DESIGN AND OPTIMISATION OF BLADE PROFILE OF 3-BLADED SAVONIUS WIND TURBINE USING CFD ANALYSIS

A Project report submitted

in partial fulfillment of the requirement for the award of the degree of

BACHELOR OF TECHNOLOGY

In

MECHANICAL ENGINEERING

By

S.Durgaprasad(318126520L34)

B.Nanda Kumar(318126520L31)

R.Tripura Varshini(317126520166)

B.Ajith(317126520121)

P.Sameer(317126520163)

Under the esteemed guidance of

Mr.A.P.S.V.R.SUBRAHMANYAM,M.Tech(PhD)

Assistant Professor

DEPARTMENT OF MECHANICAL ENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A)

(Affiliated to Andhra University, Accredited By NBA and NAAC with 'A' Grade)

SANGIVALASA, VISAKHAPATNAM (District) – 531162

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A)

(Affiliated to Andhra University, Approved by AICTE, Accredited by NBA & NAAC with A grade)

SANGIVALASA, VISAKHAPATNAM (District) – 531162

ANITS

CERTIFICATE

This is to certify that the Project Report entitled **"DESIGN AND OPTIMIZATION OF BLADE PROFILE OF 3-BLADED SAVONIUS WIND TURBINE USING CFD ANALYSIS"** being submitted by SIRAPARAPU DURGAPRASAD (318126520L34), BALIREDDI NANDA KUMAR (318126520L31), RUTHALA TRIPURA VARSHINI (317126520166), BANDELA AJITH (317126520121), PRADHAN SAMEER (317126520163) in partial fulfillments for the award of degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING**. It is the work of bona-fide, carried out under the guidance and supervision of **MR.A.P.S.V.R.SUBRAMANYAM**, Assistant Professor, Department Of Mechanical Engineering, ANITS during the academic year of 2017-2021.

Approved By

PROJECT GUIDE

HEAD OF THE DEPARTMENT

(MR.A.P.S.V.R.SUBRAMANYAM)
Assistant Professor
Mechanical Engineering Department
ANITS, Visakhapatnam.

(Dr. B. Naga Raju)
Head of the Department
Mechanical Engineering Department
ANITS, Visakhapatnam.

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCE
Sangivalasa-531 162 VISAKHAPATNAM Dist A P

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We present this report on **"DESIGN AND OPTIMISATION OF BLADE PROFILE OF 3-BLADED SAVONIUS WIND TURBINE USING CFD ANALYSIS"** in the partial fulfillment of the requirement for the award of BACHELOR OF ENGINEERING in MECHANICAL ENGINEERING.

We intend to express our thanks with sincere obedience to **Prof. T. V. Hanumantha Rao,** Principal, ANITS and **Prof. B. Naga Raju,** Head of the Department, Mechanical Engineering, ANITS for providing this opportunity to express our deep and sincere thanks to our esteemed guide **Mr. A. P. S. V. R. Subrahmanyam,** Assistant Professor, Mechanical Engineering Department, ANITS, A source of constant motivation and best critic, for his inspiring and infusing ideas in getting our project done successfully.

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S.Durgaprasad(318126520L34)
B.Nanda Kumar(318126520L31)
R.Tripura Varshini(317126520166)
B.Ajith(317126520121)
P.Sameer(317126520163)

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ABSTRACT

Savonius wind turbine is one of the prominent vertical axis wind turbine. Inspite of its simple design,these turbines have the problem of poor performance.This study aims to enhance the performance of turbine through modification of the twist angles of the blade.

Under the present study,we develop a savonius wind turbine by using CATIA and we design the savonius rotor blades with twist angles ranging from 10 to 50 degrees.For getting maximum efficiency and maximum power production, this designed turbine blade with twist angles are analysed using CFD analysis in ANSYS Fluent Workbench software.

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Nomenclature

M = Mass of Air

V = Velocity of Air

ρ = Density of Air

A = Area

V = Volume

D = Diameter

Θ = Twist Angle of Turbine Blade

d = Diameter of Rotor Shaft

l = Length of Rotor Shaft

d_1 = Diameter of Turbine Blade

l_1 = Length of Turbine Blade

P = Power

T = Torque

V_{ACT} = Actual Velocity

V_{OBT} = Obtained Velocity

P_{ACT} = Actual Pressure

P_{OBT} = Otained Pressure

Ω = Angular Velocity

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Chapter-1

INTRODUCTION

1.1 WIND ENERGY POTENTIAL

To make a complete analysis of how much wind energy is available in any particular location is not very simple. It depends on the shapes of the local landscape, height of wind mill above ground and climate cycle. Whenever wind speed is referred, we usually refer to the average wind speed. Wind speeds can be averaged for a second, a minute, a month, a year or more. For home wind power applications, it is sufficient to know the monthly and yearly average wind speeds.

Generally, areas with speed averages of 19-25 km/h are moderate to good areas with averages 12-16 km/h are adequate for the use of wind power, but the power generated might be marginal in economic value compared to cost of the system.

1.2 BASIC PRINCIPLES OF WIND ENERGY CONVERSION

1.2.1 Nature of the Wind:

Wind speeds increase with height. They have traditionally been measured at standard height of 10m where they are found to be 20 to 25 percent greater than close to the surface. At a height of 60m they may 30 to 60 percent higher because of the reduction in the drag effect of the earth surface.

1.2.2 Power and Wind

Wind possesses energy by virtue of its motion. Any device capable of slowing the mass of moving air, like a sail or propeller, can extract part of energy and convert it into useful work. Three factors determine the output from the wind energy converter:

- The wind speed.
- The cross section of wind swept by rotor.
- The overall conversion efficiency of the rotor transmission system and generator.

No device, however well designed, can extract all of the winds energy because the wind had to be brought to a halt and this would prevent the passage of more air through the rotor. The power in the wind can be computed by using the concept of kinetic. The windmill works on the principal of converting the kinetic energy of the wind into mechanical energy.

We know that,

Power=Energy/unit time

Energy, here, is the kinetic energy of the wind.

Therefore, Energy=1/2 mv^2

Now, M= ρAV

Therefore, Energy= (1/2) ρAV^3

The above equation tells that the maximum wind available is proportional to the cube of the wind speed. It is thus evident that small increase in wind speed can have a marked effect on the power in the wind. Also, the available is proportional to the air density (1.255 kg/cubic meter at sea level). It may vary 10-15% during the year because of pressure and temperature change. It is also proportional to the intercepted area. Thus, a wind turbine with a large swept area has higher power than a smaller area machine.

Since the area is normally circular of diameter D,

Then Area A=$\pi D^2/4$ m^2

Therefore, Available wind power

P (a) = (1/2) ρaV^3

The equation tells us that the maximum power available from the wind varies according to the square of the diameter of the intercepted area, normally taken as to be the swept area of the turbine. Thus the diameter of the rotor plays an important role in increasing the available wind power.

The physical conditions in a wind turbine are such that only a fraction of available wind power can be converted into useful power. The power extracted by the rotor is equal to the product of the wind speed as it passes through the rotor and the

pressure drop in the wind. In order to maximize the rotor power, it would be desirable to have both wind speed and pressure drop as large as possible .The fraction of free flow wind power that can be extracted by a rotor is called the power coefficient. Power available is calculated from air density, rotor diameter and free wind speed. According to Betz's law, the maximum theoretical power coefficient for any rotor type wind turbine is 16/27 or 0.593.

Power coefficient (Cp) = (power output from the wind machine)/ (Power available in the wind)

Thus, Cp cannot exceed 0.593 for a wind turbine.

1.3 INDIAN WIND ENERGY STATICS

Wind power generation capacity in India has significantly increased in recent years. As of 31 December 2019 the total installed wind power capacity was 37.505 GW, the **fourth largest installed wind power capacity in the world**. Wind power capacity is mainly spread across the Southern, Westrn and Northern regions.

WIND POWER INDIA 2011 is the first-of-its-kind international wind event to take place in India. It is the international counterpart of India's coveted national wind event, **WIND INDIA** which was launched in 2006 in pune, the renowned sustainability think-tank, the world institute of sustainable Energy (**WISE**).

Wind power accounts for nearly 10% of India's total installed power generation capacity and generated 62.03 TWh in the fiscal year 2018-19, which is nearly 4% of total electricity generation. The capacity utilisation factor is nearly 19.33% in the fiscal year 2018-19 (16% in 2017-18, 19.62% in 2016-17 and 14% in 2015-16). 70% of annual wind generation is during the five months duration from May to September coinciding with Southwest monsoon duration.

1.4 Wind Energy Rankings in India:

Rank	State	Total Capacity (MW)
1.	Tamil Nadu	9231.77
2.	Gujarat	7203.77
3.	Maharashtra	4794.13
4.	Karnataka	4753.40
5.	Rajasthan	4299.73
6.	**Andhra Pradesh**	**4077.37**
7.	Madhya Pradesh	2519.89
8.	Telangana	128.10
9.	Kerala	62.50
10.	Others	4.30
	Total	37090.03

1.5 TOP TEN COUNTRIES UTILIZING WIND ENERGY:

Country	Wind power production (TWh)
China	305
United States	257
Germany	106
United Kingdom	50.0
Spain	49.1
India	**47.7**
Brazil	42.3
Canada	28.8
France	24.7
Turkey	17.9

Whilst most of the countries using wind energy have up to now focused on wind generation on-land, some of these countries using wind power are now looking at establishing off-shore wind farms. The advantages of these are obvious, with land acquisition for wind farms difficult and expensive, and with wind blowing more regularly out in the sea.

Overall, wind energy holds great promise, and if the countries that use and develop wind energy stay committed to the cause, it could become a significant source of energy generation by the year 2050. In conjunction with other alternative means of energy production, there is still a chance that we can keep global warming in check and significantly reduce the amount of pollutants that we emit into the atmosphere.

1.6 ADVANTAGES AND DISADVANTAGES FOR THE USE OF WIND ENERGY

There are numerous advantages to using wind power to generate electricity as well as some disadvantages, so we have listed them here in order to help you decide if employing wind energy is the way you want to go.

Advantages:

- Wind is an ample and renewable source of energy.
- It is getting cheaper all the time to generate mechanical energy from using the wind and now costs nearly 80% less than what it did 20 to 25 years ago.
- Wind energy is not polluting and helps in reducing the greenhouse effect.
- Wind is a permanent source of renewable energy (just like the sun is with solar) and is readily available on a global basis.

Disadvantages:

- Even though wind turbines are non-polluting, some can be fairly noisy which may contribute to noise pollution factors.
- Not be suited for all type of application.
- Wind energy ids not dispatch able and is best used in conjunction with solar and/or water energy.

1.7 What Is CFD?

Computational fluid dynamics (**CFD**) is a branch of fluid mechanics that uses numerical analysis and data structures to analyze and solve problems that involve fluid flows. Computers are used to perform the calculations required to simulate the free-stream flow of the fluid, and the interaction of the fluid (liquids and gases) with surfaces defined by boundary conditions.

CFD is based on the Navier-Stokes equations. Arising from applying Newton's second law to fluid motion, together with the assumption that the stress in the fluid is the sum of a diffusing viscous term and a pressure term, these equations describe how the velocity, pressure, temperature, and density of a moving fluid are correlated.

Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows. Initial validation of such software is typically performed using experimental apparatus such as wind tunnels. In addition, previously performed analytical or empirical analysis of a particular problem can be used for comparison. A final validation is often performed using full-scale testing, such as flight tests.

1.7.1 Governing Equations In CFD:

CFD can be seen as a group of computational methodologies used to solve equations governing fluid flow. In the application of CFD, a critical step is to decide which set of physical assumptions and related equations need to be used for the problem at hand. To illustrate this step, the following summarizes the physical assumptions/simplifications taken in equations of a flow that is single-phase, single-species (i.e., it consists of one chemical species), non-reacting, and (unless said otherwise) compressible. Thermal radiation is neglected, and body forces due to gravity are considered (unless said otherwise). In addition, for this type of flow, the next discussion highlights the hierarchy of flow equations solved with CFD. Note that some of the following equations could be derived in more than one way.

Conservation laws (CL): These are the most fundamental equations considered with CFD in the sense that, for example, all the following equations can be derived from them. For a single-phase, single-specie, compressible flow one considers the conservation of mass, conservation of linear momentum, and conservation of energy.

Continuum conservation laws (CCL): Start with the CL. Assume that mass, momentum and energy are *locally* conserved: These quantities are conserved and cannot "teleport" from one place to another but can only move by a continuous flow. Another interpretation is that one starts with the CL and assumes a continuum medium. The resulting system of equations is unclosed since to solve it one needs further relationships/equations:

(a) constitutive relationships for the viscous stress tensor;
(b) constitutive relationships for the diffusive heat flux;
(c) an equation of state (EOS), such as the ideal gas law;
(d) a caloric equation of state relating temperature with quantities such as enthalpy or internal energy.

Compressible Navier-Stokes equations (C-NS): Start with the CCL. Assume a Newtonian viscous stress tensor and a Fourier heat flux. The C-NS need to be augmented with a EOS and a caloric EOS to have a closed system of equations.

Incompressible Navier-Stokes equations (I-NS): Start with the C-NS. Assume that density is always and everywhere constant. Another way to obtain the I-NS is to assume that the Mach number is very small and that temperature differences in the fluid are very small as well. As a result, the mass-conservation and momentum-conservation equations are decoupled from the energy-conservation equation, so one only needs to solve for the first two equations.

Compressible Euler equations (EE): Start with the C-NS. Assume a frictionless flow with no diffusive heat flux.

Weakly compressible Navier-Stokes equations (WC-NS): Start with the C-NS. Assume that density variations depend only on temperature and not on pressure. For example, for an ideal gas, use $\rho = p_0/(RT)$, where p_0 is a conveniently-defined reference pressure that is always and everywhere constant, ρ is density, R is the specific gas constant, and T is temperature. As a result, the WK-NS do not capture acoustic waves. It is also common in the WK-NS to

neglect the pressure-work and viscous-heating terms in the energy-conservation equation. The WK-NS are also called the C-NS with the low-Mach-number approximation.

Boussinesq equations: Start with the C-NS. Assume that density variations are always and everywhere negligible except in the gravity term of the momentum-conservation equation (where density multiplies the gravitational acceleration). Also assume that various fluid properties such as viscosity, thermal conductivity, and heat capacity are always and everywhere constant. The Boussinesq equations are widely used in microscale meteorology.

Compressible Reynolds-averaged Navier–Stokes equations and compressible Favre-averaged Navier-Stokes equations (C-RANS and C-FANS): Start with the C-NS. Assume that any flow variable f, such as density, velocity and pressure, can be represented as $f = F + f''$, where F is the ensemble-average of any flow variable, and f'' is a perturbation or fluctuation from this average. f'' is not necessarily small. If is F a classic ensemble-average one obtains the Reynolds-averaged Navier–Stokes equations. And if F is a density-weighted ensemble-average one obtains the Favre-averaged Navier-Stokes equations. As a result, and depending on the Reynolds number, the range of scales of motion is greatly reduced, something which leads to much faster solutions in comparison to solving the C-NS. However, information is lost, and the resulting system of equations requires the closure of various unclosed terms, notably the Reynolds stress.

Ideal flow or potential flow equations: Start with the EE. Assume zero fluid-particle rotation (zero vorticity) and zero flow expansion (zero divergence). The resulting flowfield is entirely determined by the geometrical boundaries. Ideal flows can be useful in modern CFD to initialize simulations.

Linearized compressible Euler equations (LEE): Start with the EE. Assume that any flow variable f, such as density, velocity and pressure, can be represented as $f = f_0 + f'$, where is the value of the flow variable at some reference or base state, and f' is a perturbation or fluctuation from this state. Furthermore, assume that this perturbation f' is very small in comparison with some reference value. Finally, assume that f_0 satisfies "its own" equation, such as the EE. The LEE and its many variations are widely used in computational aeroacoustics.

Sound wave or acoustic wave equation: Start with the LEE. Neglect all gradients of f_0 and f', and assume that the Mach number at the reference or base state is very small. The resulting equations for density, momentum and energy can be manipulated into a pressure equation, giving the well-known sound wave equation.

