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**VERTICAL AXIS HYBRID WIND
TURBINE**
T H E S I S

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Table of Notations

W	[m/s]	Relative velocity upstream
H	[m]	Height of the blade/turbine
w	[rad/s]	Angular velocity
ρ	$\left[\frac{\text{kg}}{\text{m}^3}\right]$	density
R	[m]	Radius
P	[watt]	Power
v	[m/s]	Velocity
A	[m ²]	Efficiency
L	[m]	Length
D	[m]	Diameter
N	[–]	Number of blades
C	[m]	Chord length
σ	[–]	Rotor Solidity

1 Introduction

Renewable energy has emerged as a critical answer to the pressing issues of climate change, energy security, and sustainable development. Wind energy has received substantial attention in various renewable energy types as a clean, plentiful, and cost-effective alternative to traditional fossil fuel-based power generation. Its intrinsic properties, such as being renewable, widely available, and ecologically acceptable, make it a feasible way to reduce greenhouse gas emissions and handle the world's growing energy demand.

Because of growing worries about climate change, finite fossil fuel supplies, and the need for energy sustainability, the development of sustainable energy sources has become increasingly critical in recent years. Wind power stands out as a prominent and realistic alternative among the vast range of renewable energy options. Traditional horizontal axis wind turbines (HAWT) ruled the wind energy scene for many years. However, the development of vertical axis hybrid wind turbines (VAHWTs) offers a viable alternative, with significant benefits in terms of design, efficiency, and adaptability.

As I was doing an online course about wind energy, I got increasingly enthralled by its potential and significance. The training gave important insights into the technical elements of wind energy as well as its environmental impact. Inspired by the knowledge I received and the potential I saw, I felt inspired to go deeper into a specific sector of wind energy. This prompted me to focus my thesis on vertical-axis hybrid wind turbines and how the self-starting issue can be tackled.

My thesis' main purpose is to look into the potential and practicality of vertical axis hybrid wind turbines (VAHWTs) for sustainable electricity generation. To begin, I intend to present a detailed overview of the original design and development process of wind turbines. Secondly, I would analyze the possible turbine types and materials that can be used. Furthermore, VAWT will be compared with HAWT, the possible conclusions will be written, and the efficiency based on the location and production output will be analyzed.

2 Literature Review

2.1 History of Wind Energy

Since at least 3000 years ago, people have used windmills primarily for water pumping and grain milling, and wind has been a vital source of propulsion in sailing ships for far longer. Windmills (or wind turbines) have been used to produce energy since the late nineteenth century when Charles Brush in the United States built a 12-kW direct current windmill generator and Poul la Cour in Denmark conducted research. Wind energy was first used as a source of energy in the ancient times. Vertical axis windmills were used in Persia in the 10th century and in China in the 13th century. The wind energy was once an important source of energy for transportation, grain grinding, and water pumping. Windmills and water mills were the greatest sources of energy prior to the introduction of the steam engines. Windmills, numbering in the hundreds, were ubiquitous across Europe for grinding grain and pumping drainage water, and some were also employed for industrial uses like cutting wood. Windmills were created all over the world as Europeans conquered it. Except for sailing, the primary long-term use of wind has been to pump water. Aside from the well-known Dutch windmills, another well-known example is the ancient usage of sail-wing blades to pump water for agriculture on the Greek island of Crete. When the winds were too strong, one of the blades of these windmills had a whistle on it to alert the operator to modify the sail area. [2] The electricity generation trends using wind energy over the years can be seen in the graph below.

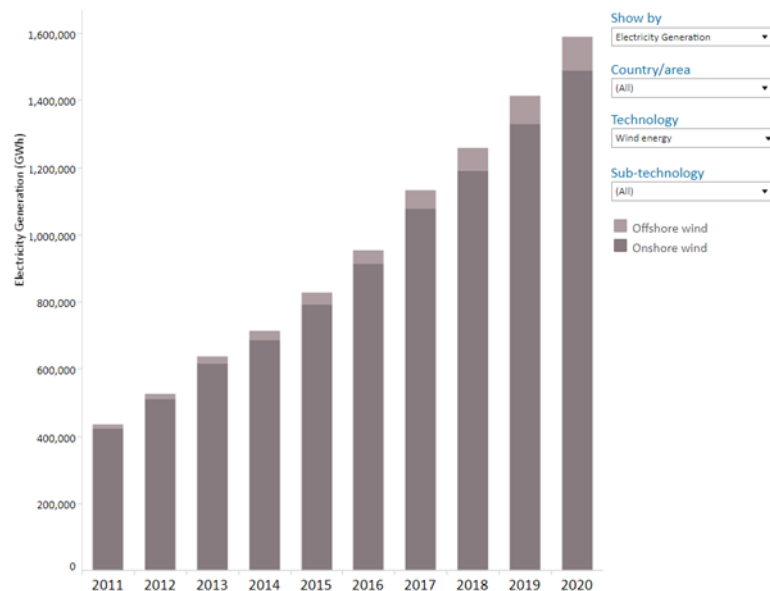


Figure 1 Electricity Generation Trends [3]

2.1.1 Wind Energy Working Overview

The wind is the movement of air relative to the earth's surface. Kinetic Energy is therefore present in a moving body or object. The law of conservation of energy states that "one form of energy can be converted into another, and total energy remains constant." Wind Energy is the KE of the air that is transformed into electricity using a turbine known as a wind turbine. Wind energy is a free renewable energy source that has captivated humans for millennia. Obviously, obtaining this free energy (which is launched by solar radiation and hence infinite on the human timeline) is one of the finest development alternatives. In this context, wind power has made significant investments in R&D, building, unique laws, and economic incentives. This has resulted in continuing capacity expansions, greater efficiency and scale, and the development of novel technologies such as floating wind turbines to acquire additional high-quality wind resources. [1]

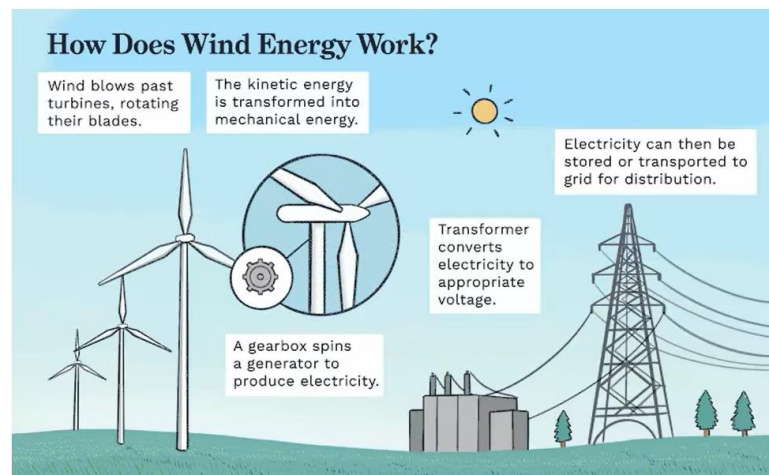


Figure 2 Wind Energy Working [1]

A wind turbine's function is to gather wind kinetic energy through the use of varied shaped blades. The wind raises the blades in the same way that a sail raises to propel a boat. The wind pushes the blades, causing the driving shaft to spin. This shaft then spins a pump of some sort, either directly moving a piece of stone over grain (windmill) or transferring that energy to a generator, which produces power that may be used immediately or stored in a battery. A wind turbine's revolving driving shaft is connected to a gearbox, which multiplies the rotational speed by 100, turning a generator. As a result, the gears spin far faster than the blades powered by the wind. These gears may be able to power an electric generator if they reach a suitable speed. The turbine's gearbox is the most expensive and heaviest component, and engineers are working on direct drive generators that can run at lower speeds and hence do not require a gearbox. [1]

2.2 An Overview of Wind Turbine Types

Wind turbines are classified into two types: horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines (VAWTs). The most prevalent type of wind turbine is the HAWT. They often feature two or three long, thin blades, similar to an airplane propeller. These are the most prevalent wind turbine kinds. The blades are oriented such that they face straight into the wind. VAWTs, like electric mixer beaters, feature curved blades that are shorter and broader. VAWTs can catch wind from any direction and are commonly utilized in low-wind conditions. Aside from the two primary varieties, there are also Onshore Wind Turbines, which are meant to be put on land. They're ubiquitous in wind farms and come in a variety of sizes and capacities. Offshore Wind Turbines are specially built for installation in bodies of water, generally along coastlines or offshore. Floating Wind Turbines are a form of offshore wind turbine that floats on the water's surface rather than being attached to the seabed. They may be used in deeper oceans where typical fixed-bottom offshore turbines cannot be used. Wind Turbines Darrieus: These turbines, also known as vertical axis wind turbines (VAWTs), feature an eggbeater-like design with curved blades that resemble aerofoils. They are intended to work irrespective of wind direction and are hence suited for low-wind circumstances. Savonius Wind Turbines: Similar to a drum or an S-shaped bent rotor, Savonius turbines are another form of VAWT. They start themselves and can catch wind from any direction. [4]

