CFD Analysis of Vertical Axis Wind Turbine with Different Types of Blades

Md Zaka Ullah[1], Dr. Sohail bux[2]
[1]M.Tech Scholar, Department of Mechanical Engineering, Agnos College of Technology, RKDF University
Bhopal (M.P.)
[2]HOD, Department of Mechanical Engineering, Agnos College of Technology, RKDF University
Bhopal (M.P.)
Email: [1]zakaullahrps@gmail.com [2]buxsohail@gmail.com

* Corresponding Author: Md Zaka Ullah

Abstract: *The average wind velocity in urban areas is not sufficient to operate Horizontal Axis Wind Turbine (HAWT), hence Vertical Axis Wind Turbines (VAWT) are sought after. Vertical Axis Wind Turbine is of Savonius (Drag) type and Darrieus (Lift) type with helical blades. The present study is focused on the comparison of the coefficient of performance (COP) of Savonius and Darrieus types of Vertical Axis Wind Turbine. The above mentioned VAWTs are numerically analyzed using SOLIDWORKS flow simulation - Computational Fluid Dynamics (CFD) software. The design of the blades of both the turbines is chosen such that it is optimized for the best output for the given input. For the same input parameters, the output parameters of the wind turbines are obtained separately and are compared. This comparison provides a basis for choosing the type of VAWT to be implemented according to the function.*

Keywords: *Vertical Axis Wind Turbines (VAWT), Horizontal Axis Wind Turbine (HAWT), CFD, Coefficient of performance (COP)*

I. INTRODUCTION

Continuous improvement in this world is based on technological progress. And technological progress refers directly to the use of energy. The requirements for energy crawls daily because of increasing the population, industrial and agricultural progress. However, conventional energy sources are limited, which is ultimately more expensive. In addition, everyone is concerned about global climate change. This entire scenario urges the world to find alternative energy sources. Providing electricity to distant and central/national power networks throughout the world is now a financially feasible and ecologically responsible choice thanks to variable renewable energy sources (VRES). However, they are unable to offer the grid with a number of additional and essential services beyond supplying a certain amount of energy due to their intermittent, variable, stochastic, and non-dispatchable characteristics. [1] The foundation of economic expansion is said to be energy. The availability of energy sources to power our globe is necessary for the continuous industrialization and expansion of the global economy. However, the ecosystem is impacted by every energy conversion and transmission operation. Utilizing fossil fuels may affect animals and the environment by polluting the land, the air, and the water [2].

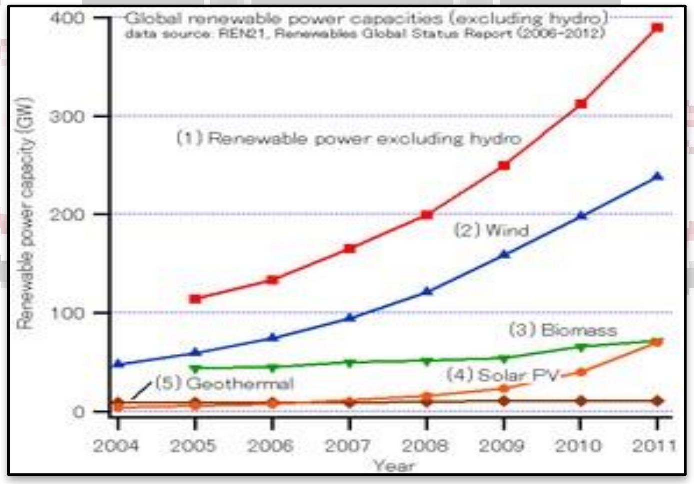

Figure 1: Global Renewable Power Capacity (REN21 2014)

