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Design and fabrication of a helical vertical axis wind turbine for electricity supply

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Abstract

In an effort to find solutions for global energy crisis, an analysis on a helical vertical axis wind turbine was conducted with the consideration of renewables and energy efficiency. This study was carried out in two steps: the realization of the analytical calculation of a helical wind turbine power output which then informed the design and construction of the rotor blades. The paper particularly aimed to address its use as the electricity supply for residential properties or any other places with less ideal economy conditions. The uncomplicated and highly accessible mechanism using basic materials is to give people to have a viable option on their own electricity production. The world is increasingly going green in its energy use. Wind power is a green renewable source of energy that can compete effectively with fossil fuel as a generator of power in the electricity market. For this effective competition, the production cost must be comparable to that of fossil fuels or other sources of energy. The initial capital investment in wind power goes to machine and the supporting infrastructure. Any factors that lead to decrease in cost of energy such as turbine design, construction and operation are key to making wind power competitive as an alternative source of energy.

Keywords: Energy; Turbine; Renewable; Helical; Economy

1. Introduction

Wind energy is a clean and inexhaustible energy source widely used as a working fluid for wind farms for centuries. However, its use as a means of electricity supply began modern era due to the rise of environmental concerns and fuel resources issues. The global demand for sustainable and renewable energy has created the necessity for research and the development of new technology. Hence, the wind energy has been the focus of the industry and has considerably grown its use but just in a large scale production. In recent years, significant increase of more efficient, larger and expensive horizontal axis wind turbines (HAWT) appeared to create onshore and offshore wind-turbine fields.

This study aims to produce electricity on a lower scale by using a small wind turbine in order to generate a house-hold electricity supply and build a cost-effective and accessible turbine for people who need an alternative option to cover their own electricity demand. This report presents the rotor blade design, turbine construction and the results of the experimentation of a helical vertical axis wind turbine (VAWT). These turbines come with a few specific advantages over the horizontal ones, and those advantages make this kind of turbine a better option in a city or more challenging locations.

The wind energy is the kinetic energy of air in motion. When such energy passes through the turbine rotor, the kinetic energy is transformed into mechanical energy which makes the blades starting to move. The power output of the wind turbine is given by

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Equation 1:

$$P = \frac{1}{2}\rho A v^3 \text{ ………………….. (1)}$$

Where:
P=Power output (W)
A=Sweep area (m^2)
ρ =Air density (Kg/m^3)
v=Wind velocity (m/s)

The equation shows the velocity cubed (v^3), the rotor sweep area, the air density and the turbine and generator efficiencies, hence, it is important to contemplate the turbine size to catch most out of the air mass, the installation place and the wind speed conditions [2].

A wind turbine must be built under specific requirements according the purpose and usage. In this report, the objective is to produce a residential electricity supply, which is 1500 kW/per year on average. Using the power output equation and the environment conditions, it is possible to make an analytical calculation and determine the right rotor dimensions.

1.1. Different types and design configurations for wind turbine

A great degree of design versatility is available in the wind turbines design configurations. There are a few problems inherent to the currently available designs including low starting torque, turbine blade lift forces, lower efficiency, poor building and foundation integration, etc. In the past few decades, the engineers came up with many innovative design approaches to address these issues associated with wind turbines design. Following sections mentions different available configurations with their respective features and concerns.

1.1.1. Horizontal axis wind turbine (HAWT)

The rotational axis of this turbine must be oriented parallel to the wind in order to produce power. Numerous sources claim a major efficiency per same swept area and the majority of wind turbines are of this type. Currently horizontal axis turbines are the most used due to its higher performance featuring high winds, easy maintenance and low cost. Although there are various configurations of wind turbines, one blade, two blades, three and Multi blades, removing the one blade and multi blades which are for special cases, the two blades and three blades are the most used. But the three blades are used more because its energy produced is greater and its robustness makes them stronger to stronger winds and it is created less impact visual. Following are disadvantages of HAWT taken from study article of Young-Tae Lee.

1.1.2. Vertical Axis Wind Turbine (VAWT):

The rotational axis is perpendicular to the wind direction or the mounting surface. The main advantage is that the generator is on ground level so they are more accessible and thus don't need a yaw system. Because of its proximity to ground, wind speeds available are lower. It is a vertical axis machine, very simple from the standpoint of constructive and operational. Besides simplicity, has the advantage of being very robust and have a strong starting torque, that possible the starting even with very weak winds. But can be used only with reduced powers and that the turbine works well with light winds, while its yield decreases with high winds and even becomes vulnerable, so their size cannot exceed certain limits.

1.1.3. Objectives

Objectives of this paper are-

- To study about Vertical Axis Wind Turbine.
- Design a new type of turbine blade (helical).
- To study CFD analysis using ANSYS.
- Compare the results between Practical data and Simulation data.

1.2. Advantages of vertical axis wind turbine (VWAT)

- **Work speed range:** The VAWT starts to work under lower wind speeds (about 3 m/s) and can still work on high wind velocities (about 40 m/s).
- **Capturing all wind directions**: Such turbines can catch wind in all directions without requiring the heavy and expensive directional mechanisms.
- **Efficiency over higher turbulence levels**: The HAWT needs an axial wind incidence on the blades. Therefore, when wind turbulence increases, the efficiency decreases. However, VAWT catches the wind in all directions, so the change of wind directions, which is common in cities, does not affect its efficiency.
- **Turbine size:** The mechanism of VAWT is simpler and much smaller. HAWT can be over 30 m high and 20 m diameter. VAWT is approximately 3m high and 1.5m diameter.
- **Construction, maintenance and transportation costs:** As mentioned the VAWT is simpler and smaller therefore, the construction and maintenance are not complicated and due to the smaller scale, the cost for transportation is significantly lower than HAWT.
- **Reduced noise pollution and visual disturbance level:** This operating mode helps the helical vertical axis wind turbine make less noise (about 50 DB) and its twist geometry eliminates the flickering moving shadows casted by the blades.

1.3. Limitations of vertical axis wind turbine

- One of the major outstanding challenges facing vertical axis wind turbine technology is dynamic stall of the blades as the angle of attack varies rapidly.
- The vertically oriented blades can twist and bend during each turn, causing them to break apart.
- The centrifugal force generated by the spinning blades has been reported to cause stress and fatigue on some blade designs that occasionally results in them breaking.
- VAWTs are less reliable than HAWTs.

2. Literature Review

2.1. Historical background

Wind energy has been used for thousands of years for milling grain, pumping water and other mechanical power applications. Wind power is not a new concept. The first accepted establishment of the use of windmills was in the tenth century in Persia [1]. Today, there are several hundred thousand windmills in operation around the world. Modern windmills tend to be called wind turbines partly because of their functional similarity to the steam and gas turbines and partly to distinguish them from their traditional forbears [2].

