



Finite Elementary Analysis of Electrical Performance for Glass Type Insulator Under the Inclination Effects

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ABSTRACT

This paper presents the modelling of a glass type of insulator with a voltage rating of 132 kV. The insulators play a critical role in transmission lines to ensure the stability and reliability of the system. Glass insulators are still widely used in overhead transmission systems because of their dielectric strength capability. Whenever faults occur in the transmission line or system, a considerable cost for maintenance and repair is required. The outdoor application of the insulator has resulted in exposure to various service conditions such as weather, pollution and lightning. Indeed, the inclination effect under the wind load is one of the significant challenges for outdoor insulators. Therefore, this paper studied the electrical performance of the 132 kV glass insulators under the inclination effects through Finite Elementary Modelling (FEM). In this simulation, the model of the glass insulator is constructed in four different inclination angles using the modelling software Ansys Maxwell 3D. From the results, the electric field distribution for the insulator became uneven when the insulator was inclined. With the reduction of clearance distance under inclination effects, the localised electric field form may increase the electrical discharge and arcing likelihood. In a worst-case scenario, the flashover may cause faulty transmission equipment. In either case, the electrical performance of the insulator is reduced under the inclination effects.

1. Introduction

Nowadays, electricity demand in Malaysia is growing significantly and energy consumption is expected to grow uptrend. Therefore, the electrical performance of the transmission system is becoming important [1] In the transmission system, insulators play a vital role in the safety of the electrical system to ensure the stability and reliability of the system[2] It provides mechanical support for the cable and is designed to withstand the weight of the cable [3]. Glass suspension insulators are composed of a series of cap and pin glass disc. Nowadays, glass insulators are still widely used in transmission lines because of the high dielectric strength and the strength in corrosion proof [3, 4]. Thus, it reduces the chances of flashover current and breakdown voltage in the distribution system. Any insulator failure may lead to short circuits and damage of high voltage equipment [5]. An

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important factor affecting insulators' electrical performance in high voltage transmission is the inclination effects [6]. The wind load action on the transmission system causes the effect of inclination. Under the high velocity wind effects, the glass insulator swings at different inclination angles with respect to the cross arm especially in heavy rain and thunderstorms [7]. Then, the lifespan of insulation will be reduced dramatically due to this effect. Figure 1 shows the inclination of the insulator with respect to the cross arm [8].

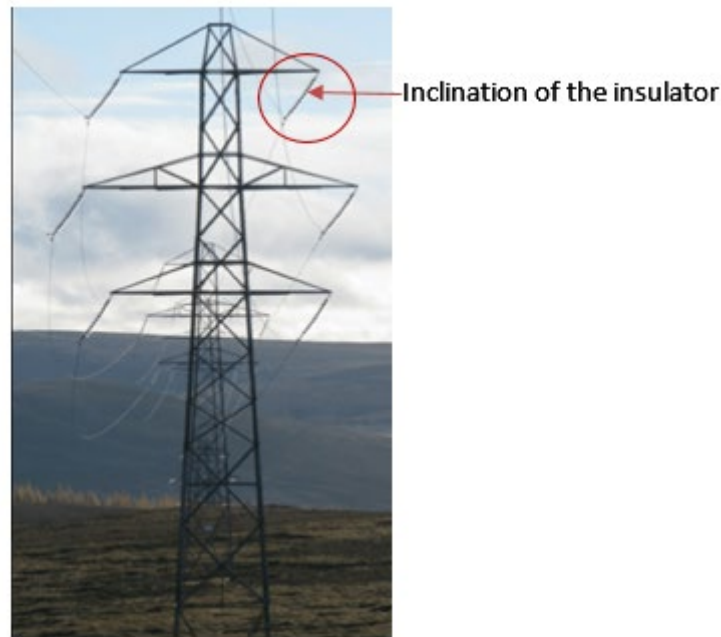


Fig. 1. Inclination of insulation due to wind load [8]

Typically, glass insulators provide sufficient creepage length to avoid the flashover from occurring. Previous research has focused on high power transmission systems to improve their safety and performance [9]. However, studies of insulator performance related to the inclination effects are still insufficient. In this paper, the electric field distribution of the glass insulator under the inclination effects will be focused by using the Finite Elementary Modelling (FEM).

