 2: Salinity and pollution level for insulator

Salinity S_a (g/L)	**Pollution level**
10	Light
20	Medium
30	High
40	Very High

4. Results and discussion

From the model, three different inclination angles were selected in this study. There were 45º, 60º and 90º of inclination angle with respect to cross arm. These angles are selected according to the possible swing angle in position of insulator with respect to cross arm of transmission line under the wind load. Figure 5 shows the glass insulator in different inclination angle respect to cross arm.

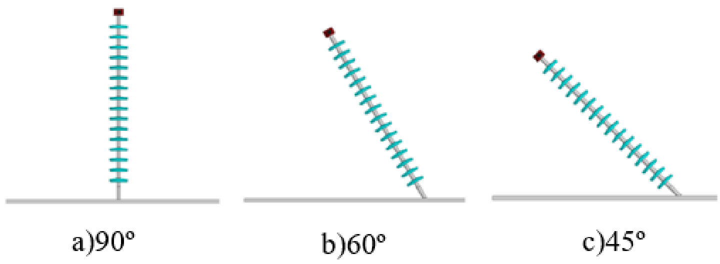


Figure 5: Inclination of insulator respect to cross arm

In this study, electric field distribution across the glass disc was analyse under normal operating voltage. By referring to Figure 6, the highest electric field was recorded for inclination angle 90º, 60ºand 45º are 78.21 kV/m, 81.36 kV/m and 89.69 kV/m, respectively. The maximum electric field at 45º has increases 14.68% compared to vertical insulator. From the result, the smaller the inclination angle respect to cross arm, the higher the electric field. Moreover, the area recorded the highest electric field distribution is located at the edges metal cap for the glass insulator. Due to this, sharp edge of metal cap is the area may have high possibility to initiate the arc.

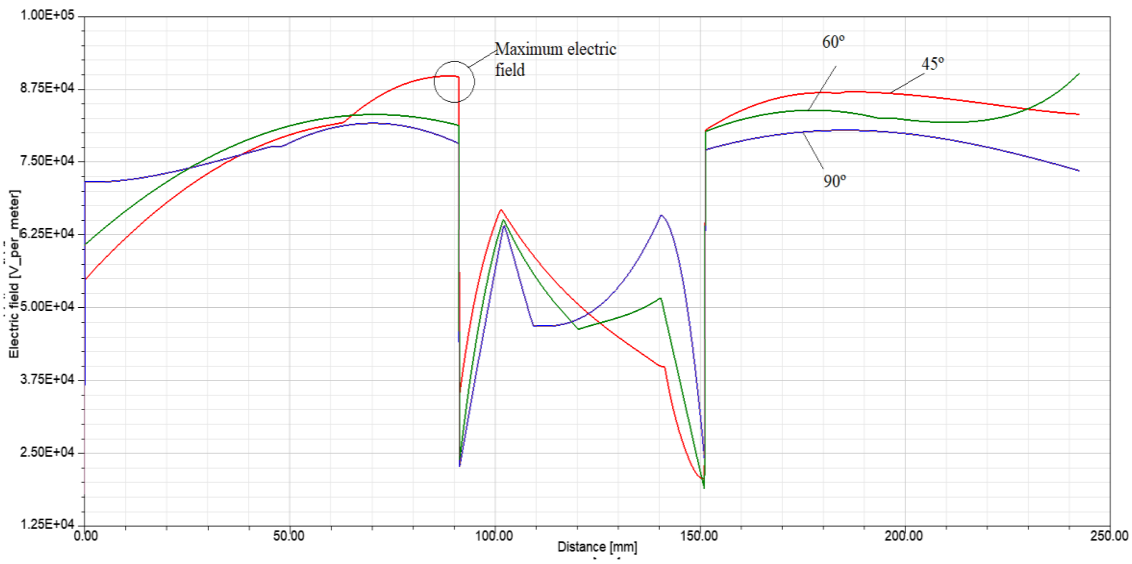
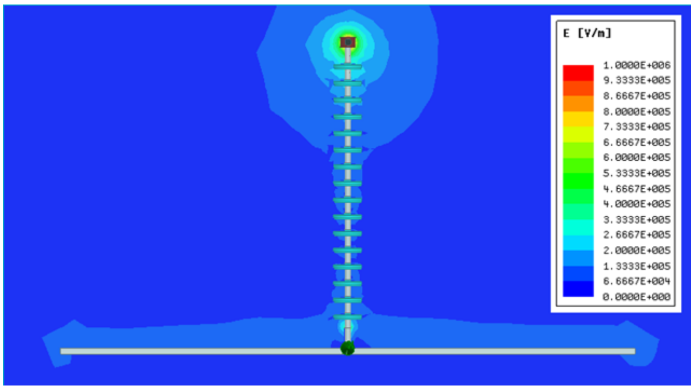