Wind energy was the fastest growing energy technology in the 1990s, in terms of percentage of yearly growth of installed capacity per technology source. The growth of wind energy, however, is not evenly distributed around the world. By the end of 1999, around 69% of the worldwide wind energy capacity was installed in Europe, a further 19% in North America and 10% in Asia and the Pacific [3]. Wind energy is expected to play an increasingly important role in the future national energy scene [4, 5]. Wind turbines convert the kinetic energy of the wind to electrical energy by rotating the blades. Greenpeace states that about 10% of electricity can be supplied by the wind by the year 2020 [6].

2.2. Cost of wind turbines

In the 1990s, the cost for manufacturing wind turbines declined by about 20% every time the number of manufactured wind turbines doubled. Currently, the production of large-scale, grid-connected wind turbines doubles almost every 3 years. A similar cost reduction was achieved during the first years of oil exploitation about 100 years ago. The Danish Energy Agency predicts that a further cost reduction of 50% can be achieved until 2020, and the EU Commission estimates in its White Book that energy cost from wind power will be reduced by at least 30% between 1998 and 2010 [8].

A general comparison of the electricity production costs, however, is very difficult as production costs vary significantly between countries, due to the availability of resources, different tax structures or other reasons. In addition, market regulations can affect the electricity prices in different countries. The competitive bidding processes for renewable power generation in England and Wales (The Non-Fossil Fuel Obligation, D NFFO), however, provides a good comparison of power production prices. Within this bidding process, potential paper developers for renewable energy papers are invited to bid for building new papers. The developers bid under different technology brands, e.g. wind or solar, for a feed-in tariff or for an amount of financial incentives to be paid for each kWh fed into the grid by renewable energy systems. The best bidder(s) will be awarded their bid feed-in tariff for a predefined period [7].

2.3. Environmental impact and reliability of wind turbines

Wind energy can be regarded as environmentally friendly; however, it is not free of emissions. The production of the blades, the nacelle, the tower, etc., the exploration of the material and the transport of equipment leads to the consumption of energy resources; hence emissions are produced as long as these energy resources are based on fossil fuel. These emissions are known as indirect emissions. In addition, the noise and the visual impact of wind turbines are important considerations for a public acceptance of wind energy technology, particular if the wind turbines are located close to human settlements. The noise impact can be reduced with technical means, e.g. variable speed or reduced rotational speed. The noise impact as well as the visual impact can also be reduced with appropriate siting of wind turbines in the landscape [9].

Reliability of wind turbine system is based on the performance of its components under assigned environment, manufacturing process, handling, and the stress and aging process. Chands et al. had studied the expert-based maintenance methodology. It has the potential to improve the reliability of systems, besides the conventional monitoring function [10]. Denson analyzed the failure causes for electronic systems and factors contributing to failure cause parts [11].

2.4. Physics of wind turbines [16]

The power in the wind is the total available energy per time unit. The power in the wind is converted into the mechanical-rotational energy of the wind turbine rotor, which results in a reduced speed of the air mass. The power in the wind cannot be extracted completely by a wind turbine, as the air mass would be stopped completely in the intercepting rotor area. This would cause a `congestion' of the cross-sectional area for the following air masses.

The theoretical optimum for utilizing the power in the wind by reducing its velocity was first discovered by Betz, in 1926. According to Betz, the theoretically maximum power that can be extracted from the wind is-

Equation 1:

$$P = \frac{1}{2}\rho A v^3 \quad \text{…………………} \ (1)$$

Where:
P=Power output (W)
A=Sweep area (m^2)
ρ =Air density (Kg/m^3)
v=Wind velocity (m/s)

Wind turbines operate by the action of the relative wind. Relative wind is a combination of natural wind plus wind caused by rotor motion and the rotor induced flow. The result of the relative wind are the aerodynamic forces which are created on the rotating blades. These aerodynamic forces are called drag and lift forces [17].

The drag force is the component that is in line with the direction of the air stream. A flat plate in an air stream, for example, experiences maximum drag forces when the direction of the air flow is perpendicular to the flat side of the plate; when the direction of the air stream is in line with the flat side of the plate, the drag forces are at a minimum. The lift force is the component that is at right angles to the direction of the air stream. Lift forces acting on a flat plate are smallest when the direction of the air stream is at a zero angle to the flat surface of the plate. At small angles relative to the direction of the air stream, a low pressure region is created on the downstream side of the plate as a result of an increase in the air velocity on that side [18].

2.5. Two-Dimensional flow

Two-dimensional (2D) flow is confined to a plane and if this plane is described with a Cartesian coordinate system as shown in Figure 1, the velocity component w in the z-direction is zero. In order to realize a two-dimensional flow it is necessary to extrude an airfoil into a wing of infinite span. On a real wing the planform and the twist change along the span and the wing starts at a hub and ends in a tip. In cases where long slender wings, as on modern gliders and wind turbines, the span wise velocity component is normally small compared to the stream wise component. Moreover, Prandtl has shown local 2-D accordingly, with the trailing vortices behind the wind [19].

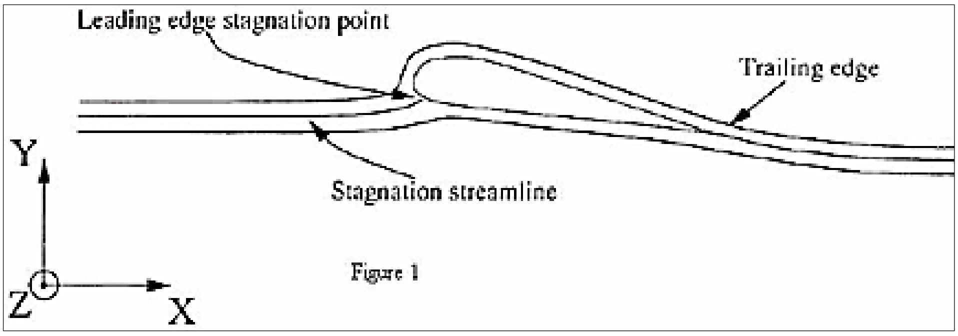

Figure 1 Two-D fluid flow in airfoil [1]

Pure drag surfaces can achieve the simplest type of wind energy conversion. When rotors rely on drag forces, they have a large area perpendicular to the flow in order to be able to capture the energy of the wind. Nevertheless, these kinds of motors have low speed, high torque and low efficiency thus they are not widely used to electricity generation. Also, the maximum efficiency that can be obtained from a drag type motor is one third of the ideal power coefficient (Cp). In contrast with drag type turbines power coefficient as well as the speed of rotation of the turbine will be increased if a lift type rotor is used. However, the most critical factor for generating lifts the blade design which allows them to achieve faster speeds than the wind speed [20].