According to recent scientific literacy works, about 78–80% of the world commercial energy comes from fossil fuels, such as, petroleum, coal and natural gas. Those high-carbon sources have negative effects in our environments, such as, effects on heath, land, air and rain. In view of that, the attention of most countries around the globe has been shifted to low-carbon energy. Renewable energy is naturally abundant resources, which can be harnessed without compromising future energy needs. Unlike fossil fuels, which depletes as time goes on. Renewable energy sources like wind, solar, biomass, wave and tidal are abundant sources that can produce clean energy. On recent time, series of renewable energy technology improvement has been witnessed, because the cost of generating electrical power is decreasing. India's electricity industry is one of the world's most diverse. The energy sources used to generate electricity range from traditional sources such as coal, lignite, natural gas, oil, hydro, and nuclear to feasible non-traditional sources such as wind and solar. Power demand in the country has risen quickly in recent years and is anticipated to continue to do so in the coming years. The Indian power sector is heavily reliant on thermal energy, which accounts for around 61% of the total market share [3]. The challenges of growing energy demand and environmental pollution require policies and governance on energy resources. A systematic transition toward more effective energy regimes necessitates a well planned series of operations involving all political spheres, from the local to the international. A wide range of policy instruments, including feed-in tariffs for the generation of renewable energy and tradable emission rights, taxes, and subsidies, have been adopted. Given China's rapid economic growth, the overconsumption of energy and heavy carbonisation of the economy make it an important player in oil and gas markets. The US energy policy has focused on four traditional objectives: 1. Secure, plentiful, diverse energy supply; 2. Robust, reliable energy infrastructure; 3. Affordable and stable energy price; 4. Environmentally sustainable energy production and use [4].

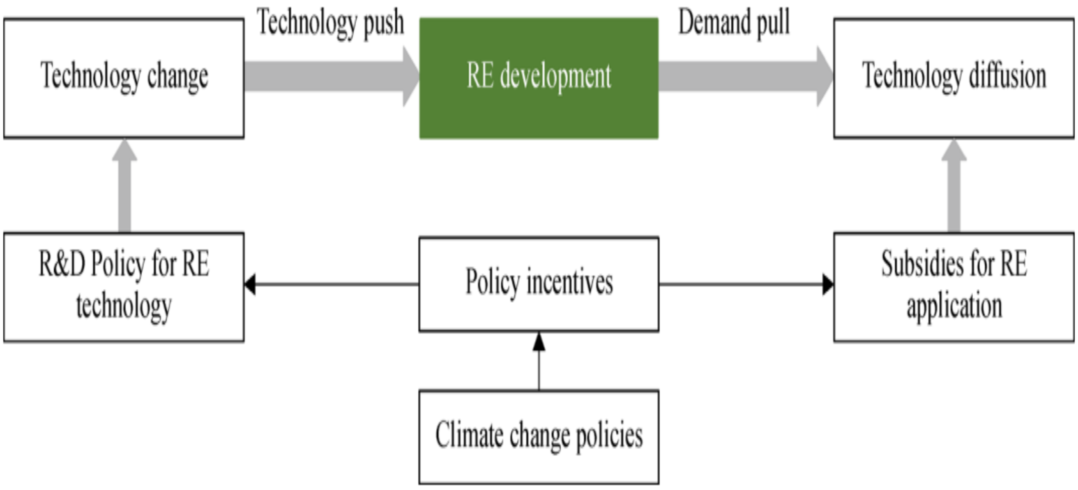

Figure 2: Driving forces of RE development [5].

A wind turbine converts wind energy into mechanical energy and that mechanical energy is used for electricity production. There are two types of primary wind turbines; they are wind turbines Horizontal axis (HAWT) and vertical axis wind turbines (VAWT), which both brags to be better than the other. HAWTS include both addition and downwind configurations with different power groups such as diffusers and concentrators. HAWT is more popular because you have a better efficiency, but only suitable for places with high wind speed. Due to better aerodynamic behavior and greater efficiency, HAWT was the popular choice of researchers. Different factors, however, lead the head of the researchers in the VAWT area. They are, VAWT can create in a small scale as a HAWT. VAWTS may be suitable for power generation in which traditional -HAWTS cannot give adequate efficiency such as low wind speeds and turbulent wind flows. VAWT can work without dependence on the wind direction. The silent behavior is more attractive for very populated places. The cost of the complex structure of HAWT blades are higher than simpler VAWT leaves. Due to a striking behavior, the resistance to the wind, wind can be resistant, which is much safer during the weather conditions.

In general, VAWT is driven by two types of forces of wind, drag and lift force. Savonius rotor is the simplest kind of VAWTs is a drag-type configuration and a bit complex type is Darrieus rotor which is lift-type configuration.