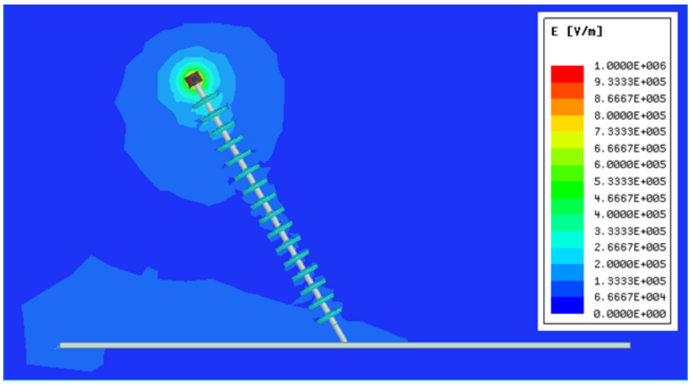
Figure 6: Electric field distribution across glass discs

A distinctive distribution of electric filed of the inclined insulator was observed in FEM analysis. Intense electric field distribution in one side of insulator increases the possibility of electrical discharge. By referring to the counter plot of electric field as shown in Figure 7, the electric field is intensified on the core and the end fitting of the insulator due to its high conductivity. In addition, the electric field is localized on the sharp edge of the insulator due to fringing electric field. When the insulator inclined, the surrounding air between the insulators start to ionize by high electric field. The ionization of the air increases the chance of the gaseous electrical breakdown between the insulator and the cross arm. The avalanche of excited electron may initiate at conductor and distributes to cross arm, this condition creates the conductive path to initiate the flashover of the insulator. Besides that, inclined insulator is having high electric field strength distribution at the end fitting of insulator. This is because joint effect that occurs between the glass, steel and air contributes the localization of electric field strength. Through this plot, the clearance distance between the conductor and the cross arm is reduced when the insulator is inclined. Hence, the high intensity of electric field generated in one area or the electric field localization found in insulator at inclination angle 45° has increases the possibility of insulator flashover.

Inclination angle at 90°



Inclination angle at 60°



Inclination angle at 45°

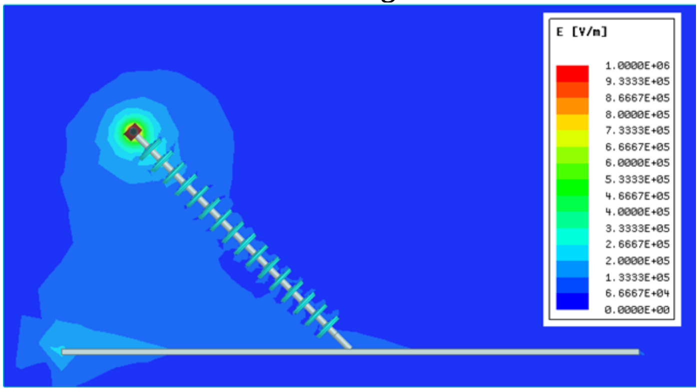


Figure 7: Electric filed plot diagram for glass insulator

Through electric filed plot, the flashover path of the insulator is predicted under incline and vertical condition in this modelling. With this alternative pathway, it skips the creepage length of the insulator and move directly to the grounded cross arm. It is predictable that initiation of free mobile electron to create a flashover path which the flashover occurs within this region. Red line from Figure 8 shows the flashover line prediction by referring to counter plot diagram.

