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Design and Performance Evaluation of FRP Cross Arm for Transmission Line Towers

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The technology of compaction of power transmission lines is being increasingly adopted by power industry to effectively make use of the Right of Way (ROW). For technical, aesthetic and economical reasons, our future transmission lines will have to be built with new design concepts using new materials. An attempt was made to build the transmission line tower cross arm with pultruded sections of Fibre Glass Reinforced Plastic (FRP) as a substitute for steel. The metallic towers have been deteriorating and corroding as a result of being in hostile environment i.e., wind, rain and salty environment etc. This paper describes the mechanical behaviour of FRP tower cross arm assembly simulated using Finite Element Analysis (FEA) software and compared with experimental results.

Keywords : *compact transmission, cross arm, Right of Way*

1.0 INTRODUCTION

Nowadays by developing the cities and industrial centers will cause the growth of load and so the need of electrical energy. Sometimes it requires installing new Extra High Voltage (EHV)/Ultra High Voltage (UHV) transmission lines to meet the ever increasing demand of power. Accelerated urbanization and industrialization has forced the power industry on limiting the size of the way-leave corridor. The transmission lines Right of Way (ROW) is a strip of land that is used to construct, operate, maintain and repair transmission line facilities. The transmission line towers are needed to keep the power conductors at a safe height from the ground level. However, difficulties are being experienced by power utilities in finding corridors for new EHV and UHV transmission lines due to stiff resistance from the public for construction of these lines due to their adverse visual impact and electromagnetic interference, and also due to density of population in the urban areas, obtaining forest clearances and nature preservation philosophy. Further transmission line structures constitute substantial component of transmission network and call for heavy investments about 35% to 40% of total transmission line cost [1]-[2]. One of the methods is to optimise the use of existing transmission lines by upgrading/up rating using tower with polymer insulator cross arms. Design and development of transmission line towers with polymer composite materials is one such new concept being attempted. The metallic towers have been deteriorating and corroding as a result of being in hostile environment i.e., wind, rain and salty environment. to prevent further deterioration and the corrosion, composite materials will be used as an alternate

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materials to steel. FRP cross arms are light in weight about one-fifth of steel, transportation costs are reduced and these cross arms are very easy to erect on the tower strructure. Due to good insulating property of FRP, the birdcage problem is eliminated and flashing of insulators (particularly in coastal areas) is minimized. Due to corrosion resistance properties, no painting is required, thereby saving periodical costs and labour. Unlike steel, fibreglass is a non-conductive material allowing the reduction or elimination of insulator strings which makes the towers cheaper to construct[3]. The non-conductive material also improves the safety of hotline maintenance. The FRP insulated cross arm will have twin advantages of supporting (load bearing) the power conductor and providing necessary insulation is done by newer development concept and hence paves way for complete compaction. Composite material towers can be shorter than steel towers and arranged in closer proximity to each other, allowing for more efficient use of Right of Way (ROW) along the transmission lines. The more compact placement of conductors could also reduce the ground level electromagnetic field (EMF) readings at the edge of the transmission line ROW because the towers are self insulating. Bringing conductors on the insulated towers closer together cancels magnetic field more effectively [4], [5], [6]. The design and performance evaluation aspects of FRP cross arms are discussed in this paper.

2.0 COMPOSITE CROSS ARMS FOR TRANSMISSION TOWERS

2.1 Polymer insulator cross arm

Overhead transmission lines require both cables to conduct the electricity and insulators to isolate the cables from steel towers by which they are supported. The insulators have conventionally been made of ceramics or glass. These materials have outstanding insulating properties and weather resistance, but have the disadvantages of being heavy, easily fractured and subject to degradation of their withstand voltage properties when polluted. In conventional steel cross arms, the functions of separating the phase conductors electrically from one another and from the tower body and also connecting the phase conductors mechanically to the tower cross arm are performed separately by the chain of porcelain insulators. Therefore to develop a insulated cross arm using new materials (non-ceramic) that would overcome these drawbacks is the need of the hour. In the case of insulated cross arm, these two functions are grouped together in one device. Because of this grouping lot of simplifications are possible in the support structure and hence it can be used for all voltage levels. They not only offer advantages in permitting compact tower design and narrow right of way but have the additional features of supporting higher mechanical loads, which are more fitting to the EHV/UHV transmission lines [7].

