

DESIGN AND FABRICATION OF VERTICAL AXIS WIND TURBINES

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ABSTRACT

The development and analysis of new vertical axis wind turbines is an important area of research due to their unique features. Unlike conventional horizontal axis wind turbines, vertical axis wind turbines can accept wind from any direction without the need for complicated head mechanisms. This means that they can be placed in a wider range of locations and can potentially generate more power than their horizontal counterparts. One particular concept that has been studied is the Wollongong vertical axis wind turbine. This turbine has a self-starting mechanism, which means that it can begin generating power without the need for external power or assistance. Additionally, it produces relatively high torque, which is a measure of rotational force, making it an attractive option for generating electricity. The study of the Wollongong vertical axis wind turbine is important because it could lead to the development of more efficient and effective wind turbines in the future. By analyzing the design and performance of this turbine, researchers can gain insights into the factors that affect its efficiency and identify areas for improvement. Ultimately, the goal is to create wind turbines that can generate even higher levels of power while also being more cost-effective and environmentally sustainable.

Keywords: Vertical axis windmills; torque; self-start

1. INTRODUCTION

Vertical axis windmills, also known as vertical axis wind turbines, are a type of wind turbine that has blades that rotate around a vertical axis rather than a horizontal one. Unlike horizontal axis wind turbines, which have to face directly into the wind to generate power, vertical axis wind turbines can accept wind from any direction, making them more versatile in terms of placement and orientation. There are several different designs of vertical axis windmills, including Darrieus, Savonius, and Giromill. Each design has its own unique features and advantages, and researchers continue to explore new designs and improvements to existing ones. One of the main advantages of vertical axis windmills is their ability to generate power in areas with changing wind directions, such as urban environments or mountainous regions. They are also generally more compact and easier to install than horizontal axis wind turbines, which can make them more cost-effective. However, vertical axis windmills also have some limitations. They tend to be less efficient than horizontal axis wind turbines, particularly at higher wind speeds, and they can be more prone to vibration and noise. Additionally, their vertical orientation can make them more susceptible to damage from strong winds or storms. Despite these limitations, vertical axis windmills remain an important area of research and development in the field of renewable energy. As technology continues to advance, it is possible that new designs and

improvements will make vertical axis wind turbines an even more attractive option for generating clean and sustainable energy. There are several types of windmills, each with its own unique design and purpose. The post mill is one of the oldest types of windmills and consists of a wooden post mounted on a base. The post can be rotated to face the wind, and the sails are attached to a wooden framework, which is also mounted on the post. Post mills were used for grinding grain or pumping water. Tower mills are similar to post mills, but instead of a post, they have a tower that can be rotated to face the wind. The sails are attached to a cap that sits on top of the tower, and the grain is ground in the base of the tower. Smock mills are a type of tower mill that has a wooden tower with a thatched roof, which gives them a distinctive appearance. The sails are attached to a cap that can be rotated to face the wind, and the grain is ground in the base of the tower. Wind pumps are small windmills that are used to pump water from wells or other sources. They are often found in rural areas where electricity is not readily available. Horizontal axis wind turbines are a modern type of windmill that generates electricity by converting the energy of the wind into rotational energy. The blades are mounted on a horizontal axis and face directly into the wind. They are often used in wind farms to generate electricity on a large scale. Vertical axis wind turbines are another modern type of windmill that generates electricity by converting the energy of the wind into rotational energy. The blades are mounted on a vertical axis and can accept