2. Glass Insulator

2.1 Insulator Specification

In this simulation work, a typical glass type insulator was chosen. A Glass disc insulator is separated into a metal cap and pin. Then, the glass disc will be composed in series to become the glass suspension insulator [10]. This study selected the Glass type insulator due to its stable performance and still widely served in overhead transmission. The dimensions of the glass disc are shown in Figure 2 and Table 1 [11]. Table 2 shows the materials and electrical parameters of the glass insulator.

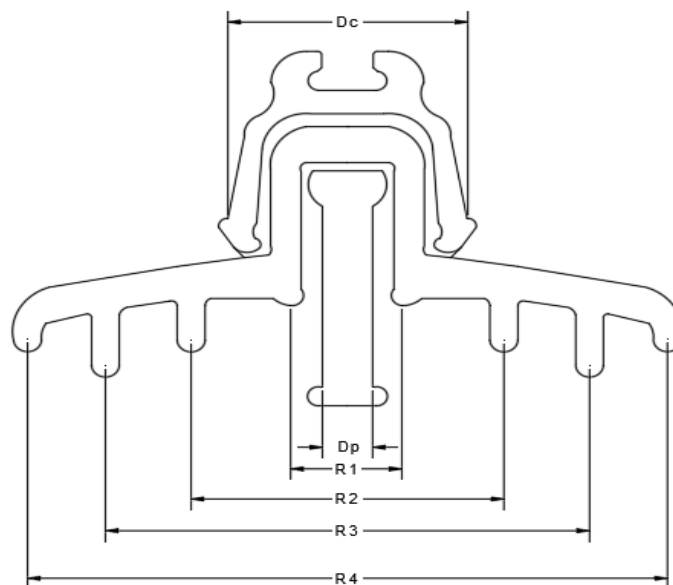


Fig. 2. 2D view of the glass insulator

Table 1

Technical specification of the glass discs [11]

Parameter	Value
Creepage length, Cd	320 mm
Disc diameter, D	255 mm
No of ribs	4
Rib diameter, Rd1	50 mm
Rib diameter, Rd2	120 mm
Rib diameter, Rd3	190 mm
Rib diameter, Rd4	255 mm
Insulator Pin Diameter, Dp	30 mm
Insulator Cap diameter, Dc	80 mm
Weight	4 kg

Table 2

Materials and electrical parameters of the glass insulator

Type of Materials	Relative Permittivity (ϵ_r)	Bulk conductivity (σ) S/m
Glass	4.2	0
Cement	15	1×10^{-4}
Insulator cap	1000	5.9×10^{-7}
Insulator pin	1000	5.9×10^{-7}

2.2 Inclination effects on the insulator

The wind load exerted on the insulators are highly fluctuating and dynamic. According to the Malaysia standard, the maximum wind velocity value (V_s) stated is between 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 the 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 [12, 13]. Overhead Line towers and outdoor insulators are usually subjected to strong wind because of tall structures. Under the high wind speed, the insulator will swing away from and closer to the tower body. Therefore, the

inclination effect of the insulator on the cross arm occurs. Notably, the windspeed is increasing with the altitude [14]. When the insulators move towards the tower body, the clearance distance is reduced and the possibility of electrical arcing and flashover increases [15]. Figure 3 shows the inclination of the insulator at different angles [16, 17].

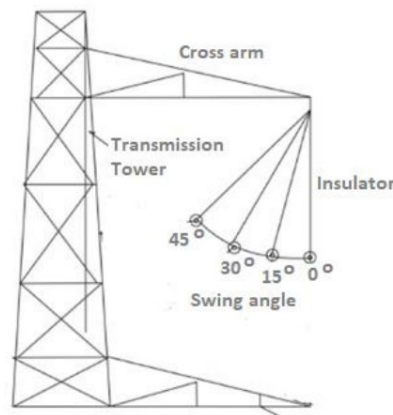


Fig. 3. Inclination angle of insulation due to wind load [16, 17]

3. Methodology

In this paper, Ansys Maxwell 3D is selected to perform the Finite Elementary Analysis. The glass disc was drawn and designed in AutoCAD in the modelling process based on the standard technical specification. Then, the drawing in CAD is imported to the Ansys Maxwell for simulation purposes. The overview of the simulation model is shown in Figure 4.

