Application of distributed solar photovoltaic power generation in highway field

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Abstract. Natural resources are the most critical material basis for national economic and social development, and the key guarantee for improving national viability. With the development of national economy and the progress of society, people's awareness of the importance of resources is also growing, and the issue of resources has begun to become an important topic of common concern for governments around the world. At a time when non-renewable resources such as coal and natural gas are in urgent need, and energy shortage has gradually become a problem endangering global economic development, more and more countries have begun to actively implement the "sunshine plan", that is, to develop and utilize sunlight resources to find new impetus for economic and social development. Solar energy resource is a very important resource, which is inexhaustible, non-polluting, and relatively cheap and can be used at will. Vigorously developing and using solar energy is the most effective way to solve the shortage of resources and achieve sustainable economic development. Therefore, the application in the highway field is very necessary to promote the construction of distributed photovoltaic power generation system.

1. Introduction

With the rapid development of China's road construction, the transportation department has also put forward new requirements for the construction of highways under the condition of continuous progress. China's highway engineering is undergoing a major change, especially after the upgrading of the road service equipment, the service facilities of the highway have also been further expanded and improved, making the daily traffic flow continuously increasing. In order to solve the problem of increasing electricity consumption in China's road construction and reasonably improve the utilization rate of land resources, the promotion and application of solar photovoltaic power generation system in the field of China's roads is not only a long-term strategic significance of ensuring land energy supply and improving the quality of ecological environment, but also a practical economic significance of saving resources and reducing energy costs.

In recent years, scholars have conducted extensive research on distributed solar photovoltaic power generation, among which Lei Shihuan [1], Qi Jianyong [2] and Zhou Tongwen [3] and others have put forward the scheme of applying distributed solar photovoltaic power generation in the expressway service area. These scholars introduced the principle and system structure of the technology in detail, and analyzed the reasons for the application of solar photovoltaic power stations in the expressway service area and the potential advantages of the technology. For the relevant units to save the cost, save natural resources, reduce waste emissions and other aspects, distributed solar photovoltaic power station has more obvious advantages, so the application prospect in the service area is broad.

In order to further explore the practical application of this technology in the service area, the scholars have carried out a detailed discussion combined with the actual cases, in order to promote the efficient utilization and sustainable development of energy in China.

2. Introduction to photovoltaic power generation system

2.1. Principle

The power generation system of photovoltaic technology refers to the power generation system that uses solar cell modules to directly convert sunlight into energy. The main components are solar cells, power storage batteries, controllers, and inverters. Photovoltaic power generation system is an internationally recognized and respected green power generation method, which has the

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advantages of saving energy and reducing environmental pollution.

After decades of development, photovoltaic power generation technology has been mature, safe and applicable. The service life of photovoltaic power generation system is usually about 25 years.

2.2. Classification

Solar photovoltaic power generation system can generally be divided into independent photovoltaic control system and grid-connected photovoltaic control system. (1) Independent photovoltaic power generation: also known as off-grid photovoltaic power generation, which is generally, composed of photovoltaic elements, handles, and energy storage tanks. However, to provide load power supply, switching inverters are required. (2) Grid-connected photovoltaic system: DC power generated by photovoltaic power generation device is converted into AC power meeting the requirements of the power market through grid-connected inverter, and then connected to the power system by the power company, and then into the public grid.

The application of distributed photovoltaic management system in the power grid refers to the installation of smaller photovoltaic control system in the place of use or close to the place of power supply. It has gained a lot of applications in recent years due to its advantages of close power supply load location and nearby absorption. In the case of solar radiation, the basic operation mode of distributed photovoltaic power generation is to use the solar cell block matrix to directly convert the sunlight into electricity, and the grid-connected inverter converts it into electricity for the building itself, while the excess or insufficient electricity can be adjusted after being connected to the grid.

