

Comparative Application Research of Wind Energy and Solar Energy

Zhuo Song*

Department of International Education, Hebei University of Technology, Tianjin, 300401, China

* Corresponding Author Email: 214861@stu.hebut.edu.cn

Abstract. The global demand for energy is increasing, promoting the development and utilization of renewable energy. Wind and solar power, as green energy sources, provide fossil fuel alternatives for climate change mitigation. In this paper, the principles, technological progress, environmental benefits and challenges of wind farms and solar photovoltaic plants, as well as their important role in modern energy systems, are studied. This paper presents a comprehensive comparison of wind and solar energy, focusing on three key aspects of cost, efficiency and environmental impact. Comparisons include the initial and ongoing costs associated with establishing and maintaining each energy system, the efficiency of converting natural resources into available electricity, and environmental impacts, including potential disruption to local ecosystems and land use considerations. Based on the findings of this paper, it proposes targeted improvements designed to improve the overall performance of these two renewable energy technologies, laying a solid foundation for future sustainable development.

Keywords: Wind energy, Solar energy, Sustainable development, Environmental impact.

1. Introduction

With the continuous growth of global energy demand, the development and utilization of renewable energy has become a focus of general concern in the international community. Under these circumstances, wind power and solar power generation, as the most promising green energy technologies, can be the right alternative energy sources to meet global demand and protect the atmospheric environment. At present, it has been widely promoted and applied worldwide. This paper will provide an in-depth discussion of the operation principles, technological development, environmental benefits and challenges of wind farms and solar photovoltaic farms, aiming to provide a comprehensive understanding of the important role of these two technologies in the modern energy structure [1].

Wind power generation uses wind energy into mechanical energy, and then into electric energy through a generator. It is a way of power generation using natural wind resources. Solar photovoltaic power generation is through the photovoltaic effect to directly convert sunlight into electricity. Neither type of power generation relies on fossil fuels, thus significantly reducing greenhouse gas emissions and fighting global climate change.

However, wind and solar power generation also face technological and economic challenges, such as cost and technological development. This paper will explore these challenges and discuss how we can overcome them through technological innovation and policy support to achieve the wider use and sustainable development of wind and solar power generation. By gaining insight into the potential and limitations of these renewable energy sources, we can better assess their location and role in future energy systems.

After further research, this paper focuses on two key renewable energy sources: wind and solar energy. And the article begins with summarizing the basic principles of how these two technologies use natural resources to convert into electricity. It explains in detail the mechanism of how wind turbines and photovoltaic cells convert wind and sunlight into electricity. In addition, the paper explores the grid connection technologies that are closely related to these two modes of power generation, which is crucial for connecting the power generated seamlessly to the existing grid system. Then, this paper makes a comprehensive comparison between the two power generation methods

from three dimensions: cost, power generation efficiency and environmental impact. This comparison involves not only the initial and ongoing costs associated with building and maintaining each energy system, but also evaluates the efficiency of wind turbines and solar panels in converting natural energy into available electricity. It also explores the potential environmental impacts of each method, including potential disruption to local ecosystems and land use considerations. Based on the above comparison results, this paper finally proposes a targeted improvement scheme, aiming to improve the comprehensive performance of these two renewable energy technologies and provide more solid technical support for the future sustainable development.

2. Grid connection of new energy sources

2.1. Wind power generation

2.1.1. Principle of wind power generation

Wind power is one of the most rapidly developing technologies in renewable energy, and is seen as a core element of the global sustainable energy transition. As a clean energy source, wind power generation does not produce greenhouse gas emissions during the operation process, which is of positive significance to reduce the pressure of climate change [1]. In addition, wind resources have renewable and sustainable characteristics, making them an ideal alternative energy source to fossil fuels.

In recent years, the wind power industry has been developing rapidly around the world, thanks to the policy support and continuous technological progress of various countries. The innovation and improvement of production and manufacturing technology, control technology and other aspects provide strong support for the wide application of wind power generation. Wind power uses the kinetic energy of the wind into mechanical energy or wind energy, which is then converted into the form of available energy, usually electricity. This process makes full use of the natural wind power in the atmosphere and realizes the effective use of energy [2].

