

Investigation on Aerodynamic characteristics of Vertical Axis Wind Turbine with SG Series Airfoil

Submitted in partial fulfilment of the requirements for the award of Bachelor of
Engineering degree in Aeronautical

By

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SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with grade "A" by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of KRISHNA KAANTH B.S (392600012), SRI GANESH. H (39260038), SUSIL JACKWYN KESHATH S (39260040) who carried out the Project entitled "Investigation on Aerodynamic characteristics of Vertical Axis Wind Turbine" under our supervision from June 2022 to April 2023.

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1. 

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Dr. P. BOOMADEVI, ME., PhD., _____

ABSTRACT

Wind energy is the alternate most available source of renewable energy and we have been rooting and exercising wind energy in numerous ways since the dawn of time. In the current period we're exercising HAWTs and VAWTs to do the same. The major issue we face in both is the problem caused due to climate. This design is concentrated on reduction of climate in the perpendicular axis wind turbine and also on optimization of the turbine blade. The blades flow simulation is done using the finite element law Fluent in ANSYS software Workbench. The palace of the wind turbine is imaged in the 3D modelling software CATIA The Model is also Fabricated. The turbine blades using 3D Printing technology in PLA material. The body of the VAWT using PVC, and Steel. It's also experimented in the wind lair and the wobbling frequencies, wind pets, rpm of the turbine and the power produced are Measured. The vibrational frequencies are linked to not be snooping with the natural frequency of the wind turbine, this is done by comparing the measured frequency with the numerical results attained by doing a Modal analysis using the ANSYS software Workbench, Modal Module. The results attained give suggestions suitable for perfecting unborn Installations.

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CHAPTER 1

INTRODUCTION

1.1 Introduction:

Nowadays the trend is to become energy self-sufficient or at least reduce the dependence on the grid. For this most of us are using photovoltaic cells to generate power from solar energy. Since we use energy faster than we can generate, the need to depend on more than one source of energy is high. Since Wind is caused by the solar energy irradiating the earth, hence wind becomes an indirect manifestation of solar energy. Hence the source is not going to diminish with use or time. Since wind's kinetic energy is an inexhaustible fuel, wind energy harvesting has been the fastest-growing alternative energy source worldwide. Utilizing a horizontal axis wind turbine or a vertical axis wind turbine are the two primary methods for harvesting wind energy. The level hub wind turbine (HAWT) is not an answer for neighbourhood's or thick areas since it decreases the effectiveness of the turbine and furthermore acts like an irritation to the nearby populace of the two people also, creates the same, the need to use an effective vertical pivot wind turbine (VAWT) is fundamental.



Fig.1.1 Integrated Solar and wind power production

1.2 WIND ENERGY

A wind turbine is a rotating device that uses wind energy. A windmill is a type of machine in which the mechanical energy is directly utilized by machinery, such as for cutting wood, pumping water, or grinding stones. A wind generator, wind turbine, wind turbine generator (WTG), wind power unit (WPU), wind energy converter (WEC), or aero-generator is a machine that converts mechanical energy into electricity. Wind energy is generated by the kinetic energy of the motion of air caused by a pressure gradient. The pressure gradient is brought about by the sun's radiation constantly heating and cooling the planet. The best renewable energy is wind, which comes from the sun and is abundant in nature. It is spotless, contamination free, cost serious and there is compelling reason need to construct any repositories to gather the hotspot for use. Wind was used in many ancient cultures for this reason. We have been completing tasks like milling, forging, and agricultural irrigation by utilizing wind variety Of ways.



Fig.1.2 Wind energy harvested in high altitude locations

Wind energy is an extremely practical type of sustainable power and since it costs just 40% however much sun based power it is an extremely worthwhile wellspring of energy

nearly. Similar to how solar energy harvesting has decreased in cost over time, wind energy will become less expensive as research and use increase. Since the 1980s, the cost of producing wind energy has already decreased by 80%.

1.3 WIND TURBINES

The system used to convert kinetic energy into usable energy like mechanical energy or electrical energy. In olden times the converted mechanical energy was used to pump water for irrigation or used to crush grain in the mills or sawing wood or powering up a sail boat.



Fig.1.3 Horizontal Axis Wind Turbines Offshore

Wind turbines extract the kinetic energy present in the wind and convert it to rotary shaft motion, this in turn is transmitted to the generator using gearboxes, belts, pulleys or by hydraulic transmissions.

The maximum power that a Turbine can produce is denoted by (P_{max}).

$$P_{max} = \frac{1}{2} m V_o^2$$

Where, mass flow (m) = $\rho A V_o$

ρ = Density

A = Area where wind of mass (m) is flowing.

V_o = Velocity

Hence the power in the wind is proportional to the cube of wind velocity:

$$P_{\max} = \frac{1}{2} \rho A V_0^3$$

The principle of wind energy conversion is simple, the energy available in wind is the kinetic energy of the mass of air that is in motion, the blades of the turbine convert this kinetic energy into mechanical or electrical energy depending on the application. The energy produced is dependent on the efficiency of the rotor in converting the kinetic energy into usable energy. The wind turbines are classified based on the axis of the rotor as horizontal axis wind turbine and vertical axis wind turbine.

1.4 HORIZONTAL AXIS WIND TURBINE

Even hub wind turbines (HAWT) have the primary rotor shaft and electrical generator at the highest point of a pinnacle, and should be pointed into the breeze. Little turbines are pointed by a basic breeze vane, while enormous turbines for the most part utilize a wind sensor combined with a servo engine. Most have a gearbox, which turns the slow revolution of the edges into a speedier pivot that is more reasonable to drive an electrical generator.