Shallow water equations (SW): Consider a flow near a wall where the wall-parallel length-scale of interest is much larger than the wall-normal length-scale of interest. Start with the EE. Assume that density is always and everywhere constant, neglect the velocity component perpendicular to the wall, and consider the velocity parallel to the wall to be spatially-constant.

Boundary layer equations (BL): Start with the C-NS (I-NS) for compressible (incompressible) boundary layers. Assume that there are thin regions next to walls where spatial gradients perpendicular to the wall are much larger than those parallel to the wall.

Bernoulli equation: Start with the EE. Assume that density variations depend only on pressure variations.

Steady Bernoulli equation: Start with the Bernoulli Equation and assume a steady flow. Or start with the EE and assume that the flow is steady and integrate the resulting equation along a streamline.

Stokes Flow or creeping flow equations: Start with the C-NS or I-NS. Neglect the inertia of the flow. Such an assumption can be justified when the Reynolds number is very low. As a result, the resulting set of equations is linear, something which simplifies greatly their solution.

Two-dimensional channel flow equation: Consider the flow between two infinite parallel plates. Start with the C-NS. Assume that the flow is steady, two-dimensional, and fully developed (i.e., the velocity profile does not change along the streamwise direction). Note that this widely-used fully-developed assumption can be inadequate in some instances, such as some compressible, microchannel flows, in which case it can be supplanted by a *locally* fully-developed assumption.

One-dimensional Euler equations or one-dimensional gas-dynamic equations (1D-EE): Start with the EE. Assume that all flow quantities depend only on one spatial dimension.

Fanno flow equation: Consider the flow inside a duct with constant area and adiabatic walls. Start with the 1D-EE. Assume a steady flow, no gravity effects, and introduce in the momentum-conservation equation an empirical term to recover the effect of wall friction (neglected in the EE). To close the Fanno flow equation, a model for this friction term is needed. Such a closure involves problem-dependent assumptions.

Rayleigh flow equation. Consider the flow inside a duct with constant area and either non-adiabatic walls without volumetric heat sources or adiabatic walls with volumetric heat sources. Start with the 1D-EE. Assume a steady flow, no gravity effects, and introduce in the energy-conservation equation an empirical term to recover the effect of wall heat transfer or the effect of the heat sources (neglected in the EE).

1.8 Applications Of CFD:

CFD is applied to a wide range of research and engineering problems in many fields of study and industries, including aerodynamics and aerospace analysis, weather simulation, natural science and environmental engineering, industrial system design and analysis, biological engineering and fluid flows, and engine and combustion analysis.

1.8.1 CFD In Bio-Medical Engineering:

CFD investigations are used to clarify the characteristics of aortic flow in detail that are otherwise invisible to experimental measurements. To analyze these conditions, CAD models of the human vascular system are extracted employing modern imaging techniques. A 3D model is reconstructed from this data and the fluid flow can be computed. Blood properties like Non-Newtonian behavior and realistic boundary conditions (e.g. systemic pressure) have to be taken into consideration. Therefore, making it possible to analyze and optimize the flow in the cardiovascular system for different applications.

1.9 CFD ANALYSIS:

Computational fluid dynamics or CFD analysis is one of the key analysis methods used in engineering applications. The origins of CFD lies in the mankind's efforts to better understand the power of natural elements like wind, storms, floods, or sea waves.

1.9.1. Use Of CFD ANALYSIS:

With a CFD analysis, we can understand the flow and heat transfer throughout a design process. The basic methodology for any engineering CFD analysis is based on a few procedures:
• Understanding flow model — Flow separations, transient effect, physical interactions;
• Proving assumed model — Experimental results validation, parametric studies, structural simulations;
• Model optimizing — Reducing pressure drops, flow homogenization, improving laminar and turbulent mixing.

Without numerical simulations of fluid flow, it is very difficult to imagine how:
• Meteorologists can forecast the weather and warn of natural disasters;
• Vehicle designers can improve aerodynamic characteristics;
• Architects can design energy-saving and safe-living environments;
• Oil and gas engineers can design and maintain optimal pipes networks;
• Doctors can prevent and cure arterial diseases by computational hemodynamic.

1.9.2. Advantages of CFD:

A) **Gain insight** into systems that might be difficult to test through experimentation.

B) **Foresee performance and optimise the design accordingly.** Without modifying or installing real systems, CFD simulation can forecast which changes in design are most vital for improving performance.

C) **Predict** mass flow rates, pressure drops, heat transfer rates, and fluid dynamic forces such as lift, drag and pitching moments.

D) **Lower costs** by using CFD simulations instead of physical experimentation to retrieve essential engineering data.

E) **Introduce engineering data early in the design process.** Simulations can be executed in a far shorter period of time when compared to physical testing.

F) **Simulate real conditions.** Some flow and heat transfer processes cannot be physically tested, e.g. hypersonic flow. But CFD provides the ability to theoretically simulate any physical condition.

G) **Simulate ideal conditions.** CFD permits great control over the physical processes, and offers the ability to isolate specific phenomena for study.

H) Examine data from a large number of locations. Physical testing limits the number of locations that can be examined in the system. CFD permits the examination of a large number of locations in the area of interest, and yields a comprehensive set of flow parameters for examination.

1.9.3. Disadvantages Of CFD:

A) PHYSICAL MODELS
   – CFD relies upon physical models of real world processes.
   – CFD solutions can only be as accurate as the physical models.

B) NUMERICAL ERRORS
   – Solving equations on a machine also introduces numerical errors,
   – Round-off error (due to finite word size available on computer, round-off errors will always exist).
   – Truncation error (due to approximations in the numerical models).

C) BOUNDARY CONDITIONS
   – Similar to physical models.
   – The accuracy of the CFD solution is only as good as the initial boundary conditions provided to the numerical model.

CHAPTER 2

LITERATURE REVIEW

Salih Meri AR, et al., "Performance Evaluation of Savonius Wind Turbine based on a New Design of Blade Shape" explained about the effect of the parameters of the blade shape and the overlap ratio on the performance efficiency of the elliptical Savonius wind turbine. A new model of Savonius blade has been designed by changing the inner surface of the concave blade with an overlap ratio of (0.2). The new model is printed using 3D-printer technology for experimental testing in the wind tunnel at different wind speeds of (6 m/s, 8 m/s, and 10 m/s)

R. Gokulnath, et.al., "CFD Analysis of Savonius type Vertical Axis Wind Turbine", discussed how to produce electricity for street lights through a Savonius wind turbine which is a type of VAWT (Vertical Axis Wind Turbine). The modelling and analysis process of the rotor blade is done by the **Computational Fluid Dynamics (CFD)**.

M. Saqib Hameed and Farzeen Shahid, "Evaluation of Aerodynamic Forces over a Vertical Axis Wind Turbine Blade through CFD analysis", compared about the aerodynamic design of a VAWT blade using the **analytical and CFD techniques** for a small scale vertical axis wind turbine (VAWT), aiming 1 kW power output which may be used for domestic purposes to power a single room. The aerodynamic forces evaluated are comparable with the analytical values at a similar location as that of the experimented one.

Arifin Sanusi, et.al., "Performance Analysis of a Combined Blade Savonius Wind Turbines", experimented on how to improve wind turbine performance by combining a conventional blade with an elliptical blade into a combined blade rotor. The analysis was performed on three-blade models in computational fluid dynamics (CFD) using **ANSYS Fluent.** Then the results were **verified experimentally using an open wind tunnel system**.

N.Dibankar Reddy, et.al., "CFD Analysis on a Savonius Rotor Wind Turbine made Using Mild Steel Material" analysed how a wind turbine helps in extraction of electrical energy from wind energy. This work was an effort to prove that mild steel material can be used to make such wind turbines which provide strength as well as desired output. The design is done in CREO 2.0. The Computational Fluid dynamics analysis is performed in ANSYS 15.0.

Dr T.Mothilal, et.al., "CFD Analysis of Different Blades in Vertical Axis Wind Turbine" tried to compare the coefficient of performance (COP) of Savonius and Darrieus types of Vertical Axis Wind Turbine. The above mentioned VAWTs are numerically analyzed using ANSYS Fluent- Computational Fluid Dynamics (CFD) software. The design of the blades of both the turbines was chosen such that it is optimized for the best output for the given input.

Mr.Laxmikant, et.al., "CFD Analysis of Savonius Vertical Axis Wind Turbine: A Review" tried to present a review on performance and testing methodology of savonius vertical axis wind turbine. In this paper various factors such as aspect ratio, overlap ratio, number of blade, interference of shaft, influence of stator, influence of Reynolds number, shape of rotor,and how they affect the performance of turbine are discussed. Intension of this

paper is to gather information and bring it into discussion about their performance of savonius wind turbine for future studies.

N.H. Mahmoud, et.al., "An experimental study on improvement of Savonius rotor performance" explained about different geometries of Savonius wind turbine that are experimentally studied in order to determine the most effective operation parameters. The rotor with end plates gives higher effifiency than those of without end plates. Double stage rotors have higher performance compared to single stage rotors.

Frederikus Wenehenubun, et.al., "An experimental study on the performance of Savonius wind turbines related with the number of blades" discussed the experimental study conducted in this paper and how it aims to investigate the effect of number of blades on the performance of the Savonius type wind turbine. The experiments used to compare 2, 3, and 4 blades wind turbines to show tip speed ratio, torque and power coefficient related with wind speed. A simulation using ANSYS 13.0 software will show pressure distribution of wind turbine. The results of study showed that number of blades influence the performance of wind turbine.

A. Meana-Fernández, et.al., "An optimized airfoil geometry for vertical-axis wind turbine applications", analysed a new airfoil shape optimized for vertical-axis wind turbine applications. Different airfoil shapes have been analyzed with JavaFoil, a panel method software. Then, the results from the analysis have been used to optimize the performance of the new airfoil shape. Afterward, Computational Fluid Dynamics (CFD) simulations of the proposed airfoil, UO-17-LDA, are run for different angles of attack to provide insight into the flow field and the mechanisms related to this increase in performance and as well as to obtain a richer analysis of the flow field and the mechanisms related to the airfoil performance.

Indala Nageswara Rao and V.V.R.Murthy, "Performance Analysis of Vertical Axis Wind Turbines", discussed about a new model for the design and performance of a vertical axis wind turbine for small scale energy applications. Based on the wind speed, Small 4 & 8 bladed turbines will be constructed and investigated for the performance of turbines at various speeds. An artificial wind speed is created in a closed room to test the Coefficient of Performance of the Wind turbines.

Ryo Amano, et.al., "Power, structural and noise performance tests on different wind turbine rotor blade designs", explained the possibility of increasing the effifiency of the blades by modifying the blade design to incorporate a swept edge. The design intends to maintain effifiency at low to medium wind speeds by selecting the appropriate orientation and size of the airfoil cross-sections based on an oncoming wind speed and given constant rotation rate. The torque generated from a blade with straight-edge geometry is compared with that generated from a blade with a swept edge as predicted by CFD simulations.

Mohammed Hadi Ali "Experimental Comparison Study for Savonius Wind Turbine of Two & Three Blades At Low Wind Speed", compared between the experimental comparison and investigations carried out to study the performance and to make a comparison between two and three blades Savonius wind turbine. Two models were tested and investigated by using a subsonic wind tunnel that was fabricated for this purpose under a low wind speed.

A. Zakaria and M.S.N. Ibrahim "Analysis of Savonius Rotor Performance Operating at Low Wind Speeds Using Numerical Study", explained the sensitivity of time step and time increment on the performance of 180-degree twist helical Savonius rotor using commercial computational fluid dynamic code based on flow-driven method. This paper concludes that an accurate prediction of rotor rotational speed can be achieved by setting the right combination of time step and time increment.

Ahmed S. Saad, et.al., "Performance Analysis of a Helical Savonius Wind Turbine with Modified Rotor", aimed to investigate the numerical performance of a helical Savonius wind rotor with a twist angle of 45°. The twist is performed on a modified profile of the rotor blade. The numerical results presented in this paper are obtained using the three-dimensional incompressible unsteady Reynolds-Averaged Navier-Stokes equations along with the RNG k- ε turbulence model.

A.A. Kadam and S.S. Patil, "A Review Study on Savonius Wind Rotors for Accessing the Power Performance", the study of Savonius wind rotors and identifying the various performance parameters to increase its power performance. The power coefficient increases with increasing the aspect ratio. The rotor blades with end plates give higher efficiency than those of without end plates.

T. Sathish , "Fluid Flow Analysis of Composite Material based wind turbine Blades using Ansys", explained how to tackle design problems through the optimization of the present technology and improvement in the efficiency of the wind turbines for long-term sustainability. Therefore, the present research analyzes the performance of wind turbine blade with aerodynamic and structural integrity challenges.

Chapter-3

WIND TURBINES

3.1 WIND TURBINE: Wind machines were used in Persia as early as 200 B.C. wind machines were later introduced into the Roman Empire around 250 AD. However, the first practical windmills were built in Iran around 700 AD. These were vertical axis windmills (VAWM) which had long vertical drive shafts with rectangle shaped blades. Made of six to twelve sails covered in reed matting or cloth material, these windmills were used for various tasks such as draw up water and milling grain and sugarcane.

A forerunner of modern horizontal axis wind turbine (HAWT) energy generator was in service in USSR in 1931. This was a 100 kW generator on a 100 ft tower connected to the local 6.3 kV distribution system. It was reported to have an annual capacity factor of 32 percent which is not much different from current wind machines.

The first utility grid-connected wind turbine operated in the UK was built by the John Brown Company in 1954 in the Orkney Islands. It had an 18 meter diameter, three-bladed rotor and a rated output of 100 kW.

They were later adopted in Europe, particularly The Netherlands and Denmark from 1300 to present. Between 1850 and 1970, over six million wind machines were sold for use in the United States primary used to pump water, and later provide electricity in rural areas.

Fig: 3.1Wind turbines

THE FACTS:

Wind turbines are modern windmills that take advantage of aerodynamics and engineering advances to convert wind energy into force to directly operate machinery or to produce electricity. The horizontal axis wind turbine (HAWT) consists of a turbine or propeller having two or more blades that rotate a horizontal drive shaft. This shaft provides torque to produce mechanical or electrical energy. Electricity is generated when the torque is converted through a gearbox into a higher rotation speed that drives a generator. Vertical axis wind turbines have a vertical drive axis and much less common than HAWTs.

THE FRAME MATERIAL:

From 500 AD to present; windmills primarily used to pump water and grind grain.

From 1888; windmills are first used to produce electricity.

During the 1920's Airfoil blade design borrowed from aviation increases efficiency versus fan blades.

In recent years, **China** has increased its investments in the renewable energy sector with a focus on wind power. By the end of 2017, **China** has installed a total 188,392 MW wind power capacity, making it the world's largest wind energy producing country once again.

CONSIDERATIONS

Large HAWT's have several engineering problems to overcome. In most areas wind speed increases with altitude, causing the rotor to experienced higher force when at its zenith compared to when it is pointed at the ground. This causes uneven load on the bearings and can cause premature failures. Pre-fabricated structures as long as several hundred maters including turbine blades and towers are extremely expensive to transport from manufacture site to their final location.

3.2 HISTORY OF WIND TURBINES:

Fig: 3.2 Offshore wind farm using 5mw turbines repower m5 in the north sea off Belgium

A wind turbine is a device that converts kinetic energy from the wind into mechanical energy. If the mechanical energy is used to produce electricity, the device may be called a wind generator or wind charger. If the mechanical energy is used to drive machinery such as for grinding grain or pumping water, the device is called a windmill or wind pump. Developed for over a millennium, today's wind turbines are manufactured in a range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging or auxiliary power on sailing boats while large grid-connected arrays of turbines are becoming an increasingly large source of commercial electric power.
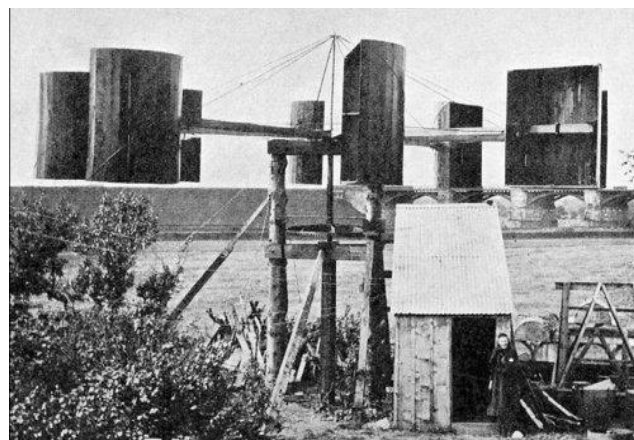

Fig: 3.3 James Blyth's electricity generating wind turbine photograph(1887).

