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# Location and Structural Optimization of Transmission Tower in Hilly Region

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## ABSTRACT

In the energy sector for infrastructure development, a major problem encountered is losses during transmission. In view of this, an important problem in energy transmission is to design an optimal route for the minimization of losses and structural configuration. The literature suggests the optimization for location (routing) and structure separately. To compare the efficiency of the components, both location and structural optimization have to be performed. In the present study, a detailed methodology for location and structural optimization of a transmission tower has been developed and performed. To validate the methodology a 132 kV single circuit angle tower transmission line tower was considered for location and structural optimization as a case study. To see the performance of the location and structural optimization, two types of conductors were chosen. Sag tension calculation was done for different temperatures: ice and wind cases. The transmission tower was configured by satisfying peak clearance, electrical clearance, and mid-span clearance using AutoCAD. Routing optimization of the transmission line was done using Dijkstra's Algorithm-based Least Cost Path tool in ArcGIS. The criteria (slope, elevation, and restricted area) were ranked and weighted using Analytic Hierarchy Process (AHP). Tower spotting was done along the optimized route using sag temple through AutoCAD for both conductor types. The configured tower was modeled using AutoCAD, and analysis and design of the transmission tower were carried out in three dimensions using STAAD.Pro v8i software as per IS 800-2007. The size optimization method developed for transmission tower, both conductor types, gives directly the optimal section from user-provided steel table. The developed optimization method was compared with existing literature and the results were found satisfactory. By incorporating real cost factors in identifying the relative importance of location and structural aspects best configuration of the transmission line tower may be chosen using the developed methodology.

Keywords: Size Optimization, Analytic Hierarchy Process, Least Cost Path, GIS, Tower Spotting, Transmission Line.

## I. INTRODUCTION

The spread of the Indian population all over the country generates the requirement for a large electrical transmission system (Murthy and Santhakumar 1990). The routing is the initial stage in the design of an electrical transmission system, where a planner decides a route according to existing constraints (Monteiro et al. 2005). Routing involves optimization of equipment installation and maintenance costs subject to geographic, environmental, social, and legal constraints (Roopesh et al. 2006). Conductor size, bundling and material, structure type, span, phase geometry, structure geometry and height, and foundation type are a few variables that have prominent effects on the cost of a transmission system (Grant and Clayton 1987).

An electrical transmission system normally consists of steel lattice towers. The cost of towers constitutes about 28 - 42 % of the cost of the transmission system and hence optimum tower design brings in substantial savings (Rao 1995). The main objective in designing of an overhead transmission line is to maintain adequate clearance between energized conductors and ground to prevent dangerous contact with the line and to provide reliable support for conductors, resilient to storms, ice load, earthquakes, and other potential causes of damage (CBIP - 268).

The design of an electricity transmission system is a complex sequence of interlinked activities. Obtaining the most economic design that meets all requirements is difficult. To achieve the best design performance at minimum cost various methods have been developed for many years through comparative estimates of the present worth of revenue required (PWRR). The methods have most commonly been used for conductor selection, however, economic returns from other parameters are largely unknown (Grant and Clayton 1987).

In the present study, two different conductors have been chosen to check the efficiency of a transmission line with respect to location and structural optimization. The structural design of an electric power line involves gathering, manipulating, and storing a large amount of information that is traditionally on paper in miscellaneous locations: plan and profiles, design specifications, insulator data, cable, structure drawings, structural calculations, etc. Improved engineering productivity requires that all that information be accessed interactively on a computer workstation (Carton and Peyrot 1992). An automated MS-Excel program has been developed in the present study, to describe the contents of the various databases that are needed to describe an entire line thereby simplifying the design process.

The manual design of a new electric power line is a time-consuming and costly activity that requires massive and detailed spatial information and an experienced project engineer. It usually involves two steps viz. line routing selection or equipment placement determination, and detailed sizing of all the elements (Monteiro et al. 2005). In the present study, the first step is named as location optimization which includes routing and tower spotting and the second step is designated as structural optimization.

Geographic Information Systems (GIS) is used in transmission line routing as a technical tool. During the route selection for a transmission line, a straight route with minimum curves is desirable as it gives the best engineering and economic solution. To achieve this route the line may have to pass through certain places which are already inhabited by people or areas that are unsuitable for locating the transmission towers. Environmental criteria and soil type also play a significant part in the selection location of transmission lines. Soil stability is an important factor when locating transmission towers (Hassan and Akthar 2012). GIS is used to analyze the selection of suitable locations for transmission lines so that there is minimal environmental disruption such as minimizing cutting trees in a forest area, implementing optimal routing algorithms based on electrical and material properties in addition to locational characteristics, visualizing the network on a map helps make an appropriate decision. Geospatial analysis help in routing High tension transmission line near to a populated area, where spatial buffer help in protecting the inhabitants from strong electric and magnetic field effects.

Geographic Information System (GIS) is used as an efficient method for finding an appropriate assessment model. To select the best route for constructing a network of power transmission lines, Qiu et al. (2004) optimized the route for power transmission lines with the geographical information of an area and a knowledge-based Genetic Algorithm (GA). Monteiro et al. (2005) presented a new methodology for automated route selection and optimization, for the construction of new electric power supply lines by utilizing GIS and dynamic programming. Environmental constraints are taken into account together with all of the operating, maintenance, and equipment installation costs, including a new approach to the costs associated with the slope of the terrain crossed by the power lines. Rajeev and Krishnamoorthy (1992) presented a simple GA for optimizing structural systems with discrete design variables illustrated using160-bar transmission tower.

The first step in the installation of an electric power line is to find an adequate criterion for the assessment and selection of nodes for installing power towers. Various algorithms are available to calculate the cost of a power line between nodes in complex cases (Hosseini and Bahmani 2011). In the present study, a route optimization process uses a multi-criteria decision analysis (MCDA) named Analytic Hierarchy Process (AHP) (Haas and Meixner) and Dijkstra's Algorithm based Least Cost Path in ArcGIS. The selection of a tower type, conductor system, and span must precede tower spotting. Tower spotting is another significant part of the optimization process where the total tower cost for the line is minimized through tower location and allocation of the tower family. The dynamic programming application for optimal tower spotting location has been reformulated by Vieraand Toledo (2006). Reformulation refers to redefining optimal policy to represent adequately constraints determined by 3 towers (wind span, load span, distance to mass). In the present study, tower spotting has been done using a sag template through AutoCAD. Ghannoum and Kieloch (2012) used LiDAR for designing and optimization of line corridors, using Reliability-Based Design (RBD) and creating of line profiles for tower spotting.

Raghavendra (2012) modeled and analyzed a typical 132-KV double circuit transmission-line tower using STAAD.PRO and ANSYS software, which does not require any objective and constraints formulation, and gives the optimized section directly based on the design parameters from the user-provided table for every member group.