The turbine is typically aimed upwind of the tower because a tower generates turbulence behind it. The stiffness of turbine blades prevents them from being pushed into the tower by strong winds. In addition, the blades are positioned a considerable distance in front of the tower and occasionally slightly tilted toward the wind.

Despite the issue of turbulence (mast wake), downwind machines have been constructed because they do not require an additional mechanism to keep them in line with the wind and because the blades can be allowed to bend in high winds, reducing their swept area and wind resistance. The majority of HAWTs are upwind machines because fatigue failures may result from cyclic (repeating) turbulence.

Even pivot wind turbines have the principal rotor shaft and electrical generator at the highest point of a pinnacle, and should be pointed into the breeze stream. Little turbines are pointed by a straightforward breeze vane, while bigger ones utilize a breeze sensor combined with a servo engine to constantly confront the breeze stream. Additionally, HAWTs have a gearbox that speeds up the rotor shaft's slow

rotation and makes it much more suitable for driving an electric generator. stream. Additionally, HAWTs have a gearbox that speeds up the rotor shaft's slow rotation and makes it much more suitable for driving an electric generator.

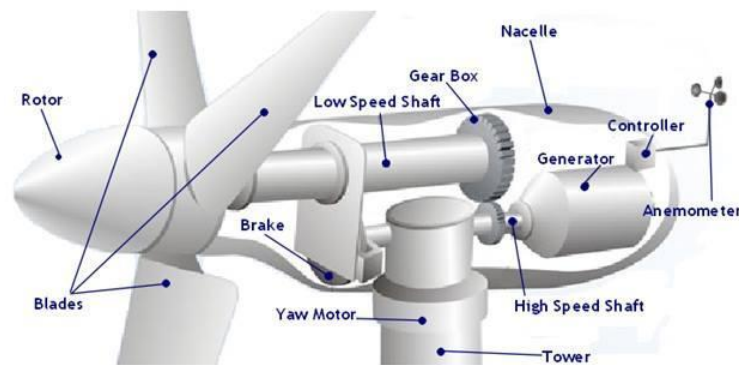


Fig.1.4 Horizontal Axis Wind Turbine Components

The rotor is upwind of its supporting tower because the tower creates turbulence in the wind stream behind it. The stiffness of the turbine blades prevents them from being pushed into the tower by strong winds. Additionally, the blades are positioned some distance in front of the tower and occasionally slightly tilted toward the wind.

In order to keep the rotor in line with the wind stream despite the issue of turbulence, machines that work with the rotor Downwind have been developed. The blades are permitted to bend in high winds, but this reduces their swept area and, consequently, their resistance to wind. The majority of HAWTs are of upwind design because fatigue failures are caused by turbulence.

1.5 VERTICAL AXIS WIND TURBINE (VAWT):

The main rotor shaft of a vertical axis wind turbine (VAWT) is oriented perpendicular to the ground. The turbine does not need to be pointed into the wind stream in this arrangement. When integrated into buildings, for instance, this is useful in close proximity to locations where the wind direction changes. The critical detriment of the

VAWTs incorporate the low rotational speed with the higher force and greater expense of the drive train, additionally the power coefficient is low, the airfoil turns 360 degrees inside the breeze stream during each cycle and the unique stacking on the airfoil, the force produced by rotor plans on the drive train, and the trouble to show the breeze stream precisely and consequently the method involved with dissecting and planning the rotor is moving before manufacturing a model.



Fig.1.5 Vertical Axis Wind Turbines

The generator and gearbox can be placed close to or on the ground with a vertical axis, eliminating the need for a nacelle and making maintenance easier. Wind shear is severe close to the ground, resulting in higher loads on the rotor, and the lower wind speeds close to the ground make less wind energy available for a given turbine height in this configuration. The wind moves quickly because of the turbulent flow of air near the ground and other objects.

stream, which presents the issues of vibration, including clamor and bearing wear which increment the support and abbreviate the assistance life. A rooftop turbine can double the wind speed at the turbine because the building directs the wind stream toward the roof. In order to produce the most amount of wind energy with the least amount of wind turbulence, the rooftop-mounted turbine should be mounted at a height that is half as high as the building. By and large, the breeze speeds are a lot of lower in thick neighbourhoods than the open provincial regions.

There are two types of vertical axis wind turbines: the lift type, or Darrieus type, and the drag type, or Savonius type.

1.5.1 DARRIUS TYPE VERTICAL AXIS WIND TURBINE:

The French inventor Georges Darrieus inspired the name Darrieus, also known as the Eggbeater turbine. Darrieus wind turbine is a sort of VAWT used to create power from the breeze energy utilizing streamlined power of Lift thus it is additionally called lift type turbines. The turbine is made up of airfoil-shaped blades that can be set up in straight, twisted, or curved configurations.

The vertical rotor's top and bottom are supported by blades in an eggbeater pattern. The curvature only causes the blades to be in tension at high speeds of rotation. The Darrieus wind turbines are efficient, but their low reliability is due to the tower's high torque and cyclical stress. Due to their low starting torque, they can't start on their own and need an external power source or an additional Savonius rotor to start turning. The force is decreased by utilizing three or on the other hand more sharp edges which works on the strength of the rotor. The ratio of the blade area to the rotor area is called solidity. The top bearing of the most recent Darrieus-type turbines is connected to an external superstructure.

In the first renditions of the Darrieus plan, the airfoils are organized so that they are even and have zero apparatus points, that is to say, the point that the airfoils are set comparative with the construction on which they are mounted. In contrast to the traditional arrangement, which must be rotated to face the wind, this one is effective regardless of which direction it is blowing. In order to reduce torque, helical blades wrapped around a vertical axis can be used. The blades of the Darrieus turbine can be twisted into a helix. As the breeze energy turns every edge around the windward and leeward sides of the turbine, this setup conveys the force equitably on the whole unr whole unrest, this way the disastrous throbs are forestalled.



