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Design of Narrow Base Tower as an Alternative to Conventional Broad Base Tower

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***Abstract*— Electric power plays an important role in the life of the community and development of various sectors of economy. In India, high priority is given to power development programmes. Due to space constraints, inadequate right of way, land acquisition problems, and urbanization the narrow base transmission line tower provides an alternative to conventional broad base tower. The right of way required for the convention broad base tower is thirty five meter as per IS 5613 (Part 2/Sec 2). But right of way of thirty five meter might not be available in metropolitan and cosmopolitan cities. Hence, a narrow base tower with a base width of 7.343 m at plinth level at body extension of 6 m and a broad base tower with a base width of 18.048 m at plinth level at body extension of 6 m will be analysed and designed. The base width of the broad base tower is chosen based on the right of way. The design wind pressure, sag and tension are obtained. The configuration of the tower is finalized after drawing electrical clearance diagram using AutoCAD. The height of the narrow base tower is 56.335 m and the height of the broad base tower is 56.735 m. Both the narrow base towers and broad base towers have six triangular cross arms and six box cross arms. The challenge of the project is to compare both the narrow base tower and the broad base tower of same height but of different width. The towers are designed using IS 802 (Part 1/Sec 1) and IS 802 (Part 1/Sec 2). The weights of the towers are obtained. The design results are also compared with the Stadd.Pro result.**

***Index Terms*— Narrow base tower; broad base tower; transmission line tower; sag and tension; electrical clearance diagram**

I. INTRODUCTION

Due to rapid urbanization the demand for electrical supply and the demand for transmission line towers are always increasing.

According to Union Ministry of Power & Energy sources, India needs around $ 2 trillion investment in distribution, transmission and generation of power to meet the ever-increasing demand of energy through 2030. The total target of hydro power capacity addition is 13.5 GW in the 12th Five-Year Plan (2012-17) [13].

In metropolitan cities the construction of conventional broad base tower is not always possible; due to space constraints. Hence, the base width of the tower is reduced and narrow base towers are constructed.

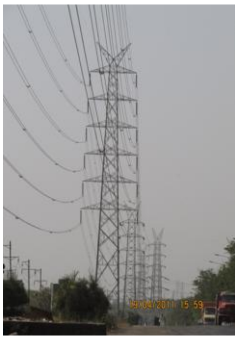

Fig. 1(a) Narrow base tower

Fig. 1(b) Broad base tower

II. OBJECTIVE

The objective of the project is to analyse and design a narrow base tower and a broad base tower of same height, but of different widths. The width of the narrow base tower is 7.343 m at plinth level at a body extension of 6 m; its height is 56.335 m. The width of the broad base tower is 18.048 m at plinth level at a body extension of 6 m; its height is 56.735 m. Both towers are dead end towers with angle of deviation of 0º-15º and angle tower with angle of deviation of 30º-60º.

The adaption of the narrow base tower as an alternative for conventional broad base tower is emphasised.

Fig. 2(a) Dead End Tower

Fig. 2(b) Angle Tower

III. LITERATURE SURVEY

Knight G. M. S and Santhakumar A. R [1] The joints in a TL should be pinned; however, due to fabrication difficulties the assumption that the joints are pinned is not realized. Hence, the tower may experience secondary stresses that are not included in the analysis. These secondary stresses are significant enough to cause failure of the leg members even under normal working-load conditions.

Alam M. J. and Santhakumar A. R [2] Tower testing is still necessary because the reliability-based load and resistance factor design (LFRD) method of analysis and design of transmission line structures can produce safe towers; but it overpredicts the individual member capacity.

If a designer takes the value of reliability based on the slenderness limit in IS 802 (Part 1/Sec 2): 1992, the values may mislead the designer regarding the design of tower based on RBD.

Albermani. F, Chan R. W. K, and Kitipornchai S [3] A nonlinear analytical technique has been proposed for predicting the transmission tower failure. The technique can be used to verify new tower designs or eliminate the need of full scale testing.

