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HVAC AND HVDC TRANSMISSION ON SAME TRANSMISSION TOWER

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ABSTRACT

Objectives: To design multi-voltage multi-circuit transmission tower to reduce right of way (RoW). Methods/Statistical Analysis: In order to reduce right of way structural optimization and electro-magnetic analysis should be carried out. Structural optimization includes various factors like conductor configuration, cross arm arrangement, wind loadings. The tower is designed using Staad Pro and the structure is validated for various wind loadings and stresses. Electro-static and magneto-static fields around the tower are analyzed and are brought down to limits by choosing optimal phase sequence. This analysis is carried out using Ansoft Maxwell. Findings: The designed structure withstands all the permissible stresses. Electro-static and magneto-static fields around the designed tower are found to be within the specified limits specified by standards. This design is found to be cost effective with respect to right of way when a transmission line is considered. Application / Improvements: Narrow base width is considered which also aids in optimized right of way. This tower design can hold three voltages (400kV, 220kV, 33kV) and six circuits. The height of the tower is maintained in normal range by structural optimization.

Keywords: MVMCT, Narrow based Tower, Right of Way

1. INTRODUCTION

The cost of towers ranges from one fourth to half of the transmission line cost and hence optimum design gives reasonable savings. Consequently, transmission line towers should be designed for structural and electrical requirements for a safe and economical design. Right Of Way (ROW) is the right to claim a land strip by various Electrical utilities for erection, operation, maintenance and repair the transmission line facilities. Its width relieson the line voltage rating, height of the structure, electromagnetic fields intensity and structure of the tower. Old transmission lines can be dismantled or renovated by configuring new MVMCT lines using same old ROW with tolerable broadening so that transmission line of higher voltage rating of MVMCT line can transmit power between major substations while that of lower voltage linecan transmit power between smaller substations. In the literature some of the tower designs include optimization of the geometry, electromagnetic field reduction, etc.which are discussed. A few solutions for reduction of electric and magnetic field emissions caused by the overhead power lines are discussed. Calculations carried out for existing high voltage 400kV overhead lines in Slovenia show that the emissions of electric and magnetic field at the border of overhead line ROW could be too high. The analysis is carried out for single voltage but it would be economical if many voltages are also incorporated in the design. Structural optimization of a typical 132-kV double circuit transmission-line tower with respect to configuration and different materials as variable parameters, the tower is modeled and analyzed using STAAD-PRO and ANSYS softwares. A number of experimental configurations of the tower are obtained by increasing the base width of thetower and also by decreasing the bracing patterns below the waist of the tower. In this paper only tower optimization is discussed but ROW is not reduced which may notbe economical when land issues are concerned. Narrow base multi circuit tower is analyzed for 200 KV using STADD.PRO. The choice of tower is made based on the available right of way. Narrow base toweris considered for Mumbai area so as to meet ROW constraint. In this only a single voltage is considered which MVMCT design is discussed in the third section. The results are included in the fourth section. The fifth sectiondeals with the conclusion. The following section deals with the general design concepts of a transmission tower as per Indian standards.

