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Development of Compact Overhead Power Transmission Line Tower using 8-legged Configuration

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Abstract

For transmission of electricity from power generation plant to substations, 4-legged lattice towers and monopoles are widely used, but the monopoles are much costlier than 4-legged lattice towers. To avoid the use of monopoles, in the present work, an approach has been adopted to use a special lattice type structure with eight legs. A 220kV multi-circuit suspension tower with 0 to 2° deviation has been considered for present study. The detail explanations, like, tower geometry, load calculations, analysis and design of the proposed structure has been covered in the paper. It has been observed that land requirement can be considerably minimized by use of the proposed 8-legged tower. The cost of the 8-legged tower is slightly higher than a 4-legged tower but much lesser than that of monopoles as the total weight of steel required is very less as compared to monopole. The results obtained from the study of the proposed tower have been compared with 4-legged tower and monopole. This paper discusses the feasibility of using the transmission line tower with 8-legs. The paper also discusses a comparative study of cost, right of way, height and base width of 4-legged tower and monopole with proposed 8-legged tower.

Keywords: Compact Lattice Tower, Land Cost, Monopole, Right of Way, 8-legged Tower

1. Introduction

Transmission Line Towers are the major part of the power grid as they contribute about quarter to half of the total cost of the transmission line[1]. Lattice towers are widely used for this purpose throughout the world, because they are most economical and fulfill all requirements related to electricity transmission. The only problem in lattice tower is that, they require a large area to stand as their base width is large. In last few decades many concepts have emerged in overhead power line designs mainly considering growing environmental constraints despite increase in power demand. One of the concerns is the area of the land that is allocated for transmission line, which depends on voltage and technical specification of the line. High price and limited availability of land, legal constraints on obtaining necessary permissions particularly in urban areas have created urge to think about reduction of land needed for the transmission line. Now a day it became necessary to design and construct a tower with minimum base width, which can be erected by using minimum land. Selvaraj et al[2]. introduced new concept to minimize Right of Way (ROW) as well as land requirements by using composite angle and box sections and by replacing steel cross arm by insulated cross arm. The study revealed that considerable reduction in height as well as ROW can be achieved by introducing new material instead of steel. Rao[3] presented a method for the development of optimized tower designs for extra high-voltage transmission lines. The optimization was with reference to both tower weight and geometry. It was achieved by the control of a chosen set of key design parameters. Fuzziness in the definition of these control variables was also included in the design process. Monopoles are also sometimes used at the place of lattice towers as they acquire very less land as compared to 4-legged tower. Prasad Rao et al[4]. sug-

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gested to use pole structure instead of lattice structures in urban areas, where the land availability is very less. The authors studied a 400kV and a 132kV pole structure and compared with lattice tower. Chugh[5], analyzed the steel transmission pole by displacement and stiffness method and suggested the use of compact pole structure instead of large base width towers where adequate land is not available. In the present work a special type of 8-legged compact lattice tower has been developed, the base width of which is considerably less than that of 4-legged lattice tower. In this special configuration, bracings have been provided in such a way that major portion of force has been taken by the leg. Not fully, but up to some extent, the structure behaves like monopole. In monopole, all forces have been taken by walls of the pole, whereas, in the proposed configuration, the forces have been taken by angle sections. The calculation of loads and design of tower has been done as per IS: 802 (Part-1/Sec-1)[6] for different conditions. Finally, a comparative study has been done between traditional 4-legged tower and proposed 8-legged tower.

