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Magnetic Field Level Improvement using the Composite Cross-Arm Method for Overhead Transmission Lines by Ansys Maxwell Finite Element Model

Matiullah Ahsan[1,*], Md Nor Ramdon Baharom[2], Zainab Zainal[3], Luqman Hakim Mahmod[1], Nor Akmal Mohd Jamail[1], Rahisham Abdul Rahman[1], Lam Hong Yin[2], Omar Abu Hasan[2], Azuwein Aida Bohari[2], Norain Sahari[2], Mustafa Ayub[4]

1 Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja Campus, 86400 Batu Pahat, Johor Malaysia
2 Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Campus, 84600 Muar, Johor, Malaysia
3 Diploma Study Center, Universiti Tun Hussein Onn Malaysia, Pagoh Campus, 84600 Muar, Johor, Malaysia
4 National Institute of Transportation, National University of Sciences and Technology, Islamabad, Islamabad Capital Territory, Pakistan

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ABSTRACT

Living near overhead transmission lines has become more common nowadays, where magnetic field radiation has always been a public concern regarding the effect of MF radiation from OTL on the occurrence probability of cancerous diseases. In addition to the increasing trend of electricity consumption, people are getting more exposed to magnetic field radiation. As an initiative, this study computes magnetic field improvement that can be achieved on existing 132 kV and 275 kV overhead transmission lines in Malaysia by implementing a composite cross-arms method. Computations are carried out through Ansys Maxwell 2D electromagnetic simulation software using parameters based on previous researchers. The results provide up to 36% (132 kV) and 48% (275 kV) of magnetic field improvement with the composite cross-arms method. Not only does this method offer a healthier environment, but it also provides the opportunity to improve ampacity in the future.

1. Introduction

Nowadays, the construction of residential areas near overhead transmission line (OTL) systems and vice versa has become more common. The OTL conductors transmit a high amount of current that radiates a magnetic field (MF) to its surroundings. According to the International Agency for Research on Cancer (IARC) Working Group [1], prolonged exposure to MF radiation has caused concerns about adverse health effects such as childhood leukaemia. Ahlbom *et al.,* [2] and Greenland *et al.,* [3] have also published review papers on MF. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) [4] has addressed such concerns worldwide, leading to the public MF exposure guideline limits of 100 μT at ground level.

* *Corresponding author.*
E-mail address: he210038@student.uthm.edu.my

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According to Ahsan *et al.,* [5] have provided MF measurements from OTL systems near residential areas, which recorded less than two µT far below the 100 µT limits. However, with the increasing trend of electricity consumption in Malaysia, the MF radiation level might increase. In that case, there is a need to find an alternative to reduce MF radiation from existing OTL as an initiative to provide a healthier environment in the future.

According to Medved *et al.,* [17], based on Biot-Savart's Law, MF strength is proportional to the distance from the MF source. The further away the point of MF measurement from the source of MF, the lower the MF strength will be.

Kimoto *et al*., [8] have stated that, to reduce MF radiation from OTL systems, the distance of conductors from ground level can be increased by implementing the composite cross-arms (CCA) method. This method allows insulator length elimination while still providing sufficient electrical clearances. By eliminating insulators, conductors are elevated from ground level, reducing MF radiation.

Ab Ghani *et al.,* [16] research findings state that the MF radiation level from OTL systems can be determined through measurements and computations. While conducting measurement is essential to acquire the exact MF level readings in an area, the computations approach offers unlimited conditions as desired. In this research, the desired shape is computing the MF radiation level from the typical 132 kV and 275 kV OTL systems in Malaysia, operated at a maximum conductor working temperature (CWT) of 75°C, with and without CCA method implementations. Computations are carried out using Ansys Maxwell simulation software, which offers a low-frequency electromagnetic field solver. Rowland *et al.,* [10] and Zachariades *et al.,* [11] have published articles papers on low-frequency electromagnetic field solvers [10,11].

