Use Low Wind Speed to Meet Electricity Demand in Remote Areas

Zhengye Xie *

Guangzhou Maritime University, Guangdong, Guangzhou, China

* Corresponding Author Email: xiezhengye@fsu.edu.pa

Abstract: Around the world, remote areas face difficulties in accessing electricity. Therefore, studying multiple energy supply options to find solutions is an important topic. This paper takes Chinese studies as an example, the advantages and disadvantages of various power generation modes are compared. From the degree of environmental impact, power generation cost, and the needs of people in remote areas, the study found that the use of wind power is the most suitable for research objectives. A comparison was made between conventional wind turbines and existing low wind speed wind turbine studies in China. It is concluded that low wind speed wind turbine equipment is more suitable for remote areas (Low wind speed refers to wind resources with wind speed below 4m/s in airspace below 50m). In this paper, the low wind speed wind turbine is analyzed, and it is found that it has a special structure, which can make it operate in the place of variable wind direction. Therefore, a low wind speed wind turbine is proposed to solve the difficulty of electricity consumption in remote areas.

Keywords: Low wind speed, Remote area, Wind power generation.

1. Introduction

In recent years, China has promoted the dual-carbon policy and the development of new energy sources, among which wind energy resources are considered to have important potential. Although China's wind energy resources are very rich, the existing commercial wind power generation equipment is mainly aimed at the collection of high-grade wind energy with a wind speed above 4m/s at an altitude of 50 meters [1]. The annual average near-earth wind speed in China is only about 1m/s [1]. The capture rate of wind energy in the airspace below 50m is too low for ordinary wind power facilities to be profitable.

To this problem, a study by Hua analyzed wind resources in urban areas of Jilin, China [2]. Through 30 days of observation data, wind gusts can reach more than 2m/s, accounting for 45% of the total time [2]. This works out to about 2,600 hours of continuous wind energy per year. The study shows that there is still a large amount of low-wind energy untapped along rivers around the world.

Li studied a type of wind concentrator that allows airflow to enter at one of the wide openings, pass through a narrow channel in the middle, and exit at another wide opening [3]. Through the fluid continuity equation, this type of wind concentrator can accelerate a large area of low-wind speed wind to a small area of high-wind speed wind. According to the experimental results, this type of duct can increase the wind speed by 1.5 times [3]. By accelerating low-speed wind energy, low-speed wind energy is captured and utilized. This study solves the problem that mini-type aerogenerators are difficult to operate when the wind speed is less than 3m/s [3].

In 2011, the Mechanical Equipment Research Institute of Xinjiang Academy of Agricultural Reclamation Sciences introduced a set of FDQ3-1/9 wind turbines from Shanghai Forevoo Windpower Technology Co., LTD., with a rated power of 1Kw [4]. FDQ3-1/9 type wind turbine adopts horizontal axis type, which is mainly composed of an auxiliary impeller, clutch, main impeller, generator, tail (direction adjuster), and so on. The device can be started at 1.8m/s in the light wind of Class 2 and can generate electricity continuously at 3-5 m/s in the low wind speed of Class 3 [4]. This device provides an idea for a low wind speed wind turbine. The orientation uncertainty of wind energy is adapted by adjusting the position of the tail. This not only improves the efficiency of wind energy capture but also reduces the chance of damage to the installation.

Aiming at remote areas with wind and no electricity, this paper presents an array type compensated low wind speed wind turbines by studying the power generation facilities worldwide. The device combines the characteristics of wind concentrators and horizontal axis mini-type aerogenerators and adds an array mode. The purpose is to solve the problem of electricity difficulty in remote areas by using the device.