The main objective of the present study was to develop the methodology for locational and structural optimization of a tower of a transmission line. Tower outline and sag tension are calculated using MS-Excel. Weighting is done using the Analytic hierarchy process (AHP) and routing optimization of the transmission line is done through GIS. A sag template has been developed for tower spotting using AutoCAD. The analysis and design of the tower have been carried out as per recommendations of IS: 802-2006 using STAAD.Pro. The complete work has been divided into two phases. The first phase is comprised of optimization of the structural configuration of the tower and the second phase includes line routing optimization. The results have been compared with the existing literature.

## II. METHODS AND MATERIAL

Transmission line optimization has several stages as illustrated in Figure 1. In the present study, a program has been developed in the MS-Excel for the calculation of tower configuration, sag tension, and wind load. Line routing, tower spotting, and size optimization of towers are significant parts of the optimization process where the total tower cost for a line is minimized.

**Selection of Components of Transmission Lines**

Selection of components like conductor and ground wire depends upon sag characteristics of both and also on span of transmission line which in turn relates to the spotting of towers along a route. The span of the transmission line and angle of line deviation are also variables for optimization. Even footing type is also a function of these two parameters. The judicious selection of the conductors, insulators, and ground wire and the design of towers with their spotting and erection can bring the cost-effectiveness of the transmission line. The transmission line and its components are assumed as per guidelines of IS: 802 Part1/sec 1- 1995 (reaffirmed 2006), IS: 5613 Part 2/ Sec 1-1985 (Reaffirmed 2002) CBIP manual no. 268.

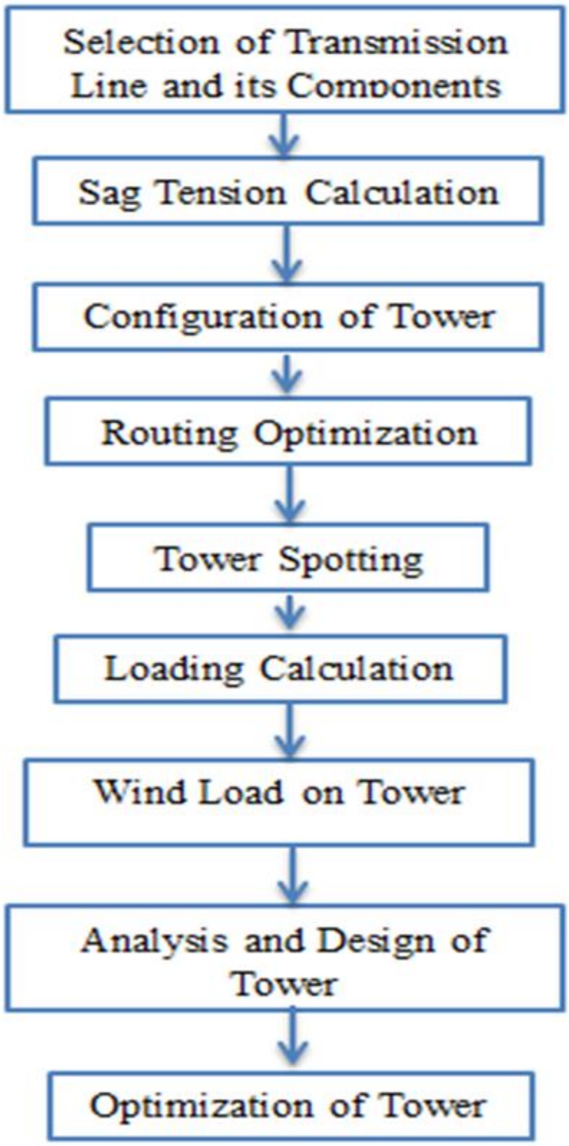



Figure 1: Methodology for optimization

**Sag Tension Calculation**

A sag tension calculation decides the conductor and insulator sub-system. It is required in the decision for fixing up the ruling span and in fixing up the outline of the tower, thus, indirectly also deciding the tower subsystem. The spacing required between the ground wires and conductors at null points to ensure that a lightning stroke that hits the ground wire does not flash over to the conductor is called mid-span clearance. Thus, from the protection point of view, the ground wire is strung with a lesser sag (10 to 15%) than the conductor so as to give a mid-span separation greater than the supports (Murthy and Santhakumar 1990).

Indian standard, IS: 802 (1/1) – 2006, code of practice for use of structural steel in overhead transmission line towers prescribes the following conditions for the sag tension calculations for the conductor and the ground wire.

- Maximum temperature of 75°C for ASCR and 53°C for ground wire with design wind pressure ranging between 0% & 36%.
- Every day temperature, 32°C, and design wind pressure of 100%, 75% & 0%.
- Minimum temperature 0°C with design wind pressure 0% & 36%.

IS 802: (1/1) - 2006 recommends that conductor/ground wire tension at everyday temperature and without external load should not exceed 25 % (up to 220 KV) for conductors and 20% for ground wires of their ultimate tensile strength. Sag tensions are calculated and shown in Table1 by using the parabolic equations as per the recommendation of IS: 5613 (2/1) - 1989 for both the conductor and ground wire.

$$F_2^2.\left(F_2-(K-\propto tE)\right)=L^2\partial^2q_2^2\,{}^E/_{24},\ \text{where} K=F_1-\left(L^2\partial^2q_o^2\,{}^E/_{24\,F_1^2}\right)$$

The sag tension calculation for the conductor and ground wire has been calculated by using a parabolic equation at different combinations of the temperature and the percentages of wind as per the IS: 875-1987.

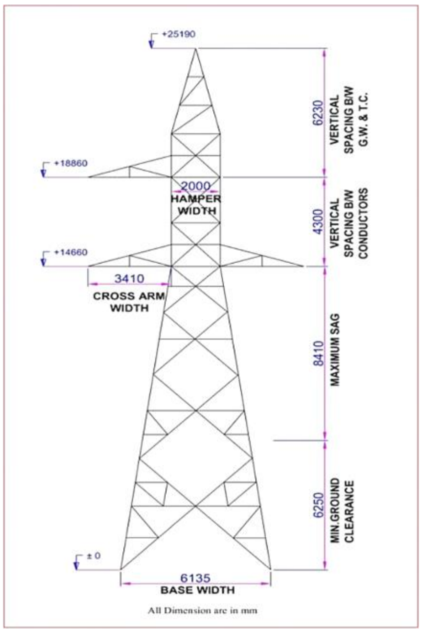
**Table 1:** Sag Tension for Conductor (ASCR) and Ground wire

| Temperature Variation | ( °C) | -7.5 | 0 | | 32 | | 75 |
|---|---|---|---|---|---|---|---|
| Wind Variation | ( %) | 0 | 0 | 0 | 0 | 1 | 0 |
| Ice | ( %) | 1 | 1 | 0 | 0 | 0 | 0 |
| ***Conductor (Panther)*** | | | | | | | |
| Tension (F*A) | (Kg) | 4013.62 | 3904.56 | 2406.49 | 1982.8 | 2317.33 | 1610.24 |
| Sag w.L$^2$/8T | (m) | 7.71 | 7.92 | 5.67 | 6.88 | 8.28 | 8.48 |
| ***Conductor (wolf)*** | | | | | | | |
| Tension (F*A) | (Kg) | 2990.84 | 2909.57 | 1793.25 | 1477.56 | 1713.00 | 1199.91 |
| Sag w.L$^2$/8T | (m) | 8.69 | 8.94 | 5.68 | 6.89 | 7.99 | 8.49 |
| ***Ground Wire*** | | | | | | | |
| Tension (F*A) | (Kg) | 2373.66 | 2331.55 | 1400.16 | 1189.46 | 1403.60 | 1076.15 |
| Sag w.L$^2$/8T | (m) | 7.32 | 7.45 | 4.29 | 5.05 | 5.84 | 5.58 |