wind from any direction. They are often used in urban environments or in areas with changing wind directions. These are just a few examples of the many types of windmills that have been developed over the centuries. Each type has its own unique features and advantages, and researchers continue to explore new designs and improvements to existing ones. India has emerged as one of the world's largest producers of wind energy, with a total installed capacity of over 39,000 MW as of 2021. Wind energy accounts for nearly 10% of the country's total installed power capacity, making it a significant contributor to India's renewable energy mix. The growth of wind energy in India has been driven by a combination of government policies, private sector investment, and technological advancements. The Indian government has set ambitious targets for renewable energy, including a target of 175 GW of renewable energy capacity by 2022, which includes 60 GW from wind power. A few major players, including Suzlon Energy, Vestas, and GE Wind Energy, dominate India's wind energy market. These companies have a significant presence in India and have invested heavily in developing wind energy projects in the country. In recent years, there has been a shift towards larger wind turbines, which are capable of generating more power than smaller turbines. This has led to an increase in the average turbine size in India, with many new projects now using turbines with a capacity of 2-3 MW or more. The Indian government has also introduced a number of policies to support the growth of wind energy, including a generation-based incentive (GBI) scheme and a competitive bidding process for wind energy projects. These policies have helped to attract private sector investment and have driven down the cost of wind energy in India. Despite the growth of wind energy in India, there are still challenges that need to be addressed. These include issues related to grid integration, land acquisition, and financing. However, with continued government support and private sector investment, the future of wind energy in India looks bright, and it is likely to play an increasingly important role in the country's energy mix in the years to come.

Problem statement

The need for more efficient and effective vertical axis wind turbines that can generate high power output while eliminating the complicated head mechanisms of conventional horizontal axis wind turbines. The statement highlights the importance of developing new vertical axis wind turbines that can operate in any direction, have self-starting capabilities, and produce high torque. The purpose

of the study of the Wollongong vertical axis wind turbine is to analyze its performance and determine its potential as a highly attractive device for generating wind energy.

Contributions

The study of the Wollongong vertical axis wind turbine can contribute in several ways:

- **Technology advancement:** The study can contribute to the advancement of wind turbine technology, especially vertical axis wind turbines, by identifying the design and operational features of the Wollongong turbine that make it self-starting and capable of producing high torque.
- **Improved efficiency:** The study can help identify ways to improve the efficiency of vertical axis wind turbines, especially in terms of power output and the ability to generate electricity in low wind speeds.
- **Cost-effectiveness:** By identifying the design features and operational characteristics of the Wollongong turbine, the study can contribute to the development of more cost-effective wind turbines, which can help reduce the overall cost of generating wind energy.
- **Environmental benefits:** The study can contribute to the development of more sustainable and environmentally-friendly energy sources by promoting the use of wind energy as a clean alternative to fossil fuels.
- **Practical applications:** The findings of the study can have practical applications for the development and implementation of vertical axis wind turbines in a range of settings, including urban and remote areas.

2. LITERATURE SURVEY

The design and performance enhancement of Savonius wind turbines review various studies on the optimization of Savonius turbines using techniques such as numerical simulations, experimental investigations, and design modifications. The authors discuss the advantages and disadvantages of the Savonius design, including its simple construction, low noise level, and suitability for low wind speed conditions [1]. The use of unsteady vorticity for thrust and torque enhancement of vertical-axis wind turbines is explored. They present a method for controlling the unsteady flow around the turbine using an active

flow control system, resulting in improved power output [2]. The performance and wake characteristics of a vertical-axis wind turbine using both computational simulations and experimental measurements are investigated. They evaluate the effects of blade number, chord length, and blade shape on the turbine's performance, and analyze the wake flow patterns [3]. A comprehensive review of vertical-axis wind turbines, covering their history, design principles, and current challenges are provided. They discuss various types of vertical-axis turbines, including Savonius, Darrieus, and straight-bladed turbines, and highlight the key design factors that affect their performance [4]. The performance of a vertical-axis wind turbine in a 3D turbulent flow using computational simulations analyze the effects of blade geometry, rotational speed, and wind speed on the turbine's performance, and examine the wake characteristics downstream of the turbine [5]. The design and wind tunnel testing of a new vertical-axis wind turbine suitable for urban areas discuss the challenges of designing a turbine that can operate in the complex and variable wind conditions found in urban environments [6]. A high-order adjoint method to optimize the aerodynamic design of a vertical-axis wind turbine shows that the optimized turbine has significantly improved power output compared to a baseline design [7]. Recent advancements in vertical-axis wind turbine technology, including the use of novel blade designs, control systems, and materials reviewed. They discuss the advantages and disadvantages of vertical-axis turbines compared to horizontal-axis turbines, and highlight the potential applications of vertical-axis turbines in urban and remote areas [8]. Wind turbine noise, including its sources, measurement, and mitigation are discuss the effects of wind turbine noise on human health and the environment, and examine various strategies for reducing turbine noise [9]. The design and performance of a vertical-axis wind turbine using a combination of experimental measurements and numerical simulations are optimized. They analyze the effects of blade angle, blade chord length, and rotational speed on the turbine's performance, and compare the experimental and simulated results [10]. It presents a comprehensive overview of vertical-axis wind turbines, covering their history, design principles, and applications. The book covers various types of vertical-axis turbines, including Savonius, Darrieus, and Giromill turbines, and discusses their advantages and disadvantages. The performance of a novel vertical-axis wind turbine based on the Savonius rotor using computational simulations examines the effects of blade geometry, rotational

