Research on the area of mechanized construction of transmission lines

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Abstract. In order to continuously improve the construction capacity of power grid projects, improve the level of construction technology, and promote the transformation and upgrading of construction enterprises, power companies actively promote the mechanized construction of transmission lines. On the basis of summarizing the existing calculation rules of mechanized construction area, through on-site investigation and extensive collection of funds, research and excavate indicators that adapt to the new situation and new regulations. According to the actual area composition of the mechanized construction site, scientific calculation rules are formulated by modeling analysis and other methods. Compare and verify the calculated area of the new rule with the actual compensation area and the calculated area of the original rule, and propose a complete set of calculation rules for mechanized construction area, which has the conditions and value for popularization and application.

Keywords: Transmission line; mechanized construction; compensation area; scientific model.

1. Introduction

The mechanized construction of the transmission line is to use the mechanized construction equipment in the whole process of the construction of the transmission line to complete the construction tasks of each construction process. The area occupied by the mechanized construction of transmission lines refers to the area occupied during the construction of transmission lines due to the use of machinery for transportation, stacking of materials, equipment, excavation of earth and stone, construction of foundations, erection of towers, and deployment of guide and ground wires. This area corresponds to the area for compensation for young crops, which is related to how to calculate compensation for young crops. At present, the construction area of the transmission line is calculated by referring to the "Detailed Rules for the Compilation of Estimated Estimates for Power Transmission Projects". According to different voltage levels and line length, after deducting the proportion of the area without young crops to the entire length of the line, it is multiplied by the "comprehensive width of the temporary construction site"[1]. This construction area calculation method is suitable for the case where the line conductor cross-section, towers and foundation works are small, and the construction is carried out manually, and it fails to reflect important technical parameters such as the line loop, foundation form, tower type, average span and other important technical parameters. Differences, without considering the area added by the line crossing and spanning construction. With the increase of social demand for electricity consumption, the transmission capacity of lines of various voltage levels has increased significantly, the cross-section of conductors, towers and foundation works have increased significantly, and the number of objects along the line has also increased significantly. Coupled with the extensive promotion of mechanized construction, and manpower The calculation method of the construction site area of the transmission line that matches the construction has not matched the on-site situation of the mechanized construction, and cannot meet the requirements of the accurate calculation of the budget site area for the mechanized construction of the transmission line project. It is urgent to conduct an in-depth analysis of the area of the mechanized construction of the transmission line, and calculations.

On the basis of the current mechanized construction area calculation rules, through on-site research and extensive collection of funds, according to the actual area composition of the mechanized construction site, using modeling analysis and other methods to formulate scientific calculation rules, and calculate the new rules. The area is compared with the actual compensation area and the original calculation area, and a set of perfect calculation rules is proposed for the calculation of the area of the mechanized construction site, which has the conditions and value of popularization and application.
2. Analysis on the composition of mechanized construction area

According to the on-site investigation and actual measurement, the analysis shows that the area occupied by the mechanized construction site is closely related to the technical indicators such as the number of tower bases, the single-base engineering volume and the average span of the line. The composition of the site area is mainly divided into six parts: construction road, foundation site, tower site, spanning frame site, wire channel and accessory installation site and traction tension field, as shown in Table 1.

<table>
<thead>
<tr>
<th>serial number</th>
<th>The composition of mechanized construction area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>construction road area</td>
</tr>
<tr>
<td>2</td>
<td>foundation site area</td>
</tr>
<tr>
<td>3</td>
<td>tower site area</td>
</tr>
<tr>
<td>4</td>
<td>spanning frame site area</td>
</tr>
<tr>
<td>5</td>
<td>wire channel and accessory installation site area</td>
</tr>
<tr>
<td>6</td>
<td>traction tension field area</td>
</tr>
</tbody>
</table>

The analysis of the area of each part is as follows:
(1) The construction road area refers to the area of the road that needs to be kept for the passage of the machinery itself when large and medium-sized machinery is used for construction. This area is related to factors such as the number of towers, the width of the road occupied by machinery, and the total length of the line.
(2) The area of the foundation site refers to the area occupied by the foundation materials, construction machinery, and excavation earthwork of the stacking site. The area is related to the foundation type, the amount of earthwork excavation and other factors.
(3) The tower site area refers to the area occupied by the stacking tower materials and construction machinery. The area is related to factors such as the opening of the tower and the amount of material of the tower. Generally, after the foundation construction is completed, the tower construction is carried out, and the area of the tower site basically coincides with the area of the foundation site. The area related to the length, width, etc. of the span.
(4) The area of the spanning rack site refers to the area occupied by the spanning rack that needs to be erected due to the line crossing over the high-speed rail, high-speed rail, etc. The area is related to the length, width, etc. of the span.
(5) The area of the installation site for the wiring channel and accessories refers to the area occupied by the work that needs to be coordinated during the installation of the wiring and accessories. The area is related to factors such as cross arm length and path length.
(6) The area of the traction tension field refers to the area occupied by the construction of the stretcher. The area is related to factors such as the number of stretch sites and the area of stretch sites.