2. Wind Power Advantages

2.1. International Situation

Since the United Nations adopted the Convention on Climate Change in 1992, the current situation of environmental deterioration has been emphasized worldwide, and the requirements for reducing greenhouse gas emissions have been put forward. In the new energy category, the productivity ratio of wind power generation is the highest among existing power generation models. If 1% of the world's surface wind resources can be fully collected, the converted electricity can meet the global electricity demand [1]. Therefore, making full use of pollution-free wind energy for energy supply has become an important program in the world's energy transformation. Taking China as an example, the capture of wind resources in China is still in the rising stage of the industry, and it is expected that wind power generation in China will account for 21% of the total power generation in 2030[1].

2.2. Solar Power Generation

Solar power belongs to a wide range of easy access to clean energy, in the use of solar energy for electricity conversion less noise, less waste, small impact on the environment. The installation of a 1kW solar photovoltaic system can reduce the emission of CO exhaust gas 2300 ~ 2600kg per year, NOx16kg, SOxkg, and other particles 0.6kg [5]. However, ordinary solar power needs to occupy a larger position, and small solar photovoltaic power generation models are costly. At present, Japan is popularizing solar power generation devices mainly for residential use, and the power generation cost is about 46~47 yen /(kWh), which is still 1 times higher than the average household electricity price of 23 yen /(kWh). In addition, solar energy is scarce in low-lying terrain such as the Sichuan Basin in China [6]. Its power generation conditions will be greatly affected by the local weather, with intermittent, fluctuating, and unstable characteristics.

2.3. Fuel Power Generation

According to a research report released by the China Institute of Energy Economics research, the thermal power model will have the largest proportion in China's power generation structure in 2024. Among them, coal-fired power generation is still one of the major modes of power generation in China. The reason is that the price of coal is cheap, and the average ex-factory price of standard coal is 579.3 yuan/ton [7]. However, thermal power generation has many shortcomings. Worldwide, the power generation efficiency of ordinary coal-fired power generation is relatively low, generally less than 50% [8]. Thermal power plants in China are designed with a calorific value of 210,000 to 230,000 kilojoules per kilogram [8]. However, due to heat loss, the calorific value of thermal coal received by each power plant has dropped to about 170,000 kilojoules per kilogram [8]. In addition to low power generation efficiency, for remote areas, conventional coal-fired and oil-fired power generation will release a lot of CO_2, SO_2, NO_x, soot, and other pollutants, which will affect residents' lives and the ecological environment. In addition, the distribution of coal minerals in remote areas is unknown. Power plants in remote areas are difficult to operate without a lot of human resources to support them.

2.4. Hydroelectric Power Generation

Hydroelectric power generation is highly profitable. The unit generation cost and unit profit of thermal power generation are 5.65 times and about 1/8 times of hydropower [9]. For example, in

China, hydropower can generate more than half of the profits for the Chinese grid with about 15% of the electricity generation [9]. Hydropower is a kind of renewable energy, which uses the potential energy of water to convert electric energy. The construction of hydroelectric power plants will carry out a large degree of transformation of the local environment and have a relatively large impact on the local ecology. Taking the Three Gorges of the Yangtze River in China as an example, the Yangtze River water conservancy project has damaged the continuity of the river and adversely affected the integrity of fish and other biological components [10]. The Yangtze River water conservancy project is a major reason for the extinction of Chinese sturgeon [11]. In addition, the regional distribution of hydropower resources in the world is extremely uneven. Take China as an example, water energy is mainly concentrated in western China, such as the upper reaches of the Yellow River and the upper reaches of the Yangtze River [12]. High-density hydroelectric resources are scarce in remote areas and cannot meet the harsh natural conditions required for hydroelectric power generation.

2.5. Wind Power Generation

The world is rich in wind energy resources. Taking China as an example, the annual wind energy reaches 3.226 billion kilowatt-hours [1]. As one of the most barren regions in China, the wind energy in the Sichuan Basin is less than 50W/m2 [13]. If fully developed, it can also solve the problem of electricity consumption without affecting the environment. However, remote areas such as underdeveloped mountainous areas, due to their environment are not suitable for the development of large-scale wind power generation equipment (The current wind-driven generator is more than 50 meters high, easy to contact with the mountain, and the cost of developing wind farms is high), wind resources are wasted [1]. In response to this situation, China has a variety of low-wind power research results. In a variety of regional environments, low wind speed wind power generation can be easily used to meet the daily basic electricity demand. When low wind-speed power generation is applied in remote areas, the development cost is low compared to hydropower and solar power generation. Make full use of the local abundant wind resources, and have less impact on the environment and ecology. The low wind speed wind power generation device is cost-effective, the cost is about 20 yuan/piece, which meets the needs of the people in remote areas.