Savonius rotor: A Savonius rotor operates by generating a drag force difference when wind strikes the concave and convex sides of the semi-spherical blades. In comparison to Darrieus' rotor, Savonius' rotor consumes less flow energy.

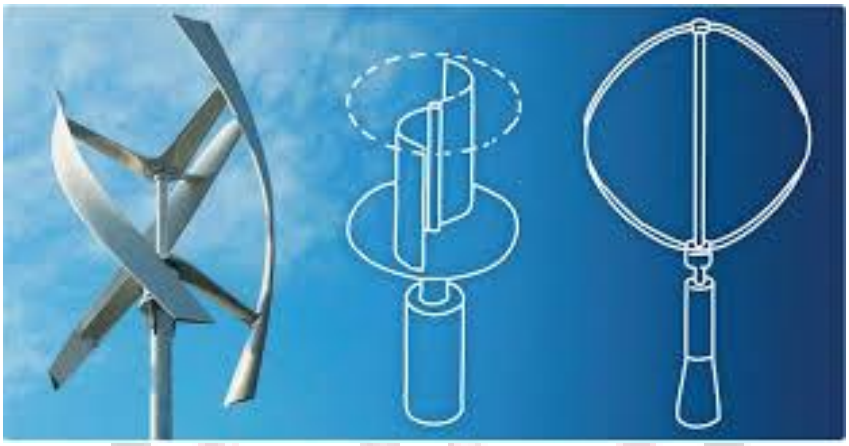

Figure 3: Darrieus and Savonius

The objective of this comparative study using SOLIDWORKS flow simulation is to analyze and evaluate the performance of Savonius and Darrieus wind turbines with helical blade shapes. The study aims to assess various parameters such as drag force, torque, downstream velocity, free stream velocity, pressure drops, and the suitability of the turbines based on velocity profiles and pressure contours. The first objective is to perform a parametric analysis of the two turbine types and determine the drag force characteristics at different speeds and angular velocities. Specifically, the study aims to compare the drag forces between the turbines, noting that the Darrieus turbine exhibits higher drag force at low speeds but decreases after 8 m/s. This trend is also observed at an angular velocity of 10 rad/s. The second objective is to evaluate the torque of the rotor for both turbine types. It is expected that the Darrieus wind turbine will have lower torque due to the aerodynamic cross-section of its helical blades. The third objective focuses on assessing the downstream velocity of air for each turbine. It is anticipated that the Savonius rotor will have lower downstream velocity compared to the Darrieus turbine with helical blades, primarily due to the lower dynamic pressure along the flow. The fourth objective is to analyze the effect of angular velocity and free stream velocity on the free stream velocity of air along the flow direction. This analysis is particularly relevant for windmill applications as it determines the suitability of placing multiple turbines along the direction of flow. The fifth objective is to examine the pressure drops around the rotating domain in the downstream direction for both turbine types. The study will compare the magnitude of pressure drops, with a focus on noting higher pressure drops for the Savonius turbine at high speeds. Finally, the study aims to justify the torque requirements of the Savonius rotor based on the values of drag force and pressure drop along the flow direction. This analysis will provide insights into the starting torque characteristics of the Savonius turbine. Overall, by studying the velocity profiles and pressure contours inside and outside the rotor, the objective is to determine the suitability of Darrieus wind turbines with helical blades, taking into account all the analyzed parameters.

II. LITERATURE REVIEW

(Anupam Dewan et. al., 2021) [6] The energy problem brought on by increasing globalization and the negative impacts of climate change has boosted the need for unconventional energy sources. Significant research has recently been done in the subject of renewable energy, namely in the production of solar and wind energy. Vertical axis wind turbines (VAWT) and horizontal axis wind turbines (HAWT) are two types of wind turbines. The function of the Savonius rotor (S-type), a form of VAWT, is dependent on the drag force. It has various benefits, including simple design, quick installation, strong self-starting ability, low speed operation, and wind direction independence. However, the returning blade's low efficiency is caused by the negative torque that is created on it. To enhance the functionality of Savonius rotor for satisfying large-scale energy demands, researchers have carried out several examinations.