speed, and wind speed on the turbine's performance, and compare the results to experimental data. The design of a Darrieus vertical-axis wind turbine for low wind speed conditions using computational fluid dynamics is optimized [11-15].

Inferences from literature survey

The literature survey suggests that there is significant interest in the design and optimization of vertical-axis wind turbines, including the Savonius and Darrieus designs. Researchers are using various techniques such as numerical simulations, experimental investigations, and design modifications to improve the performance of these turbines. The advantages of vertical-axis turbines, such as their suitability for low wind speed conditions, simple construction, and low noise level, are highlighted in several studies. Researchers are also exploring novel blade designs, control systems, and materials to improve the performance of these turbines. Additionally, there is a growing interest in the use of vertical-axis turbines for urban and remote areas. Finally, wind turbine noise and its effects on human health and the environment are also discussed in several studies, and researchers are exploring strategies for reducing turbine noise.

3. MATERIAL AND METHODS

A shaft is a mechanical component that transmits rotational motion and torque from a power source to a driven component. It is a long, cylindrical metal rod that typically has a round cross-section and is used to connect different components of a mechanical system, such as gears, pulleys, and sprockets. The shaft rotates within bearings that are mounted in the system and transfers power to the driven components through the use of couplings, keys, and other connecting mechanisms. Shafts are commonly used in a variety of industrial applications, such as pumps, turbines, motors, and other machines that require rotary motion. They are typically made from high-strength materials such as steel or titanium to withstand the high torque and stress that they are subjected to during operation. Blades are an essential component of a wind turbine, which are designed to capture wind energy and convert it into rotational motion. The blades are mounted on a hub, which is connected to a shaft, and the rotation of the blades drives a generator to produce electricity. The shape and size of the blades are important factors in determining the efficiency of the wind turbine, as well as its power output. Wind turbine blades are typically made from composite materials such as fiberglass, carbon fiber, or other

materials that provide strength and durability. The blades are curved or twisted to optimize their aerodynamic properties, allowing them to capture the maximum amount of wind energy and convert it into rotational motion. There are different types of blades used in wind turbines, including the straight blade, the curved blade, and the variable pitch blade. Straight blades are simple in design and are used in smaller wind turbines, while curved blades are used in larger turbines and are more complex in design. Variable pitch blades can adjust the angle of attack depending on wind conditions, which allows for better control of the turbine and higher energy output. Blades are a critical component of a wind turbine, and their design and construction are essential to the efficient and reliable operation of the turbine. Ongoing research and development in blade technology are focused on improving their performance, reducing their cost, and increasing their durability, with the ultimate goal of making wind energy more accessible and cost-effective.

