Wind Power Generation Technology and Sustainable Development

Zhuoru Li
Environmental Science and Engineering, Shandong University, 266237, Qingdao, China

Keywords: Wind Power Generation, New Energy, Energy Relationship, Economic Feasibility, Sustainable Development.

Abstract: With consumption of the world's fossil energy, there is an increasingly sharp demand of new energy. Wind energy is a renewable, pollution-free renewable source, and also is the orientation of future development. This paper aims to find the connection between wind power and other energy, by analysing the feasibility of technique and economy and sustainability of environment, to reach the sustainable development goal. This paper finds that third-generation high-power wind turbine has three major features, namely multiple blades, variable blade pitch angle, and variable speed control, and the single-unit capacity can reach 2-5 MW, which means wind power technology has begun to be applied maturely. At the same time, with the expansion of the wind power market, many governments coincide to implement various policy to stimulate the wind power developing. They also try to solve the problem caused by wind turbine such as reasonable site selection, noise reduction technology, and ultrasonic repelling. However, the application the wind power still needs to solve technical barriers such as energy conversion efficiency and intermittent volatility. In the future, it is important to settle the above problems through innovation of the technology and energy integration so that human can achieve the wide application of generation by wind power and the goal of sustainable development.

1 INTRODUCTION

Humanity has a growing demand in new energy because of the consumption of fossil fuel. Wind energy is a renewable, pollution-free new energy source, which is the orientation of future development. Although breakthroughs have been made in wind energy technology, there are still some problems, such as low energy conversion efficiency, intermittency and fluctuation, and the impact of wind turbines on surrounding environment.

Nowadays, China has already formed a completely industrial chain, including wind turbine manufacturing, wind farm construction, and wind farm operation. China's wind power is mainly distributed in the northwest and northern parts of the country. Gansu, Xinjiang, and Inner Mongolia have the largest installed wind power capacity. China is trying to achieve their goal that the installed wind power capacity to reach 600 billion watts by 2030, accounting for 20% of the total power generation. Because of the national policies, the wind power is developing rapidly in China, and by the end of 2020, the wind power installed capacity of China has reached 281 million kilowatts, which is the highest in the world (Geng, 2021). The Chinese government tries to have more international cooperation, and more connection to work with other countries and regions to encourage to develop power by wind. For example, China and the European Union have signed the "Supporting the construction of renewable generation in the EU and China", and the two sides will cooperate in wind energy technology and development, wind power construction, and wind power operation and maintenance and other parts (Monique, Shi and Zhong, 2020).

This paper analysed the main application methods of wind power, the influence of wind power generation on environment, and how to develop this energy in the future in the background of China's goal on carbon peaking and carbon neutrality (Wang and Zhang, 2020). First, start with the background of wind energy, and introduce the principle of the conversion from wind to electricity, also common technologies and equipment, to explore the current situation of wind power. Then, explore the market of it, government's policies, the feasibility of wind power generation, and the influence on environment

Li, Z.
Wind Power Generation Technology and Sustainable Development.
DOI: 10.5220/0013847200004914

In *Proceedings of the 2nd International Conference on Renewable Energy and Ecosystem (ICREE 2024)*, pages 97-102
ISBN: 978-989-758-776-4

and sustainable development. Finally, this paper discusses the future and developing trend of the wind generation, also analyse connection between wind energy and other energy.

2 DEVELOPMENT AND PRINCIPLE OF WIND POWER GENERATION

2.1 History of Wind Power Generation

There are three stages of wind power generation. The first generation appeared in the 1880s, and each unit capacity of the wind turbines was small. In the 1990s, the development of the two-bladed wind turbine technology made a step to the second stage of wind power, and each unit capacity increased to hundreds of kilowatts. After the 21st century, the third generation came out, which equipped with multiple blades, variable blade pitch angle, and variable speed control technology, and each unit capacity can reach 2-5 MW. Wind power technology has begun to be applied maturely. The 2.5 MW wind turbine used in Taizhou Wind Farm in China is a typical third-generation wind turbine.

2.2 Source and Characteristics of Wind Energy

The power of the wind comes from the sun. It is the kinetic energy of air movement caused by uneven solar radiation on the Earth's surface. The wind speed depends on the difference of the air pressure, with molecules moving from high-pressure to low-pressure areas, creating wind. Regions with higher wind speeds are mainly found in the ocean, coastal areas, and some high-altitude areas. China's northwest, northeast, coastal regions, and other areas have abundant wind energy resources (Chen, 2023).