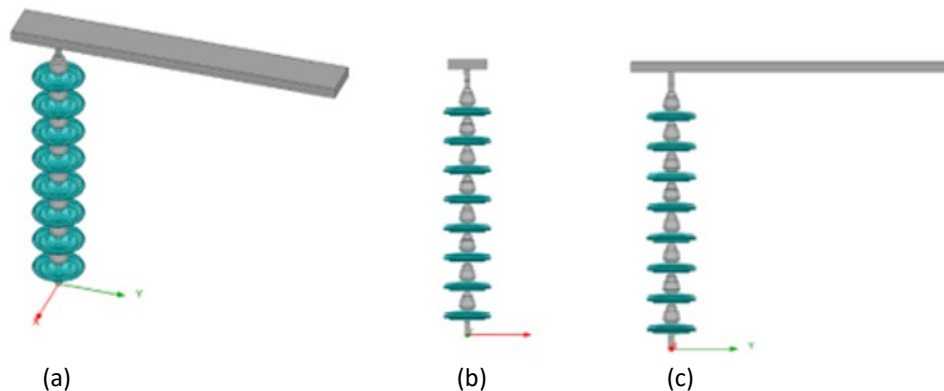


Fig. 4. Overview of the glass insulator 3D model (a) Isometric view (b) Side view (c) Front view

Then, the electrical parameters of the 132 kV glass insulator were assigned based on their material properties for each part of the insulator. The relative permeability and bulk conductivity are determined according to the materials used and the manufacturer's datasheet. The modelling process has five essential parts: metal cap, steel pin, glass discs, steel fittings, and cross arm. Adding the air as surrounding services environment to the model is essential. Further, another vacuum region is added to restrict the solving area or act as the second boundary condition. In this simulation, the red part is applied to the model shown in Figure 5 as a restriction region for insulator modelling.

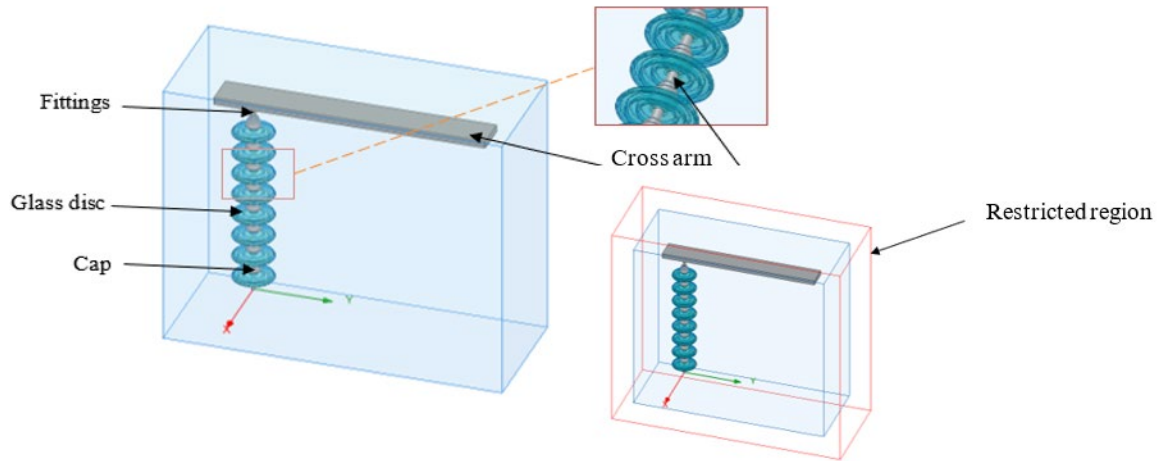


Fig. 5. Glass insulator model

Four sets of insulators were drawn in different inclination conditions. There were 0° , 15° , 30° and 45° of inclination angle with respect to cross arm. These angles are selected according to the possible swing angle in the insulator's position with respect to the transmission line's cross arm under the wind load. Then, electrical performance was investigated. Figure 6 shows the insulator's inclination angle with respect to the cross arm. Under this inclination angle condition, the other parameters remain the same, such as material types and dimensions. The insulator is set to be inclined to only a side of the cross arm because of the reduced clearance distance. In particular, reducing the clearance distance increases the risk of electrical discharge [18]. The focus point is to measure the impact of the insulation inclination to the electric field distribution through the modelling work. Hence, only one side of the inclination of the insulator is focused as shown in Figure 5.

