Dynamic Analysis of Transmission Tower

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Abstract:
Transmission line towers carry heavy electrical transmission conductors at a sufficient and safe height from ground. In addition to their self-weight they have to withstand all forces of nature like strong wind, earthquake and snow load. Therefore transmission line towers should be designed considering both structural and electrical requirements for a safe and economical design. This paper introduces different types of transmission tower and its configuration as per Indian Standard IS-802. A typical type of transmission line tower carrying 220kV double circuit conductors is modeled and analyzed using STAAD-Pro considering forces like wind load, dead load of the structure and earthquake load as per Indian Standard IS1893:2000(part 1).

The transmission tower has height of 40m which includes the ground clearance(h1),maximum sag of the lower most conductors wire(h2),vertical spacing between the conductors wires(h3) and vertical distance of earth wire from the uppermost conductor wire(h3).The earth wire or ground wire is always located at the top of the transmission tower. It has a square base width of 11.5m. The type of transmission tower considered is a tangent tower having no deviation located on a plain landscape with minimal obstacles. It is located at the wind zone 6 with basic wind speed of 55m/s. The wind pressure on the tower depends on the gust response factor (GT) which increases with height.

The transmission tower is situated in the most seismic sensitive region i.e. Zone V where response reduction factor steel frame with concentric braces is of 4 and the damping for steel structures is 2%.The members are designed for maximum deflection and load for the most critical load combination as per code IS802. The members are also grouped for better fabrication. Steel optimization has been carried out to find the most suitable and economical section for the design.

Introduction:
In every country, the need of electric power consumption has continued to increase, the rate of demand being greater in the developing countries. Transmission tower lines are one of most important life-line structures. Transmission towers are necessary for the purpose of supplying electricity to various regions of the nation .This has led to the increase in the building of power stations and consequent increase in power transmission lines from the generating stations to the different corners where it’s needed. Interconnections between systems are also increasing to enhance reliability and economy. Transmission line should be stable and carefully designed so that they do not fail during natural disaster. It should also conform to the national and international standard. In the planning and design of a transmission line, a number of requirements have to be met from both structural and electrical point of view.

From the electrical point of view, the most important requirement is insulation and safe clearances of the power carrying conductors from the ground. The cross-section of conductors, the spacing between conductors, and the location of ground wires with respect to the conductors will decide the design of towers and foundations. The major components of a transmission line consist of the conductors, ground wires, insulation, towers and foundations. Most of the time transmission lines are designed for wind and ice in the transverse direction. However, the Indian Sub-continent is prone to moderate to severe earthquakes seismic loads may be important because the transmission line towers and the cables may be subjected to higher force and stressed during ground motion. However, the major concern of the transmission line during high earthquakes may be that the large displacements do not causes the cables to touch each other or any surrounding objects, causing power failure and accidents. Therefore, earthquake forces may be important in design in high earthquake zones of the country.
In this project Seismic behavior of transmission line is determined from the dynamics analysis of the tower and the cable subjected to earthquake ground motion.

Types of towers clause 6 IS 802 (Part 1/Set 1) : 1995:
The selection of the most suitable types of tower for transmission lines depends on the actual terrain through which the line traverses. Experience has, however, shown that any combination of the following types of towers are generally suitable for most of the lines:

Suspension towers:
Suspension towers are used primarily on tangents but often are designed to withstand angles in the line up to two degrees or higher in addition to the wind, ice, and broken-conductor loads. If the transmission line traverses relatively flat, featureless terrain, 90 percent of the line may be composed of this type of tower.

Tension towers:
As they must resist a transverse load from the components of the line tension induced by this angle, in addition to the usual wind, ice and broken conductor loads, they are necessarily heavier than suspension towers.

Following are the different parts of a transmission tower,

1) Peak of the tower
2) Cage or hamper of the tower, that supports the cross arm.
3) Cross arm for carrying conductors.
4) Tower body, includes bracing
5) Legs of the tower

Tower configuration:
The selection of a best outline and the bracing system patterns contributes to a great extent in developing an economical and safer design of a transmission line tower. For a particular tower configuration selected, the outline decided shall satisfy both electrical and structural requirements at the same time the configuration should be economical. The square type broad base tower are the most economical and most commonly used in India.

The tower outline diagram comprises
(a) Tower height considered from ground level
(b) Length of the cross-arm, and phase spacing
(c) Tower width at (i) base (ii) top hamper
(d) Bracing pattern considered.

Determination of tower height:
The factors that govern the height of the tower are:
1. Minimum permissible ground clearance (h1)
2. Maximum sag of the lowermost conductor wires (h2)
3. Vertical spacing between conductors (h3)
4. Vertical distance between ground wire and top conductor (h4)
Minimum permissible ground clearance (h1):
For safety, power carrying conductors along the path of the transmission line should maintain minimal clearance to ground, highways roads, rivers, railways tracks, telecommunication lines, other power lines, etc., as according to the Indian Electricity Rules, or as per Indian standards. Rule 77(4) of the Indian Electricity Rules, 1956, suggests the following minimum clearances above ground of the lowest point of the conductor:

The clearance above ground shall not be less than the following figures plus the height of the nearby obstacles. The values of minimum ground clearance for the various voltages ranging from 66kV to 400 kV, are:
- 66kV – 5.47m
- 132kV – 6.10m
- 220kV – 7.01m
- 400kV – 8.84m

Maximum sag of the lowermost conductor (h2):
The power carrying conductors sags due to its self-weight and the sag is maximum when the temperature is maximum and when there is no wind condition. The maximum sag occurs at the mid-section between the two towers in open country.