3. Methodology

3.1. Introduction

The objective of this report is to study and manufacture a wind turbine of vertical axis, helical type. In particular, what will be studied is which geometrical design of the wings of the wind turbine is the most efficient, while taking into account the cost, the elegance, the simplicity, the feasibility and the durability. Fabrication of vertical axis wind turbine (helical) consists of different parts which are needed to be fabricated as parts of main assembly.

In this paper, various software simulation tests and the electrical installment of the wind turbine are needed. After the analysis is over, the next step is the manufacturing part which are followed in detail and the design that had been preceded. Finally, a compatibility check was performed of the theoretical sizes compared to the ones that the final construction showed.

- We are going to need these below **components** to fabricate this helical wind turbine:-
- **Blades-** fabrication of blade consists of Aluminium blades, steel pipes and Aluminium sheet circular cross section base.
- **Adjustable Shaft-** fabrication of adjustable shaft consists of hallow shaft, threaded solid shaft and guide rod.
- **Lower column-** fabrication of column consists of selecting the shaft and welding of supporting discs.
- **Generator-** uses the turning motion of the shaft to rotate a rotor which has oppositely charge magnets and is surrounded by copper wire loops. Electromagnetic induction is created by the rotor spinning around the inside of the core, generating electricity.
- **Transmission Systems-** The chain and sprocket system is used as the transmission system in this wind mill.

3.2. Governing equations

There are two fundamental approaches to design and analysis of engineering systems that involve fluid flow: experimentation and calculation. Modern engineers apply both experimental and CFD analysis, and the two complement each other. For example, engineers may obtain global properties, such as lift, drag, pressure drop, or power, experimentally, but use CFD to obtain details about the flow field, such as shear stresses, velocity and pressure profiles.

In fluid dynamics there are three governing equations. These are momentum, continuity and energy equation. Since vehicle travels relatively low speed, Ma<0.3 and constant temperature the flow can be assumed incompressible and isothermal, the energy equation can then be neglected.

3.2.1. Conservation of Mass- The Continuity Equation [29]

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0$$

As the flow is approximated as incompressible, density is not a function of time or space. Thus $\frac{\partial \boldsymbol{u}}{\partial \boldsymbol{t}} \cong 0$. So we can write the above equation as-

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

3.2.2. Conservation of Linear Momentum- Navier-Stokes Equation [18]

The x-component of the momentum equation as-

$$\rho \frac{Du}{Dt}= -\frac{\partial P}{\partial x}+\rho g_x+\mu \nabla^2 u$$

In similar fashion, we write the y-and z-components of the momentum equation as-

$$\rho \frac{Dv}{Dt}= -\frac{\partial P}{\partial y}+\rho y+\mu \nabla^2 v$$

$$\rho \frac{Dw}{Dt}= -\frac{\partial P}{\partial z}+\rho g_z+\mu \nabla^2 w$$

Hence the equation of lift and drag force co-efficient are-

Drag co-efficient, $C_D = \frac{F_D}{\frac{1}{2}\rho V^2 A}$ Lift co-efficient, $C_L = \frac{F_L}{\frac{1}{2}\rho V^2 A}$

Basically, three governing equations are available. Since vehicles and other mechanical components run at low speed so here conservation of energy equation is neglected. So, this paper is done on two governing equations.

3.3. Flow chart of the paper

- First of all, a newly type of turbine blade is designed with solid works that is in helical shape.
- Next step is to add a vertical shaft in turbine blade.
- After adding vertical shaft, flow simulation is done on ANSYS 18.2 (student version).
- From ANSYS simulation, for given velocity of wind and rpm corresponding torque is found.
- On the other hand, specific velocity changes graph is also found for different velocities.
- The next step is to make a proto-type of Vertical Axis Wind Turbine (VWAT) with the specified design.
- After making the proto-type, experimental work in done. For different wind velocity, different output voltage and current is found.

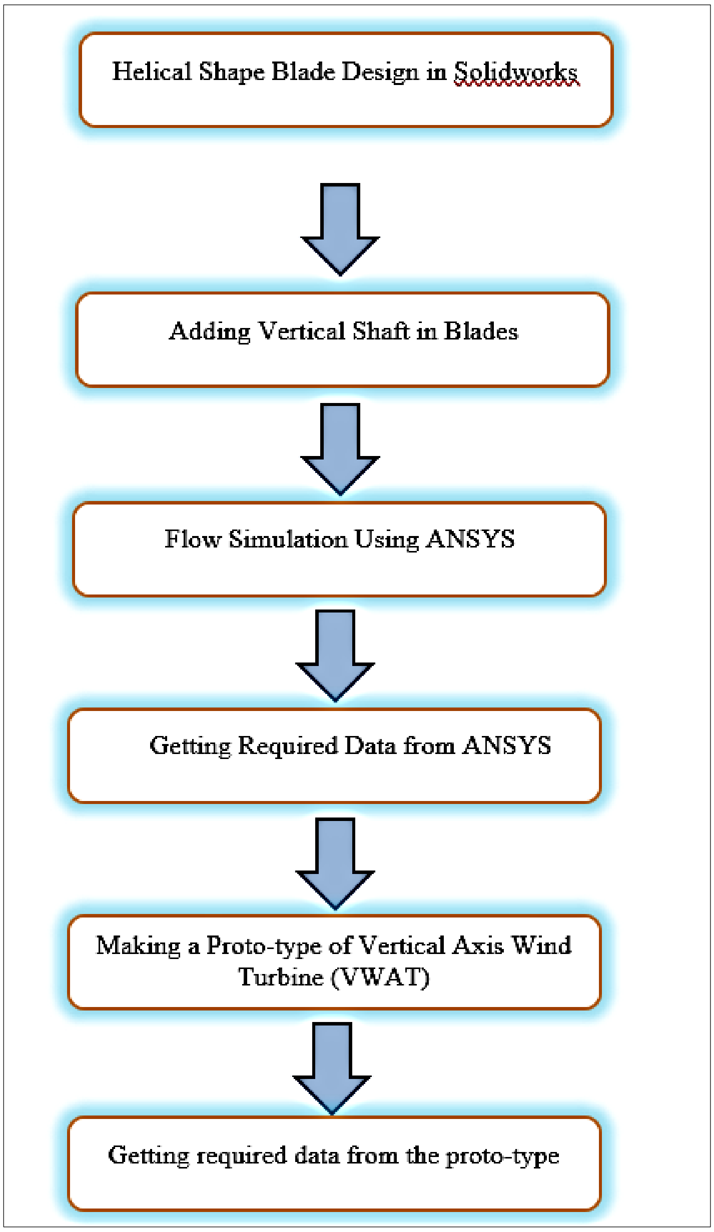

Figure 2 Steps of the process

3.4. Model of the paper

Helical shape wind turbine blade is designed by solid works. The diameter of the blade is 0.41 m. Length is 0.73 m. Two helical shape blade is meshed with a vertical shaft. The design specification and different views of the model is given below-

3.4.1. Design Specification

- Diameter of the blade, D = 0.41 m
- Length of the wind turbine, L = 0.73 m
- Air density, ρ = 1.2 kg/m^3
- Swept area, A = 0.94 m^2

Basically there are two blades which are welded with a vertical shaft. Vertical shaft is placed in a ball bearing which is in the base of wind turbine. In the base there are an idle shaft and a dynamo. When the blade rotates, the idle shaft rotates with a pulley. Idle shaft transforms the rotational power to the shaft of dynamo.

