

# Research for the Working Method of Live Replacing the L-type Insulator String on $\pm 800\text{kV}$ DC Transmission Lines

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**Abstract.** It would be hard to be repaired in the case of a power outage if the  $\pm 800\text{kV}$  ultra high voltage DC (UHVDC) transmission line was put into operation, so live working is the guarantee for its security and stability. Insulator strings of duplex L-type are widely used in UHVDC small angle towers. In the meantime, the tower structure and the insulator strings' arrangement type is different than the V-type. In order to ensure the security and stability of the transmission line, this paper presents a method of live replacing the duplex L-type insulators based on the actual parameter of the UHVDC L tower type and develops apparatus as a complementary supporting by mechanics analysis. In order to ensure the safety of working staff, the safe distance and combined gap of the hanging basket method are checked. Safety precautions are also proposed in the paper by the calculation of body surface field strength of the persons doing live working in the finite element method. It is shown by the field application that the live working task of replacing the L-type insulator strings can be accomplished successfully by the method put forward in this paper, which provides reference for the following live working on the UHV transmission line.

## 1. Introduction

The large capacity, long distance, low loss transmission ability can be realized by the UHV transmission system, which can promote energy structure adjustment and optimized layout. With the development of the UHV lines, Insulator strings of duplex L-type are widely used in UHVDC small angle towers. The insulators in service will be damaged because of the influence of the working voltage, switching overvoltage, lightning overvoltages, the lead weight, wind and the external force, which will affect the safe operation of the lines. However, The UHV transmission lines have less maintenance chance. In order to ensure the power supply reliability, the broken insulators need to be replaced timely [1-4].

As the tower structure and the insulator strings' arrangement of the L-type is different than the V-type, the method and matching tools of live replacing V-type insulators are not suitable for the L-type insulators. Take the  $\pm 800\text{ kV}$  UHV small angle tower of the binjin line as an example, a new method of live replacing the duplex L-type insulators based on the actual parameter of the UHVDC L-type tower is put forward and the matching tools are developed. Moreover, the insulation pull rods can apply to the insulator string's replacing in the two different orientation by the adjustable structure of the length. In the meantime, the electric field intensity of the equipotential worker are calculated by



the finite method and so the shielding efficiency of the shielding clothes is confirmed. The task of live replacing the L-type insulator strings can be accomplished successfully by using the method put forward in this paper, which provides the reference for the following live working on the UHV transmission line.

## 2. Presentation of New Method

The  $\pm 800$  kV small angle tower is used as the selected model and its field arrangement of duplex L-type insulator string is shown in Fig.1, its total height is 57.8 m and the nominal height is 51 m. The rotation degree is about  $12^\circ$ . The wire is arranged as regular hexagon and its type is ASCR-720/50; its bundle spacing is 450 mm and the diameter of the branch wire is 36.24 mm. The length of the composite insulator strings is 9.6 m, however, the lengths of the connecting fittings are different because of the unique tower structure. And the length of the insulator string and fittings in one direction is 11.925m; the length in the other direction is 10.96m. Considering the practicability and economy, the construction holes and united board are determined as the fulcrum according to the field situation. In order to meet the requirements of generality, the insulation pull rods' length should be adjustable.



**Figure 1.** The field arrangement of L-type insulator string



**Figure 2.** The tools of replacing the L-type insulator string

The developed matching tools are shown in Fig.2. In the device, a broadsword card, a hydraulic tightener, a mechanical screw, insulation pull rods and cross-arm fixtures are connected with one another sequentially in turn. The load-transition of the insulator string can be realized when the equipotential worker tightens the screw and then the insulator string can be replaced. In order to meet the actual demand, the cross-arm fixtures need to be changed and the length of the insulation pull rods need to be adjusted when the workers need replacing the different-direction insulator strings.

## 3. The mechanical analysis and verification

The total cross-sectional area of the wire is  $973.16 \text{ mm}^2$ ; the stress of the wire is 92.075 Mpa. The technical parameters of the calculated tower and the adjacent ones are shown in table 1. The nominal height of the 1382 tower is 51 m; the elevation is 304.3 m; the span of the front side is 556 m and the one of the rear side is 404 m. In the meantime, the nominal height of the 1381 tower is 69 m and the elevation is 364.9 m; the nominal height of the 1383 tower is 51 m and the elevation is 327.8 m.