2. GENERAL TOWER DESIGN CONCEPTS

A comparative study of electromagnetic field distribu- tion near ground (1.5m above the ground) for 500/220kV dual voltage quadruple circuit transmission line of 3typical tower types and 12 phase sequence arrangementsare calculated, and from the comparison optimal phase sequence arrangement is found. The sequences are givenwhich may not ensure that row is also justified by the pro- posed sequence. The electric and magnetic fields distribution under EHV transmission lines are analyzed using finite elementanalysis. From these results, most reliable position of transmission lines is achieved on tower and the best phaseline sequence with least electromagnetic field intensityin 500kV/220kV dual voltage quadruple circuit trans- mission lines on same tower. The fields are less for the proposed sequence but it is not justified with geometry optimization which is the need of the hour. Design optimization of 220KV and 110KV dual volt-age multi circuit self-supporting lattice tower with narrowbase is carried out. Design and analysis are done using STAAD PRO. Only geometry is optimized but the corre-sponding fields are not calculated as the multi circuits arehighly prone to electromagnetic fields due to interaction among themselves. When considering all the limitations the proposed MVMCT would solve all the issues of a transmission tower according to the present needs. Due to technical and financial reasons, future electrical transmission tow- ers need to adopt new design concepts by maximizing power delivery with confined ROW. In this paper we are optimizing the tower geometry by adopting narrow base which is not only economical but also reduces the ROW width. Narrow based steel lat- tice transmission tower structure plays a vital role in its performance especially when there are eccentric loadingconditions for higher altitude as compared to conventional tower. The paper is organized as follows: General design concepts are presented in the second section. Proposed. The basic tower designing steps are simplified and givenbelow in a flow chart. Geometry of tower plays a crucialrole in understanding the basic design concepts. Tower geometry includes the voltage level, base width, type, height, conductor configuration, type of conductors and number of circuits. The number of cross arms depends on the voltage level and number of circuits. ROW is the right to claim a land strip by various Electrical utilities for erec- tion, operation, maintenance and repair the transmission line facilities. Its width relies on the line voltage rating, height of the structure, electromagnetic fields intensity and structure of the tower. ROW is fixed based on the tower geometry and Electromagnetic fields.

Sag- The power conductors sags because of its self-weight andthe maximum sag is observed under maximum tempera- ture and no wind condition. Sag and tension are calculatedfor various wind and temperature combinations as per IS802 standard. Maximum sag value is also used to deter-mine the height of a transmission tower.

Height Determination- Various factors that influence the height of the tower are:

- Minimum permissible ground clearance (h1)
- Maximum sag (h2)
- Vertical spacing between phase conductors (h3)
- Vertical clearance between top conductor andground wire (h4)

Hence, the total height of the tower is given by$H = h1 + h2 + h3 + h4$

When multi circuits are considered, circuit to circuit clearance will be added to the height of the tower accordingly

Electrical Clearances- The electrical clearances involve selection of minimum air gap clearances, to avoid distracting sources between live and earthed parts of the transmission line. All the minimum electrical clearances are maintained accordingto CBIP guidelines[8].

Wind Loadings- The calculated loads as per the particular wind zone are applied to the tower structure. Loadings include self- weight, transverse loads, longitudinal loads, compression loads and tension loads. No deflection is observed in tower after applying these loads that are calculated as perstandards. The loadings determination is done using vari- ous inputs like design wind pressure, angle of deviation, design wind span, pressure due to wind on conductor andground wire, type of ground wire, insulator strings, etc. All the members of the tower are applied with the cor- responding loading combinations.

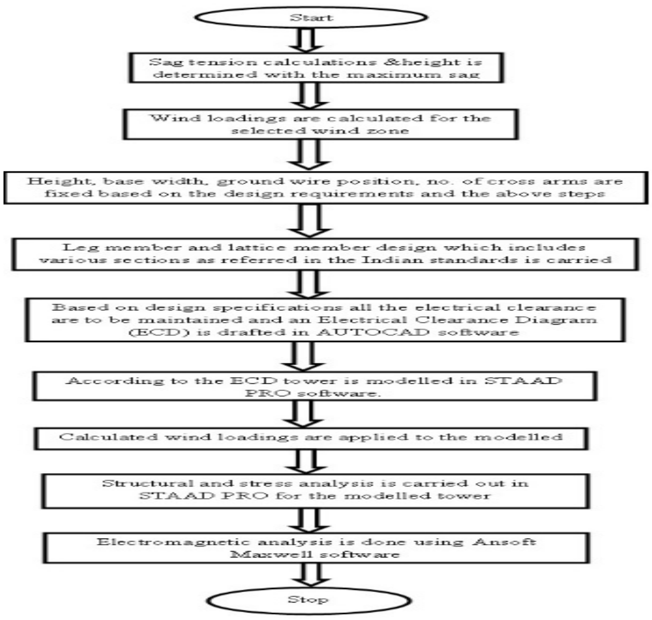

Figure 1. Tower design flowchart.

