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New Approach to Lightning Strike Risk Assessment of Wind Farm

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Abstract In the past, lightning strike risk assessment of buildings mainly referred to the *Protection against Lightning—Part 2: Risk Management* (IEC 62305-2-2010) based on protection angle method. Lightning strike risk assessment of wind farms was conducted according to the *Lightning Protection for Wind Energy System* (IEC 61400-24-2019), which proposed the method of lightning strike risk assessment for wind turbine. In fact, the basic idea of the two is the same, that is, the source of the lightning strike wind turbine is transformed from the former $S1-S4$ to the latter N_D-N_{DJ}. According to the above method, wind farm was evaluated, and it has been proved that the practice can not achieve good results. After 2018, China has issued the *Guide to Evaluation of Lightning Protection Technology in Buildings* (T/GZLY 3-2022) and the *Technical Specifications for Lightning Interception in Forest Areas* (T/LYCY 4062-2024) based on semicircle protection, in which the source of risk defined by lightning point was closer to the reality, highly targeted and effective. Taking offshore wind farm as an example, this paper introduced a new method of establishing six evaluation indicators to determine the risk level according to the principle of compliance and the new protection technology of semi-circular method, which can be used as a reference for technical personnel.

Key words Lightning strike risk assessment; New protection technology of semi-circular method; Basic principle; New evaluation method

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The implementation of lightning risk assessment for buildings in China began with the *Protection against Lightning—Part 2: Risk Management* (GB/T 21714.2-2008/IEC 62305-2: 2006)[1]. In 2019, the International Electrotechnical Commission issued the *Lightning Protection for Wind Energy System* (IEC 61400-24-2019), proposing a method for assessing the risk of lightning strikes on wind turbines[2]. In fact, the basic idea of the two is consistent, that is, the source of the lightning strike wind turbine is transformed from the former $S1-S4$ to the latter N_D-N_{DJ}.

In 2018, Yang Hui *et al.* proposed a new concept of regional lightning protection and the semi-circular method[3]. The protection angle method is current lightning protection design, and it protects the individual building itself and has no protective effect on the surrounding buildings. In regional lightning protection, after installing lightning arrester in the upwind direction of the protected area to effectively intercept lightning strikes, the probability of direct lightning strikes occurring in the building complex within the protected area is greatly reduced, and it protects an area[4]. Regional lightning protection and semi-circular protection were first applied to 33 wind turbines in Dianbai Wind Farm. Before June 2019, the lightning protection design adopted the protection angle method[5], and 16 wind turbines have been damaged by lightning strikes. Since June 2019, it has withstood multiple typhoons, squall lines, and other severe lightning strikes, achieving zero lightning damage to wind turbines[6].

Practice has proven that the lightning risk assessment method based on the protection angle method is not suitable for guiding effective lightning protection in wind farms. In 2022, China issued the *Guide to Evaluation of Lightning Protection Technology in Buildings* (T/GZLY 3-2022) and the *Technical Specifications for Lightning Interception in Forest Areas* (T/LYCY 4062-2024)[8] based on regional lightning protection and semi-circular protection[7]. The source of risk was defined based on lightning strike points, which was more closely to reality and had strong pertinence and significant effects.

In this paper, Sichuan Xiaogaoshan Wind Farm was taken as the research object. The evaluation method of six compliance indicators was established based on the compliance principle and the semi-circular protection new technology, which can be used as a reference for technical personnel.