Fig.1.6 Darrieus type Vertical Axis Wind Turbines

Figure 1.6 depicts the Darrieus rotors, which are the most successful VAWT. The benefit of this kind of turbine is that the generator and transmission gadgets are situated at ground level. They don't have to yaw because they can catch the wind from any direction. Because of these advantages, the turbine also captures less energy. Mechanical devices called wind turbines are made to convert the wind's kinetic energy into usable mechanical energy. Over time, a number of designs have been created. The majority of them consist of a rotor that is propelled by lift or drag forces generated by the wind's interaction. Besides, regardless of having the generator and transmission at ground level, upkeep isn't basic since it normally requires rotor expulsion. In addition, these rotors are held in place by guy ropes that extend far out onto the land. The use of VAWT has decreased significantly over the past few decades as a result of these factors. The fact that the turbine's angle of attack changes as it spins is one of the design's drawbacks; one blade can only produce maximum torque at two points on its cycle—the front and back of the turbine. Because of this, the power cycle becomes sinusoidal or pulsing, which makes design more difficult. Nearly all Darrieus turbines have resonant modes, in which the pulsing occurs at the natural frequency of the blades at a specific rotational speed and can cause them to break due to resonance. In order to prevent the turbine from reaching resonance, the majority of Darrieus turbines are constructed with a mechanical brake or other speed control device.

1.6 SAVONIUS TYPE VERTICAL AXIS WIND TURBINE:

The Savonius turbine is a drag-type turbine that has two or more blades that are shaped like anemometer-like scoops or flat boards. These are high-dependability, low-effectiveness power turbines. With at least three scoops or blades, they can start on their own without any help from outside. Using long helical scoops increases the torque.

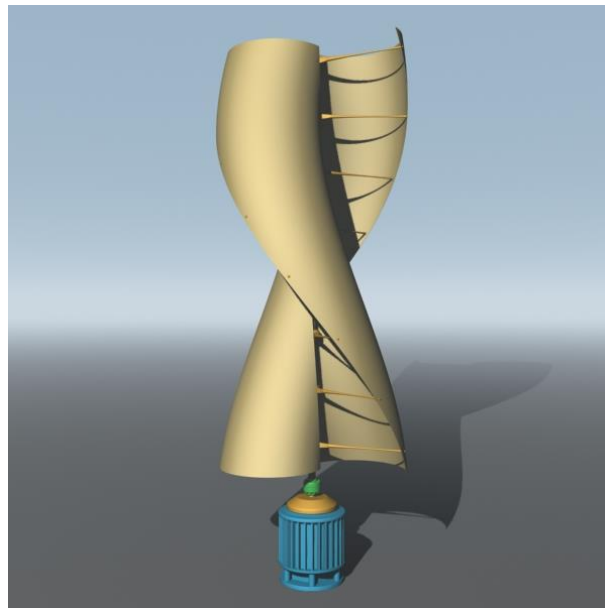


Fig.1.7 Savonius type Vertical Axis Wind Turbines

In the 1920s, a Finnish engineer named Sigurd J. Savonius created the Savonius wind turbine. Windmills with a horizontal axis were already in use in the 1920s. Early customary windmill plans were perplexing and exorbitant to construct and keep up with. The Savonius wind turbine emerged as an ideal replacement. They were modified for grain grinding and pumping 10 water. Aerodynamically, the Savonius turbine is a straightforward drag-type device with two or three scoops. The rotor with a two scoop design, whenever looked from the top would seem to be an 'S' shape incross-area. As a result of the shape, the scoops experience low drag while moving contrary to the natural flow stream than with the breeze stream. The Savonius turbine spins because of the variation in drag caused by the scoops. The drag-type turbines extricate a lot less of the breeze's power than other comparatively estimated lift-type turbines.

A large part of the cleared region of a Savonius rotor might be close to the ground, the generally speaking energy extraction can be improved in the event that it is put on a structure or on a pinnacle or on the other hand present due on the lower wind speeds found at lower levels. They can be made in a variety of sizes and shapes, like oil drums, paddles, sails, and buckets. All of these designs have high torque but low rpm. Grain grinding, water pumping, and other tasks call for them. The Savonius wind turbines, on the other hand, do not produce a lot of electricity. The drag-based VAWTs generally have low rpm under 100 RPM. We can increase the rpm with a gearbox, but efficiency suffers and the machine may not start at all.

The ease of maintenance is a significant benefit of VAWT. This is due to the fact that all of the functioning parts are at ground level. This eliminates the need to scale tall buildings to get to the blades. Another benefit is site determination, no estimations for wind heading and speed are required. The turbine operates quietly due to its low rpm, and for the same reason, it will produce steady, small amounts of electricity. The Savonius turbine can't be used on a large scale because it needs to be started by hand and has a low rpm, which limits how much power it can produce. As a result, they are utilized in power generation for the advantages of continuing to generate electricity even in the strongest winds without sustaining damage, being relatively silent, and being simpler and less complicated to construct. However, the Savonius turbines are best suited for small-scale domestic power generation because they are not designed to scale well. They are ideal for tasks requiring high torque and low rpm, such as grain grinding and water pumping. The high torque of the Savonius wind turbine necessitates that the bearings be extremely robust and undergo maintenance every few years.