Tower modelling

After designing a tower and based on its Electrical Clearance Diagram (ECD) the tower is modelled in STAAD.PRO software and the corresponding calculatedloads are applied to the members.

Stress Analysis

The accurate stress analysis for a transmission towerincludes calculation of the total forces in each member of the tower with various combination of loads externallyapplied plus the self-weight of structure. All values are calculated according to permissible values. The flowchartgiven in the following Figure 1 gives the basic design pro- cess for any transmission tower.

3. PROPOSED MVMCT DESIGN

The conductor configuration is considered to reduce the electro-magnetic fields and also to optimize the design. The combination of delta and horizontal for 220kV & 33 kV with a defined phase sequence which is [ABC-ABC], [ABC-CAB], [ABC-ABC] for 400kV,220kV,33kV respectively is selected to reduce the overall electromagnetic fields.

EMF Analysis

The Electro Magnetic Field analysis is done using finite element analysis in Ansoft Maxwell software. The accu- racy of finite element analysis depends on the mesh topology. The mesh is a significant feature of any finite ele- ment model. The Magneto static field limits confinement are given in ICNIRP and those limits are considered for the proposed design. Electrostatic field ought to be under 5 kV/m at the edge of the right of way. The magnetic field should be less than 100µT. The current carrying capac- ity considered are 800.4A, 705A, 464A for 400kV, 220kV, 33kV respectively. Electro-static field relies on voltage and magneto-static field relies on current.

The energy efficient voltage conversion can also be determined in multiple voltage domains.The soil resis- tivity is also checked for safety purposes in order to avoid back flashover.

4. RESULTS AND DISCUSSION

A case study has been conducted using the 400kV/220kV/33kV for the proposed methodology to reduce the right of way by considering three voltages andeach voltage level holding two circuits on the same tower.The results obtained are presented in this section. The following Table 1 gives the maximum sag and the corre-sponding tension values.

Based on all clearances mentioned in Indian standards and the maximum sag value calculated above is used to determine the height of the tower. After determination ofheight the cross arm lengths are decided and fixed considering all the design requirements. The maximum height calculated is 56.2 m. The maximum cross arm length fromthe center of the tower for 400kV line is 7.525m which isused to determine the ROW width.

The line diagram representing all the cross arms, height of

conductors from the ground levels is given in following Figure 2.

Table 1. Sag and Tension

Voltage (kV)	Max. Sag (m)	Tension (Kg)
400	4.29	2334.80
220	3.96	2046.50
33	3.52	1385.33

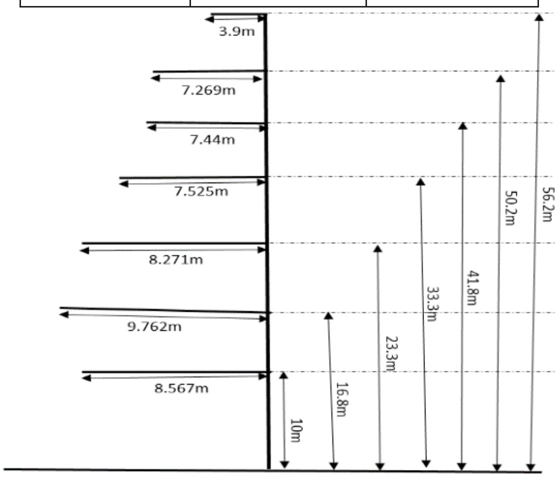

Figure 2. Line diagram representing geometry of the tower.

The following Figure 3 gives the basic structural details for the MVMCT. This Table 2 includes all the structural design data for MVMCT.

Table 2. Tower geometry

Height	56.2 Meters
Conductor configuration	vertical , delta , horizontal
Conductors	ACSR MOOSE (twin), ZEBRA,PANTHER
Number of circuits	6
Voltage levels	400kV, 220kV, 33kV
Base width	7 Meters
Type	Narrow base
Angle of line deviation	$0^0 – 2^0$
Span	200 m
Tower shape	Barrel

Electrical Clearance Diagram has been drafted in AutoCAD software based on the clearances and basic design requirements and is given in the following figure.Design parameters are given in Table 3.

