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Lightning Impulse Strength of 275 kV and 132 kV Tower with Composite Crossarm

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***Abstract*—Severe lightning overvoltage is regarded to the multiple flashovers on the overhead lines. Therefore, it signifies the needs of having a robust insulation system, especially to those which highly susceptible to lightning strikes. In order to minimize the impact of lightning, it is necessary to evaluate lightning performance of the tower and its components before implementing any proposed design. Therefore, in this work, a feasibility study was done on proposed 275 kV and 132 kV transmission tower with composite crossarm installed. In order to assess the insulation strength of the tower against the lightning activities, lightning caused events i.e. backflashover and shielding failure were applied onto the tower models by using FEM based software. The CFO of the tower insulation were calculated based on the design provided, whereby it was complementary verified by the voltage and electric field profiles of the simulation. For each case, none had shown a voltage magnitude higher than the voltage supposed to possibly cause 50% chance of flashover.**

Keywords—Composite crossarm, tower insulation, ANSYS Maxwell, CFO

I. INTRODUCTION

Lightning is a phenomenon that happens due to the formation of spark or flash originating in a cloud charge [1]. Lightning activities are proven to be catastrophic to an entire electrical system. Malaysia is a country with one of highest lightning densities in the world that the 70% of the power outage within the country caused by the lightning surges [2]. This threat directly affects the power equipment, automated network systems, causes data losses and monetary losses within the nation. Lightning surges or lightning overvoltage can be appeared within the electrical lines by three ways: (i) Direct lightning strike to the phase conductor (due to shielding failure), (ii) Direct lightning strike to the tower/shield wires (leading to backflashover) and (iii) Lightning strikes the earth in the vicinity (causing induced overvoltage). In either event, there are three factors determine whether the line insulation will occur: (i) The waveshape and polarity of the lightning surge voltage, (ii) the withstand strength of the insulators which specified by the number of disks of insulator string or by the arcing distance of the conductor to tower, and (iii) power frequency component of the voltage across the insulator.

In transmission lines, a lightning strike generates travelling voltage generated along the line could cause a significant flashovers to the entire overhead line. Although most of transmission towers are equipped by shield wires to divert the lightning stroke away from the conductors, it is possible for the lightning strike to penetrate the shield, eventually causing shielding failure.

On the other hand, when lightning strikes the tower or shield wire, it causes current passing to the earth through the tower steelwork and causing a potential to exist between the line crossarm and phase conductors. If the potential is large enough, a flashover will occur across the tower and a phase conductor causing the event of backflashover.

Eventually, it is mandatory for a transmission tower to have a resilient insulation which works optimally under their operating conditions. The insulation usually consists of insulator strings alone or combination of insulator string and crossarm. They shall play an important role to isolate and withstand such enormous voltage from being discharged to or from the phase conductor.

There are many previous research were conducted to evaluate the performance of tower insulation by assessing the performance of crossarm and insulators. A few test data were presented by Grzybowski concerning on the lightning impulse (LI) strength of the fibreglass rods in combination with glass suspension insulators [3]. The critical flashover voltage (CFO) of used and new crossarm under several condition have been compared to reveal the degradation of insulation for aged crossarm.

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Moreover, Goffinett has evaluated the feasibility of 380 kV crossarm by modelling one lattice tower with a single crossarm arrangement in FEM based software [4]. The E-field calculation obtained by this method has successfully revealead the flaw of crossarm design, thus allow for a prompt adjustment.

In Malaysia, the fibreglass crossarm have been used in transmission line in recent years to replace the conventional wooden crossarm made by Chengal wood (Neobalanocarpus) [5]. A composite material like fibreglass or rather called fibre reinforced polymer (FRP) has shown a superior properties such as high strength to weight ratio, capable to withstand into extreme environmental condition, corrosion resistance. In addition, FRP inherent a good chemical stability and able to endure lightning impulse [6].

II. Simulation And Modelling

In this study, FRP crossarm performance of a transmission tower was studied under lightning impulse voltage, considering the effect of shielding failure and backflashover event. The study focused on the performance of the FRP crossarm for 275 kV and 132 kV transmission line as Fig. 1 via finite element based software (ANSYS Maxwell). The software fundamentally has the ability to model the component of the tower, based on its properties such as permittivity and conductivity of the materials. It allows the user to closely examine electrical fields under any specified excitation.