2.3. Composition of distributed photovoltaic power generation system

The square array of solar cells and the two parts connected to the grid form a distributed photovoltaic power generation system. The solar cell combined array can convert sunlight into renewable electric energy, and can convert DC electric energy into renewable AC electric energy through grid-connected inverter under sufficient sunshine conditions, so as to achieve the purpose of energy conservation and emission reduction. Then enter the LAN, connect a solar module to the input system of the grid-connected inverter, and connect its output system to the AC power supply. In addition to the ordinary inverter function, it should also have the following functions:

Sine wave synchronous grid connection: DC or AC voltage source inverter is used to monitor the voltage in real time, adjust the current to 50Hz sine, and then synchronize with the power grid, and then input from the power supply. The use of sine wave for grid-connected transmission will not cause harmonic waves in the power grid, nor will it cause excessive reactive load.

Key technology of maximum output power tracking of solar cell module: solar cell module based on crystalline silicon material has different I-V characteristic curve under different irradiation intensity and high temperature, and its output power and I-V characteristic also have a relatively large energy input and output point, so, The tracking technology of maximum output power point of solar cell module (MPPT) has become the focus of improving the efficiency of the whole system.

Anti-island operation skills: in the grid-connected power generation operation, when the power grid system is interrupted due to unexpected conditions, the grid-connected operation device should be able to accurately detect the power supply interruption status, and timely disconnect the equipment, immediately stop the power supply to the equipment, so as to ensure the safety of human body and facilities.

3. Current situation of photovoltaic power generation industry

China is a country with rich energy reserves, but this reserve only accounts for 10% of the global average. China has a vast territory and abundant solar energy resources, which are clean, safe, sufficient and economic, and is an ideal renewable energy. Therefore, the promotion of photovoltaic power generation as an emerging energy has become an important strategic choice for the Chinese government to deal with global warming, protect the environment and cope with climate change.

3.1. Current situation of photovoltaic power generation technology

In 1954, the monocrystalline silicon solar cell launched by the National Bell Research Institute laid the foundation for the comprehensive progress of China's photovoltaic power generation technology. At present, there are many kinds of solar cells, including silicon-based solar cells, multi-source compound semiconductor solar cells, etc. Among them, large solar cells have higher energy conversion efficiency and stronger stability, making them one of the most important photoelectric products in the world today. With the major breakthrough in the production technology of crystalline silicon raw materials, the conversion efficiency of monocrystalline silicon batteries has risen rapidly from 6% in the 1950s to 25% now, and the efficiency of large-scale monocrystalline silicon batteries has reached 23%, and their service life has also exceeded 15 years.

At present, photoelectric technology is generally divided into two categories: one is a separate solar power generation system, and the other is the development and management of grid-connected solar cell technology. Photovoltaic power generation refers to photovoltaic modules, controllers, charging sets, etc. In the case of AC load, switching inverters are required. Through grid connection, the DC power generated by solar cells can be converted into electricity that meets the demand of the

electricity market, thus directly connected to the power supply system. Distributed photovoltaic control is a grid-connected photovoltaic power generation technology. Because it has the advantages of close equipment distance and nearby absorption, it has obtained many applications in recent years.

3.2. Application status of photovoltaic power generation technology

In 1974, the "Sunshine Plan" was first launched in Japan; since then, Italian and American governments and similar institutions have launched "100000 roof projects" and "1 million solar roof projects"; China also introduced solar energy technology in the late 1980s and officially launched the "Bright Project" in 2002.

In 2018, the "Internet plus" smart power construction project of Shanghai Chongming Samsung Garden was completed, including installing solar photovoltaic modules on the roof to achieve the comprehensive control of "source grid load storage", and combining the grid connected control system with the off grid system, which effectively realized flexible transactions based on green resources and provided a reliable micro power supply guarantee for low-carbon parks.