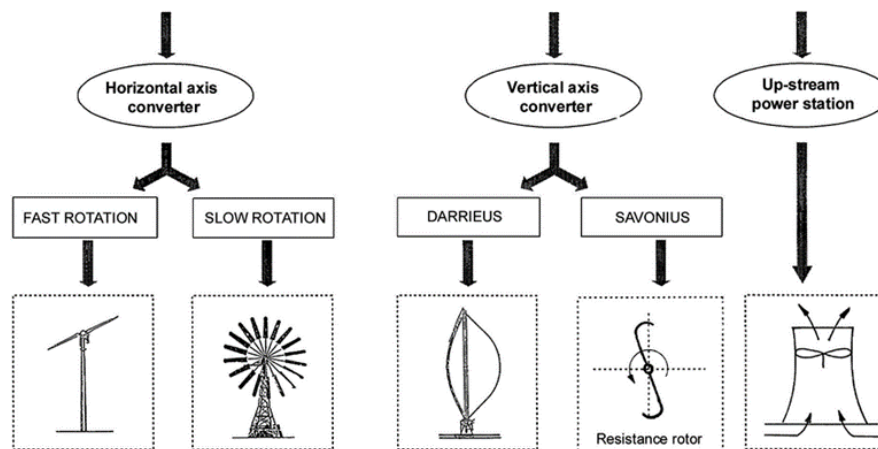


Figure 3 Wind Turbine Types [5]

2.2.1 Overview of Vertical Axis Wind Turbine

A vertical-axis wind turbine (VAWT) has its primary rotor shaft oriented transverse to the wind, and its base houses the key parts of the turbine. The generator and gearbox are easier to replace and repair since they are near the ground. VAWTs are not required to be oriented toward the wind, hence wind-sensing and orientation devices are not required. VAWT utilizes blades mounted to the top and bottom of a vertical rotor. Depending on the circumstances and location,

vertical-axis turbines can reach heights of 100 feet and widths of 50 feet. The following are the general aerodynamics of VAWT: [7]

$$\vec{W} = \vec{U} + (-\vec{\omega} \times \vec{R})$$

Savonius and Darrieus wind turbines are the primary types of VAWT to be examined. The Savonius wind turbine (SWT) is a vertical axis wind turbine (VAWT) that generates drag. The most typical configuration is a spinning shaft with two or three scoops to collect incoming wind. Because of its simple and long-lasting construction, as well as its poor efficiency, it is utilized when dependability trumps efficiency. One explanation for the low efficiency of a Savonius wind turbine is that half of the turbine creates positive torque while the other half travels against the wind and therefore generates negative torque. Darrieus is a vertical axis wind turbine (VAWT) with lift as well.. A series of curved aerofoil blades with rotating shaft connections at their tips were asked for in the original design. On the other hand, certain wind turbine designs known as H-rotor or Giromill Darrieus wind turbines use straight vertical airfoils. In addition, the Darrieus wind turbine's blades might be helix-shaped to split torque uniformly during the revolution, lessening the effect of torque ripples on the turbine. Darrieus wind turbines, being lift-type devices, may collect more wind power than drag-type wind turbines like the Savonius wind turbine. [7]

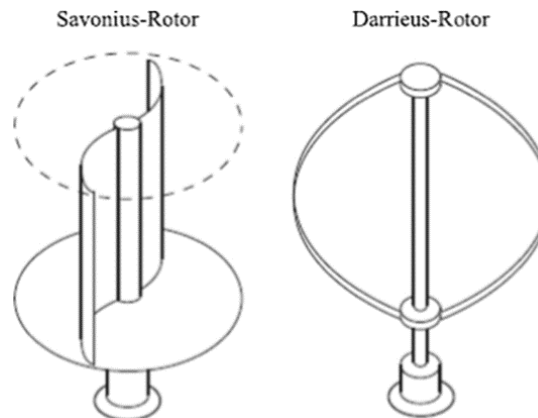


Figure 4 Savonius and Darrieus Turbines [6]

2.3 Overview of Comparison With Hawt

Despite having been covered in the discussion before, Vertical Axis Wind Turbines (VAWTS) will now be briefly examined to highlight the distinctions between them and Horizontal Axis Wind Turbines (HAWTS).

2.3.1 Advantages

The two most prevalent forms of VAWTs are the Savonius and Darrieus. The Savonius operate in the same way as a water wheel does by using drag forces. The Darrieus, on the other hand, has blades that look exactly like those shown on HAWTs. VAWTs operate closer to the ground, which allows heavy equipment, like as the gearbox and generator, to be located closer to the ground rather than in the nacelle. However, because ground-level winds are weaker, less power is created for the same wind and capture area. [8]

Being able to capture wind from all directions gives a VAWT an advantage over a HAWT in that it eliminates the requirement for a yaw mechanism. The time-varying power output caused by power changes in a single blade rotation, the need for guy wires to support the main tower, and the fact that Darrieus VAWTs do not self-start like HAWTs counterbalance this gain. VAWTs have various advantages over ordinary horizontal-axis wind turbines (HAWTs). Inside wind farms, they may be placed incredibly close together, allowing for more in any location. They are also quiet, omnidirectional, and exert less strain on the supporting structure. They also require less wind to generate power, allowing them to be placed closer to the ground when the wind speed is low. They are easier to handle since they are closer to the ground and may be utilized on tall structures. [8]

It, unlike the HAWT, does not need to be pointed into the wind to function properly. This adaptability enables simple installation in places with varied wind directions. Furthermore, because of their long-curved propellers intended to harness the force of even a tiny quantity of wind, VAWTs may generate energy even at low wind speeds. Another advantage is that VAWTs do not require tower installation, which not only avoids local ordinance constraints but also decreases construction costs. Furthermore, because VAWTs seem like solid objects visible to both humans and wildlife, their aesthetics are often more appealing and a VAWT generator can also be located at a lower level, which simplifies maintenance issues. [8]

2.3.2 Disadvantages

They are not, however, without downsides. Some of the more important ones are covered. VAWTs may not work well in windy circumstances. They have a very low starting torque and have issues with dynamic stability. VAWTs are also extremely sensitive to non-design conditions and have a limited installation height, restricting their application to areas with moderate wind speeds. The blades linked to VAWT are prone to fatigue because of the large change in applied forces with each revolution. Early versions' vertical blades become twisted with each rotation, resulting in fractures. The turbine failed because the blades wore out over time. Numerous researches have been performed to improve turbine location in wind farms in order to solve the problems and inefficiencies associated with VAWTs. Despite its modest height, physical force scaling forecasts that wind farms using VAWTs will be developed with less expensive materials, manufacturing techniques, and maintenance than conventional wind turbines. [8]

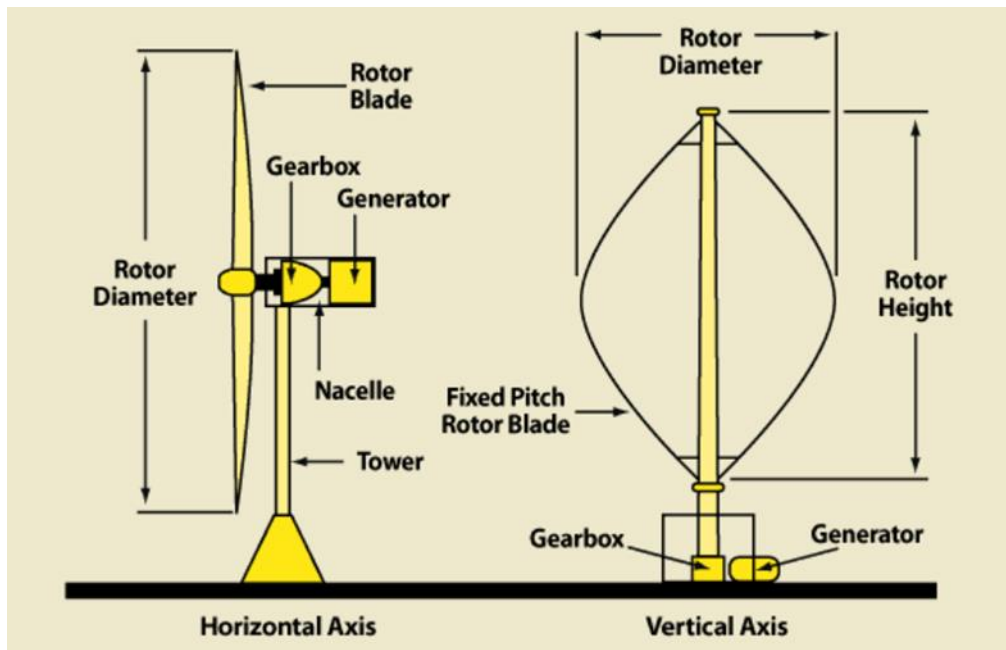


Figure 5 Comparison of VAWT & HAWT [8]

Finally, VAWTs and HAWTs each have their unique set of advantages and disadvantages. VAWTs provide placement flexibility, can function at low wind speeds, and have appealing aesthetics, but HAWTs harness larger wind speeds at higher elevations and have higher efficiency. However, VAWTs may be less efficient at lower altitudes, while HAWTs may be more costly and physically unpleasant. The exact needs and limits of the site where the wind turbine will be erected ultimately determine the decision between the two types.

