Optimizing the distribution of transmission line tower and foundation

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Abstract. In the mountainous transmission lines, in order to respond to the national and national grid requirements for environmental protection, the design institute needs to design the towers for the long and short legs and the foundation of the tower. To this end, the paper gives the design scheme of the long and short leg iron tower in Liaoning area, and analyzes the design conditions of the iron tower, the base surface measurement of the iron tower, the insulation coordination and the optimization design of the tower. The purpose of this paper is to find the mutual configuration of the long and short leg towers and the high and low foundations that can be used to optimize the transmission line in mountainous projects, and use finite element software to verify that the minimum amount of base materials is the same when the tower position is constant. The basic base surface has the least amount of shovel excavation, which can better protect the geographical environment of the area where the tower is located, and can also control the amount of basic materials to a certain extent and reduce the total investment of the project.

1. Introduction

In the general design of the national grid, the 06B1-B8 iron tower universal design chess block has been used in the design and application of the 66 kV transmission line tower. The data has been checked and 38 problems have been found. Among them, the tower type problem: the design condition table and the part of the foundation root opening bolt spacing in the structure diagram are different, the base foot bolt spacing in the tower front structure diagram is different from the tower iron foot board size, the tower type foot bolt There are 32 problems such as small specification value, unsatisfactory strength check, and the difference between the base foot bolt spacing and the size of the iron foot plate. The problem of the metal fittings: the ground hanging string, the use of the fittings is wrong, and it is impossible to install the construction. The size of the structure can not meet the installation requirements of the windshield insulator jumper string. The ground string is connected to the tower with the front and rear strings, and the series jump is not used. The ground line is not conducive to six problems such as diversion.

In the general design of the national network, 04GG1-GG5 steel pipe universal design module double-back overhead ground type is double lightning line hanging line and the universal design 06B tower universal design module double-back overhead ground type single lightning line hanging line Correspondingly, some of the 06GG steel pipe universal design modules cannot be used in actual
work, and the general design of the tower weight selection plan is too large, no drawings and other specific indicators, the guidance is not strong. In addition, when the designer provides the design to the winning bidder according to the electrical layout and application conditions, the winning bidder often artificially increases the root diameter and wall thickness of the steel pipe, and intentionally increases the weight of the tower, resulting in the amount of foundation concrete. And the increase in the amount of reinforcement, resulting in an increase in the floor area of the tower, wasting steel and valuable land resources, resulting in a substantial increase in project cost.

The emergence of all-round long and short iron towers [1-2] is a great leap in the design of mountainous routes, which greatly reduces the amount of opening caused by the excessive opening of the roots and effectively reduces the height of the upper slope after the opening. The application of the long and short legs of the 500kV tower was earlier. It was applied from the 1980s. At that time, the application of the 220kV tower was short. After the design of the long and short leg tower of the State Grid in 2005, the long and short legs of the 220 kV tower were pushed to the factory application. The practice over the years has proved that the all-round long-legged iron tower has the superiority of the flat-legged iron tower in the construction and operation of the mountain environment, which is conducive to saving the cost of the engineering body. The average direct savings per base tower is 30,000 RMB; Safe operation, reduced or no basic slope protection, greatly reduces the maintenance work and costs of the foundation slope protection; is conducive to environmental protection, conforms to the modern environmental protection concept, and maximizes the use of the natural structure of the mountain body, minimizing The destruction of mountains and vegetation.

2. Design and measurement conditions

2.1. Design conditions for transmission line towers

According to the meteorological parameters under various operating conditions, the requirements of the new technical specifications regarding the meteorological return period and the height of the wind speed sample from the ground are met. For the maximum ice-covered value, because the long and short-legged iron tower lines are in the mountainous area, the 66kV transmission line adopts JL/G1A-300/25 steel-cored aluminum stranded wire; the ground wire adopts two JLB20A-100 aluminum-clad steel stranded wires. The arrangement of the wires of the double-circuit tower is mainly divided into vertical arrangement and triangular arrangement. In the domestic double-circuit pole tower of the same pole, in addition to the large spanning tower, in order to reduce the tower height, the three-phase conductors are arranged in a triangle, and the general lines are mostly arranged in a vertical arrangement of three-phase wires. Vertically arranged lines, due to the small line corridor, clear circuit, simple structure, clear transmission force, convenient construction and maintenance, are widely used in China, and also accumulated rich operational experience; Fine, the triangular arrangement has a greater impact on the tower body, the economy is not high, and the line corridor is wider. Therefore, the engineering wires are arranged in a vertical arrangement.

The two-circuit pole tower wire vertically arranged tower type mainly has a drum type and an umbrella type. According to the regulations, the horizontal deviation between adjacent wires in the upper and lower layers of the ice-covered area is considered, and the tower adopts a drum type. The meteorological conditions used in the design are shown in Table.1.