(Elmekawy AMN et. al., 2021) [7] Savonius vertical axis wind turbines' ability to develop more power by changing the form and angle of twist of their blades is investigated using three-dimensional CFD models. Changes to the traditional blade's twisting angle and other recommended novel blade designs are offered to enhance the efficiency of the wind turbine. The ANSYS software's sliding mesh approach has been used to do CFD simulations. The simulations make use of four turbulence models: realizable k- ε, standard k- ε, SST transition, and SST k- ω. The intended size and wind speed have caused a modification to the blade twisting angle. The introduced novel blade increased the power generated compared to the classical shapes. The two proposed novel blades achieved better power coefficients. One of the proposed models achieved an increase of 31% and the other one achieved 32.2% when compared to the classical rotor shape. The optimum twist angel for the two proposed models achieved 5.66% and 5.69% when compared with zero angle of twist.

(Kollar, L. E., & Mishra, R., 2019) [8] With the functioning of wind turbines under icing circumstances in mind, a technique is developed to calculate the geometry of the two-dimensional section of wind turbine blades. By using an inverse design technique, a specified pressure or velocity distribution is employed to create the blade shape, which is then used to simulate the icing of a blade section under various climatic conditions. The analysis and comparison of the aerodynamic performances of the iced and naked blades serves as justification for the addition of a correction factor to the inverse design procedure. The inverse design method must create a blade form that can function under some icing conditions that are chosen in line with the local meteorological conditions where the wind turbine is located. The procedure presented will contribute towards the design of blade shapes that can enable wind turbines to operate under a wide range of ambient 29 conditions satisfactorily.

(Mohd Badrul Salleh et. al., 2021) [9] For hydrokinetic applications at low water flow rates, the current study investigates how a deflector impacts the self-starting speed and power capacities of two- and three-bladed Savonius rotors. The rotors were put to the test in a closed-circuit wind tunnel using air as the flow medium, both with and without a deflector. Based on the identical Reynolds number and the air data from the experiment, the corresponding water flow speed was calculated. The density and viscosity of both mediums were considered to ensure that the flows were dynamically equivalent. According on the initial rotor angle, it was discovered that the rotors' self-starting rates varied. Due to its narrower blade orientation, the 3-bladed rotor started slower than the 2-bladed rotor. Both rotors' self-starting speeds were slowed down for all evaluated deflector angles when a deflector was present upstream of the returning blade. By preventing an incoming flow from impinging on the rotors' returning blade, the deflector was able to lessen the negative torque that would otherwise prevent the rotors from rotating. The ideal arrangement, which contributed the most to the greatest decrease in the self-starting speeds for all beginning rotor angles for both rotors, was discovered to have a deflector angle of δ= 90° with regard to the incoming flow direction. The deflector that prevents the entering freestream flow from impinging on the returning blade was shown to greatly increase the coefficient of power of the rotors in terms of rotor power performance. The ideal deflector angle was discovered to be = 90°, independent of the number of blades, and the maximum coefficient of power gains of 84.6% and 227.3% were achieved with the deflector configuration δ= 90° for the 2-bladed rotor and the 3-bladed rotor, respectively.

(Kao, J. H., & Tseng, P. Y. 2018) [10] The purpose of this study is to demonstrate how CFD technology is used to match the generator and turbine blades in order to maximize the efficiency of a vertical axis wind turbine (VAWT). The study case used in this instance is a VAWT. In order to calculate the T (torque)-N (r/min) curves of the turbine blades at various wind speeds, the SST (Shear-Stress Transport) k-turbulence model using SIMPLE algorithm approach in transient state is used. We measure the generator's T-N curves for several CV (constant voltage) models. Thus, the best CV model may be determined by matching the T-N curves of the turbine blades at various wind speeds with the T-N curves of the generator at various CV models. The parameters of the operating points, such as the tip speed ratio, revolutions per minute, blade torque, and efficiency, may be determined as the best CV mode is chosen. The findings indicate that a good match between the two systems would result in a 15% improvement in ultimate output power at high wind speeds of 9–10 m/s.