A bearing is a mechanical component that supports the weight and movement of rotating or moving parts in a machine. It is designed to reduce friction and wear between two surfaces that are in contact with each other, allowing for smoother and more efficient movement of the machine. Bearings are typically made of metal, such as steel or brass, and come in different shapes and sizes depending on the application. The most common type of bearing is the ball bearing, which consists of a set of balls that roll between two rings to support the rotating shaft. Other types of bearings include roller bearings, needle bearings, and plain bearings. Bearings are found in a wide range of machines and devices, including cars, airplanes, industrial machinery, and wind turbines. In wind turbines, bearings are used to support the weight of the rotor and allow it to rotate smoothly, even under high wind loads. They are typically located at the top and bottom of the main shaft and are subject to high stresses and loads. A belt is a flexible looped component that transmits power and motion between two rotating shafts in a mechanical system. It is typically made of a durable and flexible material such as rubber, nylon, or leather, and is used in conjunction with pulleys or sprockets to transfer torque and rotational motion from one shaft to another. Belts are commonly used in a variety of industrial and consumer applications, such as in engines, conveyors, and washing machines. They come in different sizes and shapes, including V-belts, timing belts, flat belts, and ribbed belts, each designed for specific applications and power requirements. A pulley is a simple machine that consists of a grooved wheel and a rope, belt, or

chain that passes over the wheel. When one end of the rope or belt is pulled, the pulley rotates, allowing force to be transmitted from one point to another. Pulleys are used in a wide range of mechanical systems and devices, such as cranes, elevators, and conveyor belts. They can be used to transmit force and motion between two shafts that are not directly connected, or to change the direction of force or motion. There are different types of pulleys, including fixed pulleys, movable pulleys, and compound pulleys. Fixed pulleys have a stationary axle and change only the direction of the applied force, while movable pulleys have a movable axle and can amplify force. Compound pulleys are a combination of fixed and movable pulleys, and can provide a mechanical advantage for lifting heavy loads. Alternators are commonly used in vehicles, such as cars and trucks, to generate electrical power for the vehicle's electrical system and recharge the battery. They are also used in stationary applications, such as in power plants and wind turbines, to generate electricity for the grid. The main advantage of alternators over other types of generators is that they produce AC power, which is the type of power used in most electrical systems. AC power can be easily transmitted over long distances and can be easily converted to other forms of electrical power, such as direct current (DC), which is used in many electronic devices. Alternators come in different sizes and power ratings, and can be designed for specific applications and operating conditions. They typically consist of a rotor with a set of magnets, a stator with a set of coils, and a voltage regulator that controls the output voltage. Proper maintenance and testing of alternators is important to ensure their reliable operation and prevent failure. Alternators can become worn or damaged over time, leading to reduced efficiency and performance. Regular inspection and testing of the alternator's output voltage and current is important to ensure that it is operating within its specified range. An energy source is any natural or human-made substance or process that provides usable energy in a particular form for human use. The choice of energy source depends on various factors, including availability, cost, efficiency, environmental impact, and societal acceptance. As the world moves towards a more sustainable and low-carbon future, there is an increasing focus on renewable and clean energy sources to meet our energy needs. **Figure 1** shows the block diagram of wind power generation.