Kopsidas *et al.,* [14] research indicates that the overhead transmission line (OTL) system cross-arms are the part that supports insulators and conductors, which are also crucial in providing sufficient electrical clearances to avoid flashover due to overvoltage.

Additionally, according to Vornicu, Lunca and Salceanu [15], cross-arms are made from the same material types used to construct OTL towers. However, researchers have ingeniously used composite insulating material to develop a newly designed composite cross-arm (CCA). Using a composite insulating material, a CCA can be mounted directly to the tower body with the conductors attached to the insulator head. It will eliminate the conventional insulator's vertical length, increasing the conductor distance from ground level (as illustrated in Figure 1). Hence, magnetic field (MF) radiation from the ground level can be reduced. Kopsidas *et al.,* [14] and Vornicu, Lunca and Salceanu [15] have published articles on CCA.

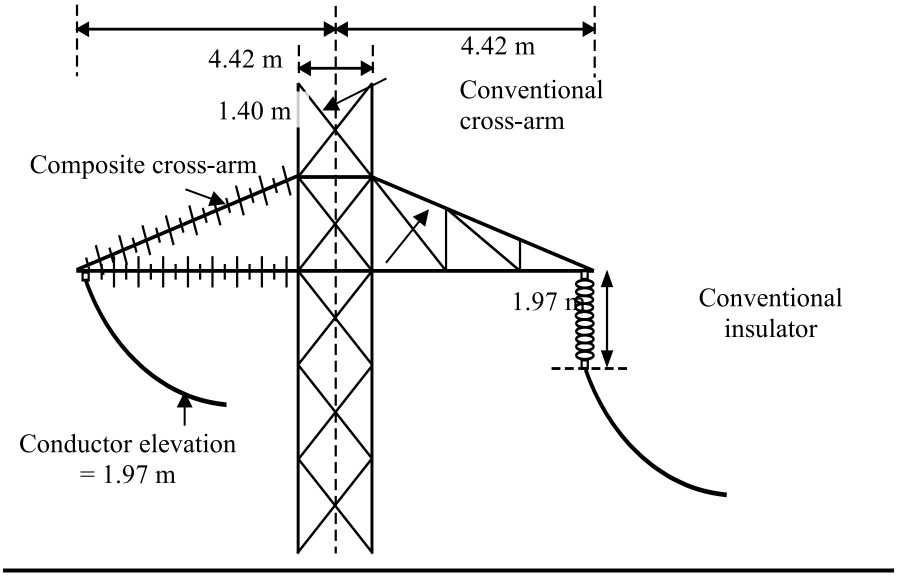

Fig. 1. Conductors position comparison with and without the implementation of composite cross-arms for 132 kV OTL

2. Historical Review of Composite Cross-Arm

High-voltage transmissions began installing composed cross-arms in the mid-60s. In the 1970s, Kimoto *et al.*, [8] developed a prototype composite cross-arm for a 345 kV EHV transmission line. Figure 2 shows Kimoto's version of the twin-arm and quadrant types. These designs don't need extra insulators.

In 1998, Medved *et al.*, [17] published their work on insulators as cross-arms for a new bi-dimensional steel tower structure. This new tower design is physically compact and reduces right-of-way, magnetic field level and tower/foundation costs by up to 10%