**Table 1.** Related line parameters

Tower number	1381	1382	1383
Tower type	ZC27154	ZJC2715	JC27151
Nominal height	69 m	51 m	51 m
Elevation	264.9 m	304.3 m	327.8 m
Span of the front side	404 m	556 m	463 m

Span of the rear side	784 m	404 m	556 m
Assembly type of the fittings	X3-1A1	XL2-1B1	N1-2/N1-2
Type of the insulator strings	duplex V-type composite insulator strings	duplex L-type composite insulator strings	three porcelain insulator strings

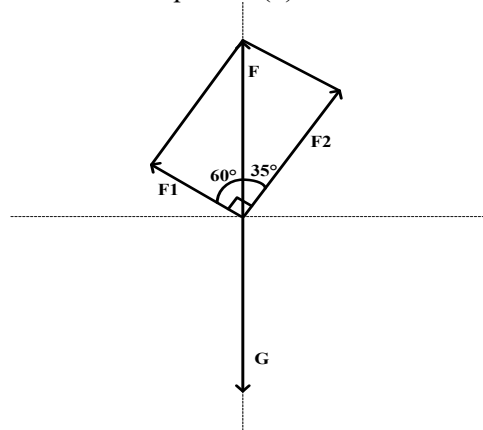
The vertical span can be obtained by the equation (1) and it is 511.5 m through the calculation .

$$l_v = \frac{1}{2}(l_1 + l_2) + \frac{\sigma}{g} \left( \frac{\pm h_1}{l_1} + \frac{\pm h_2}{l_2} \right) = \frac{1}{2}(404 + 556) + \frac{92.075}{0.03126} \left( \frac{21.4}{404} + \frac{-23.5}{556} \right) = 511.5m \quad (1)$$

The vertical load  $G$  can be obtained by the equation (2). In equation (2),  $n$  presents the amount of the bundle conductor and it is 6; the wire's weight  $m$  is 3.1047 kg/m; the vertical span of the tower  $l_v$  is 511.5 m;  $g$  presents the gravity acceleration and it is 9.8 N/kg;  $G_j$  presents the total weight of the insulator string, the fittings and the operator, which is calculated according to 5000 N. The vertical load  $G$  is 98.4 kN through the calculation.

$$G = nml_v g + G_j \quad (2)$$

According to the arrangement of the duplex L-type composite insulator strings, the stress analysis diagram was shown in Fig.3. And then the equation (3) can be obtained from the diagram.



**Figure 3.** The stress analysis diagram of L-type insulator strings

$$\begin{cases} F_1 \cos 60^\circ + F_2 \cos 35^\circ = G \\ F_1 \sin 60^\circ - F_2 \sin 35^\circ = 0 \end{cases} \quad (3)$$

The load  $F_2$  of the insulator string in the inner side is 85.6 kN and the load  $F_1$  in the lateral side is 56.6 kN through the calculation. The load that the developed tools can sustain is 90 kN, therefore, the developed tools meets the actual requirement of live replacing the L-type insulator strings.

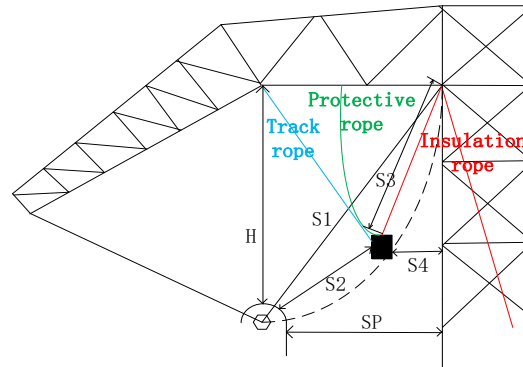
#### 4. CHECK

In order to ensure the safety of the equipotential worker, the safe distance and the combined gap need to be verified. The minimum safety distance is 6.8 m and the minimum combined gap is 6.6 m for  $\pm 800$  kV transmission lines according to the relevant standards [5].