Wind power generation system is a kind of device that uses wind power drive generator to conduct power production. The basic principle is based on aerodynamics, with the blades of wind turbines designed to capture as much wind energy as possible and convert it into mechanical energy. Subsequently, the motor converted this rotating mechanical energy into electrical energy. In order to ensure the maximum energy conversion efficiency and power quality, the system also adopts an appropriate control strategy [3]. Wind power connection to the grid is shown in Figure 1.



Fig. 1 Wind power grid connection (Photo/Picture credit: Original)

The process of connecting wind power to the grid involves several key steps. Here is a detailed introduction of the process of wind power from the unit to the grid. First, the wind drives the turbine to rotate and drives the generator to generate electricity. Efficiency is affected by the wind speed and the technology. Secondly, the power first passes through the controller to monitor and adjust the voltage and frequency to ensure the safety of the power output. When the wind speed is too high, the turbine is turned off to protect the equipment. After that, the power through the inverter from DC AC to meet the needs of home appliances and power grid. The inverter also adjusts the output frequency and phase to ensure compatibility with the power grid. Finally, the grid is connected, and the adjusted

power is transmitted through the grid interface, including protective measures such as circuit breakers and disconnecting switches. Power is distributed through power lines to large power grids for local or remote use. This process enables efficient and safe extraction of wind energy from natural wind currents and conversion into stable and reliable power supply to meet energy demand.

2.1.2. Grid-connection mode of wind power generation

There are two different types of wind power generation: independent off-grid operation. Off-grid wind power generation is small in scale, and the power supply problem in remote areas can be solved by using energy storage devices such as batteries or combining them with other energy power generation technologies. The grid-connected wind power farm connected to the power system can be compensated and supported by the large power grid and more fully develop wind resources, which is the main development direction of global wind power generation.

Wind farm networking has two ways: AC networking and DC networking. The traditional communication networking method has been applied for a long time and still occupies the main position. The past wind turbine installed capacity is small, the impact on the power grid is quite limited, then wind power grid to the system influence mainly voltage fluctuation and flash, harmonic pollution and other power quality problems, with the expansion of modern wind farm, large capacity wind turbines into the grid, wind power network to the system with negative impact extended to the stability and security of the system.

The main advantage of the AC grid-connected technology (HVAC) of wind power is that the transmission system structure is simple, and the cost is relatively low when the transmission distance is relatively close. However, there are a series of technical obstacles that are difficult to overcome, such as the capacity power of the line, the stability of the synchronous operation system, power flow control, etc.

Direct current grid-connected technology (HVDC) for wind power. HVDC line costs are low, but converter stations are high. Therefore, when long-distance transmission, DC transmission is more economical. HVDC can quickly control the power flow, stabilize the frequency and AC system. At the same time, it is suitable for the construction of multi-terminal DC transmission network, which for multiple wind farms or distributed power to the grid.

2.2. Solar power generation

2.2.1. Principle of solar power generation

Solar energy system is a system that uses solar energy as energy, which can use the thermal energy or light energy of solar energy to generate electricity. The system is mainly based on the photovoltaic effect, by using photovoltaic (PV) cells to convert sunlight directly into electricity. These cells are made of semiconductor materials, usually silicon, that are able to absorb photons in the sunlight and release electrons.

The equivalent circuit of solar cells consists of three main functional layers: n-layer, p-layer and depletion layer. In the three-layer structure, the middle layer is the depletion layer, which connects the n-type layer with the p-type layer. The n-type layer is rich in free electrons, while the p-type layer has a lot of holes. When sunlight shines on the surface of the cell, the photons interact with the material, leading to the release of free electrons. These electrons move inside the battery, creating a DC current, which converting solar energy to electricity [4].

Solar panels are composed of multiple photovoltaic cells, and their operating efficiency is affected by a variety of factors, including but not limited to the type of semiconductor materials, the specific structure of the solar cell, and the intensity of sunlight. The grid connection of solar power generation is shown in Figure 2.