1 Basis for evaluation

1.1 Entrusting unit Sichuan Yanyuan Huadian New Energy Co., Ltd.

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1.2 Technical standards They were arranged in chronological order of issuance according to applicable and latest principles: ① Design Code for Protection of Structures against Lightning (GB 50057 – 2010); ② *Protection against Lightning—Part 2: Risk Management* (IEC 62305 – 2 – 2010); ③ *Low-voltage Surge Protective Devices (SPD)—Part 11: Surge Protective Devices Connected to Low-voltage Power Systems – Requirement and Test Methods* (IEC 61643 – 11/2011); ④ *Lightning Protection: Launch Lightning Protection System in Advance* (NFC 17 – 102 /2011 0917); ⑤ *Multi-pulse Surge Protection Devices Connected to Low-voltage Power Systems—Additional Requirements and Test Methods* (IEC 61643 – 11/2PFG – 2017); ⑥ *Lightning Protection for Wind Energy System* (IEC 61400 – 2019); ⑦*Code for Design Protection of Petrochemical Plant against Lightning* (GB 50650 – 2011) (2022 version); ⑧ *Code for Design of Wind Power Projects* (NB/T 31026 – 2022); ⑨ *Surge Protective Devices Connected to Low-voltage Power Distribution Systems—Performance Requirements and Testing Methods* (T/ASC 6004 – 2022); ⑩ *Guide to Evaluation of Lightning Protection Technology in Buildings* (T/GZLY 3 – 2022); ⑪ *General Guidelines for Lightning Multi-pulse Test* (T/CMSA 0045 – 2023); ⑫ *Technical Specifications for Lightning Interception in Forest Areas* (T/LYCY 4062 – 2024).

1.3 Laws and regulations They were arranged in order of laws, regulations, and rules according to applicable and latest principles: ① *Meteorological Law of the People's Republic of China*; ② *Law of the People's Republic of China on Product Quality*; ③ *Detailed Rules for the Implementation of the Patent Law of the People's Republic of China*; ④ *Implementation Regulations of the Tendering and Bidding Law of the People's Republic of China*; ⑤ Order No. 24 of the China Meteorological Administration *Management Measures for Lightning Protection and Disaster Reduction*; ⑥ Order No. 284 of the People's Government of Guangdong Province *Regulations on the Management of Lightning Disaster Defense in Guangdong Province*; ⑦ Order [2019] No. 1 of the National Standardization Management Committee, Ministry of Civil Affairs *Group Standard Management Measures*; ⑧Order No. 59 of the State Administration for Market Regulation *National Standard Management Measures*; ⑨ Order [2022] No. 6 of the National Standardization Management Committee (17 departments) National Standard Committee Joint *Opinions on Promoting the High-quality Development of Group Standards and Norms*.

2 Risk assessment of lightning protection status

2.1 Object name Sichuan Xiaogaoshan Wind Farm.

2.2 Geographical environment The site of Sichuan Xiaogaoshan Wind Farm project is located in the ridge area at the border of Dahe Township and Pingchuan Town in Yanyuan County, Liangshan Prefecture, Sichuan Province. Its geographical coordinate is 27°30′00″ – 27°39′00″ N, 101°39′00″ – 101°45′00″ E. The site is a mountain ridge that runs approximately northeast-southwest, with a length of about 19 km. The north and south ends of the ridge are relatively flat, mainly consisting of high platforms, while the middle part is steep, and the ridge is narrow. The terrain is generally continuous, with significant elevation changes in some areas. The southern part has a lower elevation, while the northern part has a relatively higher elevation, ranging from 3 150 to 3 840 m (unless otherwise specified, the elevation is based on the 1985 national elevation system). The site covers an area of about 52 km^2.

2.3 Scale of wind farm The total planned capacity of the project is 150 MW, and it is proposed to install 75 wind turbines with a single capacity of 2 000 kW. A new 220 kV of booster station will be built near the Xiaogaoshan Wind Farm, with a scale of 75 + 80 MVA. The 35 kV of collection line will collect all the electricity from the wind farm and send it to the 220 kV of booster station. The booster station is connected to the planned 500 kV of Yanyuan Station via a 220 kV of transmission line, with a length of approximately 15 km. Layout of wind turbines in the wind farm is shown as Fig. 1.