2.4 Overview of the Impact of Wind Energy

2.4.1 Overview of the Advantages

The advantages of renewable energy include its non-depletion, global availability (as opposed to fossil fuels and minerals), and mostly non-polluting nature. Wind turbines do not need water to create electricity, making them ecologically beneficial. [2] Wind energy, being a renewable energy source, has both advantages and cons. On the plus side, wind energy does not need the use of water resources, which distinguishes it from thermal power facilities, including nuclear power plants. Wind energy is also a clean and ecologically beneficial form of energy, contributing to lower greenhouse gas emissions and climate change mitigation. Furthermore, wind farms may be built in a variety of places, both onshore and offshore, to take advantage of copious wind resources. Renewable energy sources have several advantages. Wind, sun, ocean, and geothermal energy are abundant and free to use since they are widely available and naturally replenished. One of the major benefits of renewable energy is its reduced carbon

footprint, which contributes to a cleaner and more sustainable world. Renewable energy helps to minimize climate change and its negative impacts by lowering dependency on fossil fuels. In addition, the development of renewable energy infrastructure supports economic growth and job creation, resulting in a more robust and wealthy society. Furthermore, adopting renewable energy sources increases a country's energy independence by lowering reliance on potentially unpredictable or unfriendly foreign energy providers. [11]

Despite these hurdles, the advantages of renewable energy, such as its sustainability, environmental friendliness, and economic development potential, make it an increasingly appealing and feasible alternative to traditional energy sources. Continuous technological breakthroughs and continuing research initiatives strive to address and minimize the downsides of renewable energy, enabling a more sustainable and resilient energy future. While wind energy has various advantages such as sustainability and lower emissions, it also has negatives such as intermittent power, noise problems, and potential animal damage. When considering the viability and effect of wind energy projects, several aspects must be considered. [11]

2.4.2 Overview of the Disadvantages

However, wind energy has several downsides. One significant constraint is its variability and intermittency, which means that wind turbines create power only when the wind blows fast enough. Because of this inconsistency, energy storage devices or backup power sources are required to maintain a steady electrical supply. Wind turbines may also produce noise, which may be an issue for adjacent towns. There is also the possibility of bird and bat fatalities as a result of collisions with wind turbine blades, while attempts are being made to limit this impact through good siting and design. [2] The early expenses of establishing renewable energy systems can be significant, necessitating significant expenditures in infrastructure and technology. Although abundant throughout the day, solar energy is restricted by the availability of sunshine and cannot be harnessed at night or in poor weather. While geothermal energy is a promising source, it has the ability to transport harmful compounds from deep inside the Earth, thereby causing environmental damage. Hydroelectric dams, while producing renewable electricity, are generally expensive to build and can disturb natural water flows, affecting ecosystems and wildlife habitats. Wind energy generation necessitates certain wind conditions and the correct placement of turbines, which might have an impact on bird populations owing to their height. [11]

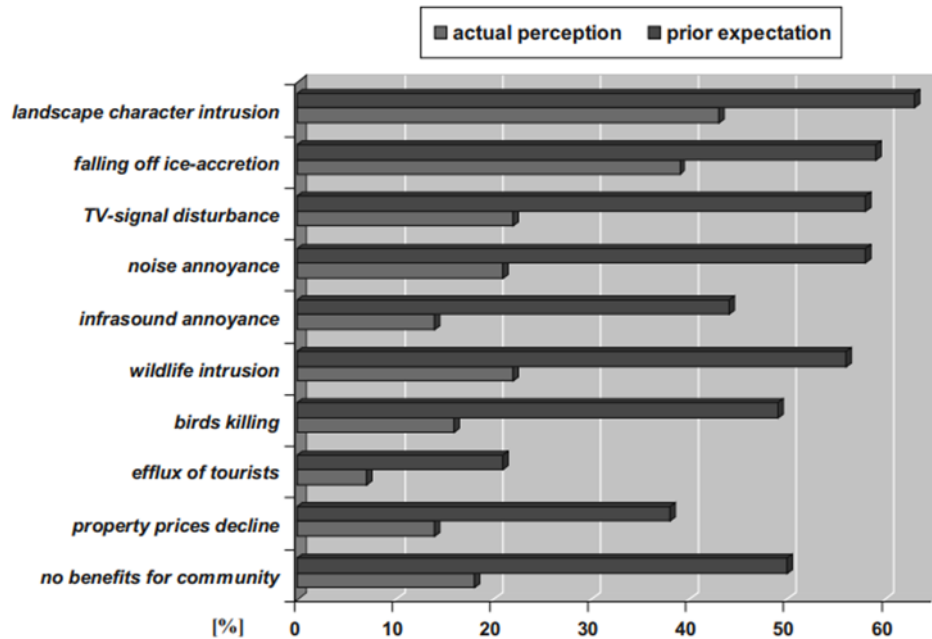


Figure 6 Negative Impacts of Wind Turbines [9]

2.4.3 Overview of the Site Evaluation Impact

Temporary operations are carried out on a lower scale during the site evaluation phase of wind energy projects compared to the building and operating stages. These operations, which include monitoring, testing, and exploring, have the potential to influence a variety of resources. One critical factor to address is air quality, where monitoring and testing operations may result in the local and temporary creation of vehicle emissions and fugitive dust. However, these effects are unlikely to surpass air quality requirements or significantly contribute to climate change.

Cultural Resources

Another crucial factor to consider during site appraisal is cultural resources. The surface disturbance is limited during this phase, which means that buried cultural materials are largely undisturbed. Surface cultural material, on the other hand, may be disrupted by car traffic, ground clearance, pedestrian activity, or artifact collecting. This data informs project design, allowing for the avoidance or reduction of impacts on these resources. It is also crucial to evaluate Native American culturally significant locations since monitoring and testing operations may have an impact on them depending on placement or visual intrusion degree. [11]

Ecological Resources

Typically, the impact on natural resources during the site appraisal phase is minimal. Because of their small scale and nature, activities such as monitoring and testing during this phase have little impact on vegetation, wildlife habitat, and aquatic environments. However, automotive activity has the potential to introduce and spread exotic vegetation. Mitigation techniques and meticulous planning are

used to reduce any possible negative impacts on air quality, cultural values, and biological resources. Wind energy projects may develop in an ecologically responsible manner by completing extensive analyses and adopting suitable safeguards, assuring the long-term sustainability of both the energy generation and the ecosystems in which they operate. [11]

Wildlife and Land

Monitoring and testing can have short-term and localized effects on land usage. There may be a brief disruption to wildlife and cattle in the immediate area of the monitoring/testing location while staff are present. Buffer zones are frequently developed to safeguard the public, wildlife, and equipment which may damage the recreational experience. Monitoring and testing efforts are unlikely to have an impact on mining operations, military operations, or aviation. [11]

Noise Pollution

In terms of noise, wind energy monitoring and testing operations create modest levels of transitory and intermittent noise. However, it is critical to emphasize that the noise problem is mostly caused by wind turbine building, operating, and maintenance operations. Wind turbine noise is a serious environmental hazard that is frequently complained about throughout their lives. As a result, a thorough discussion of the noise effect is presented separately, apart from noise created during the site appraisal phase. [11]

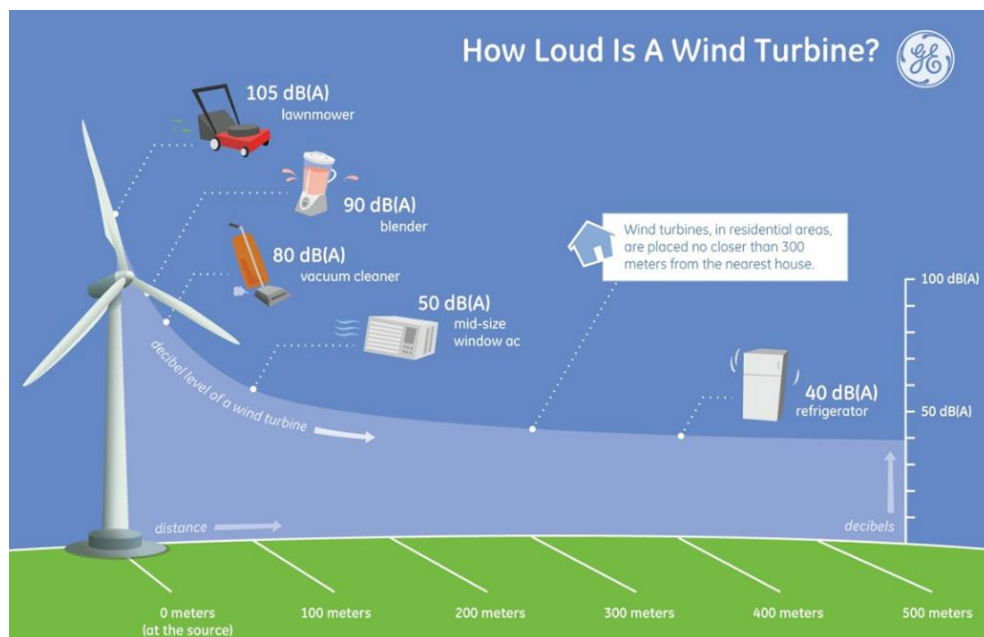


Figure 7 Noise Pollution by Wind Turbine [19]

3 Starting Process of Wind Turbine

The discovery of adequate wind conditions is the first step in operating a wind turbine. Wind speed and direction are monitored in real-time by advanced sensors such as anemometers and wind vans. An activation signal is provided to the turbine's control system when the wind speed falls within the ideal operating range. The beginning sequence is initiated by this signal. The mechanical braking mechanism, which keeps the rotor blades locked, is deactivated at this point. The blades may now revolve freely when the wind catches them. The turbine begins to generate power as soon as the blades begin to revolve. Depending on the configuration, the produced electricity is subsequently supplied into the electrical grid or stored in batteries. The starting procedure guarantees that the turbine functions safely and effectively, utilizing wind power to generate sustainable energy. [12]

3.1 Construction of Wind Turbine

A wind turbine is made up of critical components that are required for its operation. The tower, rotor, nacelle, generator, and foundation or base are all critical components. Each of these components is essential, and the lack of any of them would render the wind turbine inoperable.

