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Premature Failure and Remedial Measure for Prototype Testing of UHV Transmission Line Towers: An Overview

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The need for adopting bulk power transmission system with all possible ways to make support structures economical and also to reduce the Right of Way (ROW) requirements has arisen in view of accelerated growth of electrical network. This bulk power transmission has become compelling due to separation of power sources to the areas requiring the power located at longer ranges, namely inter-state and inter-regional. In this direction, 400 kV D/C and M/C system with a quadruple conductor configuration, 800 kV/1200 kV AC system and ±500 kV/800 kV HVDC systems are now adopted in India. Recently, CPRI has successfully tested the self supporting type of 765 kV and 800 kV AC and HVDC towers for POWERGRID. The prototype testing and the premature failure of these towers in particular and some of special towers in general are described in this paper.

Keywords: *UHV transmission line towers, Full-scale testing, Test arrangement.*

1.0 INTRODUCTION

The demand for power is growing in India continuously, and the power-generation capacity is being increased by the utilities. To meet the requirements of the increased generation, the associated transmission system necessitates the adoption of more and more EHV/UHV transmission lines.

Owing to high remarkable growth in the demand for electric power [2] due to India's high economic growth, it is becoming necessary to build higher capacity power transmission trunk lines of ±500 kV/800 kV HVDC and 800 kV AC UHV lines. In addition, adoptability of 1200 kV AC system has been tried. However, to find the requisite routes for the UHV lines [4], it is becoming difficult and also costly by the society's awareness towards the protection/conservation of environment/human habitation and farming and also low awareness of the direct relevance of power transmission lines in their daily lives.

Hence, it has become necessary to consider all possible ways to make the support structures more economical and compact to reduce the Right of Way (ROW), without scarifying the functional requirements [7].

When compared with the power-handling capacity of 400 kV and 800 kV system, four circuits of 400 kV (i.e. 2 Nos. of 400 kV D/C lines) are required to handle the same power as that of 800 kV S/C system. Hence, for the same capacity of power, the ROW requirement would be about 76 m and 58 m respectively. Thus, the power density transmitted per unit of ROW is higher in case of 800 kV systems when compared with 400 kV systems.

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Transmission line towers cost about 30–40 % of the transmission line. Hence, the design should be economical and also reliable [3]. Only type tests can ensure the economy and reliability of the new design. For past 5 years (2006–2010), some 800 kV towers of both AC and HVDC system were referred to CPRI for prototype testing. The features of the referred towers, details of testing arrangements, and testing and their performance are described in this paper.

2.0 DETAILED CONFIGURATION OF UHV TRANSMISSION LINE TOWERS

In abroad, generally for UHV transmission lines, guyed 'V' structures are preferred as the choice due to reduced weight of the tower and saving from foundation, erection and construction [1]. But in India, not much of knowledge is available on guyed towers, and also considering the safety of the line due to sabotage and vandalism, self-supporting structures are preferred. However, it is possible to achieve considerable economy by selecting proper configuration of the structure, different materials and structures for combination of line deviation.

The POWERGRID INDIA referred 765 kV towers are of 30° and 60° deviation and 800 kV HVDC suspension towers designed in accordance with probabilistic approach according to IS 802:1995, suitable to support ACSR Bersimis/AAAC Moose/Lapwing conductors(bundle) with optical fibre cables (OPGW) for earth wires.

2.1 Special Features

2.1.1 765kV Towers

The schematic diagram of 765 kV S/C towers is given in Figures 1 and 2.

The special features of these towers are that the conductors are being placed in DELTA configuration. The configurations of these towers were designed by the POWERGRID to reduce ROW further from 58 m to 48 m and compaction in physical geometry by using box cross arms wherever necessary.