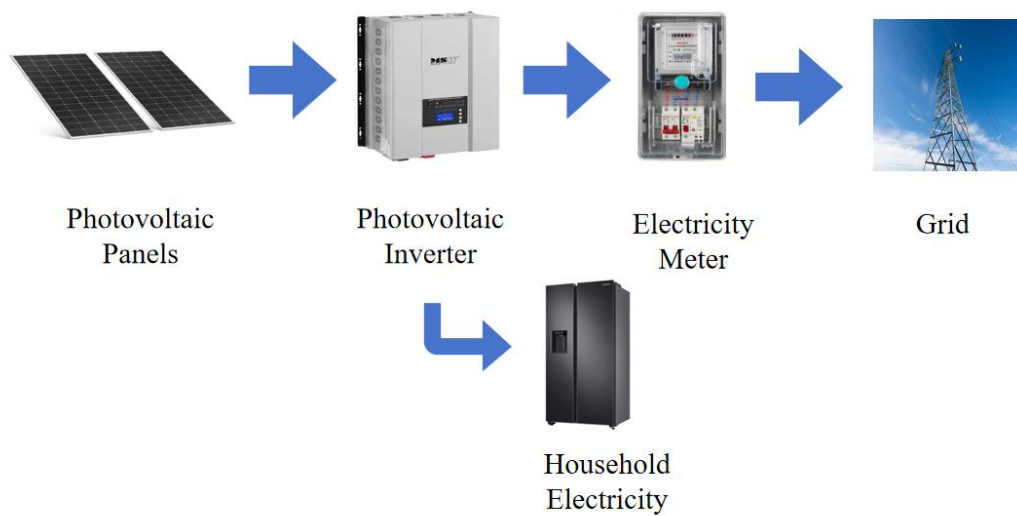


Fig. 2 Solar power grid connection (Photo/Picture credit: Original)

To be compatible with the grid and household appliances, we need to convert the direct current generated by the solar panels to alternating current. Solar panels generate direct current by capturing sunlight and are usually installed in sunny areas for optimal energy conversion efficiency. Direct current is converted to alternating current through photovoltaic inverters, compatible with household appliances and the power grid. The converted AC electricity is powered to the household appliances through the electrical panel, the unconsumed electricity is measured through the public meter, and the excess electricity is incorporated into the grid. This structured sequence effectively uses solar energy, reduces fossil fuel dependence, reduces electricity bills, and promotes environmental sustainability.

2.2.2. Grid-connection mode of solar power generation

Connecting solar power systems to the grid requires converting the direct current generated by the solar panels into alternating current that is compatible with the grid and home appliances.

The grid-connected photovoltaic system has the function of integrating with battery storage and can operate independently or in grid-connected mode. Battery storage, with its huge energy reserves, can deliver active power to the grid during peak hours. In addition, it can effectively balance the power generation process and minimize the impact of solar intermittent. Therefore, whether the photovoltaic system integrates battery storage becomes an important basis for its classification. In practice, however, most grid-connected PV systems are not equipped with battery storage.

The classification of photovoltaic systems becomes important for understanding the recent developments in improving the performance of energy collection systems. This chapter discusses the architecture and configuration of the grid-connected photovoltaic power generation system. In general, grid-connected photovoltaic power generation systems can be divided into two categories: centralized MPPT (CMPPT) and distributed MPPT (DMPPT) [5].

Basic principle of distribution: Make rational use of the surface area of the building to meet the electricity needs of the nearby residents. Throughout the power supply process, we will make full use of the adjustment function of the grid connections to ensure a stable supply of power and reasonable distribution adjustment, so as to cope with any possible differences in power supply.

Advantages: The PV power is located on the user side to supplies the local load and is regarded as a load. This configuration effectively reduces the dependence on the power grid, reduces the line loss, and improves the energy efficiency. In addition, photovoltaic cells can be skillfully integrated into the surface of the building, used as building materials, not only beautiful and practical, but also effectively reduce the footprint. At the same time, the interface between photovoltaic power supply and smart grid and micro grid is flexible and has the ability of independent operation, which provides a strong guarantee for the stable operation of the power system.

Disadvantages: The power flow direction of the distribution network leads to the increase of loss, so it is necessary to rearrange the protection and transform the transformer junction. It is difficult to adjust the voltage reactive power, the power factor control after photovoltaic access, and the short circuit power increases. The distribution network level energy management system needs to manage the load uniformly, put forward new requirements for secondary equipment and communication, and increase the complexity of the system.

