Wood and fiberglass crossarm performance against lightning strikes on transmission towers

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***Abstract*--In the early introduction of transmission lines in Malaysia, wooden crossarms were used on transmission towers where it was first introduced on 66kV lines in 1929 and later on 132kV lines in 1963. However, due to lack of supply of good quality wood, fiberglass crossarms were proposed to replace wooden crossarms on transmission towers in the Peninsular Malaysia. In this paper, an alternative solution to replace wood is discussed. This brings to the selection of Fiberglass Reinforced Polymer (FRP) as an alternative material. Simulation works using SIGMA SLP is presented to demonstrate the voltage stresses of each phase (top, middle and bottom of the crossarm). The simulation explaines the defects found on the crossarms due to lightning strikes in a case study. In the case study, the top phase was found to be most affected from lightning activity, followed by the middle and bottom phases. Meanwhile, the Maxwell 3D software was used to model the wood and FRP crossarms on the effect of backflashovers (BFR) and shielding failures (i.e direct hits) resulting in the electric field, voltage distribution and also energy dispersion along the crossarm. From the result, highest stresses were observed to be at the metal plates connecting crossarms to the tower body and the insulator strings. Therefore, to avoid similar recurrence, an extra protective layer can be applied at the joint plate or metal connection to ensure the crossarm withstands direct or indirect strikes from lightning activities. The protective layer can be of special coating material which can also enhance the crossarm performance against airborne types of contamination.**

***Keywords*: Crossarm, Transmission lines, lightning, fiberglass crossarm, FRP.**

I. Introduction

In Tenaga Nasional Berhad (TNB), Chengal wood (Neobalanocarpus) were used as crossarrms on 132kV suspension towers in 1963 after a successful performance was recorded on 66kV towers which was first commissioned in 1929 [1]. The wood crossarm was selected based on its excellent mechanical strength and good arc-quenching performance during lightning strikes [2–4]. However, in the late 90s it was found that matured Chengal can no longer be found easily available to make good quality crossarms. It was also found that these old wood started to fail due to aging after more 24 years of service [5]. Much later, in 2010, a defective wood crossarm was found after only 14 years of service. The crossarm was found failed due wood natural defect [5]. Few other cases was also reported which has created an urgency for finding alternatives to wood crossarm. In this paper, a comparison is made between 3 alternatives where fiberglass crossarm was chosen to replace the existing wood crossarm. Then, a case study on fiberglass crossarm is presented.

II. Finding the alternatives

The use of wood as crossarm was believed to be superior due to the arc quenching property which enables it to quench the arc initiated from lightning strikes [2]. However, several cases were reported on failed crossarm due to lightning strikes (see Fig. 1) after a direct hit from lightning.

Fig. 1. Failed wooden crossarm due to lightning strike
(Picture courtesy of TNB Asset Maintenance from 132 kV Kuala Krai to Gua Musang line outage due to lightning)

As a first step to find alternative to wood, few selected materials were considered which includes: compacted chip wood, Fiberglass Reinforced Polymer/Plastics (FRP) crossarm and braced post Silicon Rubber.

TABLE I.
ALTERNATIVE SOLUTION TO WOOD CROSSARM

Option no.	#1	#2	#3
Material	Compacted chip wood	FRP crossarm	Braced post SiR
Weight	Very heavy	Light*	Heavy
Expected service life	5 – 10 years	Up to 15 years*	Up to 10 years
Difficulty of installation	Easy	Very easy*	Complicated
Cost	Cheap*	Medium	Expensive
Tower modification is necessary?	No*	No*	Yes

From Table I, FRP crossarm (Option #2) was found most suitable as it provides the most favorable solution. This is evident when it allows direct replacement on the existing towers without further modification on the tower attachment fittings. In electric utilities, direct replacement allows maximizing the use of existing assets, therefore providing huge opportunity for revenue and return.

The earliest use of composite fiberglass material as a transmission tower crossarms was presented by King Jr. et al. in 1987 [6]. S. Grzybowski and E. B. Jenkins, 1993 [7] then in their study presented successful electrical performance of 115kV crossarm which shows no large difference of flashover voltage between aged crossarm and crossarm stored outdoors. Later, Duratel, 2011 discussed the successful use of Fiberglass Reinforced Polymer (FRP) as an alternative to wood poles in the United States. The use of composite fiberglass material is becoming more popular that attracts utilities to explore this option in replacing wood material [7–9].