The technology of compaction of transmission lines is being increasingly adopted like up-grading/up-rating, narrow base towers, multi-circuit towers, tubular pole structure etc., by power industry. In general for voltage up-gradation of the existing transmission lines to next higher voltage level, we can use the existing Right Of Way, the distance of the conductor from the earth (clearance), the distance of the conductor from the tower body, and the distance between the phases and at last the least modifications in the existing tower geometry. The only practical solution is using the composite insulator cross arms. In this direction, a revolutionary new design concept has been developed by replacing the conventional steel cross arm with insulator cross arm made from polymeric composite materials. Composite cross arms have been basically designed to replace steel cross arm with porcelain insulator string [8].

2.2 Comparison of structural properties

The relative structural properties of steel and composite materials are shown in Table 1.

TABLE 1

COMPARISON OF STRUCTURAL PROPERTIES

Material	Density (g/cm^3)	Tensile strength (MPa)	Tensile modulus (MPa)	Flexural modulus (MPa)	Flexural strength (MPa)
Steel	7.80	350	193055	1450	690
Aluminum	2.60	280	68950	485	280
Composite	2.00	690	41370	140	550

From the above table, it can be seen that the composite structure will be lighter in weight for an equivalent steel structure. This is due to superior specific strength and specific stiffness properties of composite materials [9].

2.3 Constructional features

Pultrusion is a continuous process of manufacturing composite materials with uniform cross section whereby reinforced fibers in the form of roving are pulled through a resin into heated die, where the resin undergoes polymerization. The structural profiles obtained through pultrusion are lighter, stronger, non-conductive and corrosion resistant which makes them suitable for outdoor structural applications. Pultrusion is the ideal technology to produce long sections of FRP composites with design variables like weight fraction of fiber and matrix and orientation of reinforcement. The FRP cross arms are fabricated using pultrusion process with E-Glass fiber 4800 TEX in roving form (75% of total volume) as a reinforcement and epoxy resin (25% of total volume) as matrix materials for building the cross arm elements. Adhesive joining method was used to join the base portion of cross arm members to the end fittings. Mechanical joints were used to join the main members of the FRP cross arm to the strain plate and bracing members to the main members of the cross arm [10].

The only metallic part of composite cross arm is the end fitting and cross arm tip with strain plate for purpose of application of loads and mounting on the tower structure. The structural arrangement of composite cross arm fabricated through pultruded solid square section for a typical 132 kV tower FRP cross arm is shown in Fig. 1.

FIG. 1 ASSEMBLY OF FRP CROSS ARM

3.0 FINITE ELEMENT ANALYSIS OF FRP CROSS ARM

Finite element analysis of FRP cross arm was carried out using ANSYS general purpose FEM software. A simple element model containing all the four members of cross arm was checked for force distribution in each of the members of the cross arm. In the analytical studies, three structural profiles like solid square section, hollow square section and rectangular section were considered for modeling the FRP cross arm. For the purpose of comparison of analytical results, only solid square section of FRP material was considered with steel angle section. The SHELL 63 element which has six degrees of freedom at each node is found to be ideal to model the cross arm, with suitable boundary condition [11]-[12].