Wind energy has three main characteristics: (i) Wind power generation is friendly to environment. During process of the wind to generate electricity, carbon dioxide or other greenhouse gases will not be released, so there is a small impact on the environment. (ii) Wind power generation is renewable. It relies on the natural circulation of wind and does not deplete. (iii) The wind energy is predictable. Through collected meteorological data and forecasting technology, wind energy generation can be reasonably predicted.

2.3 Principle of Wind Energy Conversion

The kinetic energy of the wind drives the impeller in wind turbine to rotate, and this rotation of the impeller drives the rotor of the generator through the main shaft. According to the law of electromagnetic induction, when there is relative motion between the generator rotor and the stationary sub winding, an electromotive force is generated between them. After rectified and converted, it can be output and transmitted to the grid, and finally converted into the form of electricity needed by consumers. Larger diameter wind turbine rotors rotate slower at the same wind speed, but capture more wind energy (Ren, 2023).

There are three steps of wind energy conversion: (i) The first step is the capture of wind energy. Wind energy can be captured by wind turbines, which usually consist of a rotating rotor and a stable generator. When the wind passes through rotor, the wind's horizontal kinetic energy is converted to rotational kinetic energy of the rotor. (ii) Then, the rotor is rotating. When the wind blows over the rotor of a wind turbine, the wind exerts a force on the blades, generating torque. This torque initiates the rotation of the rotor (Li, Liu and Tan, 2021). (iii) In the end, kinetic energy is converted into electricity. The rotational kinetic energy is converted into electrical energy by the generator. It contains conducting wires and magnetic fields, and the rotor makes the wire cut the magnetic field lines, result in electromagnetic induction. The current generated by this process is output through the conducting wires to form usable electrical energy.

According to the principle of wind power generation, it can be concluded that the biggest challenge is to find ways to improve the efficiency of wind energy capture. To solve this problem, research can be conducted in several directions: (i) Research can be conducted on the design of wind turbine blades to improve their aerodynamic efficiency, so that wind energy can be captured more effectively. (ii) Optimize the location selection of wind power plants. Through the interdisciplinary approach of meteorology, find the places where the most wind energy can be captured to build plants, thereby increasing the utilization efficiency of wind energy. (iii) Improve the efficiency of generators. Choosing more efficient generator types, such as permanent magnet synchronous generators and doubly fed induction generators, can improve the quality and quantity of electricity. Optimizing the generator control system, such as maximum power

point tracking control and variable pitch control, can improve the power generation efficiency.

3 CLASSIFICATION OF WIND POWER GENERATION TECHNOLOGIES AND EQUIPMENT

3.1 Offshore Wind Power Generation

Offshore wind power generation (OWPG), is a wind power plant built near the sea, usually was built on the continental shelf. OWPG can capture the energy of the wind with higher velocity than onshore wind power generation, so it can convert more energy to electricity. Two common types of offshore wind power equipment are horizontal-axis wind turbines and floating wind turbines. Horizontal-axis turbines are the most common. They are designed to be more robust to cope with harsh offshore environmental conditions. Offshore wind turbines are much bigger than onshore wind turbines, they are equipped with longer blades and taller towers to capture more wind energy. Offshore floating wind turbines are a new technology in wind power generation. It can generate wind power in deep water areas by installing wind turbines on floating platforms at sea. Floating wind turbines can be developed more flexibly in deep waters (Liu, Gao and Xue, 2020).

3.2 Onshore Wind Power Generation

Onshore wind power refers to wind farms built on land, utilizing specific technologies and equipment. Here are some of the features and common equipment for onshore wind power generation: (i) Horizontal-axis wind turbine (HAWT) is the most common onshore wind generation technology. It is composed of a large rotating blade mounted on a horizontal axis, which drives a generator to generate electricity by rotating. Onshore wind turbines are typically installed on tall towers to access stronger winds. (ii) Vertical-axis wind turbines (VAWT) have large rotating blades mounted on a vertical shaft. They generate electricity by turning the shaft to drive a generator. Unlike HAWT, VAWT can capture wind from multiple directions, making them suitable for complex wind farm environments. The structure of the VAWT is simple and VAWT is easy to maintain and repair. In small-scale wind power systems, VAWT are better suited for urban or building environments due to their ability to handle frequent wind direction changes. However, VAWT cannot capture as much wind energy as HAWT and are less efficient in conversion. Overall, VAWT offer an alternative approach to wind power generation compared to traditional HAWT. They have specific advantages in certain applications and can be part of a diversified wind energy generation system.