In TNB, the first pilot project was deployed in 1999 on 132kV Pekan to Tanjung Batu line where 3 sets of FRP crossarms were installed on a the top, middle and bottom phase of the selected tower. After 6 years in operation, the crossarms were re-tested in accordance to IEC 60060-1 (see Fig. 2).

Fig. 2. Test set up for dielectric test on 275kV FRP crossarm

The dielectric test results are presented in Table II;

TABLE II
DIELECTRIC TEST RESULT FOR 275KV CROSSARMS

Test item	Test Name	Minimum BIL* requirement	Result
Wood crossarm	**LIWV (Dry)	1050kV	1186kV
	LIWV (Wet)	1050kV	1156kV
FRP crossarm	LIWV (Dry)	1050kV	1355kV
	LIWV (Wet)	1050kV	1341kV

*BIL: Basic Insulation Level
**LIWV : Lightning Impulse Withstand Voltage

From Table II, an excellent performance was observed on FRP crossarm comparing to wood especially under wet condition. For both dry and wet condition, FRP crossarms recorded higher withstand value against lightning impulse whereby under dry condition, FRP crossarms recorded 14% higher BIL value compared to wood and 16% higher under wet condition. It was found that the water repellant property in FRP crossarm material which allowed this added advantage.

The pilot project was found successful, thus kick starting further installation on other 132kV and 275kV towers in TNB system (see Fig. 3).

Fig. 3. Installation of FRP crossarms on 132kV (left) and 275kV (right) towers

III. CASE STUDY

After few years of installing FRP crossarms on transmission towers, several defects were found and reported. One of those are on a 275kV tower where surface tracking was found on the top and middle crossarm, closer to the tower body [11]. Affected tower was located in palm oil plantation area (see Fig. 4) where air pollutant from fertilizers could promote to surface contamination on the exposed crossarms.

Fig. 4. Surrounding area of T105

A. Line details

Table III describes the transmission line details where crossarm defect was found while Fig. 5 describes the tower geometry;

TABLE III.
LINE DETAILS

Description	Details
Line voltage	275kV
Line name	Gelang Patah to Bukit Batu
Tower number	T105
Date of crossarm installed	June 2011
Date of defect found	20th May 2013
Insulator CFO	1050kV
Type of soil	Agricultural
Typical ground resistance (TFR)	10Ω

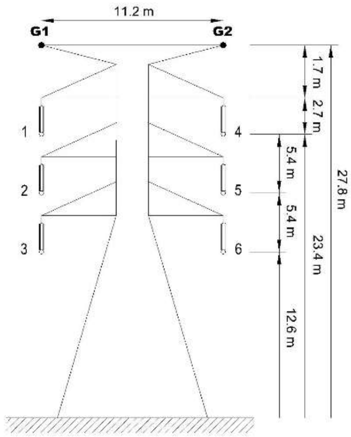


Fig. 5. 275kV tower geometry

B. Historical lightning activities

From the LDS, Ground Flash Density (GFD) map was obtained to represent historical lightning activities along the line (duration of observed year is from 2004 until 2011). The GFD map is shown in Fig. 6 where prominent stroke level of up to 20 flashes per km^2 per year was observed (see Fig. 6). For T105, GFD level is from 10 to 14 flashes per km^2 per year.

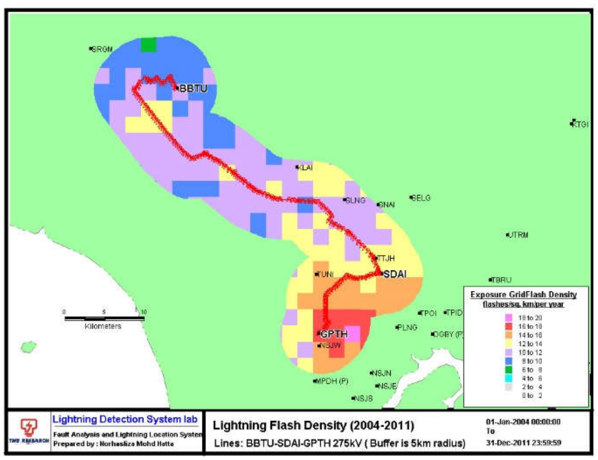


Fig. 6. GFD map for 275kV Gelang Patah to Bukit Batu line

To analyze the most possible stroke causing the crossarm defect, a set of stroke data was collected via TNB Lightning Detection System (LDS). All strokes captured within the crossarm service period were observed i.e from when the crossarm being installed, until the defect was found i.e June 2011 until May 2013.