Windmills were used in Persia (present day Iran) as early as 200 B.C. the wind wheel of Heron of Alexander marks one of the first known instances of wind powering a machine in history. However, the first known practical windmills were built in sistan, a region between Afghanistan and Iran, from the 7th century. These "panemone" were vertical axis windmills, which had long vertical drive shafts with rectangular blades. Made of six t otwelve sails covered in reed matting or cloth material, these windmills were used to grind corn or draw up water and were used in the grist milling and sugarcane industries.

Windmills first appeared in Europe during the middle ages. The first historical records for their use in England date to the 11th or 12th centuries and there are reports of German crusaders taking their windmill-making skills to Syria around 1190. By the 14th century, dutc windmills were in use to drain areas of the Rhine delta.
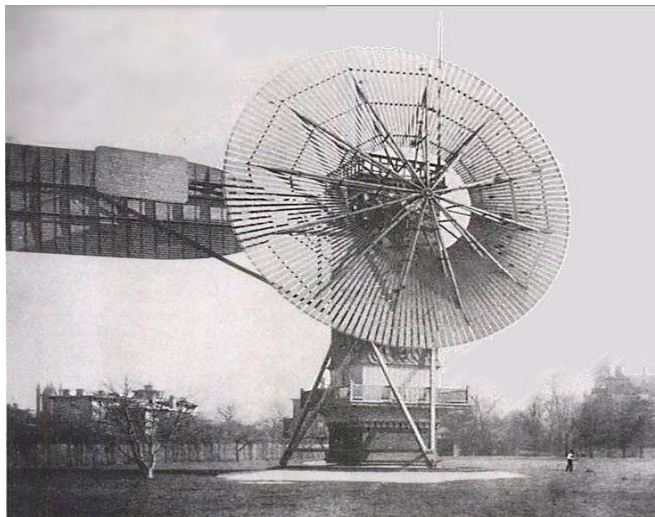

Fig 3.4: The first automatically operated wind turbine, built in cleveland in 1887

The first electricity generating wind turbine was a battery charging machine installed in July 1887 byu Scottish academic, James Biyth to light his holiday home in Marykirk, Scotland. Some month's later American inventor Charles F Brush built the first atomically operated wind turbine for electricity production in Cleveland, Ohio. Although Blyth's turbine was considered uneconomical in the United Kingdom electricity generation by wind turbines was more cost effective in countries with widely scattered populations. In Denmark by 1900, there were about 2500 windmills for mechanical loads such as pumps and mills, producing an

estimated combined peak power of about 30 MW. The largest machines were on 24-meter (79ft) towers with four-bladed 23-meter (75ft) diameter rotors. By 1908 there were 72 wind-driven electric generators operating in the US from 5 kW to 25kW. Around the time of World War 1, American windmill makers were producing 100,000 farm windmills each year, mostly for water-pumping. By the 1930's windmills for electricity were common on farms, mostly in the United States where distribution systems had not yet been installed. In this period, high – tensile steel was cheap, and windmills were placed atop prefabricated open steel lattice towers.

A forerunner of modern horizontal-axis wind generators was in service at yalta, USSR in 1931. This was a 100kW generator on a 30-meter (98ft) tower connected to the local 6.3 kV distribution system. It was reported to have an annual capacity factor of 32 percent, not much different from current wind machines. In the fall of 1941, the first megawatt-class wind turbine was synchronized to a utility grid in Vremont. The smith-Putnam wind turbine only ran for 1,100 hours before suffering a critical failure. The unit was not repaired because of shortage of materials during the water.

3.3 STANDARD WIND TURBINE DESIGN AND CONSTUCTION:

3.3.1 WIND TURBINE DESIGN:

Wind turbines are designed to exploit the wind energy that exists at a location. Aerodynamics modeling is used to determine the optimum tower height, control systems, number of blades and blade shape.

Wind turbines convert wind energy to electricity for distribution. Conventional horizontal axis turbines can be divided into three components.

A) The rotor component, which is approximately 20% of the wind turbine cost, includes the blades for converting wind energy to low speed rotational energy.
B) The generator component, which is approximately 34% of the wind turbine cost, includes the electrical generator, the control electronics, and most likely a gear box (e.g. planetary gear box, adjustable speed drive or continuously variable

transmission) component for converting the low speed incoming rotation suitable for generating electricity.

C) The structural support component, which is approximately 15% of the wind turbine cots, includes the tower and rotor yaw mechanism.

A 1.5MW wind turbine of a type frequently seen in the United States has a tower 80 meters high. The rotor assembly (blades and hub) weighs 48,000 pounds (22,000 kg).the nacelle, which contains the generator component, weighs 115,000 pounds (52,000 kg). The concrete base for the tower is constructed using 58,000 pounds (26,000 kg) of reinforcing steel and contains 250 cubic yards of concrete. The base is 50feet (15 m) in diameter and 8 feet (2.4m) thick near the center.

3.3.2 STANDARD PROTOTYPE BLADE MANUFACTURE:

The standard prototype blades models of savonius rotor fabricated from galvanized iron sheets are attached to a central shaft held between the two bearings in framework. In either case, the blades are having an aspect ratio (H/d) of 1.83, where H and d are the height and the blade chord, respectively. The main geometric parameters are the blade chord (120 mm), blade height (220 mm). The semicircular shape of the blade has been made on a rolling machine. The radius of the rotation R is measured from axis of the outer edge of the blades.

3.3.3 EXPERIMENTAL SETUP:

The experiments were carried out in an open circuit wind tunnel with the exits section of 0.013m in cross section. The air speed at the tunnel exit (wind speed) could be carried from 30m/s. A single block dynamometer was used to measure the static torque, while a digital tachometer measured the rotational speed (RPM) of the rotor. A thermal velocity probe anemometer was used to measure air velocity. The rotor consists of blades rolled from sheet metal and attached to a central vertical shaft held between two bearings in the framework. The rotor axis was kept at a distance of 200mm from the tunnel exit.

3.4 SMALL WIND TURBINE:

Small wind turbines may be as small as a fifty-watt generator for boat or caravan use. Small units often have direct drive generators, direct current output, aero elastic blades, lifetime bearing and use a vane to point into the wind.

Fig 3.5: A small wind turbine being used in Australia

More costly turbines generally have geared power trains, alternating current output, flaps and are actively pointed into the wind. Direct drive generators and aero elastic blades for large wind turbines are bearing researched.

3.5 RECORD-HOLDING TURBINES:

Largest capacity conventional drive

The Vestas V164 has a rated capacity of 8 MW,[88] later upgraded to 9.5 MW. The wind turbine has an overall height of 220 m (722 ft), a diameter of 164 m (538 ft), is for offshore use, and is the world's largest-capacity wind turbine since its introduction in 2014.

Largest capacity direct drive

The Enercon E-126 with 7.58 MW and 127 m rotor diameter is the largest direct drive turbine. However, the turbine is the world's most powerful *onshore-only* wind turbine. The turbine has parted rotor blades with 2 sections for transport. The E-126 was later overtaken by the Siemens SWT-8.0-167-DD (DD being the acronym for "direct drive"), which is the most powerful *offshore-only* wind turbine.

Largest vertical-axis

Le Nordais wind farm in Cap-Chat, Quebec, has a vertical axis wind turbine (VAWT) named Éole, which is the world's largest at 110 m. It has a nameplate capacity of 3.8 MW.

Largest 1-bladed turbine

The largest single-bladed wind turbine design to be put into complete operation is the MBB Messerschmitt Monopteros M50, with a total power output of no less than 640 kW at full capacity.

Largest 2-bladed turbine

The biggest 2-bladed turbine is built by Mingyang Wind Power in 2013. It is a SCD6.5MW offshore downwind turbine, designed by aerodyn Energiesysteme.

Largest swept area

The turbine with the largest swept area is the Samsung S7.0–171, with a diameter of 171 m, giving a total sweep of 22966 m^2.

Tallest

A Nordex 3.3 MW was installed in July 2016. It has a total height of 230m, and a hub height of 164m on 100m concrete tower bottom with steel tubes on top (hybrid tower).

Highest tower

Fuhrländer installed a 2.5 MW turbine on a 160m lattice tower in 2003.

Most rotors

Lagerwey has build Four-in-One, a multi rotor wind turbine with one tower and four rotors near Maasvlakte. In April 2016, Vestas installed a 900 kW four rotor test wind turbine at Risø, made from 4 recycled 225 kW V29 turbines.

Most productive

Four turbines at Rønland Offshore Wind Farm in Denmark share the record for the most productive wind turbines, with each having generated 63.2 GWh by June 2010.

Highest-situated

Since 2013 the world's highest-situated wind turbine was made and installed by WindAid and is located at the base of the Pastoruri Glacier in Peru at 4,877 meters (16,001 ft) above sea level. The site uses the WindAid 2.5 kW wind generator to supply power to a small rural community in Pastoruri glacier.

Largest floating wind turbine

The world's largest floating wind turbine is any of the five 6 MW turbines in the 30 MW Hywind Scotland offshore wind farm.

3.6 TYPES OF WIND TURBINE:

Wind turbines can be separated into two basic types determined by which way the turbine spins. Wind turbines that rotate around a horizontal axis are more common (like a wind mill), while vertical axis wind turbines are less frequently used (savonius and darrieus).
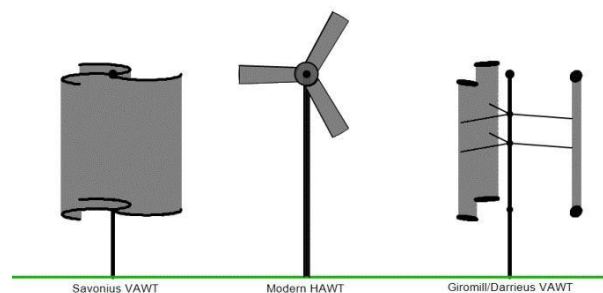
Fig 3.6: Types of turbines

3.6.1 HORIZONTAL AXIS WIND TURBINES (HAWT):

Horizontal axis wind turbines, also shortened to HAWT, are the common style that most of us think of when we think of a wind turbine. A HAWT has a similar design

to a wind mill, it has blades that look like a propeller that spin on the horizontal axis.

Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower and they must be pointed into the wind. Small turbines are pointed by a simple wind vane placed square with the rotor (blades), while large turbines generally use a wind sensor coupled with a servo motor. Most large wind turbines have a gearbox which turns the slow rotation of the rotor into a faster rotation that is more suitable to drive an electrical generator.

Since a tower produces turbulence behind it and is usually pointed upwind of the tower. Wind turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount.

Downward machines have been built despite the problem of turbulence because they don't need an additional mechanism for keeping them in line with the wind and because in high winds the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since turbulence leads to fatigue failures and reliability is so important, most HAWT are upwind machines.

Fig 3.7: Horizontal axis wind turbine

HAWT Advantages:

The tall tower base allows access to stronger wind in sites with wind shear. In some wind shear sites, every 10 meters up the wind speed can increases by 20% and the power output by 34%.

High efficiency, since the blades always move perpendicularly to the wind receiving power through the hole rotation in contrast, all vertical axis wind turbines and most proposed air borne wind turbine designs involve various types of reciprocating actions, requiring air foil surfaces to back track against the wind for part of the cycle. Back tracking against the wind leads to inherently low efficiency

HAWT Disadvantages:

1) Massive tower construction is required to support the heavy blades , gear box, and generator.

2) Components of horizontal axis wind turbine (gear box, rotor shaft and brake assembly) being lifted into the position.

3) Their height makes them obtrusively visible across large areas disrupting the appearance of the landscape and sometimes creating local opposition.

4) Downwind variants suffer from fatigue and structural failure caused by turbulence when a blade passes through the towers wind shadow (for this reason, the majority of HAWTs use an up wind design with the rotor facing the wind in front of the tower).

5) HAWTs require an additional yaw control mechanism to turn the blades towards the wind. HAWTs generally require a breaking or yawing device in high winds to stop the turbine from spinning and destroying or damaging itself.

3.6.2 VERTICAL AXIS WIND TURBINES (VAWT):

Vertical axis wind turbines (or VAWTs) have the main rotor shaft arranges vertically. key advantages of the arrangement are that the turbines doesn't need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable for example when integrated into buildings. The key disadvantages include the low rotational speed with the consequential higher torque and hence higher cost of the drive train, the inherently lower power coefficient i.e, the 360 degree rotation of the aerofoil with in the wind

flow during each cycle and hence the highly dynamic loading on the blade, the pulsating torque generated by some rotor designs on the drive train and the difficulty of modeling the wind flow accurately and hence the challenges of analyzing and designing the rotor prior to fabricating a prototype .

Fig 3.8: Vertical axis wind turbine

With the vertical axis, generator and the gear box can be placed near the ground and hence avoiding the need of a tower and improving accessibility for maintenance. Drawbacks of this configuration include

1) Wind speed are lower close to the ground, so less wind energy is available for a given size turbine.

2) Wind shear is more severe close to the ground so the rotor experiences high loads. Air flow near the ground and other objects can create turbulent flow, such as noise and bearing wear which may increase the maintenance or shorten the service life. However, when a turbine is mounted on a roof top, the building generally re directs wind over the roof and this can double the wind speed at the turbine. If the height of the roof top mounted turbine tower is approximately 50% of the building height, this is neat the optimum for maximum wind energy and minimum wind turbulence. It should be borne in mind that wind speeds within the built environment are generally much lower than at exposed rural sites.

There are four designs for vertical axis wind turbines. The savonius turbine was created by a Finnish engineer in 1922 and utilizes a drag scoop mechanism. This turbine vaguely resembles two spoons which catch the wind. The darrieus was

created by a French engineer and is the prototype of most modern machines today resembling the egg beater mentioned previously. The giromill takes the roundness of the egg beater and changes the shape to a box instead. The last form of vertical axis wind turbine is the cycloturbine which consists of a single blade turbine which rotates vertically around the axis. This type of turbine vaguely resembles a ceiling fan with only one blade.

Among the VAWT we have two main types:

Darrieus (which uses lift forces generated by aerofoils)

Savoniuos (which uses drag forces generated by aerofoils)

3.6.2.1 Darrieus:

The Darrieus constitutes a vertical rotor (see picture below) and several blades which are vertically oriented. It is not self-starting, so a small power motor is required to start the rotation. When it has enough speed, the wind passing across the aerofoil's starts to generate torque and rotor is driven around by the wind. The turbine is powered by the lift forces that are created by a set of aerofoil.

The blades allow the turbine to reach speeds that are higher than the actual speed of the wind (i.e. the tip speed ratio is greater than 1). This makes them suited to electricity generation rather than water pumping or similar activities.

Fig 3.9: *Darrieus wind turbine*

On the Darrieus rotor, the design of airfoils can be the same as for the horizontal axis turbines; however, the difference occurs because a horizontal axis turbines

swept area always faces the wind while the swept area for the Darrieus is a cylinder perpendicular to the air flow. As such, part of the "swept area" is working, while part is similarly being blown around.

By varying the blades angle as it rotates against the wind, the blade drag is minimized. This modification improves the overall efficiency of the device but also increases its complexity. The centrifugal forces generated by the Darrieus turbine are very large and act on the turbine blades which therefore have to be very strong.