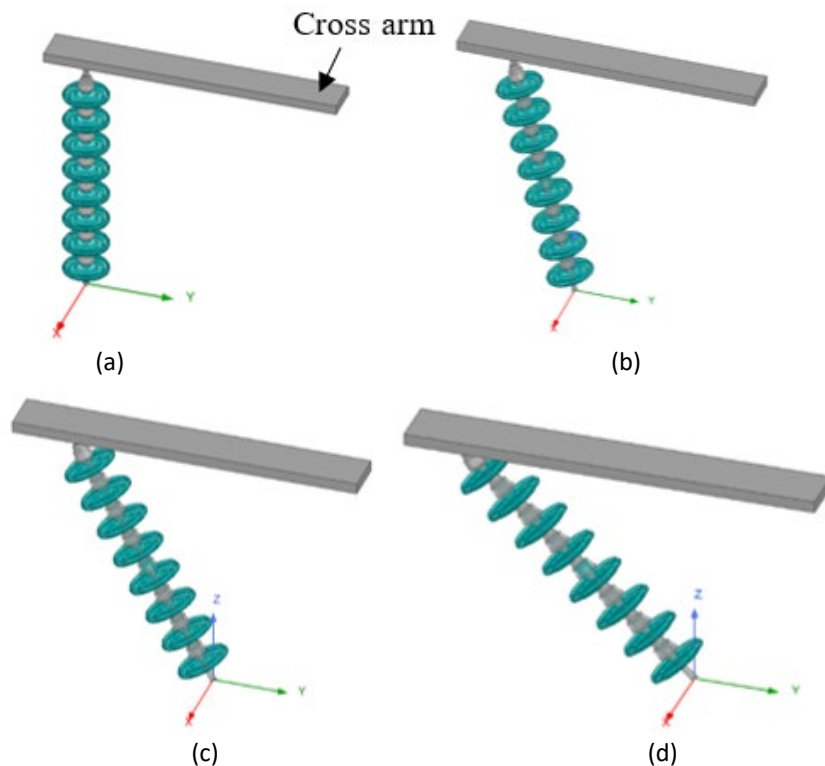


Fig. 6. Inclination angle of insulator with respect with the cross arm (a) 0° inclination (b) 15° inclination (c) 30° inclination (d) 45° inclination

The modelling of 132 kV glass insulators required nodal analysis [19]. Because of this, the meshing is required to perform the Finite Elementary Modelling before running the simulation. In this study, the meshing was set at a higher gradient at the cross arm, fittings, metal cap, glass disc and pin up to 15 mm. The reason for selecting a higher mesh gradient is to obtain the optimum mesh for accurate results. In other parts like air regions, the meshing was placed at a coarse size of 400 mm. Subsequently, re-meshing was carried out until no significant change in results compared to last. Figure 7 shows the mesh plot of FEM model.

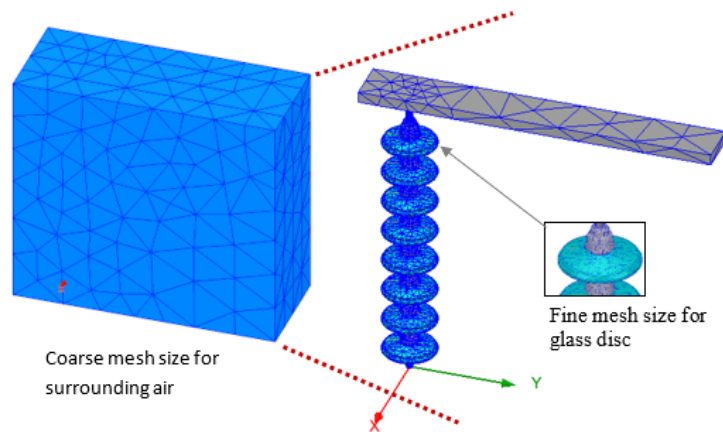


Fig. 7. Mesh plot for the insulator model in coarse and fine mesh

3. Results

This study conducted the voltage distribution and electric field distribution along the glass suspended insulator under 132 kV operation voltage. Furthermore, the possible inclination angles of the insulator respected to the cross arm due to wing load of were 0° , 15° , 30° and 45° were considered. Therefore, the 0° was represented to a vertical insulator as a reference condition for the inclination effect. The electrical performance of the insulator was evaluated through electric field distribution for vertical and inclined insulators. The results are discussed based on the insulator's profile distance across the glass discs' surface, as shown in Figure 8. Along the glass insulator string for 132kV, eight discs are connected in series to avoid the insulator shortening to the ground.

