Dean&Francis

ISSN 2959-6157

Analysis of the Future Development of Photovoltaic Power Generation

Zean Chen

College of Chemistry and Environment, Guangdong Ocean University, Guangdong Province, 524088, China
*Corresponding author: andychan@stu.gdou.edu.cn

Abstract:

Against the background of intensifying global climate change and accelerating energy structure transformation, photovoltaic (PV) power generation, as an important part of renewable energy, has received widespread attention for its technological development and application prospects. This paper analyzes the future development of photovoltaic power generation based on the current situation, starting from the status quo of different regions, analyzing the feasibility, to clarifying the future development direction. In rural areas, new technologies such as agro-photovoltaic complementary technology have been added to expand the application of PV while ensuring agricultural production, and microgrids have been added to make the power supply smarter. In urban areas, linking PV power generation to buildings makes full use of urban space, and the addition of green power trading promotes PV power generation on an economic level. The new technology of chalcogenide solar cells, which improves the efficiency of power generation and compensates for the lack of heat resistance of existing solar cells, has great potential for future expansion in different environments and across different regions.

Keywords: Photovoltaic power generation, photovoltaic planting, photovoltaic building integration, chalcogenide solar cells.

1. Introduction

Conventional power generation methods such as coal power and gas power are based on burning non-renewable energy sources to generate heat and convert it into electricity, which generates a large amount of greenhouse gases. For example, greenhouse gas emissions from coal power account for 30% of global carbon emissions from the power sector. Gas power of Greenhouse Gas (GHG) emissions are 0.35-0.5 kg CO_2 per kWh. Global energy-related CO_2 emissions in 2023 amount to 36.8 billion tons, with China accounting for 33%. Incomplete combustion of fuels during conventional power generation releases sulfur- and nitrogen-containing compounds, as well as fine particulate matter, which is harmful to humans. China is a large coal power country, coal mining, waste accumulation and thermal pollution seriously affect the ecology. It is therefore of great significance to transform the energy structure. In the transformation of energy structure, photovoltaic power generation, as a component of renewable energy, has the advantages of zero pollution and zero greenhouse gas emissions in operation. Its whole life cycle carbon emission is only 1/20 of coal power, and there is basically no harmful gas emission in the operation stage. Moreover, PV power generation occupies a small area and has a flexible layout, such as photovoltaic (PV) farming and PV building integration, which can be fully utilized by adding PV facilities to meet the original environmental needs. Relevant scholars believe that China is going to achieve carbon neutrality in 2060, according to the existing plan of photovoltaic and wind power annual power generation there is a huge gap, China is going to achieve carbon neutrality, can not only rely on "build more power plants", more need for transmission, energy storage, power use of the whole chain of optimization, so that photovoltaic and wind power is more efficient, more economical[1] . Some researchers also believe that China's short-term electricity tariffs will rise as it achieves carbon neutrality in electricity, but through technological advances and policy optimization, the costs can be kept within an acceptable range [2].

Currently, most articles analyze future renewable energy based on the macro level. But as the continuous development of photovoltaic power generation, the current stage of research does not point out from the current situation to point out the future development aspects. Therefore, this paper introduces the status quo of photovoltaic power generation from different regions, and then analyzes the feasible direction of future photovoltaic development based on the current stage of photovoltaic power generation applications. These analyses are very meaningful for the future development of photovoltaic power generation.

2. Analysis of the current status of the application of photovoltaic power generation

2.1 Current status of application in rural areas

At this stage, the specific applications of photovoltaic in agriculture are: photovoltaic planting, photovoltaic greenhouse, photovoltaic breeding, etc[3]. Among them, photovoltaic planting is a preliminary combination of crop cultivation and photovoltaic power generation, prioritizing photovoltaic power generation and improving the utilization rate of land compounding using concurrent agricultural cultivation. Under rational planning, it not only enriches local people's sources of income but also promotes their incomes [4]. However, the application focuses on photovoltaic power generation, and PV power generation and agricultural cultivation are simply superimposed. At the present stage, we are facing the problem of agricultural yield reduction due to the blockage of light as well as the over-pursuit of photovoltaic power generation, which leads to the neglect of agricultural production. In contrast, agro-photovoltaic complementarity is a technology that combines PV power generation and agriculture organically, which is different from the application of PV in agriculture, and emphasizes the mutual influence, competitive relationship and coupled symbiosis between PV power generation and agricultural production[5].