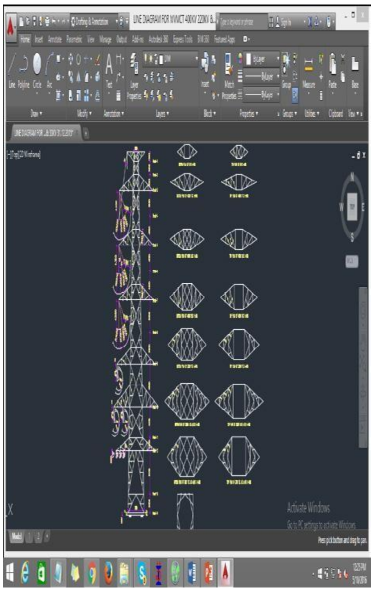

Figure 3. Electrical clearance diagram.

Table 3. Design parameters

Wind zone	5
Reliability level	2
Terrain category	2
Basic wind speed	50 m/s
Max. Temperature	85^0 C
Min. Temperature	0^0 C
Cross arm shape	Pointed
Ground wire cross arm	Inverted
Type of the tower	Suspension
Bracing pattern	X-pattern, Portal pattern (onlyfor lower panels)

With the help of the Electrical clearance diagram thetower is modelled in STAAD.PRO software in 3 dimen- sional coordinate system. The following Figure 4 shows the isometric view of the designed MVMCT in STAAD. PRO software.

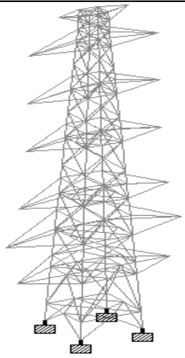

Figure 4. Isometric view of MVMCT.

The following Figure 5 shows the screenshots of vari-ous loads that are applied to the designed tower. The loadsinclude transverse, longitudinal and vertical loads. All loads are applied to all the members according to Indian standards which are inbuilt in the software. The tower should withstand all the calculated loads and this is justi-fied by stress analysis in the software.

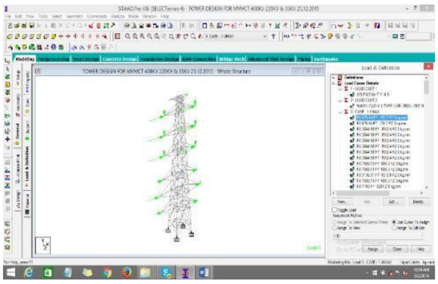

Figure 5. Screenshot of MVMCT with the assigned wind loads.

5. STRESS ANALYSIS OF MVMCT

The stress analysis includes determination of forces in every member of the tower with different load combi- nations including self-weight of the structure. Different loads are considered for stress analysis in each member ofthe tower. The loads considered are transverse loads lon-gitudinal load, vertical loads. To meet the values within the permissible limits specified in standards the slender- ness ratio should not be beyond the values specified in thefollowing Table 4.

Table 4. Slenderness ratio specified in standards

SL.NO	Slenderness ratio for the design	Ratio
1	Leg members and main members in thecross-arm in compression	**150**
2	Members carrying computed stresses	**200**
3	Redundant members and those carryingnominal stresses	**250**
4	Tension members	**350**

The following Figure 6 shows the stress analysis in STAAD.PRO for the proposed MVMCT and also the stresses on all members of the tower are within the per- missible limits.

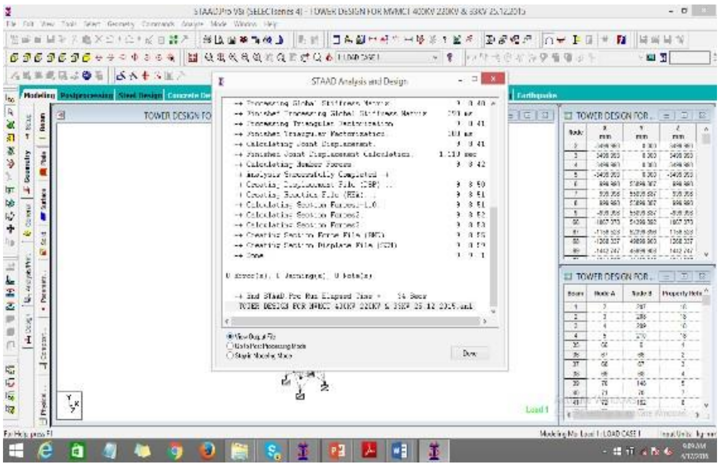

Figure 6. Screenshot Of Stress Analysis In Staad.Pro.