1.7 HORIZONTAL AXIS WIND TURBINE VS VERTICAL AXIS WIND TURBINE:

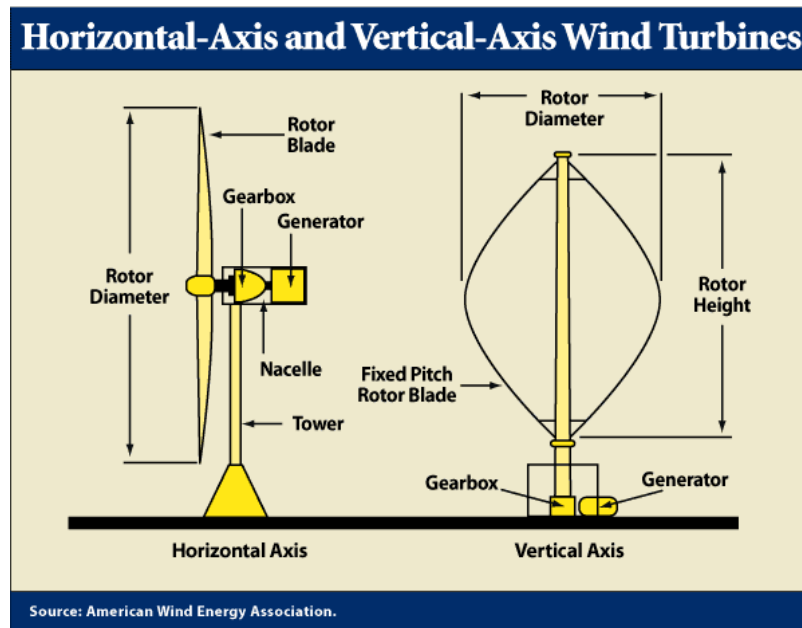


Fig.1.8 Horizontal Axis Wind Turbine Vs Vertical Axis Wind Turbine

1.7.1 ENERGY CONVERSION EFFICIENCY:

The majority of the time, the rotor blades of VAWTs turn against the wind stream because their axis of rotation is perpendicular to the ground and the blades rotate parallel to the ground. As a result, their energy conversion efficiency is lower than that of HAWTs. Since wind speeds are typically faster at higher altitudes, VAWTs produce less power than HAWTs, which are typically constructed high on top of a tower.

1.7.2 INSTALLATION:

In comparison to HAWTs, whose rotor blades must be installed at a high altitude depending on the blade length, VAWTs have their rotor blades at lower heights, making installation simpler.

1.7.3 MAINTENANCE:

For the same reason as above, maintenance of VAWTs is easier since most of them are installed at lower heights.

1.7.4 LAND AREA REQUIREMENT:

In contrast to VAWTs, which require the guy cables to ensure that the machine remains stable, HAWTs require the erection of a tower in order to mount the rotor blades at an altitude that would allow for maximum wind speeds. When compared to VAWTs, whose tower bases occupy more space due to the requirement for guy cables, HAWTs require less land space because their tower bases are smaller. VAWTs, on the other hand, would require a much larger land area.

1.7.5 RECOMMENDATIONS:

VAWTs are preferred for residential power production over HAWTs due to their ease of maintenance and lower installation height (they do not require a tall tower to hold their rotors). So, unlike installing a HAWT, residential owners don't have to spend a lot of money to start producing power. Because residential wind turbines are merely supplemental energy generators and are not really required to supply the primary energy requirements, even though the efficiency is lower in comparison, it would not make a significant difference.

For creation of force for an enormous scope, it has been verified that HAWTs are the more proficient breeze turbines. The high wind speeds that interact with the rotors at their high altitude result in a high power output. Large wind farms will benefit greatly from the tower base's smaller size.

Power generation efficiency and vibrational effects on the turbine foundation, as well as the building foundation if mounted on the building, are the primary issues that arise when using VAWTs. Therefore, optimizing the VAWT in accordance with numerical and experimental analysis of the aforementioned issues may, in the long run, lessen the turbine's impact.

CHAPTER 2

LITERATURE SURVEY

2.1 Literature Survey:

A solid understanding of the field of study is necessary prior to beginning any design process. Online libraries are currently the primary source of basic and advanced information. However, a thorough literature review ought to include a variety of informational sources and demonstrate knowledge of wind energy and vertical axis wind turbines.

This is a literature review on how to choose the right airfoil and make changes to it to make a better and better wing blade. It was finished utilizing an explorative and unstructured technique for survey which investigated the exploration done under quite a large number viewpoints, concentrating on various course books and articles on the ongoing discipline.

New perspectives and researches have been conducted on the vertical axis wind turbine over the past few decades as a result of the new tools and methods that are now available to simulate the research and cut down on the amount of time required to test the research. As a result, numerous perspectives and researches have been carried out, and a set of selection and optimizing criteria for an airfoil and the wing blade for vertical axis wind turbines has been proposed over the course of the years.

Zhenzhou et al., describes that the approaches investigated in the previous state of the art researches conducted and came to the conclusions to improve the performance and efficiencies of the vertical axis wind turbines:

- Recent research has shown that camber airfoils lead to improved performance of the vertical axis wind turbines than Symmetric airfoils. Though many researches and investigations were conducted, there was still no one airfoil that was the best.
- The performance of the VAWT can be improved by utilizing the optimal design of various geometric factors including pitch angle, aspect ratio, solidity, number of blades etc. These geometric parameters dominate¹⁴ influence the

aerodynamic interference on blades, self-start ability, the dynamic stall, peak power coefficient and the torque output.

- High solidity increases the C_p value at low Tip speed ratio and efficiency. Low solidity increases the C_p value at higher tip speed ratio and the self-start ability becomes hard to achieve.
- Flow control approaches (FCAs) are used to eliminate stall issues and also effectively delay flow separation of airfoils and improve the performance of the vertical axis wind turbine.

Riyadh Belamadi et al., did a study on the improvement of aerodynamic characteristics of wind turbine airfoils under stall conditions by using passive boundary layer control using slots. The results showed that the control system only improved the aerodynamic performance over a specific range of the angles of attack. At moderate and high angles of attack, from 10° to 20° , the slots outperform the baseline configurations.