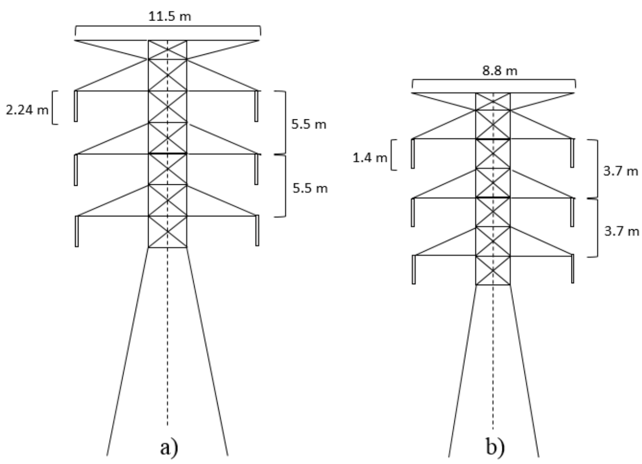


Fig 1. Proposed transmission tower for a) 275 kV and b) 132 kV

The structure of the crossarm was modelled according to the proposed crossarm designed for 275 kV and 132 kV transmission tower, the dimension shown in Fig. 2.

TABLE I. Material Parameters

Structure	Relative Permittivity (ε_r)	Bulk Conductivity (σ) S/m
FRP Crossarm	5	1×10^{-16}
Steelworks/fittings	1	2×10^{6}
Insulator disc	5.5	2×10^{-14} [7]

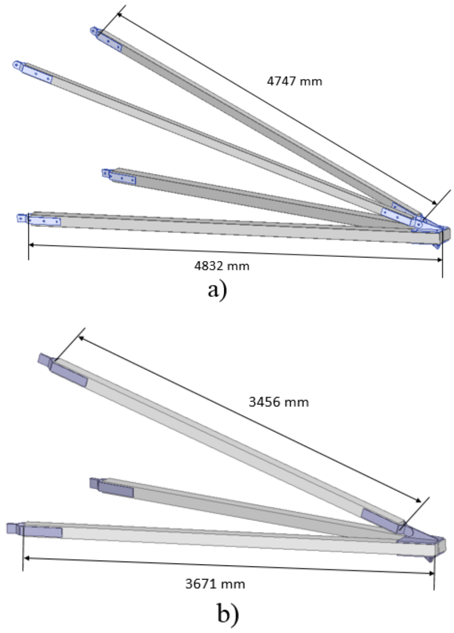


Fig 2. Dimension of typical a) 275 kV and b) 132 kV composite crossarm

As an appropriate approximation, the CFO of crossarm and insulators in series can simply be determined by the length of crossarm plus the length of the insulators multiplied by 550 kV/m for positive polarity and 605 kV/m for negative polarity [8]. The equations are as shown in (1) and (2) respectively,

$$CFO_c = 550\ (Lf + Li) \tag{1}$$

$$CFO_c = 605\ (Lf + Li) \tag{2}$$

where CFO is the CFO of the combination of fibreglass and glass insulator, Lf is the fibreglass crossarm length, and Li is the length of the insulator string. In contrast, not many studies available with regards to the insulation strength of the composite crossarm and as far as this particular case is concerned. The quick estimation for CFO of is given by formula (3),

$$CFO_{Actual} = \text{distance x } CFO_{gradient} \tag{3}$$

Defined the distance is the length of crossarm and the length of insulators while assuming $CFO_{gradient}$ equal to 550 kV/m, the actual CFO are calculated as the following.

TABLE II. Calculated CFO Of Crossarm And Insulator

System	Length (m)		CFO (kV)
275 kV	Crossarm	4.83	$CFO_{crossarm}$ = 2657 kV
	Insulator	2.24	$CFO_{insulator}$ = 1232 kV
132 kV	Crossarm	3.67	$CFO_{crossarm}$ = 2018 kV
	Insulator	1.40	$CFO_{insulator}$ = 770 kV

The 2D design complete with 16 and 10 insulator discs, for 275 kV and 132 kV respectively, was chosen to see the voltage profile and electrical stress of the crossarm when certain amount of voltage applied to it. The main purpose is to investigate if the proposed length of composite crossarm and insulator able to withstand the lightning events. Provided that BIL for 275kV and 132kV systems are 1050 kV and 650 kV respectively. As far as the safety margin 30% are concerned, the BIL + 30% (1365 kV and 845 kV) are considered separately. Note that, the safety margin is defined to reflect what happen to the insulation performance when a voltage beyond the BIL is applied.

For each of the case, the simulations were carried out for backflashover and shielding failure. Noted that excitation of standard lightning impulse voltage (1.2/50µs) were used. Details of parameters for consideration and assumptions are given in Table III.