1. Foundation

A wind turbine's foundation is a vital component that provides a sturdy and secure platform for its functioning. The base of onshore turbines lies underground, concealed beneath the earth. It is made comprised of a large concrete block that is meant to sustain the full weight of the turbine and resist the numerous forces operating on it. The foundation for offshore turbines is located underwater and cannot be seen. In other circumstances, such as offshore wind turbines, the foundation may even be floating. Despite being underwater, the foundation has enough bulk to support the weight of the turbine and withstand the forces applied to it, ensuring the turbine stays upright and functional. [14]

2. Tower:

The tower in modern wind turbines acts as a vertical framework that supports and raises the turbine's other components. The tower is typically made of tubular steel and has a spherical form with a diameter ranging from 3 to 4 meters (10 to 13 feet). The tower's height varies based on factors such as turbine size and location, although it typically ranges between 75 and 110 meters (250 and 370 ft). The tower height should equal the diameter of the circular route formed by the revolving blades, according to a basic rule in turbine design. Taller towers are useful because they allow the turbine to catch wind at the greater elevations, where wind speeds are frequently higher. This is because wind speeds tend to rise as one moves farther from the ground. Taller turbine towers allow the turbine to exploit wind resources

at greater speeds, improving overall efficiency and power generating capacities. [14]

3. Rotor

The rotor is the wind turbine's spinning component, consisting principally of three blades and a central hub to which the blades are joined. Although turbines can have a variety of blade configurations, the three-blade form is generally used due to its maximum efficiency and accompanying benefits. [4] The blades are meant to be lightweight and sturdy, with a hollow construction constructed of composite materials. Recent advances in blade design include increasing their size to provide more power while remaining lightweight and resilient. To enhance aerodynamic performance, the blades are designed in the shape of an airfoil, similar to aviation wings. Furthermore, the blades twist along their length, gradually altering the angle from root to tip. This twist improves their aerodynamic efficiency even further. Importantly, the blades may spin up to 90° around their axes, a motion known as blade pitch. This function gives you more control over the turbine's operation, allowing you to change its performance dependent on wind conditions.

4. Hub

The hub is critical in anchoring the blades and allowing them to rotate about the rest of the wind turbine structure. The hub serves as a central connecting point for the blades, ensuring that they are securely kept in place. It provides the blades with the required support and stability to withstand the forces imposed by the wind during operation. Without the hub, the blades would be unable to freely rotate and contribute to power generation. The wind turbine can successfully absorb and harness kinetic energy from the wind by enabling the blades to revolve around the hub. This rotation allows the wind's kinetic energy to be converted into mechanical energy as the blades travel through the air, providing the rotational force required to operate the turbine's generator and generate electricity. [14]

5. Nacelle

The nacelle is a housing structure positioned at the top of the wind turbine tower that serves as a container for numerous components required for the turbine to function properly. It houses a variety of components that are critical to the turbine's sophisticated electromechanical system. The generator, which is responsible for transforming the captured wind power into energy, is one of the essential components present within the nacelle. The turbine shaft, which is attached to the rotor blades, transfers rotational energy from the wind to the generator through a gearbox situated in the nacelle. The gearbox is essential in wind turbines because it increases the rotating speed of the main shaft. The primary shaft of the turbine normally revolves at a modest speed of 12 to 25 rotations per minute (rpm), but the generator requires a greater speed for effective energy generation. The gearbox does this by increasing the spinning speed to a level sufficient for the generator. The part of the turbine shaft that connects to the generator is known as the "high-speed shaft." [14]

6. Generator

The generator of a wind turbine is critical because it transforms mechanical energy from the rotor, which is propelled by the wind, into electrical energy. A generator is structurally similar to an electric motor. Electricity is often generated in three-phase alternating current at the commercial level. Wind turbine generators are often divided into two types: synchronous and asynchronous (induction). Because synchronous generators require a precisely regulated constant speed to maintain a steady frequency, induction generators are commonly utilized in wind turbines. Wind turbines, on the other hand, run at different speeds depending on wind conditions, making induction generators a better alternative. [14]

The generator must revolve at a specified speed to generate energy at the required frequency (50 or 60 Hz). This speed exceeds the rotating speed of the turbine rotor. Because such high speeds are unfeasible for the turbine rotor, a gearbox is used to boost the rotational speed of the main shaft to a level appropriate for the generator.

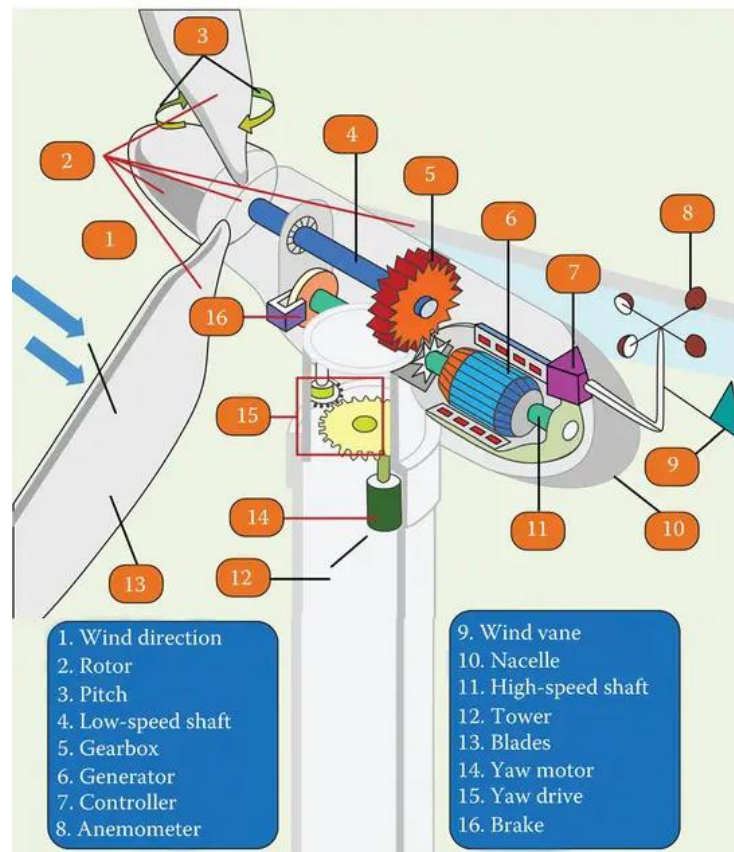


Figure 8 Wind Turbine Parts [14]

3.2 Wind Turbine Working

A wind turbine generates electricity by capturing the kinetic energy of the wind. Using a vane and anemometer at the top, the turbine automatically changes its orientation to catch the most energy from the wind. The nacelle at the tower's base revolves to align the turbine with the wind direction. As the wind blows, the turbine's blades begin to move at roughly 3.5 m/s and achieve a peak power output of around 11 m/s. In the case of extremely high winds, often more than 25 m/s, the blades are feathered, decreasing the turbine's speed and preventing damage. The rotor, which is made up of three blades attached to the hub, rotates a sluggish axis coupled to a gearbox, which raises the rotational speed from 13 to 1,500 revolutions per minute. This energy is transferred via the gearbox to a fast axis, which is coupled to a generator, which is responsible for transforming mechanical energy into electricity. The produced electricity is then transferred via the tower and sent to a substation through an underground connection. Before injecting power into the electrical grid for distribution to customers, the voltage is raised at the substation. To quickly detect and rectify any faults, the whole functioning of the wind turbine, including vital functions, is monitored and overseen from the substation and a control center. [12]

3.2.1 Explanation

A wind turbine transforms wind energy into electrical energy by using rotor blades that work similarly to airplane wings or helicopter rotor blades. The wind causes a differential in air pressure on either side of the blade as it passes over it. This pressure differential causes lift and drag forces to be generated. The rotation of the rotor is initiated by the lift force, which is greater than the drag force. The rotor is linked to a generator, either directly in the case of a direct drive turbine or indirectly through a set of gears in a gearbox for higher rotating speed and lower generator size. This mechanical revolution is subsequently transferred into power generation by the generator. The generated power is then used for a variety of purposes. [13]

3.3 Power Output

The wind turbine power output is not constant and changes with wind speed. A typical power performance curve is used to analyze and predict the energy production of a wind turbine. This curve offers information on the turbine's electrical power production depending on wind speed at the hub height without delving into the technical details of its components. The power curve may be used to assess the energy-generating capacity of a wind turbine, which aids in planning and monitoring its overall performance. Essentially, the power curve creates a link between wind speed and turbine electrical power production, offering significant insights into its efficiency under various wind conditions. [4]

Three important locations on the wind velocity scale can be used to evaluate the performance of a certain wind turbine generator. The first issue to consider is the

cut-in speed, which is the lowest wind speed necessary for the turbine to begin producing meaningful electricity. The second item is the rated wind speed, which is the wind speed at which the generator produces its maximum power output (also known as the rated power). Finally, the cut-out speed is the highest wind speed at which the turbine can generate electricity, often owing to engineering and safety concerns. [4]

Power curves illustrating the link between wind speed and power production are available from the manufacturer of a certain wind turbine. These curves are the result of field tests employing standardized testing methodologies. By analyzing the power curve, one can learn how the turbine performs at various wind speeds, such as its ability to generate power at low wind speeds (cut-in speed), reach maximum power output at a specific wind speed (rated wind speed), and stop power generation at high wind speeds (cut-out speed). These power curves are useful for analyzing and comparing the performance of various wind turbine types.