Saeidi D et al., research says that as solidity value decreases max C_p also decreases but the power curve stays flat and remains constant for wider TSR values.

Rezaeiha et al., research says that increasing solidity from 0.09 to 0.36, the tip speed ratio reduces from 4.5 to 2.0 and max C_p increases by 22%. Singh et al., research says that max C_p of 0.32 can be achieved as solidity tends closer to 1.

Jafari et al., research says max C_p of the wind turbine was attained at a solidity of 0.5 and tip speed ratio of 4.

Fernandez et al., research says that increase of solidity to 0.5 led to higher power coefficients. The optimal solidity was identified at 0.25-0.5.

Zhang et al., research says that the Max C_p is increased by 5.8% by using flow control method known as split.

Shukla et al., research says that inward dimples improved the values of lift, airfoil velocity and the aerodynamic forces on airfoil.

Sobhani et al., research says that optimal performance increased by 18% and turbine efficiency improved by 25% with the usage of flow control method known as dimples.

Mahmood M et al., After reviewing various VAWT designs, it has been identified that the coefficient of power (C_p) can be optimized with reference to tip speed ratio. And for safer operations the flow field around the blade needs to be investigated.

Ertem et al., utilization of the Flow control method of Active flap control improves the coefficient of power of the wind turbine.

Xiao et al., utilization of the Flow control method of fixed and oscillating flap improves the coefficient of power of the wind turbine by 28% compared to the traditional blade.

Wang et al., utilization of the Flow control method of Leading edge serrations improves the power of the wind turbine at low tip speed ratios. And the utilization of Micro-cylinder of leading edge the blade torque is increased by 27.3%.

Zhang et al., Studies show that the CP_{max} is increased by 5.8% after installing split flaps.

Choudhry et al., the flow control methods like vortex generators, elevated wire (micro cylinder of leading edge) and Cavity (dimple) were observed to decrease the flow separation, reduce the strength of the stall vortex and reduce the lift loss.

CHAPTER 3

AIM AND SCOPE OF THE PRESENT INVESTIGATION

3.1 Aim and Scope:

We have undertaken the project to select a wind turbine blade for vertical axis wind turbine (VAWT) and to perform numerical analysis and optimize the lift and power co-efficient of the vertical axis wind turbine. This is done by fabricating the prototype of the wind turbine and perform experimental analysis by simulating operational situation on the model and observing the results.

To simulate the working conditions, we are using a wind tunnel available at the Aerodynamics Lab at **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY**, CHENNAI. Since the available wind tunnel has a dimensional criterion at mounting area of 600mm X 600mm, the vertical axis wind turbine is downsized and non-conventional materials were used to fabricate the model and the experimental analysis was conducted.

CHAPTER 4

MATERIALS AND METHODS USED

4.1 Introduction:

It is widely known that a drag type or a Savonius vertical pivot wind turbines are not utilized for power age because of their low productivity. As a result, a Lift-type blade and a H-Darrieus-type rotor were chosen for this project. Early VAWTs used symmetric airfoils because the blade surface served as both the suction and pressure sides. VAWTs' performance is improved by camber airfoils, according to recent research. Albeit numerous explores have been directed the best series of airfoils to be utilized in VAWTs is not yet finished up. When compared to symmetrical blades, the development of lift in a downwind pass is also enhanced by unsymmetrical or cambered blades (R. Gupta et al., 24).

With both symmetrical and unsymmetrical airfoils, the performance of three-blade H-Darrieus rotors with solidity of 0.2 or 0.4 was examined. It was discovered that the starting torque and power augmentation of the unsymmetrical airfoil rotor were higher, and it was also concluded that an increase in solidity can lead to higher power outputs at a lower tip speed ratio (Deshpande et al., 27). It was seen that as thicker unsymmetrical airfoils had a more extended joined stream and high robustness unsymmetrical three bladed H-Darrieus rotors were better as far as beginning and dynamic force contrasted with balanced edges (Subramanian et al 28). Marginally unsymmetrical airfoil edges like the **SG 6043 airfoil** are equipped for working on the general execution of the rotor. (Danao et al.,)As a result, the **SG 6043 airfoil** was chosen based on the available literature and analysis results. The chosen airfoil was to be unsymmetrical or cambered.