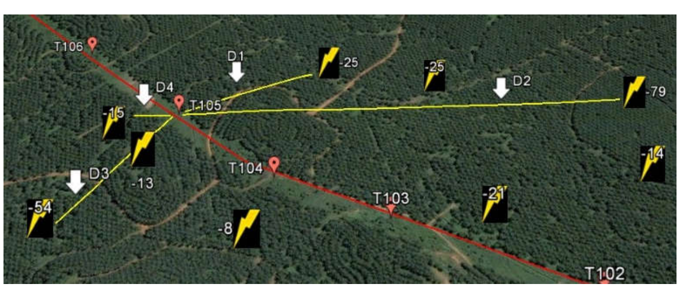


Fig. 7. Strokes nearby T105

In Fig. 7, ten strokes were found within 1 km radius from T105, where the peak current values are: 8kA, 10kA, 13kA, 14kA, 15kA, 21kA, 25kA, 25kA, 54kA and 79kA. All strokes are of negative polarities.

C. Analysis of crossarm defects

Fig. 8 and Fig. 9 shows the surface tracking on fiberglass crossarm from the top and middle crossarm of T105 respectively. It is observed that the top crossarm experienced more damage compared to middle crossarm. The tracking occurred on the body side of the tower where it started from the tip of the metal fittings. From naked eye observation, the resin was found burnt by the electrical tracking and formed a charred path, creating some cavities which revealed the glass structure [11]. No tracking was found at the bottom crossarm.

Fig. 8. Surface tracking at top crossarm

Fig. 9. Surface tracking at middle crossarm

Researchers from the University of Leicester doing studies on understanding electrical degradation on HV insulation materials shows similar tracking pattern [12].

IV. SIMULATION AND MODELING

To investigate the electrical properties along crossarm surface during lightning occurrence, 2 software: SIGMA SLP and Maxwell 3D were used.

A. SIGMA SLP

In SIGMA SLP, a single stroke study was applied on the modelled tower as per Fig. 5 to investigate the peak value of the voltage for each top, middle and bottom crossarm. Stroke currents were applied at the earthwire crossarm and voltage were measured across the insulator string for each crossarm (top, middle and bottom). Four strokes value were selected from the ten nearby observed strokes within 1 km radius to the tower T105, which were explained in section III-B. The strokes are in Table IV:

TABLE IV
LIGHTNING STROKE PEAK CURRENT NEARBY T105

Stroke No.	Distance from T105 (m)	Peak (kA)
D1	300	25
D2	870	79
D3	289	54
D4	90	15

Fig. 10 until Fig. 13 shows the simulation results where highest voltage stress was observed at the top crossarm, followed by the middle and bottom crossarms. From the results, peak value of the voltage across insulator when 15kA peak lightning current impulse was applied was less than 300kV. Slightly more than 300kV peak surge was detected when 25kA peak current was applied. For 54kA peak current value, the peak voltage is slightly more than 400 kV and finally 500kV was observed when 79kA peak current was applied. The results explained why this line has never recorded an outage from year 2011 until 2013, which was because the BIL value was never exceeded i.e. 1050kV for 275kV line.