In 2019, Baidu Group, Beijing Hainachuan Auto Parts Group Co., Ltd., Beijing Huibao Xingda Trading Co., Ltd. and other enterprises were listed in the Beijing Distributed Photovoltaic Energy Development Support Plan. Their photovoltaic power generation demonstration projects totaled 53MW, which was awarded by the national policy. Moreover, the building coverage of more than 10000 cubic meters reached 80%; this marks a major breakthrough in the development of distributed photovoltaic energy in Beijing.

Photovoltaic power generation ceiling. In 2013, Lu'an Group and China Energy Conservation Group jointly invested in the construction of an agricultural technology greenhouse with a 50 MW solar photovoltaic power generation system, and used photovoltaic cell modules to replace the roof materials of the traditional crop technology greenhouse, truly achieving "power generation under the greenhouse and cultivation under the greenhouse". At the same time, it also solved the problem of electricity consumption for greenhouse lighting, ventilation and heating, and realized three-dimensional production on the same land resources. Subsequently, the construction projects of farmers' science and technology greenhouses in Shouyang, Shanxi Province were also completed and successfully connected to the grid.

In 2019, Longji Holdings and Three Gorges New Energy jointly built the Xiaguang 250MW solar power generation system in Yijun County, which successfully achieved grid connection. The joint efforts of Kezuocheng and Aerospace Electromechanical brought new opportunities for the development of China's solar power generation system, and also provided new challenges for the development of the global solar power generation industry. With the construction of photovoltaic poverty alleviation power stations in Shanxi, Inner Mongolia and other places, solar technology has been popularized to all walks of life, providing strong support for the development of local renewable energy, and greatly improving the use efficiency of renewable energy.

4. Application conditions of distributed solar photovoltaic power generation

In order to implement the national policy of energy conservation and emission reduction, distributed solar photovoltaic power stations can be built on the highway. Before the completion of the project, the energy utilization of the expressway shall be comprehensively analyzed. When determining the power generation capacity of the power plant, a certain agreement should be signed with the power company to provide more services while providing electricity. At the same time, the power company must also provide the common electricity tariff standard for photovoltaic power generation. During the construction of the power plant, the construction technicians must also confirm the corresponding equipment installation capacity according to the specific power supply load.

4.1. Design and installation standards

4.1.1. Safety standards

In the process of implementing the design of distributed photovoltaic power generation equipment, the first thing that engineers and technicians need to ensure is the safety of all equipment. In the process of construction, the construction department must carry out relevant lightning protection settings, and carry out circuit protection before wiring to prevent exposure of any circuit. In the process of system detection and maintenance, the power supply of the system must be disconnected to prevent any live work [1].

4.1.2. Reliable standard

The distributed photovoltaic power generation system has undergone large-scale experimental research and development since its inception, and has been widely used at home and abroad. Many countries have used the distributed photovoltaic power generation technology in the design and manufacture of inverters, cable leads and junction boxes.

4.1.3. Efficient standards

When applying distributed photovoltaic power generation technology, the engineering design department fully considered the application requirements of the customer's system. In the engineering design, it not only fully considered the characteristics of the power supply system, but also considered the operation quality of the power supply system, thus effectively improving the light load efficiency of the power supply system.

4.1.4. No occlusion standard

The distributed photovoltaic power generation system often needs a lot of lighting in the process of work, so it is necessary to ensure that all solar modules can be fully illuminated during the engineering design, so as to ensure the working effect of the whole system. Therefore, in the project, the designer must also carry out appropriate non-shielded engineering design to prevent the whole system from being covered by surrounding buildings and trees, Ensure that all battery components can be illuminated to output maximum power.

4.2. System composition

The system includes: photovoltaic assembly, DC junction cabinet, inverter, grid-connected cabinet, monitoring system, etc. On the roof of the comprehensive building, power distribution room, machine repair workshop, South China branch, staff residential building and machine repair shop in the north of Feidong working area, the plane arrangement mode is used, with 250-watt polycrystalline silicon cells and 1560 solar panels, a total installed capacity of 390 kW and a paved area of 2400 square meters. The electric energy generated by the solar power generation system can be directly connected to the low-voltage side of the service area through the 380V low-voltage power grid [2].