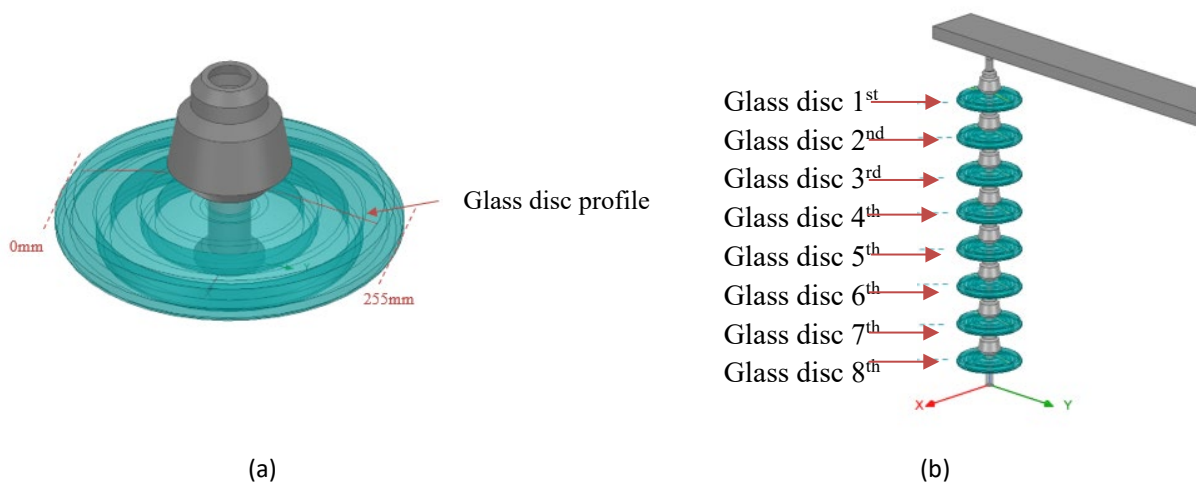


Fig. 8. Glass insulator profile (a) Glass disc profile (b) Position of the glass disc in string

Electric field distribution is vital in ensuring the insulator's stability [20]. Nonetheless, the electric performance respected with the position is considered in this study. Figure 9 and Figure 10 show the electric field distribution across every glass disc and the maximum electric field recorded on glass discs respectively without any inclination effects.