## III. TOWER CONFIGURATION

The transmission line tower is so shaped, dimensioned, and designed structurally to sustain the external loads acting on the strung cables (conductors and ground wires) and the superstructure itself. The superstructure has a trunk and a hamper (cage) to which cables are attached, either through insulators or directly.

As per the American Society of Civil Engineering (ASCE-52) guidelines, the overall configuration of a transmission line structure is distinguished on the basis of ground clearance requirements, electric air gap clearance requirements, electric and magnetic field limits, insulation requirements, number of circuits, right of way requirements and aesthetic design criteria (Fang et al. 1999). Central Board of Irrigation and Power (CBIP) recommends the total height of a transmission line tower as a summation of minimum permissible ground clearance, maximum sag, maximum sag, length of suspension insulator string, the vertical spacing between conductors, vertical clearance between the ground wire and top conductor which in turn depends on peak clearance and the mid-span clearance. On the basis of Indian standard requirements, configurations of transmission towers, considering PGCIL guidelines are worked out in an excel sheet on the recommendations contained in the literature (Gupta 2005). The clearance checks as per Indian standards are also applied. The final configured outline of the transmission tower and clearance check is shown in Figure 2.



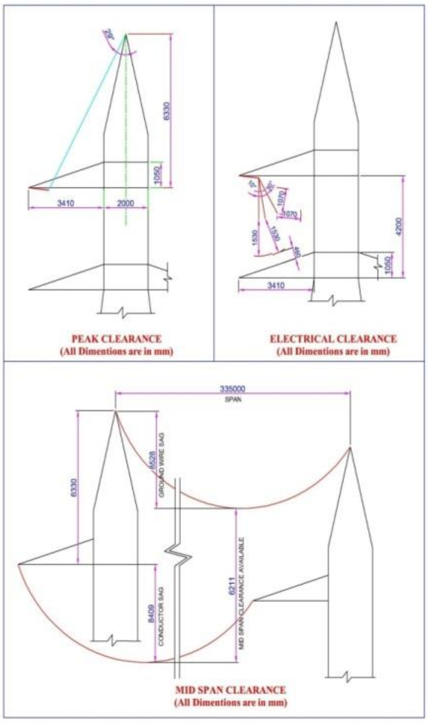




Figure 2: The final configured outline of the transmission tower and clearance check.

**Routing Optimization of Transmission Line**

GIS methodology for power-line routing having Least Cost Path (LCP) is used as the core optimization method. One of the classic LCP algorithms is Dijkstra's Algorithm, which they focused on the path-finding algorithm. In this study, we investigated the use of the LCP algorithm based on Dijkstra's Algorithm in determining the optimum routing of the transmission line. Specific tools to manage and build spatial or geographic cost databases are designed to embed LCP into GIS. The results are the optimal route to install a transmission line in a geographic region, given a definition of the origin of that line.

In LCP terminology, GIS raster line routing is based on a set of elementary cells with links between neighboring cells in a particular order along the path or route. Each cell maintains the record of an accumulated transition cost, evaluated at a particular point of the calculation process along the path between the origin of the route and that cell; the optimal path between two locations (optimal decision policy) is the sequential aggregation of optimal elementary transitions or links (optimal decision policies that lead to new states of the following stages) between neighboring cells from the origin to the end of the route.

**Case Study**

In the present study, a small area in hilly terrain covered with mountains in District Hamirpur of Himachal Pradesh in India has a latitude of 31°42'25" N and longitude is 76°54'55" E, is considered, for the transmission line routing. The area constitutes slopes and certain protected areas (academic department, residential hostel buildings, playground, and residential officer's area. The area under study is digitized on a 1/25000 standard topographic map.

**Weighing criteria**

Here three criteria (data layers) are considered that affect Electrical Transmission Line (ETL) routing, each layer representing similar features was grouped together and weighted based on its relative importance within the perspective. The weighing was based on Analytical Hierarchy Process (AHP) to set the percent influence for each layer group. The slope is classified into four groups, such as 0 – 10%, 10 – 20 %, 20 – 30 %, and greater than 30% and the corresponding weights (rank) as 1, 1/5, 1/7, and 1/9. Analytic Hierarchy Process (AHP) method is used to weigh the criteria and to check the consistency of ranking.

**Analytic Hierarchy Process (AHP)**

Various studies have shown that to make accurate selections in route optimization problems, Multi-Criteria Decision Making (MCDM) is one of the most preferred methods. AHP, a technique for decision-making developed by Thomas L. Saaty, is used widely as MCDM method in many studies. In many situations, comparison ratios are imprecise judgments, but some of the decision values can be exactly judged while others cannot in most real-world problems. Humans' predictions are more accurate and comparatively efficient in qualitative forecasting than quantitative predictions.

**Weighting with AHP**

With the AHP users can assess the relative weight of multiple criteria in a heuristic way. The most important aspect of the AHP is pair-wise comparisons used when quantitative ratings cannot be used. Saaty presented a consistent way of determining the relative priority of each of the criteria from pair-wise comparisons in simple steps to check the consistency of assigned weightage:

a) Determine the weighted sum vector by multiplying the weights by their corresponding values of the original pairwise comparison matrix, sum values over the rows.
b) Determine the consistency vector by dividing the weighted sum vector by the criterion weights determined previously.
c) After successful calculation of the consistency vector, we need to compute values for Lambda (λ) and the consistency index (CI). The value for lambda is simply the average of the Consistency vector

The calculation of CI is based on the observation that λ is always greater than or equal to the number of criteria under consideration (n) for positive, reciprocal matrixes, and λ = n if the pairwise comparison matrix is a consistent matrix. Accordingly, λ – n can be considered as a measure of the degree of inconsistency and can be normalized. CI provides a measure of departure from consistency, and the calculation of the consistency ratio (CR), which is defined as

CR = CI / RI

Where, RI is the random index, the consistency index of the randomly generated pairwise comparison matrix. The RI depends on the number of elements being compared. The defined value of CR<0.10, the ratio indicates a reasonable level of consistency in the pairwise comparisons. If the value of the consistency ratio (CR) is more than 10%, then the preferences are to be revised to get consistent results. But if the CR is less than 10%, then the results are considered consistent and can be used in the analysis. In the present study, a spreadsheet was developed for making Pairwise comparisons, finding relative importance and inconsistency ratio of comparisons, which is used for weighting the criteria and sub-criteria. After all the pair-wise comparisons are made, the inconsistency index that indicates the consistency of the comparison was calculated. All the inconsistency indexes calculated are less than 0.1, indicating better accuracy of the pair-wise comparisons of the study. The calculated weighing for slope sub-criteria is shown in Table 2.