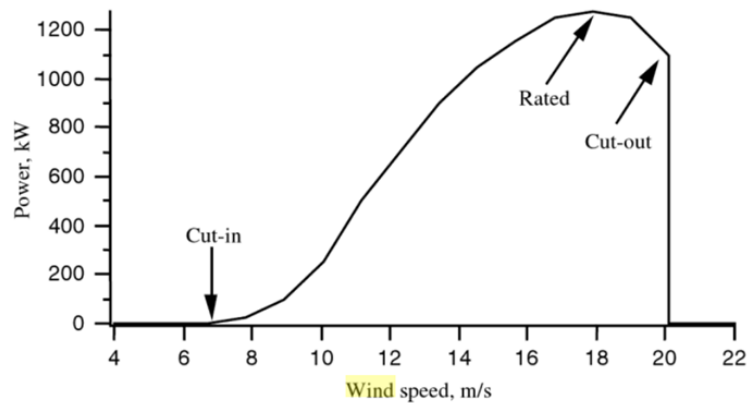


Figure 9 Wind Turbine Power Curve [4]

4 Self-Starting Problem

The VAWT is deemed to have started when it accelerates from a standstill position to a condition where the blade works at a steady speed that exceeds the wind speed (> 1). In other words, the VAWT must achieve a state in which it can successfully collect wind energy and create power. According to Lunt's analysis, VAWTs with blade angles (β) of 7.5° and 10° are incapable of self-starting. This means that these VAWT setups are unable to commence the necessary acceleration to achieve a constant blade speed that surpasses the wind speed. As a result, without self-starting capacity, these VAWTs would be unable to generate power from the wind. It's crucial to remember that the capacity of VAWTs to self-start varies based on their design, blade shape, and other considerations. While the exact VAWT configurations discussed may lack self-starting capacity, alternate designs or changes might theoretically permit self-starting in VAWTs with various parameters or features, according to Lunt's evaluation. [15]

Certainly! According to studies done by many researchers, the self-starting capability of Vertical Axis Wind Turbines (VAWTs) tends to rise with the number of blades, however, the maximum power coefficient falls with the number of blades. Sun et al. conducted a qualitative investigation that found that as the number of blades increased, the frequency of blade vortex shedding increased, resulting in a drop in power production, particularly at low Tip-Speed Ratios (TSRs). Chen et al., on the other hand, looked at a sort of VAWT known as H-VAWT, which had two sets of parallel straight blades. Although a two-bladed rotor normally has lesser power output than a one-bladed rotor, the use of two sets of blades considerably increased the static torque of the H-rotor, allowing for easy self-starting of the H-VAWT. [16]

4.1 Elaborating the Issue

Self-starting in wind turbines needs careful definition and study. Various researchers have proposed various definitions. Kirke believes a turbine to be self-starting only if it can accelerate from rest to a point where it provides a meaningful output. Ebert and Wood describe the beginning process as complete when considerable power extraction occurs. According to Lunt, a machine is considered to have begun when it has accelerated from rest to a situation where the blades run at a constant Tip-Speed Ratio (TSR) greater than 1.0. This concept implies that the turbine must function with lift rather than depending purely on the drag to exceed wind speed. Baker, on the other hand, outlines a dead region where insufficient or negative torque may prevent further acceleration, implying that atmospheric wind transients may be required to complete the self-starting process for fixed-blade darrieus turbines. Despite proof that fixed-geometry, symmetrical aerofoil blades in darrieus turbines cannot self-start, there have been field sightings of such devices self-starting, frequently without verification. In certain circumstances, air gusts may

promote self-starting, but not in all. A design's capacity to self-start is determined not only by its aerodynamic performance but also by the characteristics of the load it drives. There has, however, been a paucity of systematic investigation of turbine aerodynamic features in isolation from their resistive loads. Understanding each of these characteristics is critical for efficiently matching a turbine to its load. [17]

Vertical Axis Wind Turbines (VAWTs) driven by lift frequently have issues in generating enough torque to overcome the resistance of the electrical generator when both the Tip-Speed Ratio (TSR) and wind speeds are low. As a result, these lift-driven VAWTs require some initial energy input before they can generate power on their own, showing that they have limited self-starting capabilities. Researchers have investigated numerous strategies to increase the beginning capabilities of lift-driven VAWTs to overcome this issue. [15]

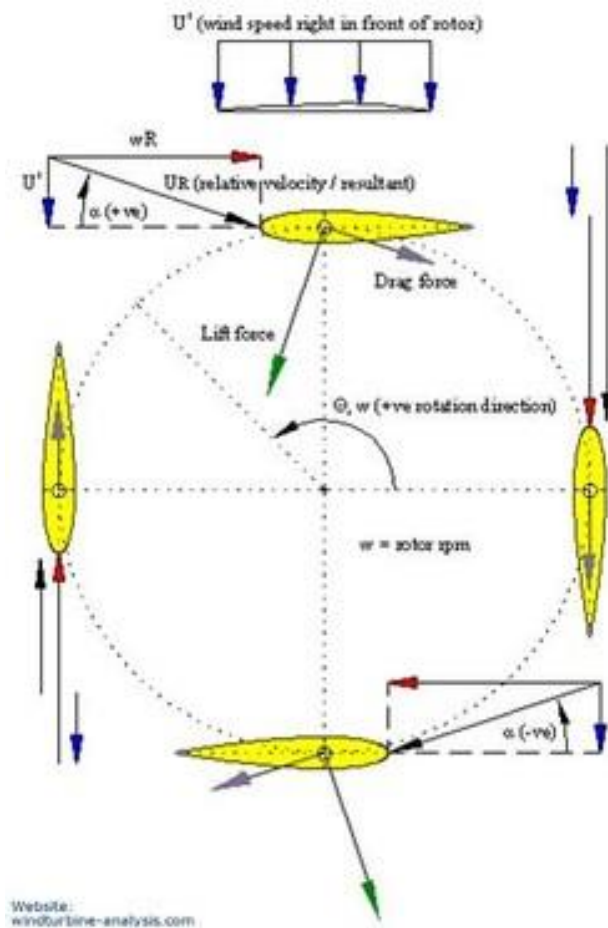


Figure 10 Darrieus Turbine Self-Starting Problem [20]

4.1.1 Tackling the Issue

To improve the self-starting capacity of VAWTs, researchers investigated the effect of blade number and relative location on self-starting and power coefficient. They developed a new VAWT type called a multi-blade local variable radius VAWT. The purpose of this research is to look at how lowering the partial blade

radius affects self-starting performance and power coefficient. The study's VAWT models had their partial blade radius lowered to 0.375, 0.5, and 0.625 times the outer radius. The researchers examined the dynamic torques, velocity contours, static torques, and static pressure contours of these various models using tests and numerical simulations. [16] One technique is to increase the solidity of the VAWT by adding additional blades to the turbine. This higher blade density can improve torque generation and self-starting. Cambered blades, which are aerodynamically bent to enhance lift and increase turbine performance at low TSRs and wind speeds, are another approach. Inclined blades, which are inclined at an angle, and helical blades, which have a twisted or spiral design, are also thought to be possible self-starting upgrades. Another way to enhance self-starting is to connect the VAWT to a generator that can also operate as a motor. The motor helps overcome the resistance of the electrical generator by first giving energy to the rotor, allowing the VAWT to begin generating power on its own. [18]

4.1.2 Savonius Wind Turbine

Savonius wind turbine is a drag-based wind turbine. A Finland scientist, Sigurd Johannes Savonius in 1992, first developed these wind turbines. He also suggested several other designs for Savonius turbines. Savonius wind turbines are Savonius rotors similar to a cup anemometer, if looking downward from the top this will look like two spoons facing opposite directions, they are linked at the center of the rotor axis, which creates an S-shape in the cross-section. These turbines have good self-starting properties. They can capture wind from all directions and operate at lower speeds. It should be noted that though they are drag-type and some lift is also produced in drag-type turbines. The geometry of Savonius wind turbines can be better understood when they are configured to two or more vertical semicircles. Due to their curvature, the drag of the concave surface is higher than the convex surface. This forces the rotor to turn when exposed to the wind. [6]

4.1.3 Darrieus Turbines

The word “Darrieus” defines a type of VAWT that is characterized by the lift phenomenon. French aerospace engineer named Georges Jean Marie Darrieus patented in 1931 a “Turbine having its shaft transverse to the flow of the current”, and his preceding patent (1927) hardly covered any possible arrangement using vertical airfoils practically 14 and stated that every blade must “have a stream-line outline curved in the form of a skipping rope.” The blade displaces to a very few degrees from its original shape due to which gravitational and centrifugal forces act and eradicates the bending stresses. This design was attempted to be implemented at a large scale by flow wind Corporation which laid the foundation for further research and study on this design and measures to improve its efficiency. [6]

5 Linking AI and Sustainable Energy Supply

AI is critical in the energy supply chain because it works with massive amounts of information and highly complex systems. [24] AI can specifically stimulate the renewable energy region by upgrading the renewable energy timely system operations and control as well as monitoring, operation, maintenance, and storage which can involve AI-driven solutions to enhance the efficiency of energy production, optimize energy distribution, reduce energy waste, and support the transition from fossil fuels to renewable energy sources.