3. Calculation of mechanized construction area

According to the composition of the area of mechanized construction, the calculation rules of the area of each part are put forward.

3.1 Construction road area
The formula for calculating the floor area of the construction road is:
Construction road area = number of towers × average road length × average road width × seasons

According to the on-site measurement, the road width is between 3-5.5m. The road width of the high-voltage grade will increase slightly due to the large tonnage of the transport vehicle and the wide wheelbase. The average width is calculated as 4m. The 35kV line project generally, the transportation volume is small, and some projects can use three motorized wheels for the secondary transportation of materials, so the width of the road can be calculated as 3m [2].

The road length of each project and each tower location is quite different. According to the on-site compensation data and the mechanized construction plan of each project, since each construction stage requires access roads, the occupied area of the road is basically the same as the number of quarters corresponding to the construction period. The construction period of individual 35kV and 110kV line projects is within one season, and most of the construction period is two quarters. Projects with a duration of more than one year are calculated in three quarters.

3.2 Foundation site area
According to the type of foundation, the foundation construction site is divided into slab foundation, cast-in-place pile foundation and excavation pile foundation. Through the analysis of the factors affecting the area of the foundation construction site of different foundation types and different voltage levels and the comparison of the corresponding site area, it can be seen that the amount of concrete and the floor area of the tower (including the two variables of foundation root opening and column width) are the most important factors affecting the area of the foundation construction site. Therefore, in order to measure the area of the foundation construction site more accurately, it can be considered to use modeling to predict the area of the construction site based on the amount of concrete of different foundation types and the area of the tower, so as to provide a more scientific basis for the calculation of the area of the foundation construction site.

3.2.1 Computational Model Building of the foundation site area

The multiple linear regression model is one of the methods often used to explore the law that the dependent variable follows the changes of multiple independent
variables. [5] In this paper, the amount of concrete and the floor area of the tower are used as independent variables, and the site area is used as the dependent variable, and the multiple linear regression method is used to establish a model and predict the area. Taking the area of the foundation construction site as the dependent variable $y$, and the single foundation concrete volume and the floor area of the tower as the independent variables $x_1$ and $x_2$, respectively, the following binary linear regression model is constructed.

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \epsilon$$  \hspace{1cm} (1)

In the formula, $y$ is the area of the foundation construction site, $x_1$ is the amount of single-base foundation concrete, $x_2$ is the floor area of the tower, $\beta_0$, $\beta_1$ and $\beta_2$ are the regression coefficients, and $\epsilon$ is the random model error. For the multiple linear regression model, the least squares method is usually used first—minimizing the sum of squares of the residuals to solve the estimation of the unknown parameters $\beta_0$, $\beta_1$, and $\beta_2$, respectively, the following binary linear regression model is constructed.

$$\min_{\beta_0, \beta_1, \beta_2} \sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$  \hspace{1cm} (2)

The calculation from the above formula is an extreme value problem. Since $Q$ is a non-negative quadratic function about $\beta_0$, $\beta_1$, and $\beta_2$, its minimum value always exists. According to the principle of finding extreme values in calculus, only the partial derivative of $Q$ with respect to the parameter to be estimated $\hat{\beta}_0$, $\hat{\beta}_1$, $\hat{\beta}_2$ is required, and set it equal to 0, the normal equation system for the parameter to be estimated can be obtained:

$$\begin{align*}
\frac{\partial Q}{\partial \beta_0} &= \sum_{i=1}^{n} (y_i - \hat{y}_i) = 0 \\
\frac{\partial Q}{\partial \beta_1} &= \sum_{i=1}^{n} (y_i - \hat{y}_i) x_1 = 0 \\
\frac{\partial Q}{\partial \beta_2} &= \sum_{i=1}^{n} (y_i - \hat{y}_i) x_2 = 0
\end{align*}$$