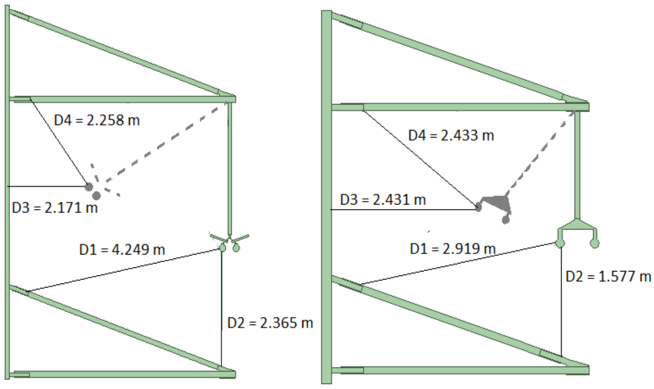
TABLE III. CASE STUDIES CONSIDERED IN THIS WORK

Tower	Case	Inclination	Applied LI (kV)
275 kV	Backflashover	Normal	1050
			1365
		Swing 57°	1050
			1365
	Shielding failure	Normal	1050
			1365
		Swing 57°	1050
			1365
132 kV	Backflashover	Normal	650
			845
		Swing 30°	650
			845
	Shielding failure	Normal	650
			845
		Swing 30°	650
			845

Two applied voltages were injected at the tower body (backflashover) and phase conductor (shielding failure). The following assumptions were also considered in this work, which later will be used to evaluate the possibility of arcing to the nearest metallic object or conductive part:

- $U_{b(air)}$ = 30 kV/cm or 3 MV/m
- Line is de-energised
- No line arrester installed.

Fig. 3 shows the configuration of the crossarm with suspension insulator and its corresponding estimated CFO or U_{50} for the given distances to the nearest metallic object for both 275 kV and 132 kV tower.



Point	Distance, m	U_b, MV
D1	4.249	12.7
D2	2.365	7.1
D3	2.171	6.5
D4	2.258	6.7

a)

Point	Distance, m	U_b, MV
D1	2.919	8.8
D2	1.577	4.7
D3	2.431	7.3
D4	2.433	7.3

b)

Fig. 3 The distance to the nearest metallic object for a) 275kV and b) 132kV system.

III. SIMULATION RESULTS

A. Insulating performance of 275 kV and 132 kV FRP crossarm

The voltage distribution and electric field (EF) profiles from the simulation were presented in this section. Under transient, the profiles were dynamically changed over time, whereas only the profiles at the peak are recorded. Fig 4 and 5 portrayed the voltage distribution and EF stress obtained for tower 275 kV. It should be mentioned, that the voltage decreased gradually from the tower to the phase conductor. Localization of electric fields can be observed near to arcing horn, which serve its purpose for insulator protection during flashover. Referring to Fig. 5, by using the rule of thumb of 3MV/m, one can observe that no flashover is expected across the tower and phase conductor regardless of the +30% voltage considered.

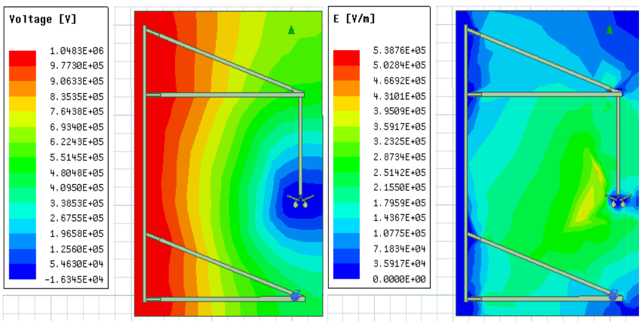


Fig 4. The voltage and electric field stress distribution for 275 kV crossarm under BIL.

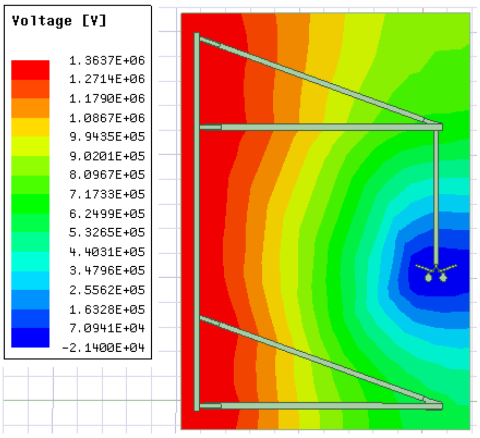


Fig 5. The voltage distribution for 275 kV crossarm under BIL+30% (backflashover)

In the event of shielding failure, high impulse voltage appears along the phase conductor and influence the spatial voltage distribution as per Fig. 6. Focused high voltage on the conductor reduced gradually in distance. Regardless of strike location, electric field pattern was found to be similar.

