

Analysis of Current Research and Future Development Trends of Applying Solar Energy in Street Lighting

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Abstract: In the context of promoting green energy transition and addressing climate change globally, solar energy, as a clean and renewable energy source, has gradually become a hot topic for research. Solar streetlight systems realize energy self-sufficiency and environment-friendly lighting by integrating photovoltaic power generation technology and efficient LED lighting technology. By comprehensively analyzing the current status of the application of solar streetlights at home and abroad, this paper discusses its technical advantages, market penetration, and challenges in its development. In terms of technical characteristics, this paper focuses on analyzing the key technologies such as energy conversion efficiency and intelligent control systems of solar streetlights.

Keywords: Solar streetlights; Green energy; Photovoltaic power generation; LED lighting; Intelligent control system

Online publication: June 14, 2024

1. Introduction

Solar streetlights, an innovative product combining renewable energy technology and modern lighting design, are gradually becoming a new favorite in global lighting. This streetlight system efficiently captures sunlight through solar photovoltaic panels and converts it into electricity, which is then stored and rationally distributed through the built-in intelligent control system to provide stable lighting service at night or on cloudy days. Compared with traditional electric lighting, solar street lights can not only significantly reduce energy consumption and operating costs, but also help reduce environmental pollution, which is an effective way to realize the goal of green, low-carbon urban development.

Thanks to the improvement of photovoltaic materials in recent years and the significant reduction of production costs, the popularity of solar streetlights has soared. In addition, the introduction of intelligent control systems has enabled solar streetlights to automatically adjust their brightness according to changes in ambient light, further improving energy utilization efficiency. Globally, many countries and regions have begun to deploy solar streetlights on a large scale, especially in remote areas and places with unstable power supplies.

The purpose of this paper is to explore the current status of solar streetlight applications and analyze and predict their future development trends, to provide valuable references and suggestions for technology research and development and market promotion ^[1].

2. Research on the current status of solar energy in street light applications

2.1. Status of domestic applications

The adoption of solar streetlights has become increasingly widespread and it signifies the advent of new energy utilization. Solar streetlights are preferred in rural areas and remote mountainous regions due to their easy installation, low maintenance costs, and lower impact on the environment. These areas often have insufficient grid coverage or unstable power supply, and solar streetlights provide a reliable lighting solution that greatly improves the quality of life of local residents and the safety of nighttime travel.

In addition to rural and remote areas, urban areas have also begun to adopt solar streetlights on a large scale. In public places such as urban roads, parks, and residential areas, solar streetlights not only provide convenient lighting services for citizens but also help cities realize the goal of energy saving and emission reduction. In addition, with the acceleration of urbanization, the demand for green and intelligent lighting systems in cities continues to grow. The intelligent design of solar streetlights, such as automatic brightness adjustment and remote monitoring and troubleshooting makes them an important part of the construction of smart cities ^[2].

According to statistics, the market size of China's solar streetlight industry reached 4.873 billion yuan in 2018 ^[3], with a year-on-year growth of 3%, showing the great potential and good growth momentum of this field. This growth is not only attributed to the expansion of market demand but also to the Chinese government's support for the new energy industry. The government has introduced a series of policies to encourage the development of new energy, including financial subsidies, tax incentives, and market access facilitation. These policies have greatly promoted the development of the solar street light industry.

Looking ahead, the market size of solar streetlights in China is expected to expand further with technological advancements and cost reductions. The market size is expected to reach 6.985 billion yuan by 2025 ^[4], with a healthy CAGR. This forecast indicates that solar streetlights have a bright future in China and will become an important growth point in the new energy sector.

2.2. Status of international applications

The application of solar streetlights has become a key factor in promoting sustainable energy development and infrastructure development globally ^[5]. In many developing countries, especially in regions such as the Middle East, Africa, and South America, solar streetlights have been widely adopted and promoted because of their unique advantages.

Firstly, there is a huge need for infrastructure development in these areas, especially in rural and remote areas where electricity supply is inadequate. Solar streetlights provide a lighting solution that is independent of the traditional power grid, helping to solve the problem of power shortages in these areas. In addition, due to the abundant sunlight resources in these areas, solar streetlights can make full use of the local natural conditions to achieve efficient energy conversion, which makes solar streetlights an ideal lighting option for these areas ^[6].