Centralized basic principle: Relying on the abundant and stable solar energy resources in desert areas, large-scale photovoltaic power stations are planned and built, and the stable power supply of remote load is realized by connecting to the high-voltage transmission network.

Advantage: The site selection is flexible, the photovoltaic output stability is improved, and the positive peak regulation characteristics of solar radiation and power load are used for peak cutting. Flexible operation mode, strong adaptability, can efficiently implement reactive power and voltage control, and actively participate in power grid frequency adjustment. The construction cycle of this project is short, with excellent environmental adaptability, and maintaining the operating cost at a relatively low level. In addition, it is easy to centralized management, small requirements for space restrictions, easy to perform capacity expansion operation.

Disadvantages: In order to ensure the safe and stable operation of the power grid, it is necessary to use long-distance transmission lines to transmit electricity to the power grid. However, large-scale photovoltaic power stations are also a major source of interference in the grid, which leads to the loss and reactive power compensation becoming particularly prominent. The large capacity photovoltaic power station is constructed in the cooperation of many transformation devices. In order to ensure the stable and efficient operation of the equipment, unified management and control measures must be implemented. Now the technology of photovoltaic access to the power grid still needs to be improved. In order to ensure the stability and safe operation of the power grid, it is necessary to introduce new functions. However, there are potential conflicts and contradictions between these technologies and the operation of the island, and it is urgent for us to conduct in-depth research and exploration to seek reasonable solutions.

3. Performance comparison

3.1. Wind power

3.1.1. Cost of wind power

Like other renewable energy technologies, wind is capital intensive but has no fuel costs. Controlling the key parameter wind economy includes: investment costs; operating and maintenance costs; economic life and capital costs [6].

The initial cost of wind power is high, accounting for a large portion of the total financial expenditure. Initial capital costs include infrastructure construction costs. The infrastructure of wind farm construction includes fan installation platform, cable laying, substation construction, etc. These infrastructures are more expensive to build. First of all, the fan installation platform needs to be reasonably designed according to the terrain and soil conditions to ensure the stable and safe operation of the fan. Secondly, the cable laying not only requires a lot of manpower and material input, but also needs to fully consider the quality and transmission capacity of the cable. As the core component of wind farm, the importance of substation construction investment is self-evident. Therefore, in the construction process of wind farms, the cost of infrastructure construction occupies a pivotal position.

As an indispensable core component of wind power plant, wind power equipment covers the fan and its related accessories. As a key link in the power generation process, the change of its price and quality is directly related to the construction investment and economic benefits of the power farm. Recently, the rise in wind turbine prices has become a common phenomenon worldwide, mainly due to the rapid demand growth in the wind power industry and supply constraints. In addition, the prices of wind turbine components are also rising trend [7]. In addition, the procurement and installation

costs of fan accessories such as towers and blades must be considered. Therefore, the cost of wind power generation equipment is one of the important factors affecting the cost of wind farm construction.

Operation and maintenance costs account for a significant proportion of the total annual cost of wind turbines. Operation and maintenance costs include equipment maintenance, operation management and other expenses. Including periodic maintenance of wind turbines is essential to ensure optimal performance, including periodic inspection, replacement of worn parts, and repair. For new turbines, operation and maintenance costs can easily account for 20-25% of the total leveling cost in the life cycle of the turbine. But by the end of the turbine life, that could increase to at least 20-35%. As a result, operating and maintenance costs are attracting increasing attention, as manufacturers try to significantly reduce these costs by developing new turbine designs [7]. With the increasing capacity of wind turbines, their investment costs are showing a decreasing trend, which reflects the characteristics of economies of scale. It suggests that operating and maintenance costs may also show similar economies of scale effects. In other words, there is a degree of correlation between the reduction in operation and maintenance costs and the expansion of wind turbines.

3.1.2. Wind power generation efficiency

The efficiency of wind power depends on a variety of factors, including turbine technology, wind speed changes, and more.

