Analysis of the Current Development Status and Prospects of Solar Charging Piles for Electric Vehicles

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Abstract. In the context of sustainable development in the world, various clean energy products have emerged, among which electric vehicles have rapidly developed and received great attention from people. This article investigates the principles and types of solar charging stations for electric vehicles, as well as the innovative research and practical design applications of previous researchers. Through research, it has been found that using sunlight to generate electricity, solar charging stations provide clean and sustainable power for electric vehicles. New energy sources such as solar energy have also been favored by the general public. In addition, solar charging stations are constantly being improved and optimized under people's research. However, at the same time, it also faces challenges such as high costs and high technological requirements. Therefore, continuously optimizing and improving the use system of new energy is of great importance to human development. People still have a long way to go in the development of new energy.

Keywords: Solar charging, Sustainable, Electric vehicles, Design, Applications.

1. Introduction

In recent years, in the context of sustainable development, various countries have actively responded to the United Nations concept of sustainable development, adhered to environmental protection, balanced energy consumption, and vigorously developed clean energy. In the background of global warming, environment pollution and so on, the demand for the utilization and exploitation of energy resources is higher. The proposal and development of clean energy can not only effectively reduce the dependence of industrial production and daily life on traditional fossil fuels, reduce greenhouse gas emissions, but also promote sustainable economic growth, enhance people's environmental awareness, and promote the process of sustainable social development. From a macro perspective, clean energy has broad development prospects and enormous potential. Among them, solar energy, as a clean and renewable energy source, has attracted much attention. Solar energy has abundant resources, wide distribution, and pollution-free characteristics, making it an important choice to replace traditional energy [1]. With the continuous progress of technology, solar energy technology is becoming increasingly mature, costs are gradually decreasing, and efficiency is constantly improving, making solar power generation a feasible clean energy solution. As an important product in the context of the new energy era, the emergence of solar charging piles in electric vehicles not only facilitates user use but also meets the requirements of sustainable development.

This article mainly introduces the principles of solar power generation, including the principles of photovoltaic cells and photovoltaic power grids. The different types and principles of solar charging piles for electric vehicles include direct charging piles and AC charging piles. The optimized design of four different solar charging piles includes a new type of solar charging station that achieves maximum power tracking control, uses solar power generation for electric vehicle loads, and adjusts the DC bus voltage; An High efficiency design of charging stations based on maximum power point tracking, PID, and current control; Hybrid charging stations, combined with the power grid and renewable energy, to address the negative impact of fast DC charging on the power grid and improve power quality; An optimized battery energy storage system for integrated solar photovoltaic power generation, utilizing PSO algorithm and artificial neural network to optimize the cost and performance of charging stations. And the application of Tesla's solar storage and charging products and BYD's public solar charging stations.

2. Fundamentals of Solar Energy Theory

2.1. The basic principles of solar power generation

2.1.1. Principles of solar cell power generation

The principle of solar cell power generation is based on photovoltaic effect, which can be transformed into electric energy at the semiconductor interface. The interface will receive photons irradiated on the metal surface [2]. When a photon possesses sufficient energy, it can elevate an electron from the covalent bond within both P-type and N-type silicon. Near the interface layer, electrons and holes are driven apart due to the spatial charge effect. Electrons migrate toward the positively charged N region, while holes shift to the negatively charged P region. Upon connecting the circuit, this movement induces a current. Schematic diagram of solar cell power generation is shown in figure 1.