After completing the photovoltaic power generation project, it must be approved by the local power company before it can be put into production. The power generation of solar power generation system varies greatly every month. The power generation of two working areas with different installed capacity is the same every month. The maximum month is more than twice the minimum month; May to October is the largest power generation month, with the total annual power generation exceeding 60%. However, the performance of solar photovoltaic system is affected by many factors such as solar radiation intensity, PV module inclination, roof material, reflection coefficient, etc. Assuming that the average annual operating capacity of the solar power generation system of the expressway is 760.7 kilowatt-hours, the solar power generation network of the expressway can be utilized 1.027 million kilowatts per year after being put into operation, and the average annual energy saving is about 338.9 tce.

4.3. Operation

The photovoltaic power generation management system has been in normal operation since 2014. After the photovoltaic grid-connected power generation management system is set up, the electric energy of the expressway mainly comes from the two components of the photovoltaic technology management system power generation energy and the municipal grid heating capacity; The electricity generated by the photovoltaic system is supplied to the municipal power facilities except for the local loss of the highway power facilities. At the 0.4kV incoming line side of the expressway distribution station, a calculation gateway electricity meter is set, and a calculation device is installed at the business network of the photovoltaic power generation system, which can calculate the expressway electricity consumption and grid power in the photovoltaic power generation system separately.

4.4. Profit mode

Most of the income of photovoltaic power generation enterprises is subsidized by local governments. China's subsidy scheme clearly states that for distributed photovoltaic power generation enterprises that directly send back the energy to the national grid, it is recommended to provide a subsidy of 0.24 yuan/kWh after purchasing according to the local desulfurization electricity price.

The desulfurized electricity purchased by the power grid company (based on the verification of the network electricity, the electricity after compensation for the desulfurized management costs of the power generation company) is 0.478 yuan/kWh+0.42 yuan/kWh (electricity subsidy)=0.898 yuan/kWh, that is, about 0.098 million yuan can be obtained for each kilowatt-hour connected to the grid. If all the electric energy generated is used, the non-ordinary industrial power consumption is 0.825 yuan/kWh, that is, the annual use of 1 kWh can yield 1.245 yuan, which can generate great economic benefits [3].

In addition, the use of photovoltaic power generation can also reduce carbon emissions. The amount of carbon emissions can be obtained by generating electricity, and then the amount of carbon emissions can be sold to companies with large carbon emissions by using the low carbon emissions trading market, and the corresponding profits can be obtained.

5. Application status of solar photovoltaic power generation system in domestic and foreign highways

The rapidly growing photovoltaic power generation technology has been widely used on highways. Here are some practical applications of photovoltaic power generation technology on highways:

5.1. Solar speed highway in Italy

In 2011, the world's first dedicated solar road was officially opened to traffic. This road is also connected to the Catania - Syracusa A18 highway in Italy (Sicily's 600km Sicily Expressway), which is currently the world's first electrified road focusing on solar power generation. It is estimated that the annual total power is about 12 million kilowatt-hours, which can fully meet the power demand of the whole road.

5.2. Chatiaoling Tunnel Photovoltaic Power Generation System

In 2014, the 110-kilowatt distributed photovoltaic power station grid-connection project built on the basis of the Chatiaoling Tunnel in the east of Hanzhong on the 10-day Chatiaoling Expressway in Shaanxi Province has been successfully completed. After the whole grid is connected to the grid, the maximum power of solar photovoltaic technology can reach 50400 kW, and its main power generation comes from the fans and fluorescent lamps in the Chatiaoling Tunnel [4].

5.3. Photovoltaic power generation management system of toll station of Yushe East Expressway

In 2018, the distributed photovoltaic power generation device at the toll station of Yushe East Expressway of Yushe to Heshun Expressway in Shanxi Province was commissioned. This project is also a zero breakthrough in this aspect of Shanxi Provincial Highway. Most of the power generated by the management system is used for the office and field power supply of the station. The project management originally planned to save 54000 tons of standard coal per year.