Progress in turbine design, blades: Blades are a very important part of the turbine, and their size and shape directly affect the efficiency of the wind turbines. At the same rotation speed, the long blades produce more torque, making the turbine more efficient. Wind turbines are driven by the wind, and the size of the turbine blades is directly proportional to the sweep. So, the larger the blade, the more the electricity is generated. With more blades, it produces more torque, but it rotates at a slower speed. The three-blade design is a good balance, simple and reliable, with high power generation and light weight. The selection of leaf number is important, and it will directly affect the overall performance and efficiency [8]. The larger rotor diameter and high tower allow wind power to capture low-speed wind energy where previously unsuitable, generating more power and making wind power feasible [7]. The efficiency also comes from better materials, which reduces the weight of the turbine and improves durability.

In addition, wind speed is one of the most important factors affecting the efficiency of wind turbines. The higher the wind speed, the greater the force the blade receives, and thus the faster the generator turns. Therefore, at higher wind speed, wind turbines can exert higher efficiency. Innovation in offshore wind farms takes advantage of higher and more stable offshore wind speeds. These advances lead in a higher capacity coefficient that measures the maximum output of a turbine over time.

3.1.3. Environmental impact of wind power generation

The construction and operation of wind power plants have a certain impact on the environment, including air quality, wildlife and birds, noise pollution, land resource utilization and so on. Air quality is less affected by wind farms, but during the construction and operation of wind farms, the emission of some air pollutants is inevitable. The construction of wind farms can damage wildlife and plant habitats, especially for birds and bats. The noise generated by wind turbines while operation may affect the communication and reproduction of birds, resulting in reduced numbers. At the same time, the rotating blades and towers of wind turbines can become obstacles for birds and bats, causing death or injuries. Wind farms occupy a large amount of land resources and may affect local ecosystems such as forests, farmland and grasslands. In addition, the process of wind farm construction may also destroy the original land ecosystem. Noise pollution is also a major factor in the environment of wind farms. When wind turbine blades rotate and make noise, they will cause disturbance to the surrounding residents and wildlife [9].

3.2. Solar power

3.2.1. Solar power generation cost

The cost of solar thermal power generation mainly includes investment cost, operation and maintenance cost, etc. The investment cost of solar thermal power generation mainly includes the equipment purchase cost, the land lease cost, etc. Equipment purchase cost is the most important investment cost of solar thermal power generation, including the purchase cost of solar photovoltaic panels, generator sets and other equipment. Land lease fee refers to the cost of leasing land for solar and thermal power generation sites. After long-term technology research and development and industrial upgrading, the cost of solar energy has been greatly reduced, and the competitiveness of traditional energy is increasingly enhanced. This remarkable achievement is mainly attributed to the continuous innovation of photovoltaic technology, the effective promotion of economies of scale, and the significant optimization of the solar panel manufacturing process [10]. The operation and maintenance cost of solar power generation mainly covers the cost of equipment maintenance. Given its lack of mechanical components, its maintenance workload is relatively small. In addition, the high durability of solar panels and the long-term warranty period provided by manufacturers further enhance the economic attractiveness of solar investment. Together, these factors provide a strong guarantee for the sustainable development of solar power generation [11].

3.2.2. Solar power generation efficiency

Solar power generation is a kind of renewable energy, with the characteristics of low carbon emissions and environmental protection. To improve the efficiency of solar power plants depends on a variety of factors, including environmental factors, dust effects, photovoltaic panel materials, etc.

The efficiency of solar power generation is also affected by environmental conditions. Environmental factors also include temperature, geographical location, the angle of the panel, light conditions, and shadows. For example, the performance of solar cells decreases as the temperature rises. Optimizing the orientation and inclination of photovoltaic panels to better accept direct solar light can improve the efficiency of power generation. The main effect of dust is that dust, dirt or other impurities may accumulate on the surface of the components during the operation of solar power stations, which will affect the absorption and conversion efficiency of light [12]. Therefore, the regular cleaning of the photovoltaic module surface is an important step to improve the efficiency of power generation. The selection of high-efficiency photovoltaic panels is the key to improving the efficiency of solar power stations. The more efficient the photovoltaic modules are, the higher the proportion that can convert solar energy into electricity. There are two silicon technologies, namely monocrystalline silicon and polysilicon. It is worth mentioning that the efficiency of single crystal cells and their modules is excellent, leading in all types of battery technologies [13].