**Table 2**: Result of analytic hierarchy process

1.Pair Wise Comarison

| Slope | 0-10% | 10-20% | 20-30% | > 30% |
|---|---|---|---|---|
| 0-10% | 1.00 | 0.20 | 0.14 | 0.11 |
| 10-20% | 5.00 | 1.00 | 0.50 | 0.17 |
| 20-30% | 7.00 | 2.00 | 1.00 | 0.20 |
| > 30% | 9.00 | 6.00 | 5.00 | 1.00 |
| Total | 22.00 | 9.20 | 6.64 | 1.48 |

2. Normalization

| Slope | 0-10% | 10-20% | 20-30% | > 30% |
|---|---|---|---|---|
| 0-10% | 0.05 | 0.02 | 0.02 | 0.08 |
| 10-20% | 0.23 | 0.11 | 0.08 | 0.11 |
| 20-30% | 0.32 | 0.22 | 0.15 | 0.14 |
| > 30% | 0.41 | 0.65 | 0.75 | 0.68 |
| Total | 1.00 | 1.00 | 1.00 | 1.00 |

3. Consistency analysis

| Total | Average | Consistency Measure |
|---|---|---|
| 0.16 | 0.03 | 4.04 |
| 0.52 | 0.10 | 4.14 |
| 0.82 | 0.16 | 4.28 |
| 2.49 | 0.50 | 4.50 |
| | Sum | 16.97 |
| | Average (λ) | 4.24 |
| | C I | 0.08 |

| | |
|---|---|
| Consisitency Index ( CI ) | $CI = \frac{\lambda - n}{n-1}$ |
| n = Order of matrix | n = 5 |

Random Index ( RI)

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.46 | 1.49 |

| | | | |
|---|---|---|---|
| Consistency Ratio (CR) | $CR = \frac{CI}{RI}$ | CR = 0.09 | The CR is less than 10% (0.1) Therefore Inputs are consistent and Acceptable |

## Collection and processing of the data

Data collection is the main task and it typically consumed the majority of the available resources. Today data collection still remains a time-consuming, tedious and expensive process. Utilizing the ESRI arc toolbox and Model Builder, separate toolbox and model were created as shown in Figure 3 for transmission line routing. To get a total weighed surface map, maps are gathered, digitized, clipped or unified, entered attributes according to weights, and converted to raster format. All the raster-based maps obtained from these processes are shown in Figures 4 to 6.

As the corridor weight of routing studies is used as 20 - 30 m., the pixel size of the map is selected as 6.0 m, reducing the pixel size will make the loss of memory and will reduce the processing time. All raster-based maps are prepared; the raster calculator toolbox is used to unify the maps with their weights. Obtained total weighed surface map as shown in Figure 7.

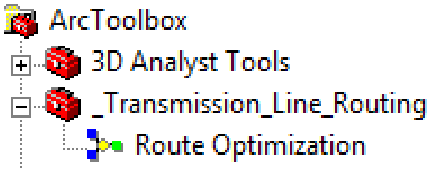



Figure 3: Optimization model in arctoolbox

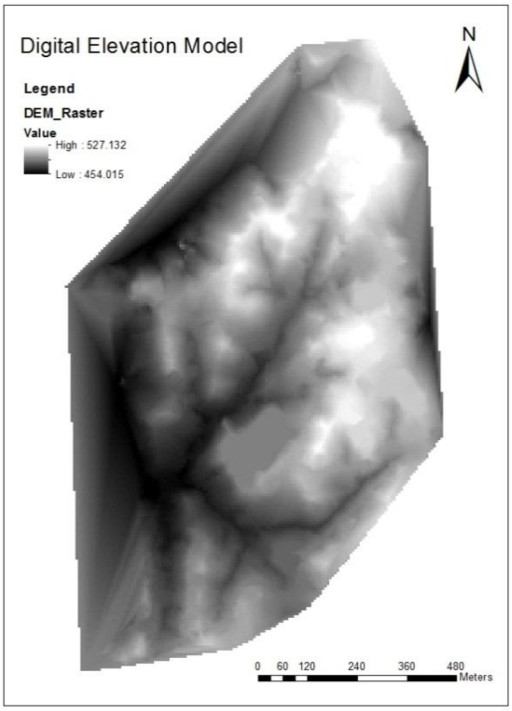



Figure 4: Raster map


Figure 5: Reclassified slope

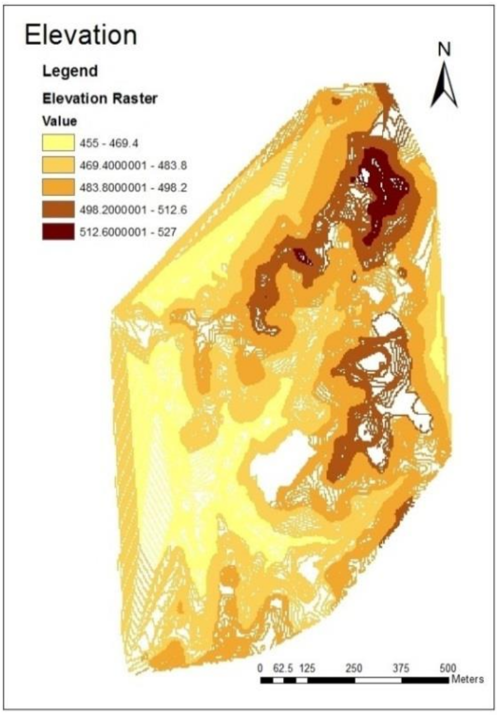



Figure 6: Reclassified elevation


Figure 7: Weighted overlay map

**Optimum ETL route finding with LCP**

Typically due to the electric and magnetic fields, especially from high voltage transmission lines, the transmission line routing is highly complex. During the route selection for a transmission line, a straight route with minimum curves is desirable as it gives the best engineering and economic solution.

LCP is an iterative Process based on Dijkstra's algorithm in ArcGIS, similar to the Euclidean tool, but instead of calculating the actual distance from one location to another, the cost distance tool determines the shortest weighted distance (1 or accumulated travel cost) from each cell to the nearest source location. This tool applies distance in cost units, not in geographic units. The cost distance tool requires both a source dataset and a cost raster as input. (ESRI 2007)

While the output cost distance raster identifies the accumulative cost for each cell to return to the closest source location, it does not show which source cell to return to or how to get there. The Cost Back Link tool returns a direction raster as output, providing what is essentially a road map that identifies the route to take from any cell, along the least-cost path, back to the nearest source. The algorithm for computing the backlink raster assigns a code to each cell.