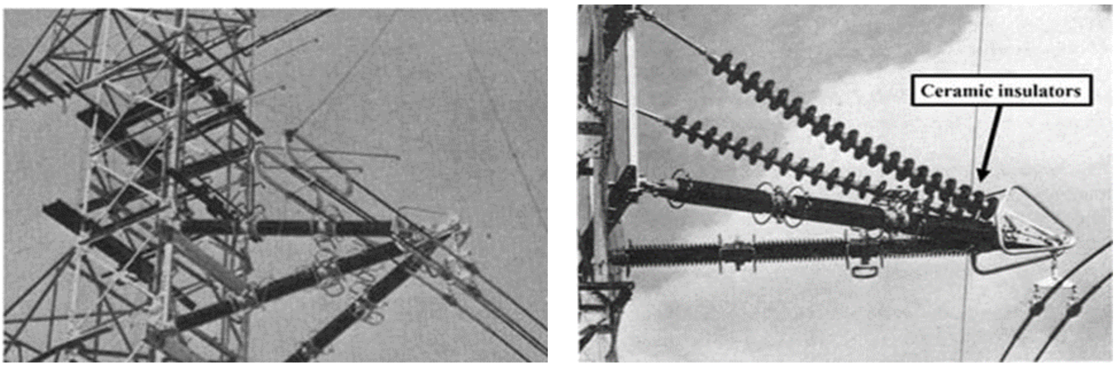

Fig. 2. Kimoto's version twin composite cross-arm type

Tenaga National Berhad (TNB) Malaysia is applying a technology similar to the full composite cross-arm type to build power transmission lines in newly developed areas, as shown in Figure 3 [18].

Fig. 3. Front view of a compact tower

However, this technology could only be utilized in newly developed areas and not on the existing lines. In 2014, Rowland *et al*., [10] developed a composite cross arm that can increase lattice tower capacity by 25%. Additionally, this method can be used to build compact towers, such as reducing the height of conventional 400 kV towers. Using a modern Electromagnetic-field calculation method, Goffinet, Gutman and Sidenvall *et al*., [13] published a paper highlighting how critical it is to design the end fitting and placement of the grading ring or arcing horn for long-term performance.

In 2019, Gul *et al*., [20] measured the lightning flashover characteristics of a full-scale transmission tower. They concluded that the composite cross-arms installation degraded the lightning-withstand and magnetic field levels.

Additional history of the advancement in insulated cross-arm technology in the transmission lines is summarized in Table 1.

Table 1
Advancement of Insulated cross arm based on yearly

Year	Country	Material	Voltage ratings	Contribution	Limitations
2008	America	Fibre cross	115 kV	In dry conditions, fibreglass cross arms have higher CFO voltages than wood and in wet conditions, they have higher voltages.	Longevity and durability may be problematic.
2009	China	Composite cross arm	110 kV and 210 kV	Lightning protection and anti-pollution flashover capabilities for transmission lines have been improved. Transmission corridor widths have been decreased.	Water repellence, electric arc resistance and erosion resistance are weak.
2010	United Kingdom	A new insulated cross invented	400kV	The insulated cross arm is resistant to buckling, lightweight, eliminates conductors and swings and forms a rigid spine via pultrusion.	Protection against transient overvoltage. Carrying HVDC using the composite cross-arm
2012	United Kingdom	Composite cross arm	400kV	It's a possible way to upgrade existing transmission towers.	During the most electrical stress on the composite insulators, how does the composite cross-arm work when wet or polluted?

2013	United Kingdom	Dual composite cross-arms	231kV	A leakage cross-arm compression has a high current profile.	The retrofitting of the new cross-arm to an existing tower must be studied.
2014	China	Composite cross arm	750kV	Composite cross-arms have the highest potential distribution.	Sheet damage is caused by high electric fields near line ends and silicone rubber sheaths without grades and shields.
2017	China	Composite cross-arm with three shape towers	500kV	Technology- and cost-wise, the compact composite cross-arm tower is the most effective.	Longevity and durability may be problematic.
2018	Malaysia	GFRP pultruded	400kV	High-quality surface, lightweight, mouldable.	Cyclic wind loads might cause tiny fractures in the crossarms. Hydrothermal aging of composites is caused by extreme heat and moisture.
2019	China	Composite cross-arm with suspension porcelain insulators	500kV	Composite cross arm.	Electric fields are not distributed uniformly along the composite insulator.
2020	Malaysia	Green composite material	500kV	Superior mechanical prowess and green technology.	There is still proposed research.
2021	China	Composite cross arm with CMCA tower	500KV	Lighting levels are superior to conventional steel towers for the CMCA tower.	Severe environmental problems include load, dynamic creep and electric stress.
2021	Malaysia	Composite cross arm (PGFRPC).	500kV	Their strengths are mechanical toughness and stiffness, long-term deterioration resistance, thermal insulation capacity and sound construction.	Composites are ageing hydrothermally because of extreme heat and moisture.
2021	Malaysia	PGFRPC honeycomb-filled structure with composite cross braces	500kV	An economical and highly efficient method of manufacturing.	Composites age hydrothermally because of extreme heat and moisture.