(4)

\[ \hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2 \] are obtained as follows:

$$\hat{\beta}_0 = \sum \left( Y_i x_0 - \sum Y_i X_0 \sum x_i X_0 \sum x_i x_0 \right) \over \sum X_0^2 \sum x_i^2 \left( \sum x_i x_0 \right)^2$$  \hspace{1cm} (5)

$$\hat{\beta}_1 = \sum \left( Y_i x_1 - \sum Y_i X_1 \sum x_i X_1 \sum x_i x_1 \right) \over \sum X_1^2 \sum x_i^2 \left( \sum x_i x_1 \right)^2$$  \hspace{1cm} (6)

$$\hat{\beta}_2 = \sum \left( Y_i x_2 - \sum Y_i X_2 \sum x_i X_2 \sum x_i x_2 \right) \over \sum X_2^2 \sum x_i^2 \left( \sum x_i x_2 \right)^2$$

(7)

where $\overline{X}_i = \frac{1}{n} \sum X_i$ is the sample mean of the dependent variable, $\overline{X}_i$ and $\overline{X}_j$ are the sample mean of the two independent variables, respectively.

Therefore, the calculation formula can be obtained:

$$\hat{y} = \hat{\beta}_0 + \hat{\beta}_1 x_1 + \hat{\beta}_2 x_2$$  \hspace{1cm} (8)

3.2.2 Calculation results

Among the projects completed and put into operation in the past two years of a company, 70 representative transmission line projects were selected, including 5 500kV projects, 18 220kV projects, 29 110kV projects, and 18 35kV projects. For different voltage levels and different foundation types, the constructed binary linear regression model was used to measure and calculate, and the calculation formula of the foundation site area was obtained as follows:

1. 500kV transmission line engineering foundation construction site area

\[ y = 507.26 + 10.46 x_1 + 2.32 x_2 \]

Among them: $x_1$ is the concrete volume of the new construction, $x_2$ is the floor space of the new construction towers (the same below).

2. 220kV transmission line engineering foundation construction site area

\[ y = 380.81 + 2.36 x_1 + 2.31 x_2 \]

3. 110kV transmission line engineering foundation construction site area

\[ y = 149.91 + 12.91 x_1 + 4.04 x_2 \]

(2)

(2)

(2)

3.2.3 Calculation results

Among them: $x_1$ is the concrete volume of the new construction, $x_2$ is the floor space of the new construction towers (the same below).

Among the projects completed and put into operation in the past two years of a company, 70 representative transmission line projects were selected, including 5 500kV projects, 18 220kV projects, 29 110kV projects, and 18 35kV projects. For different voltage levels and different foundation types, the constructed binary linear regression model was used to measure and calculate, and the calculation formula of the foundation site area was obtained as follows:

\[ y = 507.26 + 10.46 x_1 + 2.32 x_2 \]

Among them: $x_1$ is the concrete volume of the new construction, $x_2$ is the floor space of the new construction towers (the same below).

\[ y = 380.81 + 2.36 x_1 + 2.31 x_2 \]

\[ y = 149.91 + 12.91 x_1 + 4.04 x_2 \]
(2) Calculation formula of construction site area of cast-in-place pile foundation:
\[ y = 383.65 + 3.97x_1 + 1.88x_2 \]

(3) Calculation formula of construction site area of steel pipe cast-in-place pile foundation:
\[ y = 313.27 + 3.65x_1 \]

4  35kV transmission line engineering foundation construction site area
(1) Slab foundation construction site area calculation formula:
\[ y = 3.85 + 9.07x_1 + 8.34x_2 \]

(2) Calculation formula of construction site area of cast-in-place pile foundation:
\[ y = 287.08 + 6.52x_1 + 1.60x_2 \]

(3) Calculation formula of construction site area of steel pipe cast-in-place pile foundation:
\[ y = 291.63 + 4.68x_1 \]

3.3 Pole tower assembly construction site
According to the on-site investigation, after the mechanized construction is adopted, the on-site hoisting mainly relies on cranes, and the traditional construction method of "external pull wire and internal suspension holding pole" is cancelled. For the site, it is important to consider the increase in the number of compensation seasons caused by different construction periods[3]. When the construction site of the excavated piles or some cast-in-place pile foundations is small, the construction site may be appropriately expanded during the construction of the towers. It is also possible to adjust the construction organization, adopt the construction method of partial grouping and hoisting in batches to reduce the construction site occupied, but it will affect the efficiency of mechanized construction and significantly increase the number of crane shifts used. In order to take into account the site area requirements in the construction stage of the tower group, the excavation foundation construction site needs to be appropriately enlarged on the basis of formula calculation.