3.2.3. Environmental impact of solar power generation

As a clean and sustainable energy option, the solar power generation system has attracted wide attention. However, we should also recognize the possible environmental impact of solar power systems.

First, the land will be affected. To maintain the Angle of the photovoltaic panels in the solar farm, concrete structures were embedded in the soil. At the end of the life of photovoltaic panels, the soil effectiveness is weakened and the vegetation restoration process is hindered. In addition, the installation of photovoltaic panels requires a certain amount of land space [14]. Making ground photovoltaic plants likely to compete with other land uses, such as agriculture, forestry, conservation, or urban development [9]. Secondly, the photovoltaic systems installed on the roof and the ground will have a direct or indirect impact on the environment. Adding solar panels on undeveloped land may lead to the loss of animal and plant habitat. And with water pollution, visual effects, etc. And produce toxic substances, which produce flammable and toxic materials during the construction of photovoltaic panels that, if buried or burned, can seep into the soil and water and pose environmental risks. Greenhouse gas emissions are generated throughout solar power generation, during the

production of components, the handling and transportation of materials, and the installation, decommissioning and disassembly of power stations [9].

3.3. Comparison

Wind energy and solar energy are two important pillars of today's renewable energy field. They each have unique characteristics and advantages and have made important contributions to global energy transformation and sustainable development. But they also have certain differences in some aspects.

Differences in energy conversion methods. Wind energy and solar energy are both technologies that use natural forces to convert, but the energy is converted in different ways. The wind energy is rotated by the turbine, driving the generator below, and converting the wind energy into electrical energy. Solar energy produces electricity by concentrating light onto solar panels. Therefore, wind energy needs to rely on air movement to generate electricity, while solar energy requires sufficient sunlight.

Differences in costs. An important difference between wind and solar energy is the cost of installation. Although the cost of both technologies has decreased over the past few years, overall solar technology is relatively less expensive to install, making solar a more cost-effective option for home users in particular. In comparison, wind turbines are typically larger and therefore more expensive.

The level of power generation efficiency. Wind and solar energy also differ in their efficiency. The power generation efficiency of wind energy generators is usually around 30%, and under optimal conditions, wind turbines can convert up to 50% of the wind passing through the blades into electricity. The efficiency of solar panels is around 20%. This is because the wind force in wind energy is within a controllable range and changes greatly, which has a greater impact on power generation efficiency. The power generation efficiency of solar energy requires sufficient sunlight, so its efficiency will decrease in rainy weather.

Differences in impact on the environment. Wind energy and solar energy, as two green and low-carbon new energy sources, have less impact on the environment, but they are also different. Both wind energy and solar panels require large amounts of land, but wind farms can coexist with agricultural uses. Solar farms require large amounts of land and can lead to habitat loss if not managed properly. However, solar panels can also be installed on rooftops and non-cultivated land. Three Scheme comparing is shown in Table 1.

Table 1. Three Scheme comparing

Differences	Wind energy	solar energy
Conversion method	Aerodynamics	Photovoltaic effect
Cost	High	Low
Power generation efficiency	30%-50%	20%
Impact on the environment	Coexistence with the agricultural land	A lot of land

To sum up, wind energy and solar energy each have their own characteristics and have different application prospects in different scenarios. For consumers, the choice of technology depends on factors such as power requirements, installation costs, and environmental impact.

4. Improvements

4.1. Wind power improvement

For wind power, improvements focus on turbine efficiency and materials to minimize environmental impact. Optimize blade design. The efficiency of wind turbines can be improved by optimizing blade design by changing the length, shape and number of blades. Increase the speed of wind turbines. By changing the design of the rotor, the wind turbine can rotate faster at the same wind

speed, thereby improving power generation efficiency. Research on blade materials. By researching new blade materials, lighter and stronger blades can be made, further improving the efficiency of wind turbines. Using radar to detect wildlife minimizes impact on birds.