2. The Design Basis of 8-legged Lattice Tower

It has been observed in the analysis of a lattice transmission line tower, that, for the same conductor loads, the legs experience more forces when the base width of the tower decreases. A 4-legged tower can also be made compact up to a certain limit, but after reaching a minimum base width limit, the legs experience such heavy tension and compression force, the angle sections are not available to provide to take that heavy axial forces. After this limit, if further decrement in base width is required, it becomes necessary to go for monopoles, which can be designed and constructed with a very less base width as compared to the 4-legged tower. The problem with the use of monopole is that they are very uneconomical and costs more than double the cost of a 4-legged lattice tower. The cross section of a monopoles is generally dodecagonal, and the forces are taken by the walls of the pole like they are taken by the angle sections in 4-legged tower. The behavior of a special type lattice tower made of eight legs at the corners of an octagon has been observed like monopole and the analysis of the structure can be done as a pin jointed space truss. These types of multi-leg lattice structures sometimes used to support overhead water tanks. The arrangements of legs and bracings of the proposed 8-legged tower are represented in Figure 1. The proposed tower is the combination of two individual very narrow based square towers arranged in such a way, that their legs are at the corners of an octagon. It can be seen from the figure, the bracings are arranged in such a way, that their assembly should not become much complicated. The bracings of both the individual towers crosses each other at middle, while with the other tower, they cross at about one fourth of their length. This arrangement resists the buckling of bracing at each quarter length. Unlike the 4-legged tower, secondary members are not required to reduce the unsupported length of bracing members.

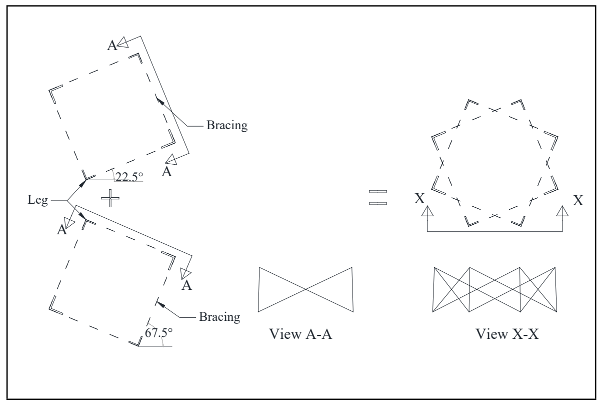

Figure 1. Arrangements of leg and bracings in 8-legged tower.

Mainly the base of these masts is triangular but sometimes square or special type's base is also adopted for suitability. The cables are given initial tensions to resist the lateral force. The different types of bracing system in steel towers are used according to the structural behavior.

3. Geometric Parameters

The basic requirement of any transmission line structure is that the structure should meet all the requirements specified in standards and should maintain clearances required in between various components of structure. Since the study has been done in accordance with Indian standards, all the parameters are selected with reference to IS: 802 Part-1: 1995. Following Table 1 describes various parameters required for a typical 220kV transmission line.

Table 1. Standard parameters for a 220kv transmission line tower

Sl. No.	Standard Specifications for 220kV Line	Required Parameters	
1	Ground clearance	7015 mm	
2	Maximum leg extension to be considered	9000 mm	
3	Maximum conductor sag (350m span)	9240 mm	
4	Height of suspension insulator + insulator connection	2640 mm	
5	Minimum vertical spacing between conductors	4900 mm	
6	Minimum horizontal spacing between conductors	8400 mm	
7	Top conductor to ground wire clearance	30° shield	
8	Swing clearances	0°	2130 mm
		15°	1980 mm
		30°	1830 mm
		45°	1675 mm

A clearance between the power conductors and metal body has to be maintained for various swing angles of insulators. Based on the clearance diagram, the total height of a transmission line structure has been finalized. The clearance diagrams of a 220kV line for the 4-legged tower, monopole and the proposed 8-legged tower has been given in Figure 2. Based on the clearance diagrams, the vertical spacing between conductors are calculated for the three structures. The total height of the tower has been calculated as per the parameters given in Table 1. The maximum conductor sag given in Table 1 has been calculated as per IS:5613 (Part2/Sec-1)[7]. Figure 3 shows the outline diagram of 4-legged tower, 8-legged tower and monopole for a typical 220kV multi-circuit (0-2°) suspension tower. For 220kV double circuit line, the 4-legged tower has been designed for 12235 mm base width. For the same voltage, a monopole with base diameter 2200 mm has been designed. A base width, about one third of the base width of 4-legged tower has been chosen for the of the proposed 8-legged tower. Figure 4 shows the plan of the base of 4-legged tower, proposed 8-legged tower and monopole. The sizes of angle sections used in 4-legged tower and 8-legged tower and the thickness of the walls of the pole vary through the height as per forces obtained from the design.