3. Technical Characteristics of Wind Power Generation

3.1. Wind Turbine Shaft

3.1.1. Vertical Axis Wind Power Plant

The vertical axis wind turbine can accept 360° incoming wind, so there is no steering mechanism to adjust the upwind direction. Its advantages include long service life, easy maintenance, and no windage losses [14]. However, the starting performance of the vertical axis generator is poor, and at the same time, the speed and duration of the wind at high altitudes are unstable, resulting in the power generation effect of the vertical axis wind turbine being very unstable. Therefore, most of the current large-scale commercial wind turbines use horizontal axis power generation devices for power generation. In remote areas such as the Sichuan Basin, China, the average wind speed is about 1m/s, making it difficult to drive vertical axis wind power turbines [13].

3.1.2. Horizontal Axis Wind Power Generation Device

Compared with vertical wind turbines, horizontal axis wind turbine has better starting performance and higher power generation efficiency. Nowadays, horizontal axes are widely used in power plants, such as CGN Yangjiang Offshore Wind Farm. Because in the low air below 50m, the wind direction will change frequently, and the wind volume is not stable. In some low-wind areas, the annual average wind speed does not exceed 2m/s [13]. Therefore, the horizontal axis is more suitable for power supply in remote areas than the vertical axis.

3.2. A low Wind Speed Wind Power Generation Device in China

3.2.1. Low wind speed wind turbine blades

A low wind speed power generation device in China uses a horizontal axis design and its motion power comes from low wind speed. The airflow is captured by the impeller, entering through the wide mouth and exiting through the narrow mouth. Under the contraction of the shrinking pipe wall, the airspeed is accelerated according to the law of conservation of energy:

$$V_1A_1 = V_2A_2 = Q \tag{1}$$

In the formula, V_1denotes the inlet wind speed at the wide opening of the blade; A_1 represents the windward area of the wide mouth of the blade; V_2 represents the wind velocity at the narrow opening of the blade; A_2 represents the air discharge area of the narrow mouth of the blade; Q represents the energy contained in the wind passing through the winding tube of the blade.

Under the action of pressure, part of the airflow passes through the gradually shrunk blade and flows to the broad mouth of the next blade to catch the wind, as shown in Figure 1. The airflow continues to push the next gradual blade, increasing the rotational torque of the impeller and increasing the rotational speed of the impeller. When the impeller rotates, the impeller drives the generator to rotate and generate electricity. The greater the number of impellers, the greater the rotational torque. However, the speed of the impeller will be reduced [3]. The reduced blade makes up for the problem of reduced speed and increases the power generation efficiency.

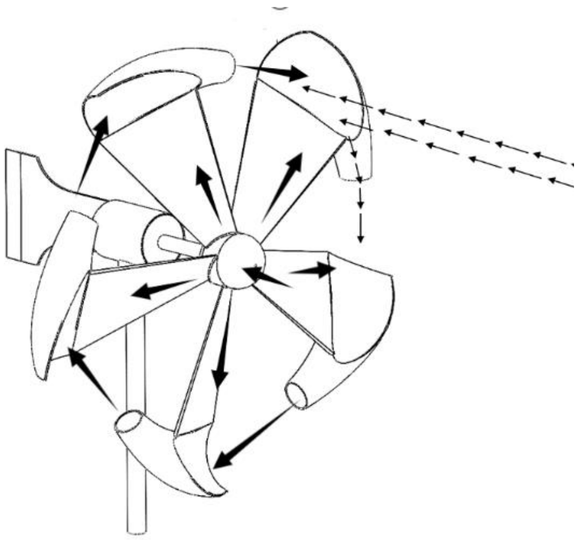

Fig. 1 A low wind speed wind turbine in China (Photo/Picture credit: Original).