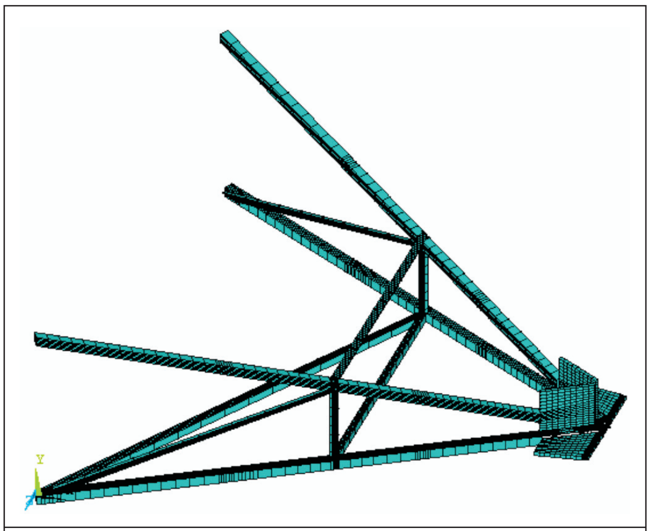

FIG. 2 GEOMETRIC MODEL OF FRP CROSS ARM

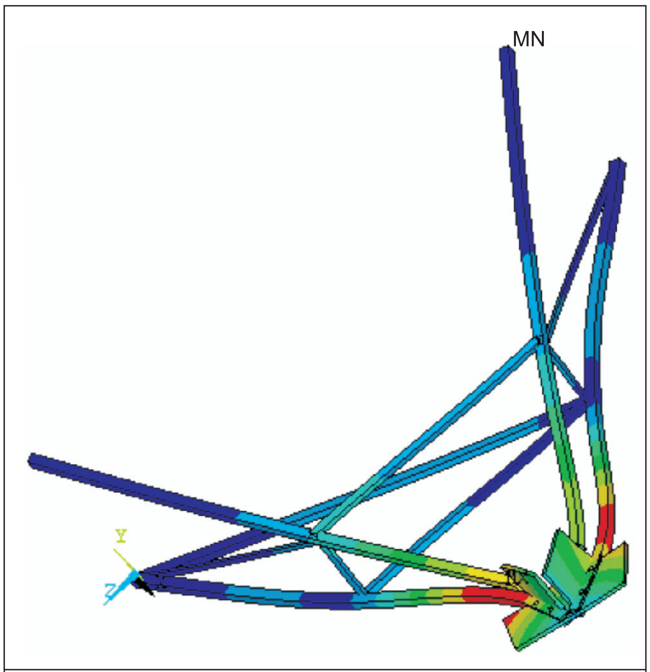

FIG. 3 DEFLECTED SHAPE OF FE MODEL

The geometric model and finite element model of FRP cross arm with solid square cross section considered for Finite Element (FE) analysis are shown in Figs. 2 and 3 respectively.

The following material properties were considered for the Finite Element analysis. The isotropic material properties for conventional steel cross arm are :-

Young's Modulus	E	:	200 GPa
Poison ratio	γ	:	0.3
Density	ν	:	7800 kg/m^3

The orthotropic material properties for FRP cross arm are :-

E_{1-1} : 50 GPa, E_{2-2} : 16 GPa, E_{3-3} : 16 GPa,

$\gamma_{1-2\,:}$ 0.3, $\gamma_{2-3\,:}$ 0.23, $\gamma_{1-3\,:}$ 0.23

$G_{1-2\,:}$ 4 GPa, G_{2-3} : 4 GPa, G_{1-3} : 4 GPa.

The following loads were applied at the appropriate nodes in the Finite Element model to simulate the loads acting on the cross arm through strain plate.

14850 N along longitudinal direction (Z)

2500 N along transverse direction (X)

3400 N along vertical direction (Y)

The Finite element model of FRP cross arm was analyzed and the stress distribution pattern and displacements at the tip of cross arm were compared with experimental results.

4.0 EXPERIMENTAL WORK

4.1 Test Set up

The FRP cross arm was mounted horizontally on steel tower body for supporting purpose. The typical test setup for mechanical load test on 132 kV FRP cross arm is shown in Figs. 4 and 5.

FIG. 4 TEST SET UP FOR 132 kV FRP CROSS ARM

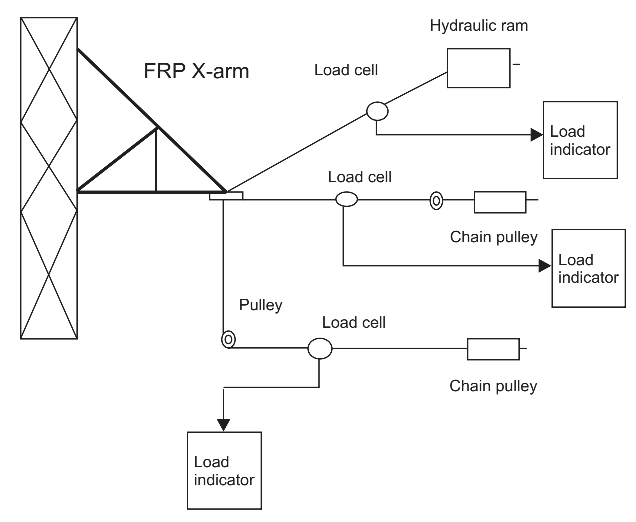

FIG. 5 SCHEMATIC DIGRAM OF TEST SET UP FOR FRP CROSS ARM

4.2 Loading condition

The full scale FRP cross arm was tested for mechanical strength as per IS:802 (Part-III): 1978 for various loading conditions listed below:

a) Reliability condition

b) Security condition

c) Safety condition

4.3 Performance during test

Design loads as shown in Table 2 were applied gradually on the FRP cross arm in such a way that there was no impact loads induced on the cross arm. These loads were applied in three directions in steps of 50%, 75%, 90%, 95% and 100% of design loads. Deflection on the tip of cross arm was recorded at the end of each steps of loading using optical theodolite. The cross arm was kept under observation for any visible sign of failure by holding it for two minutes for all intermediate steps of loading and five minutes for 100 % loads [13]-[14].