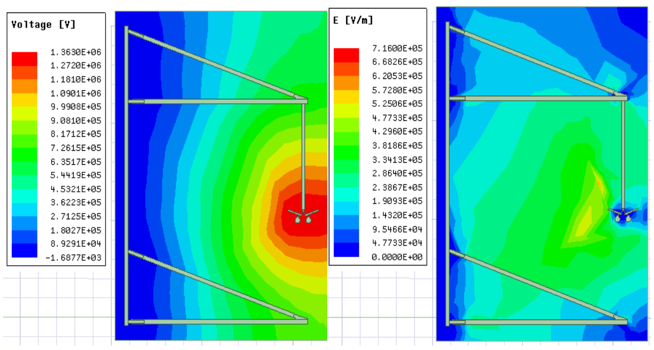


Fig 6. The voltage distribution and EF for 275 kV crossarm under BIL+30% (shielding failure)

Other than voltage distribution, one of the most important parameters to be considered in insulation study was the EF stress. Electric field localisation in such high magnitude might sufficiently initiate a flashover. In this study, the maximum electric field shall be less than 3MV/m to ensure the probability of flashover across the air to happen is low. Table IV summarised maximum EF obtained in all case studies for normal inclination.

TABLE IV. MAXIMUM ELECTRIC FIELD UNDER LIGHTNING EVENTS

Tower	Case	Applied LI (kV)	Maximum EF (MV/m)
275 kV	Back-flashover	1050	0.539
		1365	0.001
	Shielding failure	1050	0.554
		1365	0.716
132 kV	Back-flashover	650	2.145
		845	2.788
	Shielding failure	650	2.144
		845	2.788

From the results obtained, it was found that none of the case experience high stress or having the maximum voltage exceeds the CFO (or U_b) for the distances that could potentially give the 50% of having the flashover. However, most of the cases were expected to have the corona and streamer inception that most probably occur within the given threshold in Table V [9-11].

TABLE V. MAXIMUM ELECTRIC FIELD UNDER LIGHTNING EVENTS

Discharges	Electric Fields Threshold (MV/m)
Corona	0.5-0.7
Streamer	>0.55

B. *FRP crossarm against steel crossarm*

This section provides the results obtained from the simulation carried out for 132 kV system considering the BIL + 30% of backflashover event. Fig 7 and 8 illustrates the results for voltage distribution and EF stress for both towers using FRP and conventional steel crossarm respectively.

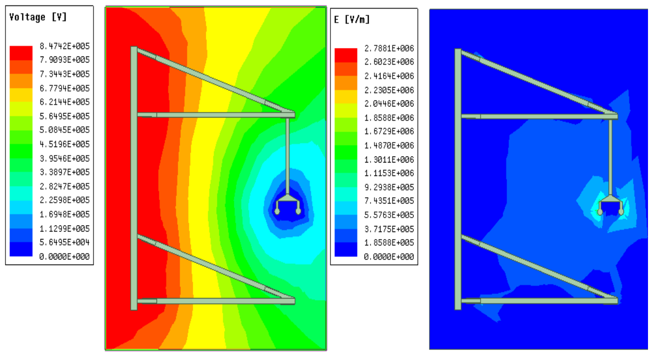


Fig 7. The voltage distribution and EF for system 132 kV under BIL+30% (845kV) using FRP crossarm

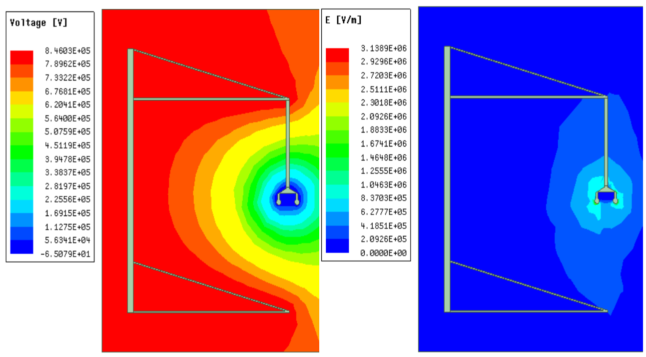


Fig 8. The voltage distribution and EF for system 132 kV under BIL+30% (845 kV) using steel crossarm

Comparing system with FRP crossarm to steel crossarm, one may notice that the FRP crossarm clearly having a higher insulation strength compared to the tower using steel crossarm. In addition, less intense EF was found around the tower that using FRP crossarm compared to those using steel crossarm It should be noted that the EF stress for configuration using steel crossarm (3.138 MV/m) exceeding the dielectric strength of air which may initiate the flashover. It shall be agreed that the configuration (combination of composite crossarm and suspension insulator) has benefited the insulation strength of the system more than configuration with steel crossarm.