Spacing of conductors (h3):
They should be adequate vertical space between the conductors so that they do not touch each other during dynamic loads such as during high earthquake and high wind. The following is the vertical clearances generally allowed at the mid of the span between the conductors.

Vertical clearance between ground wire and top conductor (h4):
The vertical spacing between conductors and the earth wires is governed by shield angle, i.e. angle which the line joining the ground wire and the outermost conductor makes with the vertical which is required to protect the conductors wires and the transmission tower form the direct lighting strokes. Generally the shield angle varies from 250 to 300 which depend on the overall configuration of the transmission tower and the amount of voltage the transmission line carries.

LOADS:
The load acting on the towers are
1. Dead load. Self-weight of the tower and the conductors and wires.
2. Wind load calculated as per IS 802 (part1/sec 1): 1995
3. Earthquake load as per IS1893(part1):2000

Wind load, clause 8 IS 802 ( Part l/Set 1 ) : 1995:
Figure 5 shows basic wind speed map of India as applicable at 10 m height above mean ground Level for the six wind zones of the country. Basic wind speed ‘Vb’ is based on peak gust velocity averaged over a short time interval of about 3 seconds, corresponds to mean heights above ground level in an open terrain ( Category 2 ) and have been worked out for a 50 years return period [ Refer IS 875 ( Part 3 ) : 1987]India is divided into 6 wind zones. Basic wind speeds for the six wind zones (see Fig. 5) are

Table 5 basic wind speed

<table>
<thead>
<tr>
<th>Wind Zone</th>
<th>Basic Wind Speed, Vb m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>33</td>
</tr>
<tr>
<td>2</td>
<td>39</td>
</tr>
<tr>
<td>3</td>
<td>44</td>
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<td>4</td>
<td>47</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>55</td>
</tr>
</tbody>
</table>

Design Wind speed, Vd
To get the design wind speed the basic wind speed is modified to include the following effects:
a ) Risk coefficient, K1; and
b ) Terrain roughness coefficient, K2.
Hence it may be expressed as follows:
Vd=VR × K1 × K2

Risk Coefficient, K1
Terrain Roughness Coefficient, K2
Table 7. The values of coefficient K, for the three categories of terrain roughness corresponding to 10 minutes averaged wind speed.

<table>
<thead>
<tr>
<th>Terrain Category</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient, K2</td>
<td>1.08</td>
<td>1.00</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Terrain Roughness Coefficient, K2

The values of coefficient K, for the three categories of terrain roughness corresponding to 10 minutes averaged wind speed

Design Wind Pressure, Pd:
The design wind pressure which is distributed along the height of the towers, conductors and insulators shall be determined by the following expression:

\[ P_d = 0.6V_e^2 \]

where.

\[ P_e = \text{design wind pressure in } \text{n/m}^2 \]
\[ V_e = \text{design wind speed in } \text{m/s} \]

Transverse load:
The transverse load consists of loads at the points of conductor and ground wire support in a direction Parallel to the longitudinal axis of the cross arms, plus a load distributed over the transverse face of the structure due to wind on the tower. Thus total transvers load.

Vertical load:
Vertical load is applied to the ends of the cross-arms and on the ground wire peak and consists of the following vertical downward

Components:
1. Weight of bare or ice-covered conductor, as specified, over the governing weight span.
2. Weight of insulators, hardware, etc., covered with ice, if applicable.
3. Arbitrary load to provide for the weight of a man with tools. Dead load of the wire and insulator disk=7000 N =7kN.
Earthquake load:
Steel frames shall be so designed and detailed as to give them adequate strength, stability and ductility to resist severe earthquakes in all zones classified in IS 1893 (Part 1) without collapse. Frames, which form a part of the gravity load resisting system but are not intended to resist the lateral earthquake loads, need not satisfy the requirements of this section, provided they can accommodate the resulting deformation. Following figure show the seismic parameters considered for defining the earthquake load case in STAADPro.

STAADPRO ANALYSIS:
GEOMETRY:
Total of 665 no of beam angle section ranging from ISA150x150x18 to ISA45x45x10 are modeled using coordinated system.

The column and the bracing at the lower part of the transmission tower has been assigned with higher angle section than that of upper part of the tower. This is due to the fact that the lower members have to withstand more loads than that at upper part.

RESULTS:
Displacement:
Maximum displacement of 350mm in the direction on wind due to the load combination 9 (1.7xdead load and 1.7xwind load).
Force summary: Table 13. Force summary, Maximum compression force is experienced by beam 284 by load combination (9) and maximum tensile force is at beam 598 due to load combination (10) i.e. member at the windward side experiences tension and members at the leeward side experiences compression.

Steel takeoff: The following table gives the total amount and type of ISA sections required for the safe and economical transmission tower.

References:
2. STAAD PRO, Bentley Corporation.
3. IS 802 Part 1 Sec 1 1995 Code of practice for use of structural steel in overhead transmission line towers, Part 1
4. IS 1893:2000 part 1