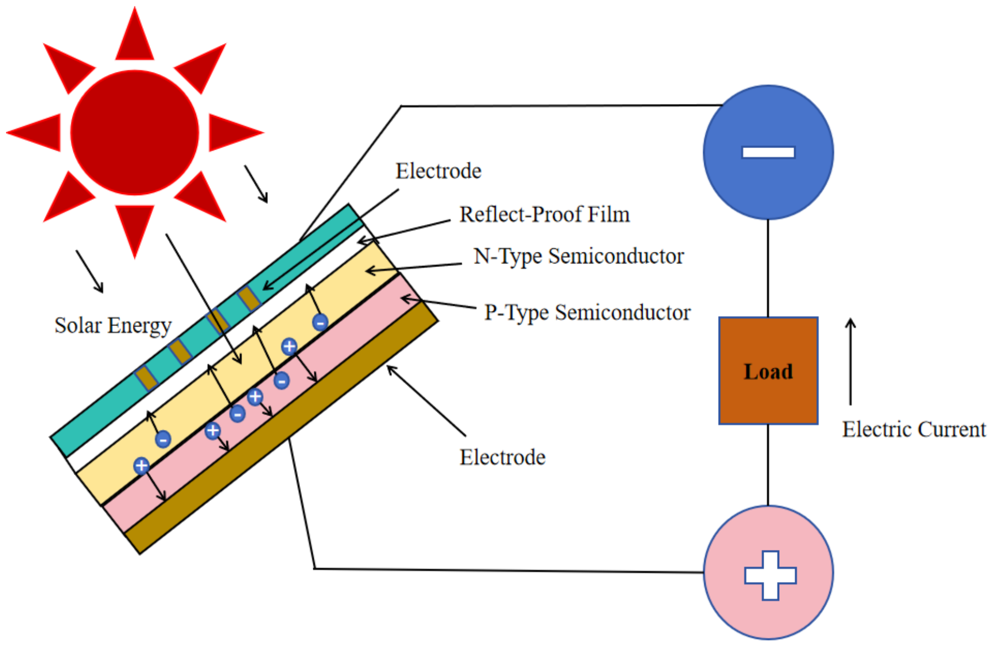

Fig. 1 Schematic diagram of solar cell power generation (Photo/Picture credit: Original)

2.1.2. The structural composition of solar power generation systems

Solar cell arrays, battery packs, charge controllers, inverters, AC distribution cabinets, solar tracking systems, and other related equipment are crucial elements of grid-connected solar power generation systems. The composition of a solar cell array mainly includes a large number of series and parallel solar cell modules. Under illuminated conditions, the battery absorbs light energy. Under the photovoltaic effect, an electromotive force is generated at both ends of the battery, converting light energy into electrical energy. Solar cells are mainly composed of monocrystalline silicon, which can generally be divided into three types: monocrystalline silicon, polycrystalline silicon, and amorphous silicon. The main function of a battery pack is to store solar energy for power generation, and then provide power to the load at any time. The controller is a device that prevents overcharging and discharging of the battery, which can effectively protect the battery's lifespan [3]. An inverter is a device that converts direct current into alternating current. Solar power generation systems are categorized into three types: standalone photovoltaic systems, grid-connected photovoltaic systems, and distributed photovoltaic systems. An independent photovoltaic power generation system, also known as off grid photovoltaic power generation, is a method of operating by utilizing the direct current energy generated by a solar cell array, which is stored in a battery through a controller. If the load is a DC load, it can be directly supplied to the load without connecting to the inverter power supply. If the load is an AC load, it is necessary to connect an off-grid inverter power supply to the controller and then provide the power to the AC load. The working principle of a distributed photovoltaic power generation system is to pass the DC energy generated by photovoltaic modules through the busbar, through the busbar converter, then through the distribution network, and finally detected by a voltmeter before being input into the power grid. Grid side structure diagram of solar power generation is shown in figure 2.

