10446-B2 Session 2022

PS 1 / CHALLENGES & NEW SOLUTIONS IN DESIGN AND CONSTRUCTION OF NEW OHL

Design and testing of monopole structures for ~~UHV 765/~~400kV and 765kV ~~transmission line monopole structures~~Overhead lines-POWERGRID's experience

Karanvir Singh Pundir*, Hemant Tiwari, Sumana Mukherjee, Nitesh Kumar Sinha*, Subhash C Taneja,
Power G~~g~~rid C~~c~~orporation of ~~i~~India L~~l~~imited
India
karan_pundir@powergrid.in

SUMMARY

With the rising living standards, demand for electricity is on the rise, along with the continued increase in urbanization in India, the original suburbs/rural areas are gradually becoming the new cities. Building new transmission line corridors with conventional lattice towers which are having large footprint are often difficult to construct through these clusters of urbanized areas. These transmission lines have to be located by maintaining adequate right of way (ROW) requirements, which consequently leads to more difficult passage for these transmission line corridors. In order to solve this issue in particular, many monopoles from 132 kV to 400 kV voltage level have earlier been developed. As the requirement of bulk power transmission in urban area grown further, monopoles of 765 kV Single circuit towers with hex bundle configuration and 400 kV Double circuits with Quad bundle configuration have been developed. Suspension/tangent towers and large angle tension type towers were developed for catering the present requirement. The design, fabrication, construction, assembly and finally proto type testing of these monopoles has put many challenges and this process has been performed with taking due consideration of all these aspects. In this paper, these special features which have been considered during its development are discussed and presented. It also discusses the design criteria/ standards followed for the design of monopole structures and the processes adopted for its manufacturing in India. The monopole developed is made up of structural steel and visually appears like truncated cone tapering from wide base at bottom to top. The base of the monopole is welded to baseplate provided with holes for anchor bolts which shall then be embedded in foundation concrete. Cross arm of these monopoles is also tapered. The cross section of the monopole main body has been made by bending the plates into maximum number of possible bends to give them a circular appearance. The special feature that has been employed to weld these pieces seamlessly and then joining two such pieces by sliding one into another smoothly so as to make them appear like a monolithic appearance without any protrusion. In addition, a special arrangement for making connection of cross arm to monopole body has also been made using a plate passing through main monopole body and jacket plate installed at the end of the shaft to give strength to the shaft on the edges.

KEYWORDS

Monopole - ROW- testing –design-UHV

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As a part of technology up gradation, design and testing of UHV 400kV D/C (QUAD) and 765kV S/C (HEXA) monopole structures has been carried out to use these structure in highly populated areas/city premises, severe ROW constraints are faced and it is also difficult to spot towers. In this endeavor followings ultra-high voltage monopoles with respective circuit and conductor configurations. have been designed, developed and successfully tested.

1. 765KV S/C HEXA ACSR ZEBRA conductor Suspension monopole.
2. 765KV S/C HEXA ACSR ZEBRA conductor (0-60 Deg)/Dead End monopole.
3. 400KV D/C QUAD ACSR MOOSE conductor Suspension monopole.
4. 400KV D/C QUAD ACSR MOOSE conductor (0-60 Deg)/Dead End monopole.

Pictorial view of these monopoles has been shown in Fig 1 & 2

Fig 1. 765 KV S/C MONOPOLE

Fig 2. 400 kV D/C MONOPOLE

The design and manufacturing details of the above 400kV and 765kV monopoles shall be discussed in the subsequent segments.

2.1 Parameters

The design of the monopoles is in line with ASCE-48-11and IS 802-2015 (Part 1/sec1). The basic wind speed considered for design is 47 m/s which is recorded at 10 m height above Mean ground level based on peak gust velocity averaged over a short time interval of about 3s. The reliability level has been considered as per national guidelines. Design parameters for the monopoles are given in the Table 1. One of the most important design parameter "Design Span" has been chosen so as to limit the loading on pole to an extent considering fabrication and testing capability of the testing stations in India.