3. Magnetic Field Simulation Model using Ansys Maxwell Software

Previous researchers have proved the reliability of Ansys Maxwell software in determining the magnetic field (MF) radiation level from overhead transmission line (OTL) systems [20]. This research is based on the work published by Vornicu, Lunca and Salceanu [15], which observes magnetic field (MF) radiation levels from OTL system conductors with and without implementing the composite cross-arms (CCA) method. The basic Ansys Maxwell simulation design.

Luqman *et al.,* [19] presented findings that the 75°C of CWT is the standard practice for the final temperature parameters in both equations. Additionally, the transposed conductor phase configurations (RYB – B’Y’R') are considered due to their ability to provide the lowest peak MF level in comparison to the un-transposed conductor phase configurations (RYB – R’Y’B'). Ahmed *et al.,* [22]; Yow, Abdul Razak and Alheemar [23]; Abu, Ab Aziz and Noor [24] and Azmar and Raja Ma [25] also published an ampacity and sag.

A simple 2-dimensional (2D) finite element model is used to compute the root-mean-square (RMS) MF flux density generated by a 132 kV double-circuit OTL system using Ansys Maxwell 2D electromagnetic simulation software. The only OTL components modelled are the conductors acting as the MF radiation source. Conductors are modelled as single infinite aluminium cylinders with electrical conductivity, σ_c of 3.8×10^7 S/m and relative permeability equal to 1. The boundary conditions applied are of a Balloon type, which mimics the space extending to infinity, which consists of the air and soil, which has conductivity, σ_c of zero and 0.05 S/m, respectively and relative permeability, μ for both equals 1. Table 2 summarizes the parameters used for the Ansys Maxwell 2D simulation model.

Table 2
Parameters used for Ansys Maxwell 2D simulation model

Parameters	Values
Conductors	ACSR
Conductivity	3.8×10^7 S/m
Permeability	1
Ground	0 V
Conductivity	0.05 S/m
Permeability	1
Width	100 m
Air	1.0006
Conductivity	Null
Permeability	1
Width	100 m
Boundary type	Tangential fields
Air	Balloon
Ground	Balloon
Solution type	Eddy current
Frequency	50 Hz

Other conductor parameters are based on the typical conductors used for 132 kV (ACSR Batang) and 275 kV (ACSR Zebra) in Malaysia, as presented in Table 3 and Table 4. The conductors' ampacity and sag values provided in these tables are given based on the steady-state heat balance equation and parabolic sag equation mathematical calculations at 75°C of conductor working temperature (CWT).

The conductors' positions specified in Table 3 and Table 4 are based on Malaysia's typical 132 kV and 275 kV OTL tower dimensions without implementing CCA. The x-position indicates the conductors' horizontal distance from the OTL tower midpoint according to the cross-arm length. In comparison, the y-position shows the conductors' vertical distance according to the cross-arm height subtracted with the sum of insulator length and conductor sag. The conductors' position in the y-direction is added to implement the CCA method with the insulator lengths.

According to ICNIRP guidelines [4]. As commonly practiced in MF exposure assessment studies, MF measurements are typically taken 1 m above ground level along 40 m of right-of-way (ROW). As the model is solved using an eddy current solver, which allows the calculation of MF oscillating with 50 Hz of frequency, results are generated in instantaneous magnetic flux density values over a 20 ms period. According to Vornicu, Lunca and Salceanu [15]*, to obtain the RMS magnetic flux density, these instantaneous magnetic flux density profiles are exported into Microsoft Excel and average values of magnetic fields are calculated*.

