Systematic Characteristics of Vertical and Horizontal Axis Wind Turbine

Minxing Wang [1,*], Xintao Yu [2] and Wenbo Zhao [3]

[1] Wuxi Dipont School of Arts and Science, Wuxi, Jiangsu, 214125, China

[2] Weifang No.1 Middle School, Weifang, Shandong, 261072, China

[3] Suzhou No.1 Middle School, Suzhou, Jiangsu, 215006, China

* Corresponding Author Email: 001147@nkcswx.cn

Abstract. Wind power is one of the main directions of future renewable energy development. Wind turbines can be classified according to their axes. The two major categories are vertical axis wind turbines and horizontal axis wind turbines, both types have their unique characteristics in efficiency, operating principle, and operating environment. Based on the study on structure and power generating mechanism of vertical axis and horizontal axis wind turbines, compare the characteristics and point out the advantages and disadvantages of both types of wind turbines. This research aims to study the use of vertical-axis and horizontal-axis wind turbines, to achieve better efficiency at different working conditions. Compared to other clean energy sources, wind power has the advantages of mature technology, but it still has room for improvement. For example, the blade design on wind turbines can be optimized to increase the efficiency. The prospect of wind power cannot be ignored.

Keywords: Vertical axis wind turbine; horizontal axis wind turbine; wind power, efficiency.

1. Introduction

In today's era of very serious pollution, people can be said to be thoughtful to deal with environmental problems. Today the topic of wind power generation is attracting more attentions. First of all, wind power generation is an important part of developing new energy and improving the environment [1]. In addition, compared with coal-fired power plants of the same scale, wind farms emit zero pollutants into the atmosphere, achieving zero solid and gas emissions. It has a positive effect on protecting the atmospheric environment. Secondly, compared with coal-fired power plants, wind farms can save a lot of freshwater resources and reduce water environmental pollution. It is especially important for coastal and arid areas that lack freshwater resources. These are the prospects and uses of wind power.

2. Generating Mechanism and Characteristics of Horizontal Axis Wind Turbine

2.1. Structure of Horizontal Axis Wind Turbine

The wind turbine tower supports the wind turbine and is attached to the foundation. The wind turbine nacelle is an automobile-type box, and the interior is the installation space for the core parts such as the generator, pitch mechanism, and control system. The pitch mechanism is used to generate kinetic energy by rotating the blades on the wind wheel. Three blades are used to draw kinetic energy from the wind through the wind wheel. The pitch mechanism changes the angle of the blade according to the wind speed, to adjust the blade's force and achieve speed adjustment of the wind wheel. The wind wheel's rotation causes the generator to convert mechanical energy into electrical energy. The tower is a steel structure that is used to support important components like wind turbines and generators. The electrical energy from the generators is transmitted to the substation and distribution facilities through cables and control cabinets. The control system consists of a control box, a controller, a wind speed sensor, a risk sensor, and other components. The monitoring system consists

of vibration monitoring, temperature monitoring, lubricating oil pressure monitoring, speed monitoring, and electrical systems, among others.

Hai et al. proposed an optimal design scheme for the blade structure of a large horizontal axis wind turbine in the optimization design and analysis of the blade structure, and the aerodynamic performance of the airfoil is the change law of the lift, drag, and moment coefficient of the airfoil with different angles of attack. By comparing the aerodynamic performance of the airfoil NACA2412 and HN-832TA, the airfoil HN-832TA with better aerodynamic performance was selected as the blade design airfoil. It was found that the wind energy utilization rate of the wind turbine could be improved by optimizing the design of the wind turbine blades of the large horizontal axis wind turbine. Jin et al. proposed in the research on the structural design and optimization of stator and rotor brackets for permanent magnet direct-drive wind turbines, the structural composition of permanent magnet direct-drive generators and the structure and function of key components, the design requirements, design inputs, and design indicators were explained, and the structural design of stator and rotor brackets and the calculation of air gap size chain were carried out according to the requirements. The stator and rotor bracket adopt welded parts, which can meet the basic operation needs of the equipment while ensuring the overall operation to achieve the goal of saving costs.

2.2. Generating Mechanism of Horizontal Axis Wind Turbine

The basic principle of wind power generation is that the wind blows through the blades, rotating them, converting the kinetic energy of the wind into rotational kinetic energy of the blades. The blades drive the hub and the low-speed shaft to rotate, and the gearbox accelerates the rotation of the low-speed shaft through the gears step by step, so that the speed of the high-speed shaft reaches the speed required by the generator to generate electricity, and the high-speed shaft then drives the generator to generate electricity. Generally speaking, the wind wheel of a horizontal-axis wind turbine usually consists of three blades. The speed and torque of the wind turbine can be adjusted by altering the angle and number of blades. Mechanical energy is converted into electrical energy by the generator, which is the core component. There is a magnetic field between the rotor and stator in the generator, and the rotation of the rotor causes a change in the magnetic field, which induces a voltage on the stator and outputs electrical energy.