2.2. Method for measuring the base surface of an iron tower

The basic base surface measurement of the iron tower is mainly to measure the terrain trend around the foundation in order to meet the requirements of the tower foundation for uplifting, that is, to indirectly consider the volume of the uplifting soil. The foundation pull stability is the ability to calculate the tower foundation against the uplift load. Two methods are used in engineering: shearing method and soil weight method. The shearing method is in line with the failure mechanism of the uplifting soil. It not only considers the self-weight of the soil and foundation, but also makes full use of the soil’s own pullout resistance, but it is difficult to determine the physical and mechanical properties of the backfilled soil. The shearing method is only used for the original anti-soil body. The soil weight method is an empirical method that has been used for many years. It relies mainly on the
self-weight of the foundation and the soil above the foundation floor to resist the pull-up force. The principle is simple, the calculation is simple, and it has been widely used in the design. Therefore, before the configuration of the tower's long and short legs and high and low foundations, we must first accurately measure the tower base surface (relative elevation). At present, the major design institutes in China mainly use GPS to measure the basic surface of the transmission tower. It is characterized by high accuracy, high speed, automatic recording of all information (coordinates and elevations) of the sampling points, and automatic mapping by post-software, when the designer is positioned in the final survey.

| Terms                  | Air temperature $T$ (℃) | Wind speed $v$ (m/s) | Ice thickness $b$ (mm) |
|------------------------|--------------------------|----------------------|------------------------|
| Maximum temperature    | 40                       | 0                    | 0                      |
| Minimum temperature    | -40                      | 0                    | 0                      |
| Icing                  | -5                       | 10                   | 0                      |
| Basic wind speed       | -5                       | 29                   | 0                      |
| Installation condition | -15                      | 10                   | 0                      |
| Mean temperature       | -5                       | 0                    | 0                      |
| Lightning Overvoltage  | 15                       | 10                   | 0                      |
| Operating Overvoltage  | -5                       | 15                   | 0                      |

3. Insulator coordination design

3.1 Insulator selection for transmission line towers

According to the investigation of the transmission line projects that have been put into operation, synthetic insulators, suspended glass insulators and stain-resistant ceramic insulators are the main types of insulators in 110 kV transmission lines. Therefore, the design of insulators [3-6] in this paper is based on composite insulators, suspended glass insulators and stain-proof porcelain insulators. The selection of insulator types is as follows: 1) conductor suspended insulator strings: composite insulators; 2) conductor jumper insulator strings: fixed wind-proof composite insulators; 3) conductor tension-proof insulators. String: Composite insulators are used in the feeding gear, and suspended glass insulators or stain-resistant ceramic insulators are used in the rest.

According to the requirements of relevant documents: the external insulation of transmission lines should be arranged according to the requirements of pollution grade, ordinary porcelain or glass insulators can be used in pollution areas of grade B and below, and anti-pollution insulators or composite insulators can be used when approaching the upper limit value; composite insulators or anti-pollution insulators with good self-cleaning property should be used in pollution areas of grade C; Composite insulators should be used in the area. If the use of ceramic or glass insulators does not meet the requirements, measures such as coating anti-pollution flashover coatings or composite insulators of porcelain and glass can be taken in the design and construction stages.

3.2 Determination of insulator technical parameters

The mechanical strength of double and multiple insulator strings should be checked after one connection is broken, and the load and safety factor should be considered according to the situation of disconnection. Insulators should also meet the normal operating conditions under perennial load
condition, the safety factor is not less than 4.0. The safety factor of mechanical strength of insulators \( K_I \) shall be calculated according to the following formula:

\[
K_I = \frac{T_R}{T}
\]  

(1)

In formula (1), \( T_R \) denotes the rated mechanical failure load of insulators, in terms of kN; \( T \) denotes the maximum service load, broken line, broken connection, checked load or perennial load that insulators bear, respectively, in terms of kN.

Perennial load refers to the load that insulators bear under the condition of annual average temperature. The checking load is the load that the insulator bears under the checking condition. The meteorological conditions of disconnection are windless, ice-free, \(-5^\circ\text{C}\), 10 mm and below ice conduction. In order to ensure the safety of the suspension insulator, the maximum load of the suspension insulator should be calculated. In order to ensure the safety of the tension insulator, it is necessary to check the strength of the tension insulator string. The allowable load should be equal to or greater than the maximum suspension point tension of the conductor, and the tension of the suspension point of the conductor should be calculated by formula. The insulator creeping distance should be selected and the insulating level of the conductor should meet the requirement of leakage ratio distance [7-8].

The first fittings of V-type suspension string of steel tube towers are U-type hanging rings, and the first fittings of I-type, L-type and long I-type suspension string are UB-type hanging plates. UB hanging plate is the first fittings of the suspension string of steel tube towers.