(Mishnaevsky L et. al., 2017) [11] Requirements for the materials, loads, and available materials for wind turbines are examined. In addition to the traditional composites (glass fibers/epoxy matrix composites) used for wind turbine blades, natural composites, hybrid composites, and nanoengineered composites are also included. We discuss wind turbine composite manufacturing methods as well as testing and modeling frameworks.

III. METHODOLOGY

For each simulation, the numerical research is done using the processes outlined in the flowchart in Fig. 4. In Solidworks, the geometry of the blade section and fluid domain are first simulated. In this research, we look at a blade section with a length measured from 53 percent R to tip. MEXICO turbine blades had a rotor radius of 2.25 metres in its original design. The blade is made up of three different types of airfoils that are dispersed span-wise. Similarly, for the blade section chosen in this investigation, the relationship between twist angles and chord length distribution along the span has been shown. A cylinder encapsulating the blade is introduced in the main fluid domain for the fluid domain to permit angle of attack adjustment and mesh refinement around the blade to capture boundary layers on blade surfaces. The red stripes on the blade show computational positions of interest that have been identified.

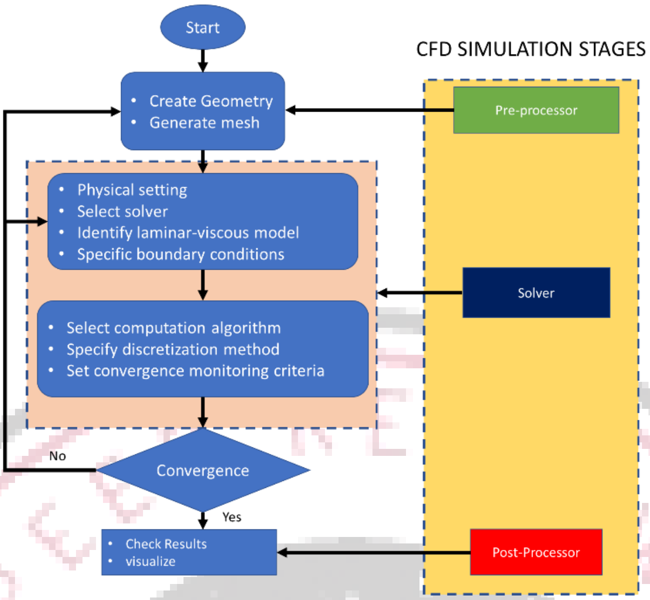

Figure 2: CFD Numerical Methodology Flow Chart

The flow in wind turbines is still fundamentally incompressible, according to Yuwei et al. (2012) [11], with Mach values based on blade tip speeds seldom exceeding 0.25. Because the Mach numbers based on the blade tip speed in this investigation were less than 0.25, it was fair to consider the flow incompressible in this paper. The mass and momentum conservation equations can be stated as follows using the assumptions of incompressible and turbulent-steady flow:

$$\frac{\partial \bar{u}_j}{\partial x_j} = 0$$

$$\rho \frac{\partial \bar{u}_i}{\partial_t} + \rho \bar{u}_j \frac{\partial (\bar{u}_i)}{\partial x_j} = -\frac{\partial \bar{P}}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial (\bar{u}_i)}{\partial x_j}\right) + \frac{\partial R_{ij}}{\partial x_j}$$

u_j is the average velocity along the x_j direction, ρ the fluid density, P average pressure, R_{ij} the Reyonlds stress.

$$R_{ij} = -\rho u_i u_j$$

A few elements were considered during the design of the Savonius vertical axis wind turbine, and entire design calculations were carried out based on this input data. During the design process, the following elements are taken into account.

d – diameter of blade [m]

D –diameter wing spread of rotor [m]

e – pipe spacing [m]

h – height of blades [m]

v – wind speed [m/s]

F – diameter of end plates [m]

Cp - Betz coefficient

a- sweep area of the rotor blade [mm2]

n- speed of rotor [rpm]

r- radius of the rotor [mm]

ω- angular velocity [rad/sec]

λ - tip-speed ratio.

