Research on New Strategies and Applications for Solar Power Generation

Ziming Li *

Department of Enviromental Engineering, Dalian Jiaotong University, Dalian, China

* Corresponding Author Email: 7050888@qq.com

Abstract. Environmental pollution and energy depletion pose a threat to the development of human society, and the development of clean energy has become a global consensus. As a dominant clean energy technology, solar photovoltaic power generation technology has achieved a series of important achievements in areas such as materials science, advanced equipment, and control systems in recent years. Current research mainly focuses on system construction and cost reduction. An in-depth analysis of the domestic and international research progress and current status of solar photovoltaic power generation technology is provided, and the application progress of photovoltaic power generation technology is comprehensively discussed in this paper. Finally, the future development prospects of photovoltaic power generation technology are summarized , elaborated and a reference and basis for related research and development in the field of new energy are provided.

Keywords: Solar Power Generation, Technologies, Application, Material.

1. Introduction

The development of human society is closely linked to energy consumption. Since the Industrial Revolution, fossil fuels such as coal, oil, and natural gas have supported the rapid growth of the global economy. However, as human society continues to increase both its energy consumption and demand, problems of environmental pollution and energy depletion have become increasingly severe, posing serious threats to the future survival and development of humanity. Therefore, seeking clean and renewable alternative energy has become a global consensus and an urgent task. Among the many new energy sources, solar energy has received widespread attention and application due to its advantages of being clean, abundant, and widely applicable. Sunlight can be directly converted into electricity, making solar energy simple and flexible to use. At the same time, the sun's energy reserves are extremely abundant, potentially addressing the issue of energy depletion[1]. Solar photovoltaic power generation is currently one of the main new energy strategies and holds promise for solving current environmental problems.

Solar photovoltaic power generation is a technology that directly converts solar energy into electricity through the photovoltaic effect. When sunlight shines on the surface of a solar cell or photovoltaic material, it generates holes and photoelectrons, which are regulated by an internal electric field to form a photovoltage. Through this process, light energy is directly converted into electrical energy, which is then connected to a load, allowing the photovoltage to drive the flow of electrons, completing the output and utilization of electrical energy[2]. The development of solar photovoltaic power generation has been extremely rapid, evolving from early laboratory theoretical research to becoming an important part of global power production [3].

However, there are still certain issues with current solar photovoltaic (PV) power generation technology. First, structural problems such as the PV materials used, shading, and system integration losses can affect the overall efficiency of PV power generation. The theoretical efficiency limit of mainstream crystalline silicon cells is about 29%, but in actual production, the efficiency can only reach around 22%[4]. Second, the raw materials, research and development, and production equipment for PV power generation are expensive, and the recycling and disposal of materials remain a challenge, which affects the promotion and adoption of the technology[5]. Third, the batteries used in PV energy storage have issues such as low energy density and short cycle life, making it currently difficult to

achieve sustainable development goals. This paper mainly analyzes the current research status and application progress of solar PV power generation technology, examines its future development prospects, and provides support and reference for the research and development of this technology.

2. Research Progress

2.1. Research Progress in China

As a clean energy source, solar photovoltaic power generation technology meets the current development needs in China and has good development potential. China began researching solar photovoltaic power generation in the early 1970s, and with the support of policies and technological innovation, it has achieved a series of results[6].

Currently, China is promoting the application of artificial intelligence in solar photovoltaic power generation systems. By leveraging the advantages of machine learning algorithms, artificial intelligence can promptly determine whether the system is operating stably and infer changes in the surrounding climate environment, which can reduce system maintenance costs and significantly improve production efficiency[7]. At the same time, efforts are being made to advance grid-connected photovoltaic power generation systems. The working principle of this system is simple and efficient: after converting solar energy into electrical energy, it is connected to the public power grid, allowing the electricity to be shared. The public power grid can store electricity, regulate peak loads, reduce losses, and improve power supply reliability. In 2008, a 100 kWp grid-connected photovoltaic power station was installed at the Bird's Nest stadium. This power station not only meets the daily electricity needs of the stadium facilities but also supplies power to the surrounding areas through the grid. As technology continues to mature, more and more regions are beginning to install solar panels on rooftops and integrate the generated electricity into the grid system[8].

In China, there have also been a series of breakthroughs in power generation materials, among which perovskite materials have good development prospects. Common solar photovoltaic materials are usually crystalline silicon materials, which are widely present in quartz and sand in ionic form. Therefore, high-temperature melting and other methods are required to reduce silicon ions and improve material purity. This leads to problems such as high energy consumption, high pollution, low efficiency, and high cost. Perovskite, as an organic-inorganic hybrid material, has higher light absorption and charge transport rates than most other materials, and its preparation process is simple and consumes little energy. At present, China is working on improving the conversion efficiency of perovskite materials by altering their structure and promoting the use of this material in more fields[9].