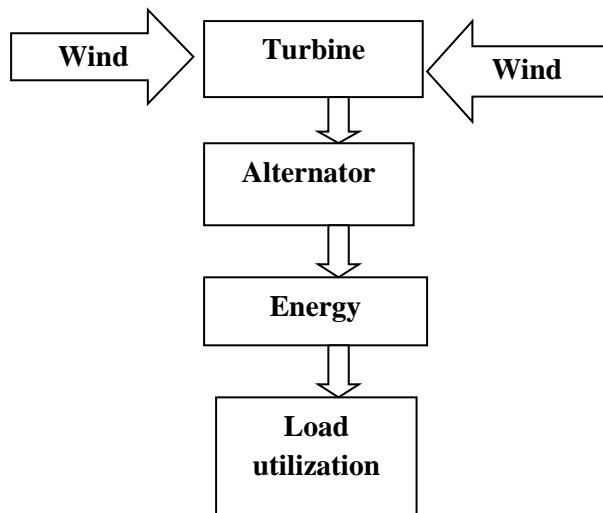


Fig 1 block diagram of wind power generation

4. RESULTS AND DISCUSSION

Gas cutting is a process used to cut metal using a fuel gas flame. It is commonly used in industrial applications, such as shipbuilding, metal fabrication, and construction. The process involves heating the metal to its ignition temperature with a flame produced by a fuel gas, typically acetylene, propane, or natural gas, and oxygen. The metal is then oxidized by the oxygen, which creates a chemical reaction that produces a stream of molten metal. The molten metal is blown away by the force of the oxygen, resulting in a cut. Gas cutting can be done manually or with the help of machines. Manual gas cutting is done with a hand-held torch that is moved along the metal to create the cut. Machine gas cutting is done with computer-controlled machines that follow a pre-programmed cutting path, resulting in higher precision and efficiency. Gas cutting has some advantages over other cutting methods, such as plasma cutting or laser cutting. It is less expensive and more portable than other methods, making it a popular choice for on-site cutting. It can also cut thicker materials than some other methods and is less sensitive to surface conditions or impurities on the metal. However, gas cutting does have some limitations, such as the need for a fuel gas source, which can be a safety hazard if not used properly. It can also create heat-affected zones and produce more rough edges than other cutting methods. Overall, gas cutting is a widely used method for cutting metal in various industries, and its applications continue to evolve with advancements in technology and safety measures.

Arc welding is a welding process that uses an electric arc to create a fusion between metals. It is one of the most widely used welding processes in

the manufacturing industry due to its versatility, speed, and low cost. The process involves creating an electric arc between an electrode (a metal rod) and the workpiece to be welded. The heat generated by the arc melts the electrode and the base metal, which then fuse together to form a welded joint. The process can be done manually, semi-automatically or fully-automatically, depending on the application.

There are several different types of arc welding processes, including:

1. Shielded metal arc welding (SMAW): This is the most basic and commonly used arc welding process. It uses a consumable electrode coated in a flux material that protects the weld from contamination.
2. Gas metal arc welding (GMAW): This process uses a wire electrode that is fed continuously through a welding gun. The welding gun also feeds shielding gas, which protects the weld from contamination.
3. Flux-cored arc welding (FCAW): This is a variation of GMAW that uses a tubular electrode filled with flux material, which creates a shielding gas when heated.
4. Gas tungsten arc welding (GTAW): Also known as TIG welding, this process uses a non-consumable tungsten electrode that is heated by an electric arc. A separate filler material is used to join the two pieces of metal.

Arc welding has many advantages, including the ability to weld a wide range of metals, such as steel, aluminium, and copper. It can also be used in a variety of positions, including overhead, horizontal, and vertical. However, it can be challenging to use in outdoor or windy conditions due to the need for shielding gas. Additionally, it requires proper training and safety precautions to avoid risks such as electric shock, eye damage, and burns.

Grinding is a metalworking process that involves using an abrasive material to remove material from a work piece. It is commonly used in manufacturing and metalworking to create smooth surfaces or to remove excess material from a work piece. Grinding can be done manually or with the help of machines. Manual grinding is done using hand-held tools such as angle grinders or grinding wheels, while machine grinding is done using computer-controlled machines such as surface grinders or cylindrical

grinders. The grinding process involves moving an abrasive material, such as a grinding wheel or belt, over the surface of the work piece to remove material. The abrasive material is typically made of silicon carbide, aluminium oxide, or diamond. The choice of abrasive material depends on the type of material being ground and the desired surface finish.

There are several different types of grinding processes, including:

1. **Surface grinding:** This process is used to create a flat surface on a work piece. It involves moving an abrasive material back and forth over the surface of the work piece until it is smooth and flat.
2. **Cylindrical grinding:** This process is used to grind the outside diameter of a cylindrical work piece. The work piece is held in place while an abrasive material moves along the length of the work piece to remove material and create a smooth surface.
3. **Centerless grinding:** This process is used to grind the outside diameter of a cylindrical work piece without using a center. The work piece is held in place by a support blade while an abrasive material moves along the length of the work piece to remove material and create a smooth surface.