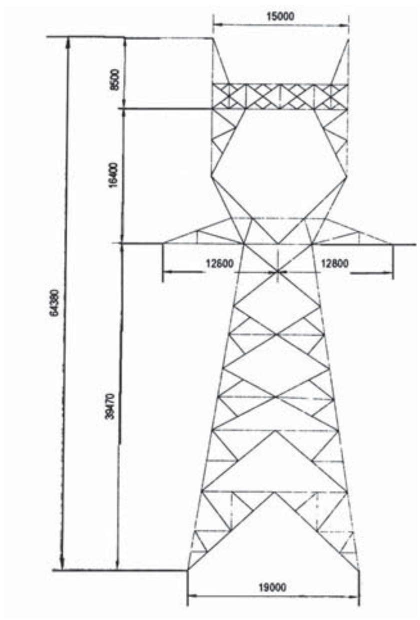

FIG. 1 765 KV S/C TYPE 'C' TOWER

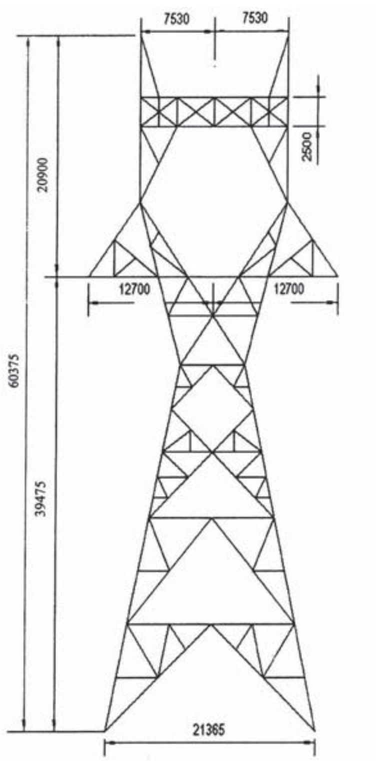

FIG. 2 765 kV S/C TYPE 'D' TOWER

2.1.2 800 kV HVDC 'V' String Tower

Figure 3 shows the 800 kV HVDC suspension tower. The bipole tower had the configuration of V-string to support six bundle Lapwing conductor. The major features of the tower are crossarm length (conductor to conductor) 29.10 m and height of the tower 59.55 m. However, due to premature failure of 'N' type configuration of crossarm, the customer redesigned the crossarm with 'X' type configuration and supplied for testing, which withstood all the load cases successfully.

