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Research and Analysis on Anti-corrosion of Mountain Photovoltaic Brackets

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Abstract With the increasing global demand for renewable energy, solar photovoltaic power generation technology has been widely applied in China and even globally. Especially in mountainous areas, complex terrain resources are cleverly utilized in the construction of photovoltaic power stations, but this also brings severe challenges to the anti-corrosion of photovoltaic brackets. This paper focuses on the anti-corrosion technology of mountain photovoltaic brackets, and deeply explores the influence of natural factors such as mountain climate, sandstorms, and precipitation on the corrosion of photovoltaic brackets. The research results show that the key to improving anti-corrosion performance lies in the selection of bracket materials and optimization of coating processes. After comparing various anti-corrosion treatment methods such as hot-dip galvanizing, spray aluminum coating, and new anti-corrosion materials, it is found that nano coating technology exhibits excellent protective effects in corrosive environments. This study is of great significance for promoting the sustainable development of photovoltaic power generation, providing solid theoretical support and practical guidance for the anti-corrosion design of mountain photovoltaic power stations.

Key words Mountain photovoltaic, Bracket, Corrosion, Nano coating

1 Introduction

Against the macro background of accelerating global energy structure transformation and environmental protection becoming a global consensus, solar photovoltaic power generation technology, with its significant advantages of cleanliness, emission free, and renewability, is gradually becoming a key driving force for the development of renewable energy[1]. Especially in China, since the implementation of the "13th Five-year Plan", the installed capacity of photovoltaic power generation has achieved a leapfrog growth, with the construction of mountainous photovoltaic power stations in the northwest and southwest regions being the most significant. The unique geographical features of these regions, such as complex terrain conditions and relatively low land use rates, provide a unique advantage for the deployment of photovoltaic power plants[2]. However, the complexity and variability of mountainous environments also pose a serious challenge to the durability of photovoltaic brackets, among which the anti-corrosion problem of brackets is a key technical problem that urgently needs to be solved. The research on anti-corrosion technology for photovoltaic brackets has made significant progress worldwide, mainly focusing on innovation of anti-corrosion materials, optimization of anti-corrosion coatings, and environmental adaptability assessment. Developed countries in Europe and America such as Germany and the United States have demonstrated a high level of technological maturity in this field, widely adopting advanced anti-corrosion technologies such as hot-dip galvanizing, aluminum spray coating, and multi-layer composite coating, and accumulating rich application experience in long-term engineering practice[3]. Especially in Germany, the research and development of anti-corrosion technology for photovoltaic brackets place more emphasis on the comprehensive performance of materials and their compatibility with the environment. Through diversified coating strategies, the service life of the brackets has been effectively extended. With the increasing emphasis on new energy technologies in China, the research and development of anti-corrosion technology for photovoltaic brackets has also entered the fast lane. Universities and research institutions represented by the Chinese Academy of Sciences and Tsinghua University have made breakthroughs in the development of new anti-corrosion materials and in the innovation of coating technology. For example, a research team from Tsinghua University has successfully introduced nano coating technology on the basis of traditional hot-dip galvanizing, significantly improving the corrosion resistance of the bracket in acidic environments, with an increase of over 30%. However, it is worth noting that current research mostly focuses on plain or relatively mild environmental conditions, and there is still a lack of research and development on anti-corrosion technology for the special application scenario of mountain photovoltaic power stations, resulting in a research gap. Given this, exploring and developing efficient, economical, and environmentally friendly anti-corrosion technologies in response to the complex and ever-changing environmental characteristics of mountain photovoltaic power stations is not only crucial for improving the overall performance of the photovoltaic system, but also a key link in extending the service life of photovoltaic power stations and promoting the sustainable development of renewable energy sources. Therefore, it has important academic value and broad socio-economic significance by strengthening the research and appli-

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cation of anti-corrosion technology for mountain photovoltaic brackets.

2 Influence of mountainous environment on the corrosion of photovoltaic brackets

The corrosion process of mountain photovoltaic brackets is significantly affected by factors such as high humidity, large temperature differences, high wind speed, and strong ultraviolet radiation in mountainous areas. Moreover, the corrosion process of photovoltaic brackets is further accelerated due to the interaction of these climatic factors.

The humidity changes in mountainous climate are more significant. Mountainous areas are often affected by clouds, mist, and precipitation, resulting in high humidity and a significant increase in water content in the air, especially during the rainy and snowy season. Metal surfaces are prone to form water films in high humidity environments, providing the necessary electrolyte environment of electrochemical corrosion for accelerating the corrosion process. Precipitation also has different effects on the corrosion of photovoltaic brackets. There are various types of precipitation in mountainous climates, including rain, snow, frost, *etc.* Rainwater may contain acidic substances, especially in areas with heavy industrial pollution. Acid rain can exacerbate the corrosion of metals, which is an acidic substance. The melting process of snow and frost will form salt deposits on the metal surface, which further promotes corrosion reactions.