Prasad Rao. N, Samuel Knight. G. M, Seetharaman. S, Lakshmanan N, and Nagesh Iyer R [4] The load-carrying capacity of the tower not only depends on the individual member capacity, but also on other aspects like joint detailing, framing eccentricities, force fitting of members, unequal force distribution in bolts, and gusset plate connections. Few of the authors' recommendations are as follows:

- Bracing members with slenderness ratios above 170 become ineffective, even though they carry only small forces
- Nonlinear FE analysis of transmission line towers leads to increased member forces. In horizontal configuration towers, the forces in the leg members increased by 5-8%, and the forces in bracing members increased by 10-20% compared with conventional linear static analysis. In the case of multicircuit tower, the nonlinear analysis forces in the bracing members have increased by 10%

All redundant members shall be checked based on British standard provisions or it shall be designed for 2.5% of the axial force in the main member as recommended in the Indian standard.

Napa Prasad Rao, Samuel Knight G. M, Lakshmanan N, and Nagesh Iyer R [5] In the analysis and design of towers, effects of deflections are generally ignored. However, if the tower is sufficiently tall and flexible, then deflections will be considerable and cannot be ignored, because they can cause secondary stresses. The test deformations are 32-60% more compared with analytical deformation for all towers at full load and 50-85% more at 50% load due to the occurrence of additional rotation caused by bolt slip.

On the basis of tests conducted, a factor that gives the relationship between experimental and theoretical deformation is suggested to modify the analytical deformation.

IV. Methodology

The methodology includes,

- Determination of wind pressure
- Determination of sag and tension
- Determination of loads on conductor, insulator, and ground wire
- Obtaining electrical clearance diagram
- Modelling of tower using Staad.Pro
- Determination of redundant members
- Determination of body wind acting on tower
- Analysis using Staad.Pro
- Designing of towers, and comparing the results

V. Specifications of Tower

TABLE I. General Specifications of Towers

Tower Specifications	Parameter	Data
1	Location of Tower	Mumbai
2	KV rating of tower	220 KV
3	Number of circuits	4
4	Number of cross arms	6 box cross arms and 6 triangular cross arms
5	Width at bottom cross arm of narrow base tower	4 m
6	Width at top cross arm of narrow base tower	2.4 m
7	Widht at bottom cross arm of broad base tower	6 m
8	Width at top cross arm of broad base tower	3.5 m

VI. Determination of Wind Pressure

The location of the tower is Mumbai. The parameters of the tower related to the design wind pressure are, wind zone: 3, reliability level: 2, and terrain category: 2. The basic wind speed map of India is applicable at 10 m height above mean ground level for the six wind zones of the country. As per clause 9.1 of IS (802 Part 1/Sec 1) the basic wind speed V_b is 44 m/s. The metrological wind speed which is the extreme value of wind speed over an averaging period of ten minutes duration and it is calculated from basic wind speed 'V_b' as,

$$V_R=V_b/K_0 \quad (1)$$

As per the parameters given for the calculation of the design wind pressure the meteorological wind speed V_R is 32 m/s. The design wind speed is obtained using the following equation,

$$V_d=V_R x K_1 x K_2 \quad (2)$$

K_1 = Risk Coefficient

K_2 = Terrain Roughness Coefficient

The risk coefficient K_1 is dependent on reliability level and wind zone. As per the parameters for calculation of design wind pressure; the risk coefficient K_1 is 1.11. The terrain roughness coefficient K_2 for terrain category 2 is 1 (Table 3, IS 802 (Part 1/Sec1)). As per clause 8.3.2.1 of IS 801 (Part1/Sec 1), terrain category 2 is open terrain with well scattered obstructions having height generally between 1.5 m to 10 m. The design wind pressure on towers, conductors, and insulators are obtained by the relationship,

$$P_d = 0.6 V_d^2 \quad (3)$$

P_d = design wind pressure in N/m^2

V_d = design wind speed in m/s

As per the parameters given for the calculation of the design wind pressure, the design wind pressure is P_d = 757 N/m^2. The obtained design wind pressure converged exactly with the design wind pressure value in table 4 of IS 802 (Part 1/ Sec1).The obtained design wind pressure converged exactly with the design wind pressure value in table 4 of IS 802 (Part 1/ Sec1).

VII. Determination of Sag and Tension

Adequate sag and tension of conductor should be provided for long and trouble free service. The sag is calculated for various temperature and wind pressure conditions. It could be calculated by catenary method or by parabolic method. The parabolic method of sag and tension calculation is followed in IS: 5613 (Part 2/Sec 1).