2.4 Lightning strike path EN – WS, SW – NE, and NW – SE (Fig. 2).

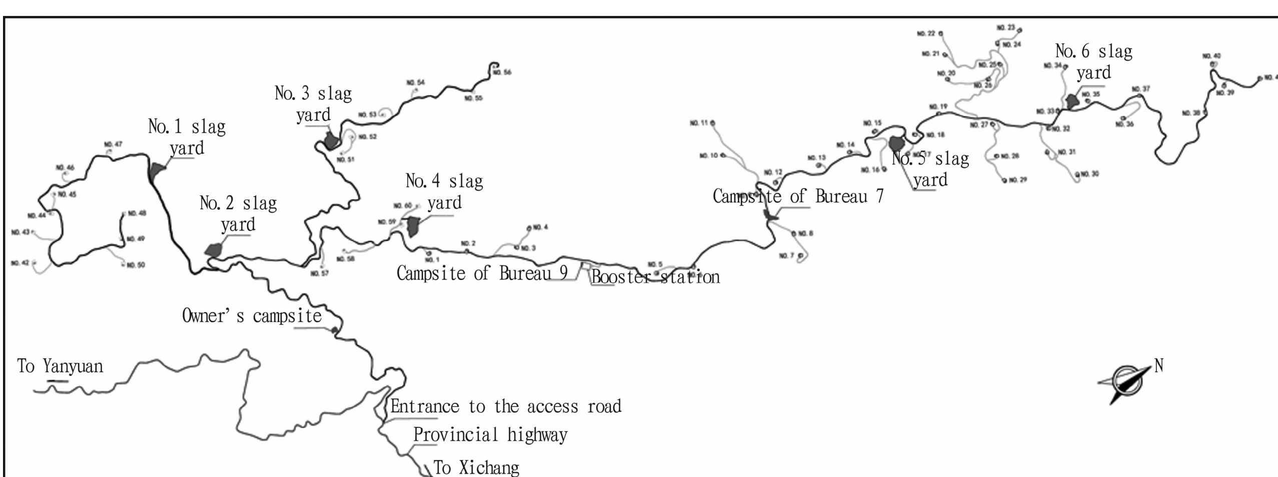

Fig. 1 Layout of wind turbines in the wind farm

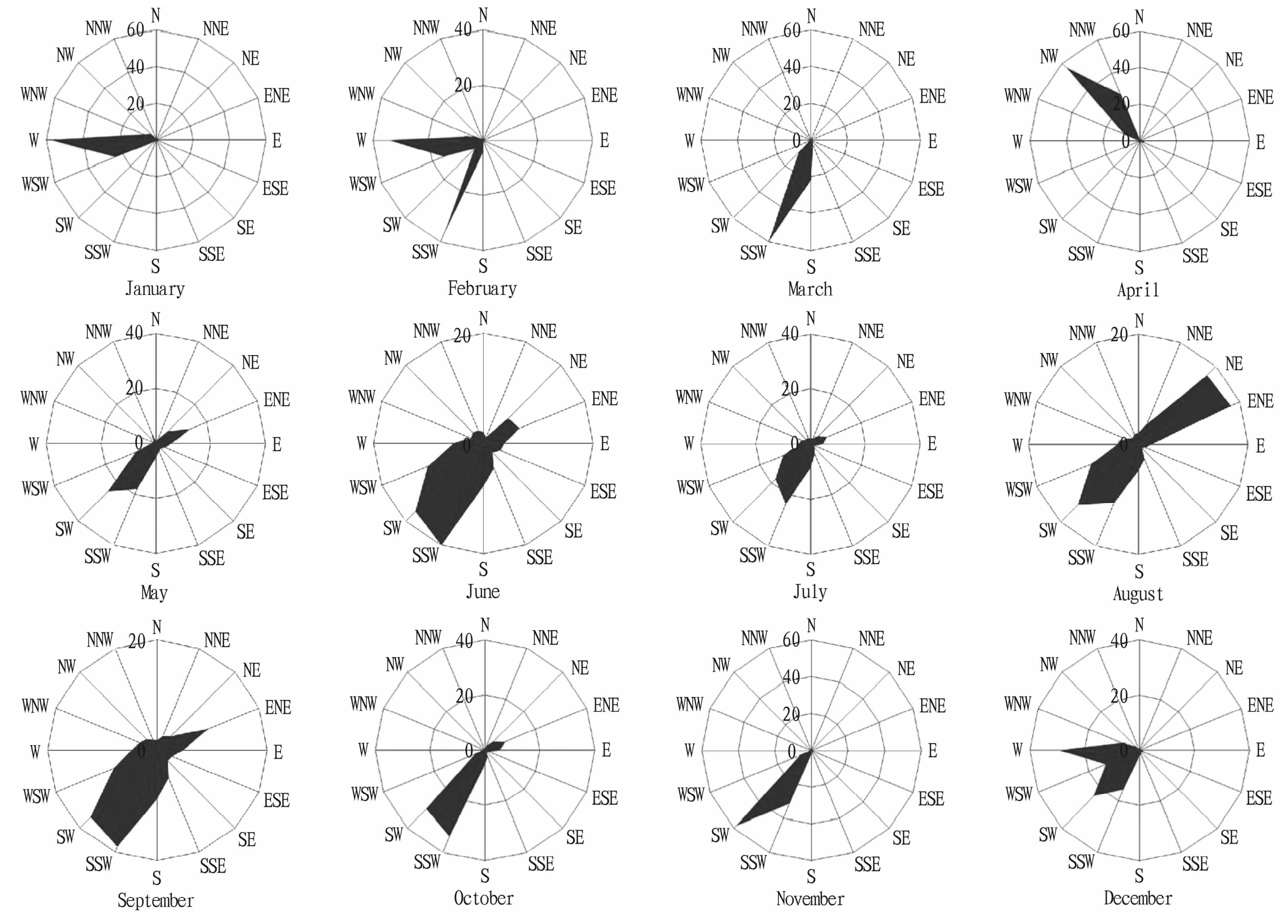

Fig. 2 Monthly wind direction rose chart of the wind farm

2.5 Lightning protection design basis On-site inspection of design documents: ① Design Code for Protection of Structures against Lightning (GB 50057 – 2010); ② *Low-voltage Surge Protective Devices—Part 11: Surge Protective Devices Connected to Low-voltage Power Systems: Requirements and Test Methods* (IEC 61643 – 11/2011); ③ *Lightning Protection: Pre-corona Lightning Protection System* (NFC 17 – 102 /2011 0917); ④ *Multi-pulse Surge Protection Devices Connected to Low-voltage Power Systems – Additional Requirements and Test Methods* (IEC 61643 – 11/2PFG – 2017); ⑤ *Code for Design of Wind Power Projects* (NB/T 31026 – 2022); ⑥ *Surge Protective Devices Connected to Low-voltage Power Distribution Systems – Performance Requirements and Testing Methods* (T/ASC 6004 – 2022); ⑦ *Guide to Evaluation of Lightning Protection Technology in Buildings* (T/GZLY 3 – 2022); ⑧ *General Guidelines for Lightning Multi-pulse Test* (T/CMSA 0045 – 2023); ⑨ *Technical Specifications for Lightning Interception in Forest Areas* (T/LYCY 4062 – 2024).

The design bases should comply with the provisions and technical specifications of order No. 59 of the State Administration for Market Regulation *National Standard Management Measures*, and order [2019] No. 1 of the National Standardization Management Committee, Ministry of Civil Affairs *Group Standard Management Measures*.

2.6 Lightning protection measures Direct lightning protection: regional lightning protection technology, using lightning interceptor JD-MS-T45-1[9]. Protection method: semicircle method. Strong electromagnetic pulse protection of lightning: using multi-pulse surge protector 690V/MSPD[10-11]. Grounding: utilizing the existing grounding system.