Formulae & Calculations

Assume diameter of blade d = 30mm

(Reference: F. Sigernes, University Centre in Svalbard (UNIS), Norway)

Then, e =d/3 =30/3= 10mm

D=5e =5*10 = 50mm

f = 1.2D = 1.2*50 = 60mm

h= 1mm

The rotational speed is defined as $n= (60/2\pi\times\omega)$ [rpm]

Where, $=\lambda\cdot v/r$ is the angular velocity in units of radians per second,

=1*6/25

=36.04 rad/s

Here r=D/2 the radius of the rotor

=50/2

= 25mm and

$\lambda = 1$ the tip-speed ratio

Then $n = (60/2\pi\times\omega)$

$= (60/2\pi * 30.04)$

= 344rpm

The height of the rotor is h=1m. The wind start speed v =6 m/s.

IV. RESULTS

In results global goal are taken are solved. For Global goals fluid domain at inlet and outlet of the turbine are selected. Parameters which are to be solved are shown in the table for each cases. Parametric study is also done for different boundary conditions.

Parametric study

The ability to perform optimization is built into many modern FEA software programmes. These routines essentially automate the traditional trial-and-error method of adjusting design factors and determining the impact of these changes. The benefit of putting these tools into an automated algorithm is that the program can "keep an eye on" other variables that could be affected by changing the variable of interest.

Designers can use the Parametric Study Mode to run several fluid flow tests automatically and then analyse the results to find the optimal design. This mode simplifies the process of evaluating design scenarios. Click the Parametric Study toolbar or right-click a boundary condition and select Parametric Study to establish a parametric study. The new parametric study helps designers solve a wide range of difficulties. With a new, user-friendly interface, you can:

- Set an input variable as boundary condition (input data), a model dimension or mate, and a Design Table parameter.
- Set output parameters as the study goals.
- Display a compare goals report that you can export into Excel.

There are 5 design points in the parametric study and all these are same for all the cases.in first five velocity along x-axis design points varies as 4,6,8,10 and 12 m/s and other is angular velocity varies as 20 and 10 rad/s.

- **Velocity Contour comparison of Savonius and Darrieus wind turbine at 20 rad/s**