The sag and tension are determined for the following temperature and wind pressure combinations,

- Everyday temperature and nil wind
- Everyday temperature and full wind
- Maximum temperature and nil wind
- Minimum temperature and 36 % of full wind
- Minimum temperature and nil wind

The maximum temperature of all aluminium alloy conductor is 85º (Clause 10.2.4, IS: 802 (Part 1/Sec 1). The maximum temperature of the ground wire is 53º (Clause 10.2.4, IS: 802 (Part 1/Sec 1). The maximum conductor sag occurs at maximum temperature and nil wind. The maximum sag is 9.626 m.

TABLE II Sag and Tension of Conductor

Temp º C	Wind Pressure (kg/m^2)	Tension (Kg)	Factor of Safety (Required)	Factor of Safety (Actual)	Vertical Sag (m)	Tension %
0	0	4030.11	1.4285	3.62	5.50	27.60
32	0	3138.37	4.5454	4.65	7.06	21.49
32	175.22	7564.48	1.4285	1.93	2.93	51.80
85	0	2303.50	1.4285	6.34	9.626	15.77
0	63.08	5198.40	1.4285	2.81	4.27	35.60

VIII. Determination of Loads on Tower

The loads acting on the conductor, insulator, and ground wire are calculated.

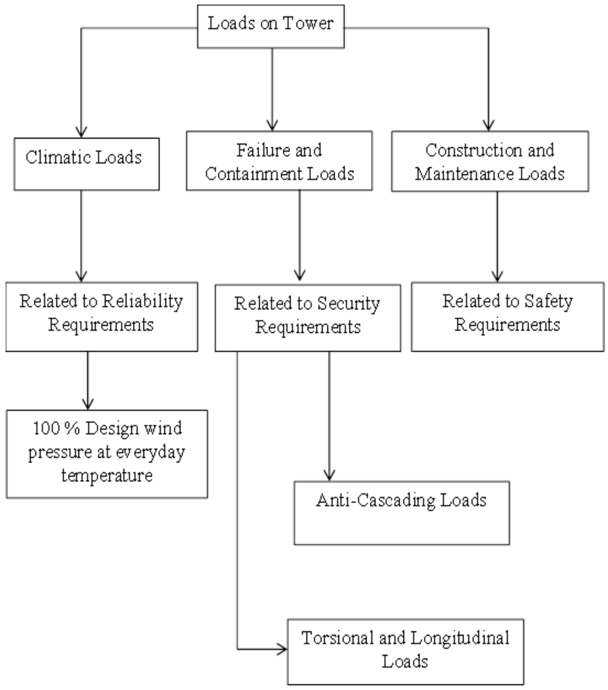

Fig. 3 Loads on Tower

IX. Load Conditions

The tower is designed as dead end and angle tower. The loads acting on the tower are considered for the following loading conditions, for angle tower (30º-60º) and for dead end tower (0º-15º).

- 30º deviation reliability condition
- 30º deviation security condition – Loads for intact spans
- 30º deviation security condition – Loads for broken spans
- 30º deviation safety normal condition
- 30º deviation safety broken condition – Loads for intact spans
- 30º deviation safety broken condition – Loads for broken spans
- 30º deviation anticascading condition
- 60º deviation reliability condition
- 60º deviation security condition – Loads for intact spans
- 60º deviation security condition – Loads for broken spans
- 60º deviation safety normal condition
- 60º deviation safety broken condition – Loads for intact spans
- 60º deviation safety broken condition – Loads for broken spans
- 60º deviation anticascading condition
- 0º deviation reliability condition
- 0º deviation security condition – Loads for intact spans
- 0º deviation safety normal condition

- 15º deviation reliability condition
- 15º deviation security condition – Loads for intact spans
- 15º deviation safety normal condition

X. ELECTRICAL CLEARANCE DIAGRAM

Due The design of transmission line towers are classified into structural design and electrical design. The electrical clearance forms the electrical design of transmission line tower. As per clause 13.1 of IS 5613 (Part 2/Sec 1) a minimum ground clearance of 7 meter is provided. As per clause 7.3.2 the vertical spacing between conductors is a minimum of 4.9 meter. As per clause 13.2 the mid span clearance between earth wire and power conductor is 8.5 m.

XI. MODELLING OF TOWERS

The tower is modelled using Staad.Pro and trial sections are assigned. The body wind acting on the tower is found. The tower is designed based on IS 802 (Part 1/Sec 2). The designed is calculated until the required factor of safety of 1.2 for bracing, and belt members; and factor of safety of 1.01-1 for leg members are obtained.