3.4 Spanning frame site area
spanning frame site area=The length of the spanning frame × the width of the spanning frame × the adjustment factor of the average intersection angle × the increase coefficient of transportation, stacking, and cable.
According to the design data, the width of the spanning frame is determined as the total width of the wire cross-arm. Considering the wind deviation allowance, the two sides are expanded by 1 meter. The form of spanning frame is determined according to the site conditions. The average spacing of each row is considered to be 1.5 meters, and the front and rear of the construction site are expanded by 1 meter. The inclined span is considered at an average angle of 70°, and the area is increased by 6.4%. The area of transportation, stacking and pulling wire during the erection of the spanning frame shall be calculated as 40% of the net area. According to the above calculation principles, the spanning area of each voltage level is determined as shown in Table 2.

<table>
<thead>
<tr>
<th>No.</th>
<th>Crossed line</th>
<th>Cross frame form</th>
<th>Cross frame height</th>
<th>35kV</th>
<th>110kV</th>
<th>220kV</th>
<th>500kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low-voltage line</td>
<td>Two rows on one side</td>
<td>3.5m</td>
<td>38</td>
<td>52</td>
<td>88</td>
<td>142</td>
</tr>
<tr>
<td>2</td>
<td>10kV</td>
<td>Double side two rows</td>
<td>7m</td>
<td>75</td>
<td>104</td>
<td>175</td>
<td>284</td>
</tr>
<tr>
<td>3</td>
<td>35kV</td>
<td>Double side three rows</td>
<td>10m</td>
<td>107</td>
<td>149</td>
<td>250</td>
<td>405</td>
</tr>
<tr>
<td>4</td>
<td>110kV</td>
<td>Double side three-row, four-row each 50%</td>
<td>11.5m</td>
<td>\</td>
<td>171</td>
<td>288</td>
<td>466</td>
</tr>
<tr>
<td>5</td>
<td>220kV</td>
<td>Double side four-row</td>
<td>13m</td>
<td>\</td>
<td>\</td>
<td>325</td>
<td>527</td>
</tr>
<tr>
<td>6</td>
<td>500kV</td>
<td>Double Side Five Row</td>
<td>16m</td>
<td>\</td>
<td>\</td>
<td>\</td>
<td>648</td>
</tr>
</tbody>
</table>

3.5 Wire channel and accessory installation site area
Wire channel and accessory installation site area=Transmission line path length × comprehensive channel width.
It can be seen from the on-site investigation and young crop compensation data that the occupied area of the on-site pay-off channel is small. When the width of the cross arm is small, the single-circuit or double-circuit line can be combined into one construction along the center line of the line during the process of unwinding the traction rope. Therefore, the width of the wiring construction channel of 35-220kV voltage level can be calculated as 1m wide. The installation of inter-phase spacers in the stalls needs to occupy the construction area of the pressure channel. Due to the small number of inter-phase spacers, the increase of the site area is not obvious, so they can be incorporated into the wire construction channel. A set of conductor spacer bars is installed at an average of 40-60m per phase conductor, and the number of installations is large. The 500kV conductor generally adopts four splits, and the weight of the spacer bar is obviously doubled compared to 110kV and 220kV (see the table below for the weight of the spacer bar for each voltage level). It is installed on the tower by the climbing operator and needs to be installed by the ground operators at the installation point, so the increase in the construction area is obvious. The length of the 500kV wire cross-arm is long, and it is difficult to merge the traction rope into the same channel during the deployment process. Therefore, the width of the construction channel width for single and double circuits of 500kV voltage level is calculated as 2m wide. The attachment installation construction site at the base of the straight tower is obviously smaller than the construction site of the group tower, and the installation
of the hanging line of the corner tower and the installation of the insulator string basically overlaps the construction site of the pole tower. After the construction of the tower group is completed, in order to reduce the difficulty of on-site coordination and avoid secondary compensation, the construction site is generally reserved until the attachment is installed and completed. Due to the different construction periods, the number of construction site compensation seasons may be increased for each project.

3.6 Traction tension field area
Traction tension field area = The total number of venues across the board × venue area
The traction field is mainly used to pull the wire, and also store the ground wire or optical cable; the tension field needs to store the wire, and carry out the work of tension spreading and wire crimping, and two consecutive pay-off segments can share the same tension field, so The site area is significantly larger than the traction field. According to the past billing habits, combined with the actual compensation data, the traction and tension field site area of each voltage level is set to 2000 m²/place for 35kV line projects, 2500 m²/place for 110kV line projects, 3000 m²/place for 220kV line projects, and 5000 m²/place for 500kV line projects. Line engineering 4000 m²/place. According to the third chapter of "110kV ~ 750kV Overhead Transmission Line Tension Line Construction Technology Guidelines" (DL T5343-2018), the tension line section should generally be controlled within 20 base towers, and high-speed railways, railways, and high-voltage power lines should be comprehensively considered. Discontinuous construction caused by special spanning and separate lay-out segments are considered on average as 15 bases/place, and are calculated by rounding up to an integer. [4]