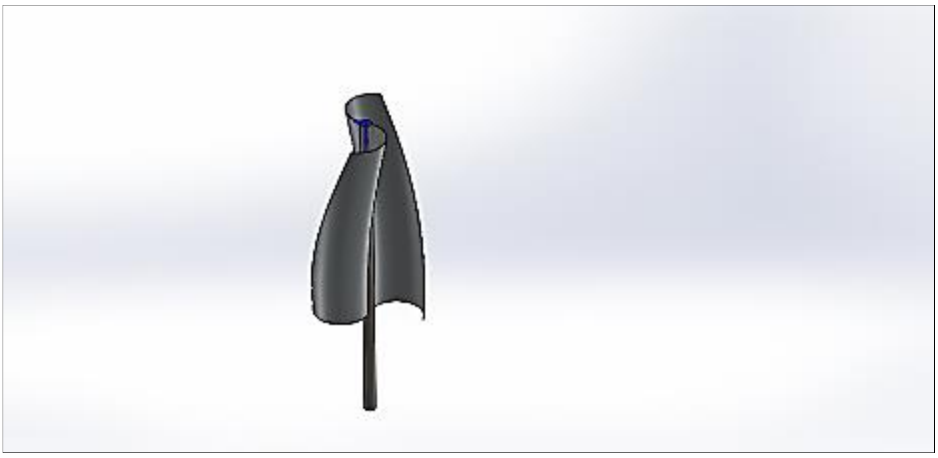

Figure 3 CAD Modelling of Helical Blade in a Vertical Axis Wind Turbine [4]

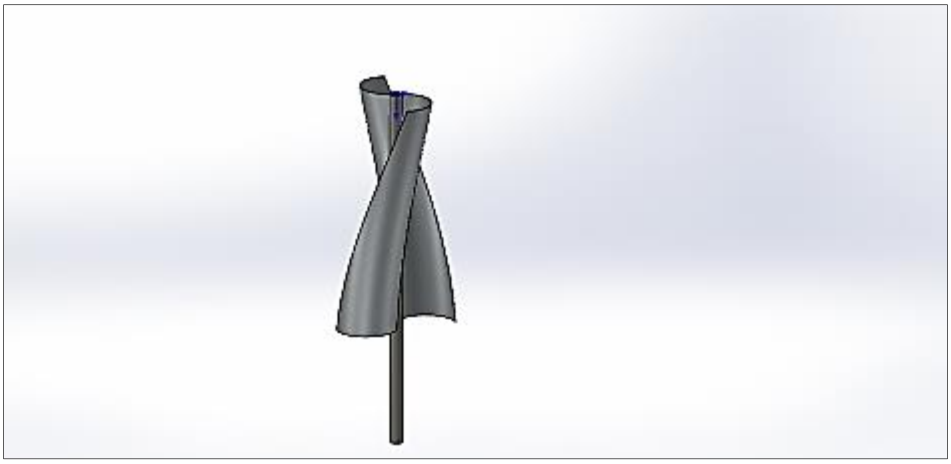

Figure 4 CAD Modelling of Helical Blade in a Vertical Axis Wind Turbine [4]

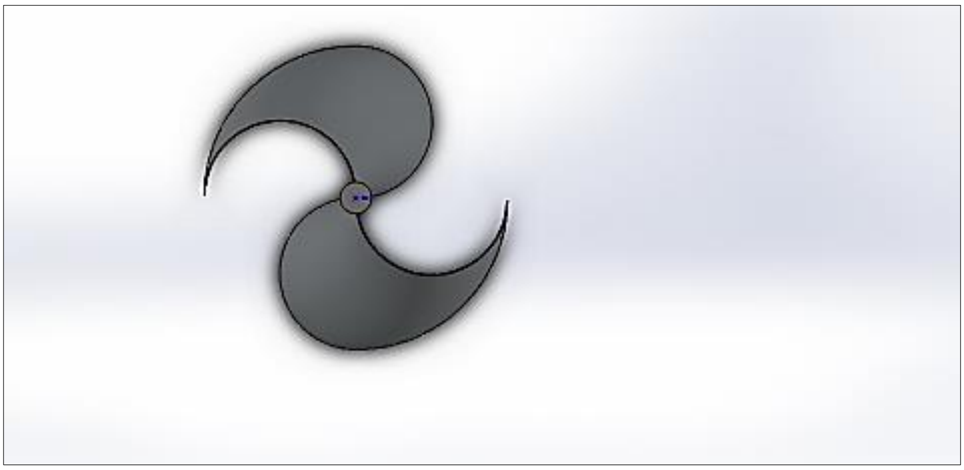

Figure 5 Top View of Helical Blade [4]

3.4.2. Ansys modeling of the paper

- A computational domain is chosen and a grid (also called a mesh) is generated; the domain is divided into many small elements called cells.
- Boundary conditions are specified on each edge of the computational domain (2-D) flows) or on each face of the domain (3-D flows).
- The type of fluid (air) is specified, along with fluid properties (temperatures, density, viscosity etc.).
- Numerical Parameters and solution algorithms are selected. These are specific to each CFD code.
- Properties of flow field, such as pressure drop and integral properties such as forces (lift and drag) and moments acting on a body are calculated from the converged solution.
- The inlet air velocities are 5 m/s, 4.3 m/s, 3.2 m/s.
- The input RPM is 110 and different torque is found with velocity and rpm value.
- The size function of mesh is curvature.
- Transition ratio is 0.77 and growth rate is 1.2.
- There are around 39575 nodes in total mesh analysis.
- The no slip shear condition is applied on the turbine blade.