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6. DISCRETIZATION OF MVMCT FORELECTROMAGNETIC ANALYSIS

The input given to the software is simplified into simple problems which is called discretization/mesh conver-sion and the analysis is carried out for this mesh plot using Maxwells' applications in the Ansoft Maxwell soft-ware. The first circles from the top indicate vertical 400 kV vertical conductor arrangement, next three indicate delta conductor arrangement of 220 kV and the last threeindicate horizontal arrangement of conductors of 33 kV respectively. We use different program options which arecalled solvers in the software for mathematical conversionof the algebraic equations of the physical arrangement of MVMCT. The solvers used are Electro-static, Magneto- static for the proposed MVMCT. The mesh plot of the MVMCT is given in following Figure 7.

7. ELECTROMAGNETIC FIELDS ANALYSIS

The mesh plot generated gives the analysis of fields aftercomplete validation of the inputs. The following Figures8, 9 represent the electrostatic field overlays and the Magneto-static field overlays around conductors of 400 kV/220kV/33kV and the fields are in volts/meter & µT respectively.

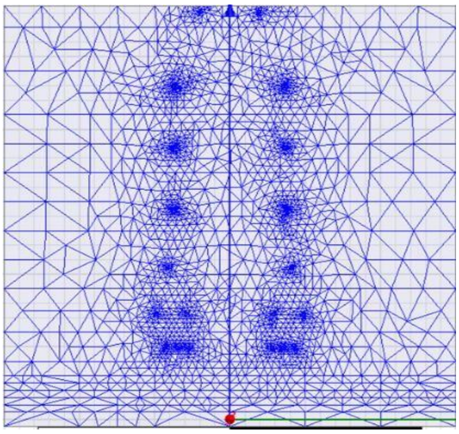

Figure 7. Mesh plot of MVMCT in Ansoft Maxwell.

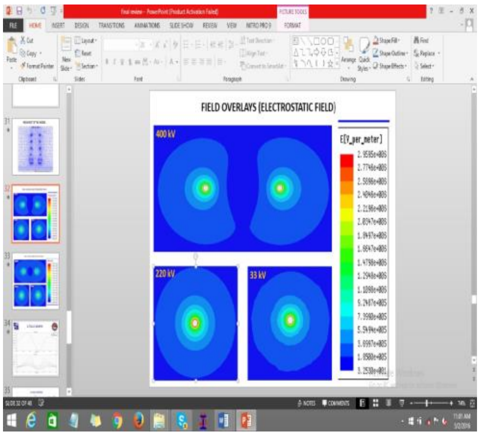

Figure 8. Electro-static field overlays.

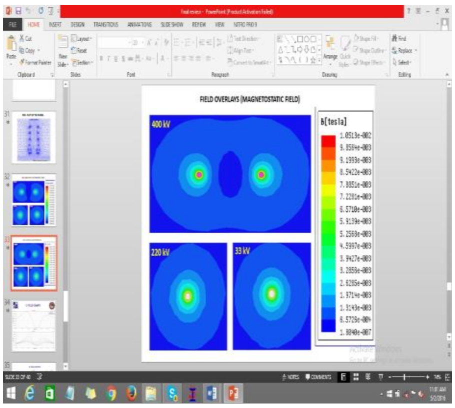

Figure 9. Magneto-static field overlays.

The plots in Figures 10, 11 present electrostatic field curve and magneto-static field curve considered one meter above the ground level and this curve gives the maximum value of electro-static field and magneto-staticfield respectively.