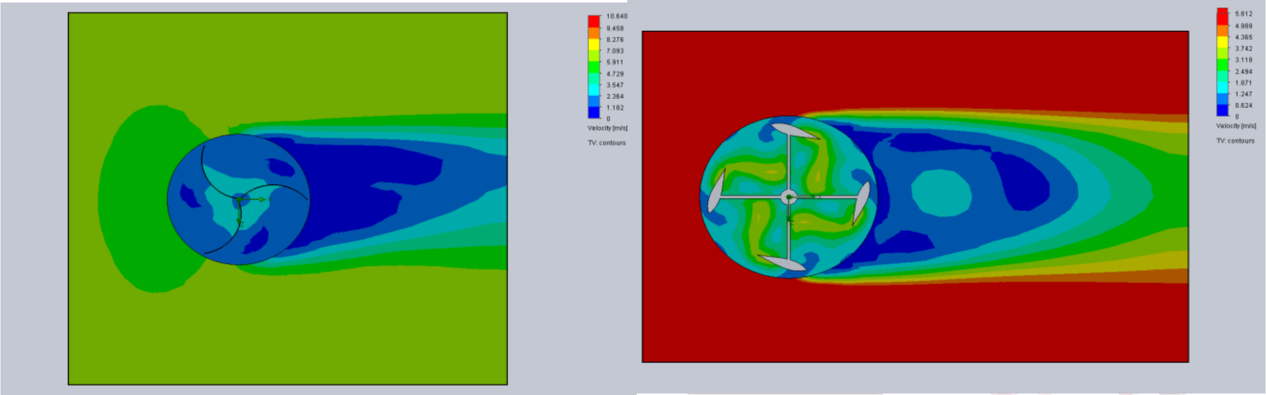

Figure 5: Velocity Contour along the section parallel to Top Plane at v= 6 m/s

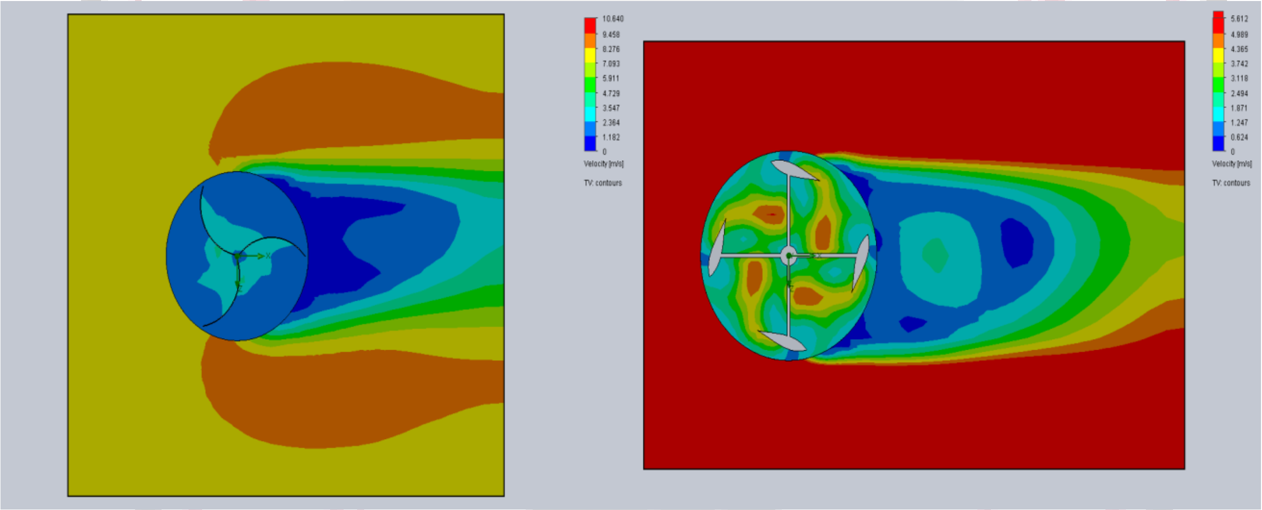

Figure 6: Velocity Contour along the section parallel to Top Plane at v= 8 m/s

- **Pressure Contour comparison of Savonius and Darrieus wind turbine at 20 rad/s**