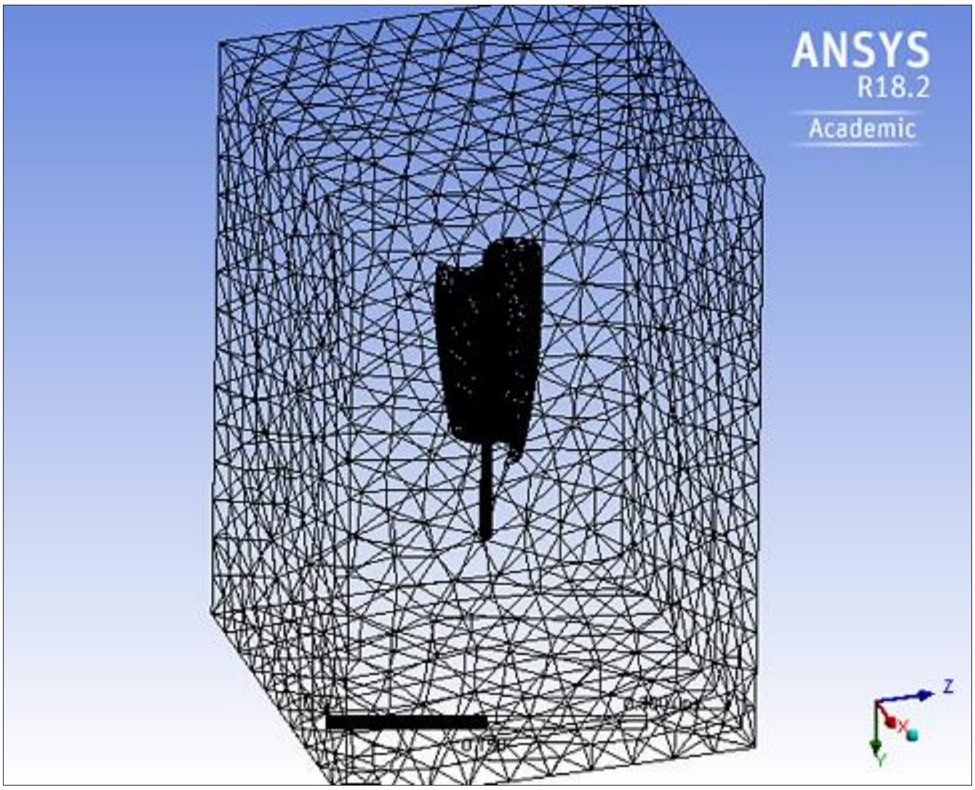

Figure 6 Mesh and Grid making of the paper using ANSYS-18.2 [21]

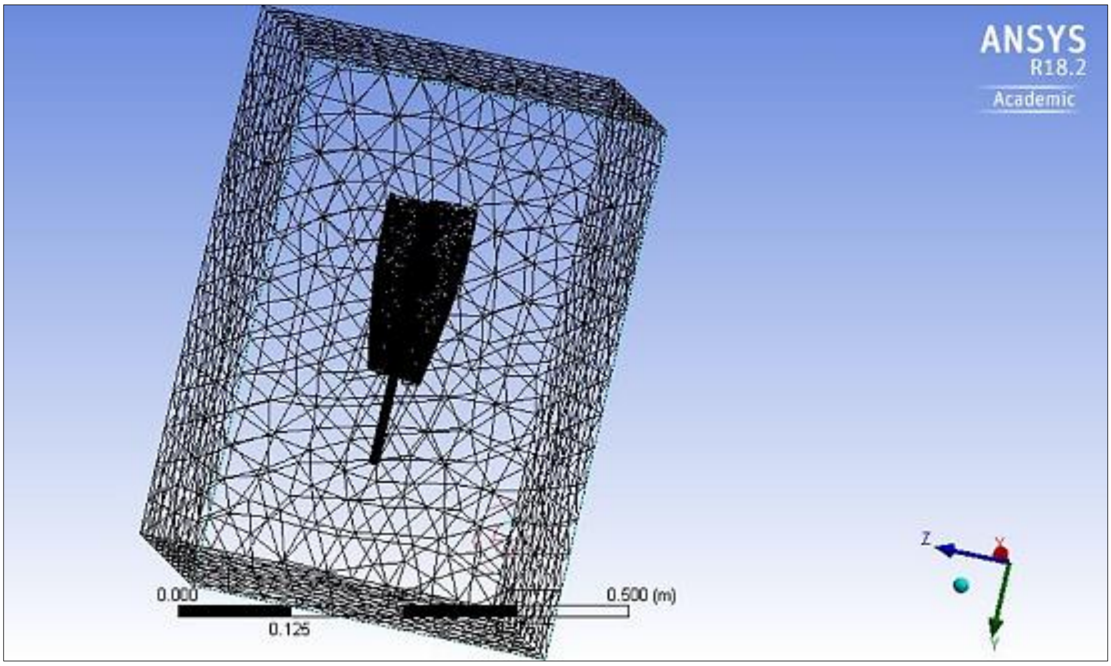

Figure 7 Mesh and Grid making of the paper using ANSYS-18.2 [21]