Once the accumulative cost and backlink raster are created, the LCP route can be derived from any designated destination cell or zones. The Cost Path tool retraces the destination cells through the backlink raster to a source. By selecting different start and end points in this study area, the accuracy and performance of the best routes according to the LCP algorithm has been assessed and the optimized Transmission Line is shown in Figure 8.

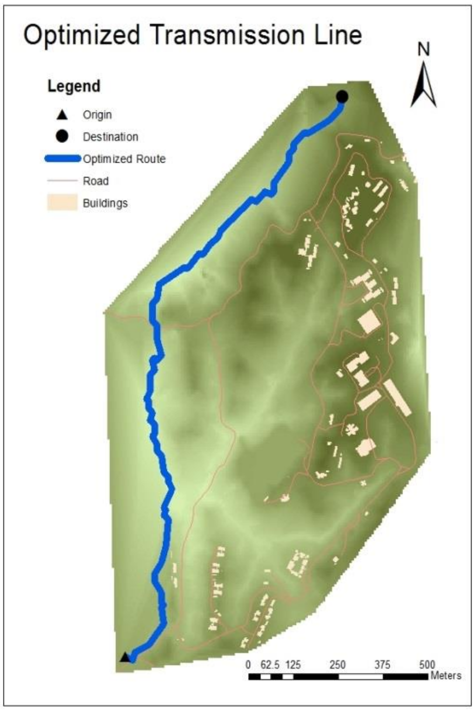



Figure 8: Optimized route of transmission line

## TOWER SPOTTING

Tower Spotting was another objective of the study which includes locating structures in a right-of-way and selecting their type and height. Specifically, the most economical combination of structures and spans that will satisfy the electrical requirements, starting with a profile of the right-of-way, towers are spotted by the manual template method.

In recent years, tower spotting was done with the aid of a sophisticated computer program using the dynamic programming method of optimization. Such programming would include the limits of utilization and costs of various types of towers, employed with extensions or reductions for different heights, and the different types of foundations, corresponding to the family of towers and characteristics of the soil, as input data. Wind and weight spans at each location should be checked while spotting towers. Most locations of angle and anchor towers are dictated by the plan of the line. As far as possible, tower spotting in marshy, water-logged areas, low-lying areas, rocky locations, etc. should be avoided.

Most locations of angle and anchor towers are dictated by the plan of the line. Wherever possible, uplift under conditions of minimum sag should be avoided on all towers, but if impossible, special consideration should be given to the attachment of the conductor at the uplift point. In some cases, weight may be attached to the insulator strings, but the use of strain connections is recommended for cases of excessive uplift. (Murthy and Santhakumar1990). Tower spotting is a significant part of the optimization process where the total tower cost for the line can be minimized through tower location and allocation of the tower family. (Grant and Clayton 1987).

## SAG TEMPLATE

A Sag template is a very important tool with the help of which the position of towers (Tower Spotting) on the profile is decided so that they conform to the limitations of vertical and wind loads on any particular tower, and minimum clearances, as per Indian Standards, required to be maintained between the line conductor to ground, telephone lines, buildings, streets, navigable canals, power lines, or any other object coming under or near the line.

A Sag Template is specific for the particular line voltage, the conductor used, and the applicable design conditions. In the present study, a Sag Template (consists of a set of parabolic curves) drawn on AutoCAD Software, the set of curves in the sag template consists of:

- 'Hot or Maximum Sag Curve' showing maximum sag of conductor at maximum temperature and still wind including sag tolerances allowed (normally 4%), under maximum ice condition.
- 'Ground Clearance Curve' is drawn parallel to the 'Hot or Maximum Sag Curve' and at a distance equal to the specified minimum ground clearance.
- 'Tower Footing Curve' is drawn parallel to the 'Ground Clearance Curve' and separated by a minimum distance equal to the maximum sag at the basic design span.

The Sag Template is plotted to the same scale as the profile, i.e., 1 cm = 20 Units horizontal and 1 cm = 2 Units vertical. It is generally plotted for spans up to 1000 meters. This is necessary for tower spotting in hill regions where large variations in the ground levels along the line route.

The profile of the optimized route has been imported on the same workspace in AutoCAD. The Sag Template is applied to the profile by moving the same horizontally while always ensuring that the vertical axis is held vertical, i.e., in line with the vertical lines on the profile sheet. The left-hand side of the tower footing curve is placed at the starting point of each section. Initially, the template is shifted to the right, ensuring at all times that the tower footing curve is touching the starting point, to a position where the ground clearance curve is just above the ground profile, i.e., the ground clearance curve should not touch or cross the ground line plotted on the profile. The second tower location is then marked at the point where the tower footing curve on the right hand side cuts the ground profile.

The second tower location is then used as the reference and the third tower location is marked in a similar manner as above. This is continued till the end of the section is reached. It may be possible that a very short or very long span remains at the end of the section. In such cases, depending on the economics of the options, the span can be distributed evenly or other spans in the section can be increased (not normally exceeding the basic span) by using tower extensions wherever possible. Besides normal ground clearance, the clearance between power conductors and objects like other power or telecommunication lines, houses, trolley wires, roads, railway tracks, canal embankments, etc., has also been checked. In these cases, the clearances of the conductor from these objects were maintained. Details of tower spotting are shown in Table 3 and the application of a sag template on the profile is shown in Figure 9.

**Table 3**: Details of tower spotting along the optimized profile

| **Tower numbers** | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| **Conductor Type 1(panther)** | **Distance (m)** | 0 | 281 | 568 | 870 | 1173 | 1468 |
| **Conductor Type 2 ( wolf )** | **Distance (m)** | 0 | 262 | 540 | 845 | 1139 | 1445 |