Table 3
132 kV overhead transmission line system simulation model parameters without composite cross-arms implementation

Parameters	Values		
Conductors'	Circuit 1		
Position	x	y	Phase
R	- 4.42 m	23.85 m	0°
Y	- 4.42 m	20.15 m	120°
B	- 4.42 m	16.45 m	240°
	Circuit 2		
B'	4.42 m	23.85 m	240°
Y'	4.42 m	20.15 m	120°
R'	4.42 m	16.45 m	0°
Type	ACSR Batang (18/7)		
Ampacity	2111 A		
Sag	8.36 m		
Diameter	24.16 mm		
Insulator length	1.97 m		

Table 4
275 kV overhead transmission line system simulation model parameters without composite cross-arms implementation

Parameters	Values		
Conductors'	Circuit 1		
Position	x	y	Phase
R	- 6.50 m	30.19 m	0°
Y	- 6.50 m	22.68 m	120°
B	- 6.50 m	15.17 m	240°
	Circuit 2		
B'	6.50 m	30.19 m	240°
Y'	6.50 m	22.68 m	120°
R'	6.50 m	15.17 m	0°
Type	ACSR Zebra (54/7)		
Ampacity	2552 A		
Sag	6.17 m		
Diameter	28.62 mm		
Insulator length	4.17 m		

4. Magnetic Field Simulation Results

The magnetic field (MF) distribution level from ACSR Batang for the 132 kV overhead transmission line (OTL) system at 75°C of conductor working temperature (CWT) within the span of 40 m right-of-way (ROW) at 1 m above ground level is presented in Figure 3. Upon observation, the MF level is the highest at the midpoint between conductors Circuit 1 and Circuit 2. The MF level decreases as the distance from the midpoint increases towards the edge of ROW (further from conductors). Without the implementation of composite cross-arms (CCA), the highest MF level is recorded at 32.43 µT (midpoint), with the lowest recorded at 4.29 µT (edge of ROW). With the implementation of CCA, the highest MF level is recorded at 20.90 µT (midpoint), with the lowest recorded at 3.75 µT (edge of ROW). Based on these numbers, implementing CCA on 132 kV OTL systems reduces MF by up to 36% (midpoint) and 13% (edge of ROW) compared to without CCA.

Similarly, the MF distribution level from ACSR Zebra for the 275 kV OTL system at 75°C of CWT within the span of 40 m right-of-way (ROW) at 1 m above ground level behaves in the same manner as presented in Figure 4.

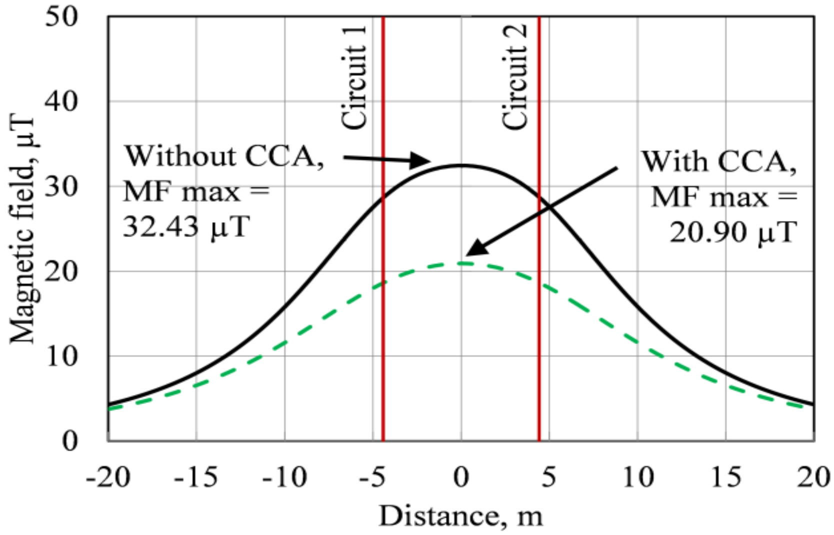

Fig. 4. Magnetic field distribution from ACSR Batang for 132 kV overhead transmission line systems at 1 m above ground level

In this case, without the implementation of CCA, the highest MF level is recorded at 42.06 µT (midpoint), with the lowest recorded at 10.79 µT (edge of ROW). With the implementation of CCA, the highest MF level is recorded at 21.72 µT (midpoint), with the lowest recorded at 7.83 µT (edge of ROW).