In addition to PV agriculture, microgrid systems, as an important complement to PV on the rural energy supply side, have also been widely used in practice. A microgrid is a small-scale power generation and distribution system that integrates distributed power sources (PV, wind, etc.), energy storage, loads, inverters, and protection devices. Microgrids have more applications in rural areas. Microgrids are categorized into grid-connected operation mode and islanded operation mode[6]. Grid-connected operation mode integrates the local microgrid into the main grid, effectively reducing load fluctuations [7]. The islanding mode of operation, on the other hand, strips the microgrid from the main grid when an abnormality in the main grid is detected, forming a small power system. This requires the control of the microgrid to require suitable control strategies [8] to stabilize the fluctuations brought about when disconnecting from the main grid. Difficulty in the scientific construction of microgrids in rural areas, high maintenance costs, lack of relevant equipment packages, energy fluctuations due to the high randomness of photovoltaic and wind power generation in remote areas, and the high cost of energy storage are the main challenges at present.

2.2 Current status of application in cities

Building Attached Photovoltaics (BAPV) refers to systems where PV power generation modules are mounted as additions on top of existing or new building structures. BIPV refers to a system where the PV power generation function is directly integrated into the building envelope itself, replacing or being part of the traditional building materials. BAPV is mainly characterized by the direct integration of the PV system into the building, whereas BIPV is the organic integration of the PV system into the building. BAPV installs PV panels on an existing building to generate electricity only, without assuming the building functions. BIPV integrates photovoltaic power generation systems into the roof, curtain wall, windows and other structures of a building, with functions such as temperature regulation. It is characterized by long service life and

ISSN 2959-6157

aesthetics. Some old buildings in the city usually take the building and photovoltaic combined relationship straight on the roof of the building to install photovoltaic facilities. Photovoltaic integration of the building will be installed in the building of solar panels on the curtain wall can be in the hot summer to achieve the cooling effect, in the cold winter, can be constructed photovoltaic/photothermal building integration (BIPV/T) system to achieve the effect of reducing the heating load in winter. Urban buildings utilizing BIPV technology have the option of changing transparency for lower heat gain and higher power generation[9].

Green power trading refers to a market-based mechanism whereby users purchase green power produced by renewable energy power producers and its corresponding environmental value through the electricity trading market. Its core lies in packaging or splitting the “physical power” and “environmental rights” of renewable energy power to form a closed loop of consumption. Photovoltaic power generation produces green power, and green power trading is a way to realize the environmental value. As of the first quarter of 2025, China’s direct intra-provincial green power trading has been as high as 80.75 billion kWh [10]. This demonstrates the vibrant and vast potential of China’s green power trading market. Innovations in financial and business models have energized the flow of capital and products. The inclusion of cities in the green power trading system means that the energy-consuming side of the city has a channel to directly purchase and use low-carbon electricity and reduce carbon emissions from electricity consumption[11]. Rural incorporation of green power trading, in addition to driving the flow of capital, the flow of products to make up for the lack of rural products, but also to ease the overcapacity of solar products in the city, but also to promote the flow of urban services to the countryside.