Looking to the future, in terms of material technology, it is necessary to continuously develop new materials, reduce the impact of material defects on efficiency, and promote technological upgrades, so that power generation efficiency can be further improved. In terms of technology dissemination, at present, solar photovoltaic power generation technology in China is mainly applied in sparsely populated areas. In the future, distributed small-scale photovoltaic power plants can be developed and built in line with actual application scenarios to promote the use of solar photovoltaic power generation technology in densely populated areas[10].

Overall, the development of photovoltaic power generation in China is currently relatively mature. Future trends are expected to focus on researching new high-efficiency photovoltaic materials (such as new perovskite materials), promoting technological upgrades (such as artificial intelligence and grid-connected photovoltaic power generation systems), and improving overall efficiency[11].

2.2. Research Progress globally

The development of solar photovoltaic power generation has broad prospects. In the future, by actively promoting the development of solar photovoltaic technology through measures such as technological innovation and government support, this technology is expected to become a core part of the global energy transition and support the goal of carbon neutrality.

In 1954, American scientists developed single-crystal silicon solar cells, turning solar power generation from theory into reality. After years of research and development, photovoltaic technology has become increasingly sophisticated, and the types of materials have also diversified. With growing attention to energy and environmental issues worldwide, the technology's potential and the interest it receives have continued to expand. Due to the rapid increase in demand for solar cells, countries have introduced relevant policies to promote the large-scale development of photovoltaic technology[10].

In 1990, Germany proposed the 'Thousand Roofs Program,' encouraging the public to use solar power by providing subsidies through the government to each household that installed a solar roof. Later, in 1998, the 'Hundred Thousand Solar Roofs Program' was introduced, planning to install 300–500 megawatts of photovoltaic systems within six years. In 2015, the United States launched the 'Solar for All' project, installing power generation devices on building rooftops to ensure maximum utilization of solar energy[9].

In Japan, since the government passed the "New Energy Outline" in 1994, it has been actively promoting the adoption and popularization of new energy sources. In recent years, in order to stimulate market consumption and the development of emerging technologies, the Japanese government has implemented a series of preferential policy measures. In 2021, the central government passed the "Renewable Energy Act," further simplifying the approval procedures for photovoltaic power generation projects. Local governments have introduced various subsidy measures, such as providing financing for photovoltaic systems installed by residents and businesses to reduce installation costs[12].

Currently, the global prospects for solar photovoltaic power generation are promising. In Europe and the United States, where technology development started early, solar energy is steadily growing and is expected to become a mainstream new energy source. In 2018, India surpassed the United States in new solar power capacity, with an additional 4.6 GW, becoming the world's second-largest solar market. Its total installed capacity reached 81.813 GW in 2024. According to statistics from the U.S. Energy Information Administration and the Solar Energy Industries Association, U.S. Adds 11.7 GW of New Solar Capacity in The third quarter of 2025, Third Largest Quarter on record[13]. In the same year, the European market saw an additional installed capacity of 66 GW, a significant increase compared to the past.

On the other hand, this technology still faces many challenges. The current cost of installing photovoltaic power generation technology is relatively high, which affects its promotion. For example, Germany began to scale down photovoltaic construction in 2013 due to the inability to bear financial pressure. Insufficient grid capacity and complex project approval are also issues that countries currently need to address[14].

3. Advances in Technology Applications

With the growing demand for new energy and advances in technology, solar photovoltaic power generation technology has developed rapidly in recent years and has been widely applied in many fields.

In the field of architecture, this technology is mainly used to provide electricity for buildings. By installing solar photovoltaic (PV) modules in unused areas on building rooftops, buildings can achieve partial self-sufficiency in electricity. Currently, China is actively promoting Building-Integrated Photovoltaics (BIPV) technology, which integrates PV modules into buildings according to different building designs and geographic locations, achieving an organic combination of building and photovoltaic technology. This technology not only enhances the aesthetic appeal of buildings but also effectively improves their energy performance, reducing dependence on external energy sources. Similar initiatives include the "Solar Roof Program" in the United States and Germany, where solar PV components are installed on residential rooftops, significantly increasing the usage and coverage of solar energy [15].

The application of photovoltaic power generation in Japan spans buildings, transportation, agriculture, and other fields, with photovoltaic wireless power supply systems for electric vehicles being one of the significant achievements. By installing photovoltaic power generation systems at both ends and beneath roads, as well as on the floors of new energy vehicles, cars can simultaneously cruise and charge while driving, thereby increasing the driving range of new energy vehicles and potentially becoming one of the solutions to the range problem of new energy vehicles[12].