During the waiting period there was no sign of visible failure of cross was observed. The cross arm had successfully withstood the design loads, a small crack was initiated at the joint while increasing the loads further.

TABLE:2

LOAD VALUES (IN N) FOR 132 KV TOWER

Sl. No.	Test condition	Vertical	Transverse	Longitudinal
1.	Reliability	5000	6100	—
2.	Security	3400	2500	14850
3.	Safety	11900	200	—

4.4 Deflection values

The deflection at conductor end of the cross arm in longitudinal direction was recorded at different stages of loading. The maximum deflection was observed under security loading condition. The deflection values recorded in each stage of loading compared with Finite element analysis and shown in Fig. 6.

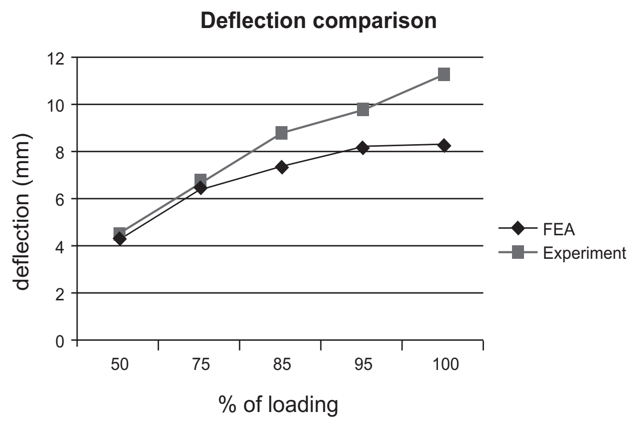

FIG. 6 COMPARISON ON DEFLECTION OF FRP CROSS ARM

From the above plot, as the intensity of loading increases the deflection in actual testing is slightly more which can be accounted for structural connections and non-linearities present in the FRP cross arm. Further the trend implies that FEA method can be used to analyze the FRP cross arm.

5.0 RESULTS AND DISCUSSION

The mechanical properties like tensile strength, compressive strength, flexural strength were determined for the proposed composite material were found to be comparable with conventional steel. The maximum deflection of 11.25 mm was observed at the tip of the cross arm and maximum stress on the bottom member was 200 MPa under security loading condition. The horizontal phase clearance for 132 kV with proposed FRP insulated cross arm was found to be 3.0 m only as against 6.8 m with steel cross arm therby the Right of Way (ROW) for a typical 132 kV tower was brought down about 20%. The weight of FRP cross arm is about 20 to 25 kg only as against 150 to 200 kg of steel cross arm.

In addition, material suitable for cross arm element needs to be less water absorbing as this leads to decrease the breakdown voltage reduction in electrical properties. Average percentage of water absorption for the proposed materials were found to be about 0.038% which is within the prescribed limit of 0.05%. If the development proves successful, the traditional steel transmission tower, assembled with bolts and nuts and equipped with a chain of porcelain/ ceramic insulators could eventually become obsolete. The transmission tower of the future that are custom designed to obtain desired physical, mechanical and electrical characterictics. They will be lighter, easier to assemble and more efficient. Initially the FRP cross arm was chosen to functionally replace the steel cross arm of 132 kV/220 kV voltage levels to reduce the ROW requirement in order to achieve the compact transmission line towers.

7.0 CONCLUSIONS

The reduction of transmission corridor can be achieved by compacting the tower geometry by using insulator cross arm where stringent constraints for land occupation exist. Compact design of towers results into further reduction in width of Right Of Way. The weight of the FRP cross arm is about one fifth of the weight of the steel cross arm and this indicates that overall weight of the tower could further be minimized if the entire tower is made of FRP material. Towers using insulated cross arms of polymeric composite material will help in up-grading/up-rating of existing transmission lines.

The result of this study encourages that building the transmission line tower/cross arm with new and better materials like E-glass with epoxy/ polyester/vinyl ester resin is feasible.

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