Advantages with variable pitch:

- High starting torque
- A lower blade speed ratio.
- A higher coefficient of performance
- More efficient operation in turbulent wind
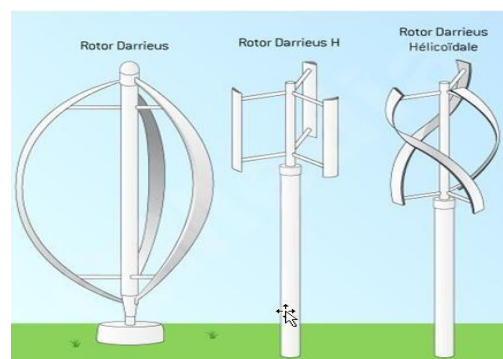
Fig 3.10: *The three main kind of Darrieus VAWT(including giromill)*

Advantages of Darrieus:

- The equipment (gear box and generator) can be placed close to the ground
- We don't need a mechanism to turn the rotor against the wind.

Drawbacks:

- The efficiency is not very remarkable.
- The Darrieus isn't a self-starting turbine, the starting torque is very low but it can be reduced by using three or more blades which results in a higher solidity for the rotor.

- Because wind speeds are closer to ground level, there is very low wind speed on the lower part of the rotor.

3.6.2.2 Giromill

A speed type of the Darrieus turbine is the so-called "Giromill". It uses the same principal as a Darrieus wind turbine to captures wind energy, but uses 2 or 3 straight blades individually attached to a vertical axis instead of curved blades.

Fig 3.11: Helical blade vawt (giromill)

It is also possible to use helical blades wrapped around a vertical axis, in order to minimize the pulsating torque.

3.6.2.3 Savonius:

The savonius turbine is one of the simplest turbines. Aerodynamically, it is a drag-type device, consisting of two or three scoops. Because of the curvature, the scoops experience less drag when moving against the wind than when moving with the wind. The differential drag causes the savonius turbine to spin. Because they are drag-type devices, savonius turbines extract much less of the wind's power than other similarly-sized lift turbines.
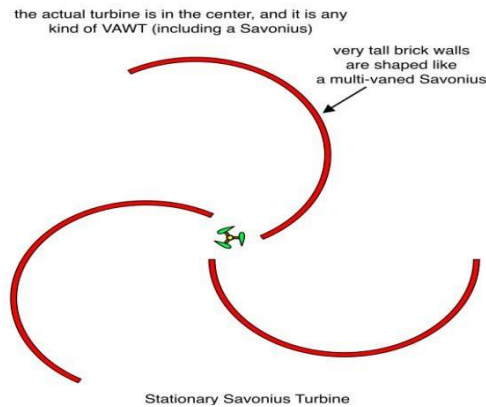
3.12: Savonious wind turbine with 3 scoops

It typically only has an efficiency of around 5 to 15%, that is, just 15% of the wind energy hitting the rotor is turned into rotational mechanical energy. This is much less than can be achieved with a Darrieus wind turbine which uses *lift* rather than drag.
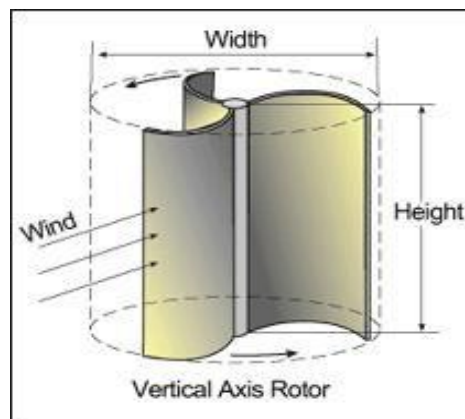
Fig 3.13: How the wind rotaoes the scoops

Savonius wind turbines can and are used in electricity generation with the benefit that they continueto generate electricity in the strongest winds without being damaged. They are very quiet compared to other wind turbines and are useful for small scale domestic electricity generation, especially in locations with strong turbulent winds. Usually, the Savonius turbines are used whenever cost or reliability is more important than efficiency.

Savonius wind turbines are also ideally suited to applications such as pumping water and grinding grain for which, slow rotation and high torque are essential.

Because of the torque yield of a Savonius wind turbine, the bearings used must be very robust.

Advantages of savonius:

- They are always self-starting if they are at least three scoops
- They are relatively easy to make

Drawback:

Low efficiency around 5-15%

Fig 3.14: Savonious Wind turbine , Japan.

VAWT advantages:

- No yaw mechanism is needed
- A VAWT can be located nearer the ground, making it easier to maintain the moving parts.
- VAWTs have lower wind startup speeds than the typical the HAWTs
- VAWTs may be built at locations where taller structures are prohibited
- VAWTs situated close to d ground can take advantage of locations where rooftops, mesas, hilltops, ridgelines, and passes funnel the wind and increase wind velocity.

VAWT disadvantages:

- Most VAWTs have an average decreased efficiency from a common HAWT, mainly because of the additional drag that they

have as their blades rotate into the wind. Versions that reduce drag produce more energy especially those that funnel wind into the collector area.

- Having rotors located close to the ground where wind speeds are lower due and do not take advantage of higher wind speeds above.

- Because VAWTs are not commonly deployed due mainly to the serious disadvantages mentioned above they appear novel to those not familiar with the wind industry. This has often made them the subject of wild claims and investment scams over the last 50 years.

3.7 Betz Limit:

Albert Betz was a German physicist who in 1919 concluded that no wind turbine can convert more than $16/27$ (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. To this day this is known as the Betz Limit or Betz' Law. This limit has nothing to do with inefficiencies in the generator, but in the very nature of wind turbines themselves.
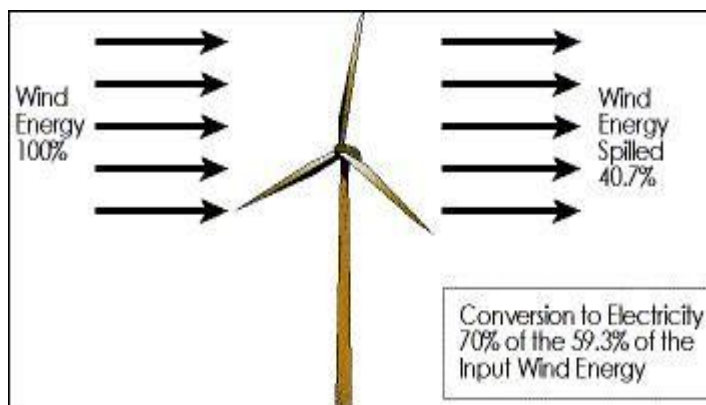
Fig 3.15: Betz's Law

Wind turbines extract energy by slowing down the wind. for a wind turbine to be 100% efficient it would need to stop 100% of the wind-but then the rotor would have to be a solid disk and it would not turn and no kinetic energy would be converted. On the other extreme, if you had a wind turbine with just one rotor

blade most of the wind passing through the area swept by the turbine blade would miss the blade completely and so the kinetic energy would be kept by the wind.

3.8 RESOURCES:

A quantitative measure of the wind energy available at any location is called the Wind Power Density (WPD) it is a calculation of the mean annual power available per square meter of swept area of a turbine, and is tabulated for different heights above ground. Calculation of wind power density includes the effect of wind velocity and air density. Color-coded maps are prepared for a particular area described, for example, as "Mean Annual Power Density at 50 meters". In the United States, the results of the above calculations are included in an index developed by the U.S. national Renewable Energy Lab and referred to as "NREL CLASS". Te larger the WPS calculation, the higher it is rated by class. Classes range from class 1 (200 watts/square meter or less at 50 meters altitude) to class 7 (800 to 2000 watts/square meter). Commercial wind farms generally are sited in class 3 or higher areas, although isolated points in an otherwise Class 1 area may be practical to exploit.

3.9 Importance of Turbine Blade:

Wind is a very unpredictable and an unreliable source of energy as it is constantly changing in both strength and direction. To produce useful amounts of power, wind turbines generally need to be large and tall, but to work efficiently they also need to be well designed and engineered which makes them expensive too.

Most wind turbines designed for the production of electricity have consisted of a two or three bladed propeller rotating around a horizontal axis. It's obvious to say that these propeller like wind turbine blade designs convert the energy of the wind into usable shaft power called torque. This is achieved by extracting the energy from the wind by slowing it down or decelerating the wind as it passes over the blades. The forces which decelerate the wind are equal and opposite to the thrust type lifting forces which rotates the blades.

Just like an aeroplane wing, wind turbine blades work by generating lift due to their curved shape. The side with the most curve generates low air pressure while high pressure air beneath pushes on the other side of the blade shaped aerofoil. The net result is a lifting force perpendicular to the direction of flow of the air over the turbines blade. The trick here is to

design the rotor blade in such a way as to create the right amount of rotor blade lift and thrust producing optimum deceleration of the air and therefore better blade efficiency.

If the turbines propeller blades rotate too slowly, it allows too much wind to pass through undisturbed, and thus does not extract as much energy as it potentially could. On the other hand, if the propeller blade rotates too quickly, it appears to the wind as a large flat rotating disc, which creates a large amount of drag.

Then the optimal tip speed ratio, TSR, which is defined as the ratio of the speed of the rotor tip to the wind speed, depends on the rotor blade shape profile, the number of turbine blades, and the wind turbine propeller blade design itself. So which is the best blade shape and design for wind turbine blades.

Generally, wind turbine blades are shaped to generate the maximum power from the wind at the minimum construction cost. But wind turbine blade manufacturers are always looking to develop a more efficient blade design. Constant improvements in the design of wind blades has produced new wind turbine designs which are more compact, quieter and are capable of generating more power from less wind. Its believed that by slightly curving the turbine blade, they're able to capture 5 to 10 percent more wind energy and operate more efficiently in areas that have typically lower wind speeds.

So which type of blade shape would produce the greatest amount of energy for a wind turbine? Flat blades are the oldest blade design and have been used for thousands of years on windmills, but this flat broad shape is becoming less common than other types of blade design. The flat blades push against the wind, and the wind pushes against the blades. The resulting rotation is very slow because the blades that are rotating back on the up stroke after generating power are in opposition to the power output. This is because the blades are acting like huge paddles moving in the wrong direction, pushing against the wind giving them the name of drag-based rotor blades.

However, flat blade designs offer significant benefits for the DIY'er compared to other wind blade designs. Flat rotor blades are easy and cheap to cut from a sheets of plywood or metal ensuring that the blades have a consistent shape and size. They are also the easiest to understand requiring less design and construction skills, but there efficiency and the ease of generating electrical power is very low.

Curved blades are very similar to a long aeroplane wing (also known as an aerofoil) which has a curved surface on top. The curved blade has air flowing around it with the air moving

over the curved top of the blade faster than it does under the flat side of the blade, which makes a lower pressure area on top, and therefore, as a result, is subjected to aerodynamic lifting forces which create movement.

These lifting forces are always perpendicular to the curved blade's upper surface which causes the blade to move rotating around the central hub. The faster the wind blows, the more lift that is produced on the blade, hence the faster the rotation. The advantages of a curved rotor blade compared to a flat blade is that lift forces allow the blade tips of a wind turbine to move faster than the wind is moving generating more power and higher efficiencies. As a result, lift based wind turbine blades are becoming more common now. Also, home made pvc wind turbine blades can be cut from standard sized drainage pipes having the curved shape already built-in giving them the best blade shape.

Chapter 4

PROJECT DESCRIPTION AND PROCEDURE

4.1 SAVONIUS WIND TURBINE:

Savonius wind turbine was invented by the Finnish engineer Sigurd Savonius in 1922.

Its most basic design is S-shaped with two blades. The Savonius turbine uses drag to push the curved blades to generate a torque that will make the rotor turn. Aerodynamically it is the simplest wind turbine to design and build which reduces its cost drastically compared to the aerofoil blade designs of the other VAWTs and HAWTs.

4.2 WORKING PRINCIPLE:

The savonius wind turbine works due to the difference in forces exert on each blade. The lower blade (the concave half to the wind direction) caught the air wind and forces the blade to rotate around its central vertical shaft. Whereas, the upper blade (the convex half to wind direction) hits the blade and causes the wind to be deflected sideway around it.
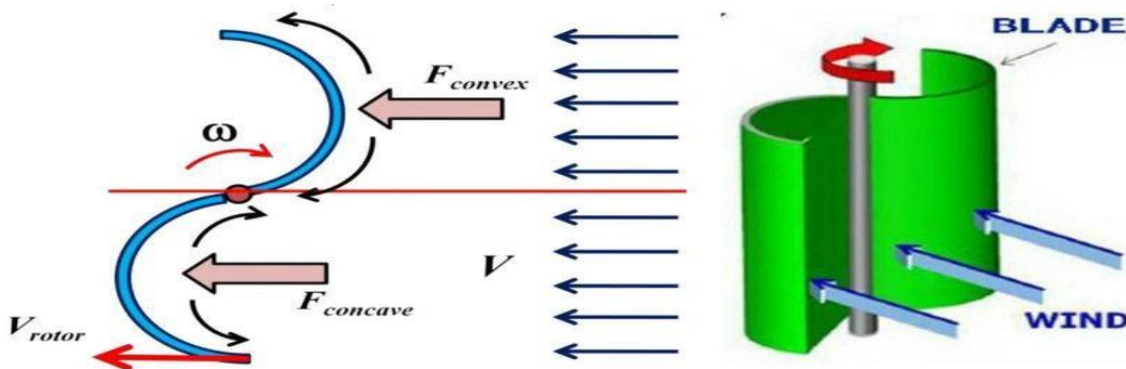
Fig 4.1: Schematic drawing showing the drag forces exert on two blade Savonius.

Because of the blades curvature, the blades experience less drag force (*Fconvex*) when moving against the wind than the blades when moving with the wind (*Fconcave*). Hence, the half cylinder with concave side facing the wind will experience more drag force than the other cylinder, thus forcing the rotor to rotate. The differential drag causes the Savonius turbine to spin. For this reason, Savonius turbines extract much less of the wind's power than other similarly sized lift type turbines because much of the power that might be captured has used up pushing the convex half, so savonius wind turbine has a lower efficiency.

Similarly, the three blade savonius wind turbine is constructed from three half cylinders, they are arranged at 120 deg relative to each other as shown in figure 4.1.1
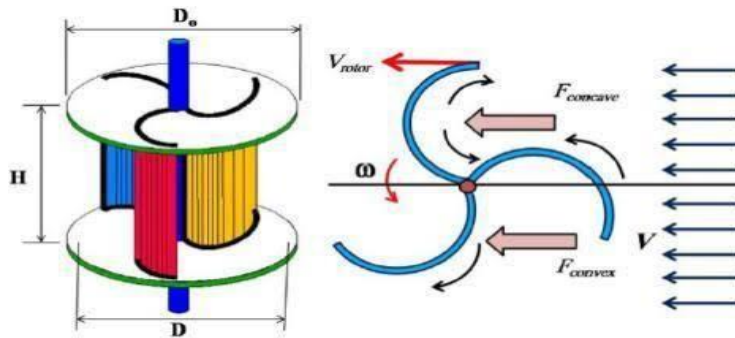
Fig 4.1.1 Schematic drawing showing the drag forces exert on three blade Savonius.

A Savonius rotor requires 30 times more surface for the same power as a conventional rotor blade wind-turbine. Therefore it is only useful and economical for small power requirements." This makes Savonius ideal for small applications with low wind speeds. Savonius are hence desirable for their reliability, as they are able to work at several magnitudes of wind speed.

4.3 Two blade Savonius Turbine Vs. Three Blade Savonius Turbine:

Experimental studies confirm that Savonius wind turbines do perform well at low wind speeds (cut in speed at around 2.5 m/s). According experimental studies, two blade savonius wind turbine perform better than three blade savonius wind turbine as more drag is wasted in the three blades versions. The power coefficient of the two blade design is higher than that of the three blade design. They also found that 4 blades perform even better than 2 blades at low tip speed ratio (TSR), and that 3 blades perform better at higher TSR.

4.4 Project Description:

This work is an effort to develop a Savonius Wind Turbine with the help of CATIA to design the Savonius Rotor Blades with twist angles ranging from 10 to 90 deg. The designed Turbine blades are then analysed for multiple vector integrals and pressure contours using CFD Analysis in ANSYS Fluent Workbench software to find out optimum angle for maximum efficiency and maximum power production.