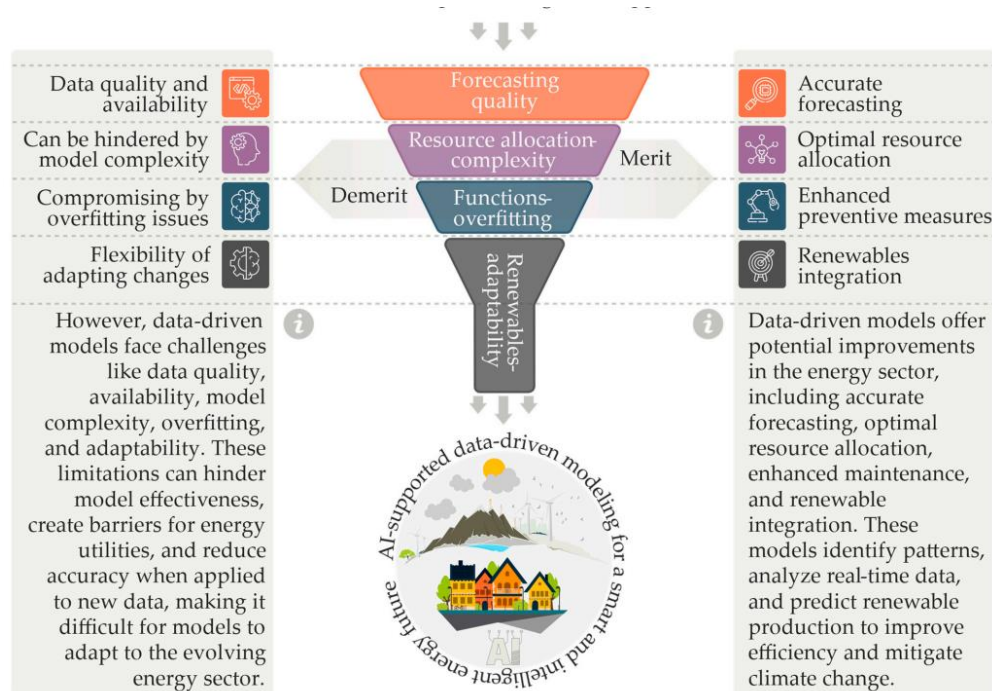


Figure 11 Pros and cons of AI-based data-driven models [23]

But the question still stands as to how AI-based systems can act as a solution to a more sustainable energy supply? To answer the question and explain the topic in depth I will discuss the recently used methods in this regard.

5.1 Methodologies Being Used

5.1.1 Smart Grids and AI

Artificial Intelligence serves as the guiding force within smart grids, functioning as an "intelligent agent" that assesses the environment and commences actions to advance specific objectives. AI is quite important in incorporating renewable

energy sources, stabilizing energy grids, and mitigating financial risks linked to infrastructure instability. The integration of AI into the grid infrastructure is essential to promoting a more dependable and sustainable energy supply.

5.1.2 Energy Forecasting

The technique of projecting a variable's future via the examination of past data trends is known as forecasting. AI has the potential to provide accurate forecasting of sustainable energy power availability, allowing us to seamlessly adapt operations, ensure plans remain unaffected, and efficiently meet current customer demands. Adopting AI also entails automating processes, which is a critical activity on a large scale for improving energy efficiency. [24]

The availability of data on power use has greatly expanded, mostly because of the widespread installation of smart meters worldwide.[11] The ultimate goal is to maximize energy input from production capacities while taking volatility and uncertainty costs into account. AI is crucial in forecasting energy demand, allowing for better peak-period adjustments. During periods of high traffic, AI may be utilized to actively select the most efficient power source. For instance, AI can foresee and switch the air conditioners' power source from batteries to the electrical grid based on which is most energy-efficient during peak and off-peak hours.

5.1.3 Energy Storage Based on AI

In the absence of sufficient storage capacity, sustainable energy supply may face reliability issues in the future due to market complexities, demand fluctuations, and changing customer behaviors. Innovations in storage and transmission networks offer major advantages for incorporating renewable energy sources into the electrical grid.[24] An energy storage system is used on the power supply side to improve the practicability and operation of the energy supply system. Furthermore, in communities focused on local energy solutions, energy storage systems are essential players as they work behind the scenes, ensuring a balanced energy flow across different periods. These systems offer a smart way to manage energy use, shifting it from high-demand moments to more stable times.

5.1.4 Predictive Maintenance

The AI models may generate proactive predictions based on consumption trends, informing maintenance staff of anticipated equipment breakdowns in advance. As of today, AI-based predictive maintenance stands as a vital solution in ensuring a sustainable energy supply. This approach minimizes downtime, reduces maintenance costs, and prolongs the lifespan of renewable energy assets and as a result, enhances the overall sustainability of energy production and distribution.

5.1.5 Cyber Security

Regardless of on-grid and domestic smart infrastructure, energy systems are not protected from associated risks such as breaches by third parties. AI has the

potential to enhance energy grid security by detecting trends in energy data that may suggest a breach and blocking intrusions before they occur. By continuously learning from patterns and anomalies, AI can strengthen defenses against cyberattacks, safeguarding crucial energy infrastructure that will ensure uninterrupted energy production and distribution resulting in a more sustainable energy supply system.

5.1.6 Optimization of Energy Distribution

By utilizing AI-based algorithms, energy suppliers may more precisely forecast energy supply and demand hence improving grid balance and minimizing energy waste. Energy outages may also be identified and handled by artificial intelligence, which can also be used to improve energy distribution routes and lower transmission losses. Data from energy storage systems can be analyzed by AI-powered algorithms to determine the best times to store energy and when to release it back into the grid, in addition to guaranteeing that energy is accessible when it is most required, this helps to decrease energy waste as well.

6 Analytical Study and Calculation

We do the analytical study and calculation of design parameters and some parameters that are necessary for the complete design. In the literature review, we discussed different types of turbines and the airfoil shape of different turbines. Based on different simulation results we selected a number of blades and their airfoil shape. The parameters like aspect ratio, solidity, power calculation, swept area dimensions of the turbine blades, number of blades, and selection of airfoil are done and calculated based on the literature review. More parameters will be studied after the calculation of the above-mentioned parameters.

6.1 Calculations

Calculation of the above parameters is done below:

6.1.1 Power

A wind turbine is designed for the wind power of, $P_w = 100W$.

6.1.2 Actual Power

The relation between actual power and gross power is given as, $P_w = P_a / c_p$

Where c_p is the power coefficient which is 0.4 as optimized from the graph given below, By putting values, we get, $P_a = 40W$

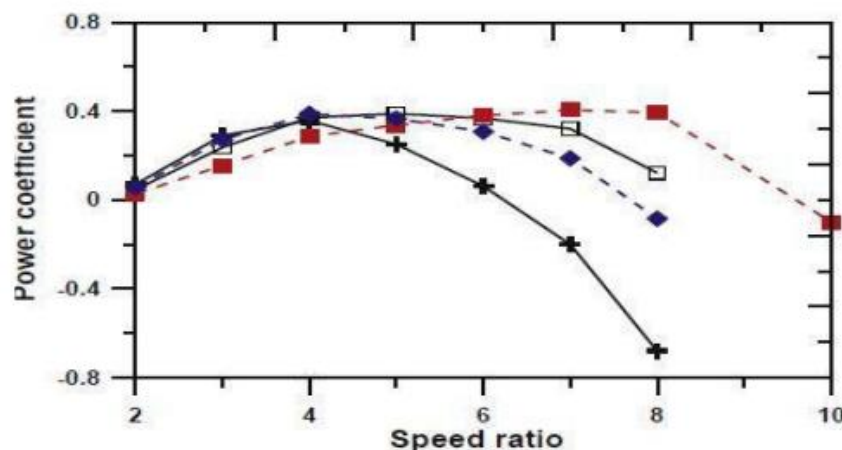


Figure 12 Power Coefficient vs Tip Speed Ratio

6.1.3 Electrical Generator Efficiency

The efficiency of the electrical generator used in the turbine is, $\eta = 0.8$

So, the power output will be,

$$P = Pa * \eta$$

This implies that, $P = 32W$

6.1.4 Swept Area

The formula for wind power is given by; $P = \rho A v^3$

Density of air, $\rho = 1.2\text{kg/m}^3$

The velocity of air, $v = 5\text{m/s}$

The wind turbine was designed for $P = 100W$

After solving we get, $A = 1.334 \text{ m}^2$

6.1.5 Aspect Ratio

For H-type VAWT: $AR = 3.6$, this implies that $AR = 1.57/0.425$

$L = 1.57\text{m}$ (length of the rotor)

$D = 0.85\text{m}$ (average diameter)

6.1.6 Solidity

The solidity formula is given by;

$$\sigma = N * C / 2R$$

Where, N = number of blades

C = chord length

R = radius of rotor

Solidity is directly related to the speed of blades and torque. High solidity will result in low speed but high initial torque and vice versa.

After putting the values, we get the solidity value of $\sigma = 0.71$

7 Darrieus Rotor Blade Design

In order to design blades, we first need to calculate the various parameters like chord length, solidity, blade length, swept area, and calculation of power by using reverse engineering technique. All these parameters are already calculated in the calculation chapter. The length of the rotor blade is 1.57m and the rotor diameter is 0.85m as the swept area was 1.334 m^2 .