4. Loads Calculation and Structural Analysis and Design of Proposed 8-legged Tower

The loads are calculated as per IS: 802 (Part-1/Sec-1): 1995 for Reliability and Security conditions. The

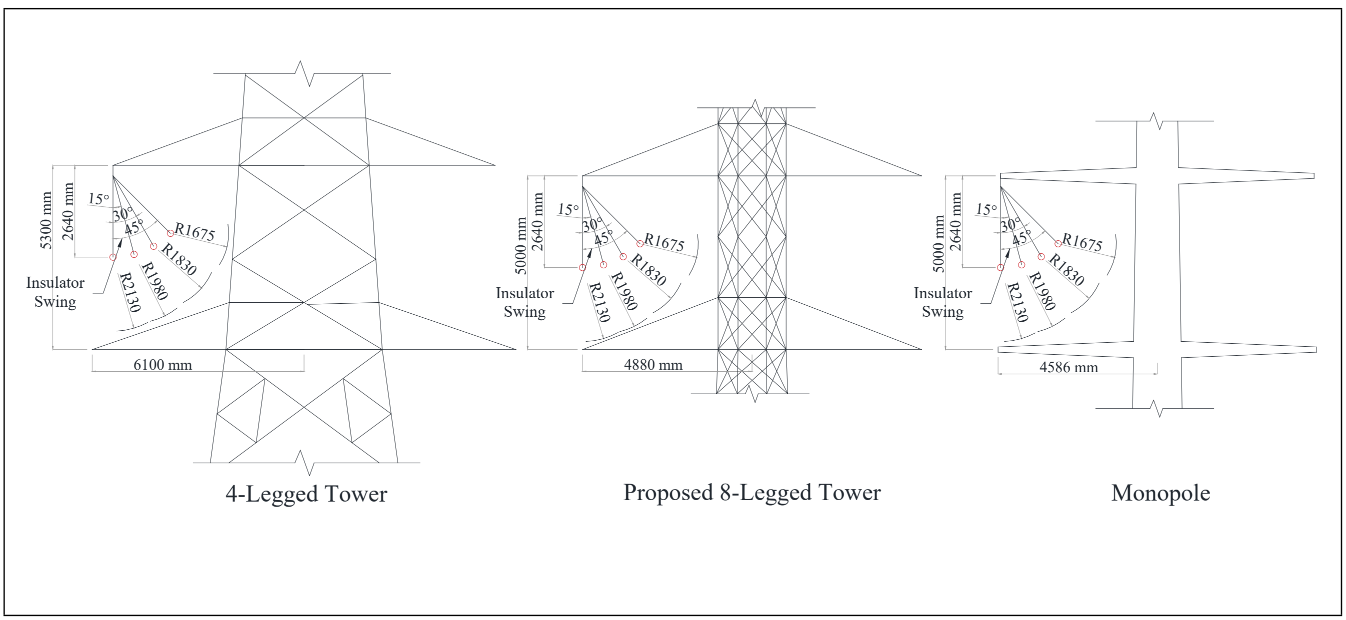

Figure 2. Clearance diagrams for the 4-legged tower, proposed 8-legged tower and monopole.