Table 1. Design parameters for UHV 765/400kV transmission line monopole

Sno.	Parameters	400KV D/C QUAD PA	400KV D/C QUAD PD	765 KV S/C PA	765 KV S/C PD
1	Line Voltage	400 KV	400 KV	765 KV	765 KV
2	Circuit	2 Nos.	2 Nos.	1 Nos.	1 Nos.
3	Pole Type	Suspension Type	Tension/Dead End Type	Suspension Type	Tension/Dead End Type
4	Angle of Deviation	PA(0-2d)	PD(0-60d) /DE(0-15d)	PA(0-2d)	PD(0-60d) /DE(0-15d)

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5	Design Span	250 Mtr.	150 Mtr.	250 Mtr.	150 Mtr.
6	Wind Zone	IV	IV	IV	IV
7	Reliability level	1	1	2	2
8	Terrain category	2	2	2	2
9	Conductor Name	ACSR-MOOSE	ACSR-MOOSE	ACSR-ZEBRA	ACSR-ZEBRA
10	Sub-Conductor	QUAD BUNDLE	QUAD BUNDLE	HEXA BUNDLE	HEXA BUNDLE
11	Conductor Configuration	54/3.53 mm AL+7/3.53 mm Steel	54/3.53 mm AL+7/3.53 mm Steel	54/3.18 mm AL+7/3.18 mm Steel	54/3.18 mm AL+7/3.18 mm Steel
12	Operating Temperature (°C)	85	85	85	85

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2.2 Modeling

All these four structures were modeled in ~~PLS POLE~~ software by maintaining necessary electrical clearances required. (Fig 3.)

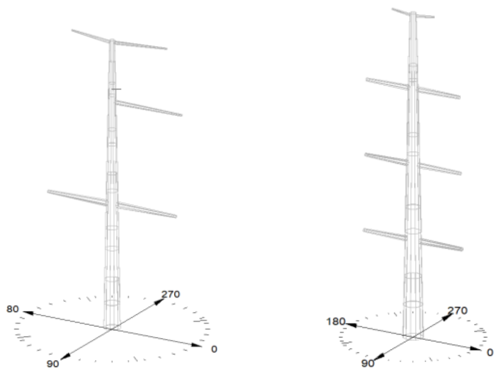

Fig 3. Models of 765kV and 400kV Monopoles

2.3 Monopole Parts

Monopole consists of two main parts. One is tubular steel shaft and the cross arms (Davit arms). The shaft is truncated cone with top and bottom diameter approx. 800 mm and 2300 mm respectively. Main shaft is made by bending the plate and turning into circular shape. As maximum width of plate presently manufactured/available is 2.0 m and maximum circumferential length (perimeter) of the pole body is 7-7.5 m, in view of above main pole shaft is made by welding two or more pieces along its seam.

At the same time, maximum width of hot dip galvanizing bath is approx. 2.0 m, it has been ensured that width of welded pieces which will go into the galvanizing bath does not exceed by 2.0 m. Considering above, provision with regard to maximum number of parts for fabrication has also been specified in technical specification and the same is depicted at Table 2.

Table 2. The maximum permissible parts fabricated parts per pole segment/seams:

Sr no	**Outer diameter of pole segment (mm)**	**Max permissible no of fabricated parts per pole segment/seams**
1	Up to 600	1
2	greater than 600 and up to 1200	2
3	greater than 1200 and less than 2000	3
4	greater and equal to 2000	4

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The main shaft body consists of many segments which are fitted by slipping above piece into bottom one. The slip length is chosen in such a way that sufficient strength is developed to sustain all possible loading condition. The maximum length of such segment is 3.0 m and has been chosen in such to make it convenient to lift/handle/transport. Cross arm for conductor & earth wire of the monopole has also been by bending the plate and top of the crossarm has been made flat so as to make is easy for worker movement on it.

The cross arm is also fitted with numerous hooks welded on it for locking worker belts. These cross arms are connected to main shaft body by a plate which pierces through main shaft body called vang plate. The monopole is fixed with a base plate at bottom and base plate is provided with holes for anchor bolts embedded into the foundation concrete.

The thickness of base plate is in the range of 55mm to 63 mm. and no/size of anchor bolts is in the range of 36 no.s/56Φ to 44 no.s/64Φ . The base plate is welded annular plates provided with vertical stiffeners welded along main shaft body.