Figure 13 Blade Design

7.1 Components

All the designing has been done in solid works and the CAD pictures of each component are attached below:

7.1.1 Struts For Blades

Struts are the main component of the turbine as they hold and connect the blades to the rotor shaft due to which the shaft rotates. In this turbine, the struts are aligned along the hexagon at an angle of 120° . The material of struts is stainless steel due to its low weight and high strength to support the blade rotation. The length of each strut is 1.5ft.

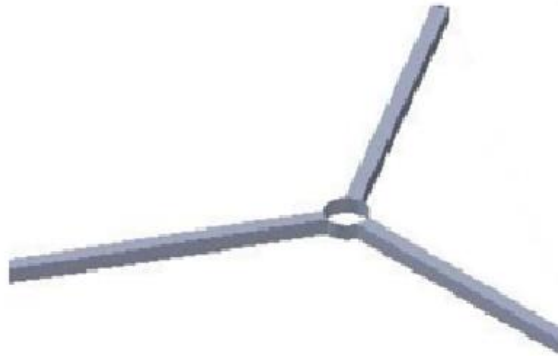


Figure 14 Struts for Blades

7.1.2 Rotor Shaft

Struts are connected to the rotor shaft which rotates the generator. The rotor shaft is made up of stainless steel due to its high strength and good corrosion properties. The length of the rotor 47 shaft is 7ft and struts are connected at the top and bottom of the rotor shaft for further working of the wind turbine. The rotor shaft was 18 gauge and made of stainless steel.



Figure 15 Rotor Shaft

7.1.3 Savonius Rotor Blades

The Savonius rotor blades have a half-cut bucket-type shape and the Savonius blades are three in number. Normally the blades of the Savonius rotor are straight but an angle of 12° is given at the end of the blades in order to enhance the efficiency. The material of the blades is fiberglass sheet.

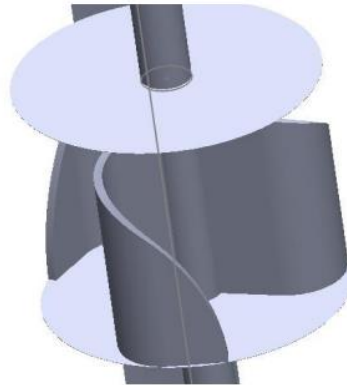


Figure 16 Savonius Rotor Blades

7.1.4 Savonius Rotor Plates

The Savonius rotor plates are of circular shape as expressed below. Three circular arcs are cut down into the plates and the blades are entangled into these hollow arcs in between the plate. The material of the plate is ply wood. The rotor plate has an external diameter of 1ft and an internal diameter of 1 inch.

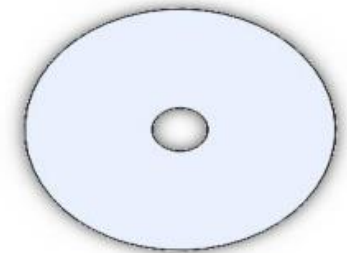


Figure 17 Savonius Rotor Plates

7.1.5 Turbine Base

The turbine base is made up of mild steel to provide high strength. Base is made heavier and low to ground to provide the stability to the turbine. The dimension of base is 2*2*1ft. CAD model of the base is attached below.



Figure 18 Turbine Base

7.1.6 Turbine Assembly

After assembling all the component, the turbine is formed. The final shape of the turbine is attached below.

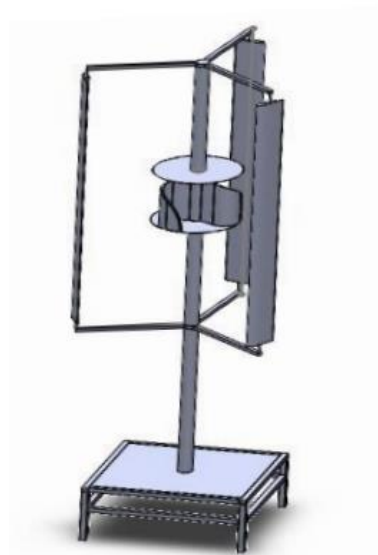


Figure 19 Turbine Assembly

8 Inspection of Installation Sites

8.1 Analysis of Wind Conditions

As outlined in the introduction, our objective is to assess turbines suitable for installation at the facility or urban level. These turbines are typically designed for low-altitude applications, making them highly sensitive to the surrounding natural and artificial topographical conditions. This sensitivity precludes the extension of measurement results to the broader environment, necessitating the theoretical placement of installation based on designated wind measurement points. Our study exclusively relies on locally measured results due to their predominant influence.[21] Consequently, we did not analyze wind conditions applicable to the general local environment, and no overarching conclusions were drawn. The selection of measurement points in our study was based on information obtained from freely available databases.



Figure 20 Measurement points [21]

8.2 Wind conditions in Hajdu Szoboszlo

To effectively demonstrate the operational efficiency of the Hungarian wind turbine across diverse geographical and anemographic conditions, actual data from the Hajdusoboszlo airport was utilized in our calculations. Positioned in the northeastern part of the city, the wind measurement point at the airport is situated 9 meters above the ground, mirroring the height above the winter construction site of the windmill to ensure optimization.

Hungary's wind patterns are predominantly influenced by the prevailing wind direction, with air movements generated by cyclones, anticyclones, convection, and topography affecting ground-level conditions. Given these factors, accurate measurement of the winter construction site's location is crucial for turbine placement. The wind data from Hajdusoboszlo, analyzed since 2011, provides a nuanced understanding of the prevalent wind conditions. Generally, the prevailing wind direction was observed to be northeast, with an average wind speed of 3.2 m/s

over the examined period, aligning with the broader averages for the Great Plains region.

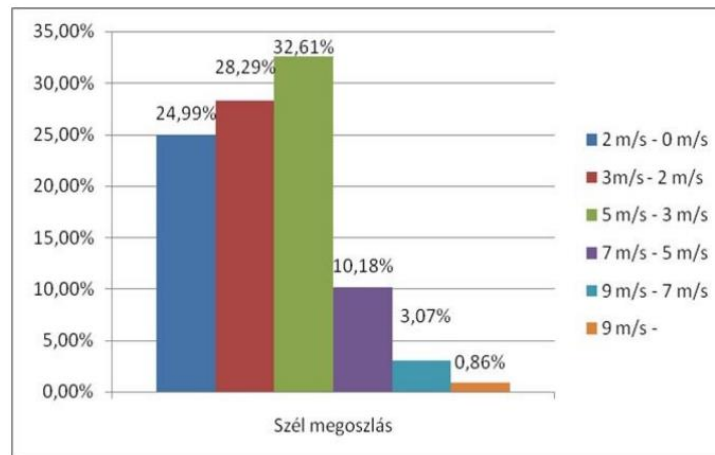


Figure 21 Wind data measured at the installation site 2011-2015 [22]

8.3 Reviewing Suitable Turbines

Referring to our shaft alignment guide, we distinguish between turbines featuring horizontal and vertical shafts. Horizontal-axis turbines, particularly those with wing-profiled blades and edge space, stand out for their enhanced ability to efficiently harness the kinetic energy of the wind compared to other turbine types. However, a drawback of highly efficient turbines with a high-speed factor is their noise and limited functionality in low wind conditions, restricting their suitability to specific environments. [22]

8.4 Recommended Turbine Design

The disparity between the upstream and downstream pressures in the turbine is shaped by the follower on the formed rod. The total pressure of the air emanating surpasses both static and total dynamic pressure. The pressure at the rod's end, akin to the confuser's silent part at the rendezvous, is influenced by the prevailing air conditions nearby. The confuser's half-life represents the reduction of static pressure equal to the dynamic pressure it generates.

$$\Delta p = p_{stat\ be} + p_{din} - p_{vesz} - p_{stat\ ki} = p_{stat\ be} + p_{din} - p_{vesz} - (p_{stat\ be} - p_{din\ confuser}) = p_{din} - p_{vesz} + p_{din\ confuser} \quad [22]$$

The semi-usable pressure drop on the turbine can be expressed as the difference between the static pressure on, dynamic pressure in, pressure loss, static pressure off, and dynamic pressure from the confuser. The maximum pressure drops achievable by the turbine, as illustrated in the figure, result from the dynamic pressure of the incoming air into the main body and the dynamic pressure generated by the confusion after the turbine. Extracting energy from this combination using

the strainer allows for utilization in the half-turbine. My established system features a 4-meter-diameter turbine soaring in the sky, a design aspect that posed challenges in our research endeavors. To address this, we considered its impact when formulating the pipe rule. Notably, 30% of renewable energy in Vienna is harnessed by the turbine, but its efficiency experiences a 50% reduction within the wind range of 2-5.5 m/s, a prevalent interval in the winter construction area. The table provided in the summer showcases the Air Force's contribution to winter performance. Notably, the table indicates that even with a relatively small turbine diameter and wind speed, it is possible to achieve high winter performance.[22]

9 Future Recommendations

The evolution of Vertical Axis Horizontal Wind Turbines (VAHWT) hinges on the establishment of uniform testing protocols for 2D and 3D designs, promising a paradigm shift in the industry. These standardized methods promise not just streamlined testing but also the assurance of consistent evaluation, fueling more effective design enhancements and superior performance across turbine models. Similarly, the push for commercialization and integration of these turbines into the national energy grid marks a significant way toward a more sustainable energy landscape, reducing dependence on conventional sources.