4.2. Solar power improvement

For the application of solar energy, the core of current research is to improve battery efficiency, discover more sustainable materials, and improve energy storage solutions. The quality and light absorption capabilities of photovoltaic materials need to be improved to ensure optimal performance. At present, silicon materials occupy an important position in the photovoltaic field, but its conversion efficiency still needs to be further improved. To this end, we need to actively explore new photovoltaic materials, such as perovskites, to replace traditional silicon materials and optimize the overall performance of the photovoltaic system.

In terms of improving the efficiency of photovoltaic cells, we will explore multiple ways such as optimizing cell structure, improving electrode materials, and enhancing light capture technology. At the same time, in order to improve the efficiency of light utilization, the research and development of high-efficiency mirror and lens technology cannot be ignored. In view of the instability of solar power generation, such as day and night changes and weather effects, innovation in energy storage technology plays a crucial role in improving the reliability and stability of solar power generation systems.

In terms of energy storage technology, we will be committed to developing efficient electrochemical energy storage technology. Although battery technology currently occupies the mainstream position, its limited energy density and scarcity of materials cannot be ignored. Therefore, it has become our important task to increase investment in R&D, explore new battery materials and structures, and improve energy storage efficiency and capacity. In addition, we will also actively research other energy storage technologies, such as supercapacitors, hydrogen storage and thermal storage technologies. These technologies have the advantages of high energy density and fast charge and discharge speed, providing more choices and flexibility for solar power generation systems.

5. Conclusion

After in-depth research, the integration scheme of wind energy and solar energy has shown broad application prospects and great potential in the energy field. With the continuous progress of technology and the significant reduction of cost, wind power generation and solar photovoltaic systems are expected to achieve a larger scale layout and application in the future. At the same time, we propose innovative integration strategies, such as wind-solar complementary and multi-energy complementary systems, to further promote the improvement of energy efficiency and meet the growing energy demand. These strategies have achieved remarkable results in practice, demonstrating the feasibility and advantages of wind and solar fusion schemes. Looking forward to the future, with the continuous breakthrough and innovation of technology, the use of wind and solar energy to solve energy problems will become the mainstream trend, and inject new vitality into energy efficiency and sustainable development.

References

- [1] Zendehboudi A, Baseer M A, Saidur R. Application of support vector machine models for forecasting solar and wind energy resources: A review. *Journal of cleaner production*, 2018, 199: 272-285.
- [2] Maojiu W. Analysis of wind power generation technology and its application in energy saving. *ACE*. 2023, 10: 250-255.
- [3] Chen H, Zuo Y, Chau K T, et al. Modern electric machines and drives for wind power generation: A review of opportunities and challenges. *IET Renewable Power Generation*, 2021, 15(9): 1864-1887.

- [4] Rachid A, Goren A, Becerra V, et al. Fundamentals of Solar Energy. Solar Energy Engineering and Applications. Cham: Springer International Publishing, 2023: 1-15.
- [5] Xiao W. Photovoltaic power system: modeling, design, and control. John Wiley & Sons, 2017.
- [6] IRENA. W. Wind Power. IRENA, 2012.
- [7] European Wind Energy Association. Wind energy-the facts: a guide to the technology, economics and future of wind power. Routledge, 2012.
- [8] Adeyeye K A, Ijumba N, Colton J. The effect of the number of blades on the efficiency of a wind turbine. IOP Conference Series: Earth and Environmental Science. IOP Publishing, 2021, 801(1): 012020.
- [9] Rahman A, Farrok O, Haque M M. Environmental impact of renewable energy source based electrical power plants: Solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic. Renewable and Sustainable Energy Reviews, 2022, 161: 112279.
- [10] Di Bari A. A real options approach to valuate solar energy investment with public authority incentives: The Italian case. Energies, 2020, 13(16): 4181.
- [11] Pablo-Romero M P. Solar energy: Incentives to promote PV in EU27. AIMS Energy, 2013, 1(1): 28-47.
- [12] Singh A K, Singh R R. An overview of factors influencing solar power efficiency and strategies for enhancing. 2021 Innovations in Power and Advanced Computing Technologies (i-PACT), 2021: 1-6.
- [13] Fraas L M, O'Neill M J. Low-cost solar electric power. New York: Springer, 2014.
- [14] Bošnjaković M, Santa R, Crnac Z, et al. Environmental Impact of PV power systems. Sustainability, 2023, 15(15): 11888.