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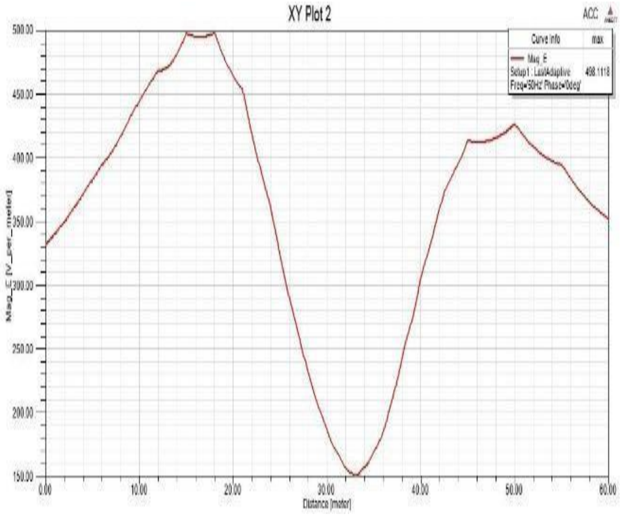

Figure 10. Electro-static field curve.

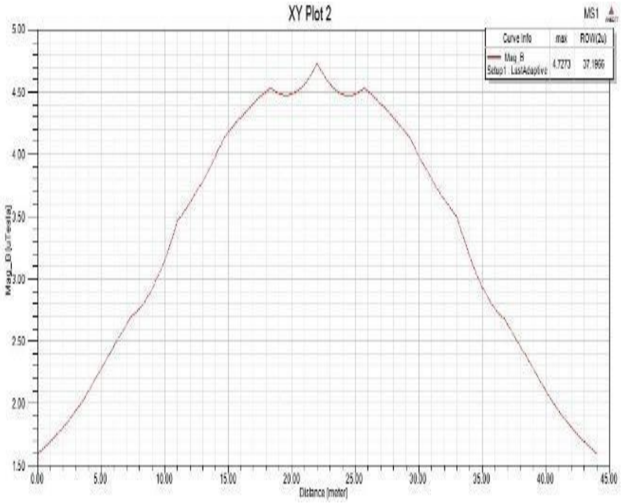

Figure 11. Magneto-static field curve.

The following Table 5 shows that the maximum simulated value is within the prescribed limits given in standards.

Table 5. Electric and magnetic field limits

Field	Specified (1m above theground level)	Simulated Values	
		Max.Value	At the Edgeof ROW
Electric field(kV/m)	5	0.498	0.440
Magnetic field(μT)	100	4.7273	2

8. TOWER ECONOMICS

When compared to conventional towers MVMCT gives huge savings in cost. The following Table 6 shows the difference between MVMCT and combination of three individual towers. All cost calculations are considered for 100Km line with a design span of 200m.The cost per square meter is taken as 100 Rs per square meter. Total towers include 70% of A, 15% of B, 10 % of C, 5% of Dtype as per regular consideration of utilities. Types of tow-ers A, B, C& D are based on deviation angle of the line specified in standards.

Table 6. Cost calculations

	3 IndividualTowers	MVMCT
ROW Width (m)	98	40
Cost of steel (in lakhs)	45572.59	7054.70
Total cost (in lakhs)	19451.93	13048.71
Savings (in lakhs)	6403.22	

9. CONCLUSION

An innovative method to reduce the ROW width in the design of MVMCT has been proposed in this paper. A case study on MVMCT containing three different volt- ages such as 400kV/220kV/33kV has been done and is demonstrated that the proposed design offers technically superior method and is also cost effective. ROW width is reduced to 40 (from 48) meters when compared to con- ventional broad base towers which leads to a huge cost savings when a transmission line is considered. MVMCTalso improves the transmission capacity. The EMF's are also in the specified limits with in the ROW. All stressesare within the permissible limits. Cost savings can be around 30-50% when ROW is constrained Thus MVMCT with narrow base may become a headway in India both on economic issues and minimization of legal issues withrespect to the land.

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