4.5 Project Specifications:

The rotor shaft dimension for the Savonius Wind Turbine are same for the designs consisting of twist angles ranging from 0 to 90 deg.

The dimensions are as follows:

- Diameter : 25mm
- Length : 500mm

The Turbine Blade dimensions for the Savonius Wind Turbine are same for the designs consisting of twist angles ranging from 0 to 90 deg.

The dimensions are as follows:

- Diameter : 220mm
- Length: 400mm

The designs of Savonius Wind Turbine with twist angles are as follows:

0 deg:
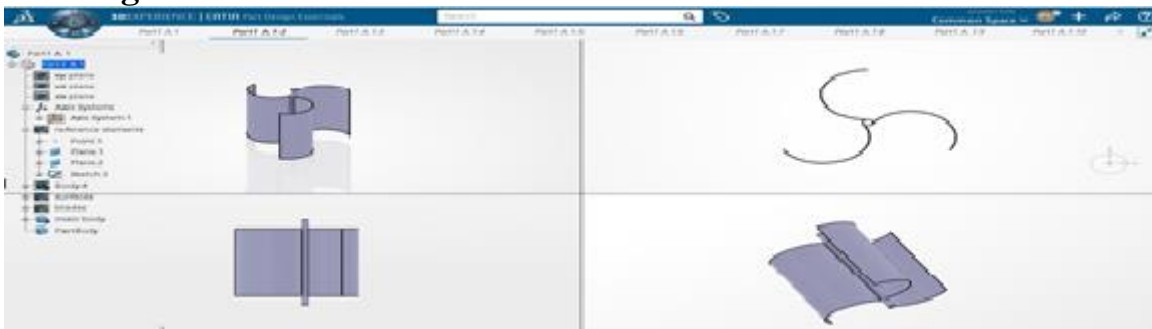
Fig 4.2.0 Savonius Wind Turbine with 0 deg twist in blades

10 deg:
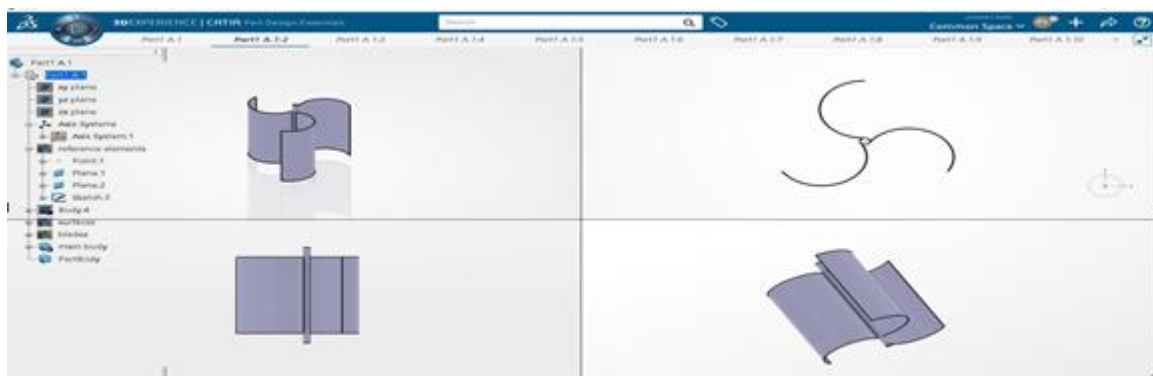
Fig 4.2.1 Savonius Wind Turbine with 10 deg twist in blades

20 deg:
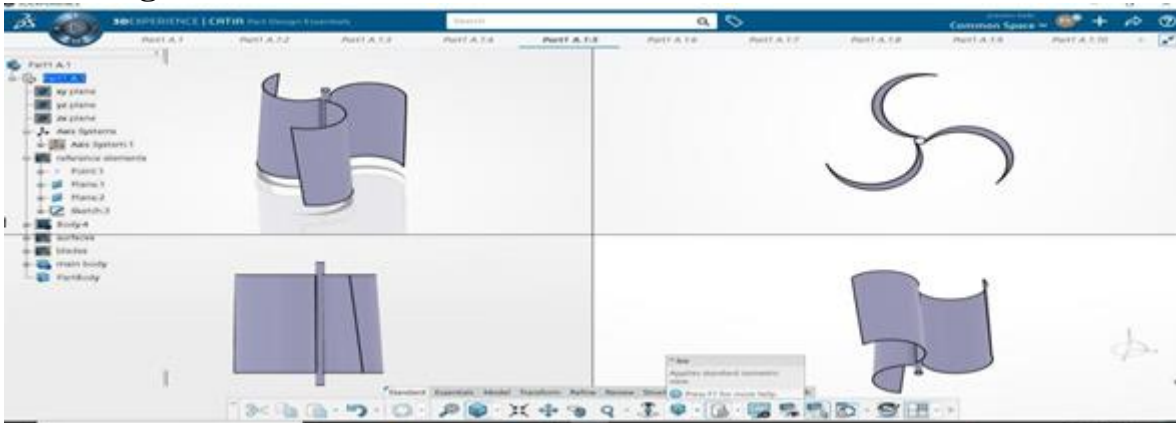
Fig 4.2.2 Savonius Wind Turbine with 20 deg twist in blades

30 deg:

Fig 4.2.3 Savonius Wind Turbine with 30 deg twist in blades

40 deg:
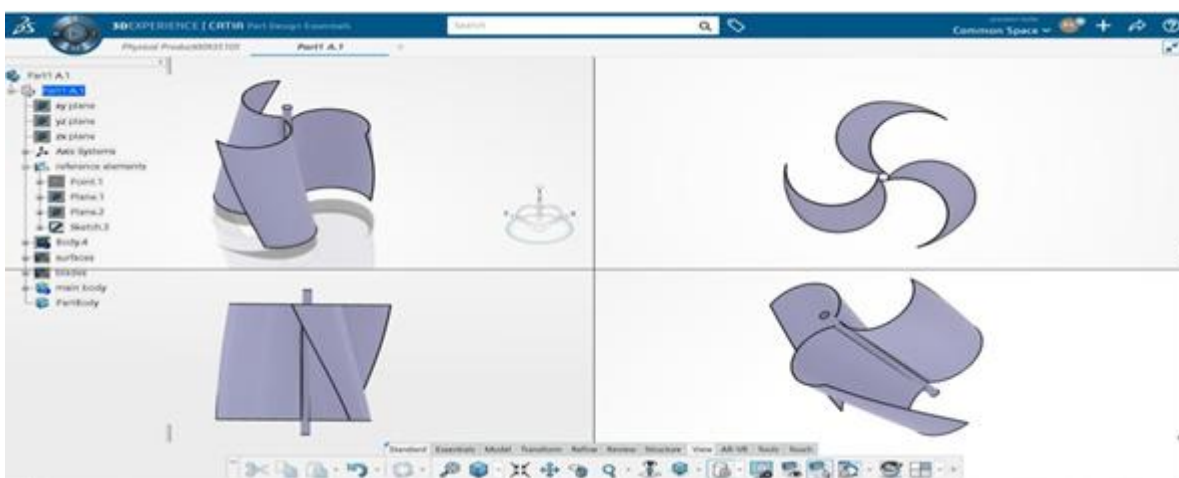
Fig 4.2.4 Savonius Wind Turbine with 40 deg twist in blades

50 deg:

Fig 4.2.5 Savonius Wind Turbine with 50 deg twist in blades

4.6 PROCEDURE:

The design of the Savonius Wind Turbine with twist angles 0 deg to 50 deg is done in CATIA Software. The designed Turbine is then analysed in the ANSYS Workbench 2019 R3 Software to find out the vector integrals and pressure contours to calculate the maximum power output and efficiency of the designed Savonius Wind Turbine.

The detailed procedure of Savonius Wind Turbine design in CATIA and analysis done in ANSYS Workbench 2019 R3 Softwares is mentioned below.

4.6.1 Design Procedure of Savonius Wind Turbine in CATIA:

ROTOR SHAFT: Firstly, open Part Design in CATIA Software. Then create a point, geometrical set and rename the geometrical set to Reference element. Now create a body and name it as Main Body. Create another body and select Sketch Icon to sketch the design of the rotor shaft. To create a Rotor Shaft firstly select a plane on which the sketch has to made and sketch a circle with required radius and extrude it by giving height. Then come out of sketch.

TURBINE BLADE: To create the Savonius Wind Turbine Blades create or sketch a Wind Turbine Blade, in the Sketch Mode of CATIA Software. Now sketch the cross-section and come out of the sketch mode. For the second Turbine Blade use mirror option which is known as Multi-Section Tool in CATIA. Using the Multi-

Section Tool, mirror the first Balde to create the second Wind Turbine Blade. Using Rotate option create another Blade such that the Blade is separated by 120 deg. Now using Boolean Operations in CATIA add all three Turbine Blades to the Main Body which is the Rotor Shaft. Thus the Assembly of the Savonius Wind Turbine's Rotor Shaft and the Savonius Wind Turbine's Blades is completed.
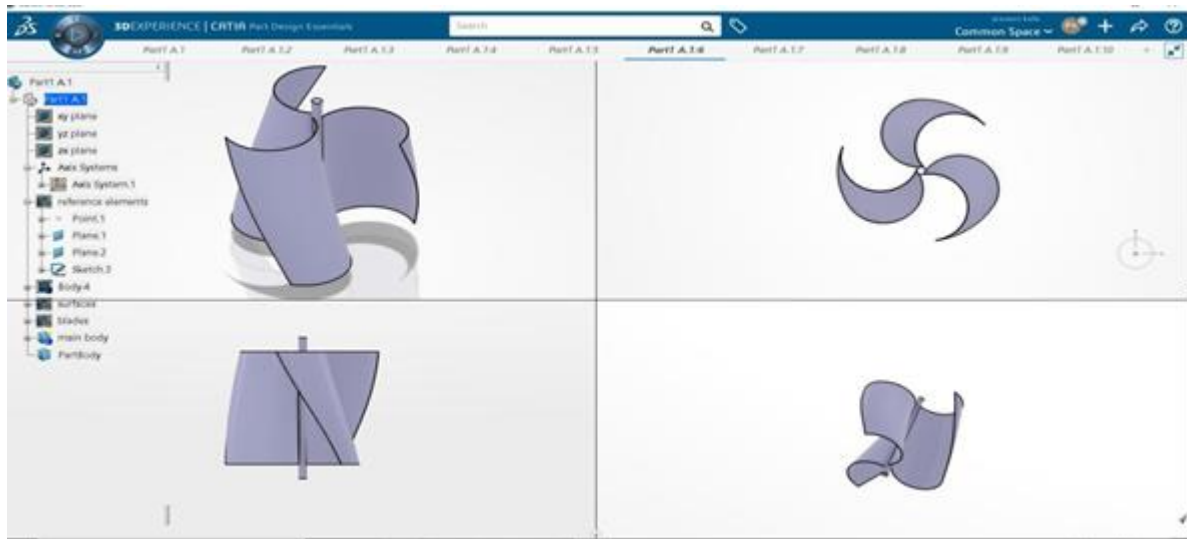
Fig 4.3.0 Savonius Wind Turbine with 50 deg twist in blades

TURBINE BLADE WITH TWIST ANGLE: To create a twist angle in the Turbine Blade go into the Main Body sketch, select the free end of the Turbine Blade to which the twist angle has to be given as the first object and select the Turbine Blade in the direction of the twist. Thus the twist angle for the Turbine Blade is done. Follow the same procedure to create the twist angles ranging from 10 to 50 deg. Save the files in .igs format.

4.6.2 Analysis Procedure of Savonius Wind Turbine in ANSYS Workbench 2019 R3:

GEOMETRY: Firstly open ANSYS Workbench Software. Click on Geometry and select import to import the desired Wind Turbine Blade on which the analysis has to be done. Then click on Edit Geometry in Design Modeler and select generate. The design will be displayed. Now using Tools option create two Enclosures namely Rotating Domain and a Fluid Flow Domain.(The Rotating Domain is used to rotate the Wind Turbine based on the input parameters given by the user. The Fluid Flow Domain is used to simulate the air flow with inlet and outlet parameters given by the user.)

Using Boolean Operation option subtract the Wind Turbine from the Rotating Domain and delete the Turbine. Because the Turbine won't rotate in the analysis, only the Rotating Domain rotates. Also subtract the Rotating Domain from the Fluid Flow Domain but don't delete the Rotating Domain. Then press update and save the file.
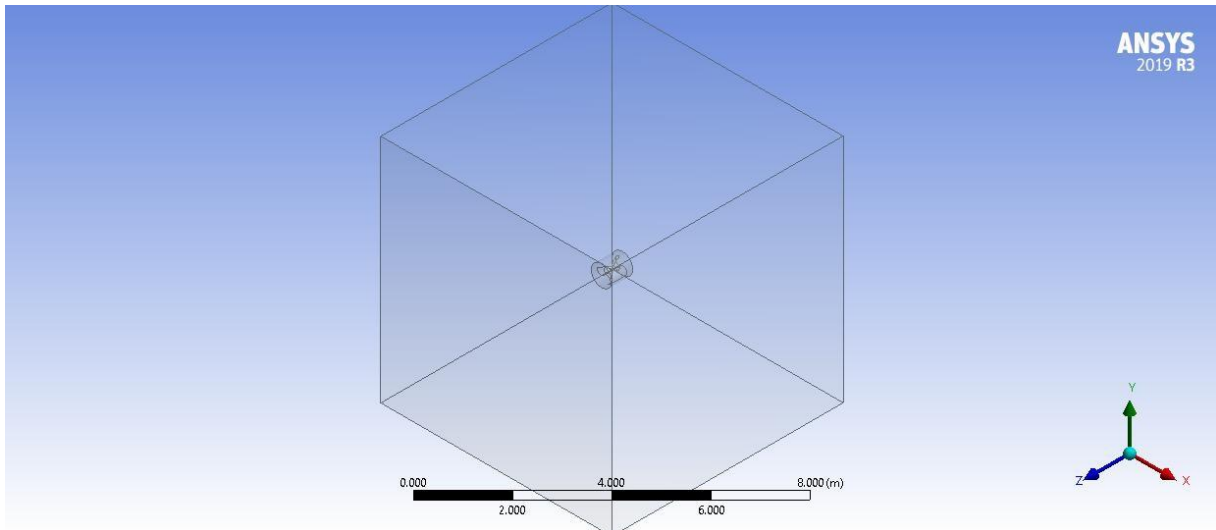
Fig 4.4.0 The Savonius Wind Turbine created in Geometry with Enclosures.