In addition, an imminent innovation lies in the development of a specialized braking system capable of managing high-speed winds. This pivotal safety feature ensures the turbines can adapt to various wind intensities, bolstering their resilience against extreme weather conditions. Also, using AI in the integration of Structural Health Monitoring (SHM) systems emerges as a critical strategy, enabling real-time assessment of turbine structural integrity for proactive maintenance, thereby ensuring prolonged and optimal functionality. Moreover, a hybrid energy approach should be followed resulting in uniting solar panels with wind turbines. This hybrid setup taps into diverse renewable sources, optimizing energy capture and fortifying reliability. By leveraging both wind and solar power, this approach will mitigate the challenges posed by intermittent energy generation, fostering a more consistent and robust energy supply.

Furthermore, advancements in generator design, particularly in refining rotor and stator plate configurations, hold immense potential for future research. These enhancements are poised to elevate generator efficiency, thereby amplifying overall turbine performance and energy conversion rates. As research and development are enhanced, these innovative strides would collectively pave the way for a dynamic future in the vertical axis hybrid wind turbine domain, where efficiency, reliability, and sustainability converge to redefine renewable energy landscapes.

10 Result

I determined the critical cut-in speed required to set the turbine in motion. To simulate real-world wind conditions, I employed pedestal fans, ensuring a consistent air velocity within the range of 5 to 7 meters per second. Strategically positioning the turbine to face the oncoming airflow maximized its exposure to the swept area. The outcomes were quite promising, with the wind turbine operating successfully and generating an output of approximately 27 watts. This method proved effective in mimicking operational conditions and provided valuable insights into the turbine's performance under controlled circumstances.

Comparing the proposed edge arrangement with conventional wind turbines reveals a significant impact attributed to the implementation of a confusor. Unlike traditional turbines that rely solely on the dynamic pressure of the air mass passing through their cross-section, our system, enhanced by the confusor, is capable of leveraging nearly 10 times the pressure. Despite potential reductions in turbine efficiency and damage from the nozzle, our half-usable pressure value at the edge remains substantial. In practical terms, the potential winter output from our 4-meter-diameter turbine is equivalent to the lifetime potential winter output of a conventional turbine with a diameter of 17.26 meters.[22]

Moreover, AI's integration in smart grids, energy forecasting, storage systems, and cybersecurity, among other areas, stands as a beacon of hope for reshaping our energy supply system. Its adeptness in handling vast data sets and navigating intricate systems has propelled renewable energy monitoring and operation to unprecedented levels of efficiency and resilience. This collaboration not only promises heightened productivity but also signifies a shift towards environmentally friendly practices, including waste reduction and resource optimization. Additionally, the study shows that optimizing turbine design and materials can significantly enhance efficiency, especially by increasing the turbine's tangential speed, resulting in a smaller angle of attack and higher blade lift coefficient.

11 Conclusion

In conclusion, my investigation sought to pinpoint turbines well-suited for facility-level installation, emphasizing efficiency within specific wind conditions and compatibility with low-altitude sites near facilities. The provided methodology facilitates a swift and cost-effective area analysis, contributing to the preliminary estimation of project costs. While refinements are possible with additional factors, the current approach stands as a resource-efficient solution for initial calculations.

Hence the aerodynamic load and structural responses in wind turbines significantly rely on the number of blades employed. Research suggests that three-bladed turbines exhibit superior efficiency compared to their two or four-bladed counterparts, attributing this efficiency to their peak performance. This collectively suggests that optimizing the number of blades, turbine velocity, and adapting rated airspeed according to local wind conditions, alongside considering the turbine's dimensions, specifically the radius, play crucial roles in maximizing wind turbine efficiency and energy production.

It is also evident from this study that in an era marked by rising energy demand and an urgent need for long-term solutions, the collaboration of artificial intelligence (AI) and the energy sector shines as a beacon of hope. The investigation of AI's integration in smart grids, energy forecasting, storage systems, predictive maintenance, cybersecurity, and optimized distribution highlights its critical role in reshaping our energy supply system. The ability of artificial intelligence (AI) to handle massive amounts of data and navigate complex systems has opened a world of possibilities, propelling renewable energy monitoring, operation, and control to unprecedented levels of efficiency and resilience. The collaboration of AI and sustainable energy not only promises increased productivity but also represents a shift toward greener practices, such as waste reduction, resource optimization, and environmental impact reduction. Therefore, embracing AI-based systems isn't just a solution; it's a transformative journey toward a more resilient, efficient, and sustainable energy supply for future generations.

Furthermore, it is deduced that further improvements can be made by altering the design and selecting the most suitable materials. An advantage of these turbines is their lightweight nature, facilitating easy installation. So it is concluded that an increase in the turbine's tangential speed leads to a smaller angle of attack, greater Reynolds's number, and a higher blade lift coefficient. Therefore, it is inferred that a larger turbine radius enhances efficiency at the same rotational velocity.

List of References/Bibliography

- [1] <https://www.treehugger.com/what-is-wind-energy-5097217> Accessed: 01.06.2013, 08:30 a.m.
- [2] Vaughn N. – Kenneth S.: *Wind Energy: Renewable Energy and the Environment*, CRC Press, Third Edition, 2019. p. 01-19. ISBN-13: 978-1-138-61534-2
- [3] <https://www.irena.org/Energy-Transition/Technology/Wind-energy> Accessed: 01.06.2013, 08:09 a.m.
- [4] James F. – Jon G. – Anthony L.: *Wind Energy Explained: Theory, Design, and Application*, John Wiley and Sons Publication, Second Edition, 2009. ISBN 978-0-470-01500-1
- [5] https://www.researchgate.net/figure/Overview-of-the-different-types-of-wind-turbines_fig1_260633223 Accessed: 02.06.2013, 04:30 p.m.
- [6] Amin A. – Hassen M. – Ahmet Z. – Haitham M. S.: *Parametric Study and Comparison of Aerodynamics Momentum-Based Models for Straight-Bladed Vertical Axis Wind Turbines*, In: *Arabian Journal for Science and Engineering*, 2020, p. 45. ISSN 729–741
- [7] Toptas, E. – Bayrak, M.: *Vertical axis hybrid wind turbine design*, In: *Journal of Mechatronics and Artificial Intelligence in Engineering*, 2020, p. 33-40.
- [8] <https://sites.google.com/a/temple.edu/urbanwind/services/turbine-options-and-specifications> Accessed: 03.06.2013, 01:22 p.m
- [9] Bohumil F. – Petr K.: *Impacts Of The Operation Of Wind Turbines As Perceived By Residents In Concerned Areas*, In: *Moravian Geographical Reports*, 2009, p. 34-45
- [10] <https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/Research/Biomass-Solar-Wind/NY-Wind-Energy-Guide-7.pdf> Accessed: 03.06.2013, 09:49 p.m
- [11] Frank R. Spellman.: *Environmental Impacts of Renewable Energy*, CRC Press, 2015. P. 03-21. ISBN-13: 978-1-4822-4946-0
- [12] https://www.acciona.com/renewable-energy/wind-energy/wind-turbines/?_adin=02021864894 Accessed: 03.06.2013, 10:11 p.m
- [13] <https://www.energy.gov/eere/wind/how-do-wind-turbines-work> Accessed: 03.06.2013, 10:31 p.m
- [14] https://electricalacademia.com/renewable-energy/wind-turbine-parts-functions/?utm_content=cmp-true Accessed: 03.06.2013, 10:45 p.m
- [15] Jianyang Z. – Hailin H. – Hao S.: *Self-starting aerodynamics analysis of vertical axis wind turbine*, In: *Sage Journals*, 2015.
- [16] Huilan H. – Jia Li – Gang Li.: *Improving the self-starting and operating characteristics of a vertical axis wind turbine by changing center distance in part of blades*, In: *Journal of Building Engineering*, 2023, ISSN 105974

- [17] Robert G. – P. Lunt – A. Bickerdyke – J. Dominy,: *Self-starting capability of a Darrieus turbine*, In. Proceedings of the Institution of Mechanical Engineers Part A Journal of Power and Energy, 2007, ISSN PE340
- [18] Samuel M. – Iheanyichukwu O. – Konstantin V.: *Improvement of Self-Starting Capabilities of Vertical Axis Wind Turbines with New Design of Turbine Blades*, In. Kingston University, 2021.
- [19] <https://windeurope.org/policy/topics/environment-planning/>
Accessed 04.06.2013, 05:12 p.m
- [20] <https://forthewind.weebly.com/the-darrieus-self-starting-problem.html> Accessed 04.06.2013, 07:34 p.m
- [21] A. Kostyak – F. Szodrai: *Wind energy Investigation For Wind Turbines*, In. Műszaki Tudomány Az Észak-Kelet Magyarországi Régióban, ISBN 978-963-7064-33-3, 2016.
- [22] A. Kostyak – F. Szodrai: *Wind energy harnessing options at buildings*, In. International Journal of Engineering and Management Sciences (IJEMS) Vol. 1, 2016.
- [23] Mir Sayed S.: AI and Expert Insights for Sustainable Energy Future, In: *Energies*, 2023, 16(8), p. 6-11.
- [24] Andrea S. – Miltiadis D.: Artificial Intelligence for Smart Renewable Energy Sector in Europe—Smart Energy Infrastructures for Next Generation Smart Cities, In: *Special Section on Future Generation Smart Cities Research: Services, Applications, Case Studies and Policymaking Considerations for Well-Being*, 2020, 8(III), p. 77367-77369.