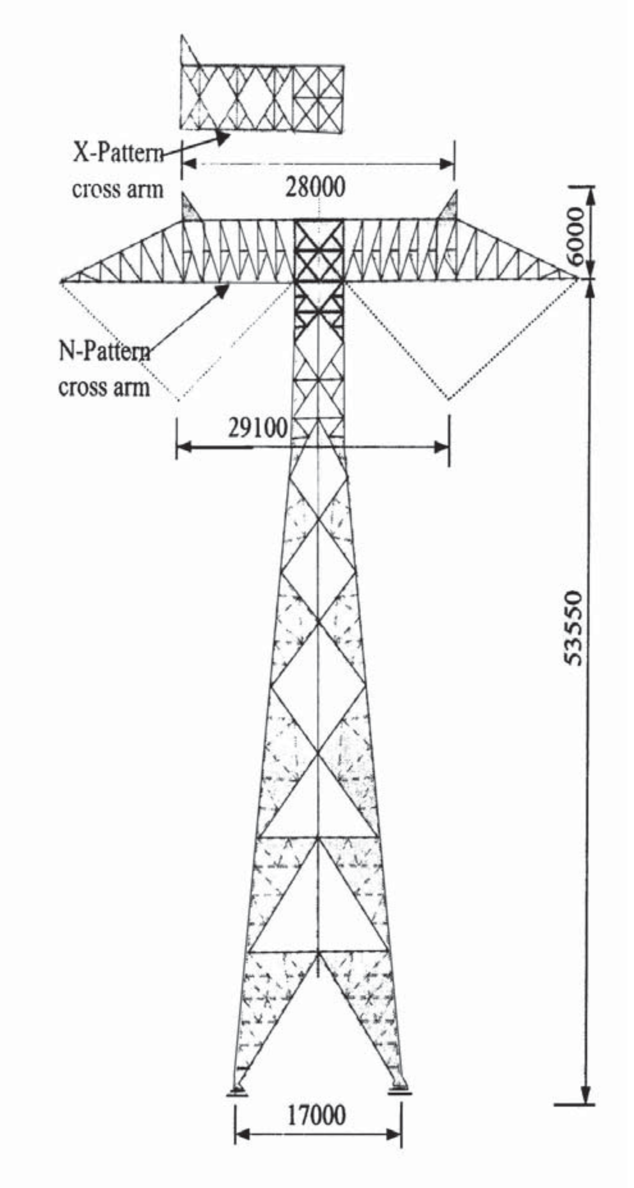

FIG. 3 800 kV HVDC 'V' STRING TOWER

2.1.3 800 kV HVDC 'Y' String Tower

Although the tower with V-string configuration was successful in testing, to have better reliable and economic structure, the redesigned tower with Y-string configuration was brought for testing. Figure 4 shows the 800 kV HVDC suspension tower having the configuration of 'Y' string. The crossarm length (conductor to conductor) was approximately 24.72 m and height of the tower was 63.15 m. Although the height of this tower was more when compared to tower with V-string configuration, the weight was less by about five times and requirement of ROW is also reduced by 4 m (approx).

In order to achieve further economics, the towers are provided with combination of materials such as Mild Steel with yield stress of 250 MPa and High Tensile Steel with yield stress of 350 MPa.

FIG. 4 800 kV HVDC 'Y' STRING TOWER

2.1.4 400 kV D/C 'SET-70' Tower

One tension tower with 70° deviation for Gulf country was referred for testing by L&T.

The 400 kV double circuit Delta configuration tower had the loadings and physical features which utilized maximum capacity of test bed having crossarm length of 42 m (end to end) to support four conductors in one level with very high magnitude of loads (vertical: 40 t, transverse: 54 t and longitudinal: 37 t). The tower was successfully tested. The rigging arrangement for the referred tower is shown in Figures 5.

FIG. 5 400 kV D/C TYPE 'SET-70' TOWER

3.0 TEST ARRANGEMENTS

3.1 Pretesting Activities

The major pretesting activities followed are given below.

(i) Stub setting and welding

(ii) Erection

(iii) Load cell calibration

(iv) Attaching haulage wire rope with load cells to the tower and rigging

3.2 Guying Arrangement

In addition to the above, as a safety measure, the towers being very tall were guyed as mentioned further.

The test towers either fail prematurely or during destruction test. Depending upon the nature of failure, the tower can be intact with mild buckling or stand precariously or collapse completely. It will be very difficult to dismantle the tower standing under precarious condition. Intensive damage to the equipment like load cells, cables, wire ropes and other test arrangements with hardware is likely to happen whenever the tower collapses. The extent of damage will be more for tall and heavy towers.

The 765/800 kV towers being tall towers, i.e. above 50 m, it is necessary to have proper guying arrangements from the safety point of view. CPRI has done extensive study in standardization of guying arrangements for a test tower. The guying positions for these towers were at waist level and at bridge level. These are guyed in a direction opposite to the probable direction of fall. While conducting the test proper, the two guys at waist level are tensioned and the other three guys are tensioned only after test depending on the nature of failure or during replacement of failed members.

3.3 Load Application Arrangements

The towers were designed in accordance with the referred code of IS 802, i.e. probabilistic approach. In view of this, the load application involved complex arrangements due to the following:

- Number of pull of points for application of loads are more with the introduction of narrowfront wind/oblique wind cases and reliability condition.
- Anticascading checks require application of all the longitudinal loads and also for security conditions.
- Heavy vertical loads due to safety condition. Adequate attention has to be given to the

simulation of field conditions during the tower test, so that the theoretical assumptions in the simulation are minimized. With the above in view, special fixtures and arrangements were made for wind load applications as explained below.

3.4 Wind Load Application Arrangements

CPRI has enough experience for simulation of four, point pulling all along the body and at crossarm levels shows in Figures 6(A) and 6(B). However, the 800 kV tower being a horizontal configuration type with the bridge being supported at eight points, the wind load was required to be properly distributed at all these eight points at the bridge level. While for transverse load application, wire ropes were connected to the specially designed plates in conjunction with spacer and pulleys. The loads were measured by a single transducer. Figure 6(C) shows the loading arrangement in transverse direction at bridge level. The rigging arrangement of the tower is shown in Figure 7.