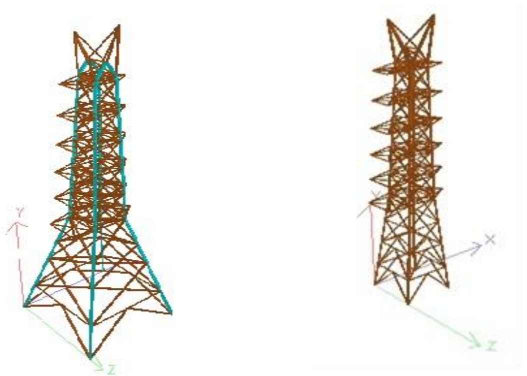

Fig. 4(a) Broad Base Tower

Fig. 4(b) Narrow Base Tower

XII. IDENTIFICATION OF BROKEN WIRE CONDITIONS

As per IS 802 (Part 1/Sec 1) any three phases broken on the same side and same span or any two of the phases and one ground wire broken on the same side and same span are considered. And there are eighteen broken wire conditions.

TABLE III Broken Wire Conditions

Condition No	Condition
1	C1+C3+C5
2	C3+C5+C7
3	C5+C7+C9
4	C7+C9+C11
5	E1+C1+C3
6	E1+C3+C5
7	E1+C5+C7
8	E1+C7+C9
9	E1+C9+C11
10	C2+C4+C6
11	C4+C6+C8
12	C6+C8+C10
13	C8+C10+C12
14	E2+C2+C4
15	E2+C4+C6
16	E2+C6+C8
17	E2+C8+C10
18	E2+C10+C12

Where E represents earth wire/ground wire and C represents the conductors and the numbers denote the name of earth wire and conductors.

XIII. BODY WIND ACTING ON TOWER

Trial sections are assigned to the generated model. The projected area and the boundary area of the tower are calculated. Then the body wind is determined on 10 wind points in the tower. Then the wind load is obtained. The body wind is applied in the longitudinal face of the tower.

TABLE IV Trial Body Wind on Tower

Wind Point (kg/m^2)	Body Wind (Kg)
10	560
9	2961
8	1994
7	1996
6	2086
5	2270
4	2543
3	3076
2	2716
1	969

XIV. DESIGN OF TOWERS

The slenderness ratio of the members is maintained as per clause 6.3 of IS 802 (Part 1/Sec 2). High tensile steel is used for members with slenderness ratio lesser than 105. Mild steel is used for members with slenderness ratio more than 105. For compression members (leg members) the slenderness ratio of lesser than 120 is maintained. For bracings, belt, and plan bracings slenderness ratio up to 200 is maintained.

As per clause 5.3 of IS 802 (Part 1/Sec 2) the redundant members are checked individually for 2.5 percent of axial load carried by the member where it is supported. The body wind is applied on the tower, the analysis of the tower is done using Staad.Pro, and the forces are obtained. The design of tower is done manually following the procedures of IS 802 (Part 1/Sec 2).

XV. RESULTS

The weight of the narrow base tower with redundant members is 44808 Kg. The weight of the broad base tower with redundant members is 104173 Kg. Quadruple and star angle sections are used for leg members. Double angle and single angle sections are used for bracings and belt members.

XVI. COMPARISON OF RESULTS

Same pattern of redundant members are adopted for narrow base and broad base towers. The broad base tower is subjected to more force than the narrow base tower due to its increase in slenderness ratio. However, the weight of broad base tower could be reduced by increasing the redundant members; even then its weight will be more than the narrow base tower. The result shows that if the tower is a very broad base tower then the length of the members of the tower body will be more. Since the length of the members of the broad base tower is more, heavy angle sections are used and its weight is more.

XVII. CONCLUSION

The narrow base tower provides a right alternative when compared to conventional broad base tower in metropolitan cities. The redundant members are provided through out the tower, and it helps in reducing the slenderness ratio of individual members, and it leads to optimizing the weight of the tower.

The maximum displacement is experienced by the dead end tower for 0º condition. Since the dead end tower will be located in the substation it may not be a narrow base tower, however if the due to space constraints if the dead end tower is supposed to be a narrow base tower then the dead end tower's safety should be given more importance than the economy.

The bottom leg member of the broad base tower experienced lesser force compared to the narrow base tower. However, the leg members of broad base tower other than the bottom member experienced more force than the leg members of the narrow base tower.

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