Grinding has several advantages, including the ability to remove material quickly and create a smooth surface finish. However, it can generate a lot of heat, which can damage the work piece if not properly controlled. Additionally, it can create dust and debris that can be a safety hazard if not properly handled.

The windmill is a device that functions by converting the kinetic energy of the wind into mechanical energy. The principle behind this process is based on the concept of the kinetic energy of any particle, which is equal to half its mass times the square of its velocity, as expressed in equation (1) as

$$KE = \frac{1}{2} mv^2 \dots\dots\dots(1)$$

Here, KE refers to the kinetic energy, m refers to the mass of the particle, and v represents its velocity. The mass of the air that flows through the blades of the windmill is determined by its volume multiplied

by the density (ρ) of the air, as expressed in equation (2) as

$$M = \rho AV \dots\dots\dots(2)$$

Substituting equation (2) in equation (1), we obtain the expression

$$KE = \frac{1}{2} \rho AV \cdot V^2 \dots\dots\dots(3)$$

$$KE = \frac{1}{2} \rho AV^3 \text{ watts} \dots\dots\dots(4)$$

Here, ρ refers to the density of the air (1.225 kg/m³), A represents the area of the blades ($\pi D^2/4$), and D is the diameter of the blade.

Using the above formula, we can calculate the available wind power (P) as $(1/2 \rho \pi D^2 V^3)/4$ or $1/8 \rho \pi D^2 V^3$ watt. For example, in trial 1, where the wind velocity is 4.5 m/s, the available wind power can be calculated as

$$Pa = (1/2 \rho \pi D^2 V^3)/4 \dots\dots\dots(5)$$

$$Pa = (1/2 \cdot 1.225 \cdot \pi \cdot 1.22^2 \cdot 4.5^3)/4 = 65.244 \text{ watts} \dots\dots\dots(6)$$

Similarly, in trial 2, where the wind velocity is 5.5 m/s, the available wind power can be calculated as

$$Pa = (1/2 \rho \pi D^2 V^3)/4 \dots\dots\dots(7)$$

$$Pa = (1/2 \cdot 1.225 \cdot \pi \cdot 1.22^2 \cdot 5.5^3)/4 = 119.12 \text{ watts} \dots\dots\dots(8)$$

The above calculations demonstrate the available wind power at different wind speeds for a wind turbine with a diameter of 1.22 meters (D=1.22m). At a wind speed of 4.5 m/s, the available wind power is 65.244 watts, and at a wind speed of 5.5 m/s, it is 119.12 watts. These calculations assume a density of air (ρ) of 1.225 kg/m³, which is the standard value at sea level and at a temperature of 15 degrees Celsius.

It is important to note that the actual power output of a wind turbine will be less than the available wind power due to various losses, such as frictional losses in the system and losses due to the inefficiency of the conversion process from mechanical energy to electrical energy. Nevertheless, these calculations provide an estimate of the available wind power that

can be harnessed by a wind turbine, and this information can be used to optimize the design and placement of wind turbines for maximum energy output. **Figure 2** shows the final design of wind power generator.

