Research on Construction Method, Risk Identification and Evaluation Technology of UHV AC Composite Cross Arm Pole and Tower

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Abstract. The research on construction method of UHV AC composite cross arm pole and tower mainly combines the material and structural characteristics of composite cross arm insulator, analyzes the danger sources which may cause damage to construction links such as packaging, transportation, storage, construction hauling, lifting and installation, and then this paper conducts evaluation, and proposes corresponding construction measures, thus forming the construction technical scheme of UHV AC composite cross arm pole and tower. This paper conducts analysis and assessment to the risk (danger source) of damage to composite cross arm insulator during the construction by utilizing the risk evaluation method, and then proposes corresponding construction full-protection measures and counter measures targeting the assessment results.

Key Words: Composite cross arm pole and tower; risk identification; risk grading

1. Introduction

Compared with routine iron tower, the requirements for technical conditions for composite cross arm pole and tower are higher, and it is required to adopt a series of special construction measures in tower assembly construction links such as packaging, transportation, assembly, lifting and installation, thus completing the installation construction of composite cross arm smoothly. In our country, although we have accumulated some experience, the research on existing construction technology of composite cross arm pole and tower, especially that the UHV AC circuit adopts new type of pole and tower construction technology of composite cross arm, is still neither systematic nor complete; in addition, the standard construction technical scheme of new type of composite cross arm insulator hasn’t been formed, and the requirements for promotion and application of composite cross arm of UHV AC circuit cannot be met yet.

The research on construction technology of UHV AC composite cross arm pole and tower mainly combines the material and structural characteristics of composite cross arm insulator, analyzes the danger sources which may cause damage to the construction links such as packaging, transportation, storage, construction and hauling, lifting and installation, and then conducts evaluation. In addition, this paper proposes corresponding construction measures, forms a systematic and complete construction technical scheme of UHV AC composite cross arm pole and tower. On the premise of guaranteeing the construction safety, the scheme can enhance the construction quality and efficiency...
of composite cross arm pole and tower, thus providing technical support for UHV AC circuit adopting composite cross arm pole and tower as well as its promotion and application. [1-5]

2. **Research on Construction Risk Evaluation Technology**

2.1. **Safety Evaluation Technology**

The risk evaluation and risk control technology origins from the 1930s, and it develops along with the development demand of insurance industry of western countries. The insurance companies undertake various risks for customers, so they have to charge fees, and the amount of fees is decided by the risk level which an insurance company undertakes. Therefore, there is a problem about balancing of risk degree, and the process of balancing and determining risk degree is a process of safety assessment, so it is also called “Risk Assessment”.

The safety evaluation and risk control technology was developed greatly in the second half of the 20th century, which benefited from the improvement and development of system safety engineering theory. The system safety theory was firstly applied into the military industry of the USA. In April 1962, the USA issued the first instructions about system safety i.e. System Safety Engineering of Ballistic Missile of Air Force, and it took this as the system safety requirements proposed for contractors related to the minuteman missile plan; and this was the first actual application of system safety theory. In 1969, the United States Department of Defense approved and issued the most typical system safety military standard Key Points of System Safety Outline (MIL-STD-822), which proposed safety requirements, procedures and targets covering the whole life cycle of the system with regard to the targets, plans and manners, including design, measures and assessment, in the aspect of safety of system completion. This Standard was revised into MIL-STD-822A in 1977. In 1984, it was revised into MIL-STD-822B, which generated huge influence on the world engineering safety and fireproof field, and was promoted to the aviation, spaceflight, nuclear industry, petroleum and chemical industry all over the world successively, and after constant development and improvement, a theory and method system of modern system safety engineering was formed. Therefore, it occupies an important position in the current safety science.