Secondly, the installation and maintenance costs of solar streetlights are relatively low ^[7], which is especially important for countries and regions with a low level of economic development. Solar streetlights do not require complex grid laying, which reduces installation costs and time, as well as long-term maintenance costs. This is particularly attractive to developing countries with limited financial budgets.

Furthermore, the environmentally friendly characteristics of solar streetlights are also in line with the general trend of global emission reduction and climate change response ^[8]. Solar streetlights use renewable energy and do not produce greenhouse gas emissions, helping to reduce the global carbon footprint, which is positive for global climate change mitigation. In addition, the use of solar streetlights can improve local energy security and stability and reduce dependence on fossil fuels.

Finally, international organizations and aid agencies are also actively promoting the application of solar streetlights in developing countries. For example, officials of the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) have indicated that China's renewable energy technologies, including solar streetlights, have served as a model for countries in the Asia-Pacific region in solving the problem of energy shortage. Such international cooperation not only promotes the dissemination and application of technology but also provides financial and technical support to developing countries, accelerating the global popularization of solar streetlights.

In summary, the international use of solar streetlights not only helps to address infrastructure needs but is also in line with global sustainable development goals. With technological advances and cost reductions, it is expected that solar streetlights will play an even more important role in the future global energy mix.

2.3. Technical characteristics

The technical characteristics of solar streetlights are elaborated as follows:

(1) High-efficiency photoelectric conversion

The core of the solar street light is the solar panel, and its conversion efficiency is a key indicator of performance. The conversion efficiency of common crystalline silicon solar panels on the market today is generally between 15% and 20% ^[9], while the conversion efficiency of high-efficiency monocrystalline silicon solar panels can reach over 22%. This means that under ideal lighting conditions, each square meter of solar panel can generate approximately 220 watts to 440 watts of electricity.

(2) Intelligent control and optimization

Modern solar streetlights are equipped with controllers that can not only achieve basic charge and discharge management but also have intelligent optimization functions. For example, some controllers can optimize the charging and discharging strategy of batteries based on historical weather data and forecasts to improve energy efficiency. In addition, some high-end controllers also support remote monitoring and wireless upgrades, improving the maintainability and adaptability of the system.

(3) High-efficiency energy storage solutions

Battery is the energy storage unit in the solar street light system, and the commonly used types include lead-acid batteries and lithium-ion batteries. Lead-acid batteries are widely used because of their lower cost, but their cycle life is generally 3 to 5 years. In contrast, lithium-ion batteries have a higher cost, but their cycle life can be more than 10 years, and they have a higher energy density (usually more than 100 Wh/kg), which makes the solar street light system more lightweight and efficient ^[10].

(4) LED lighting technology

LED lights are ideal for solar street lights because of their high efficiency, long life, and dimmable characteristics. The luminous efficacy (i.e., luminous flux per unit of electrical energy) of LED lights is typically in the range of 80 to 150 lumens per watt (lm/W), which is much higher than that of conventional lighting technologies. This means that solar streetlights can provide the same or even higher lighting effects while consuming less power.

(5) Environmental adaptability and durability

The design of solar streetlights takes full account of the complexity of the outdoor environment. For example, the battery panels are usually equipped with anti-reflective coatings and self-cleaning features to improve power generation efficiency under different weather conditions. Meanwhile, light poles and battery boxes are usually made of corrosion-resistant materials, such as stainless steel or aluminum alloy, to withstand wind, rain, and salt spray corrosion.

(6) Economic and environmental friendliness

Despite the high initial investment cost of solar streetlights, their Total Cost of Ownership (TCO) is competitive in the long run, considering that there are virtually no additional costs during operation. According to the International Renewable Energy Agency (IRENA), the cost of solar streetlights has fallen by about 80% over the past decade and is expected to continue to fall in the future.

(7) Easy installation and maintenance

Compared with traditional grid-connected streetlights, the installation process of solar streetlights is simpler and faster. Generally speaking, it takes only 1 to 2 days to install a solar street light, and there is no need for complicated underground cable laying. In terms of maintenance, due to fewer system components, the failure rate is relatively low, and most problems can be detected and solved in time through the remote monitoring system.

In summary, the technical characteristics of solar streetlights make them an adaptable, energy-saving, environmentally friendly, and cost-effective lighting option. With the continuous progress of technology and further cost reduction, solar streetlights will occupy a more important position in the future lighting market.

2.4. Problems

As a green lighting solution, although solar streetlights have the advantages of environmental protection and energy saving, some challenges remain in their adoption.