MESH: After Geometry comes the Meshing of the Turbine with Enclosures. For this click on Mesh option and generate primary mesh. Now add a method to mesh the Turbine. There are different methods to mesh the Turbine like Tetrahydrons, Hexadecimal, Sweep, Cartesian etc… But the approach we used is Tetrahydral mesh because it is more simpler method than the rest and can also mesh any complex shaped design without any errors. It is also proven to be more efficient than other mesh methods. Now after conforming the method, click on Mesh and select on Sizing option and create Body Sizing and enter the element size. As the value of the Body Sizing element decreases the Skewness value of the design decreases. The Body Sizing of the deign has to be done in order to create a good mesh and meshes the whole body at once. Click on generate option to generate mesh. After Body Sizing, create Face Meshing in order to mesh the faces seperately and enter the element size. The lesser the Face Meshing Element Size the lesser the Skewness value. Now click on generate mesh option to generate mesh. After Face Meshing, Click on Geometry inside the Meshing Interface and hide all the faces of Fluid Flow Domain and Rotating Domain. Now select the method called Box Select and select the entire Turbine. Now click on Edge option and select Sizing in Mesh to create Edge Sizing. Edge Sizing is used to smoothen

the edges of the Turbine to help the user get a good mesh. Give the element size for the Edge Sizing and click on generate mesh. After meshing is done click on Mesh Quality to check the Skewness value of the mesh. The skewness has to be less than 0.98 to consider the mesh as a good mesh. If the value is higher than 0.98 change either the Method of the Meshing or the Element Size in Body Sizing, Face Meshing and Edge Sizing. Select the inlet, outlet of the design and name them. Now after meshing click on update and save the file.
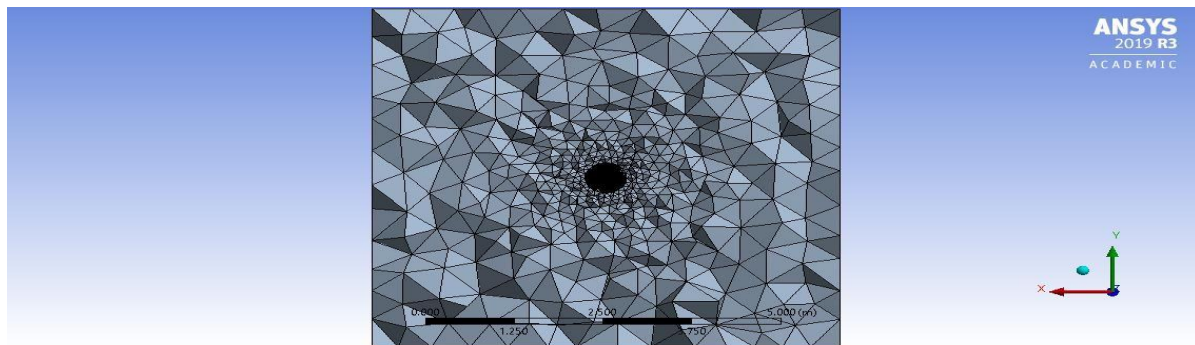
Fig 4.4.1 The Mesh of the Savonius Wind Turbine
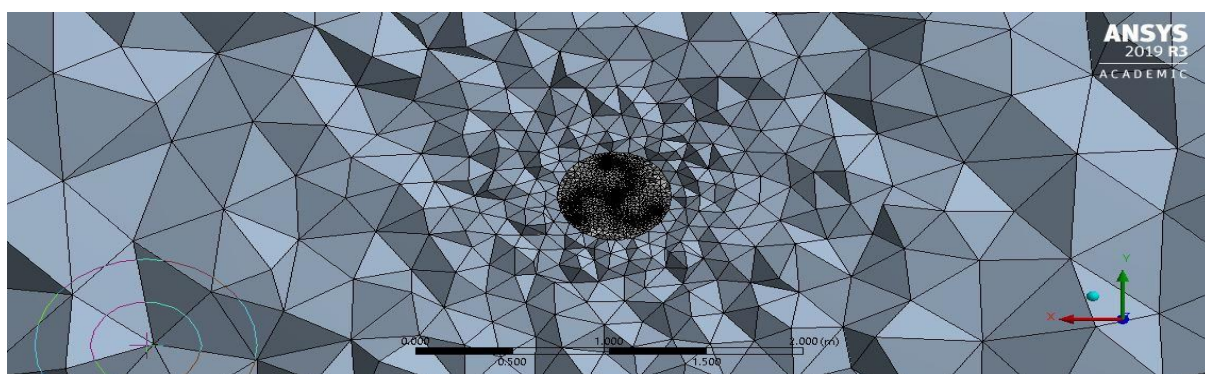
Fig 4.4.2 Sectional View of the Savonius Wind Turbine Mesh

SETUP: After meshing, analysis has to be done using Fluent solver. Double Precision and Parallel Processing Option have been selected for a faster and more accurate solution.

GENERAL PROPERTIES: The Transient Model has been selected because there is a dependence on time. No other options have been modified.
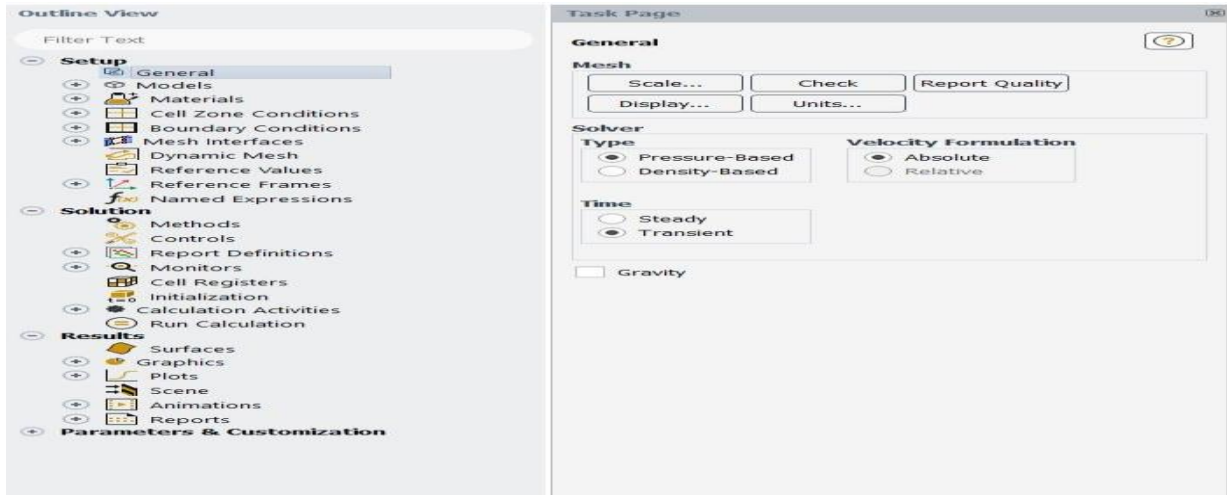
Fig 4.5.0 General Set-Up of Savonius Wind Turbine with Enclosure

MODAL SETUP: k-ω model SST turbulent model has been chosen as it is a common two-equation turbulence model, that is used as a closure for the Reynolds averaged Navier–Stokes equations (RANS equations). The model attempts to predict turbulence by two partial differential equations for two variables, k and ω, with the first variable being the turbulence kinetic energy (k) while the second (ω) is the specific rate of dissipation (of the turbulence kinetic energy k into internal thermal energy)
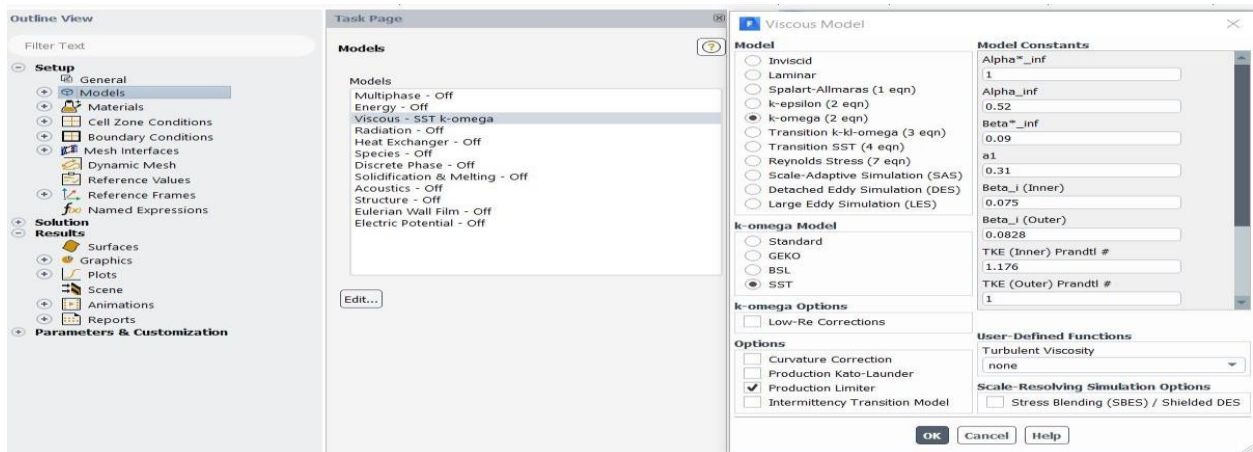
Fig 4.5.1 Model Selection of the Turbine with Enclosure

CELL ZONE CONDITIONS: This section involves imparting rotational speed and the direction of rotation to the rotating domain. A speed of 200 RPM has been given while it rotates about z-axis.
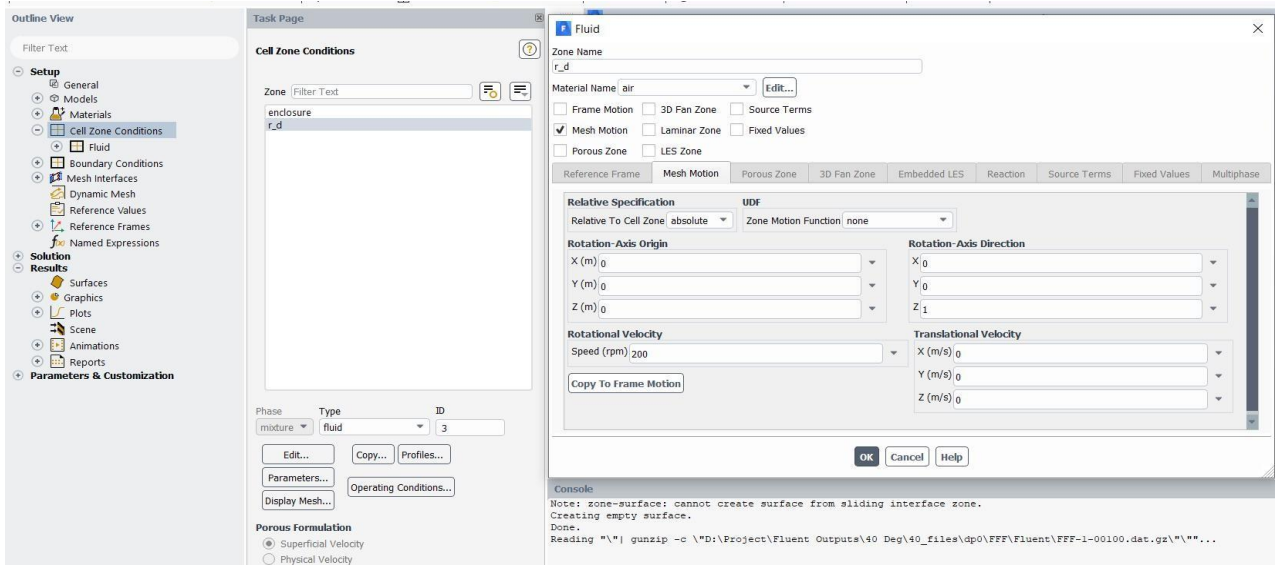
Fig 4.5.2 Cell Zone Conditions of the Turbine with Enclosure

BOUNDARY CONDITIONS: Velocity and pressure have been given as boundary conditions at the inlet and the outlet respectively. The value of velocity is 13m/s while that of pressure is set to atmospheric pressure (1 atm).
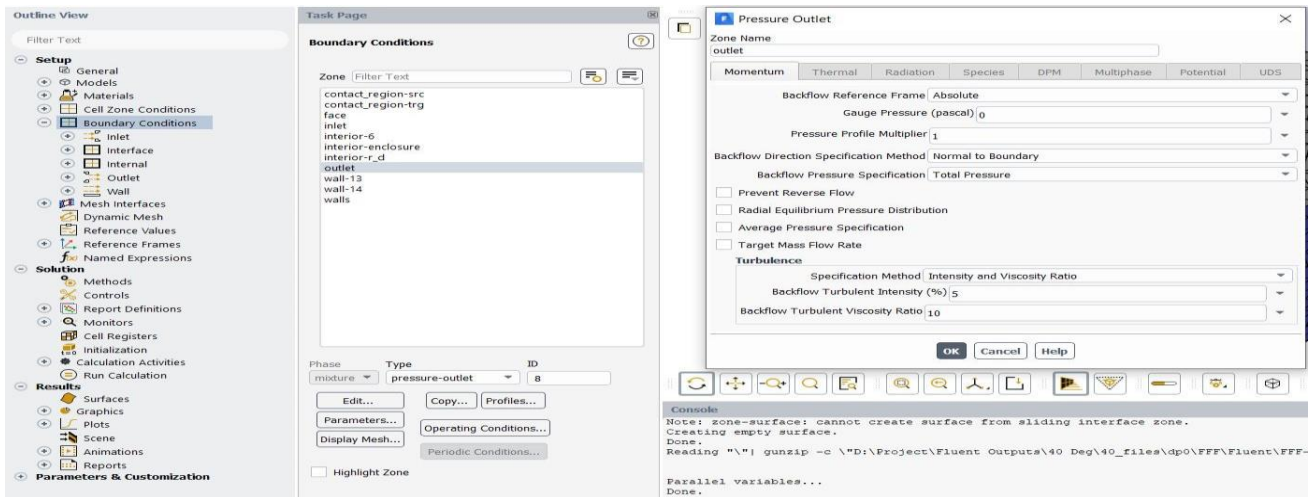
Fig4.5.3 Boundary Condition Inlet of the Turbine with Enclosure
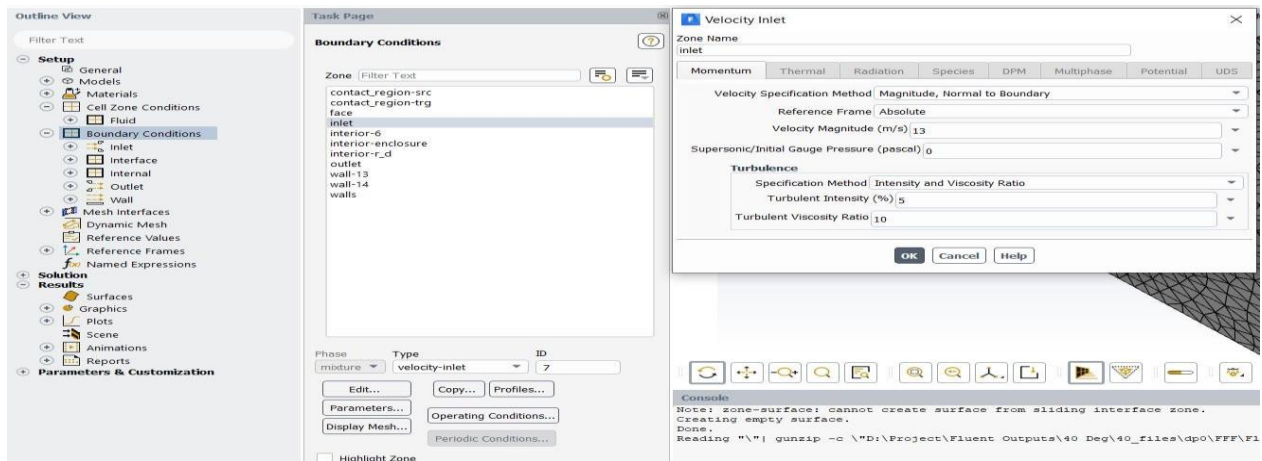
Fig 4.5.4 Boundary Condition Outlet of the Turbine with Enclosure

SOLUTION: After Set-Up, go to Solution click on Method. In Method select the Pressure-Velocity Coupling Scheme as Simple. In Spatial Discretization, select Gradient as Least Square Cell Based, Pressure as Second Order, Momentum as Second Order Upwind, Turbulent Kinetic Energy and Turbulent Dissipation Rate as First Order Upwind. For Transient Formulation select First Order Implicit and click on close.

Now click on Solution Initialization and select the Solution Initialization as Hybrid Initialization and click close.