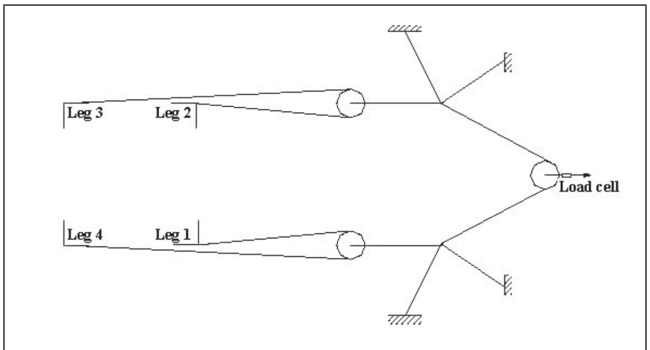

FIG. 6(A) WIND LOAD APPLICATION AT BODY

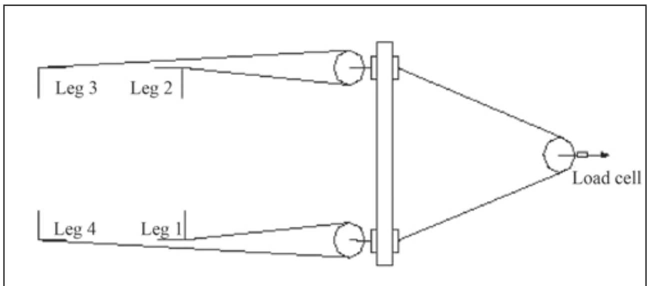

FIG. 6(B) WIND LOAD APPLICATION AT CROSSARM LEVELS

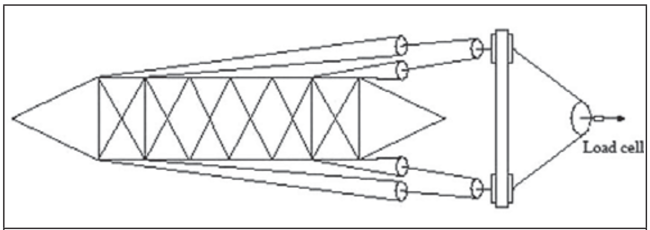

FIG. 6(C) WIND LOAD APPLICATION AT BRIDGE

FIG. 7 TOWER WITH RIGGING ARRANGEMENT

4.0 TESTING

The fullscale testing was carried out [5] according to the IS: 802 (Part-III)-1978 for the loads based on the concept of

(1) Reliability condition

(2) Security condition

(3) Safety condition

The various load cases for which the test was carried out are listed in Table 1. The maximum loads applied at each pull of points in each direction, viz., vertical, transverse and longitudinal are given in Tables 2 and 3.

TABLE 1

LOAD CASES

Sl. No.	Load cases
1	Bolt slip
2	Security/Broken wire conditions
3	Anticascading conditions
4	Safety/stringing conditions
5	Reliability conditions

TABLE 2

LOAD IN (kg) FOR 765 kV TOWERS

Type	Points	Earth wire	Conduc-tors	Wind levels
C	Trans	2000	24600	6000
D	Trans	3500	38600	6000
C&D	Long	2700	29000	–
C&D	Vert	360	9500	–
C&D	Vert	900	20000	Safety

TABLE 3

LOAD IN (kg) FOR 800 kV HVDC TOWERS

Type	Points	Earth wire	Conductors	Wind levels
V/Y	Trans	21800	24260	12000
	Long	4650	29000	–
	Vert	330	11300	–
	Vert	800	23260	Safety

5.0 TEST PROCEDURE

Tested steel wire ropes with sufficient factor of safety were used for transmitting the loads to the pull of points. Calibrated load cells were connected to the haulage ropes at the pull of points. The digital indicators housed in control room were used for precise load measurements. Remote controlled winches operated from control room were used for applying loads to the pull of points through wire ropes. The design loads were gradually applied in such a way that there was no Impact loading on the tower [6], in steps of 50 %, 75 %, 90 %, 95 % and 100 %. Sequence of load application is done for a given load case such that no local moment is created on test tower, which is an important criterion followed, where the standard does not specify explicitly. The deflection of the tower in transverse and longitudinal direction was recorded at each incremental stage. The tower was kept under observation for any visible sign of failure for two minutes for all intermediate steps of loading and five minutes for 100 % ultimate loads.

6.0 PERFORMANCE DURING TEST

6.1 765 kV Towers

During the course of test, the 'C' type 765 kV tower failed under normal condition (safety). Failure occurred at the longitudinal near face and far face bracings at crossarm level to 'K' bracing (3 panels) shown in Figure 8. and was major in nature. After taking necessary remedial measures, the tower successfully withstood all the load conditions, stringing/safety conditions.