The temperature difference between day and night in mountainous climate is significant. Due to the difference in altitude, there is a large temperature difference between day and night in mountainous areas. The thermal expansion and contraction speed of metal materials will accelerate due to frequent temperature fluctuations, resulting in the formation of small cracks on the surface of the material, which provide channels for the invasion of corrosive media. The cracks generated on the surface of these materials will gradually expand under long-term stress, leading to a decrease in the mechanical properties of the materials and accelerating the corrosion process[4-5].

The intensity of ultraviolet radiation in mountainous areas is relatively high. Long-term exposure to strong ultraviolet radiation can cause material to undergo photoaging. Photoaging can cause small cracks and peeling on the surface of materials, which facilitates the infiltration of corrosive media. Especially for some polymer materials with weak UV resistance, such as glass fiber reinforced plastics, they are prone to degradation under strong UV irradiation, resulting in a decrease in their corrosion resistance.

Another important characteristic of mountainous climate is high wind speed. Usually, the wind speed in mountainous areas is relatively high, and the dust and salt in the air will accelerate the wear and corrosion of the surface of the photovoltaic bracket under the action of high wind speed. Wind power can also affect the form and distribution of precipitation, making it easier for corrosive media to adhere to photovoltaic brackets.

In addition, the combined effect of light and humidity will further intensify the corrosion of photovoltaic brackets, resulting in a synergistic effect. During the day, strong light exposure increases the surface temperature of the bracket, accelerating the evaporation of moisture. At night, the temperature drops, the humidity rises, and the metal surface condenses moisture again. The alternation of day and night in this environment causes the metal surface to repeatedly undergo dry-wet cycle, resulting in a significant increase in corrosion rate[6].

3 Improvement of anti-corrosion technology for mountainous photovoltaic brackets

3.1 Application effect of different anti-corrosion technologies in mountain photovoltaic brackets At present, the commonly used anti-corrosion technologies for mountain photovoltaic brackets include hot-dip galvanizing, electro galvanizing, coating spray, and the application of new anti-corrosion materials. The application effects of different anti-corrosion technologies on mountain photovoltaic brackets vary, and ensuring the long-term stable operation of photovoltaic brackets requires comprehensive consideration of environmental conditions, economic costs, and maintenance needs.

The hot-dip galvanizing process is currently the most widely used anti-corrosion method. The thickness of hot-dip galvanized layer is usually between 50 and 100 μm. According to the research of Li Ming *et al.*, its corrosion rate can be reduced to 0.5-1.5 μm/yr, and its service life can reach more than 30 yr. It is a commonly used choice for mountain photovoltaic brackets. Its main advantages are uniform coating thickness, strong adhesion, and the ability to provide long-term anti-corrosion protection in harsh mountainous environments. However, the hot-dip galvanizing process is complex and costly. In order to ensure the quality of the coating during the construction process, temperature and time need to be strictly controlled.

Anti-corrosion coating spray is a highly flexible anti-corrosion technology, such as epoxy resin coating and polyurethane coating[7]. These coatings have good weather and corrosion resistance. Research has shown that the anti-corrosion life of sprayed epoxy resin coatings can reach over 20 yr, and the corrosion rate can be reduced to 0.2 μm/yr. By spraying different types of anti-corrosion coatings, multi-layer protection of photovoltaic brackets can be achieved. The advantage of spraying technology is that it is easy to construct and suitable for various complex shaped brackets. However, the durability of spray coatings is relatively poor, and they are susceptible to mechanical damage and UV radiation, requiring regular maintenance and repair.

Electrogalvanizing technology is a relatively economical anti-corrosion method suitable for large-scale production. Its coating is relatively thin, but uniformity is good, which can provide some degree of anti-corrosion protection. However, the corrosion resistance of electrogalvanizing is not as good as hot-dip galvanizing, especially in acidic or alkaline environments, where coating peeling and corrosion are prone to occur. Although electrogalvanizing has a lower cost, its protective effect is relatively weak, and it is usually used in lower corrosive environments. For complex climate conditions in mountainous areas, the effect may not be as effective as hot-dip galvanizing.

In addition, the application of new anti-corrosion materials, such as nano coatings and polymer anti-corrosion materials, is gradually receiving attention. These materials have excellent corrosion resistance and mechanical strength, providing long-term protection in extreme environments[8].

3.2 Application of environmentally friendly coating technology The application of environmentally friendly coating technology is of great significance to the improvement of anti-corrosion technology for mountain photovoltaic brackets. Traditional anti-corrosion coatings often contain a large amount of harmful chemicals, which not only pollute the environment but may also have adverse effects on the health of construction workers[9].

Nanotechnology enhances the density and adhesion of coatings, improving their anti-corrosion performance[10]. Through the study of the combination of nano alumina and epoxy resin, Li Hua *et al*. found that their salt spray resistance test time can reach over 3 000 h. When using low volatile organic compound (VOC) or VOC free coatings, pollution to the atmospheric environment can be reduced. This coating, which meets modern environmental requirements, releases very little harmful gas during the construction process. For example, as an environmentally friendly coating, water-based paint has been widely used in various anti-corrosion projects because water-based paint uses water as a solvent and has extremely low volatile organic compound content.