4 MARKET AND SUSTAINABILITY OF WIND POWER GENERATION

4.1 Global Wind Power Market

The wind power market of the world witnessed a significant increase over the past few decades and wind power now has become a major element of the renewable energy sector. The growing demand for energy, government support for renewable energy, and breakthrough in technology lead to the growth of the wind power market. Based on the International Energy Agency (IEA), the global installed wind power capacity increased from around 17 GW in 2000 to approximately 743 GW in 2020, representing a more than a 40-fold increase (Electricity Market Report, 2023). Concurrently, wind power generation has been increasing its proportion in the global electricity generation.

4.2 Government Policies and Support Mechanisms

Support of the government in policy plays an extremely important role in the wind power market. Many countries have implemented various incentive methods, such as subsidy schemes, tax breaks, preferential policies, and renewable portfolio standards, to enable a better development of wind energy. These policies and measures can spend less expenditure on wind power generation and provide a stable investment environment. Examples include the Feed-in Tariff scheme in Germany and the Production Tax Credit (PTC) and Investment Tax Credit (ITC) in the United States (Feed-in, 2009).

4.3 Economic Viability and Competitiveness

With the technological advancements, wind power generation has made significant progress in terms of economic viability and competitiveness. According

to the International Renewable Energy Agency (IRENA), the cost of wind power in the whole world has declined by approximately 70% over the past decade. This has made wind power increasingly competitive with conventional energy sources in regions with suitable wind resources. Additionally, the sustainability advantages of wind power over fossil fuels enhances its long-term viability.

Nowadays, in addition to wind energy, two common renewable energy generation technologies are solar power and hydroelectric power. The cost of solar power has significantly decreased in recent years, but its efficiency is highly dependent on sunlight duration and weather conditions. Wind power costs are also decreasing, and its efficiency is less affected by wind speed. Overall, wind power is economically competitive with solar power, but in regions with abundant wind resources, wind power demonstrates a more pronounced economic advantage. Hydropower is a mature renewable energy source with high generation efficiency, but its construction cost is high, and it is greatly limited by water resources and terrain conditions. Wind power has relatively lower construction costs and fewer geographical restrictions. Generally, wind power has an economic advantage over hydropower, particularly in regions with abundant wind resources. In comparison to wind energy, traditional coal and gas power generation have lower costs but result in significant emissions of carbon dioxide and other pollutants. Nuclear power, on the other hand, is a traditional non-renewable energy source with lower generation costs, but it poses safety risks and has challenges associated with nuclear waste disposal. Overall, the economic competitiveness of wind power is continuously improving. Compared to other renewable and non-renewable energy sources, wind power is gradually demonstrating its advantages. With technological advancements, policy support, and increased environmental awareness, wind power has enormous development potential and will play an increasingly important role in the global energy landscape.

4.4 Environmental Impact and Sustainability

Wind power generation offers environmental benefits due to its clean, renewable, and predictable characteristics: (i) Wind power generation does not produce greenhouse gases or other pollutants during operation, as wind turbines do not burn any fuel during electricity generation. Therefore, wind power is good for the environment. (ii) Aeolian energy generation can decrease the dependence on fossil fuels. Fossil fuels are non-renewable resources, and their use releases greenhouse gases and other pollutants. (iii) Wind power generation farms do not need much space to construct. Wind turbines require a relatively small land area to generate a significant amount of electricity.

At the same time, wind power generation also has some drawbacks: (i) Wind turbines can have a visual impact on the landscape. For example, in some mountainous or coastal areas, wind turbines may disrupt the natural scene. To mitigate the visual impact of wind power, wind turbines should be sited away from densely populated areas and important ecological areas, especially near national parks or nature reserves. (ii) Wind turbines can generate noise. For example, in the vicinity of some wind farms, people may be disturbed by the noise generated by wind turbines. The noise from wind turbines mainly comes from the rotating blades and mechanical transmission systems. To reduce the noise impact of wind power, wind turbine manufacturers are continuously developing low-noise wind turbines. Some wind turbine manufacturers have developed wind turbines that can reduce noise to below 40 decibels. (iii) Wind turbines can pose risks to some animals. For example, birds and bats may collide with wind turbine blades and die, and bats may be disturbed by the acoustic waves generated by wind turbines, affecting their feeding and roosting. To reduce the impact of wind power on birds and bats, wind turbine manufacturers and wind farm operators can take measures to protect birds and bats, such as installing bird and bat deterrent devices. Some wind turbine manufacturers have developed wind turbines that can emit ultrasonic waves to deter birds and bats.

Overall, wind power generation has a low environmental impact and is a sustainable form of energy.