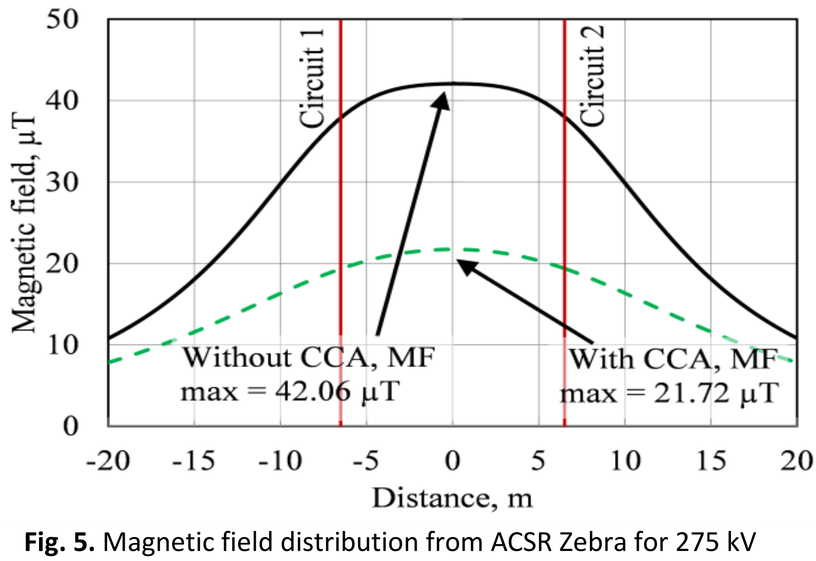

Fig. 5. Magnetic field distribution from ACSR Zebra for 275 kV overhead transmission line systems at 1 m above ground level

These numbers show that implementing CCA on the 275 kV OTL systems allows MF reduction up to 48% (midpoint) and 27% (edge of ROW). The summarization of the MF distribution level for both OTL systems with and without the implementation of CCA is presented in Table 5.

Table 5
Summarization of magnetic field distribution level for 132 and 275kV systems with and without composite cross-arms implementation

OTL type	Magnetic field, µT			
	Without CCA		With CCA	
	Midpoint	Edge	Midpoint	Edge
132 kV	32.43	4.29	20.90	3.75
275 kV	42.06	10.79	21.72	7.83

6. Conclusions

This research has been focused on the computation and analysis of magnetic field (MF) level improvement using the composite cross-arms (CCA) method for existing 132 kV and 275 kV overhead transmission line (OTL) systems in Malaysia. The computations have been carried out through Ansys Maxwell simulation software based on the 2D finite element method. According to these computations, implementing CCA on existing OTL systems allows the reduction of MF radiation at ground level. CCA eliminates conventional hanging insulators while implementing composite-based insulation material on the cross-arms. Implementing this design will elevate conductors according to the length of eliminated insulators, significantly influencing the MF reduction percentage. For instance, CCA implementation on the 275 kV OTL system provides a higher MF reduction of up to 48% (at midpoint) compared to 36% (at midpoint) for the 132 kV OTL system. It is probably due to the larger insulator lengths eliminated of 4.17 m (for 275 kV OTL) as opposed to 1.97 m (for 132 kV OTL). Nevertheless, conductors' elevation from ground level due to the elimination of insulator lengths will reduce MF radiation at ground level and improve ground clearances, thus allowing for more ampacity.

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