Environmental protection coating technology also emphasizes the renewability and degradability of materials. Coatings made from natural materials or renewable resources not only reduce the burden on the environment during production, but also naturally degrade after the end of their service life, avoiding the occurrence of secondary pollution. For example, coating materials based on vegetable oil have good anti-corrosion properties and can degrade in natural environments, making them an ideal environmentally friendly coating choice.

The application of nanotechnology also provides new directions for the development of environmentally friendly coatings[11]. Nano coatings have excellent anti-corrosion performance and durability. Due to their special physical and chemical properties, they can reduce coating thickness, lower material consumption, and further reduce their impact on the environment. For example, nano zinc oxide coating not only has good anti-corrosion effect, but also effectively blocks ultraviolet rays, providing dual protection for photovoltaic brackets.

The application of environmentally friendly coating technology in the anti-corrosion of mountain photovoltaic brackets can not only effectively extend the service life of the brackets, but also reduce environmental pollution, which is in line with the concept of sustainable development. Therefore, promoting and applying environmentally friendly coating technology is an important direction for improving the anti-corrosion technology of mountain photovoltaic brackets in the future.

3.3 Improving the anti-corrosion performance of materials Optimizing the anti-corrosion performance of materials is one of the key measures to improve the durability of mountain photovoltaic brackets when improving their anti-corrosion technology. Due to the special nature of mountainous environments, such as high humidity, large temperature differences, and strong ultraviolet radiation, photovoltaic bracket materials are prone to corrosion, which affects their lifespan and safety.

Firstly, it should choose alloy materials with high corrosion resistance. Aluminum has good corrosion resistance, especially when an aluminum oxide film is formed on its surface. The study also found that the corrosion rate of a certain high-strength aluminum alloy in salt spray testing is extremely low as 0.05 m/yr. Aluminum alloy and stainless steel materials have good corrosion resistance and can be used for a long time in harsh environments. Especially on the surface of aluminum alloy, a dense oxide film can be formed, which plays a good role in anti-corrosion protection. In addition, the chromium element in stainless steel materials can also form a passivation film on its surface, effectively preventing the invasion of corrosive media[12-14].

Secondly, the application of surface treatment technology is also an important means to improve the anti-corrosion performance of materials. Common surface treatment methods include hot-dip galvanizing, electroplating, spraying, and anodizing[15]. Hot-dip galvanizing is a commonly used anti-corrosion treatment method, which forms a protective layer on the surface of steel by coating it with a layer of zinc to prevent oxidation and corrosion. Electroplating technology can form a uniform metal coating on the surface of materials, improving their corrosion resistance. Spraying technology involves spraying anti-corrosion coatings on the surface of materials to form a physical barrier that blocks the invasion of corrosive media. Anodizing treatment is mainly used for aluminum alloy materials, forming an oxide film on their surface through electrochemical reactions to enhance their corrosion resistance[16].

Thirdly, the application of nanomaterials and intelligent anti-corrosion coatings also provides new ideas for the anti-corrosion of photovoltaic brackets. Nanomaterials, due to their unique physical and chemical properties, can significantly improve the anti-corrosion performance of materials. For example, materials such as nano zinc oxide and nano titanium dioxide can be used as additives to enhance the performance of anti-corrosion coatings[17]. Intelligent anti-corrosion coatings can automatically adjust their anti-corrosion performance according to environmental changes, providing more durable protection.

4 Conclusions and prospects

Due to the complexity and specificity of mountainous environments, the design of mountainous photovoltaic brackets should comprehensively consider corrosion resistance, wind pressure resistance, and ease of maintenance, to improve their service life and stability in complex environments. Different anti-corrosion technologies have their own advantages in materials, structures, and functions, which need to be selected according to specific application environments and needs. By selecting materials reasonably and optimizing structural design, the corrosion problem of mountain photovoltaic brackets can be effectively solved, and various challenges in complex mountain environments can be addressed, thereby achieving efficient operation and long-term stability of mountain photovoltaic systems. In the future, research on mountain photovoltaic brackets should further explore environmentally friendly, low-cost, and efficient anti-corrosion technologies, and promote the sustainable development of the photovoltaic industry combined with the development and application of new materials.

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for the government and scientific research institutes to promote the construction and operation and maintenance management of pilot base in chemical parks. Firstly, it is necessary for government departments to provide a good ecological environment for scientific and technological innovation, simplify the approval process of pilot projects, and accelerate the industrialization process of pilot projects. Secondly, it is necessary to innovate in the pilot project pilot mode, industrialization cooperation model, innovation system, *etc.*, from the mode of relying on government subsidies to maintain the normal operation and maintenance management of pilot base, to the blood making by pilot base itself, truly give full play to the scientific and technological innovation value of pilot project, and promote the transformation and upgrading of the national and local chemical industry.

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