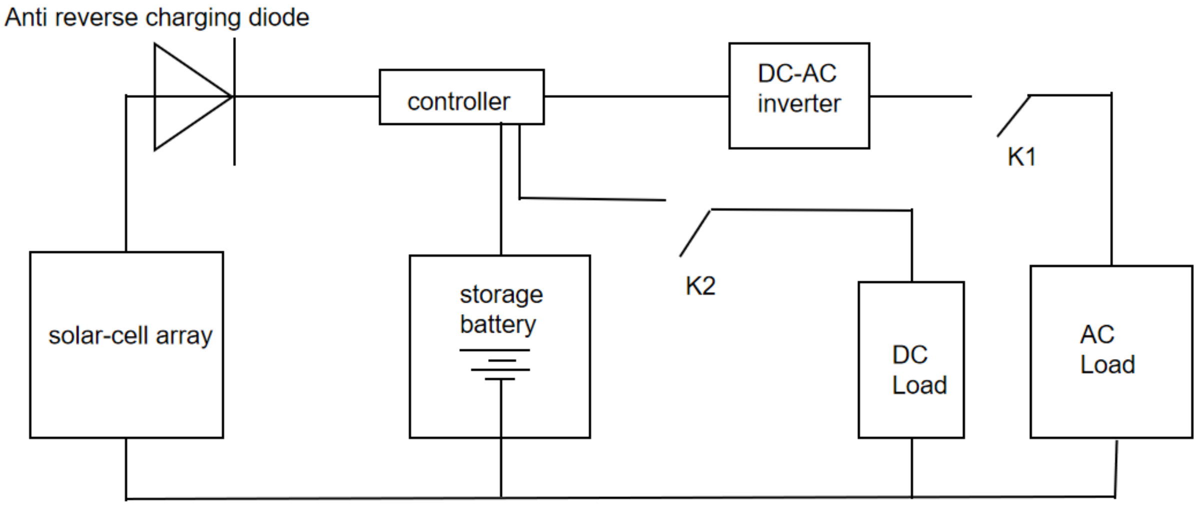

Fig. 2 Grid side structure diagram of solar power generation (Photo/Picture credit: Original)

2.2. Structural analysis of solar charging station

2.2.1. DC charging station

DC charging station, also known as off vehicle charger, is a fixed installation outside the electric vehicle, connected to the AC power grid, and directly outputs adjustable DC power to charge the onboard battery. No need for onboard charger for conversion. The voltage and current output of this charging station have a large adjustment range, high power, and fast charging speed. It takes about half an hour to reach about 80% of the electric vehicle's battery capacity, commonly known as fast charging. This type of charging station has a relatively large size and is generally installed in public places as a commercial charging station, such as parking lots, highway service areas, and on both sides of roads. The basic components of a DC charging station include: power unit, control unit, metering unit, charging interface, power supply interface, and human-machine interaction interface. The power unit refers to the DC charging module, and the control unit refers to the charging station controller. The basic process of charging is to apply a DC voltage at both ends of the battery, charge the battery with a constant high current, and gradually increase the voltage of the battery to a certain extent [4]. When the battery voltage reaches the nominal value, continue to charge the battery with a constant voltage and low current. The voltage has increased, but the battery has not been fully charged, which means it has not been fully charged. If there is time, it can be filled with a small current instead. In order to achieve this charging process, the charging station needs to have a "DC charging module" to provide DC power, and a "charging station controller" to control the "power on, power off, output voltage, and output current" of the charging module. A "touch screen" is needed as the human-machine interface to issue commands, and the controller sends commands such as "power on, power off, output voltage, and output current" to the charging module. The simplest charging station from an electrical perspective only requires a charging module, control board, and touch screen; If commands such as power on, power off, output voltage, and output current are made into several keyboards on the charging module, then a charging module can charge the battery. Structural diagram of DC charging station is shown in figure 3.