Click on Calculation Activities and click on create and select Solution Data Export. In Solution Data Report select File Type as CDAT for CFD-Post & Ensight. Then select all the displayed surfaces in Surface Tab and select all the 94 Quantities in Quantities Tab. Then select the Export Data as Every 1 Time Step and click O.K. Now click on Run Calculation. In Run Calculation, under Time Advancement Block, select Type as Fixed, Method as User Specified. In Parameters, give the required Number of Time Steps, Time Step Size, Maximum Iterations Per Time Step and click on Calculate. Thus the Solution Simulation in ANSYS Fluent is done.
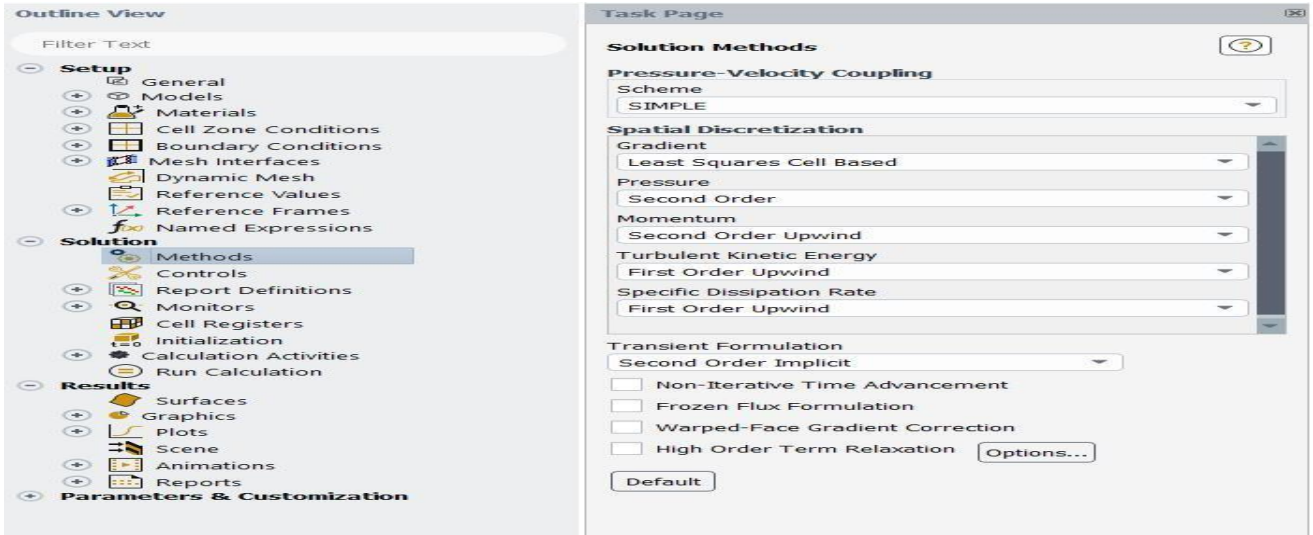
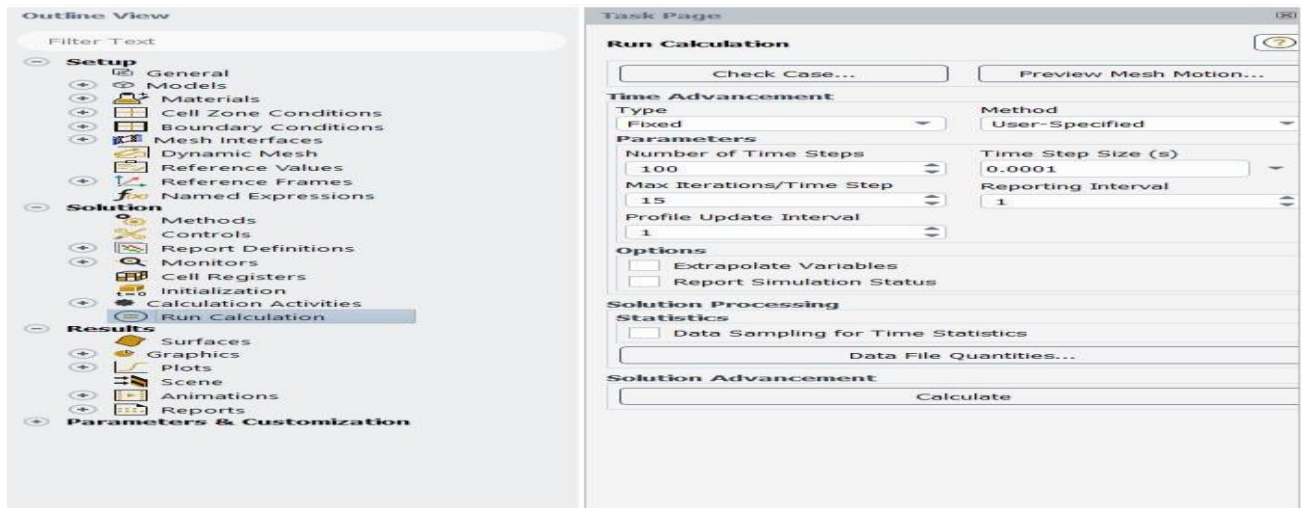Fig 4.6.0 Solution Method of Savonius Wind Turbine

Fig 4.6.1 Calculations of Savonius Wind Turbine

4.7 Validation:

To validate our project we have taken a journal named "Performance Prediction and Validation of a Small-Capacity Twisted Savonius Wind Turbine" by Deockjin Jeong. This journal mainly focuses on the study of an off-grid–type small wind turbine for street lighting along with it's design and analysis. It's performance was predicted using a computational fluid dynamics model. Ansys Fluent, a commercial computational fluid dynamics solver, was used to predict the performance, and the k-omega SST model was used as the turbulence model.

4.8 Computational Fluid Dynamics Model:

To simulate the performance of the designed wind-turbine rotor, Ansys Fluent, a commercial computational fluid dynamics solver, was used, with a shear stress transport (SST) turbulent model. All the walls except the inlet, outlet, and rotor surface were set as non-slip walls. For the initial and boundary conditions, the wind speed was given at the inlet area, and the pressure-release condition at the outlet was used. To conduct and calculate the rotor mechanical power produced by the blade rotation, a simulation was conducted with initial conditions, including the inlet speed, outlet pressure, and rotor rotational speed mesh was generated for a turbine analysis in the shape of triangular pyramid called tetrahedron. To prevent the analysis time delay and the convergence error caused by the mesh densification around complex and sharp elements, e.g., nuts and bolts, the frames are simplified or suppressed within a range that does not affect the aerodynamic performance and analysis. To perform the flow analysis the initial conditions for velocity inlet and pressure outlet were defined as the wind speed and zero Pascals in gauge pressure, respectively. For the velocity inlet, the input wind speed was selected as 13 m/s and the rotational speed of the rotor was selected 200 rpm. The final output is the force and pressure acting on the rotor surface generated by the airflow and the torque calculated in the rotational axis to calculate the mechanical power. The analysis was performed at 0.01-s intervals, with 10 seconds for case.
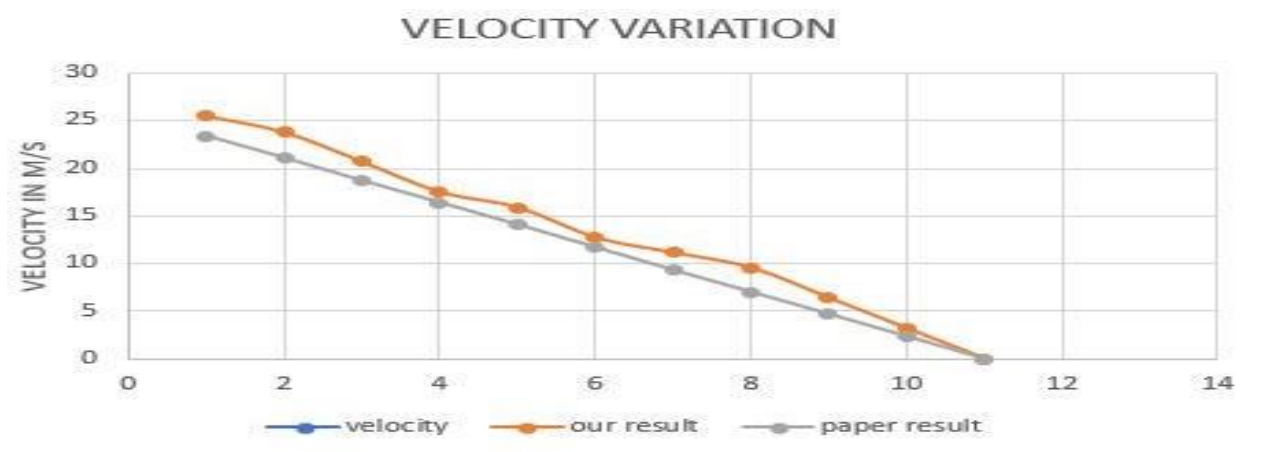
4.9 Result:

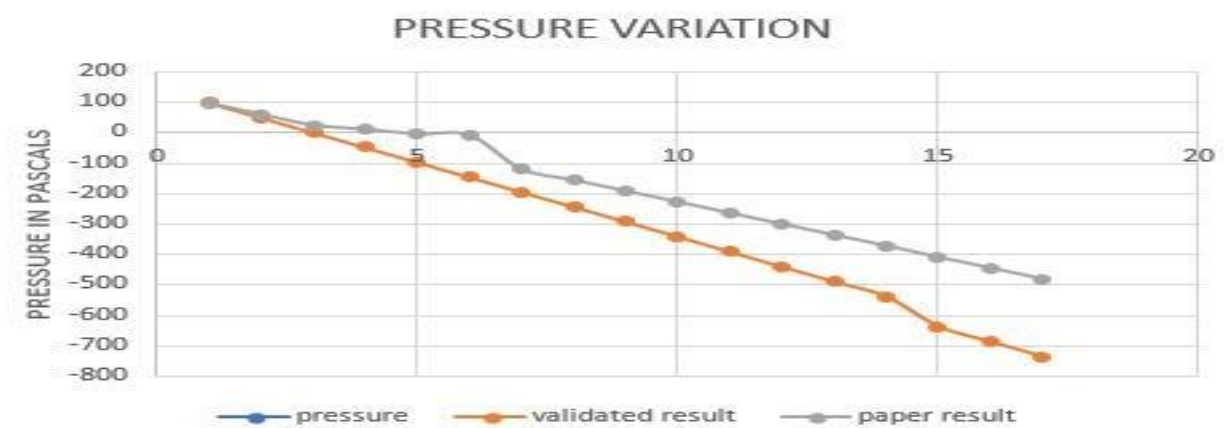4.9.1 Journal Result:
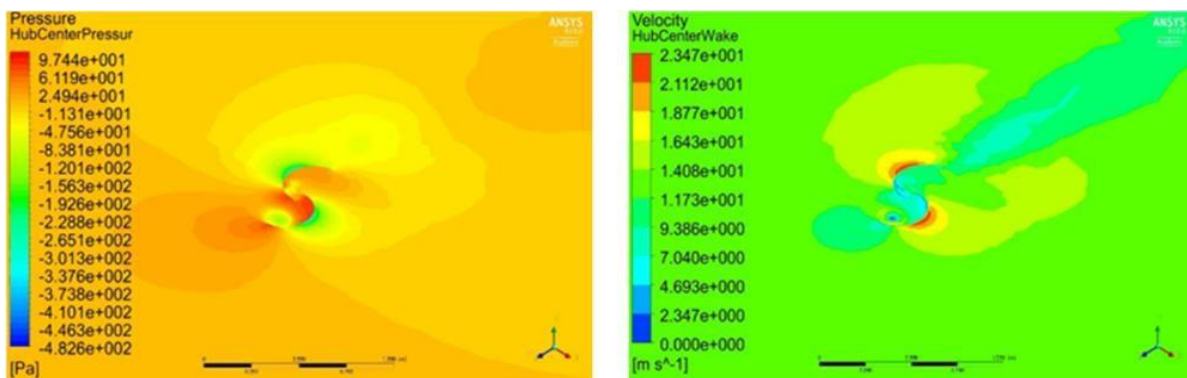
4.9.2 Validated Result:
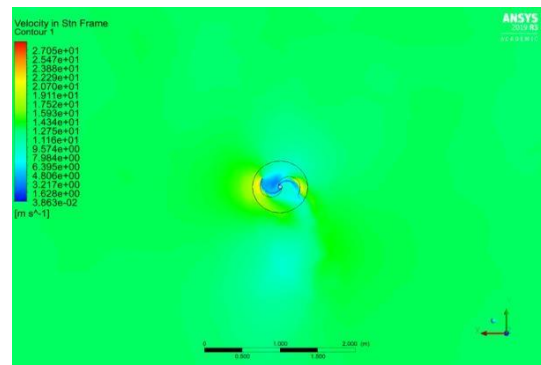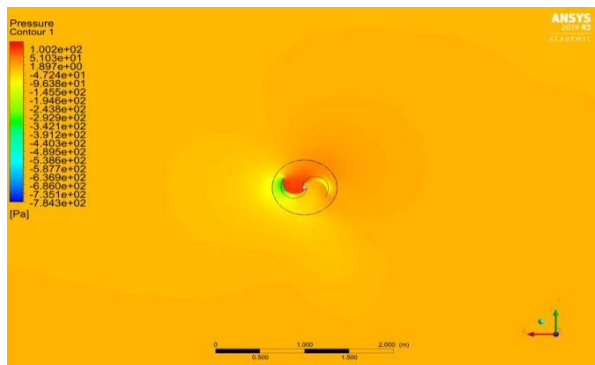
4.10 Graphs:

4.10.1 Velocity Variation:

4.10.2 Pressure Variation:

In the above depicted graphs, the Gray line indicates Velocity that has been obtained in the Journal and the Orange line indicates the Velocity that has been obtained in the process of Validation in Velocity Variation.

In Pressure Variation Graph, the Gray line indicates Pressure that has been obtained in the Journal and the Orange line indicates the Pressure that has been obtained in the process of Validation in Pressure Variation.

The Error Percentage for the Maximum Velocity when calculated by taking Actual Velocity value from the Journal and the Obtained Velocity value from the Validation Result is 7.158%.

The Error Percentage for the Maximum Pressure when calculated by taking Actual Pressure value from the Journal and the Obtained Pressure value from the Validation Result is 2.8325%.

Chapter-5

Results and Conclusions

5.1 Calculations

The following calculations are done to determine the power generated by the wind turbine.

Power produced by a wind turbine rotor is given by $P=T*\Omega$

Where ,

T=torque in Nm

Ω= Angular velocity in rad/sec

$\Omega=(2\Pi N)/60 = (2*\Pi*200)/60 = 20.994$ rad/sec

For 0° twist angle

Power = 1.1600762 * 20.994 = 24.36W

For 10° twist angle

Power = 1.1755038 * 20.994 = 24.62W

For 20° twist angle

Power = 1.1772850 * 20.994 = 24.66W

For 30° twist angle

Power = 1.1785351 * 20.994 = 24.6832W

For 40° twist angle

Power = 1.2362705 * 20.994 = 25.8924W

For 45° twist angle

Power = 1.1902858 * 20.994 = 24.9847W

For 50° twist angle

 Power = 1.1827808 * 20.994 = 24.7721W

5.2 Error Percentage Calculations:

Error Percentage in Maximum Velocity:

Actual Velocity, V_{ACT} = 23.47 m/s

Obtained Velocity, V_{OBT} = 25.15 m/s

Error Percentage = $[(V_{OBT} - V_{ACT}) / V_{ACT}] * 100$

$\qquad$ = $[(25.15 - 23.47) / 23.47] * 100$

$\qquad$ = 7.158%

Error Percentage in Maximum Pressure:

Actual Pressure, P_{ACT} = 97.44 Pa

Obtained Pressure, P_{OBT} = 100.20 Pa

Error Percentage = $[(P_{OBT} - P_{ACT}) / P_{ACT}] * 100$

$\qquad$ = $[(100.2 - 97.44) / 97.44] * 100$

$\qquad$ = 2.8325%

5.3 Results:

In this work, we have taken the same cell zone conditions and other parameters from the journal and applied it on our deign. We have obtained the torques produced by different blade twist angled turbines, and reached to a conclusion.