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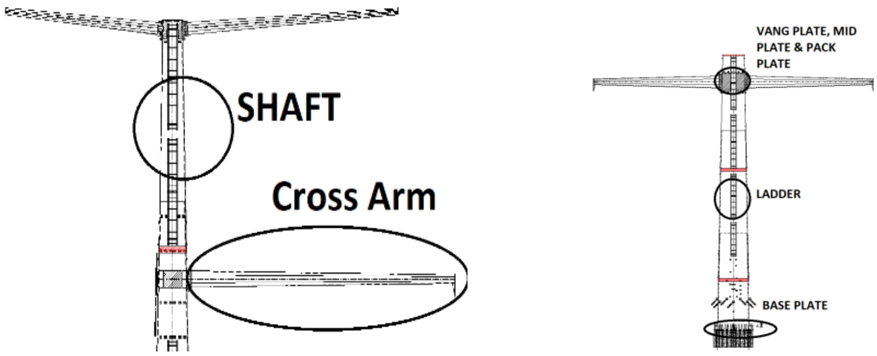


Fig 4. Different parts of monopole

2.4 Loading

Conductor and wind loadings were applied onto the monopole structures according to the codal provisions of IS 802- 2015. Different loading conditions and possible combinations as stipulated in Indian standard were simulated on the monopole. (Fig 5.)

Fig 5. Loads applied on 765kV and 400kV Monopoles

2.5 Analysis

Moments and forces were evaluated in the monopole shafts and cross arms using the ~~PLS-POLE~~ software (Fig 6.). Summary of the critical moments and forces are given in Table 3 below.

Table 3. Summary of the critical moments and forces for UHV 765/400kV transmission line monopole

Sno.	Moment/Force	400KV D/C QUAD PA	400KV D/C QUAD PD	765 KV S/C PA	765 KV S/C PD
1	Bending Moment (kN-m)	23180	41609	26219	39729
2	Shear Force (kN)	651	2019	697	1660
3	Axial Force (kN)	565	671	522	654

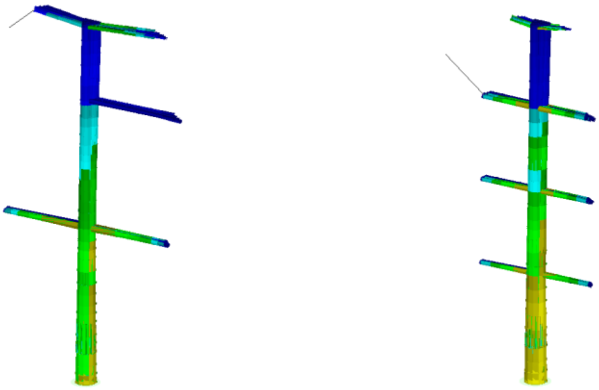


Fig 6. Analysis of 765kV and 400kV Monopoles

2.6 Pole Design

Design of monopole shafts and cross arms was done in line with ASCE 48-11 based on the stresses calculated during analysis stage. Salient design features of monopoles are tabulated in Table 4 below.

Table 4. Salient design features for UHV 765/400kV transmission line monopole

Sno.	Design features	400KV D/C QUAD PA	400KV D/C QUAD PD	765 KV S/C PA	765 KV S/C PD
1	Pole Top Dia (mm)	830	750	825	750
2	Pole Bottom Dia (mm)	2135	2268	2260	2308
3	Thickness of shaft(mm)	8-16	10-25	10-18	8-25
4	Taper Ratio (mm/m)	28	42.5	29	40.7
5	Geometry of monopole shaft	12 Sided	12 Sided	12 Sided	12 Sided

6	Thickness of cross arm(mm)	10	16	16	22
7	Geometry of cross arm	8 Sided	6 Sided	8 Sided	6 Sided
8	Total tested monopole height (m)	51.205	38.633	54.475	42.193
9	Base Plate Outer Dia (mm)	2570	2775	2700	2825
10	Weight of tested monopole(MT)	43	52	54	56
11	Grade of Steel	IS 2062 E450/E350	IS 2062 E450/E350	IS 2062 E450/E350	IS 2062 E450/E350

Vang plate (through plate) was designed to carry bending moment and vertical forces exerted by the different loading conditions through cross arms. (Fig 7)

2.7 Special design features for UHV monopoles are here under:

1) As the loading intensity was high, these monopoles were provided with extra mid plate at every cross-arm level so as to avoid collapse of the shaft at that point. (Fig 7.)