2.7 Assessment

2.7.1 Product compliance (law). It has provided the test reports of the national third-party lightning product inspection agency for the lightning interceptor JD-MS-T-45-1 and the multi-pulse surge protector 690V/MSPD, which complied with the provisions of the *Law of the People's Republic of China on Product Quality*. Inspection agencies: Beijing Lightning Protection Facility Testing Service Center, Rheinland Testing and Certification Services (China) Co., Ltd.

2.7.2 Compliance of protection methods (technology). The direct lightning protection adopted the new theory of regional lightning protection and the semicircular method, which complied with the technical specifications of the *Guide to Evaluation of Lightning Protection Technology in Buildings* (T/GZLY 3 – 2022) and the *Technical Specifications for Lightning Interception in Forest Areas* (T/LYCY 4062 – 2024).

The strong electromagnetic pulse protection method of lightning complied with the provisions of *General Guidelines for Lightning Multi-pulse Test* (T/CMSA 0045 – 2023), the *Multi-pulse Surge Protection Devices Connected to Low-voltage Power Systems—Additional Requirements and Test Methods* (IEC 61643 – 11/2PFG

-2017), the *Surge Protective Devices Connected to Low-voltage Power Distribution Systems—Performance Requirements and Testing Methods* (T/ASC 6004 -2022), and the *Low-voltage Surge Protective Devices (SPD)—Part 11: Surge Protective Devices Connected to Low-voltage Power Systems—Requirement and Test Methods* (IEC 61643 -11/2011).

2.7.3 Product innovation.

(1) Lightning interceptor. A lightning interception device, utility model patent, patent No.: ZL 202220903776.4 (China National Intellectual Property Administration).

(2) Multi-pulse surge protector. A special multi-pulse surge protection circuit and surge protector for box type substation, patent No.: ZL 202221185008.6 (China National Intellectual Property Administration).

2.7.4 Technological innovation. According to data comparison, the regional lightning protection technology adopted by Xiaogaoshan Wind Farm is the promotion and application of the regional lightning protection project experience of the Dianbai Wind Farm (Liangfengao Wind Farm). The patent application number for regional lightning protection technology is 202310518182.0.

2.8 Lightning damage (protective effect)

2.8.1 Before project implementation. Multiple flashover traces were found at the metal reinforcement bars of the fiber optic ring network communication system, and the original single pulse surge protectors at the tower bases of multiple wind turbines experienced faults such as tripping and damage.

2.8.2 After project implementation. From the completion of the project in April 2024 to October 2024, the wind farm equipment has undergone a complete thunderstorm period inspection and operated safely, achieving zero lightning damage in the first year.

2.9 Risk level

2.9.1 Principle of division. In Section 6.1 of the *Guide to Evaluation of Lightning Protection Technology in Buildings* (T/GZLY 3 -2022), the risk of lightning strikes is divided into four levels: high, medium, low, and zero risk; In Chapter 7 of the *Technical Specifications for Lightning Interception in Forest Areas* (T/LYCY 4062 -2024), the risk of lightning strikes is divided into three levels: high, medium, and low. Based on the above standards and combined with the actual situation of the wind farm, the comprehensive evaluation of six indicators including design basis compliance, product compliance, protection method compliance, product innovation, technological innovation, and lightning damage (protection effectiveness), the risk of lightning strikes is divided into three levels: high, medium, and low.

2.9.2 Risk level.

(1) Low risk: the design basis, product, and protection method are compliant, and product innovation, technological innovation, and lightning damage are zero or minor, with significant protective effects.

(2) Medium risk: there is a non-compliance in the design basis, product, and protection method, and lightning damage occasionally occurs.

(3) High risk: design basis, product, and protection method are not compliant, and serious lightning damage has occurred.