The normal split length of the optical cable is about 4km. It is considered that half of the optical cable stretch site shares the same site with the wire stretch site, and the other half needs to be set up separately. Therefore, the optical cable stretch site is added at 8km/place (or according to the designed single site. Divide the number of root sub-discs by 2 and round up to an integer), and the area of a single place is calculated as 900 square meters according to the on-site investigation.

4. Empirical Analysis

4.1 Sample selection
Among the projects completed and put into operation in the past two years of a company, 70 representative transmission line projects are selected, including 5 500kV projects, 18 220kV projects, 29 110kV projects, and 18 35kV projects. The sample receipts mainly cover the following:
(1) List of towers in the as-built drawings, foundation construction drawings, grounding construction drawings, and list of towers and towers.

(2) Commencement, completion and transition reports, approved construction organization design and special construction plans related to mechanized construction.
(3) Statistical table of completed engineering quantities (focusing on foundation opening, concrete, earthwork quantities, tower type, tower height and spanning objects).
(4) Scanned copies of compensation data for young crops and tower bases, trees, nurseries, green belts, road occupations and other compensation data within the range of the access road, and fill in the "statistical table of actual value of mechanized construction site area" according to the actual compensation data.
(5) At each construction stage, there are about 10 electronic photos that can reflect the occupancy of the construction site on site.

4.2 Mechanized construction area calculation
According to the income data of each voltage level project and the calculation rules of mechanized construction area proposed in this paper, the construction site area of each voltage level is calculated and compared with the actual compensation area, as shown in Table 3.

<table>
<thead>
<tr>
<th>N o</th>
<th>Voltage level</th>
<th>Compen sation area calculated by the original rule (per acre/km)</th>
<th>Compen sation area calculated by this rule (per acre/km)</th>
<th>Actual compensation area (per acre/km)</th>
<th>Deviation rate (the original rule is more realistic)</th>
<th>Deviation rate (the rule in this article is more realistic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35kV</td>
<td>10</td>
<td>9.56</td>
<td>10.44</td>
<td>-4.21%</td>
<td>-8.43%</td>
</tr>
<tr>
<td>2</td>
<td>110kV</td>
<td>13.41</td>
<td>14.27</td>
<td>16.68</td>
<td>-19.60%</td>
<td>-14.45%</td>
</tr>
<tr>
<td>3</td>
<td>220kV</td>
<td>11.90</td>
<td>15.57</td>
<td>15.08</td>
<td>-21.09%</td>
<td>-3.25%</td>
</tr>
<tr>
<td>4</td>
<td>500kV</td>
<td>22.79</td>
<td>15.72</td>
<td>16.38</td>
<td>39.13%</td>
<td>4.03%</td>
</tr>
</tbody>
</table>

It can be seen from Table 3 that the deviation of the compensation area calculated by the rules in this paper compared with the actual compensation area is within 15%, and except for the 110kV voltage level, the other deviations are within 10%. The compensation area calculated by the original rules has a larger deviation rate than the actual compensation area. Except for the 35kV voltage level deviation within 10%, the other deviations are greater than 15%, and the 500kV voltage level deviation rate is as high as 39.13%. The calculation rules of mechanized construction area proposed in this paper are effective.
5. Conclusion

Mechanized construction is an important measure to improve the construction efficiency and safety quality of transmission line projects. Based on the current calculation method of the construction site area of transmission lines, combined with specific projects and typical design schemes, and fully considering the difference between mechanized construction and traditional construction modes, this paper proposes the composition and calculation rules of the mechanized construction area, and draws the following conclusions.
1) The occupied area of mechanized construction can be divided into six parts: construction road, foundation site, tower site, spanning frame site, wire channel and accessory installation site and traction tension field.
2) Clarify the calculation rules for the occupied area of each part of the mechanized construction, for example, the construction road area is equal to the product of the number of towers, the average road length (or base-by-base measured calculation) and the average road width; the product of the integrated channel width, etc.

Compared with the original calculation rule, the calculation rule of mechanized construction area proposed in this paper is more suitable for the situation that the transmission capacity of the current line is significantly increased, and the cross-section of the conductor, the tower, and the amount of foundation works are greatly increased, which makes up the blank of the calculation of the mechanized construction area.

References