3. Feasibility analysis of photovoltaic power generation promotion

3.1 Future Extension Analysis

Future regional solar energy distribution affects extension. The study shows that future solar radiation in China will be higher in the west and north and lower in the east and south. This demonstrates the strategic importance of the north-western region of China for large-scale solar energy development[12], and emphasizes the need for differentiated technology deployment strategies based on regional radiation characteristics. Adopting intelligent sun-tracking photovoltaic power generation panels in areas with extremely abundant solar energy, where the total annual solar radiation is greater than 1750 kWh/m², can increase power generation capacity. In areas with lower solar radiation adopting highly efficient PV technologies such as thin film batteries to take full advantage of their low light characteristics improves power generation efficiency. In addition the impact of increased climate extremes on PV panels needs to be included in the analysis of future rollout. Global warming continues, especially with the widespread high temperatures throughout China in the summer. High temperatures lead to a decrease in the efficiency of photovoltaic power generation [13].It is particularly important to promote heat-resistant and durable photovoltaic power generation panels or to promote power generation panels that meet the requirements of autonomous heat dissipation. Weather instability also affects the stability of PV power generation. The energy storage system becomes the key to stable power generation, which improves the energy storage system, industrial follow up and appropriate supporting strategy is the future direction of industrial development.

3.2 Technical promotion analysis

Currently, crystalline silicon solar cells are the mainstream of the market. The vast majority of solar power stations in China use polycrystalline silicon solar cells instead of monocrystalline silicon solar cells. The technology of crystalline silicon solar cells is further divided into monocrystalline silicon, polycrystalline silicon, and N-type cells (TOPCon/HJT). Most of the solar power stations in China are not monocrystalline silicon solar cells, but with polycrystalline silicon solar cells. n-type cells are priced between polycrystalline silicon and monocrystalline silicon, with high conversion rate, low attenuation characteristics, the market share is rising year by year. In fact, crystalline silicon solar cells have many drawbacks, such as high temperatures will reduce its efficiency, in cloudy days, power generation significantly decreases, the price of raw material silicon fluctuates. Calcium-titanium solar cells can better solve these problems. On cloudy days calcite solar cells produce 8-12% more power than crystalline silicon solar cells, and in high-temperature environments calcite solar cells have even lower efficiency losses. Given the current crystalline silicon solar cells dominate the market, while the calcite solar cells are not in the stage of widespread application their impact is unknown impact can be considered to strengthen cooperation between enterprises and laboratories to improve the product, but also consider the integration with crystalline silicon solar cell technology.

4. Analysis of new solar technologies

4.1 An example of a new technology

The chalcogenide material acts as a light-absorbing layer that generates electron-hole pairs in response to light, and these charge carriers are separated and collected by the material's internal electric field, ultimately forming an electric current[14]. Since the first report in 2009, energy efficiencies of chalcogenide solar cells have reached 25% [15], and even as high as 39.5% for the stacked type [16]. The light transmittance of chalcogenide cells can be changed by adjusting the internal components; however, with the current technology and materials, chalcogenide's lack of stability stands out as a drawback. First of all, calcite solar cells are environmentally demanding. The full penetration of moisture leads to irreversible decomposition of the chalcogenide crystals. Secondly, ion migration ultimately leads to the deterioration of the chalcogenide solar cell triggering structural instability.

4.2 Prospects for the promotion of new technologies

The addition of new chalcogenide batteries in both urban and rural scenarios needs to overcome their original disadvantages, with environmental factors and intrinsic factors of the material contributing to their instability. Insulation of the cell from the environment through thin-film coverage improves its adaptability to the environment and increases its reliability and stability. Increase the research and development of materials, such as doping crystals in the titania to make it difficult to decompose. In research and development, we should explore the potential application scenarios, build a reliable recycling system, and combine with the existing technology promotion for the layout of its large-scale application.

5. Conclusion

This paper firstly analyzes photovoltaic power generation from the regional status quo and points out the characteristics of photovoltaic power generation in different regions at this stage. Secondly, it analyzes the feasibility of photovoltaic power generation based on the future and points out the advantages of new solar technology. Finally, the new technology is analyzed and its development direction is depicted. This analysis concludes that the future of photovoltaic power generation will be improved by the new method of technology will be added to alleviate the shortcomings of the existing photovoltaic power generation, new technology promotion is full of feasibility. This analysis focuses on the future analysis of photovoltaic power generation, which is conducive to clarifying the future development direction. Finally, the article concludes by analyzing the future technology and applications, but the policy support has a profound impact on the PV power industry, and the future can be analyzed in light of the policy and new technology on the direction of PV power generation.