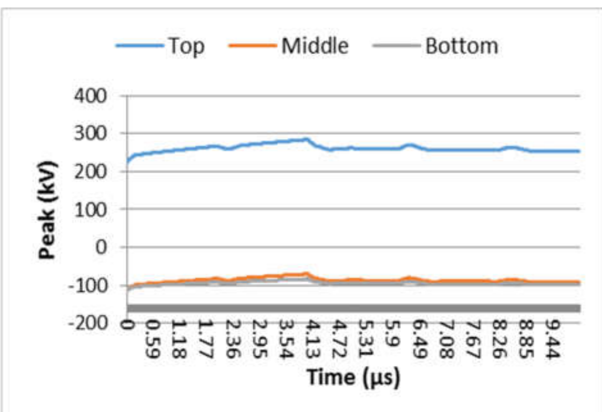


Fig. 10. Peak voltage value when 15kA peak current was applied

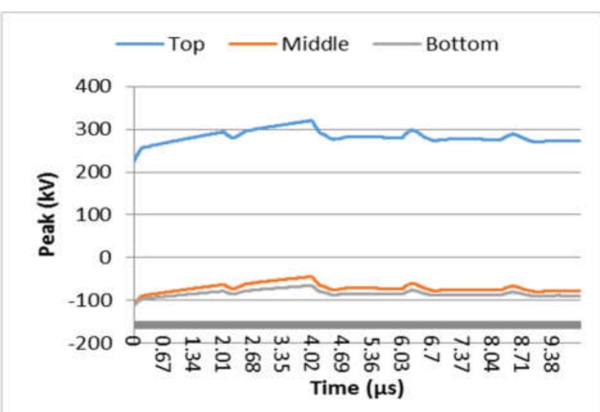


Fig. 11. Peak voltage value when 25kA peak current was applied

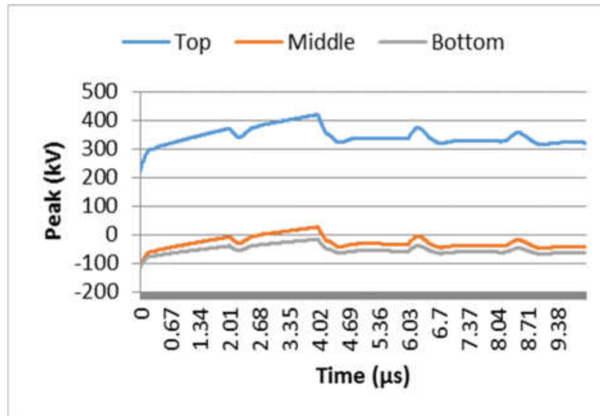


Fig. 12. Peak voltage value when 54kA peak current was applied

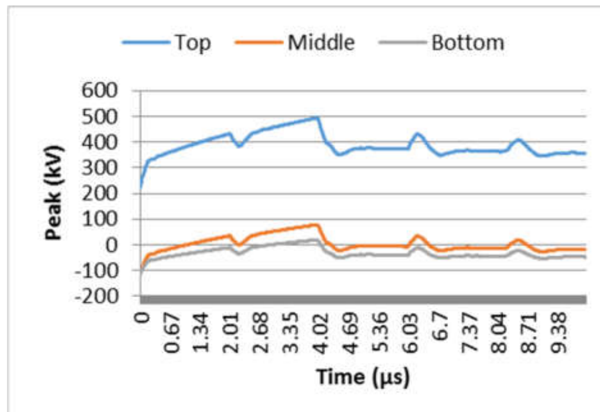


Fig. 13. Peak voltage value when 79kA peak current was applied

From SIGMA SLP single stroke study, it is summarized that;

i. Top crossarm experienced highest peak voltage during lightning striking to the earthwire crossarm. Due to the distance from the stricken point to the crossarm.

ii. Line never recorded an outage throughout the observation period because the peak voltage across insulator string has never exceeded the BIL.

B. Maxwell 3D simulation

275kV crossarm was simulated using the Maxwell 3D software to investigate the voltage, energy, electric field, and current density distribution along the crossarm. The energized part and measurement lines are indicated in Fig. 14. Under lightning stroke condition, a maximum acceptable BIL was simulated where 1,050 kV is injected at the tower body whilst the electric field and voltage distribution along the crossarm were being observed. Table V indicates the simulation parameters used in the simulation [11, 12].

The measured voltage and electric field along the measurement line are portrayed in Fig. 15 and Fig. 16 (a) and (b) respectively. From the results, it is observed that the voltage was distributed unequally along the crossarm. Also, it is noted that there is a surge of electric field observed on near the metal fittings for both wood and FRP crossarms.

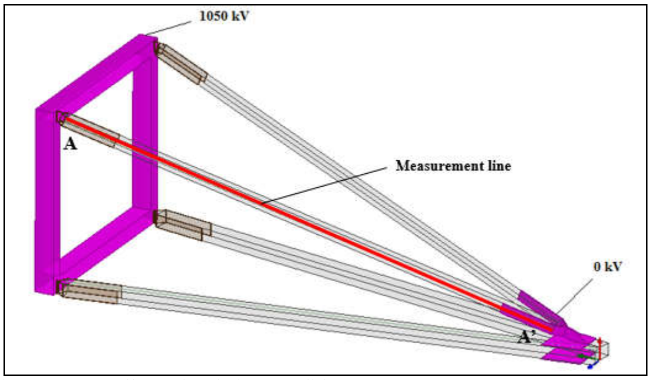


Fig. 14. Maxwell 3D simulation condition

TABLE V
MAXWELL 3D SIMULATION PARAMETERS

Structure	Relative Permittivity (εr)	Volume Conductivity (σ) S/m
Wood Crossarm	2	1x10-15
FRP Crossarm	5	1x10-16
Steel Parts	1	1x106