The final optimized angle based on the torque values obtained from different blade angles are as follows:

S.NO	BLADE ANGLE	OBTAINED TORQUE(Nm)	POWER OUTPUT(W)
1	0	1.1600762	24.36
2	10	1.1755038	24.62
3	20	1.1772850	24.66
4	30	1.1785351	24.6832
5	40	1.2362705	25.8924
6	45	1.1902858	24.9841
7	50	1.1827808	24.7721

5.4   Pressure And Velocity Contours of CFD Analysed Wind Turbines of Blades with different Twist Angles:
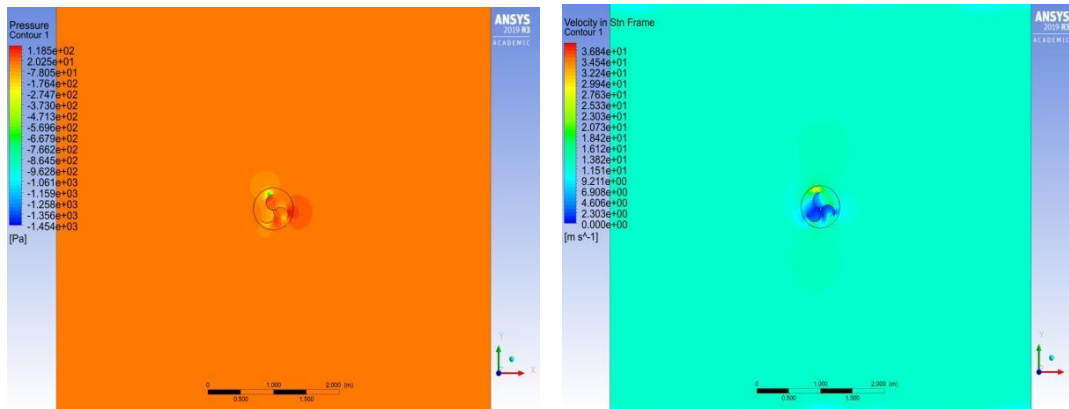
10 Deg:

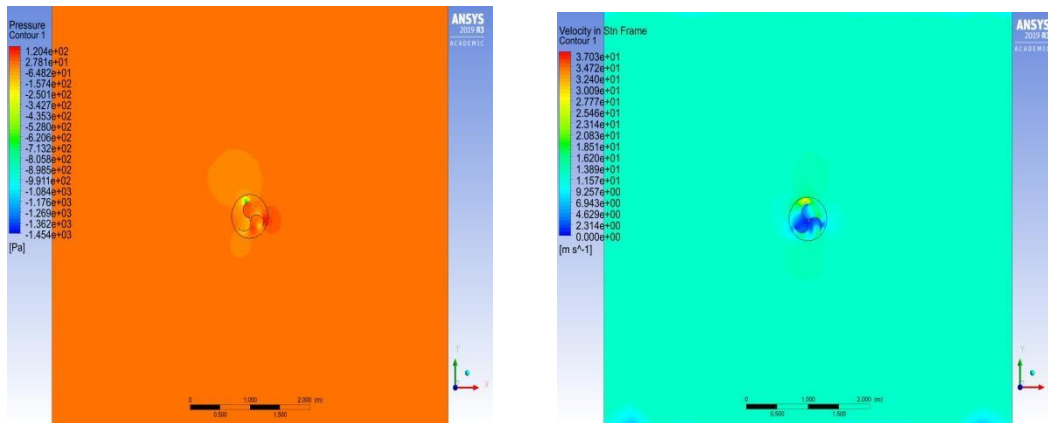Fig 5.1 Pressure And Velocity Contours of Savonius Wind Turbine (10 deg) twist

20 Deg:

Fig 5.2 Pressure And Velocity Contours of Savonius Wind Turbine (20 deg) twist
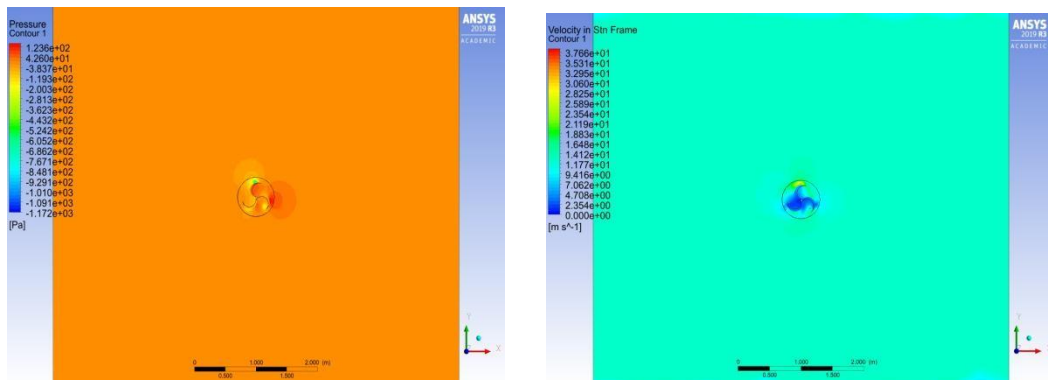
30 Deg:

Fig 5.3 Pressure And Velocity Contours of Savonius Wind Turbine (30 deg) twist
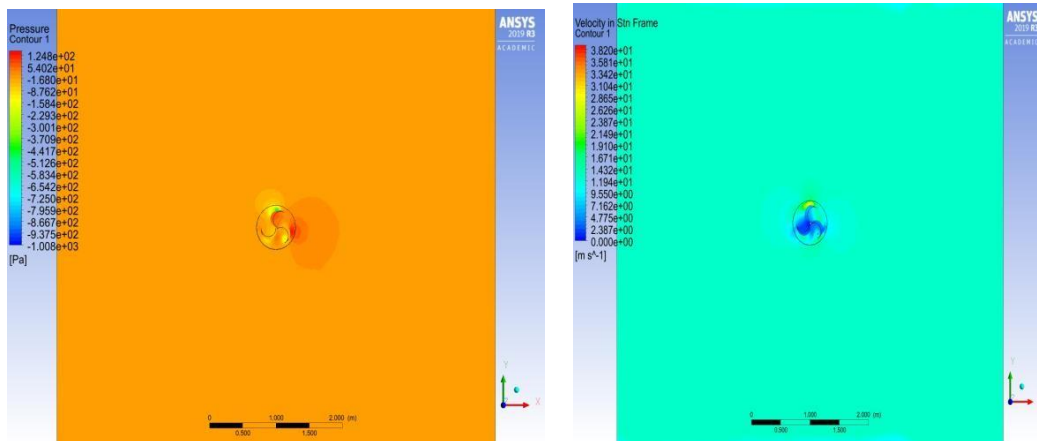
40 Deg:

Fig 5.4 Pressure And Velocity Contours of Savonius Wind Turbine (40 deg) twist
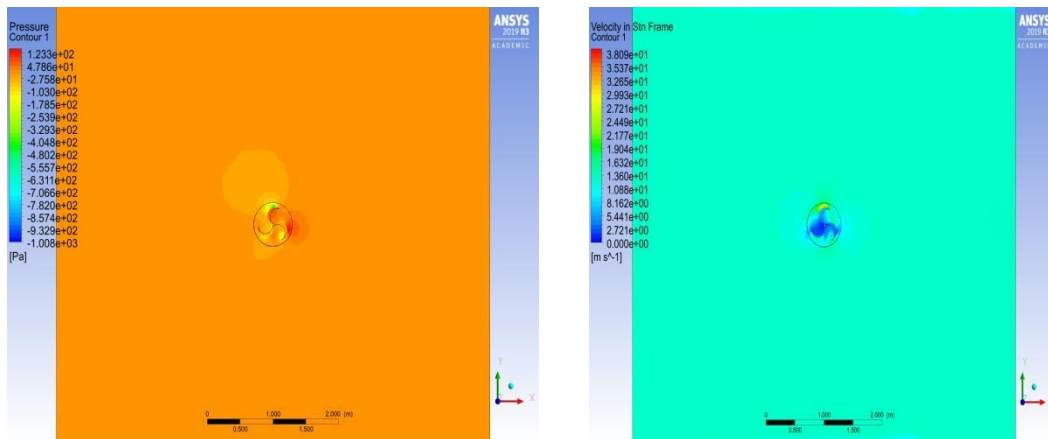
45 Deg:

Fig 5.5 Pressure And Velocity Contours of Savonius Wind Turbine (45 deg) twist
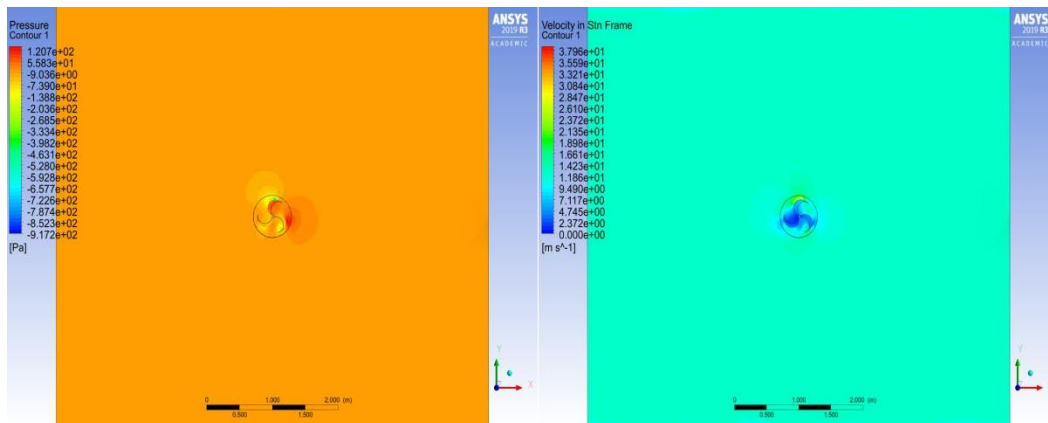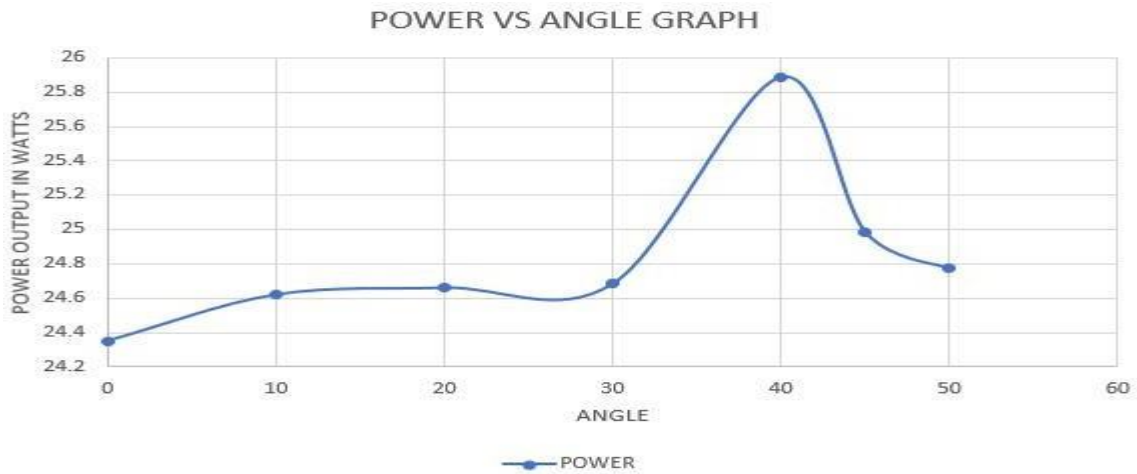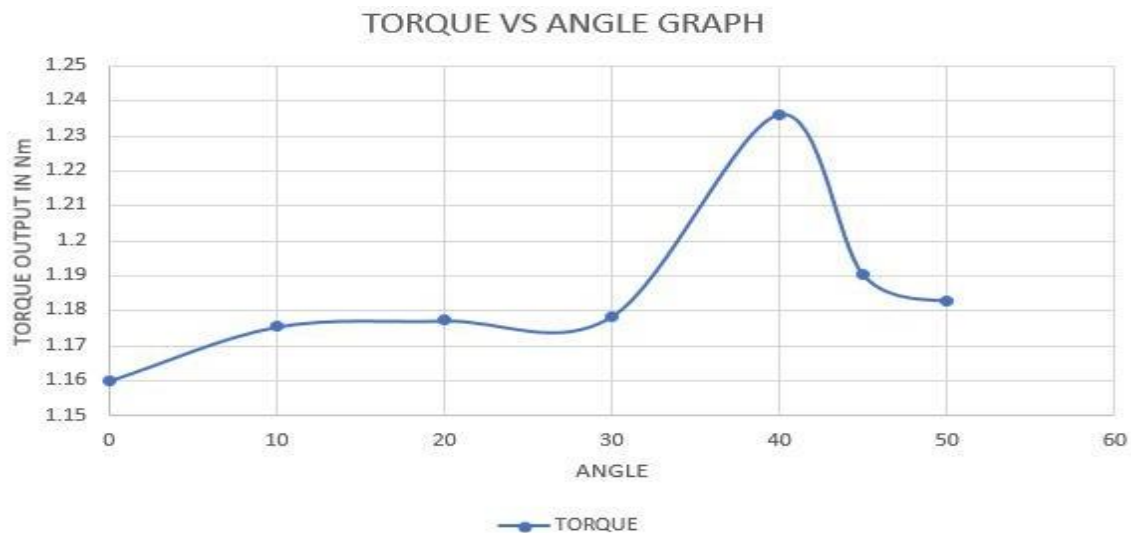
50 Deg:

Fig 5.6 Pressure And Velocity Contours of Savonius Wind Turbine (50 deg) twist

5.5 Graphs:

5.5.1 Power Vs Angle:

5.5.2 Torque Vs Angle:

The above depicted graphs are drawn by using the results obtained in the CFD analysis done in ANSYS Fluent. The graphs plotted are Power Vs Angle and Torque Vs Angle. The Torque is obtained in the CFD analysis done in ANSYS Fluent and the Power is obtained by using a set of formula's to do the calculations.

As shown in the graphs, the Bell Shaped Curve i.e., Maximum Torque and Maximum Power are obtained at 40 Deg and the value are decreasing when going forward. Since Maximum Torque and Maximum Power are obtained at 40 Deg no further analysis is done after 50 Deg Twist Angled Savonius Wind Turbine.

5.6 Conclusions:

- A comprehensive study has been carried out on wind turbines, their types and their applications in different streams of engineering.

- A comprehensive study has been carried out to illustrate the effect of blade profile on the aerodynamic performance of a vertical-axis Savonius-type wind turbine.

- From the simulation of the airflow over the Savonius wind turbine at a particular velocity, it has been found that the torque produced by the wind turbine increases up to an extent and then decreases with increase in the blade angle.

- By altering the blade profile, the torque produced has increased, compared to the blade profile with no twist.

- The performance of the turbine with different blade profiles has been simulated and basing on the results obtained, the 40° blade angle model has produced the highest amount of torque. The turbine with this amount of angle is considered optimum under the prescribed conditions.

Future Scope

Savonius Wind Turbine is a type of Vertical Axis Wind Turbine. Our project is to find a way to optimize the blade profile angle of Savonius Wind Turbine i.e., to find out maximum power output of the Savonius Wind Turbine by altering the design of the Turbine by giving twist to the Turbine Blade. The Analysis is carried out in ANSYS Fluent software and the highest power output is found to be at the Turbine with twist angle 40 deg.

The Future Scope of our project is the highest power output obtained is at an angle of 40 deg. Since the Analysis part is done and the result has obtained, the Fabrication of the Savonius Wind Turbine can be started. Fabrication of the Blades and Rotor Shaft of Savonius Wind Turbine can be done using 3D-Printing Technology because the objects obtained are light-weighted. So by using light- weighted materials more power output can be obtained.

For more power output i.e., for more energy conversion Synchronous and Asynchronous Motors and Generators, AC and DC Inverters and Rectifiers, 2- Phase and 3-Phase Trnsformers should be used. For the Generators and Motors to function they should atleast reach their Minimum RPM. If the Wind Speed is not sufficient and rated RPM has not been achieved the Gears should be used to help the Generators and Motors to achieve their Rated RPM. So that more energy can be converted and power output can be increased.

There are numerous applications for a Savonius Wind Turbine ranging from daily household applications to small scale applications. So a particular application has to be selected and then according to the selected application the design and fabrication of the Savonius Wind Turbine has to be done. And an experiment should be conducted to check whether the power output obtained by CFD Analysis and fabricated Savonius Wind Turbine is same or not i.e., whether the power output has been increased or decreased or remained same should be checked.

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