In recent years, with the growing environmental awareness within the shipping industry, ships and solar photovoltaic power generation have become connected. For small vessels, photovoltaic power systems are mainly used to provide propulsion, while for large vessels, they are primarily used to supply electricity to lighting systems. Photovoltaic power systems on large vessels generally consist of solar photovoltaic panels, an energy management system, a charge and discharge control system, and batteries. The solar photovoltaic panels absorb sunlight and convert it into electricity, which is delivered to the energy management system, responsible for distributing the energy. This electricity can be used for the lighting system or stored in batteries to serve as backup power in emergencies, reducing dependence on external energy sources[16], [17].

At present, fossil fuels still dominate human energy consumption, and solar photovoltaic power generation still requires technological upgrades and wider promotion. The high installation cost of photovoltaic technology hinders its adoption. In the future, costs need to be reduced through the development of new technologies and materials. The government should also implement corresponding policies and measures to encourage and promote the use of photovoltaic technology.

4. Conclusion

As one of the most representative clean energy technology, solar photovoltaic power generation technology, which received widespread attention due to its advantages of being clean and abundant, has gradually matured after years of development. And the related industry of solar power generation has entered a new stage of large-scale growth.

Solar power generation technology has even greater potential. Future trends are expected to focus on researching new high-efficiency photovoltaic materials (such as new perovskite materials), promoting technological upgrades (such as artificial intelligence and grid-connected photovoltaic power generation systems), and improving overall efficiency.

The expansion of PV applications such as building-integrated photovoltaics and ship lighting systems has promoted the popularization of PV technology, increasing the share of solar power in the global energy mix.

The development prospects of solar PV technology are broad, but it still faces challenges such as high material costs and the need for improved efficiency. By advancing technological innovation, industrial collaboration, and governmental support together, the further development and application of solar PV technology can be promoted, making an important contribution to achieve sustainable development for humanity.

References

[1] Yao Chunxiao. Solar Photovoltaic Power Generation Technology and Its Application Analysis. Electrical Technology and Economics [J], 2024, 10: 82-85.

[2] Zhang Yuntian. Analysis of the Application of Solar Photovoltaic Power Generation Technology in Urban Residential Communities [J]. Technology News ,2016,14(20):22-23.

[3] Yuan Yadi, Research on Grid-Connected Control Technology of Solar Photovoltaic Power Generation. Master of Engineering Professional Degree Thesis [J], China University of Mining and Technology,2020,06.

[4] Fang Qingyuan. A Brief Discussion on the Research Progress and Development Prospects of Solar Photovoltaic Power Generation Materials [J]. Contemporary Chemical Research,2020,17:12-13.

[5] Tan Wuyi. Current Status and Prospects of Solar Photovoltaic Power Generation Technology [J]. Zhangjiang Technology Review, 2025,05:35-37.

[6] Zhu Jiqing ,Song Yuang.Current Status and Prospects of Solar Photovoltaic Power Generation Technology [J]. Foreign Trade and Economic Cooperation,2024,01(355):31-34,131.

[7] Hu Ningbo. Application of Artificial Intelligence in Solar Photovoltaic Power Generation Systems [J]. Power Innovation, EPEM, 2025.08:160-162.

[8] Chen Jing,Zheng Wenjuan.The Current Status and Prospects of Solar Photovoltaic Power Generation in China [J].Times Agricultural Machinery,2018.45(3):48-49

[9] Dou Hailin,et al.Research Progress on Solar Photovoltaic Power Generation Materials [J]. China Academic Journal Electronic Publishing House,2016(12):46-48

[10] Song Jinlong.Solar Photovoltaic Power Generation Technology and Its Prospects Analysis [J]. Integrated Circuit Applications.2024,02,41(365).

[11] Wang Song. Application of Solar Photovoltaic Power Generation and Grid-Connected Technology [J]. Electronic technology,2022,51(04):204-205

[12] Che XiaoXuan.Current Status and Future Prospects of Solar Photovoltaic Power Generation in Japan [J],.Hydropower And New Energy,2025,01(39)1-7.

[13] SEIA. REPORT: U.S. Adds 11.7 GW of New Solar Capacity in Q3, Third Largest Quarter on Record. (2025). https://seia.org/news/third-largest-quarter-on-record/

[14] Shangguan,et al. Solar Power Generation Technology and Its Development Trends and Prospects [J]. Energy And Energy Conservation, 2019(162)60-63

[15] Zeng Zhifeng.Application of Solar Photovoltaic Power Generation in Urban Construction [J]. Fujian Construction Technology,2025(4)103-105

[16] Xue Rui yuan. Application of Solar Photovoltaic Power Generation Technology in Ship Lighting Systems [J]. Research on Marine Electrical Technology Applications. 2025,03(45): 20-24.

[17] Wang Lei,et al. Application of Solar Photovoltaic Power Generation Systems on Ships [J]. Ship Science And Technology,2025, 05(47): 82-86.