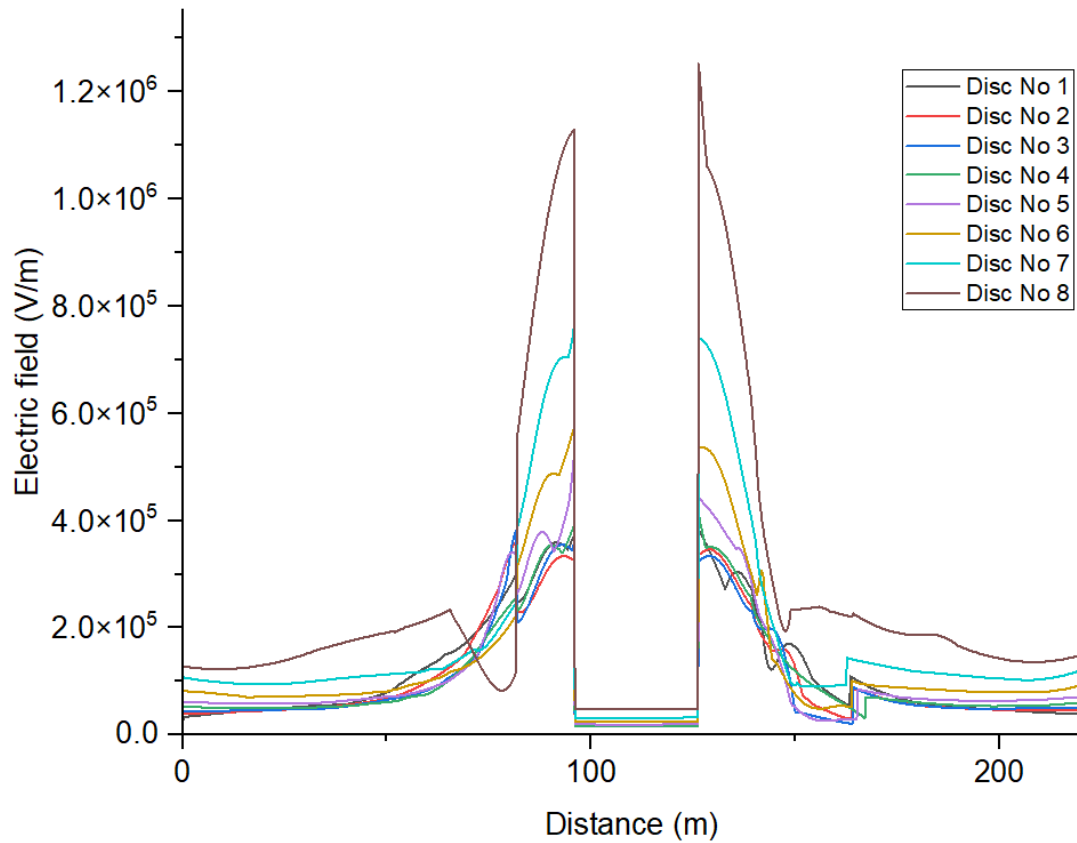


Fig. 9. Electric field distribution across the glass disc in the insulator without any inclination effects

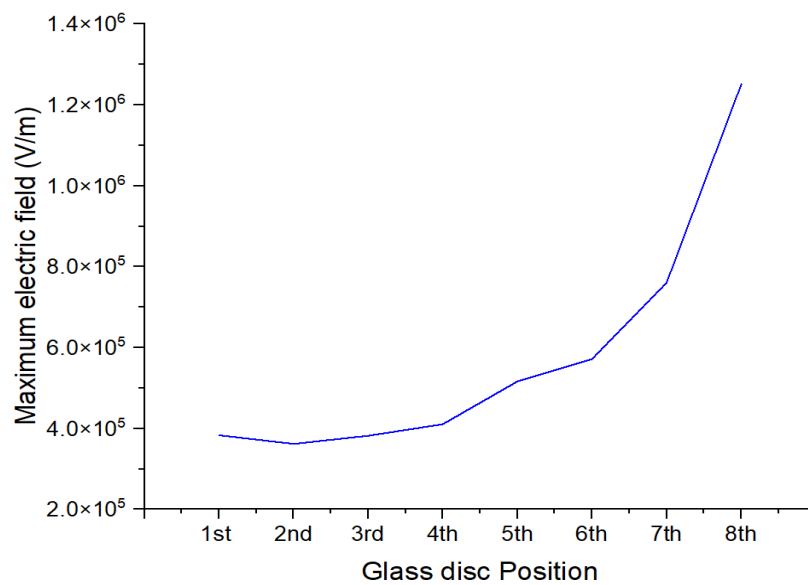


Fig. 10. Maximum electric field recorded on glass discs without any inclination effects

From the results, the electric field was distributed evenly between both sides of the insulator under normal operating conditions without any inclination effect. The electric field gradually increases until it reaches the peak value at the joint between the steel cap and glass discs. This pattern was influenced by the thickness of the glass disc and the type of materials used in the insulator [21]. Since steel and glass have different dielectric strengths, the connection parts suffer high electric field intensity. As a result, the maximum electric field was recorded at both joints of the metal cap-glass. In 8th glass disc, the disc nearest to the live conductor recorded the highest electric field, 1.25 MV/m at the metal cap and glass joint.

As mentioned, the outdoor insulator is subjected to wind load. The wind load acting on the insulator will cause the swing and inclination effects on the insulator. Indeed, the degree of inclination for the outdoor insulator depends on the wind velocity. Notably, the high altitude experiences a high wind speed. In this paper, the inclination factors for outdoor insulator is considered. Figure 12 shows the counterplot diagram for the electric field distribution for the glass insulator. The high electric field may increase the possibility of electrical discharge, arcing and flashover. Apart from this, the high electric field will expedite the ageing of the glass insulator and reduce the electrical performance.