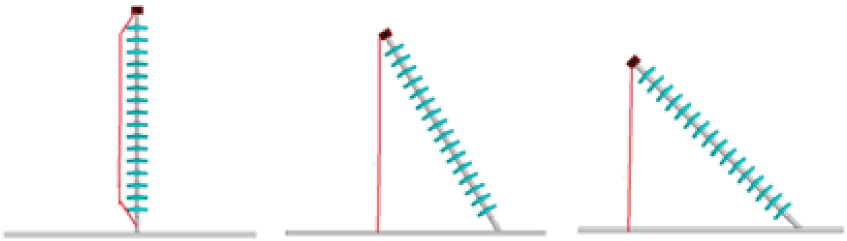


Figure 8: Flashover path for the insulator

The insulator is injected with different level of lightning impulse voltage in this section. Through this method, the insulation performance for the insulator under the lightning impulse condition is evaluated. The evaluation is carried out and results as shown in Table 3. The lightning impulse voltage was injected into insulator is increased until the breakdown occurs. The breakdown voltage of the insulator in different inclination angle caused by wind load action is determined. Whenever the electric field intensity higher that 3MV/m is considered the breakdown voltage. This is because the gaseous breakdown of electric field in air is 3 MV/m. From the results analysis, the electric field along the insulator increases significantly when the lightning impulse voltage are injected into the insulator increases. From the Table 3, the electric field indicates in red had exceeded the breakdown threshold value of the air. The possibility of flashover is highest in this point. From the simulation, the breakdown voltage drops significantly from 1500 kV to 700 kV which is drop about 53.33% when the inclination angle decreases from 90º to 45º due to the insufficient clearance distance.

Table 3: Breakdown voltage of insulator at different inclination angle

Lightning impulse volage	**45º**	**60º**	**90º**
300kV	1.62 MV/m	0.98 MV/m	0.63 MV/m
500kV	2.70 MV/m	1.33 MV/m	1.05 MV/m
700kV	3.78 MV/m	1.76 MV/m	1.48 MV/m
900kV	4.87 MV/m	2.15 MV/m	1.90 MV/m
1100kV	5.94 MV/m	2.55 MV/m	2.32 MV/m
1300kV	7.02 MV/m	2.94 MV/m	2.75 MV/m
1500kV	8.11 MV/m	3.34 MV/m	3.17 MV/m

Under polluted condition, contaminated glass insulator may form a conductive layer on the surface of glass discs. Those accumulated pollution layer mainly composed by salt, dust or sand from the surroundings. Once the conductive layer forms, current from the conductor have leaks to the glass discs through the conductive pathway. Therefore, current density profile is critically important for contaminated insulators. In Equivalent Salt Deposit Density (ESDD) analysis, when the salt salinity increases from 10 g/L to 40 g/L, the current density on the glass also increases. Because of the salt is a charge particle, the increases of salt particle on the glass discs surface may contribute to the ionization of the glass disc surface. This will increase the surface conductivity of the glass insulator surface. In addition, high current density indicates that high leakage current on the joint of glass and metal cap. Therefore, this high current leakage may cause heating, thermal losses and aging of the glass insulator. High temperature may increase the excitation energy on electron of glass discs. Localized thermal heating effect and electron excitation may change the chemical and electrical properties of glass discs. This may cause the aging of the glass insulators. Figure 9 shows the current density profile across the glass disc.