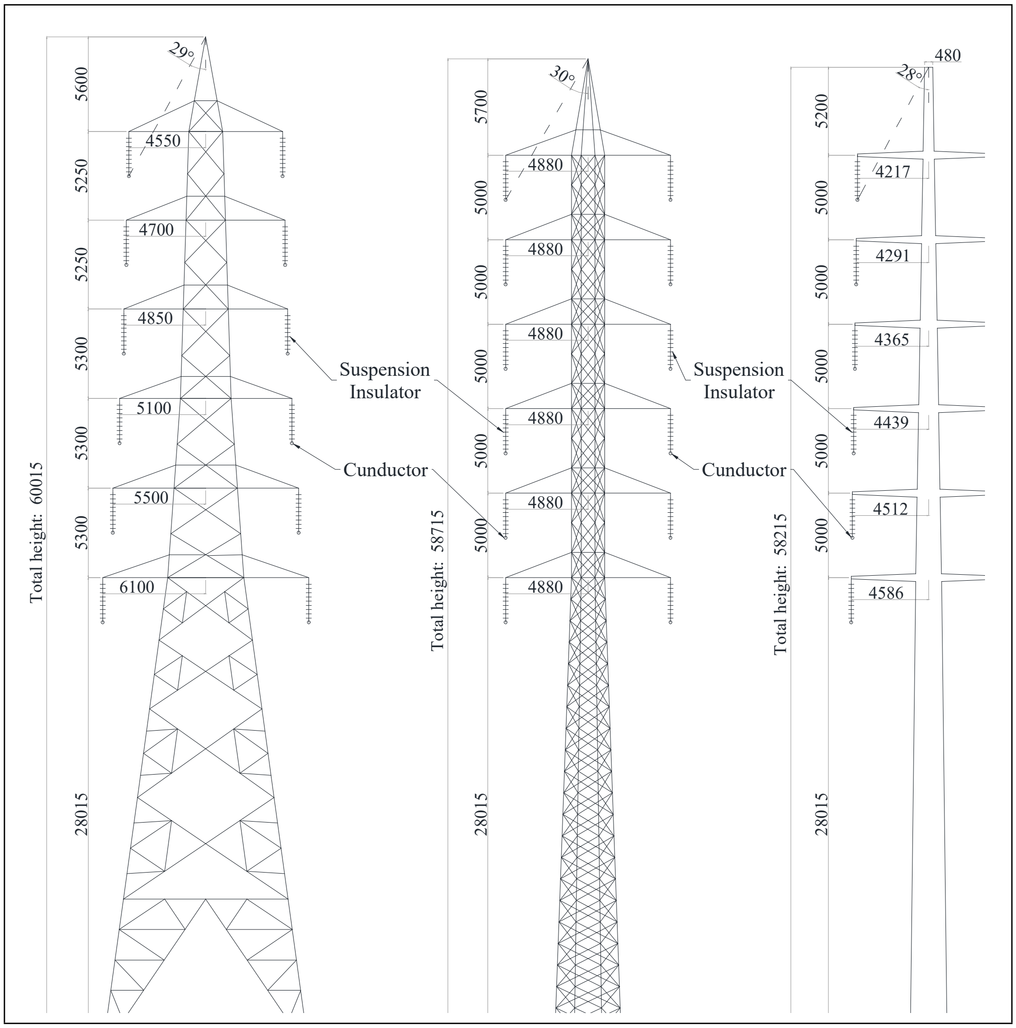

Figure 3. Outline diagram of the 4-legged tower, proposed 8-legged tower and monopole.

transverse loads acting on tower considered are wind load on conductor, insulator, ground wire and wind load on tower body and loads due to line deviation, while the longitudinal load are the result of tension in conductor due to sag and temperature variation in conductors. The 8-legged tower has been analyzed for the calculated loads. A 3D model has been created in structural analysis and design software and the calculated loads have been applied

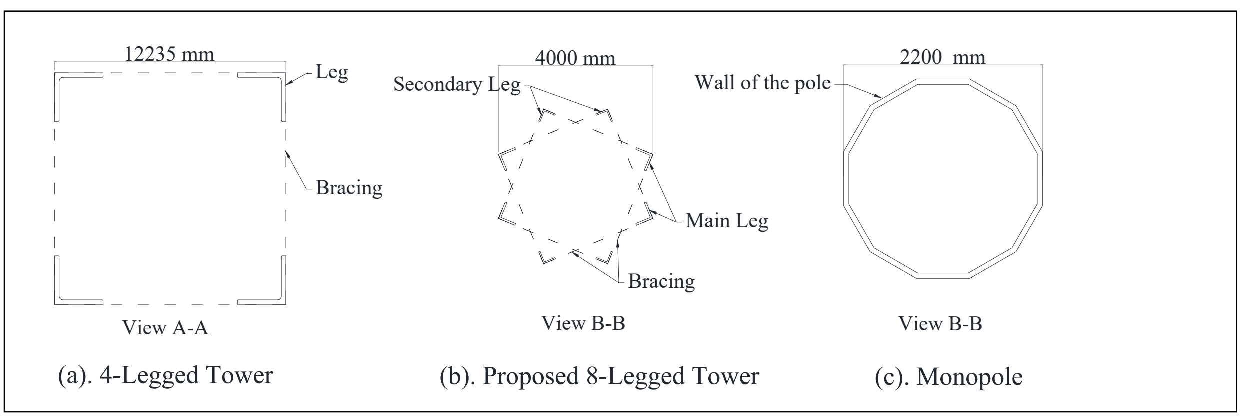

Figure 4. Plan of the 4-legged tower, proposed 8-legged tower and monopole.