The above examples show that due to the increasingly perfect science and technology of solar photovoltaic power generation, the solar photovoltaic power generation management system has become more suitable for highway and other application fields, which can be mainly used in the following aspects: (1) emergency rescue telephone management system; (2) High-speed monitoring and management system; (3) Monitoring and control system; (4) Traffic signs and warning devices; (5) Lighting of main lines, ramps, toll parks and interchanges; (6) Expressway billboard; (7) Electric control system for electronic command board working area, etc.

6. Countermeasures

Changes in national policies and construction costs are important factors affecting the economic benefits of "distributed photovoltaic projects". According to the national conditions and the investment situation of transportation infrastructure, the following treatment methods can be adopted to achieve the smooth implementation of the project and good returns in the future: ① use the cost advantage to increase the utilization ratio of electric energy and increase the investment benefit of the power station; ② Actively supervise the equipment supply and construction of photovoltaic projects, effectively deal with price fluctuations and control project production costs; ③ Strictly control the construction stage, strictly control the project quality, minimize the accident probability of the power station in the future, and reduce the operation and maintenance investment in the later stage; ④ Strengthen the inspection and maintenance of photovoltaic power generation, overcome the situation of many distributed photovoltaic power generation stations and complex maintenance, and use the most limited time and material resources to achieve the optimization of capital use; ⑤ Establish a system related to "carbon trading", face a new round of environmental protection policies, arrange the energy supply system in advance, and find new economic growth points; ⑥ Make full use of the idle resources on the highway, and establish a solar power generation facility that is "self-prepared and self-used, and the remaining electricity is connected to the grid".

7. Feasibility analysis of photovoltaic power generation industry along the highway

7.1. Technical feasibility

The distributed solar power generation equipment is relatively mature, usually the direct purchase of solar panels. The construction and maintenance of solar cells are relatively simple, and the current technology has sufficient support. With the development of technology, the operation and management of China's photovoltaic power generation enterprises have made considerable progress. The integrated management system developed by a third party can achieve microgrid control and operation control, and the relevant departments have also issued the Technical Specifications for the Operation and Maintenance of Distributed Photovoltaic Power Plants, which provides more complete professional services for the distributed photovoltaic power generation system. In order to further promote the development of distributed photovoltaic power generation, a series of technical research and development work, such as "integrated landscape design of solar cells and buildings and structures", "remote control and automatic monitoring technology of photovoltaic power stations", "optimization design research of power grid system composed of multi-loop system", has been carried out successively, and will gradually form a set of supporting technologies suitable for distributed power generation on highways [5].

7.2. Significant energy conservation and environmental protection benefits

A company in Shanxi Province made statistics on a distributed photovoltaic power station in 2019, as shown in Table 1.

Table 1. Parameter statistics of distributed photovoltaic power stations in 2019

project name	parameter
Total power generation	2 million kilowatt-hours
Self-use	1.75 million kilowatt-hours

Self-use ratio of surplus electricity on the Internet	90%
Annual and equivalent use time	1335 Hours
Electricity income	About 1.1 million yuan

According to the data of a company in Shandong Province, the specific data are shown in Table 2

Table 2. Data of a company in Shandong Province in 2020

project name	parameter
Distributed photovoltaic power	30 Rooms
installed gross capacity	Three million watts
annual energy output	Four gigawatts of hours
Electricity income	2.32 Million yuan
economic benefits	243000yuan

According to the above data, China will reduce the consumption of 1,700 tons of standard coal every year, while reducing 1,700 tons of carbon dust, 1,200 tons of carbon dioxide, 2,000 tons of sulfur dioxide and 123 tons of nitrogen oxide emissions.