##### 4.1. The Safe Distance Check

The safe distance refers to the distance between the ground potential worker and the charged body or the distance between the equipotential worker and the grounding body. The particular analysis of the safe distance is shown in Fig.4 when the worker enters the electric field by the hanging basket method. Through the calculation and analysis, the horizontal distance between the cross-arm end and the tower center is 20.826 m; the horizontal distance between the tower edge and the tower center is 2.2 m; the horizontal distance between the tower edge and the divided conductor center is 8.5 m; the length of the insulator string and fittings in the inner direction is 11.925m; and the grading ring's short connected length of the air gap is 1.0m. Considering the influence of the grading ring's short section, the minimum distance  $S_1$  is about 10.925 m; the minimum distance  $S_p$ ,  $H$  is about 7.5 m, 8.36 m

respectively after the worker entered the electric field, which accord with the requirement that the safety distance is greater than 6.8 m.



**Figure 4.** The calculation analysis of the safe distance and the combined gap by the hanging basket

#### 4.2. The Combined Gap Check

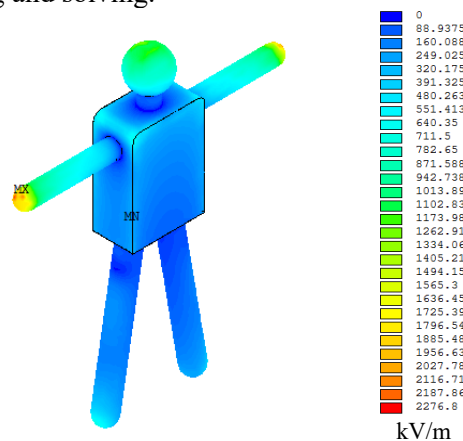
The combined gap refers to the sum distance that includes both the distance between the ground potential worker and the charged body and the distance between the equipotential worker and the grounding body. The particular analysis of the combined gap is shown in Fig.4 when the worker is entering the electric field by the hanging basket method. Both the width  $h$  and height  $b$  of the hanging basket are 0.6 m. Through the calculation and analysis as shown in equation (4) and equation (5), the minimum gap distance  $S_{g1}$ ,  $S_{g2}$  is greater than 7.764 m, 6.9 m respectively, which accord with the requirement that the combined gap is greater than 6.6 m. Therefore, the equipotential operation method is used and the hanging basket method is selected as the way of entering the electric field.

$$S_{g1}=S_2+S_3>H-h=8364-600=7764 \text{ mm} \quad (4)$$

$$S_{g2}=S_2+S_4>S_p-b=7500-600=6900 \text{ mm} \quad (5)$$

### 5. Electric Field Analysis

The electric field distribution of the live worker is calculated by the finite element method [6-8]. The established model of using the hanging basket is imported into the simulation analysis software. The electric field intensity of body surface at the equipotential location is obtained as shown in Fig.5 by the steps of the subdivision, loading and solving.



**Figure 5.** The electric field intensity of body surface at the equipotential location

Analyzing the calculated results, we can know the largest electric field intensity at the equipotential location by the hanging basket method is 2276.8 kV/m for the  $\pm 800$  kV small angle tower. In the process of live working on UHV DC transmission lines, the internal maximum electric field intensity of the screen clothes should be less than or equal to 15 kV/m and the maximum electric field intensity of the human body's exposed areas should be less than or equal to 240 kV/m [9]. Therefore, the 60 dB shielding clothes should be used in order to ensure the equipotential workers' safety.

## 6. Field Application

The live working can be carried out around the premise that the weather, temperature and humidity meet the live working requirements. The hanging basket method is selected as the way of entering the electric field and the equipotential worker wearing the 60 dB screen clothes successfully entered the strong electric field. The specific field application cases are shown in Fig.5. With the cooperation of the tower operation workers and the ground workers, the L-type insulator strings are replaced smoothly by using the new method put forward in this paper and the developed accompanying tools shown in Fig.6, which ensures the safe and stable operation of the  $\pm 800$  kV UHV DC transmission lines.



**Figure 6.** Field application of replacing the L-type insulator string by the new method

## 7. Conclusion

A new method of live replacing the duplex L-type insulators is put forward and the matching tools are developed based on the actual parameter of the UHVDC L-type tower. And the safe distance and combined gap of the new working method are checked. In addition, the 60 dB shielding clothes should be used.

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