The tension strings of steel tube towers are designed with single hanging point, with hanging plate as hanging point and U-shaped hanging ring as the first fittings. The ground tension strings of steel tubular towers are designed with single hanging point, hanging point is hanging plate, and the first fittings are U-shaped hanging rings. The jumper string adopts “T” type windproof bias fixed jumper string, and UB hanging plate is used to connect with steel pipe tower.

Compared with other types of electrical fittings, the pre-stranded fittings have the following characteristics: (1) outstanding fatigue resistance. Pre-stranded fittings have no bolts acting on the conductor to reduce the static compressive stress of the fittings on the conductor. At the same time, pre-stranded fittings have relatively long pre-formed spiral lines. Some pre-stranded fittings, such as suspension clamps, split conductor spacers, also have rubber pads, which can further reduce the static compressive stress of the fittings on the conductor. Or distribute it evenly in a larger area. In addition, the bending stiffness of the contact area between the wire and the fittings is enhanced and the dynamic bending stress caused by the breeze vibration in these areas is weakened after the pre-stranded fittings are wound on the wires. Under the same conditions, the static and dynamic stresses on the conductor are obviously reduced by using the pre-stranded metal fittings compared with the traditional bolt-compact metal fittings, which improves the harsh stress environment in the contact area between the conductor and the metal fittings, and protects the conductor from destructive vibration and fatigue. Practice has proved that it has excellent fatigue resistance and prolongs the service life of the fittings; (2) It is easy to install and has strong consistency. The utility model has the advantages of simple and fast installation, no need for installation tools for bare-handed installation, light weight, convenient carrying and transportation. These improves the installation speed, reduces the labor intensity of workers, and improves labor efficiency. Generally, skilled workers only need a few minutes to install a pre-twisted metal tool. Because of the unarmed installation, visual inspection can check the installation quality and eliminate the installation inconsistency caused by the use of tools by the installation workers. These characteristics make it more economical; (3) high efficiency and energy saving; (4) strong adaptability. Pre-stranded metal fittings can be used not only in galvanized steel strand, aluminium-clad steel strand, copper-clad steel strand, aluminium strand, aluminium alloy strand, steel-cored aluminium strand and steel-cored aluminium alloy strand, but also in high temperature conductor, insulated conductor, all-dielectric self-supporting optical cable and ground composite optical cable. It can be applied to almost all overhead lines.

According to the above analysis, considering the pollution area of grade IV, the wire suspension insulator adopts 100kN FXBW-220/100 composite insulator, and the jumper adopts 70kN LXHP5-70
tempered glass insulator. A piece of LXAP1-70 tempered glass insulator is added to the suspension point of the conductor near the suspension point of the suspension string of suspension insulator and jumper insulator string. The tension resistance of conductor is 120 kN grade LXHP4-120 tempered glass insulator, and the intake gear is 100 kN grade FXBW-220/100 composite insulator.

4. Tower optimization design

4.1 Overview of the basic situation

It can be known from the "I" type string in China for many years of operation that this type of insulator string has a large swing angle, which is the main factor causing the width of the line corridor. According to the comparison and practical experience, for the 110kV line, the following comparison is made: 1) The cross-arm of the "V" string needs to be lengthened, the weight of the tower is increased, and the cost is increased; the width of the corridor is not reduced, and since the line is located in the middle of the road, the advantage of controlling the wind bias is not obvious; 2) The "L" string can reduce the length of the crossbar of the tower without changing the conventional tower type, but the lateral supporting insulator and the fitting are not standardized, and special customization is required; the support affects the strength of the tower body, the stability of the tower body becomes higher, the tower body needs to be strengthened, the cost increases; the width of the corridor is not much reduced, and the advantage of controlling the wind bias is not obvious because the line is located in the middle of the road. 3) Although the long "I" type insulator string can be used to control the wind deflection to reduce the length of the cross arm, it needs to be fixed by the cross arm on the upper and lower sides; if the lower phase conductor is used, the cross arm should be added, and the middle phase needs to consider the horizontal spacing of the upper and lower wires. The length of the cross arm of the long "I" type string is not much reduced compared with the length of the middle phase cross arm of the ordinary "I" type string, and affects the length of the cross arm of the lower phase conductor and Force, economic applicability is not good; and the insulator structure is more complicated, there is a requirement for the distance between the upper and lower wires, and it is not universal. Therefore, only the upper phase wire is partially applied in the following tower section, and a special tower type is designed, but has its limitations.