7.3. Wide market demand

There are about 160000 kilometers of expressways open to traffic in China. According to the design standard that there is a service area every 50 kilometers along the way, it can be predicted that the number of high-speed service areas in China is about 3200 pairs; Set up a toll station according to 30 to 40 kilometers, with an estimated 4000 toll stations; The roof of the station, the isolation belt at the entrance and exit of the tunnel, the interchange hub, and the hard slope are all excellent solar power generation resources. The implementation of the solar power generation project can not only meet the power requirements of the station area lighting, heating, heating, and other power requirements, but also alleviate the problems of tunnel lighting and emergency power consumption. At the same time, it also provides an effective method for the future monitoring of infrastructure diseases in specific sections and the power supply of the intelligent network expressway.

7.4. Considerable economic benefits

Policy-oriented, science and technology promote photovoltaic power generation, so that the efficiency of crystalline silicon cells can be increased by 1%, and the power cost can be reduced by 6%. The price of mainstream PV modules and inverters and other mainstream components can be further reduced, thus greatly reducing the cost of investment. According to the current technical level, the construction cost of the solar power generation project is 5.3 yuan/watt. According to the current installed capacity, power generation efficiency and utilization rate, it is expected to be completed in about 7 years. At the same time, the power generation company should also actively connect with the relevant policies of the National Development and Reform Commission, the Energy Administration and other new energy industries, and strive for the corresponding subsidies, so as to further improve the economic benefits of the project [6].

7.5. Implement policies as needed and step by step

Through the preliminary investigation, the total installed capacity of a highway capable of developing solar distributed PV can be determined, which can be carried out in stages and gradually promoted. Select representative toll stations and service areas as regional demonstration, and obtain preliminary scale effect. We will continue to tap high-quality and high-potential power resources, develop ground distributed power stations such as tunnel entrances and high and steep slopes, and carry out the construction of smart micro-grid nationwide. According to the principle of "scientific construction", new energy sources such as photovoltaic, wind energy, air-source heat pump, phase-change heat storage, and electric energy storage are adopted, and multiple distributed and complementary power stations are built in small distribution systems.

A new management mode based on distributed solar power generation system is proposed. Establish a unified intelligent energy management network platform, realize dynamic monitoring of energy supply system equipment, manage and adjust economic operation parameters, promote energy consumption and local coordination of load, achieve the purpose of "improving quality, reducing costs, and improving efficiency", and convert energy-consuming resources into profitable and benign assets.

8. Development prospects

8.1. Energy needs for sustainable development

China has a huge population, and the traditional energy utilization technology is low, so the danger of energy shortage will appear early. The current contradiction between energy supply and demand in China has brought huge development opportunities to China's photovoltaic industry. Solar power generation is a clean energy in line with the national energy transformation and green development policy. The expressway under its

jurisdiction has good regional resources. Therefore, the development prospect of this industry is very broad [7].

8.2. Independent energy supply

In the reconstruction and upgrading of expressway station areas, we should make full use of the existing roof, intercommunication and other resources to build characteristic station areas. Establish a power supply system suitable for urban industrial power supply and municipal power supply.

8.3. Space saving and high economy

Photovoltaic power generation equipment will generally be arranged on the roof, exterior wall and well-ventilated places of buildings, giving full play to three-dimensional space, energy conservation and environmental protection. Therefore, it is necessary to build a platform that provides energy for the construction of expressway to meet the development needs of intelligent expressway.

8.4. Policy support to ensure industrial development

With the introduction of a series of national policies to "win the battle of protecting the blue sky", it will certainly promote the healthy development of China's photovoltaic industry.

9. Conclusion

Based on the above analysis, solar photovoltaic power generation is a kind of clean energy that is both environmentally friendly and economical. Its application on the road is more in line with the development path of "transportation+energy", "high-speed+photovoltaic", and "clean+low-carbon", which will certainly play a huge role in promoting the green construction of China's highways.

Acknowledgement

The project was awarded by Gezhouba Group Transportation Investment Co., Ltd. "Research on key technologies and engineering demonstration projects of integrated transportation and energy integration"(CEEC2021-KJZX-08-1).

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