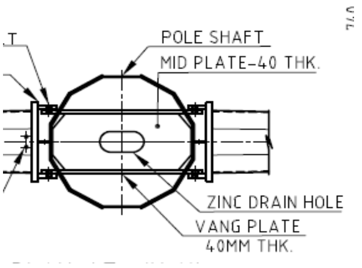


Fig 7. Vang and Mid plate at cross arm level

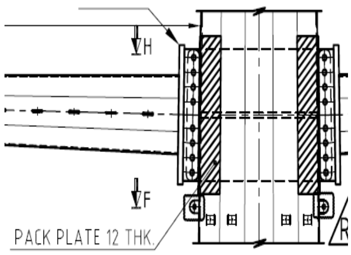
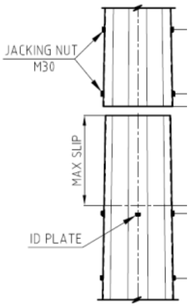


Fig 8. Pack plate at cross arm level

2) Again, due to high loading intensity pack plate were provided on to the shafts at cross arm level in order to avoid extra stress accumulation on the monopole shaft. (Fig 8.)
3) Welding penetration percentage was kept 100% instead of 60%.
4) Slips joints were used instead of flange joints in order to ease the assembly of monopole shafts using hydraulic jacks. (Fig 9.)



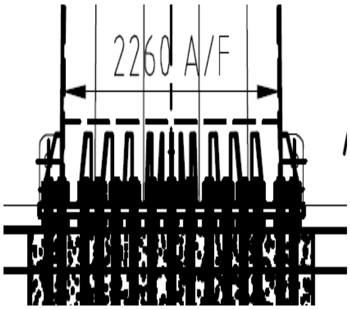


Fig 9. Slip Joint **Fig 10. Base plate with stiffeners**

5) Base plate was designed with stiffeners so as to avoid excessive bending and high thickness due to heavy loading (Fig 10.)
6) Cross arms were installed with handles so as to make the accessibility to insulators easy for the line man. (Fig 11.)

Fig 11. Handles at cross arms

9.3.MANUFACTURING

1) **Tests on raw material:** Mechanical and chemical tests are done on the raw material received from different approved sources. These tests are performed on every coil or one of three plates in a set of plates as per relevant standard.

UTM Machine **– Spectrometer**

Fig 12. Mechanical and chemical laboratory and apparatus

2) **De-coiling of the raw material (If procured in the form of coils):** Metal sheet is removed from the coil using a de coiler and is sheared as per the length required.

Fig 13. De-coiler

3) **Plasma cutting-** Plates are cut into trapezoidal shape with a plasma torch as per the size required for making the pole main body/cross arm.

Input drawing **Setting up of the machine** **Cutting starts**

Fig 14. Plasma Cutting Process

4) **Bending-** After plasma cutting machine, plats are bended to form polygonal tube in a bending press machine.

Bending press **Calibration of bending radius** **Bending**

Fig 15. Plate bending process

5) **Welding-** The one or more longitudinal pieces are joined using Submerged Arc A blanket of powdered flux generates a protective gas shield and a slag which protects the weld zone.

Preparation of shaft for welding **Insertion of Shaft inside SAW machine** **Ongoing welding**

Base plate and stiffener weld

Fig 16. Welding process

6) Galvanizing process

The segments of pole are hot-dip galvanized which passes through many stages viz surface preparation, galvanizing, Degreasing/Caustic Cleaning, Pickling, fluxing and hot dip galvanizing.