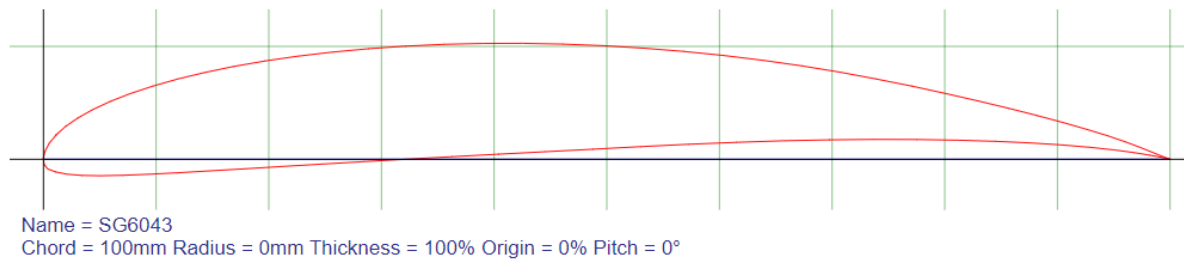
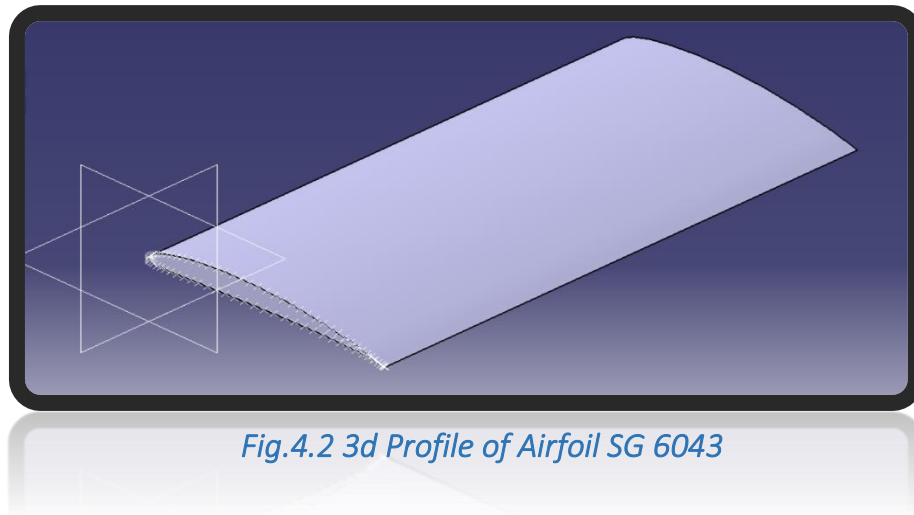
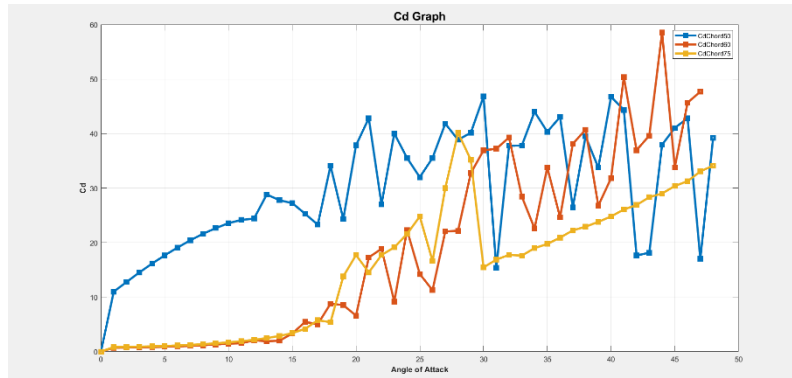


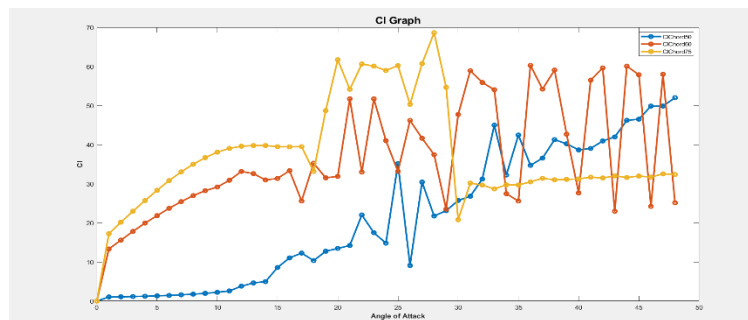
Fig.4.1 Base Profile of Airfoil SG 6043 with Chord length 100mm



The above airfoil profile has been used for design and analysis for various Flow Control Approaches, to identify the appropriate efficient lift producing model for the Wind turbines. Prior to the research on aerodynamic modifications on this airfoil, the appropriate and efficient **CHORD LENGTH** was identified.



(a)



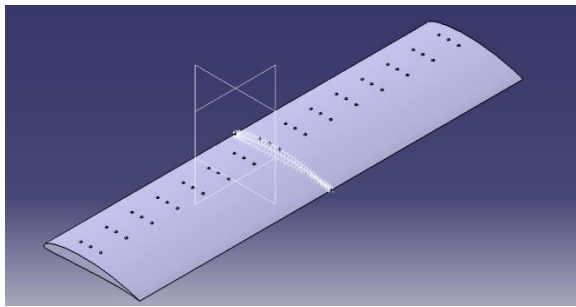
(b)

*Fig.4.3 (a) Cd graph of varying Chord analysis
(b) Cl graph of varying Chord analysis*

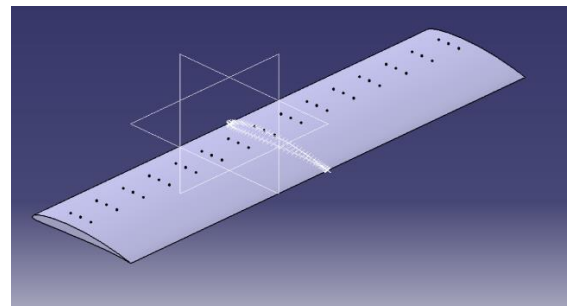
Chord 50, Chord 60 and Chord 75 had been selected for airfoil and they had been analysed in **ANSYS FLUENT**. The analysis had been done using 24,000 iterations and in time step process. The time step size selected was 0.04, number of time steps were 1200 and maximum iterations per time steps had been selected as 20. The result obtained clearly shows that Chord 75 is the best and appropriate chord length.

4.2 Bulges:

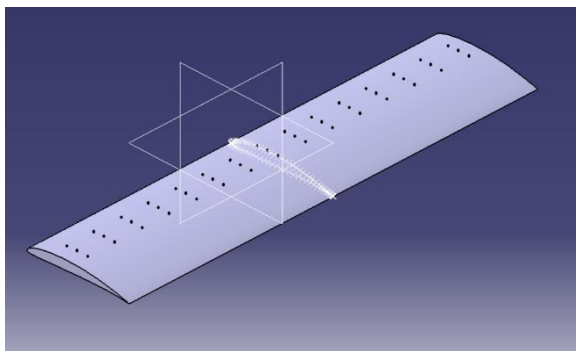
Bulges are the swelled extensions of a surface. Since, it is here used for checking its aerodynamic effects, it can be called as aerodynamic modifications. In this analysis, Bulges had been used in various shapes and sizes, (i) Conical Bulges, (ii) Spherical Bulges, (iii) Rhombus shaped Bulges, (iv) Cubical Bulges. Each and every bulges had been designed in various heights and diameters and then analysed.