At the early stage of the 1980s, the safety system engineering is introduced into our country, and many research units, industrial management departments and some enterprises start research and actual application of safety assessment method. To incorporate the safety assessment work into the legal system and use it better in the actual work, in October 1996, the former Ministry of Labor Forces issued the Decree No. 3 - Rules on Supervision of Labor Safety and Hygiene of Construction Project (Engineering); in May 1999, the former State Economic and Trade Commission issued the Notice about Conducting Qualification Recognition to Labor Safety and Hygiene Pre-assessment Units of Construction Project (Engineering) (Guo Jing Mao An Quan [1999] No. 500); in June 2002, the State Administration of Work Safety (National Coal Mine Safety Administration) issued the Opinions on Enhancing Management of Safety Assessment Mechanism. On November 1, 2002, the Production Safety Law of the People’s Republic of China was issued and implemented, which had a great promotion function to the safety assessment. With the issue of relevant matched regulations such as the Regulations on Safety Management of Dangerous Chemicals (Decree No. 344 of State Council), the safety assessment is implemented gradually. At present, the safety evaluation is expanded to 4 categories, i.e. safety pre-assessment, safety inspection & acceptance assessment, current safety status assessment and specialized safety assessment from original pre-assessment of labour safety and hygiene, covering the full life cycle of the engineering and system, which has obtained preliminary achievements.

The practice proves that the safety evaluation can not only enhance the intrinsic safety degree of enterprise and production equipment, but provide powerful technical support for decision-making, supervision and inspection of Work Safety Production, Supervision and Management Department at each level.
2.2. **LEC Safety Risk Assessment Method**

The LEC assessment method (Graham (Benjamin Graham, 1894-1976) Assessment Method) is a kind of semi-quantitative safety assessment method for danger sources in operation environments with potential dangerousness. It is used to assess the dangerousness and hazard when the operation personnel are operating in an environment with potential danger.

LEC method is a kind of semi-quantitative safety assessment method for danger sources in operation environments with potential dangerousness. This method is used to assess the personal casualty degree by multiplying the three factor index values related to the system risk, and these three factors are: L (possibility of accident occurrence), E (frequency degree of personnel exposed in dangerous environment) and C (consequences in case of occurrence of accident). Determine different scores for different grades of the three factors respectively, and then adopt the D, which is the product of the three scores, to assess the dangerousness of operation conditions, i.e. $D = L \times E \times C$.

Risk value $D = L \times E \times C$. The higher the value of D is, the higher the danger of the system will be, and it is necessary to add safety measures, or change the possibility of accident occurrence, or reduce the frequency degree of human body being exposed in the dangerous environment, or relieve the accident loss, till that the risk value is adjusted into the allowable scope.

It should be noted that the division to danger grade of LEC risk assessment method is to be judged relying on experience to some extent. During the application, it is required to consider the limit, and then conduct correction according to actual situation.

3. **Calculation of Risk Value with LEC Safety Risk Assessment Method**

The risk value adopts LEC method for quantitative calculation, and the inherent risk grade is determined according to the inherent risk value. The risk value $D = L \times E \times C$. See Table 1-Table 4 for the relationship among the value taking of risk factors L, E and C, risk value D and the risk grade:

| Score | Occurrence Possibility                      |
|-------|--------------------------------------------|
| 10    | Continuous                                  |
| 6     | Work hours each day                         |
| 3     | Once each week                              |
| 2     | Once each month                             |
| 1     | Several times each year                     |
| 0.5   | Very rarely                                 |

| Score | Occurrence Possibility                      |
|-------|--------------------------------------------|
| 10    | Unable to be predicted completely           |
| 6     | Quite likely                                |
| 3     | Likely, but not frequent                    |
| 1     | Less likely, completely accidental          |
| 0.5   | Highly unlikely, allowed to assume          |
| 0.2   | Extremely unlikely                          |
| 0.1   | Practically unlikely                        |

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**Table 1. Possibilities of Accident or Risk Event Occurrence (L)**