on 8-legged tower model. Figure 5(a) shows the model of the 8-legged tower and Figure 5(b) shows the detail view of one panel. After analyzing it has been observed that there is a pattern in forces taken by all legs in any individual panel. Transverse face legs experienced more compression and tension as compared to longitudinal face legs. To make the tower more economical, the axial forces shared by transverse face legs and longitudinal face legs have been taken individually and unlike 4-legged tower, in which all four legs are provided with same sectional properties, in the proposed tower, the two types of legs have been designed for individual forces. The transverse face leg is named as Main leg while the longitudinal face leg named as Secondary leg. In Figure 5(b), Main legs and Secondary legs of an individual panel are indicated. All the bracing members in an individual panel has been given the same sectional properties, as no considerable variation in axial forces have been observed in bracing of an individual panel.

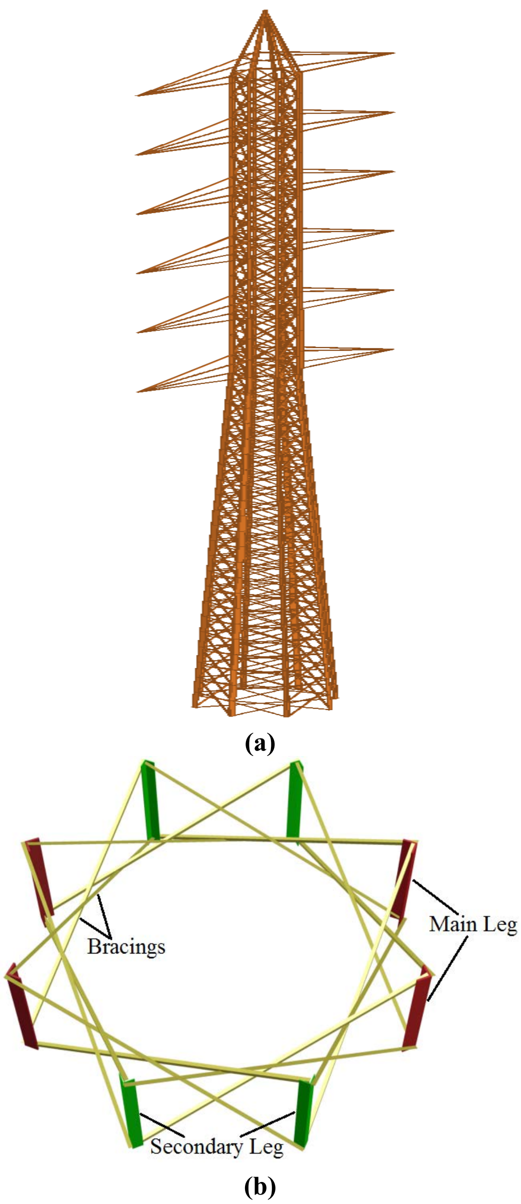

Figure 5. **(a)** 3d model of 8-legged tower. **(b)** Typical view of one panel.

The proposed 8-legged tower has 37 panels excluding earth wire peak. From bottom to top, the panels are named as Panel-1 to Panel-37. After application of loads and analyzing, axial forces in main legs, secondary legs and bracings have been obtained.

The axial forces in main legs, secondary legs and bracings have been given in Table 2. All the members have been designed for the axial compression and tension. As per IS: 802 (Part-1/Sec-1): 1995. The members have been checked for slenderness ratios specified for legs and bracings in design standards. Unlike 4-legged tower, in the proposed tower secondary members are not used and all the members are considered as design members.