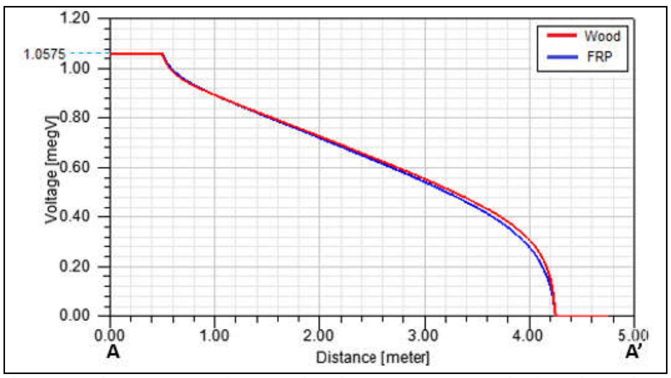
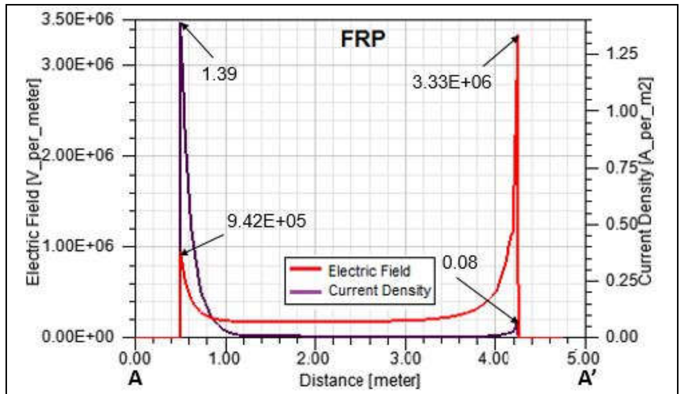
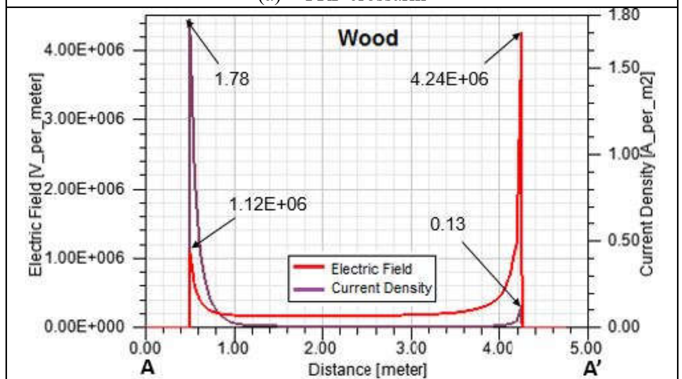


Fig. 15. Voltage measured at wood and FRP crossarm under impulse voltage 1050kV

From the measured voltage along wood and FRP crossarm, there were no significant difference in the waveshape which is shown in Fig. 15. High electric field distribution is observed at the tip of the crossarm due to the pointy shape of the crossarm, which is shown in Fig. 16 (a) and (b). This means that concentrated fields were forced into a very small area. Additionally, the vector plot of electric field for the FRP crossarm can be observed in Fig. 17. Current density distribution along crossarms (Fig. 18 & Fig. 19) were also observed where intense current density occurred near the metal fittings at the tower body which is consistent with the fault found at T105. Finally, Fig. 20 shows a gradually decreasing voltage distribution along the FRP crossarm from tower body to the tip of crossarm under impulse current of 1050kV. Similar patter is observed on wood crossarm (Fig. 21).



(a) FRP crossarm



(b) Wood crossarm

Fig. 16. Electric Field and Current Density for FRP and Wood crossarm under BIL 1050kV