Diao et al. pointed out in a brief analysis of the working principle and application of wind power generation that due to the short development time of wind energy in China and the uneven distribution of resources, wind energy is facing challenges such as low market price, immature technology, and insufficient safety assurance. At present, the commercialization level of wind energy is still very low, and there is no complete market system, to ensure the stable development of the industry, it is still necessary to invest a lot of humans, material, and financial resources to develop infrastructure and personnel. Principles of wind power generation is a basic course in new energy science and engineering. This course comprehensively uses the knowledge of pre-requisites such as motor and drag, automatic control theory, etc., covering wind characteristics, wind resource assessment, wind turbines and their transmission chains, wind turbine control systems, and offshore wind power, etc., to improve the quality of education of power system, let students understand the common line that power system has done for the development of China, and help students improve their ideological and cognitive level faster.

2.3. Characteristics of Horizontal Axis Wind Turbine

The structure is simple and compact, which greatly improves the reliability of the unit. Furthermore, the high availability of the unit leads to an increase in power generation. The rotation efficiency is high, the rotation chain is short, and the operational efficiency of the unit has been improved. The generator is maintenance-free because it doesn't have a carbon brush slip ring, the operating cost is low, there are no weak links, and the failure rate is reduced. The unit runs at low speed without any high-speed rotating parts to optimize operating conditions, improve operating life, and reduce noise. With advanced control technology, variable speed and variable pitch constant

frequency control, and superior performance at low wind speed, the unit has a better power curve, realizes flexible connection with the power grid, effectively reduces the load of the unit, and improves the operating condition of the fan.

2.4. Efficiency of Horizontal Axis Wind Turbine

Wind direction, blade design, generator speed, and other factors can affect the efficiency of a horizontal-axis wind turbine. Horizontal-axis wind turbines have a relatively high efficiency when the wind direction is stable, and the wind speed is moderate. A specific horizontal-axis wind turbine can theoretically generate 5,000 kWh (5 MW) of electricity per hour, but in reality, it may be slightly underpowered. Wen et al. (2023) used a response surface method (RSM) and archived microgenetic algorithm (AMGA) to improve the internal structural parameters and carry out dual-objective optimization to improve the productivity efficiency of the generator with the help of a RSM and an AMGA in the research on the optimization strategy of the capacity efficiency of permanent magnet wind turbines. The combination of RSM and AMGA methods is used to optimize and obtain the best structural parameters, improve the capacity efficiency of the generator, reduce power ripple, and improve power quality. Based on the theory of modern industrial engineering in the research and application of wind turbine commissioning efficiency improvement technology, the production systems elements such as people, equipment, materials or parts, information, and environment are optimally allocated, to reduce the commissioning cost of onshore and offshore wind farms, and the system planning and design, evaluation and innovation are carried out, to improve the efficiency and reduce the cost of on-site commissioning while ensuring product quality.

2.5. Working Environment of Horizontal Axis Wind Turbine

Compared to vertical-axis wind turbines, horizontal-axis wind turbines have higher requirements for starting wind speed and more stringent requirements for installation location. Generally, it is installed in mountainous areas, seashores, coasts, and other areas with high wind speeds throughout the year. Horizontal axis wind turbines require a fixed position foundation due to their large volume and high center of gravity. Deep depths in areas of the strait make offshore wind turbines unsuitable for use [1].

2.6. Stability of Horizontal-Axis Wind Turbines and Their Difficulty in Maintenance

Horizontal-axis wind turbines operate axially parallel to the wind direction, so the blade angle needs to be adjusted according to the wind direction to ensure stable operation. Large-scale wind turbines use a transmission mechanism composed of servo motors for steering, which is more complex and has a higher failure rate than vertical wind turbines. The lifespan of a conventional horizontal-axis wind turbine is about 20-25 years [2]. Offshore wind turbines are subject to corrosion by seawater and salt spray, and their life expectancy is shorter than that of conventional wind turbines, depending on the location of installation. Due to structural defects, horizontal-axis wind turbine blades are often composed of composite materials with high fatigue strength and low weight, so they are more expensive to manufacture. The horizontal axis wind turbine blades are large in size and long in length, which has high requirements for vehicles and road conditions. The blades are transported by flatbed semi-trailers, and there must be no obstacles on the curved side of the road, and the turning radius also needs to be modified according to the transportation needs. The power generation part of the horizontal-axis wind turbine is fixed at an altitude of about 65 meters by the tower, which makes it difficult to maintain the unit. Due to the particularity of its installation location, offshore wind turbines are also more difficult to install and maintain than other wind turbines. In summary, the stability of horizontal-axis wind turbines is lower than that of vertical-axis wind turbines, and their maintenance difficulty is also much higher than that of vertical-axis wind turbines.