3.4.3. Practical model of the paper

The practical model of the paper is as bellows

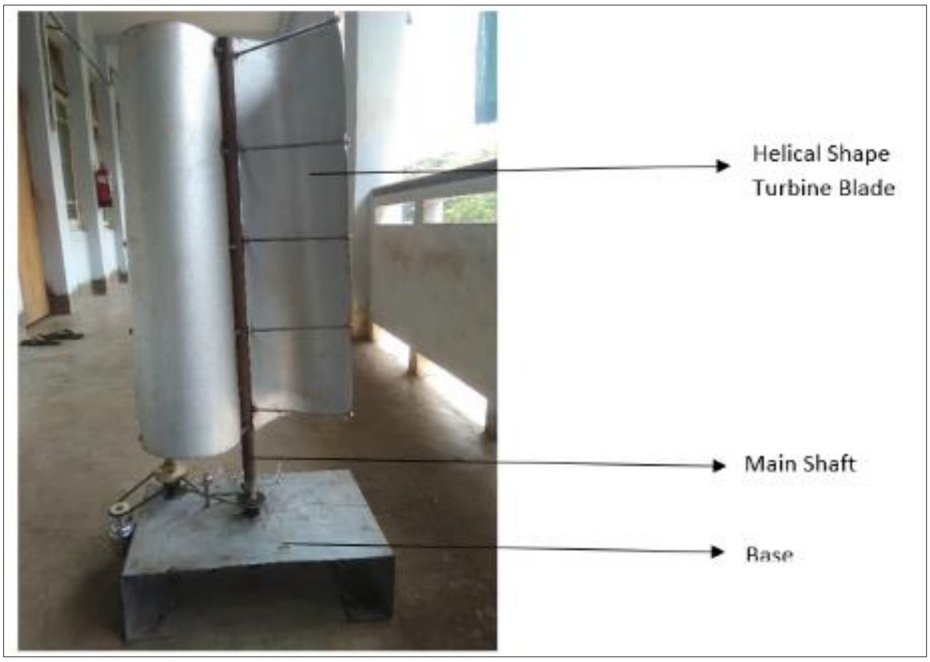

Figure 8 Practical view of the paper

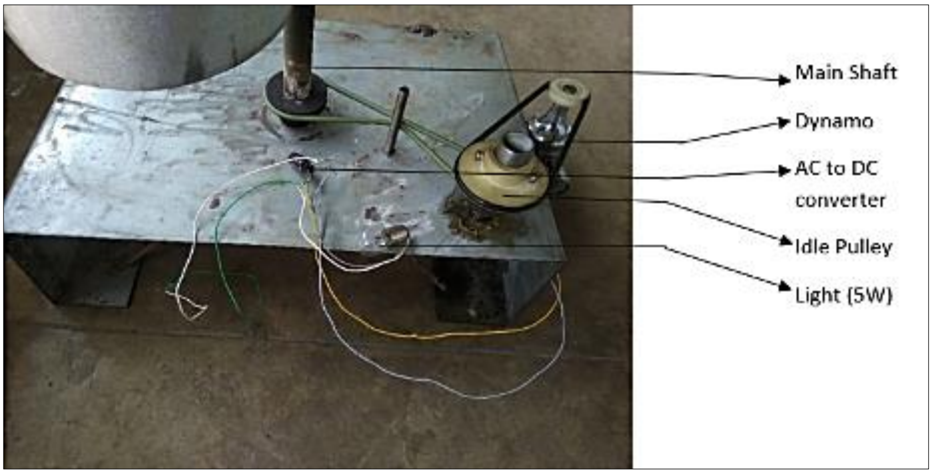

Figure 9 Practical view of the paper

3.4.4. Ansys simulation

Simulation is also done in this paper by using ANSYS 18.2 (student version). From the simulation fluid streamline and contour snaps are found. Here working fluid is air and turbine blade is in a closed boundary with an inlet and an outlet portion. Different boundary conditions and governing equations are used for the simulation.

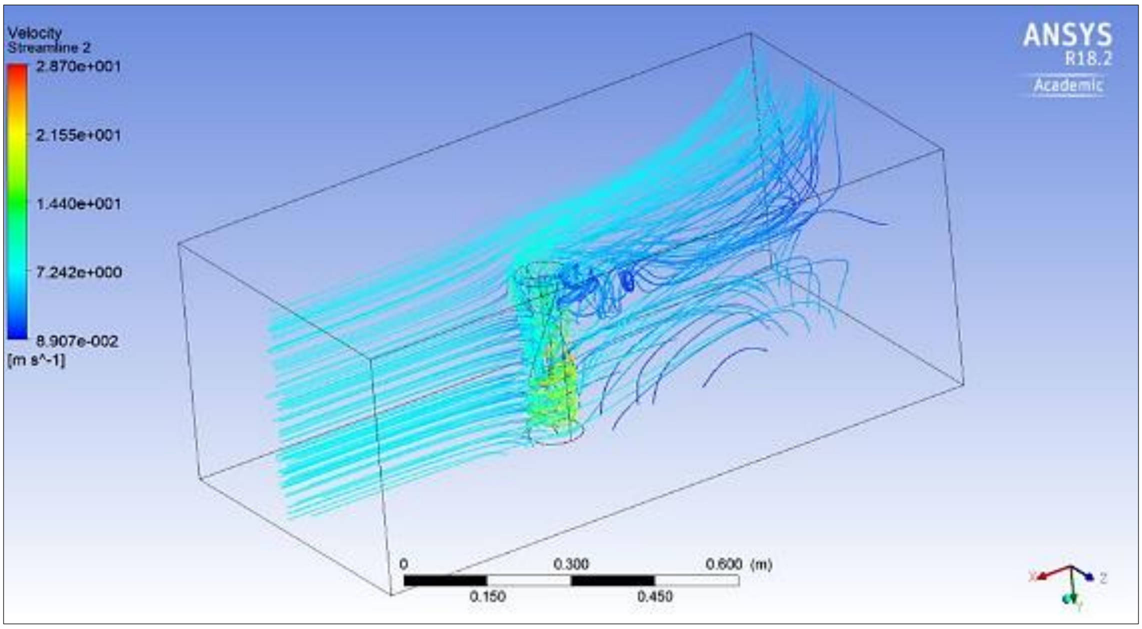

Figure 10 Velocity streamline of the wind turbine

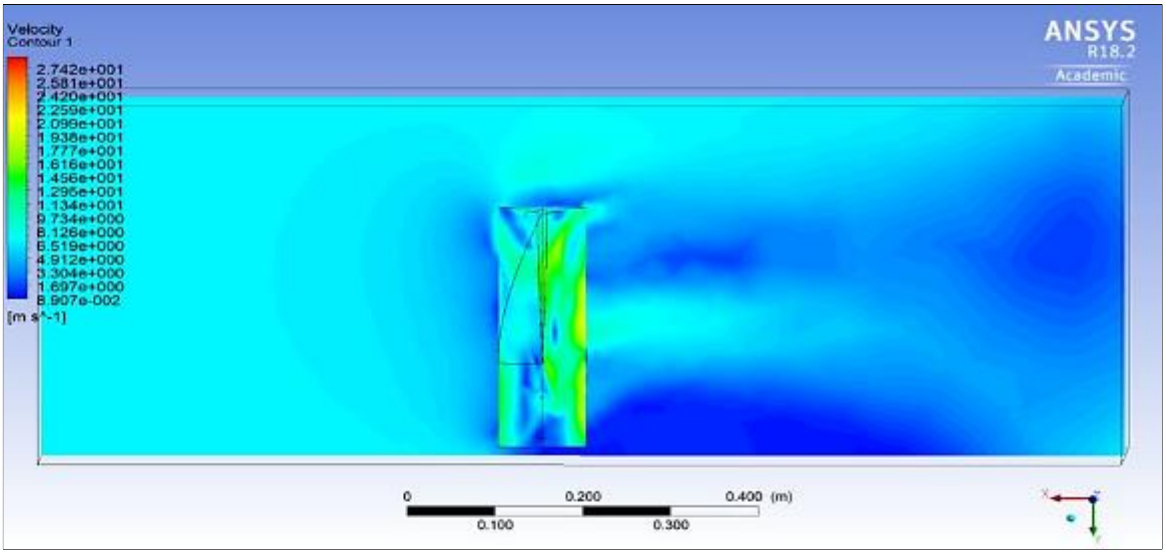

Figure 11 Velocity contour of the wind turbine

4. Data Collection Analysis

4.1. Simulation results

For different wind velocity and rpm corresponding torque and power is calculated by using ANSYS 18.2 (student version). Here initial condition for given rpm is 110. Simulation is done on a closed boundary with an inlet and an outlet section. Velocity graph shows the changes of velocity in X direction.