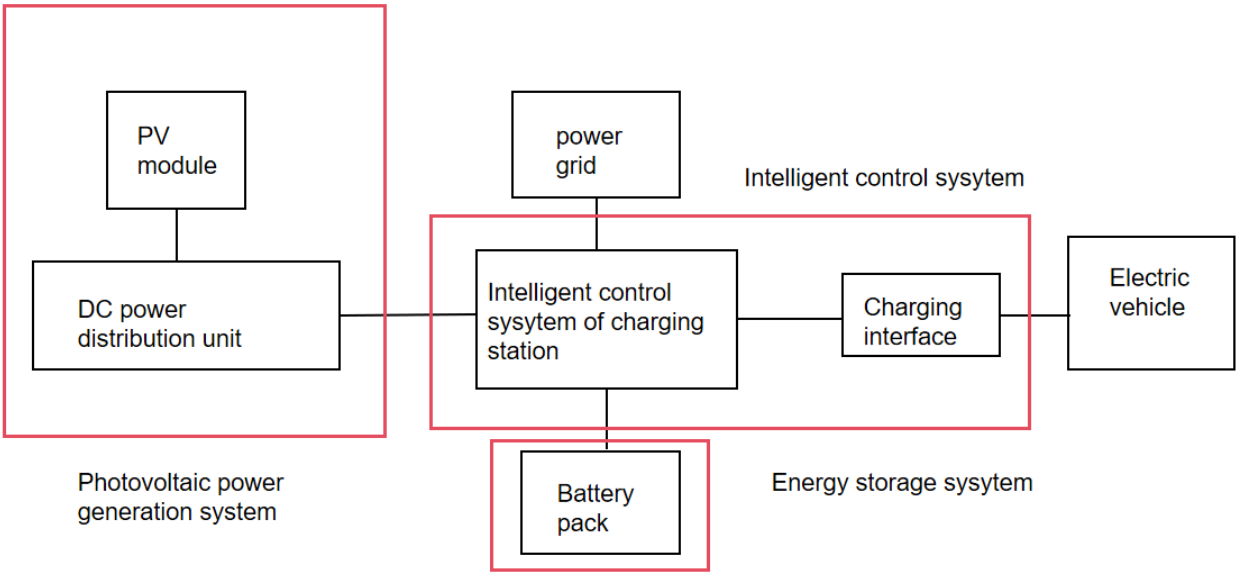

Fig. 3 Structural diagram of DC charging station (Photo/Picture credit: Original)

2.2.2. AC charging station

The AC charging station uses an AC power source, which increases the charging speed by increasing the output power. Both single-phase AC and three-phase AC can be used. At the same time, the AC charging station requires the on-board charger to convert the input AC point into DC electricity suitable for the voltage and current of the power battery during charging. The AC charging system is mainly composed of components such as AC charging equipment, high-voltage wiring harness, AC charging port, vehicle charger, high-voltage distribution box, power battery pack, battery manager, etc. Some public places may have charging stations for communication vehicles. If charging at home, there is usually a small charging box, which is portable, floor standing, or wall mounted. These two are the most common AC charging scenarios [5]. Structural diagram of AC charging station is shown in figure 4.

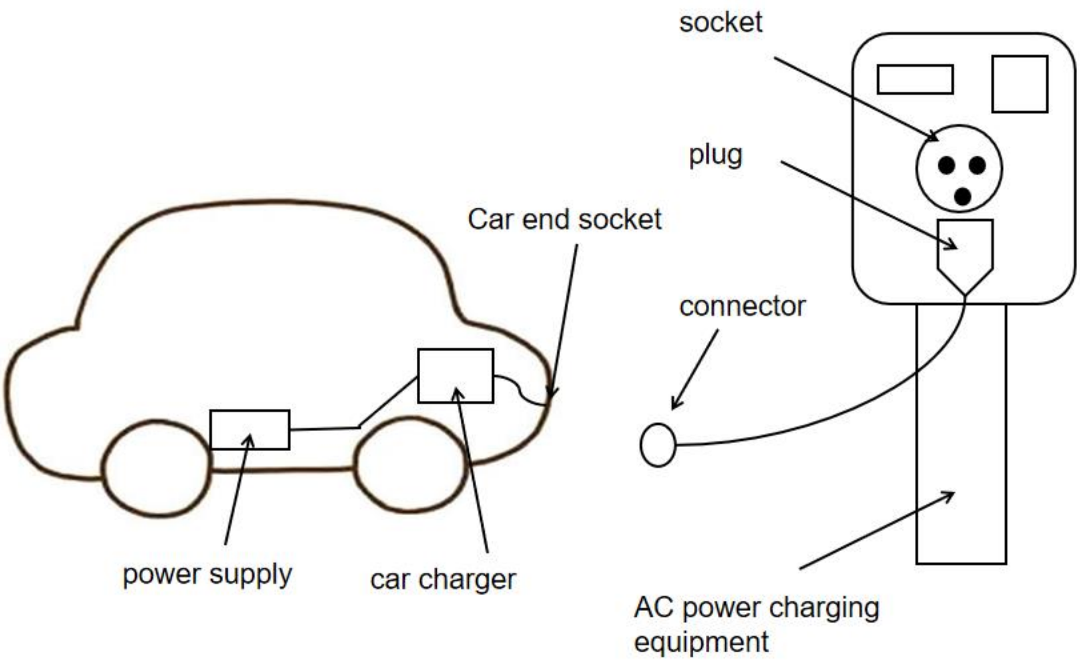

Fig. 4 Structural diagram of AC charging station (Photo/Picture credit: Original)

3. Research and analysis on the design of solar charging stations

3.1. Literature Review

Huaizhong Chen has designed a new type of solar charging station. Due to factors such as solar radiation intensity, temperature, and load, the connection between the solar cell array and the DC bus is crucial to ensure that the solar cell array operates at maximum output power. On this basis, a distributed photovoltaic system based on maximum power control strategy was designed. This design utilizes a DC bus to power solar cells for electric vehicles, while utilizing energy storage devices to adjust their voltage, achieving good results [6].