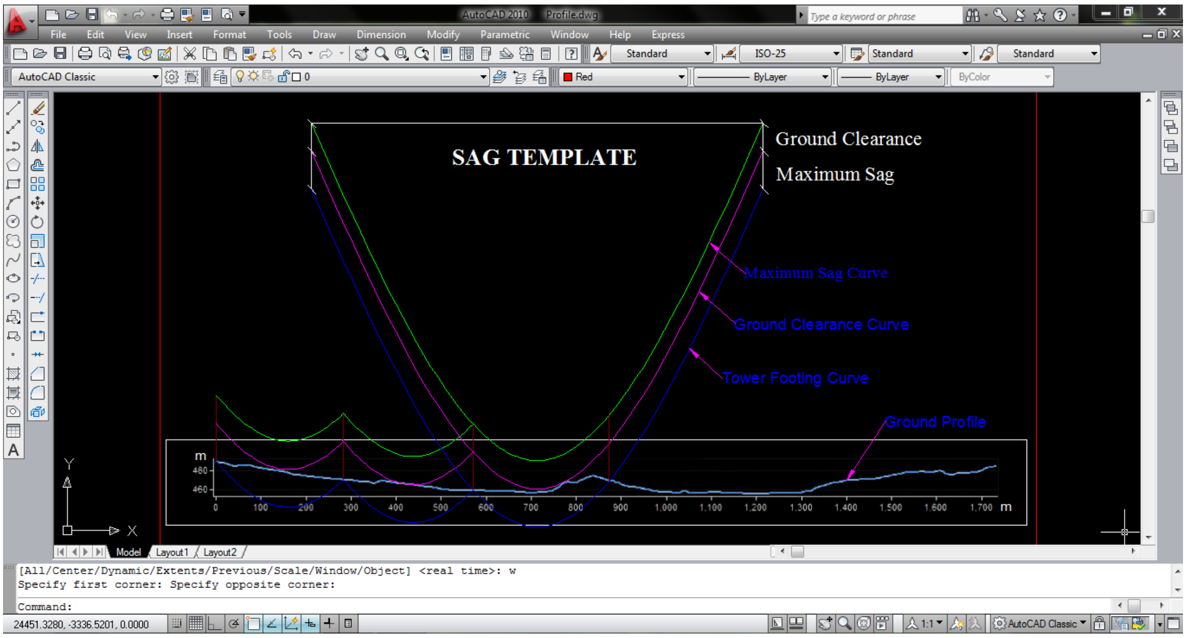


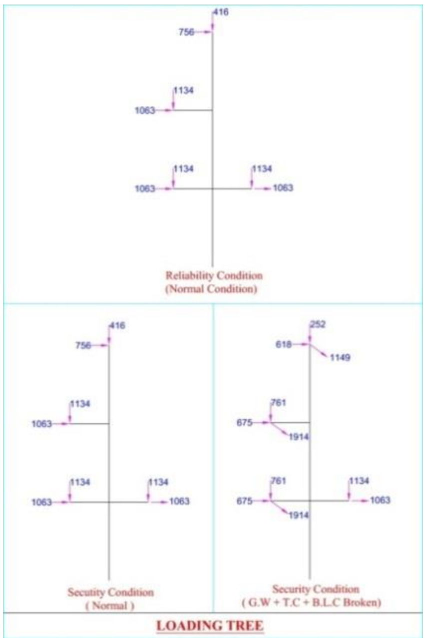

Figure 9: Application of the sag template on the profile

## IV.ANALYSIS AND DESIGN OF TOWER

**Load Calculation**

The transmission line tower is a pin-jointed light structure for which the maximum wind pressure is the main criterion for design (CBIP – 268). Further, concurrence of earthquake and maximum wind conditions is unlikely to take place together and seismic stresses are considerably diminished by the flexibility and freedom for vibration of the structure (IS: 1893 - 2003). The loading criteria for the transmission system as per CBIP-268 account for reliability, security, and safety covering transverse loads, vertical loads, longitudinal loads, and anti-cascading loads. The considered load combinations as per IS:802(1/1)-2006 corresponding to normal conditions for reliability check, broken wire conditions for security check, and for safety conditions during construction and maintenance.

The security conditions for suspension towers correspond to nil wind condition whereas for tension towers this requirement is stipulated for 100% full wind condition (IS: 802 (1/1) – 2006). But, with the operational experience of towers designed on this basis the power utilities (PGCIL) have initiated amendments through BIS stipulating security conditions of suspension and tension tower corresponding to 75% of full wind load at everyday temperature. Tower being a space truss, loadings are synchronized as the point loadings at the tip of the peak and at the three tips of the cross arms. These are shown in the form of a Load Tree in Figure 10 with the aid of AutoCAD.



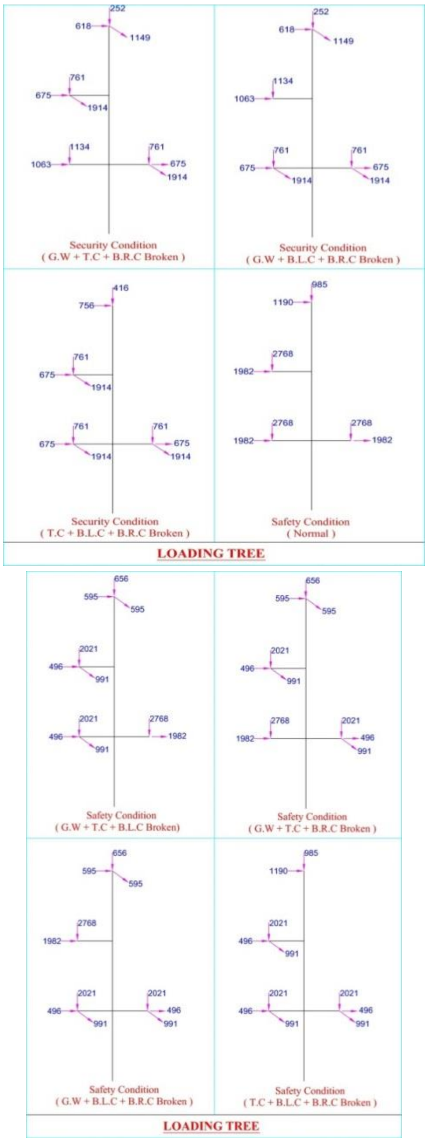



Figure10: Loading trees for different load combinations for Reliability security and safety

## Wind Loads

Wind pressures are expressed in terms of a basic pressure 'p', which is an equivalent static pressure in the windward direction (Murthy and Santhakumar 1990). In order to determine the wind load on the tower, the tower is divided into different panels having a height "h", normally taken between the intersections of the legs and bracings. For lattice towers, the wind is considered to act at the center of gravity of the panel normal to the face. In the design of lattice towers, normally a quasi-static approach is adopted with gust response factor included taking into account the dynamic nature of the wind for evaluating the peak stresses in members. The gust response factor is the multiplier used for the wind loading to obtain the peak load effect and accounts for the additional loading effects due to wind turbulence and dynamic amplification of flexible structures and cables.