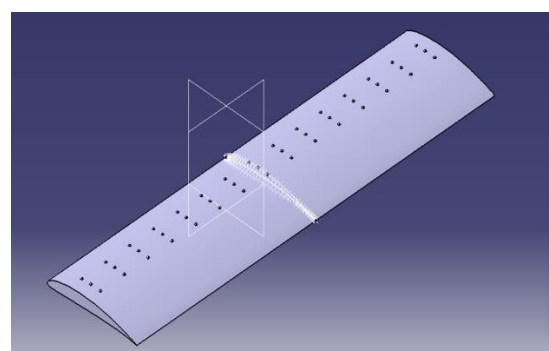
(a)



(b)



(c)



(d)

Fig. 4.4 (a) Conical bulges (b) Spherical bulges (c) Rhombus shaped bulges (d) Cubical bulges in SG 6043 airfoil of Chord 75 mm.

4.2.1 Conical bulges:

Conical bulges had been designed in SG 6043 airfoil, in 7 different specifications. (i) 0.5mm height with 1mm dia, (ii) 0.5mm height with 2mm dia, (iii) 0.5mm height with 3mm dia, (iv) 1mm height with 1mm dia, (v) 1mm height with 3mm dia, (vi) 2mm height with 1mm dia, (vii) 2mm height with 3mm dia. Each and every modifications had been analysed in a segregated manner, based on height and best had been selected for further analysis and comparison. Among these 7 different bulges, 0.5mm height with 3mm diameter, 1mm height with 3mm diameter and 2mm height with 1mm diameter had got selected and they had been compared and analysed. The results show that, 1mm height in 3mm diameter has the best lift and drag co- efficients.

4.2.2 Spherical bulges:

Spherical bulges had been designed in SG 6043 airfoil, in 3 different types. (i) 1mm diameter, (ii) 2mm diameter and (iii) 3mm diameter. These had been analysed till 20 degree angle of attack, using time step method. In this 3mm diameter bulges, had the best and appropriate lift and drag co – efficient.

4.2.3 Rhombus Shaped bulges:

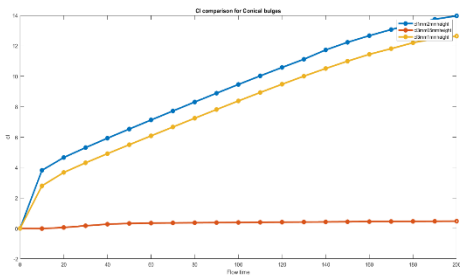
Rhombus shaped bulges had been designed by keeping square as the base design. These designs had been designed in 7 different types. (i) 0.5mm height with 1mm squared rhombus bulges, (ii) 0.5mm height with 2mm squared rhombus bulges, (iii) 0.5mm height with 3mm squared rhombus bulges, (iv) 1mm height with 1mm square rhombus bulges, (v) 1mm height with 2mm square rhombus bulges, (vi) 2mm height with 1mm square rhombus bulges, (vii) 2mm height with 2mm square rhombus bulges. Among these, 0.5mm height in 2mm squared rhombus bulges, 1mm height in 1mm squared rhombus bulges, 2mm height in 2mm squared rhombus bulges. Finally, 2mm height in 2mm squared rhombus bulges shows the optimum lift and drag co – efficient.

4.2.4 Cubical bulges:

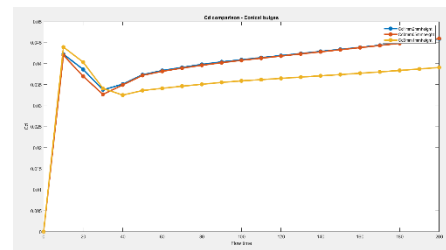
Cubical bulges in SG 6043 airfoil had been designed in 6 different types, (i) 0.5mm height in 1mm side, (ii) 0.5mm height in 2mm side, (iii) 1mm height in 1mm side, (iv) 1mm height in 2mm side, (v) 2mm height in 1mm side, (vi) 2mm height in 2mm side. Among these, 0.5mm height in 1mm side, 1mm height in 1mm side, 2mm height in 1mm side, showed best results. Therefore, they had been compared. Finally, 1mm height in 1mm side had been selected, as it showed best and optimum lift and drag co – efficient values.

4.2.5 Overall comparison:

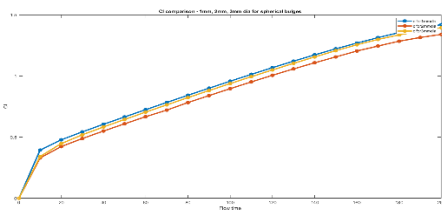
Overall comparison had been made for the selected, (i) 1mm height in 3mm diameter (conical bulges), (ii) 3mm diameter (Spherical bulges), (iii) 2mm sq. with 2mm height (rhombus bulges), (iv) 1mm side in 1mm height in 1mm side (Cubical bulges). The result shows that **Conical bulges** has the best cl and cd graphs, followed by **Cubical bulges**.