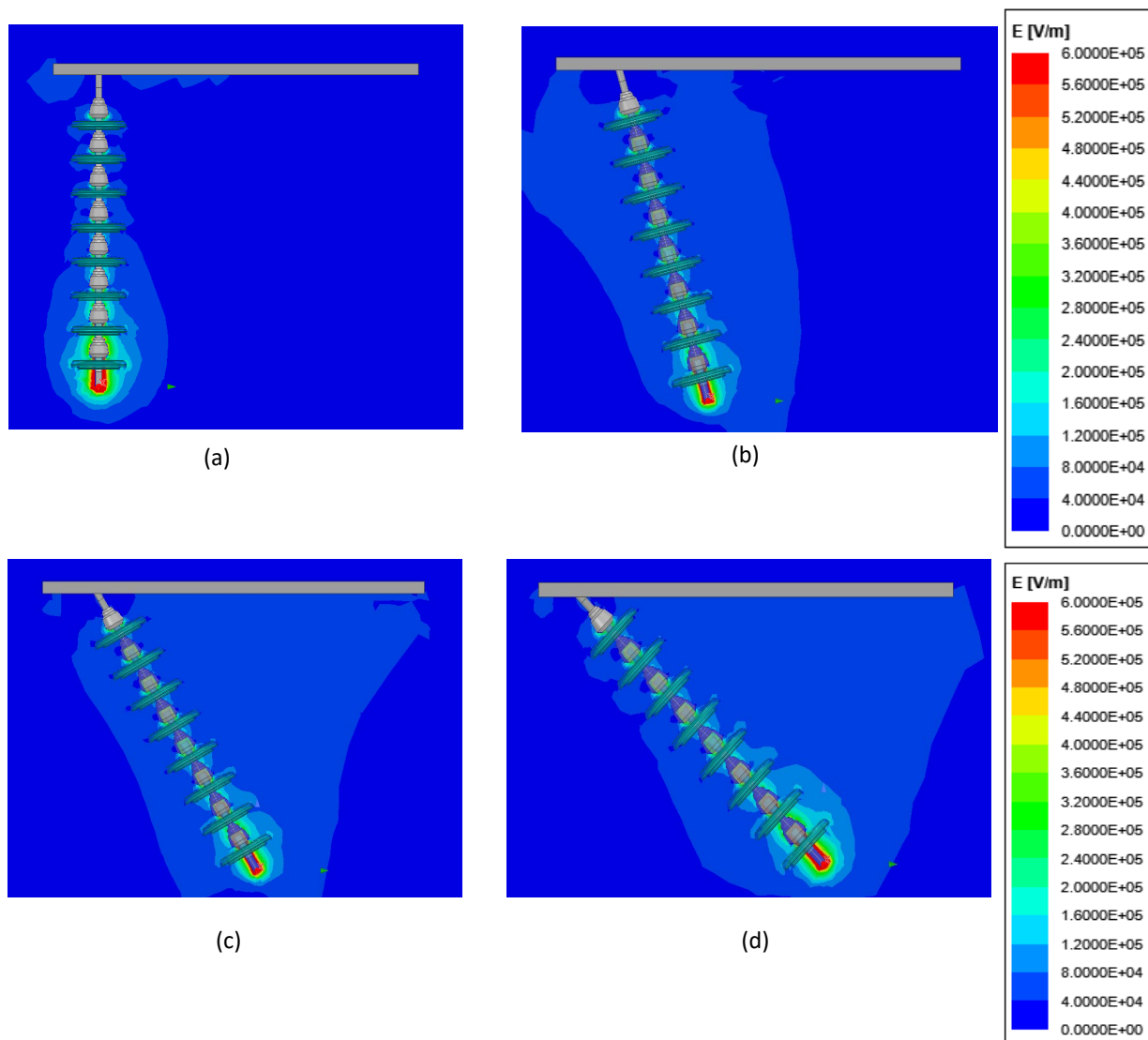


Fig. 12. Counter plot diagram for electric field distribution (a) 0° inclination angle (b) 15° inclination angle (c) 30° inclination angle (d) 45° inclination angle

The electric field is focused on the creepage pathway in vertical conditions. In this scenario, the electron can only move under the region with the intense electric field. Due to the sufficient creepage distance and controlled electric field intensity, the electrical discharge, arcing or flashover were avoided. However, when the insulator starts to incline due to external force extension, the electric field starts to ionise with the air and spread to the surroundings. The electric avalanche may form under the intense electric field. As a result, this alternative pathway may form in between and increase the possibility of flashover and arcing. The results in Figure 13 proved that the increase of the inclination effects on the insulator will reduce the electric performance of the insulator significantly. The worst case is for the inclination angle of 45° with the high intensity of the electric field and shortest clearance distance with the cross arm.