The angle sections have been given as per IS: 808[8]. The leg members are designed using high tension steel having yield stress 350MPa and the bracing members are designed using mild steel having yield stress 250Mpa. 16 mm diameter bolts are used for connection design. As it can be seen from the above table, that maximum forces are experienced by leg members. It can also be concluded that the forces in main legs are much higher than that in secondary legs. There are nominal forces coming in bracing members.

5. Result and Discussion

Based upon the above study, a comparison of various parameters of the proposed 8-legged tower is done with 4-legged tower and monopole.

5.1 Right of Way (ROW)

The ROW depends upon the voltage rating and the width of the tower body at bottom cross arm level. The ROW of the proposed tower is marginally more than that of the pole and less than the 4-legged tower.

Table 2. Axial forces and angle sections required in various panels of the 8-legged tower

PANEL (Bottom to Top)	Main Leg Force (kN)		Secondary Leg Force (kN)		Angle Section Required		Bracing Force (kN)		Angle Section Required
	C	T	C	T	Main Leg	Secondary Leg	C	T	Bracing
Panel-1	-1688.8	1646.2	-481.5	434.4	ISA150x150x20	ISA110x110x8	-26.1	27.1	ISA40x40x4
Panel-2	-1672.7	1629.9	-472.3	430.0	ISA150x150x20	ISA110x110x8	-29.2	30.5	ISA40x40x4
Panel-3	-1651.8	1609.0	-458.8	422.5	ISA150x150x20	ISA110x110x8	-31.2	31.0	ISA40x40x4
Panel-4	-1630.8	1587.9	-445.3	414.8	ISA150x150x20	ISA110x110x8	-31.9	32.0	ISA40x40x4
Panel-5	-1608.7	1565.8	-431.2	406.9	ISA150x150x20	ISA110x110x8	-32.9	32.5	ISA40x40x4
Panel-6	-1585.4	1542.4	-419.1	399.0	ISA150x150x20	ISA100x100x8	-33.7	33.3	ISA40x40x4
Panel-7	-1561.0	1518.0	-411.1	391.1	ISA150x150x20	ISA100x100x8	-34.2	34.8	ISA40x40x4
Panel-8	-1538.2	1495.0	-403.1	383.2	ISA150x150x18	ISA100x100x8	-31.5	31.6	ISA40x40x4
Panel-9	-1517.0	1473.7	-395.8	376.0	ISA150x150x18	ISA100x100x8	-32.7	32.8	ISA40x40x4
Panel-10	-1494.2	1450.8	-387.6	368.0	ISA150x150x18	ISA100x100x8	-34.1	34.2	ISA40x40x4
Panel-11	-1470.9	1426.9	-379.0	359.6	ISA200x200x12	ISA100x100x8	-35.5	34.8	ISA40x40x4
Panel-12	-1445.9	1401.4	-371.0	351.9	ISA200x200x12	ISA100x100x7	-36.3	36.0	ISA40x40x4
Panel-13	-1419.4	1374.3	-363.1	344.3	ISA200x200x12	ISA100x100x7	-37.7	38.5	ISA40x40x4
Panel-14	-1391.3	1345.5	-352.8	334.6	ISA150x150x16	ISA100x100x7	-40.4	40.3	ISA40x40x4
Panel-15	-1361.2	1314.7	-342.4	324.8	ISA150x150x16	ISA100x100x7	-42.5	42.4	ISA40x40x4
Panel-16	-1328.7	1281.1	-331.1	314.4	ISA150x150x16	ISA100x100x7	-44.9	44.7	ISA50x50x3
Panel-17	-1297.8	1248.8	-320.3	304.9	ISA150x150x15	ISA100x100x6	-43.0	43.2	ISA50x50x3
Panel-18	-1267.6	1216.9	-309.6	295.9	ISA150x150x15	ISA100x100x6	-46.5	46.3	ISA50x50x3
Panel-19	-1235.9	1182.7	-298.5	286.8	ISA150x150x15	ISA100x100x6	-49.5	49.8	ISA45x45x4
Panel-20	-1200.0	1144.6	-284.2	276.1	ISA150x150x15	ISA100x100x6	-54.2	53.8	ISA50x50x4
Panel-21	-1166.0	1105.3	-273.6	268.0	ISA130x130x16	ISA100x100x6	-58.7	60.0	ISA50x50x4
Panel-22	-1117.6	1069.8	-250.6	252.8	ISA130x130x16	ISA90x90x6	-65.0	59.6	ISA50x50x4
Panel-23	-1013.0	995.7	-241.5	222.0	ISA150x150x12	ISA100x100x6	-86.7	65.9	ISA60x60x4
Panel-24	-929.4	921.2	-224.6	200.8	ISA150x150x12	ISA100x100x6	-78.9	95.0	ISA60x60x5
Panel-25	-816.9	799.9	-184.2	176.0	ISA150x150x10	ISA90x90x6	-95.9	80.9	ISA55x55x5
Panel-26	-701.2	733.0	-182.2	144.0	ISA110x110x12	ISA80x80x6	-72.3	49.9	ISA40x40x5
Panel-27	-626.0	661.5	-153.0	124.8	ISA110x110x12	ISA90x90x6	-72.4	90.6	ISA60x60x5
Panel-28	-539.1	559.9	-120.2	110.1	ISA130x130x8	ISA80x80x6	-91.7	74.2	ISA60x60x4
Panel-29	-441.2	508.6	-132.0	118.3	ISA110x110x8	ISA75x75x6	-60.7	44.0	ISA40x40x5
Panel-30	-385.3	450.4	-131.4	105.8	ISA110x110x8	ISA80x80x6	-68.0	82.8	ISA55x55x5
Panel-31	-316.1	368.3	-121.9	114.0	ISA100x100x8	ISA80x80x6	-84.1	70.0	ISA60x60x4
Panel-32	-244.4	333.4	-111.9	130.6	ISA100x100x6	ISA75x75x5	-48.4	36.7	ISA40x40x4
Panel-33	-218.9	291.2	-119.0	109.0	ISA100x100x6	ISA80x80x6	-63.8	78.9	ISA60x60x4
Panel-34	-185.1	249.5	-103.2	115.2	ISA90x90x6	ISA75x75x6	-80.4	65.9	ISA60x60x4
Panel-35	-139.2	242.2	-105.1	156.5	ISA75x75x6	ISA70x70x5	-30.3	37.1	ISA40x40x4
Panel-36	-138.4	238.6	-86.5	139.4	ISA80x80x6	ISA75x75x5	-51.4	68.7	ISA50x50x5
Panel-37	-144.3	218.3	-88.1	145.1	ISA90x90x6	ISA75x75x5	-69.3	52.7	ISA40x40x5