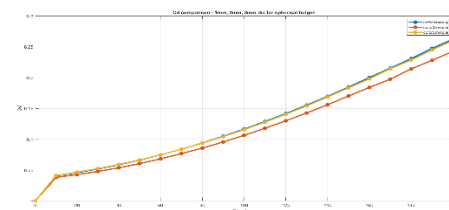
(a)



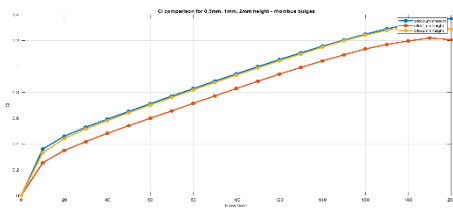
(b)



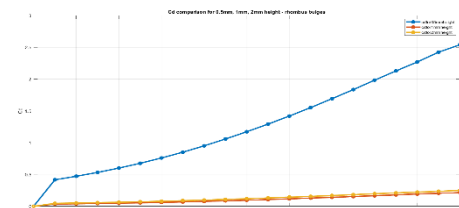
(c)



(d)



(e)



(f)

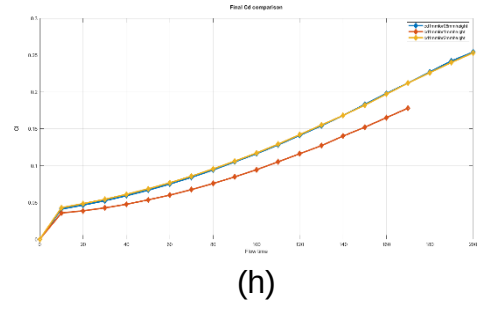
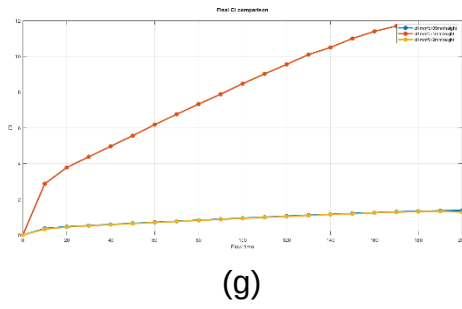


Fig.4.5 (a) Conical cl, (b) Conical cd, (c) Spherical cl, (d) Spherical cd, (e) Rhombus cl, (f) Rhombus cd, (g) Cubical cl, (h) Cubical cd.

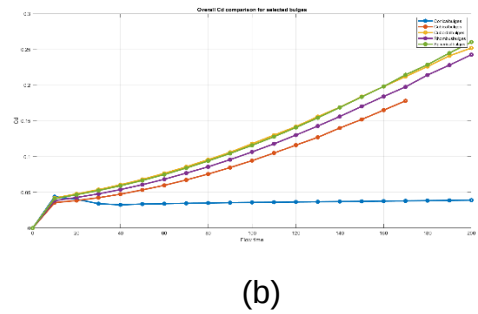
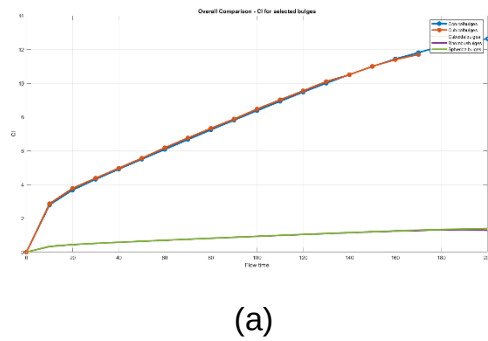


Fig.4.6 (a) Cl graph for selected bulges
(b) Cd graph for selected bulges

4.2.6 Experimental Testing:

Computational data had been taken for identifying the best and appropriate modifications. Those identified modifications had been manufactured using **3d printer** and the material selected was **PLA material**. The airfoils were mounted in a tower and kept inside the wind tunnel, for testing. The experiment had been conducted up to 20 degree angle of attack. The readings had been noted and compared with computational output.

4.3 Dimples:

Dimples had been made using GOE airfoil in various specifications and analysed.

Their result showed the best and efficient dimple design. It had been designed and experimentally analysed.

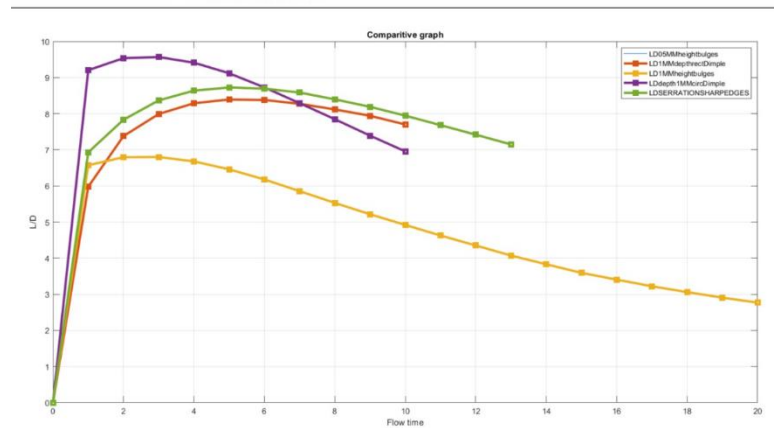


Fig.4.7 Dimple analysis graph



Fig.4.8 Tower structure of VAWT

CHAPTER FIVE

RESULT AND DISCUSSION

5.1 Result and Discussion:

Among the selected bulges, Conical bulges were selected due to its best and appropriate lift and drag co – efficient. Computational results were compared with the experimental results and the difference had been identified.

CHAPTER SIX

SUMMARY AND CONCLUSION

6.1 Summary and Conclusion:

As expected, the aerodynamic modifications increases the lift of the blade up to the desired level. If it is applied in real life scenario, definitely it will be helpful in increasing the electricity generation using wind turbine, which is the need in hour in these days.

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