(1) Insufficient light intensity

The energy supply of solar street lights relies on sunlight, so the power generation efficiency of solar panels will be affected under conditions of insufficient light intensity, such as cloudy days or areas with short sunshine hours in winter. When designing solar street lights, it is usually necessary to determine the capacity of solar modules based on local meteorological data, but this method sometimes leads to large deviations.

(2) Short battery life

The battery is a key component in a solar street light system and is used to store electricity generated during the day for use at night. However, batteries usually have a short lifespan and need to be replaced periodically. Batteries usually have a lifespan of around 5–8 years, whereas solar panels have a lifespan of up to 30 years or more. This means that the batteries may need to be replaced several times over the lifetime of the solar street light, increasing maintenance costs and workload.

(3) Low intelligence

Although modern solar street light systems are beginning to integrate intelligent control technologies, such as automatic brightness adjustment and remote monitoring and fault diagnosis, the popularization and application of these technologies still need to be improved. The development of intelligent street light systems still faces several challenges, including how to achieve a higher degree of automation and intelligence. In addition, communication technology for intelligent streetlighting systems is a key issue, and consideration needs to be given to how to achieve more stable and efficient data transmission.

(4) Maintenance cost and efficiency issues

The maintenance cost and efficiency of solar streetlights are also factors that affect their promotion. Although solar streetlights have fewer components, their long-term electricity costs are high, especially in areas where commercial electricity is used. In addition, the maintenance cycle of solar street lights is usually 8–10 years, requiring the replacement of components such as controllers, lithium batteries, and light sources, which can increase maintenance costs.

In short, the challenges in adopting solar streetlights mainly include insufficient light intensity, short battery life, low degree of intelligence, and maintenance cost and efficiency problems. These problems limit the widespread promotion and application of solar streetlights. Therefore, it is necessary to further optimize the design, improve the stability of the system, reduce maintenance costs, and continuously promote the development and application of intelligent technology.

3. Solar energy in street light application future development trend

As a kind of clean and renewable energy application, the future development trend of solar streetlights is manifested in many aspects such as technological innovation, market expansion, intelligent development, and policy support.

3.1. Technological innovation trends

Technological innovation is the core driving force to promote the development of the solar street light industry. With the improvement of solar cell conversion efficiency and the continuous optimization of LED lighting technology, the performance of solar streetlights will be significantly improved. 2023-2029 China PV lighting industry market business management and development trend will show continuous growth. In addition, the energy storage technology of solar streetlights is also progressing, such as the application of high-efficiency energy storage devices such as lithium-ion batteries, which will further improve the energy utilization efficiency of solar streetlights and the duration of continuous operation in cloudy and rainy days.

3.2. Market expansion trends

The global solar street light market is expected to continue expanding. The global solar streetlight market reached sales of RMB 38.6 billion in 2022 and is expected to reach RMB 117.2 billion by 2029, at a compound annual growth rate (CAGR) of 17.0%. The Chinese market has also grown drastically over the past few years and is expected to reach a market size of RMB 6.985 billion by 2025. This growth trend is attributed to the increasing emphasis on energy saving and emission reduction around the world, as well as the advantages of LED lighting products over traditional lighting products in terms of energy saving and environmental protection.

3.3. Intelligent development

Intellectualization is an important direction for the future development of solar streetlights. Combined with new technologies such as the Internet of Things, 5G, and other new technologies, remote monitoring, fault warning, intelligent dimming, and other functions of solar streetlights can be realized to better serve the construction of smart cities and energy-saving and emission reduction goals. For example, through the intelligent control system, the solar street light can automatically adjust the brightness according to the environmental light changes and improve energy utilization efficiency.

3.4. Policy support

Policy support is an important guarantee for the development of the solar street light industry. The “14th Five-Year Plan” of the modern energy system, the “Implementation Promoting New Energy Quality Development in the New Era,” and other policy documents clearly set out the goals and measures to promote the development of new energy sources, providing policy guidance and support for the solar street light industry. In addition, the Ministry of Industry and Information Technology and six other departments issued the “Guidance on Promoting the Development of Energy Electronics Industry” to improve the level of LED technology and promote the application of new semiconductor lighting products in smart cities, smart homes, and other areas.

3.5. Development with regional characteristics

The development of solar streetlights will also take into account regional characteristics. For example, in remote areas and places with unstable power supply, solar streetlights provide a reliable lighting solution that helps improve the quality of life of local residents and the safety of nighttime travel. On the other hand, in urban areas, the intelligent design of solar streetlights makes them an important part of smart city construction, helping to realize the goal of energy saving and emission reduction.