3. Generating Mechanism and Characteristics of Vertical Axis Wind Turbine

3.1. Structure of Vertical Axis Wind Turbine

The vertical axis wind turbine is mainly composed of wind turbine blades, main rotor shafts, power generation components, and fixed bases. Its main axis of rotation is mounted vertically to the wind direction, so there is no need for a pitch mechanism to adapt to the wind direction [3]. The blades are mounted on the main rotor shaft. The spindle is connected to the power generation module at the base. The power generation component consists of a gearbox and a generator. Vertical axis wind turbines can be classified into two types: resistance type and lift type according to blade design. Among them, the resistance blade design uses the resistance generated by air passing through the blade to drive the rotation of the main rotor shaft, and the lift blade design uses the lift generated when air flows through the blade to drive the rotation of the main rotor shaft. When the blade rotation speed is faster, the resistance generated by air passing through the blade decreases, and the lift force increases, so the vertical wind turbine blade design is dominated by the lift type (Darieu wind wheel) [4].

3.2. Generating Mechanism of Vertical Axis Wind Turbine

The vertical wind turbine blades convert the kinetic energy of the wind into which the kinetic energy of the main rotor shaft is converted. The spindle is connected to the gearbox to adjust the torque of its output rotational motion and its rotational speed to match the generator for higher power generation efficiency [5].

3.3. Characteristics of Vertical Axis Wind Turbine

Vertical-axis wind turbines do not need to counter the wind when the wind direction changes, which is a major advantage over horizontal-axis wind turbines. It not only simplifies the structural design but also reduces the torque of the wind wheel against the wind. Breeze starting (1m/s can start power generation), but the tip speed ratio is low, and the power output is low when the size, weight, and cost of the wind wheel are certain. Due to these advantages of vertical axis wind turbines, they can be applied to urban public lighting, residential gathering areas, and other areas where horizontal axis wind turbines are difficult to apply, and can also be widely used in villas, multi-story and high-rise buildings, communication base stations, urban public lighting, highways, offshore oil fields, islands, borders, and other off-grid small electricity.

3.4. Efficiency of Vertical Axis Wind Turbine

The efficiency of vertical-axis wind turbines is affected by many factors, including aerodynamic efficiency, mechanical conversion efficiency, and environmental factors. The aerodynamic efficiency is mainly related to the shape of the bearing bush, the installation Angle of the blade, the number and shape of the blade, etc. Through the rational design of these components, the dynamic efficiency and mechanical conversion efficiency of the bearing can be effectively improved. The mechanical conversion efficiency relates to the efficiency of the transmission system and the electrical conversion efficiency. The design optimization of the transmission system can reduce energy loss and thus improve the mechanical conversion efficiency. The electrical conversion efficiency needs to consider the performance of the motor and the working effect of the controller.

Environmental factors such as temperature and humidity also have an impact on the efficiency of vertical-axis wind turbines. Therefore, in practical applications, these factors should be taken into account and corresponding measures should be taken to maintain the best efficiency of the equipment [6]. At present, the efficiency of vertical axis wind turbines has been significantly improved, and some advanced vertical axis wind turbine designs can achieve aerodynamic efficiency of more than 40% and mechanical conversion efficiency of more than 90%. However, for certain models, inefficiency may still be a problem, which may be related to design, material selection, maintenance, and other factors. To sum up, the efficiency of vertical axis wind turbines is affected by many factors,

and it is necessary to achieve efficient operation through comprehensive optimization design and adjustment.

3.5. Working Environment of Vertical Axis Wind Turbine

Traditional horizontal-axis wind turbines usually require a higher starting wind speed to start generating electricity, while vertical-axis wind turbines can operate at low wind speeds and have a higher starting torque. Therefore, it is suitable for low wind speed areas, such as inland areas, mountains, and so on [7].

3.6. Stability of Vertical-Axis Wind Turbines and Their Difficulty in Maintenance

Compared with traditional horizontal axis wind turbines, the efficiency of breeze generation vertical axis motors is relatively low, and because the vertical blade area is smaller, the torque is also smaller, so the output power is smaller. Due to the special structure of the breeze power generation vertical shaft motor, the maintenance is more difficult, and the maintenance cost is relatively high [8-10].

4. Conclusion

The structural composition of wind turbines is mainly based on the research and exploration of the optimization of various components at present. The core objectives of these studies revolve around reducing costs and improving power generation efficiency. The research on the power generation principle of wind power generation is mainly to make better use of the power generation principle and realize the scientific and rational application of power resources. However, at present, there is relatively little research on its economic value, investment, and resource application for ordinary investors. The comprehensive study of the characteristics of wind turbines mainly focuses on the exploration of relevant laws, and it is necessary to reasonably plan and apply these related characteristics.

Through the research on this topic, it is understood that a wind turbine is a device that uses wind power to propel the generator to rotate. Its main structural principle is to use the design of the blades to convert aerodynamic force into mechanical energy, which in turn drives the generator to rotate. However, wind turbines also have limitations, such as wind speed, wind direction, and other conditions that affect the efficiency of power generation, in addition to the high construction cost of wind turbines, and the need for a sufficient clean energy supply. With the progress of science and technology, the research development and application of wind turbines have broad prospects and great potential.

Author Contribution

All the authors contributed equally, and their names were listed in alphabetical order.

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