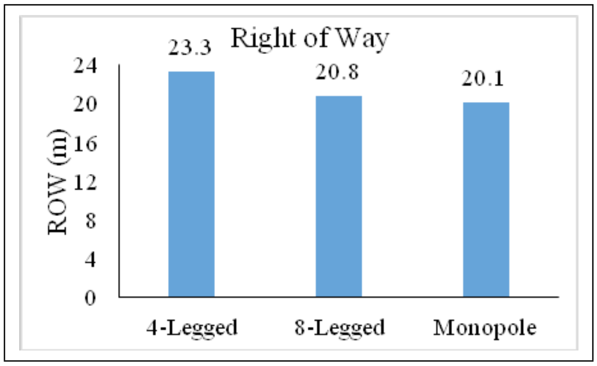

Figure 6. Graph showing row comparison.

5.2 Total Weight of the Structure

Steel sections are the main components of a transmission line tower. The total cost of the tower mainly depends upon the weight of the steel used. Figure 7 shows the graph representing the weight of steel required for 4-legged tower, proposed 8-legged tower and monopole.

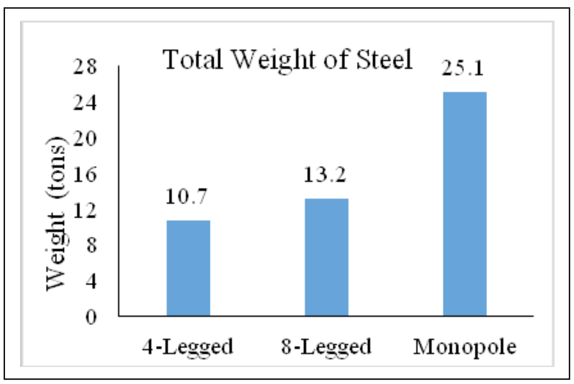

Figure 7. Graph showing weight of steel comparison.