3.6. Industry technical strength

As the market evolves, China’s photovoltaic lighting industry will increase its investment in research and development to adapt to changing application scenarios and requirements. This is expected to further enhance the industry’s technical capabilities. Some large domestic companies in the photovoltaic street lamp sector have already met or even surpassed international lighting standards.

4. Conclusion

Through the comprehensive analysis of the application status quo, technical characteristics, problems, and future development trends of solar streetlights at home and abroad, the following conclusions are drawn:

As a green and renewable lighting solution, solar streetlights have gained widespread attention and application worldwide. Its environmentally friendly and energy-saving properties, as well as its contribution to the reduction of greenhouse gas emissions, make it an important tool for combating climate change and promoting sustainable development.

Technological progress is the key driving force for the development of the solar street light industry. With the improvement of photovoltaic power generation efficiency and the continuous optimization of LED lighting technology, the performance of solar streetlights is constantly improving. The introduction of intelligent control systems enables solar streetlights to utilize energy more efficiently while reducing maintenance costs and improving system reliability.

The expansion of the market scale signals the great potential of the solar street light industry. It is expected that in the next few years, with the further reduction of cost and the maturity of technology, solar streetlights will be more widely used worldwide, especially in developing countries and remote areas, and solar streetlights will become an effective way to solve the problem of power shortage.

Policy support is an important guarantee to promote the development of solar street lights. Policies introduced by governments to encourage the development of new energy sources have provided a favorable development environment for the solar street light industry. These policies not only promote the research and development of technology and innovation but also provide impetus for the industry’s market expansion.

Although the adoption of solar streetlights comes with many challenges, such as insufficient light intensity,

short battery life, low intelligence, and issues with maintenance costs and efficiency, these problems can be overcome with the progress of technology and the maturity of the industry. The industry needs to continue to increase R&D investment, optimize product design, improve system stability, and promote the development of intelligent technology.

The future development of solar streetlights will shift towards combining regional characteristics to meet the energy needs and environmental conditions of different regions. At the same time, technological advancements will make solar streetlights more competitive in the international market, driving the transformation and upgrading of the global energy structure.

In summary, the solar streetlight industry has demonstrated strong development momentum and broad application prospects. With the global emphasis on green energy and sustainable development, solar streetlights are poised to become a key focus in the future of lighting.

Disclosure statement

The authors declare no conflict of interest.

References

- [1] Zeng P, Fan F, Yan D, 2023, Intelligent Monitoring and Control of Street Lights Based on STM32 System Design. *Light Source and Lighting*, 2023(07): 68–70.
- [2] Jang H, Jin G, Guo S, 2021, Current Status of Solar Photovoltaic Power Generation Technology. *Journal of Heilongjiang Institute of Technology (General Edition)*, 21(10): 83–87.
- [3] Lin J, 2021, Research on LED Dimming Technology and its Application on Roadway Lighting. *Light Source and Lighting*, 2021(10): 34–36 + 76.
- [4] Zou Y, 2021, Research on Key Technologies of Internet of Things Infrastructure for Smart City. *Economic Research*, 2021(11): 50–51.
- [5] Wang S, 2022, Application of Internet of Things Technology in Smart City Construction. *Computer Knowledge and Technology*, 2022(5): 54–55.
- [6] Xie X, 2021, Application of Internet of Things Technology in Smart City Construction. *Small and Medium-Sized Enterprises Management and Science and Technology (Zhongdianjian)*, 2021(3): 189–190.
- [7] Wang ZG, Zhu XJ, 2020, Application of Solar Photovoltaic Power Generation Technology in Green Buildings and its Energy Saving Research. *Construction Science Technology*, 2020(23): 98–102 + 106.
- [8] Wang S, 2022, Application of Solar Photovoltaic Power Generation and Grid-Connected Technology. *Electronic Technology*, 51(04): 204–205.
- [9] Fu Y, Yang C, Zhang L, et al., 2024, Regional Feed-In Tariff Mechanism for Photovoltaic Power Generation in China Considering Tradable Green Certificate Revenue. *Journal of Cleaner Production*, 436: 140641.
- [10] Singh SC, Ankit G, Rahul C, et al., 2023, Review of Deep Learning Techniques for Power Generation Prediction of Industrial Solar Photovoltaic Plants. *Solar Compass*, 8: 100061.

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