References

[1] Wang, Y., Wang, R., Tanaka, K. et al. Accelerating the energy transition towards photovoltaic and wind in China. Nature 619, 761–767 (2023). https://doi.org/10.1038/s41586-023-06180-8

[2] Zhuo, Z., Du, E., Zhang, N. et al. Cost increase in the electricity supply to achieve carbon neutrality in China. Nat Commun 13, 3172 (2022). https://doi.org/10.1038/s41467-022-30747-0

[3] Chen Jian,Wang Lingjun. Research review and outlook of agricultural light complementation[J]. Jiangsu Agricultural Science ,2022,50(05):1-9.DOI:10.15889/j.issn.1002-1302.2022.05.001.

[4] M. E. Ya'acob, N. F. Othman, M. Buda, E. Jani and A. S. Mat Su, "Field assessment on Agrivoltaic Misai Kucing Techno-economical approach in Solar Farming," 2021 International Conference on Electrical, Computer and Energy Technologies (ICECET), Cape Town, South Africa, 2021, pp. 1-6.

[5] Wang Lingjun,Chen Jian. A review of relevant research on the combination of photovoltaic and agriculture[J]. Anhui Agricultural Science. 2021,49(18):18-21+29.

[6] YUAN Haozhe, YE Huanhuan, CHEN Yaoting, et al. Study on optimal allocation of optical storage capacity for rural microgrid[J]. Guangdong Electric Power, 2023,36(05):49-57.

[7] Shanshan Shi, Zongxiang Lu, Shuangxi Zhou, et al. Characteristics and development direction of microgrid in China[J]. China Electric Power, 2009,42(07):21-25.

[8] V. Motjoadi, P. N. Bokoro and M. O. Onibonoje, "Review of Switching and Control Techniques of Solar Microgrids," 2020 IEEE PES/IAS PowerAfrica, Nairobi, Kenya, 2020, pp. 1-5, doi: 10.1109/PowerAfrica49420.2020.9219836.

[9] S. Jois, K. Ramamritham and V. Agarwal, "Impact of Facade based Building Integrated Photovoltaics on Indoor Thermal Conditions in Mumbai," 2020 47th IEEE Photovoltaic Specialists Conference (PVSC), Calgary, AB, Canada, 2020, pp. 0636-0639.

[10] China Energy Storage Network - Electricity Spot Market - National Electricity Market Transactions in January-April

[11] GUO Shengwei, MEN Xiujie, SUN Haiping, et al. A comparative study on the status and trend of green power, green certificate and CCER policies in China[J]. China Energy, Inc. 2022,44(03):75-80.

[12] Yong Zhou, Xueli Sha, Lingyu Wang, Xiang Li, Zhihao Zhang, Spatial and temporal dynamics of solar energy resources

ISSN 2959-6157

in China and forecast of future solar radiation, Journal of Atmospheric and Solar-Terrestrial Physics, Volume 269, 2025, 106463, ISSN 1364-6826.

[13] Ho Hyeon Jo, Jimin Kim, Sumin Kim, Enhancing the power generation performance of photovoltaic system: Impact of environmental and system factors, Applied Thermal Engineering, Volume 240, 2024, 122221, ISSN 1359-4311.

[14] SUN Jing, LIU Yueqiu, ZHAO Haozhe, et al. Research and progress on thin films of chalcogenide solar cells[J]. Chemical Design Newsletter, 2025,51(03):133-135.

[15] SUN Haifeng, WANG Li, ZHANG Lijiu, et al. Progress and prospects of research on chalcogenide standards[J/OL]. Materials Herald, 1-9[2025-06-01].http://kns.cnki.net/kcms/detail/50.1078.TB.20250402.1946.004.html.

[16] O. Er-raji et al., "Perovskite Silicon Tandem Solar Cells with 39.5% Power Conversion Efficiency: Science or Fiction?," 2024 IEEE 52nd Photovoltaic Specialist Conference (PVSC), Seattle, WA, USA, 2024, pp. 0350-0350.