**Table 2. Frequency Degree of Risk Event Occurrence (E)**
Table 3. Consequences of Risk Event Occurrence (C)

| Score | Consequences of Risk Event Occurrence                  |
|-------|--------------------------------------------------------|
| 100   | Catastrophe, unable to bear the loss                   |
| 40    | Disaster, almost unable to bear the loss               |
| 15    | Extremely severe, extremely major loss                |
| 7     | Severe loss                                            |
| 3     | Major loss                                             |
| 1     | General loss                                           |

Table 4. Table of Relationship between Risk Value D and Risk Grade

| Risk Value D | Risk Degree                                                                 | Risk Grade |
|--------------|------------------------------------------------------------------------------|------------|
| >320         | Extremely high risk. It is required to adopt measures to reduce risk grade, otherwise, the operation cannot be continued. | 5          |
| 160~320      | High risk. It is required to conduct rectification instantly.                | 4          |
| 70~160       | Obvious risk. It is required to conduct rectification.                       | 3          |
| 20~70        | General risk. Please pay attention to this.                                  | 2          |
| <20          | Slight risk, but acceptable.                                                 | 1          |

4. Division of Risk Grade of Construction Safety

The construction safety risk grade of power transmission and transformation engineering is divided into five grades in total:

Grade-I risk (slight risk): it refers to the construction operation that there is relatively low safety risk during the operation process, and if no control is conducted, there may be minor injury or event below this degree;

Grade-II risk (general risk): it refers to the construction operation that there is a certain safety risk during the operation process, and if no control is conducted, there may be minor personal injury accident;

Grade-III risk (obvious risk): it refers to the construction operation that there is relatively high safety risk during the operation process, and if no control is conducted, there may be severe personal injury or death accident, or there may be Grade-VII power grid event;

Grade-IV risk (high risk): it refers to the construction operation that there is very high safety risk during the operation process, and if no control is conducted, there may be personal death accident easily, or there may be Grade-VI power grid event;

Grade-V risk (extremely high risk): it refers to the construction operation that there is extremely high safety risk during the operation process, and if no control is conducted, there may be mass death or casualty accident, or there may be Grade-V power grid event.

5. Dynamic Risk Calculation

Calculation method of dynamic adjustment coefficient

Dynamic risk value D1 = D/k

Dynamic adjustment coefficient k:
In the formula: $N = 4$ (4 dimensions)  
$\text{ai}$ - it corresponds to the weighted value of importance assessment of the dimension $U_i$.  
$\text{bj}$ - it corresponds to the average value of various sub-item risk factors of the dimension $U_i$.  

In the power transmission and transformation engineering, the relative importance of each dimension is considered as per the higher one temporarily, i.e. $\text{ai}=1$, and the dynamic risk adjustment coefficient of the Project adopts the simple assessment method, i.e.:

$$k = \frac{\sum_{i=1}^{4} b_i}{N}$$  

Relationship between actual situation of dimension and risk value taking of risk factor at each dimension.

6. Research on Assessment Technology of Construction Safety and Quality Risk of Composite Cross Arm Pole and Tower

6.1. Packaging Requirements and Risk Analysis

- With regard to the composite insulator, prior to storage of the Using Unit, it is required to inspect and make sure that there is no obvious extrusion or damage trace on the external packaging of composite cross arm part, and the part shall not be stored unless the external packaging is proved to be qualified.
- The composite cross arm part shall be stored in a dry and ventilated warehouse, so as to avoid damage due to external force such as water logging and damage by rats. It is prohibited to put heavy objects or stack sharp objects with corner angles onto the composite cross arm accessories directly, so as to avoid deformation or mechanical damage of umbrella skirt.
- The stacking height of packing object shall meet requirements of the manufacturer, and the number of layers should not exceed 8.
- With regard to outdoor storage, besides meeting above ruled requirements, it is still necessary to adopt rainproof measures.