The vertical span has the maximum vertical span and the minimum vertical span. As the vertical span for determining the head gap is generally the minimum vertical span. The minimum vertical span is generally determined by the coefficient method. For different terrains, the coefficient selection is different. The coefficient of the coefficient of the tower head is about 0.75 when drawn. The maximum vertical span selection is also related to the terrain, generally taking 1.2 to 1.3. The horizontal distance between the center line of the gear is mainly determined by the condition that the wire is not synchronized (or galloping) caused by the wind, so that the air gap should not be broken under normal working voltage. As for the operation overvoltage and the lightning overvoltage, since it has a small probability of simultaneous occurrence of a large wind and causing the wires to be asynchronously oscillated (or galloping), it is not a control condition for determining the horizontal distance between the center conductors of the gear pitch.

4.2 Finite element analysis of dynamic characteristics and stability of long and short leg iron towers

In the current engineering design calculations, the calculation of the displacement of the steel tube tower head adopts the industry standard, the empirical formula combined with the chart and various correction factors. The empirical formula generally has low calculation accuracy and poor theoretical theory. The finite element method [9-10] is a numerical calculation method for structural analysis, and it is the application and development of the matrix method in the fields of structural mechanics and elastic mechanics. The finite element method relies on mathematical tools such as matrices. Although the computational workload is large, the whole analysis is consistent and has strong regularity, so it is especially suitable for programming computer programs. This time, the long and short towers were analyzed by dynamic and static analysis using the finite element general program software Midas Gen to verify the correctness of the design and the accuracy of the design software.
The basic idea of the finite element method is to regard the complex structure as a whole connected by a finite number of elements only at the node. The elastic continuous structure to be studied is divided into finite units, which are connected to each other on a finite number of nodes. Firstly, each unit is analyzed for its characteristics. Under certain precision requirements, each unit is described with a finite number of parameters to describe its mechanical characteristics, and the correlation between related physical quantities is established. Then, according to the association combines the various units into a whole, thus establishing a balance equation of the continuum, and applying the corresponding solution of the equation, the analysis of the whole problem can be completed.

Due to the structural characteristics of the tower, it is sensitive to wind vibration and earthquake. The vibration response of the tower structure is related to the dynamic characteristics of the structure itself and the lateral load, and the vibration mode and frequency affecting the dynamic characteristics of the structure. It is related to many factors such as the form of the iron tower, the nature of the material, the size of the section of the rod, the mass distribution, and the weight of the wire.

Firstly, the basic cost in the design of power transmission lines accounts for about 14 to 24% of the cost of the project. The ratio fluctuates greatly, which is related to the terrain, geological conditions and tower type of the line, indicating the basic selection.

The importance of the basic selection will directly affect the indicators of the cost of transmission line engineering. With the continuous development of economic construction, the auxiliary construction cost of transmission lines has an increasing impact on the overall cost of the project, mainly reflected in the awareness of the whole society on environmental protection and the awareness and requirements for sustainable development. Therefore, the basic selection and planning as well as the application of high and low foundations should not only consider safe and stable operation and economic benefits, but also consider social benefits. Choose a reasonable basic type and optimize the configuration to reduce the amount of excavation of the construction earth and reduce damage to the environment. Achieve a win-win goal of safety, environmental protection and economy.

Secondly, the mountain towers that are usually used are often set with high and low legs with a height difference of -1 or -1.5 depending on the length of the main material of the leg and the actual engineering needs (such as leg lengths of 0, -1, -2...-6, or -1.5, -3...-6, etc.). Then configure different high and low legs according to the actual terrain to meet the terrain needs. In addition, the use of high and low foundations as a way of coordinating the terrain, which relatively reduces the use of the tower's high and low legs, makes construction measurement convenient, but relatively increases the amount of concrete. The material of the tower is Q345 and Q235. Bolts are rated 4.8 and 6.8, and all components of the tower are hot-dip galvanized. In order to ensure the safe operation of the line, anti-theft bolts are used within 8m of the tower (from the ground), and other bolts are used [11-12].

In the design of the tower, the static internal force of the iron tower and the static force (basic force) of the tower to the foundation are usually used as the design basis. The basic force of the whole tower under various dangerous conditions, the distribution of the internal force of the rod and the deformation of the tower are obtained by software Midas Gen.

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5. Conclusions

The core content of this paper is the optimal configuration of the long and short legs and the high and low base of the transmission line tower. The main determinants are three. The first is the accurate measurement of the base surface of the tower; the second is to determine the variables that need to be optimized during the optimization configuration process, and to build a complete, detailed and accurate configuration calculation model that conforms to the actual engineering practices to achieve qualitative and quantitative analysis and optimization; The final screening of the configuration results is based on the actual engineering conditions. Through the research and analysis, summarization and summary of this paper, the optimal configuration of the long and short legs and the high and low
foundations of the tower is proposed. The optimal configuration scheme is verified by the actual mountain line engineering. The dynamic characteristics and stability analysis of the long and short towers are carried out by using the finite element method simulation software.

6. References

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