Pickling tank

Fluxing tank

Galvanization tank

Galvanized pole shaft

Fig 17 Galvanization process

3.2 Special manufacturing process of UHV monopoles are here under:

1) Due to thickness of plate lying in the range of 24-25mm used for making polygonal monopole shaft, high capacity bending machine was used.
2) As the diameter of the poles was in the higher range of 2.2-2.3m and due to restriction of width (2.0m) of galvanization tank, the monopole shaft was galvanized in two halves and welded together after the dip. These welding joints after the dip were galvanized by metallizing using molten zinc technique as per ANSI/AWS WCZ/D19.0-72
3) As the diameter of the poles was in the higher range of 2.2-2.3m and due to restriction of 2m width of steel plate, the monopole shaft was welded in four parts.

The manufactured monopole is then thoroughly checked w.r.t the final structural drawing or design and afterwards dispatched to test bed for assembly /proto type testing.

Cross Arm **Base Plate**

Shaft sections

Fig 18 Proto Assembly of monopole

The proto type testing for 765kV and 400kV suspension monopoles was done at testing station. The proto type testing involved the following process:

Erection of the monopole was done at the test bed using stationary/mobile cranes (depending upon the weight of the monopole sections). Initially an adaptor was installed to make the base plate and anchor bolt assembly compatible with the test bed, after which the subsequent shaft sections and cross arms were lifted and erected.

Fig 19 Erection of monopole

5.2 Rigging

The monopole was rigged in after the erection.

Attachment of load cells **Installing wire rope in winches** **Fixing wire ropes on Monopole**

Fig 20 Rigging of monopole

5.3 Application of loads

Loads are applied on to the monopole through winches. The loads applied are as per the relevant standard and in three directions (Vertical, Transverse and Longitudinal).

Fig 21. Control panels **Fig 22. 765kv PA pole being tested**

As the moment carrying capacity of testing bed was limited to 29000 KN-m which is very close to the base moment of 26219 KN-m for 765 KV PA, few of the precautionary steps to safe guard the test bed were taken.

1) A safety girder was installed on the two uplift beams of the test bed, in order to avoid uplift of the beams. (Fig 23.)

Fig 23. Safety girder and Stiffeners for test bed

4)3) During the testing of 765kV PA type monopole, failure of the shaft happened due high concentration of the stresses at the end of the slip joint. (Fig 24.)

Fig 24. Failure of shaft.

5)4) As a part of rectification, a jacket plate was installed at the end of the shaft in order to counter the stress concentration. (Fig 25). This was done in other 400kV and 765 kV monopoles also which were about to be tested. After this rectification all the UHV monopoles were successfully type tested.

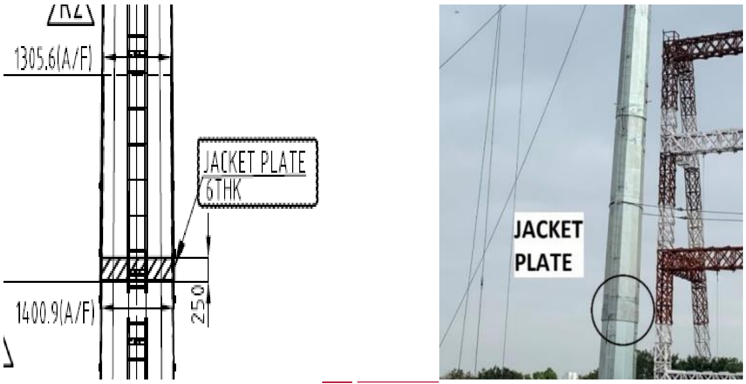


Fig 25. Jacket Plate.

14.6. CONCLUSION.

As transmission lines transverse through many dense urban areas where it is difficult to spot lattice towers due to ROW issue as they are having larger foot prints, monopoles provide a more feasible solution. UHV monopoles developed by POWERGRID are useful to carry more power through such corridors and areas where ROW issues persist. This endeavor of developing UHV monopole will not only help in hurdle free execution of project but will also save time, which was lost by adopting longer line length in order to avoid dense urban areas

[3][2] MANUAL ON TRANSMISSION LINES (Publication no. 323)-CENTRAL BOARD OF IRRIGATION & POWER

[4][3] IS 802-2015 (Sec 1/ Part 1) Use of Structural Steel in Overhead Transmission Line Towers-Materials, Loads and Design Strengths.

[5][4] IS 802-1978 (Part 3) Use of Structural Steel in Overhead Transmission Line Towers- TESTING