According to above packaging and storage requirements, analyze main risk sources in the packaging and storage, as shown in Table 5 below:

| No. | Risk Source                  | Risk Factor                   | Possible Risk                | Risk Assessment D | Risk Grade |
|-----|------------------------------|-------------------------------|------------------------------|------------------|------------|
| 1   | External packaging of composite cross arm part | There is packaging damage. | There may be part damage. | 18               | 1          |
| 2   | Storage of composite cross arm part      | The environment is not suitable. | There may be part damage or mildew. | 50               | 2          |
| 3   | Storage of composite cross arm part      | The packing doesn’t meet requirements. | There may be part damage. | 40               | 2          |
| 4   | Outdoor storage of composite cross arm part | No rainproof measure is adopted. | There may be part damage or mildew. | 50               | 2          |
6.2. Transportation Requirements and Risk Analysis
The transportation refers to transporting the composite cross arm part from the storage location to the installation site. Both the transportation and hauling shall be conducted when the package is intact.

- In case of adopting automobile for transportation, the stacking of packaging box (drum) of composite cross arm part shall meet stacking rules. In case of unloading, it is strictly prohibited to conduct dragging or throwing, so as to guarantee that the packaging box (drum) can fall to the ground stably.
- Both transportation and hauling shall be conducted when the packaging box (drum) is intact, so as to prevent the material from being damaged or deformed, especially that the umbrella skirt part shall not be stressed, and it is required to avoid the contact friction with the ground.

According to above transportation requirements, the analysis on main risk sources in the transportation is as shown in Table 6 below:

| No. | Risk Source                           | Risk Factor                                      | Possible Risk                  | Risk Assessment D | Risk Grade |
|-----|--------------------------------------|--------------------------------------------------|--------------------------------|-------------------|------------|
| 1   | Automobile transportation            | Stacking failing to meet requirements            | Part damage                    | 40                | 2          |
| 2   | Automobile transportation            | Vehicle injury and traffic accident              | Personal casualty and property loss | 54                | 2          |
| 3   | Hauling                              | Falling, object crashing, and umbrella skirt wear | Personal injury and part damage | 50                | 2          |
| 4   | Transportation and lifting           | General lifting collision                        | Lifting injury                  | 63                | 2          |
| 5   | Transportation and lifting           | The weight reaches 95% of the rated load of lifting machinery, and the lifting machinery conducts lifting below the power transmission line or in the place relatively close to the charged boy in a special way. | Mechanical injury, lifting injury, and electric shock | 240               | 4          |

6.3. Research on Construction Risk of UHV Composite Cross Arm Pole and Tower
The construction of composite cross arm is mainly divided into ground assembly and lifting. During the construction, there are mainly safety and quality risks, and after sorting its construction flow, the analysis on ground assembly and lifting risk is shown as below:

6.3.1. Analysis on Ground Assembly Risk. The ground assembly should adopt crane, and the crane shall be assembled according to the sequence ruled by the Manufacturer. When the Manufacturer has no rules, it is necessary to assemble the pressure lever on the tower body side, and then assemble it to the side of cross arm head successively; prior to connection of pressure lever, it is required to check the alignment; adopt support to connect two sections of pressure levers which have been assembled
well, and then install the front support; two pieces of pulling rods shall be lifted independently after the cross arm is in place; the shielding ring on both sides of the cross arm head shall be installed at the accessory stage after the stringing is completed. According to above main construction process, the analysis on main risk sources at the ground assembly stage is as shown in Table 7 below:

**Table 7. Table of Analysis and Assessment of Ground Assembly Danger Sources**

| No. | Risk Source                               | Risk Factor                          | Possible Risk     | Risk Assessment D | Risk Grade |
|-----|------------------------------------------|--------------------------------------|-------------------|-------------------|------------|
| 1   | Lifting of crane                         | General lifting collision.            | Lifting injury    | 63                | 2          |
| 2   | Assembly of composite cross arm          | The assembly is not conducted as per ruled sequence. | The assembly cannot be completed or there is member damage. | 40 | 2 |
| 3   |                                          | There is collision between it and the umbrella skirt of silicon rubber | Umbrella skirt damage | 100 | 3 |
| 4   |                                          | The umbrella contacts oily, acidic or alkaline substances. | Umbrella skirt damage | 90 | 3 |
| 5   |                                          | No measure is adopted to isolate it from the ground in case of assembly. | Umbrella skirt damage | 100 | 3 |