2.9.3 Conclusion of lightning risk assessment for Xiaogaoshan Wind Farm. Low risk[12].

2.10 Problems

2.10.1 No specific measures to consolidate the application effectiveness of regional lightning protection. In general, after the project is completed, adding or changing equipment, cable layout, grounding down conductors, *etc.* inside the wind turbine will change the electromagnetic field environment of the wind farm and wind turbine, and the lightning protection effect of the original design. Therefore, a communication mechanism should be established with the project implementation party (party B) to ensure the lightning safety of the wind turbine and the equipment inside the wind turbine.

Regional lightning protection technology, lightning interceptors, and multi-pulse surge protectors (MSPD) are all patented technologies[13-15]. According to relevant regulations, lightning protection devices need to be tested and operated annually. There is no long-term operation and maintenance agreement between Xiaogaoshan Wind Farm and party B (or patent authorized unit[16]).

2.10.2 Retaining the lightning rod of the meteorological mast. The lightning rod is a lightning triggering device that does not attenuate the lightning current[17]. Whether it constitutes an impact on the lightning interception effect needs further observation and research.

3 Conclusions

3.1 Mastering national laws, regulations, and technical standards being the foundation for conducting lightning risk assessment of wind farms It must be based on relevant national laws, regulations, and technical standards when conducting lightning risk assessment for wind farms. The case listed 9 laws, regulations, and 12 technical standards that must be implemented. One of the similar technical standards can be selected to be included in the evaluation criteria. For example, the buildings lightning protection of wind farm only listed the *Design Code for Protection of Structures against Lightning* (GB 50057 -2010). The risk assessment of lightning strikes in wind farms involves the theoretical basis and methods of lightning protection. Therefore, four standards were listed, including the *Protection against Lightning—Part 2: Risk Management* (IEC 62305 -2:2010) and the *Guide to Evaluation of Lightning Protection Technology in Buildings* (T/GZLY 3 -2022).

It is very important to study and understand laws, regulations, and technical standards seriously. As required by the *Law of the People's Republic of China on Product Quality*, products must be inspected and qualified by a national third-party inspection agency. In the evaluation, the client should be required to submit a product inspection report. In direct lightning protection, the installation of lightning rods is considered to comply with the requirements of the *Design Code for Protection of Structures against Lightning* (GB 50057 -2010), which has strict requirements for the use of lightning rods[18]. Obviously, it is the foundation for conducting lightning risk assessment of wind farms by mastering national laws, regulations, and technical standards.

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erally advocate the concept of addressing global climate change, while measures driven by carbon finance often focus on "hardware" low-carbon improvements, neglecting the carbon sink functionnecessary to further strengthen data resource sharing, improve ecosystem carbon measurement methods and means, strengthen ecosystem positioning observation and environmental monitoring, and improve the predictive warning and emergency response capabilities in response to climate change. It should regularly evaluate the role of ecosystem activities such as forest vegetation, wetlands, and soil in reducing emissions and increasing carbon sinks, effectively manage ecosystem carbon sinks, and better leverage the role of wetlands in achieving carbon peak goals and carbon neutrality visions.

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3.2 A new method for lightning risk assessment of wind farms being an exploration The comprehensive evaluation of lightning protection status in wind farms based on six indicators (referred to as three regulations, two new, and one effect) including design basis compliance, product compliance, protection method compliance, product innovation, technological innovation, and lightning damage (protection effectiveness), and dividing it into high, medium, and low risk levels, is a new method and exploration.

Unlike the lightning risk assessment method based on the protection angle method, the lightning risk assessment method based on regional lightning protection and semicircular protection defines the sources of risk as direct lightning strike S1, side lightning strike S2, adjacent lightning strike S3, lightning electromagnetic pulse S4, and ground potential counterattack S5 based on the lightning strike point, with high pertinence. It has achieved significant results in application of wind farms[19-20].

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