Table 1 Simulation based power output based on wind velocity

Wind Velocity (m/s)	Torque (N-m)	RPM (rev/min)	Power (W)
5	0.0278	110	0.32
4.3	0.0219	110	0.25
3.2	0.0142	110	0.16

Power is calculated with this following equation:-

$$\text{Power, } P = \tau \times \omega = .0278 \times (2\pi N/60) = 0.32 \text{ W (for 5 m/s).}$$

4.2. Experimental results

With the use of anemometer we got the wind velocity and from the wind velocity we got the corresponding output voltage by using a multimeter.

Table 2 Experimental based power output based on wind velocity

Wind Velocity (m/s)	Output Voltage (V)	Current (I)	Power (P)
5	3.82	0.135	0.52
4.3	3.66	0.128	0.47
3.2	3.18	0.109	0.35

$$\text{Power, } P = V \times I = (3.82 \times 0.135) = 0.52 \text{ W (for 5 m/s).}$$

4.3. Velocity Changes Graph (from simulation)

For different wind velocities there is some change in X-direction. The effects of changes are as bellows:-

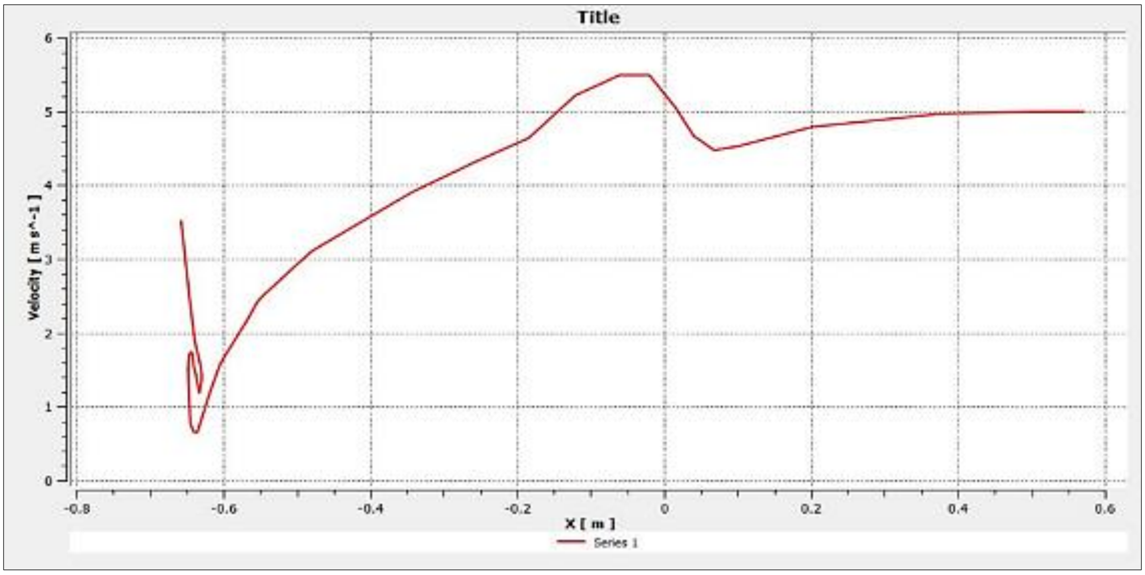

Figure 12 Velocity Changes Graph (for 5 m/s)

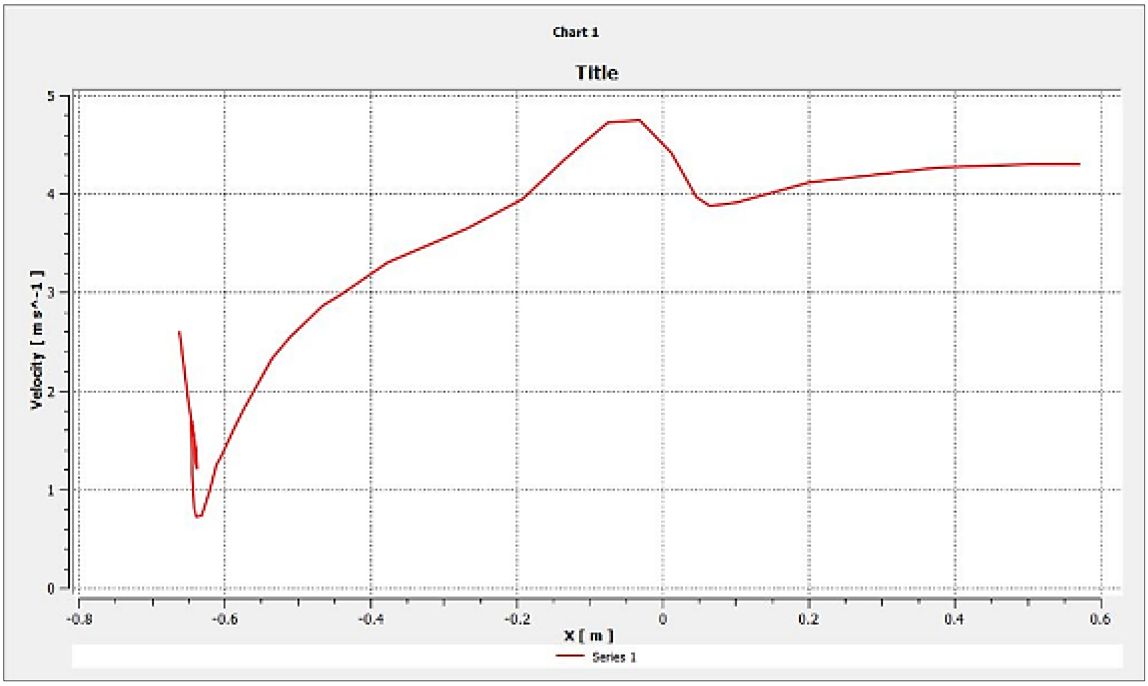

Figure 13 Velocity Changes Graph (for 4.3 m/s)