In the context of global warming, electric vehicles are becoming increasingly popular, and according to the current situation, T S. Biya; M. R. Sindhu and his team designed an electric vehicle charging station that integrates solar and battery energy storage systems (BESS). It is feasible to provide additional grid support for uninterrupted power supply to charging stations without increasing grid load. So this article developed an efficient design device for charging stations with MPPT, PID, and current control strategies for electric vehicles used in solar energy, BESS, and optimized power networks and charging stations. The significance of its design is to enable the charging station to provide continuous power supply at night, and to achieve automation of its charging station through optimized control system design [7].

The speed of DC charging is relatively fast, so it is commonly referred to as fast charging. DC charging consumes a lot of energy and can shorten the charging time. When the state of charge (SOC) of the battery changes from 0 to 100%, the power level also changes accordingly. During extremely fast charging, charging stations require high power. This will bring adverse consequences to the power grid, such as voltage drop, power loss, and harmonics. Considering this issue, Harshita Arya and Moumita Das suggest that using a hybrid charging station with a power network and renewable energy can solve the above problems. With the widespread application of new energy sources such as solar photovoltaics, the dependence on the power grid has been reduced. Combining electric vehicles with hybrid drive systems can effectively improve the communication capability between vehicles and the power grid. The proposed micro-grid system proposes five modes, i. e., fast charging or grid to vehicle operation (G2V), as well as their influence on the peak demand. A grid connected solar photovoltaic system or a combination of a grid and a solar photovoltaic system is used to charge a vehicle (G + PV) 2 V, a solar photovoltaic to a grid (PV2G), and a vehicle-to-grid power injection (V2G). The system designed in this article can maintain the voltage between the power grid and the DC busbar in a fast-charging state. Therefore, if solar cells are applied to fast charging stations, it can improve the quality of the power system [8].

Megha Fatnani; Dipanshu Naware; Arghya Mitra has designed a new type of battery energy storage system that integrates the energy of solar energy and batteries into the charging device, thereby improving the operational efficiency of the entire system. The Particle Swarm Optimization (PSO) algorithm takes into account factors such as parking lot capacity, photovoltaic power generation capacity, load connected to solar photovoltaic power generation, and new energy vehicles to calculate the optimal battery cost. The optimal charging/discharging rate of BES will ensure an extended battery life cycle. At the same time, artificial neural networks are used to predict the existing photovoltaic power and load demand, predict the capacity of the energy storage system, and store energy in the energy storage system. This article introduces the design of a nine-way fast charging station. The system load refers to the number of electric vehicles charged into the charging station. Use artificial neural networks to predict the load for the next month and predict the load for the following month. On this basis, a new energy storage method is proposed, which utilizes the energy storage device to meet the demand for solar cells and optimizes it. Using PSO algorithm to optimize the operating cost of solar photovoltaic charging stations with batteries as energy storage devices to reduce charging time [9].

3.2. Case Study

Tesla's charging station business is a key link in driving the development of electric vehicles, and Tesla solves the range problem of electric vehicles by building a charging network worldwide. Tesla has made significant progress in photovoltaic energy storage, which refers to the conversion of solar energy into electricity and the storage of electricity. Tesla has developed a series of photovoltaic energy storage products, most notably solar roof tiles and battery storage systems. Solar roof tiles are a type of tile material that can convert solar energy into electricity and cover the roof of a house. This design integrates power generation and storage, and the battery storage system can store excess electricity for future use [10]. Tesla's integrated photovoltaic charging station is equipped with V3 super charging stations and destination charging stations. The integrated photovoltaic charging station generates electricity through a solar rooftop system, stores the energy in Powerwall batteries, and can ultimately be used for daily charging of some pure electric vehicles. Solar charging panels, Powerwall energy storage batteries, and charging facilities form a microgrid to jointly achieve the sustainable utilization of sunlight as a clean energy source. The capacity of a single Powerwall energy storage battery is 13.5kWh, with a continuous output power of 5kW.