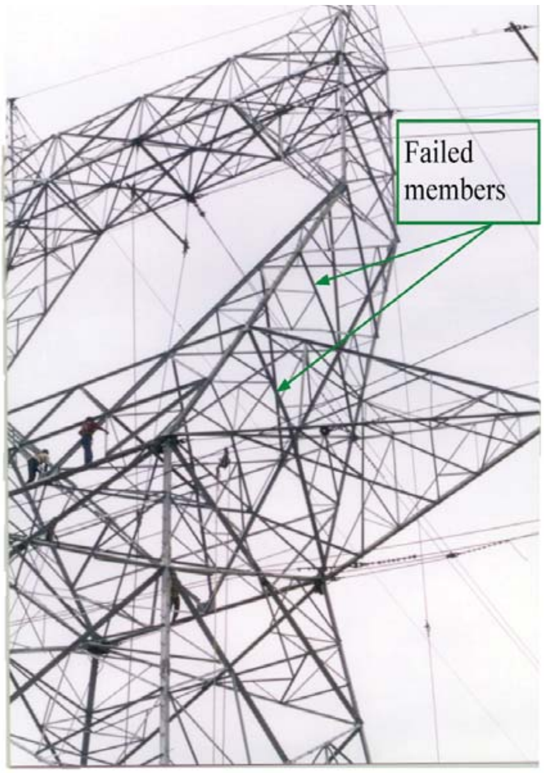

FIG. 8 TOWER FAILED AT LONGITUDINAL FACE

6.2 800 kV HVDC Towers

The 800 kV HVDC tower was the first of its kind to test in India. During testing of the tower with V-string, under ground wire broken condition, the crossarm with N type configuration failed. The pictorial view of the failure portion is shown in Figure 9.

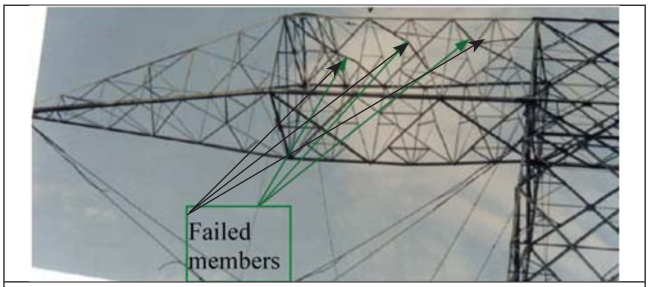

FIG. 9 CROSSARM (N TYPE) FAILURE AT TOP PLAN

After redesigning and replacing the crossarm with X-type configuration, the tower withstood the all design loads successfully.

6.3 Tower Deflection

Deflection at crossarm point and ground wire point was recorded at different stages of loading under all tests. The maximum deflections are given in Tables 4 and 5.

TABLE 4

DEFLECTION VALUES (mm) FOR 765 kV

Loading points	Earth wire	Conductors	Body wind levels
TRANS	–	460	20
LONG	100	230	20

TABLE 5

DEFLECTION VALUES (mm) FOR 800 kV HVDC TOWERS

Loading points	Conductors (beam)	Body wind levels
TRANS	370	10
LONG	550	10

7.0 CONCLUSIONS

The paper describes the premature failure of latticed transmission towers on ultimate strength test with full-scale loading, and their structural responses are recorded for further analysis. Accurate structural analysis of towers is complicated because the structure is three-dimensional and comprises of angle section members eccentrically connected. The influence of geometric and material nonlinearities plays a very important role in determining the ultimate behavior of the structure. The case study has been conducted for three different towers of various voltages ranging from 400 kV to 800 kV vertical configuration, which failed during testing and the corresponding suggestions/remedial actions have been taken care for redesign/refabrication, and retesting was conducted. It has been seen that most of the towers passed successfully under 100 % of the designed ultimate tests.

The successful testing of 800 kV towers with high magnitude of loads and complex testing arrangements will go a long way in adopting 800 kV/1200 kV rating. CPRI is confident of testing any special tower involving complex testing arrangements by suitably augmenting the existing capacity of the testing station.

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