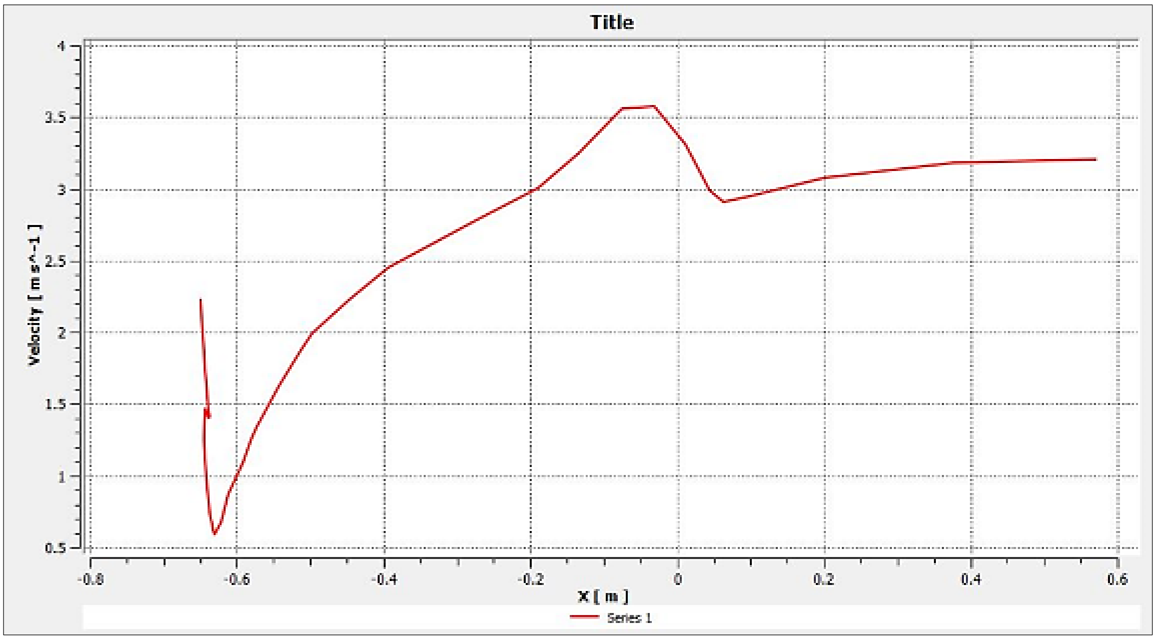

Figure 14 Velocity Changes Graph (for 3.2 m/s)

4.4. Velocity vs Voltage Changes Graph (from experiment)

For different wind velocities corresponding output voltage is found. The changes of velocity and voltage are as follows:-

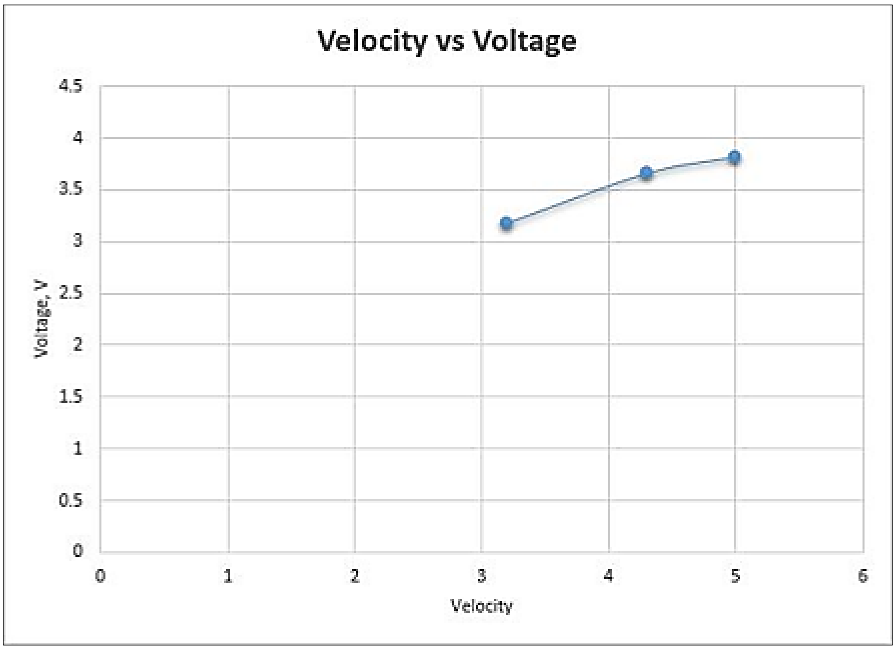

Figure 15 Velocity vs Voltage Changes Graph (from experiment)

5. Results

5.1. Introduction

In this paper, first of all a new kind of turbine blade is designed by solid works. After the design, simulation is done on ANSYS 18.2 (student version). From simulation the required torque values is found from given wind velocities and rpm. There are some difficulties faced in simulation. Initial condition, boundary condition and governing equations are properly applied. Velocity changes graph also determines the relative changes of velocity in X- direction.

5.2. Comparison Between Simulation Results and Experimental Results

This is the data analysis between simulation results and experimental results-

Table 3 Comparison on simulation and experimental output

Velocity	Power Output		% Deviation
	From Simulation	From Experiment	
5 m/s	0.32 W	0.52 W	38%
4.3 m/s	0.25 W	0.47 W	46%
3.2 m/s	0.16 W	0.35 W	54%

6. Discussions

Here results are found in two ways. One is simulation result and another is experimental results. From simulation, the initial given values are wind velocity and turbine blade rpm. The wind velocities are 5m/s, 4.3 m/s, 3.2 m/s. The wind turbine rpm is 110. From these values, maximum power output is got from 5 m/s wind velocity and the value is 0.32 watt.

From experiment, the given wind velocities are also 5 m/s, 4.3 m/s and 3.2 m/s. For different velocities, output voltage is measured by using a multimeter. So, the maximum output voltage is found from 5 m/s wind velocity. The value of maximum output voltage is 3.82 V and current is 0.13 A. Maximum power output is 0.52 Watt.

There are some changes in the values of power output both for simulation and experimental results. Since the rpm value is not good enough so that the torque values are less in simulation. From the experiment as there are accuracy and precision in design, since there are some voltage drops too. On the other hand, since the dynamo's maximum output voltage is 12V but in experiment maximum 3.82V is found because the rpm of the blade is between 80-110 rpm.

7. Conclusion

A helical vertical axis wind turbine was built with the purpose of covering the electricity supply for a household with an average consumption of approximately 1500 kW/h per year. The turbine was subjected under many tests to confirm its performance and operation ranges. After analyzing and comparing the results with the analytical data, it was determined that the helical wind turbine could be a viable alternative option for its use to generate cost-competitive energy. Wind power is a clean and inexhaustible source of renewable energy, which has experienced dramatic growth in the last decade. Considering the featured benefits, such as the construction and maintenance costs, turbine size and operation requirements, this rotor mechanism could be a scalable solution, which has a significant expansion potential to address the current renewable energy demands.

7.1. Discussions on results

In this paper, simulation and practical analysis both are done. From simulation, for a specific helical design of a wind turbine the torque values are found with respect to given wind velocity in a closed boundary. From experiment, maximum 3.82 V is found for 5 m/s wind velocity.

7.2. Suggestions for future study

In this paper, output voltage is about 3.8 V and it is not sufficient enough. Here belt drive mechanism is applied so for this reason there may be some friction occurred. If anyone use gear train mechanism or two or three pulleys, the friction will be less and output voltage will be more. On the other hand, if anyone use higher capacity dynamo then higher output voltage will be gained.

Compliance with ethical standards

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Disclosure of conflict of interest

The article originated from the authors and they have declared that no conflict of interest with any individual or group.

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