The BYD 800V platform architecture has received high attention recently, but soon faced new problems. Currently, only 2% of public overcharged piles have a current exceeding 300A, while fast charging piles are widely popular and overcharged piles are extremely scarce. BYD quickly proposed a solution of "dual gun overcharging" technology for passenger cars, fully utilizing the existing public fast charging pile resources of over a million units. Specifically, it means that without changing the hardware, the vehicle can significantly increase the charging current by inserting two charging guns at the same time, allowing the entire vehicle to break through the maximum current limit of 250A according to the national standard for public fast charging piles (the maximum charging current can be doubled to 500A). Combining with the mainstream 80-120kW public fast charging pile ecosystem in China, the charging power can be doubled through dual gun overcharging technology. According to Ling Heping, with the support of "dual gun overcharging technology", both dual gun and single gun modes have 100% compatibility with vehicle charging, regardless of single or double guns, and can be adapted upon insertion. Based on the data of the already launched Tengshi N7, in the dual gun state, the maximum charging power of the vehicle can reach 230kW, with a maximum supplementary energy of 350km in 15 minutes, and it is also suitable for over 95% of public fast charging stations nationwide, greatly expanding the use of overcharging scenarios. In addition, both Tengshi N7 guns can be boosted and charged, allowing users to charge both guns simultaneously even at low voltage piles (500V). In single gun mode, the Tengshi N7 can easily achieve an efficient charging experience with a charging power of up to 150kW. Of course, BYD, which has always adhered to safety as its root, not only needs to be fast and sustainable, but also safe and fast. Due to the stricter test of battery thermal management by upflow technology, BYD is the world's first composite direct cooling technology. Through the design of straight cooling plates on both upper and lower sides of the battery, as well as two sets of independent refrigerant control systems, a compensating flow channel design is carried out. The cooling area of the battery is increased by 100%, and the heat exchange capacity is increased by more than 85%, providing users with safe overcharging protection.

4. Challenges and Prospects of Solar Charging Stations

Under the background of sustainable development, electrical vehlical has become the main stream of society. Meanwhile, the demand for charging stations is also growing.Therefore, the emergence of solar charging stations not only meets the charging needs of users, but also helps to promote the development of clean energy. With the continuous development of technology, the technology and performance of photovoltaic charging piles are also constantly improving, making them more intelligent, efficient, and energy-saving. The technological competition and innovation in this field will also promote the further development of photovoltaic charging piles, solve energy distribution problems in different regions, improve the efficiency of car owners, and also reduce the pressure on the power grid [11]. The application of photovoltaic charging piles can greatly save resources, convert solar energy into electricity, replace traditional non renewable energy, and also save the consumption of other energy sources. In the application process of photovoltaic charging piles, they can utilize about 90% of solar energy, ultimately improving electricity efficiency. For traditional solar power generation, the integrated improvement of photovoltaic, energy storage, and charging effectively solves the problem of climate change and provides more stable charging services for homeowners. With the promotion of new energy vehicles, the demand for charging station facilities in the market is gradually increasing. At the same time, different user needs are constantly upgrading, from simple charging facilities to intelligent charging stations that achieve functions such as parking, charging, energy storage, and car locking. The market demand for photovoltaic charging pile facilities in the future will be more extensive, and it will maintain strong market competitiveness under sustainable development.

Overall, the development of solar charging stations still faces many challenges. Solar power generation belongs to new energy technology, which requires relatively high requirements for technology and equipment maintenance. The initial investment for construction is relatively high, and according to calculations, the investment payback period for the 6-car charging station is about 5-6 years [12]. If you want to reduce costs, you can choose to use layered batteries, but they need to be replaced every four to five years. Therefore, in terms of revenue, the profitability of charging stations has greatly improved. At the same time, the cost of energy storage batteries is high, and with the development of the energy storage industry, the government is investing more and more in firefighting and emergency management.

5. Conclusion

As an important component of clean energy development, solar charging stations have enormous development potential. Through in-depth analysis of DC charging piles, AC charging piles, relevant literature, and practical cases, we can clearly see the important position and role of solar charging piles in promoting the transformation of clean energy.

In the future society, the development of solar charging stations needs to focus on technological innovation and system optimization to achieve their efficient, reliable, and sustainable development. In addition, improving charging efficiency and reducing costs are key issues that urgently need to be addressed in the development of solar charging piles. With the continuous expansion of the clean energy market and the gradual improvement of technology, solar charging piles will play a more important role in the future, making greater contributions to environmental protection and sustainable development. Therefore, continuous improvement and enhancement of solar charging station technology will become an important direction and challenge for future development.

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