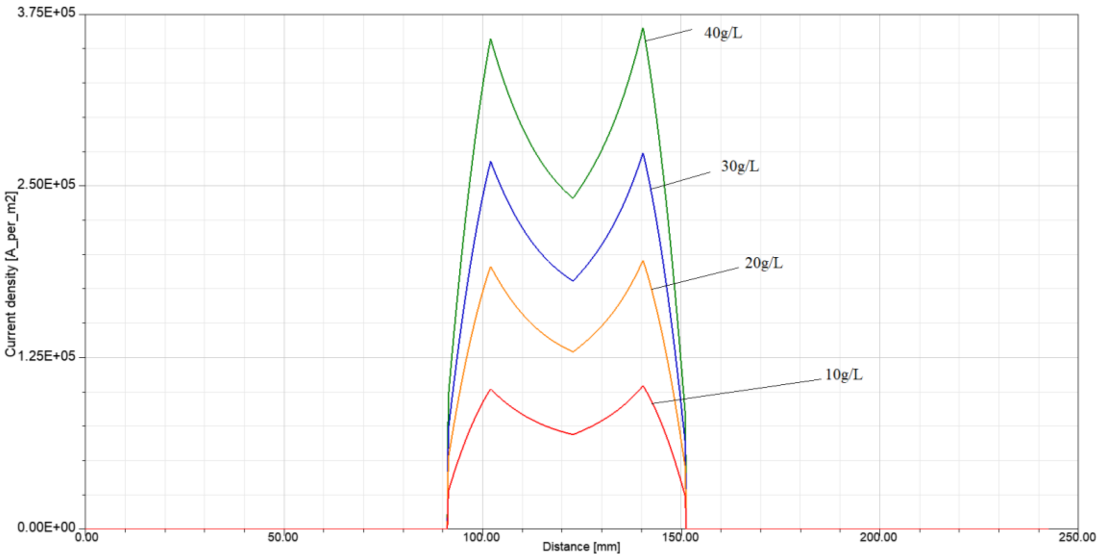


Figure 9: Current density profile for polluted discs

Figure 10 illustrated the counter plot of current density for the glass insulator under different level of pollution. Maximum current density is located at on metal surface due to high electrical conductivity. However, the current density does not evenly distribute on the glass disc surface. The glass disc with the high current density may create a dry band path. The formation of dry band on the polluted insulator efficiently reduces the resistivity and insulation within the dry band area. Therefore, the chance of arching is higher in dry band of the glass disc. Furthermore, the current density was distributed inconsistently on the glass surface due to salt pollutant. This tends to reduce the stability of the insulator.

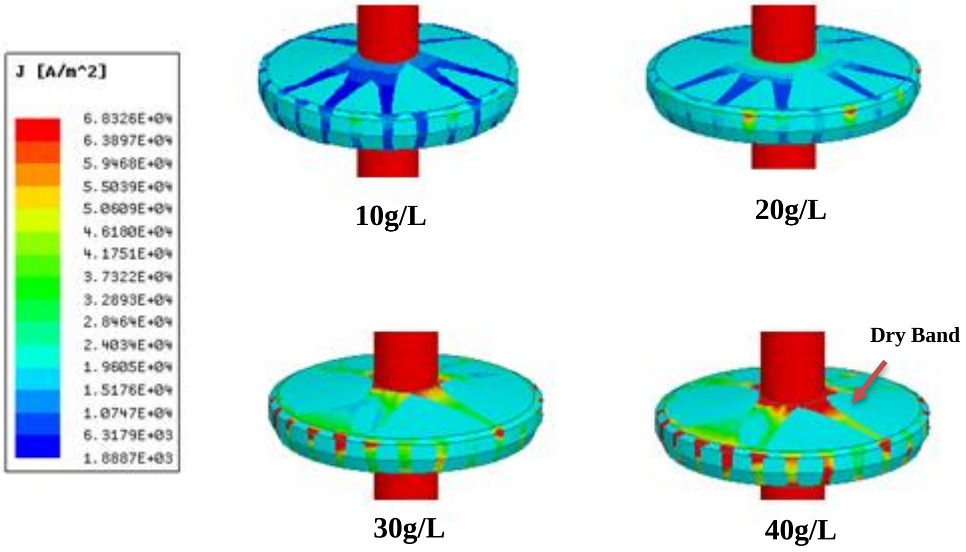


Figure 10: Dry band path for polluted insulator

5. Conclusion

Glass insulators are widely serving as outdoor insulator in power system. During service lifetime, the weathering and contamination may influence the electrical performance of the insulator. Insufficient care, monitoring and operating measures cause the insulators have higher risk to degrade, arching and flashover where damage the transmission system. In this research, the wind load swings the insulator to inclined during bad weather where it can be a weak spot for the transmission system especially in high altitude. On the other hand, an inclined insulator suffers higher electric field under the nominal voltage 275 kV AC. The maximum electric field on glass disc is found up 14.68% higher than vertical insulator. Different level of lightning impulse voltage and lightning impulse current are found significantly influence the breakdown strength of the insulator. The high electric is recorded at the flashover path when the insulator inclined. Therefore, the chance of flashover increases due to high electric field and reduction of flashover distance. The insulator at 45° is recorded the lowest breakdown strength under the lightning impulse voltage, the breakdown voltage is reduced about 53.33% compared to the vertical insulator. The simulation study also indicated that the dielectric strength is reduced by the increasing of pollution salinity. The high current density is found on the insulator surface which the dry band may formed on the surface.

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