3.2.2. The invention relates to a shaft structure of a low wind speed wind turbine

The low wind speed wind power generation device is mainly composed of polylactic acid (PLA), which has the characteristics of economic benefit and is lightweight (The general density of PLA material is 1.26g/cm3) [15]. The low wind speed wind turbine combines the structural design of vertical and horizontal axes. The blade is rotated by the horizontal axis, and the axial direction of the horizontal axis is changed by the vertical axis. Therefore, it can use wind energy to steer, the windward side against the wind. Combined with the horizontal shaft starting performance, it can also fully collect low wind speed wind energy. Therefore, low wind-speed wind turbines can operate normally in places with less wind energy and instability. In addition, PLA material also has the property that it is not easy to curl. This makes the low wind speed wind turbine made of PLA material not easy to damage and long service life.

4. Wind Power Dilemma

4.1. Wind Resource

The instability of wind resources is a major problem facing wind power generation. From an economic perspective, commercial wind turbines are installed in areas with high wind speed with a mode of 7.88m/s [16]. Even so, the maximum efficiency of energy conversion from wind power is still only 59.3% (the Betz limit). Wind energy resources are unstable in areas with complex terrain. In the process of wind power conversion, there will still be a lot of wind energy wasted. Increasing the sensitivity of wind direction and reducing generator start-up wind speed are unavoidable problems when low wind speed wind power is used in remote areas.

4.2. Energy Storage

When wind energy pushes the impeller to convert wind energy into mechanical energy, alternating current is generated. At this time, the battery needs to be collected and stored, and then it can be used as daily life electricity. At present, the power of the accumulator on the market is 60% to 80% [17]. This means that there is still a loss when the stored energy is used. However, the accumulator is a more affordable battery, and its economic performance makes it more suitable for use in remote areas. At present, sodium-sulfur batteries have been listed as government-funded wind energy storage power sources in Japan, and there are specific promotion plans [18]. It can be seen that accumulators can be used as energy storage components for wind power generation in remote areas. However, most accumulators on the market still need to be improved to better use in low wind speed power generation.

5. Study the Future

Low wind speed wind power generation is not a new concept in the world, and the market is relatively broad. China is now encouraging the development of clean energy generation, and the government supports wind power generation [19]. At present, electricity consumption in remote areas and underdeveloped areas is still a major problem. The use of low wind speed wind power generation can better avoid the application of other power generation modes in remote areas. In the future, low wind speed wind power generation can enhance the conversion efficiency of wind energy and electric energy by improving the energy storage structure or optimizing the design structure. Increase the power generation of a single power generation unit to ensure that less wind weather can also meet the daily life of remote areas.

6. Conclusion

It is a trend to innovate and adjust the electricity production structure of daily consumption by utilizing the abundant wind energy resources in the world. This paper finds that compared with other power generation modes, wind power generation has a lower environmental cost and economic cost, and can effectively meet the power demand in remote areas. Among wind power generation types, low wind speed wind turbines have lower environmental requirements than ordinary large-scale wind power generation devices and can provide daily power supply to underdeveloped and remote areas. In terms of ecological benefits, low-wind power generation uses widely available wind power generation, does not produce pollution during operation, and has little impact on the environment. In the use of the environment, the device structure is small, safe, and reliable, with maintenance boundaries and a small footprint. In terms of power generation performance, the device has a low starting wind speed, long power generation time, and good power generation effect, which is superior to other energy applications.

The use of low wind-speed wind power generation to meet the remote areas of power supply in line with the requirements of green and low-carbon development has good promotion value. Low wind speed wind power generation has proposed a way of thinking for energy innovation and power supply in remote areas around the world.

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