6.3.2. Analysis on Lifting Risk. Prior to lifting of composite cross arm, fasten the iron tower body bolt in place (except the part connected with the cross arm) firstly. It would be better to adopt the crane or other routine tower assembly methods for overall lifting. Prior to lifting, it is necessary to design the arrangement of lifting points or adopt auxiliary hanging bracket for lifting firstly; tie two pulling rods on the lifting belt, and it is not necessary to conduct reinforcement; keep two pressure levers at a design included angle at the root for auxiliary support and reinforcement. In addition, conduct lifting point binding according to the position and method ruled in the operation instructions. When the cross arm is 0.5m away from the ground, the lifting shall be paused temporarily, and it is necessary to adjust the pressure lever angle to make it close to the angle after installation. The Field Commander is responsible for inspecting stress situation of each part, and after making sure that there is no error, loosen the control rope slowly, and then continue to lift the cross arm. During the process of cross arm lifting, the Commander shall stand in a safe position in favour of observing cross arm status exactly, pay close attention to the distance away from the tower body, command and coordinate the lifting of cross arm and loosening of control rope, and adopt effective measures to make sure that the cross arm doesn’t collide with the tower body. After the lifting is in place, it is required to install the pressure lever firstly, and finally install the pulling rod.

According to above main construction process, the analysis on main risk sources at the lifting stage is as shown in Table 8:

**Table 8. Table of Analysis and Assessment of Lifting Danger Sources**
| No. | Risk Source | Risk Factor | Possible Risk | Risk Assessment D | Risk Grade |
|-----|-------------|-------------|---------------|-------------------|------------|
| 1   | Lifting of Crane | General lifting collision | Lifting injury | 63 | 2 |
|     |              | The weight reaches 95% of the rated load of lifting machinery, and the lifting machinery conducts lifting below the power transmission line or in the place relatively close to the charged boy in a special way. | Mechanical injury, lifting injury, and electric shock | 240 | 4 |
| 2   | Lifting of Suspending Pole | Temporary grounding | Electric shock | 45 | 2 |
|     |              | Arrangement of pole system | Lifting injury | 90 | 3 |
|     |              | Selection and setting of ground anchor pit | Object striking, lifting injury, and ground anchor pulling | 120 | 3 |
|     |              | Installing pole upright | Machine and tool injury | 45 | 2 |
|     |              | Lifting cross arm | Object striking, and falling from height | 63 | 2 |
|     |              | Enhancing pole | Object striking | 63 | 2 |
|     |              | Removing pole | Object striking | 63 | 2 |
| 3   | Lifting of Powered Winching (Utilizing Ground Wire Support) | Insufficient ground wire support strength | Object striking, and falling from height | 150 | 3 |
| 4   | Quality Risk | Colliding tower body during the lifting process | Cross arm structure and umbrella skirt damage | 120 | 3 |
|     |              | Firm installation of cross arm | Non-uniform fastening, insufficient fastening torque, and non-tight joint of connection surface | 70 | 2 |
|     |              | Pre-arch of cross arm | The pre-arch fails to meet design requirements. | 45 | 2 |

7. Conclusions
The research on construction method of UHV AC composite cross arm pole and tower mainly combines the material and structural characteristics of composite cross arm insulator, analyses the danger sources which may cause damage to construction links such as packaging, transportation, storage, construction hauling, lifting and installation, and then this paper conducts evaluation, and proposes corresponding construction measures, thus forming the construction technical scheme of UHV AC composite cross arm pole and tower. This paper conducts analysis and assessment to the risk (danger source) of damage to composite cross arm insulator during the construction by utilizing the risk evaluation method, and then proposes corresponding construction full-protection measures and counter measures targeting the assessment results.

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