5 FUTURE DEVELOPMENT TRENDS OF WIND POWER GENERATION

5.1 Technological Innovations and Trends

Technological innovation in aeolian energy generation is a key factor in its future development. With the continuous advancement of technology,

aeolian energy generation technology is also constantly evolving and improving. The following are some trends in wind power generation technology innovation: (i) Continuous technological advancements to improve the design of wind turbines, to increase the efficiency and reliability. For example, traditional horizontal axis wind turbines have evolved to have larger rotor diameters and higher tower heights to utilize higher wind speed layers and reduce aerodynamic losses. In addition, new types of wind turbines such as VAWT, floating wind turbines, and deep-water wind turbines have also been researched and applied to a certain extent (Wang, 2024). (ii) The application of artificial intelligence and digital technologies brings higher levels of automation, data analysis capabilities, and operation and maintenance efficiency to wind power generation. For example, wind farm monitoring systems can monitor the situation and performance of wind turbines in any time and do predictive maintenance, thereby improving the reliability and maintenance efficiency of wind turbines (Li, 2019). (iii) The development of energy storage technology is very important in enhancing the reliability and viability of wind power generation. By combining wind power generation and energy storage technology, it is possible to solve the problems of mismatch in grid load demand and wind speed fluctuations. Energy storage technologies such as battery storage, pumped hydro storage, and thermal storage systems can store wind energy when wind speeds are low or too high, and release it when needed. (iv) In addition to onshore wind power generation, the offshore technology also plays a vital role in the future development directions. Offshore wind power has more stable wind resources and greater development potential. In addition, high-altitude areas, offshore islands, and areas far from the grid are also potential wind power generation sites.

5.2 Relationship Between Wind Power Generation and Other Energy Forms

The relationship between wind energy and other energy sources is mainly reflected in the following aspects: (i) Wind energy is complementary to other energy sources. Wind energy is an intermittent energy source, that means the output of this type of generation is directly influenced by wind velocity, resulting in its inherent variability. Therefore, wind power generation needs to be complemented by other energy sources, for instance, hydropower, thermal power, nuclear power, to maintain the stability in the operation of the grid. (ii) Wind energy also competes with other energy sources. As the cost of wind power generation continues to decrease, it is increasingly vying for market share against other renewable energy sources such as thermal power and nuclear power. (iii) Wind energy can also be developed in synergy with other energy sources. For example, the combination of the aeolian energy and solar energy is robust to form a complementary energy system. Aeolian energy generation can also be combined with energy storage technology to solve the intermittency problem of wind power generation.

6 CONCLUSION

Energy progress is an essential part of human development, and aeolian energy plays a crucial role in settling climate change problems and achieving energy transformation. After decades of development, the efficiency of wind energy conversion has been continuously improving, and the capacity of wind power has also been increasing, making wind energy a technically feasible alternative energy source. At the same time, wind power generation has also shown great potential in the market and sustainability aspects. Governments around the world are implementing policies that foster the advancement of wind energy, which has contributed to the expansion of the global wind power market. But wind power generation also has certain shortcomings. The energy conversion efficiency is an issue that needs to be urgently coped with in the future. In addition, wind power generation can cause noise, visual impact, and hinder the life of flying animals, which is subject to site selection. Finally, the future development of wind power generation needs to focus on technological innovation and the connection with other energy forms. Through technological innovation, the wind energy conversion efficiency will be further improved, and the intermittency and volatility of wind power generation will be solved. Finding a way to closely connect wind energy with other energy sources will promote the mixed use of energy and the coordinated development of energy systems, and realize the stable supply of sustainable energy. In summary, wind power generation has great potential in the future energy field, but it also faces technical and economic challenges to achieve

the widespread application and sustainable development goals of wind power generation.

REFERENCES

Geng H, 2021 *Engineer. Tech. Res*. **3** 65-66.
Monique V, Shi J and Zhong K, 2020 *Beijing: EU-China Energy Cooperation Platform.*
Wang C and Zhang Y, 2020 *Chinese J. Enviro. Man.* **12** 58-64.
Chen X, 2023 *Hydro. Sci. & Tech.*, **6** 67-69.
Ren N, 2023 *Mech. and Elec. Cont. Engineer.* **5** 190-192.
Li S, Liu Q and Tan S, 2021 *Wat. Supp. and Dra.* **57** 276-279.
Liu X, Gao R and Xue Y, 2020 *Dist. Ener.* **5** 39-46.
Electricity Market Report. 2023 https://www.iea.org/reports/electricity-market-report-2023.
2009 *Feed-in. Tariff.* https://www.seia.org/research-resources/policymakers-guide-feed-tariff-policy-design.
Wang Y, 2024 *Engineer. Tech. Innova. and Devel.* **2** 99-101.
Li J, 2019 *China Sci. Dail.* **6** 13-14.