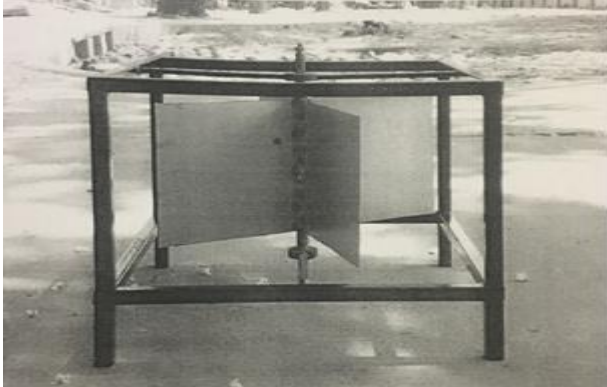


Fig 2 Final design of wind power generator

Wind energy has a wide range of applications across different sectors. Wind energy is widely used for electricity generation. Large-scale wind turbines are installed in wind farms, which generate electricity that is supplied to the grid. Wind energy can also be used to pump water in areas where there is no access to electricity. Small wind turbines are installed for this purpose, and they power water pumps that lift water from wells or boreholes. Wind energy is used in farming for various purposes, such as grinding grain, pumping water, and generating electricity for farm operations. Wind energy can be used to power homes, businesses, and other facilities that are not connected to the grid. Small wind turbines are installed, which generate electricity for the local consumption. Wind energy can be used to power vehicles, such as sailboats and wind-powered cars. In disaster-affected areas, wind energy can be used to generate electricity for emergency operations, such as lighting and communication. Wind energy can be used to power remote facilities, such as weather stations, telecommunication towers, and remote sensing equipment. Overall, wind energy has numerous applications, and it is a clean and renewable source of energy that can help reduce the dependency on fossil fuels and mitigate the impact of climate change.

Wind turbines have been developed in a variety of power outputs, ranging from a few kilowatts to

several thousand kilowatts. Even turbines with low power output can generate enough electricity for domestic appliances, space heating and cooling. For instance, low-power wind energy conversion generators have been used for protecting buried metal pipelines from corrosion for many years. Wind turbines with a power output of up to 50 kW are suitable for operating irrigation pumps and navigational signals. Additionally, aero generators in the intermediate power range, between roughly 25 to 100 kW, can provide electricity to remote communities.

Wind energy is a renewable source of energy, which means it is constantly replenished by nature and will not run out like finite resources such as coal, oil, and natural gas. Wind energy is a clean source of energy that does not produce harmful greenhouse gas emissions or air pollutants. The cost of wind energy has decreased significantly in recent years and has become one of the most cost-effective sources of energy. Once a wind turbine is installed, the cost of generating electricity is relatively low. The wind energy sector creates jobs in various areas such as manufacturing, installation, operation, and maintenance of wind turbines. Wind turbines can be installed on land that is also used for other purposes such as farming or grazing, allowing landowners to diversify their income streams. Wind energy can provide energy independence, reducing dependence on foreign oil and other non-renewable sources of energy. Wind energy projects can range in size from a single small wind turbine to large wind farms with hundreds of turbines, making it a scalable energy source.

Some advantages of vertical axis wind turbines (VAWTs) over horizontal axis wind turbines (HAWTs) include: VAWTs can capture wind from any direction without the need for a yaw mechanism to align the turbine with the wind. This makes them more suitable for urban and suburban areas where wind direction is often variable and unpredictable. VAWTs can have a more compact design compared to HAWTs, which makes them easier to install in areas with limited space. VAWTs tend to produce less noise than HAWTs, which can be important for installations close to residential areas. VAWTs can start rotating at lower wind speeds compared to

HAWTs, making them more efficient in low wind conditions. VAWTs can be mounted on shorter towers compared to HAWTs, which can reduce installation costs and make them more suitable for areas with height restrictions. However, it's worth noting that there are also some disadvantages of VAWTs compared to HAWTs, such as lower efficiency and higher maintenance requirements. The choice between VAWTs and HAWTs depends on a variety of factors, including the location, wind conditions, and energy needs.

5. CONCLUSION

The work and research conducted so far on vertical axis wind energy conversion systems have yielded encouraging results. These systems have the potential to significantly contribute to the production of clean, renewable electricity from wind energy, even in locations that are not ideal for wind energy production. This reinforces the conviction that these systems are practical and efficient. In more developed nations, it is possible to construct these wind energy systems using high-strength, low-weight materials, which would make them more efficient and cost-effective. However, in less developed countries, it is also possible to construct these systems using locally available materials and low-tech methods. This would allow these countries to harness the power of wind energy using their own resources and skills. Overall, the potential for vertical axis wind energy conversion systems to provide clean, renewable electricity is significant, and the research conducted so far is promising. With continued development and investment, these systems could play a major role in reducing our reliance on fossil fuels and mitigating the impacts of climate change.

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