C. *Effect of inclined insulator*

For towers located in high altitude terrain, the wind factors have always been a concerned [12]. The suspension insulator may incline during service in which the insulating distance will relatively reduce during inwards inclination. Provided that, the maximum inclination for 275kV and 132kV insulator are 57° and 30° respectively. Fig. 8 and Fig. 9 revealed the interaction of EF with the nearest metallic object where the magnitude was much higher than the case with non-inclined insulator.

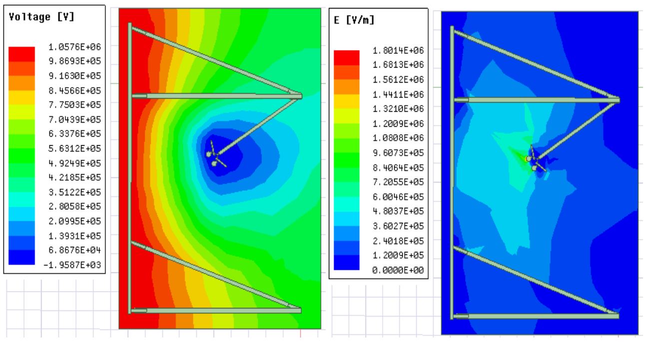


Fig 8. The voltage distribution and EF of an incline insulator for 275kV system (57° inclination)

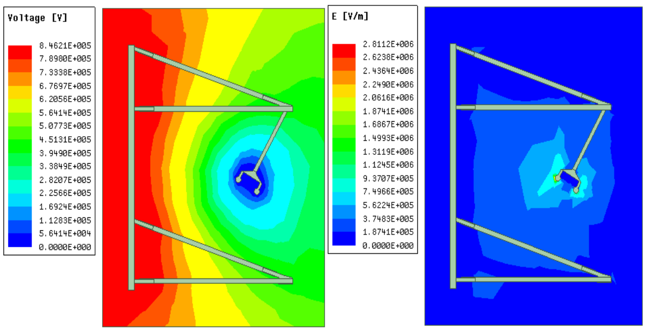


Fig 9. The voltage and electric field distribution of an incline insulator for 132kV system (30°inclination)

Table VI summarised the maximum EF found for inclined insulator during the lightning activities. In comparison with data recorded in Table IV, the magnitude of EF were found much higher due to high voltage gradient across the nearest metallic object. In these cases whereby D3 and D4 were concerned, none of the calculated value expected to result any flashover.

However, it can be agreed that the chances of flashover to happen is higher because the maximum EF obtained were approaching the dielectric strength of air (3MV/m).

TABLE VI. MAXIMUM ELECTRIC FIELD FOR INCLINED INSULATOR CASE

Tower	Case	Inclination	Applied LI (kV)	Maximum EF (MV/m)
275 kV	Back-flashover	Swing 57°	1050	1.801
			1365	3.053
	Shielding failure	Swing 57°	1050	1.802
			1365	2.344
132 kV	Back-flashover	Swing 30°	650	2.162
			845	2.811
	Shielding failure	Swing 30°	650	2.163
			845	2.812

IV. CONCLUSION

From the simulation works carried out in this study, the following findings can be drawn;

- The use of the composite crossarm has provided the extra withstanding capability and thus increased the insulation strength of the line, as opposed to the conventional steel.
- No voltage found to be exceeded the estimated CFO that could potentially cause the flashover

The estimated values of CFOs and BILs were used to theoretically show the insulation strength of each component and what it takes to cause the probability of flashover and thus affects the system performance. The focus of comparison was on the maximum voltage appeared at the crossarm (as a result of backflashover) or phase conductor (bottom part of the insulator due to shielding failure) and to determine whether those voltages were exceeded the breakdown voltage required between those nearest points. Additionally, electric field stress was also recorded as a complementary of this study. Ultimately, in this study, the insulation strength of the current configuration installed at both 275 and 132 kV are clearly benefited from the combinational strength and withstanding capability of composite crossarm and the insulator.

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