Gust response factor for conductor and ground wire depends on the terrain categories, height above the ground, and the span. Gust response factor for tower depends upon the terrain categories and the height above the ground. Gust response factor for insulator depends on the ground roughness and height of insulator attachment above ground. Drag coefficients under the wind effect are considered for the conductor, ground wire, tower, and insulator (CBIP – 268). The final calculated application of wind load on the tower has shown in Table 4.

| Panel No. | Wind Load on Tower | | Panel Distribution | Load Distr. Factor | Distributed Load | | | | Final Applied Load (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.75 | 1 | | | 0.75 | 1 | 0.75 | 1 | 0.75 | 1 |
| 10 | 36 | 48 | **Top** | 0.67 | 24 | 32 | 116 | 154 | **116** | **154** |
| | | | Bottom | 0.33 | 12 | 16 | | | | |
| 9 | 80 | 107 | Top | 0.55 | 44 | 59 | | | | |
| | | | Bottom | 0.45 | 36 | 48 | | | | |
| 8 | 105 | 141 | Top | 0.53 | 56 | 75 | | | | |
| | | | Bottom | 0.47 | 50 | 66 | | | | |
| 7 | 133 | 177 | Top | 0.5 | 66 | 89 | | | | |
| | | | Bottom | 0.5 | 66 | 89 | 238 | 318 | | |
| 6 | 130 | 173 | **Top** | 0.5 | 65 | 87 | 155 | 206 | **393** | **524** |
| | | | Bottom | 0.5 | 65 | 87 | | | | |
| 12 | 25 | 33 | Top | 0.5 | 12 | 16 | | | | |
| | | | Bottom | 0.5 | 12 | 16 | | | | |
| 11 | 25 | 33 | Top | 0.5 | 12 | 16 | | | | |
| | | | Bottom | 0.5 | 12 | 16 | | | | |
| 5 | 129 | 171 | Top | 0.5 | 64 | 86 | | | | |
| | | | Bottom | 0.5 | 64 | 86 | 153 | 204 | | |
| 4 | 199 | 265 | **Top** | 0.53 | 106 | 141 | 199 | 265 | **352** | **470** |
| | | | Bottom | 0.47 | 94 | 125 | | | | |
| 3 | 234 | 312 | Top | 0.52 | 122 | 162 | | | | |
| | | | Bottom | 0.48 | 112 | 150 | 234 | 312 | | |
| 2 | 293 | 391 | **Top** | 0.52 | 153 | 203 | 293 | 391 | **527** | **703** |
| | | | Bottom | 0.48 | 141 | 188 | | | | |
| 1 | 293 | 391 | Top | 0.52 | 153 | 203 | | | | |
| | | | **Bottom** | 0.48 | 141 | 188 | 293 | 391 | **293** | **391** |
| **Check** | 1681 | 2242 | | | 1681 | 2242 | 1681 | 2242 | 1681 | 2242 |

Table 4: Application of wind load on the tower

For simplification, the 3-D model was imported from AutoCAD to STAAD.Pro V8i. As per node and member numbering, all space (X, Y, and Z) nodal coordinates and member connecting nodes have been entered in Excel Sheet from the tower modeled in AutoCAD. All nodal coordinates and member connecting nodes have been placed on the editor page of STAAD.Pro V8i editor page. A 132kV Transmission tower has been modeled in STAAD.Pro V8i working environment is shown in Figure 11.

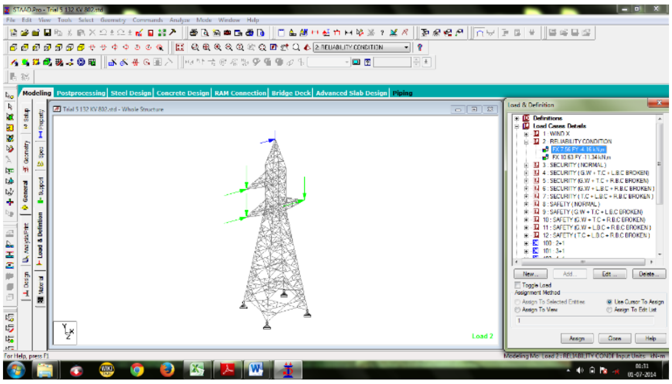


Figure 11: 132kV transmission tower STAAD Pro v8i model

In the present study, the hinged supports are assigned to the bottom of four legs of the transmission tower. The separate load case details and load combination have been developed as per IS 802: 1992. Since the transmission tower members are considered as connected with pinned joints all the members have been defined as truss members. The design parameters such as minimum thickness, yield stress, slenderness ratio, and deflection criteria were assigned as per IS 802: 2006 'Use of Structural Steel in Overhead Transmission Line Tower – Code of Practice. Since axial force is the only force for a truss element, the member has to be designed for either compression or tension. But the reversal of loads may also induce alternate nature of forces; hence these members are to be designed for both compression and tension. The total force acting on any individual member under the normal condition and also under the broken wire condition is multiplied by the corresponding factor of safety and it is ensured that the values are within the permissible ultimate strength of the particular steel used. (CBIP – 268) IS 802: Part 2 / Sec 1: 1995 restricts the slenderness ratio as follows:

- Leg members, G.W. Peak, X arm lower member < 120
- Bracings < 200
- Redundant / Nominal stress carrying members < 250
- Tension members < 400

Optimization of tower

Two computer-aided design methods are in vogue, depending on the computer memory. The first one uses a fixed geometry (configuration) and minimizes the weight of the tower, while the second method assumes the geometry as unknown and derives the minimization of weight.

The present work was aimed at developing a software technique to minimize the weight of the transmission tower with fixed geometry. Since transmission line towers are large structural systems, it is slightly difficult to optimize the area of individual members, as it leads to a large number of design variables. Hence, some sort of member grouping should be done to reduce the design variables. The member groups are formed after performing a preliminary analysis. If the structure, as well as the loading, is symmetric, it is natural to expect the distribution of members also to be symmetric. The same 132kV single circuit angle tower is chosen for study. In the basic structure, sectional plans at various levels and the loading conditions are fixed as per the calculated value in the previous session. The members have been divided into 26 groups, such as leg groups, diagonal groups, and horizontal groups, based on various panels of the tower. For each group, a different section is specified. For the given loading conditions, the forces in the various members are computed, from which the actual stresses are found. These are compared with allowable stresses and the most stressed member (critical) is found out for each group. Thereafter, an initial design is evolved as a fully stressed design in which critical members are stressed up to an allowable limit. This is given as the initial solution to the Simplex method, from which the weight of the tower is formed. The initial solution so obtained is sequentially improved, subjected to the iterations, and the optimal solution is obtained.

**Comparison of optimization method**

In order to know the efficiency of optimization, the present optimization technique has been validated with the solved problem from Roopesh et al. (2006). The configuration of the 160-bar transmission line tower is modeled in STAAD.Pro V8i. The details of the loading considered and the grouping of members are the same as per the literature. The results with respect to the optimal area of section and minimized weight were compared.

## V. RESULTS AND DISCUSSIONS

A 132 kV single circuit angle transmission line tower was considered for optimization. Sag tension calculation was done for temperature difference, ice, and wind cases. The transmission tower was configured by satisfying peak clearance, electrical clearance, and mid-span clearance. Routing optimization of transmission towers has been presented using Least Cost Path Tool in ArcGIS. The criteria were ranked and weighted using Analytic Hierarchy Process (AHP). Tower spotting was done along the optimized route using sag temple through AutoCAD for both conductors. The nodal and member coordinates of the tower were transferred to STAAD.Pro V8i. Parameters such as supports, loads, and member property were assigned to the tower. Analysis and design of transmission tower were done as per IS 800-1984. The transmission tower has been optimized using STAAD.Pro V8i. The developed size optimization method was compared with existing literature and the above results are discussed as follows.