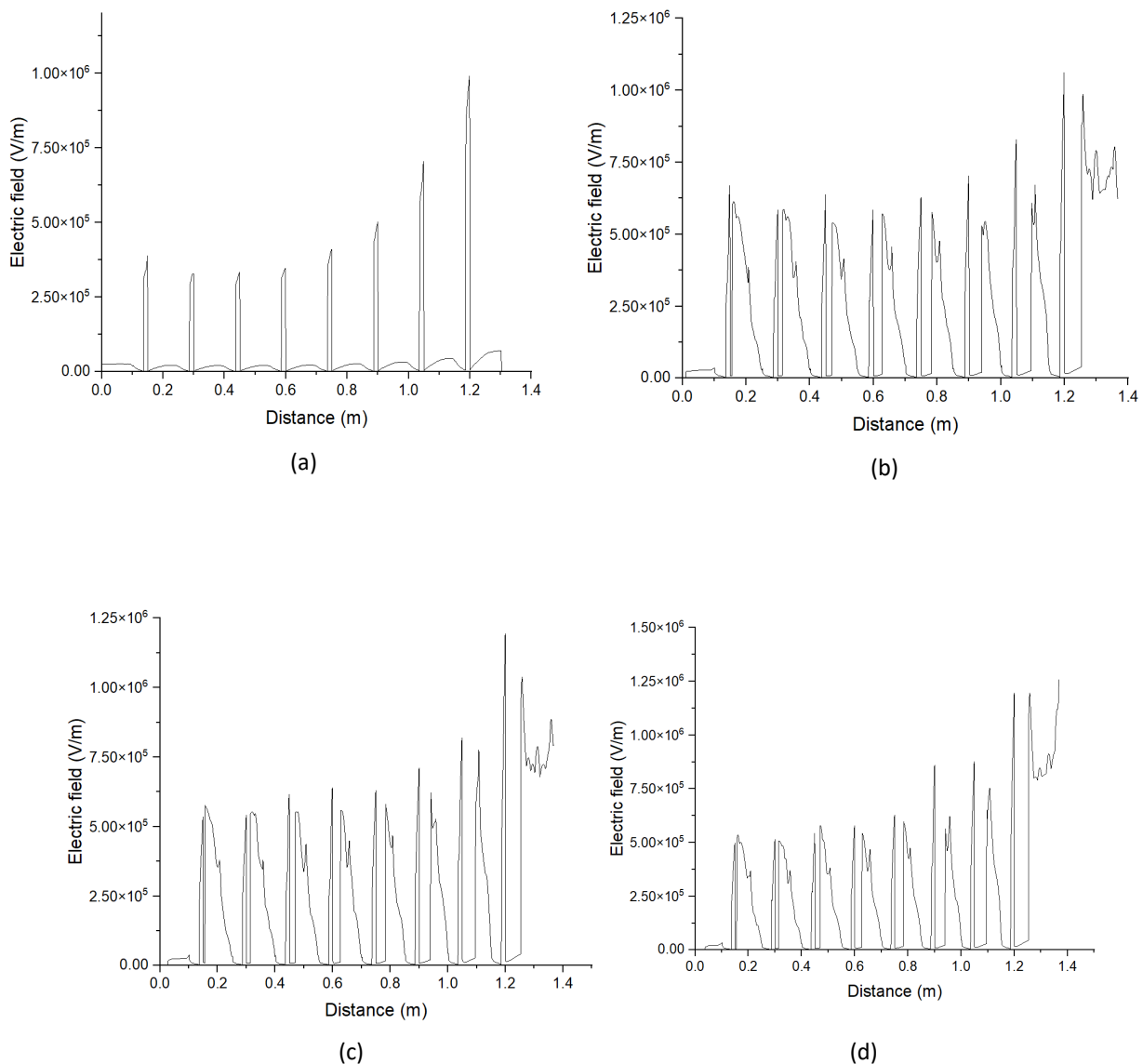


Fig. 13. Electric field distribution along the string (a) Electric field distribution at 0° inclination angle (b) Electric field distribution at 15° inclination angle (c) Electric field distribution at 30° inclination angle (d) Electric field distribution at 45° inclination angle

4. Conclusions

In conclusion, this paper presented the electrical performance of a 132 kV glass insulator under vertical conditions and different angles of inclination. By referring to the results, the wind load swings the insulator to inclined during extreme weather, which can be a weak spot for the transmission system. In insulator string, glass discs near the HV end which is disc 8th experience the highest electrical stress compared to other discs. Therefore, disc 8th is the critical area to be studied and analysed. The clean and vertical insulator without the inclination effects has uniform electric field distribution along the string. The electric field distribution became uneven when the insulator's string was swing under the wind load effects. It creates the net force for the mobilisation of the electron.

Consequently, it increases the likelihood of arching, flashover, or electrical discharge in an area with an intense electric field. With the reduced clearance distance, the localised electric field is from the area between the live conductor and the cross arm. This situation may lead the electron to skip the creepage length and move to the cross arm. These findings presented the critical area of insulator and inclination effects on the glass insulator throughout this study.

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