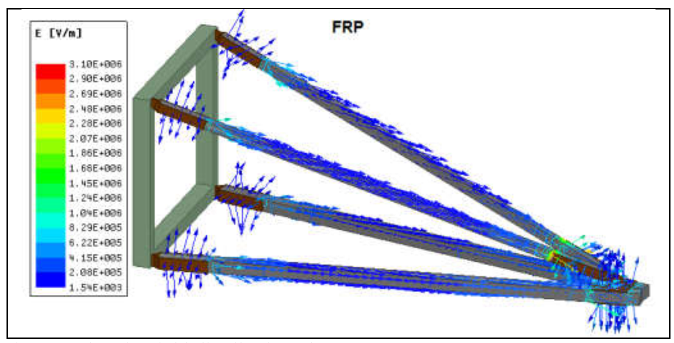


Fig. 17. Electric Field distribution along FRP crossarm

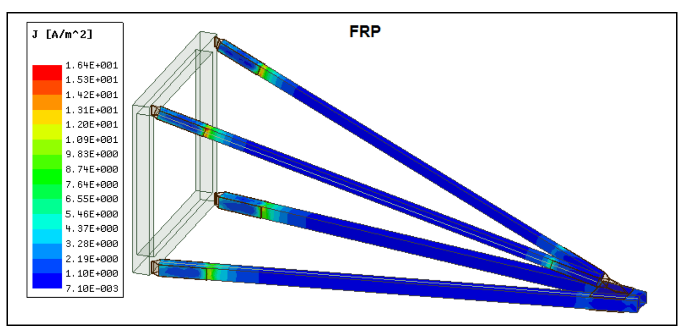


Fig. 18. Current density distribution along FRP crossarm

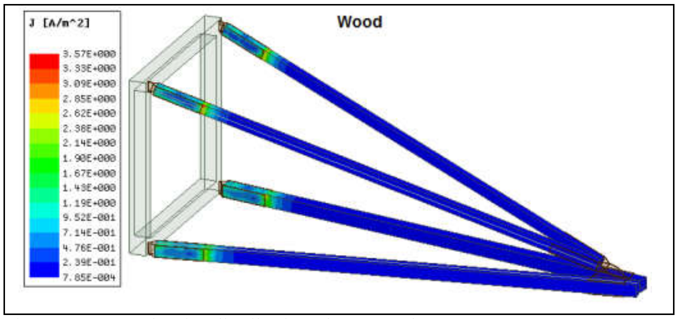


Fig. 19. Current density distribution along wood crossarm

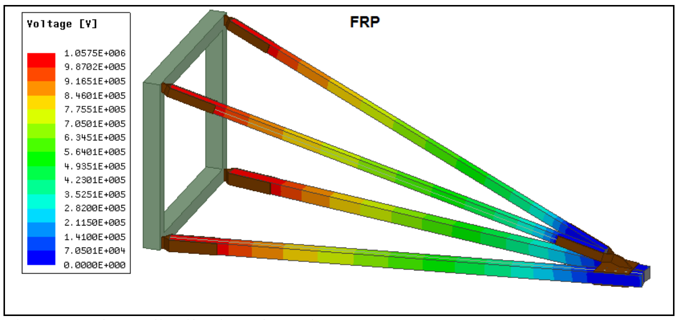


Fig. 20. Voltage distribution along the FRP cross-arm

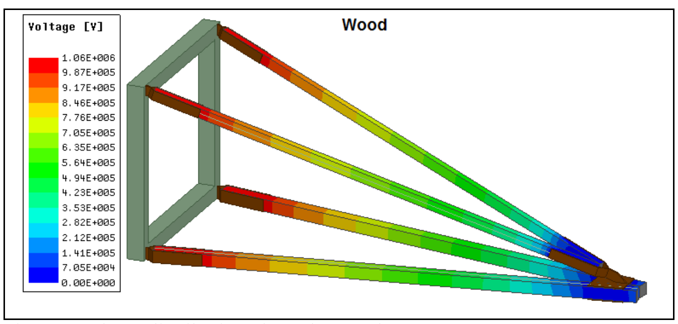


Fig. 21. Voltage distribution along the wood cross-arm

From Maxwell 3D simulation, it is summarized as follows;

i. Higher electric filed distribution is observed at the tip of the crossarm where concentrated area accumulates fields from 4 crossarm members.

ii. Large current density distribution was observed near metal fittings, close to the current injection point.

V. Conclusions

From experimental and simulation works, it can be concluded that, FRP crossarm was found to be having higher dielectric strength compared to wood crossarms. It is also concluded that, defects found on crossarm member 132kV were initiated from lightning strike, followed by surface tracking along the contaminated crossarm surface. Simulation results using SIGMA SLP demonstrated higher voltage stresses at top crossarm, followed by the middle and bottom phases. Maxwell 3D simulation demonstrated higher current density distribution near the metal fittings which also explained the surface tracking described in the case study.

VI. Acknowledgment

The author would like to thank the management of Tenaga Nasional Berhad especially the Asset Maintenance engineers for their assistance in providing technical data and information on the events.

VII. References

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