## VI. DISCUSSIONS

- Sag tension calculation has been done for conductor and ground wire for different temperature, ice, and wind cases as IS: 802 using MS-Excel. The maximum sag tension has been observed for minimum temperature with ice with maximum wind pressure combination for both conductor and ground wire.
- The routing of the transmission line was optimized using three features such as slope, elevation, and restricted area with weightage of 60, 20, and 20% respectively. The slope features are further classified as 0 to 10%, 10 to 20%, 20 to 30%, and greater than 30% with 9, 7, 5, and 1 ranks respectively.
- The tower was analyzed for 11 load cases covering normal and broken wire cases under reliability, security, and safety condition for ground wire or conductor points. The member forces are compared for all 11 cases and it is observed that the compression and tension force are critical/maximum for case number four which is ground wire, bottom left and right conductor is broken.
- The tower members have been divided into 26 groups, such as leg groups, diagonal groups, and horizontal groups, based on various panels of the tower. The size of optimization of transmission tower has done both conductor types (Table 5) for minimum weight design with fixed geometry using STAAD.Pro V8i through a separate user-provided steel table (UPT). Table 6 shows the optimized areas of the 132kV transmission line tower for conductor type 1 (panther)
- The proposed optimized method was compared with existing literature and Table 7 shows the comparison of the results obtained and with that in literature.
- The solution of the proposed technique is 1052.3 Kg, and the solution obtained by Roopesh et al. (2006) is 986.5 Kg. On comparing the results of optimization solutions, the proposed technique gives reasonable minimum weight with less effort. The present method can give better results for large problems also.

**Table 5**: Optimized weight of 132kV transmission tower

| Description | Conductor Type 1(Panther) | Conductor Type 2 (wolf) |
|---|---|---|
| Total weight of tower (kg) | 7991 | 6336 |

**Table 6:** Optimal areas of 132kV transmission line tower

| Member Group No. | Member No. | Area ($mm^2$ ) | Steel Section | Governing Member No. |
|---|---|---|---|---|
| 1 | 1 TO 16 | 526 | 65X45X5 | 15 |
| 2 | 17 TO 44 | 866 | 75X75X6 | 35 |
| 3 | 45 TO 60 | 656 | 70X45X6 | 58 |
| 4 | 61 TO 76 | 2022 | 130X130X8 | 75 |
| 5 | 77 TO 92 | 2022 | 130X130X8 | 91 |
| 6 | 93 TO 108 | 3400 | 200X15X10 | 107 |
| 7 | 109 TO 124 | 4278 | 150X150X15 | 123 |
| 8 | 125 TO 136 | 575 | 60X60X5 | 135 |
| 9 | 137 TO 232 | 727 | 75X75X5 | 220 |
| 10 | 233 TO 264 | 677 | 70X70X5 | 256 |
| 11 | 265 TO 296 | 1650 | 100X75X10 | 284 |
| 12 | 297 TO 328 | 1698 | 125X95X8 | 320 |
| 13 | 329 TO 352 3370 3380 3390 3400 3410 3420 3430 3440 | 929 | 80X80X6 | 337 |
| 14 | 353 TO 384 | 1221 | 80X80X8 | 368 |
| 15 | 385 TO 396 | | 45X45X4 | 396 |
| 16 | 397 TO 400 409 TO 412 | 575 | 60X60X5 | 412 |
| 17 | 401 TO 408 413 TO 436 | 1047 | 90X90X6 | 425 |
| 18 | 437 TO 460 3441 TO 3452 | 1903 | 100X100X10 | 3445 |
| 19 | 461 TO 492 | 1286 | 125X95X6 | 480 |
| 20 | 493 TO 548 | 226 | 30X30X4 | 495 |
| 21 | 549 TO 556 | 479 | 50X50X5 | 549 |
| 22 | 557 TO 732 | 1200 | 65X65X10 | 611 |
| 23 | 733 TO 750 | 1166 | 125X75X6 | 749 |
| 24 | 751 TO 768 | 1166 | 125X75X6 | 768 |
| 25 | 769 TO 816 | 575 | 60X60X5 | 810 |
| 26 | 817 TO 824 | 575 | 60X60X5 | 824 |

**Table 7:** Optimal areas of 160 bars transmission line tower

| Member Group No. | Roopesh ( 2006 ) | Present study | | |
|---|---|---|---|---|
| | Area ( $mm^2$) | Area ($mm^2$ ) | Steel Section | Governing member No. |
| 1 | 301.29 | 327 | 35X35X5 | 12 |
| 2 | 64.52 | 327 | 35X35X5 | 56 |
| 3 | 82.58 | 327 | 35X35X5 | 64 |
| 4 | 156 | 327 | 35X35X5 | 100 |
| 5 | 374.12 | 428 | 45X45X5 | 19 |
| 6 | 64.52 | 327 | 35X35X5 | 156 |
| 7 | 714.83 | 1100 | 60X60X10 | 35 |
| 8 | 115.48 | 327 | 35X35X5 | 96 |
| 9 | 158.06 | 479 | 50X50X5 | 160 |
| 10 | 98.71 | 428 | 45X45X5 | 121 |
| 11 | 1114.2 | 1302 | 70X70X10 | 47 |
| 12 | 69.67 | 479 | 50X50X5 | 148 |

## VII. CONCLUSION

A GIS-based application has been developed for route optimization of the transmission line. In the study, three criteria i.e. slope, elevation, and restricted area were considered for the route optimization. The consistency of assigned rank and weightage for the above three criteria were checked using Analytic Hierarchy Process (AHP). It is shown that the routing process can be made simpler and less time-consuming by the use of a GIS-based approach with AHP using LCP Dijkstra's Algorithm. Although this methodology has been developed for route optimization of overhead electric power lines, it is easily extendable to other line routing problems, such as power underground distribution feeders, and takes advantage of the processing and viewing capabilities of GIS.

The method for structural (size) optimization has been developed using STAAD.Pro V8i software in which the user provides steel table as the input. As per member groups, separate member properties are assigned to every member group using user provided steel table. The optimal sectional area is obtained for every member group directly from the user-provided steel table in the developed methodology. This makes the optimization process more simple and efficient.

Location and structural optimization of a 132kV transmission tower for conductor types 1(panther) and 2(wolf) have been done as a case study. It was observed that conductor type 1 covers more tower distance showing better location optimization and conductor type 2 has less tower weight showing better structural optimization results. Therefore, by identifying the relative importance of location and structural aspects best configuration of the transmission line tower may be chosen. If the location aspect is given more importance than conductor Type 1 shows better results otherwise for the structural aspect conductor Type 2 gives better results.

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