5.3 Base Width

Figure 8 shows the base width of the 4 legged tower, proposed 8-legged tower and base diameter of the monopole. The land required for the 8-legged tower is slightly more than that for monopole but is very less than that of a 4-legged tower.

The base width of the proposed tower is about 67 percent lesser than that of the 4-legged tower.

5.4 Deflection of Tower

After analysis and design, the deflections of tower for various loading assumptions is calculated using computer software. Figure 9 shows the graph representing the

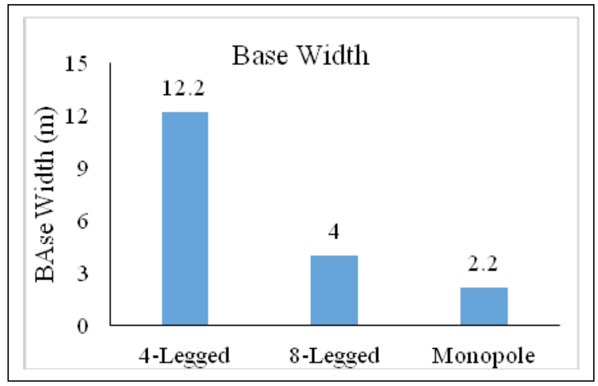

Figure 8. Graph showing base width comparison.

deflections at various sections of the 4-legged tower, proposed 8-legged tower and monopole.

The maximum deflection at the peak of 4-legged tower, proposed 8-legged tower and monopole is 667 mm, 1742 mm and 2652 mm respectively. The deflection of the proposed tower is more than that of the 4-legged tower but less than the deflection of the monopole. The permissible deflection of a transmission line structure if that the at any condition, the deflection should not go beyond 5 percent of the total height of the tower. In all the three cases, the deflections are within permissible limit. The deflections can be minimized by using heavy sections in lattice towers or by increasing the wall thickness in case of monopoles.

6. Conclusion

A 220kV multi-circuit 0-2° deviation line has been considered for the study. A 4-legged tower and a monopole has been designed for the line. The weight of steel required for the design of the monopole is much more than the weight of steel required for 4-legged tower. To make the tower economical, use of an 8-legged special type of lattice tower has been proposed. The proposed 8-legged tower has been analyzed and designed for various loading conditions. Results obtained from the design of the 8-legged tower has been compared with 4-legged tower and monopole. A considerable saving in land has been observed by using 8-legged tower. The ROW has also been reduced by the use of proposed tower. Section deflections of 8-legged tower are compared with 4-legged tower and monopole. The deflection of the proposed tower is within the specified limit and less than that of monopole. The

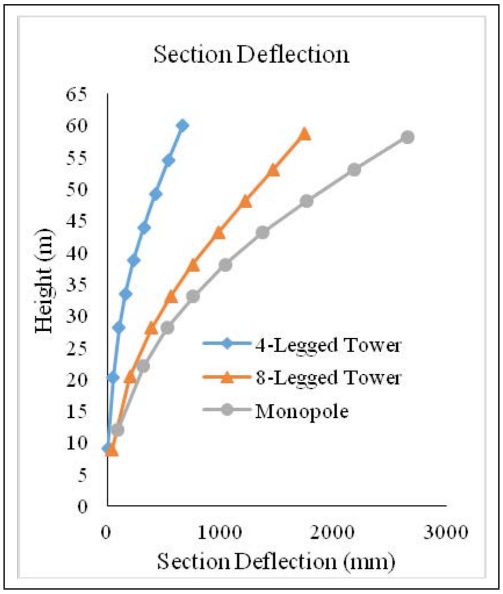

Figure 9. Graph showing section deflection comparison.

proposed tower can be used in areas, where, adequate land is not available to construct a 4-legged tower.

7. Acknowledgement

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