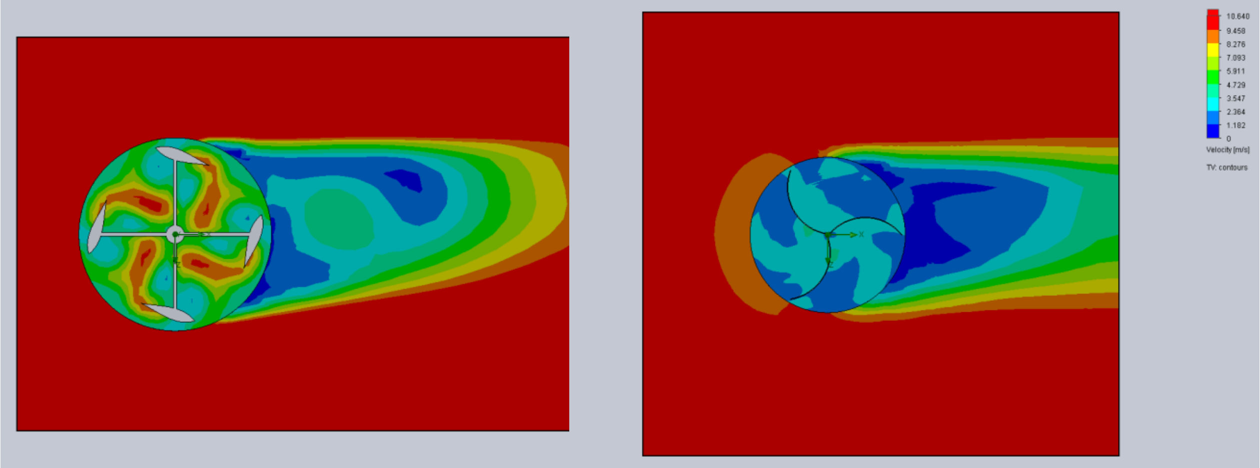

Figure 7: Velocity Contour along the section parallel to Top Plane at v= 10 m/s

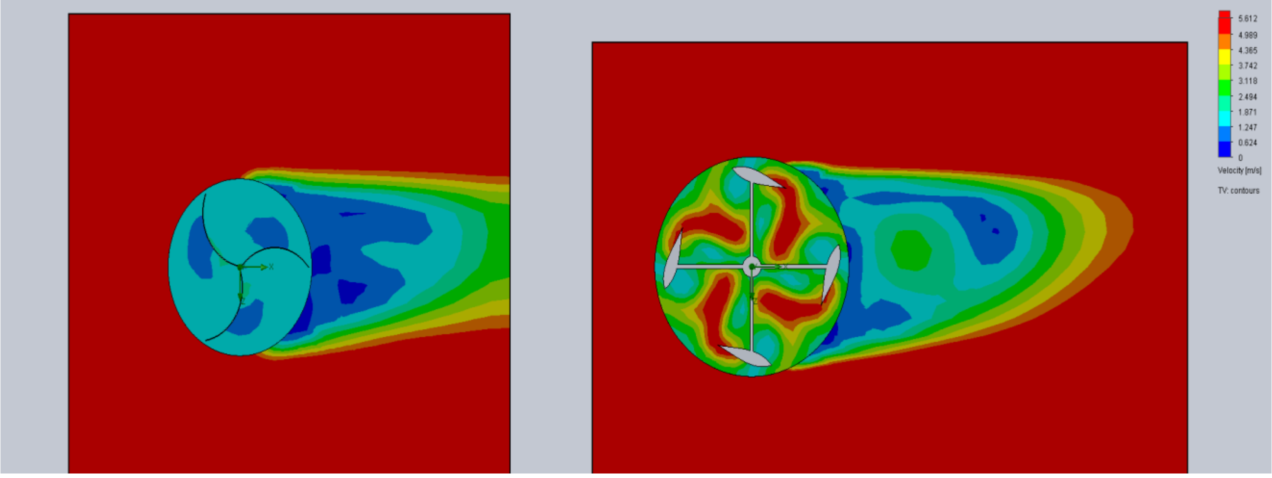

Figure 8: Velocity Contour along the section parallel to Top Plane at v= 12 m/s

- **Pressure Contour comparison of Savonius and Darrieus wind turbine at 20 rad/s**

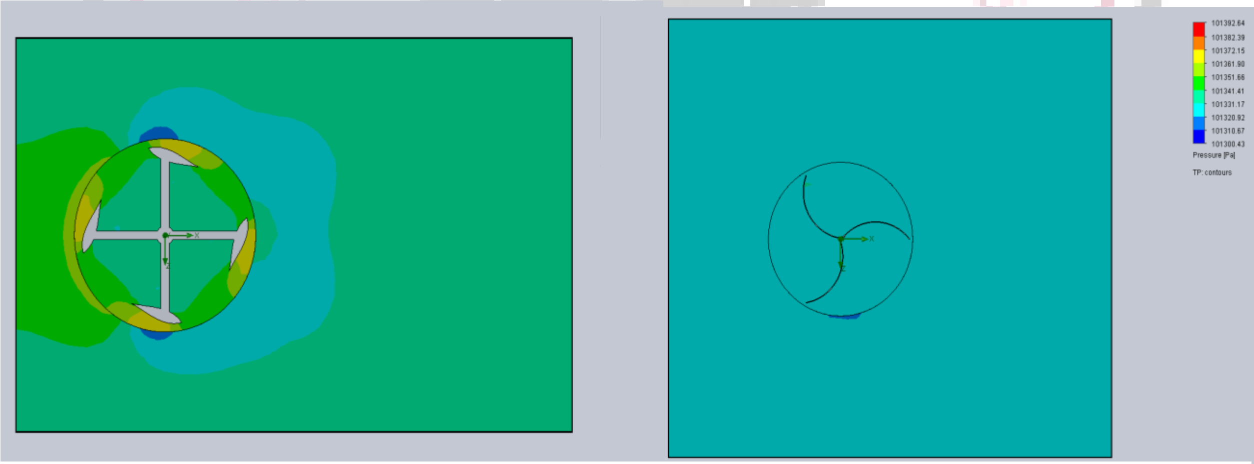

Figure 9: Pressure Contour along the section parallel to Top Plane at v= 4 m/s

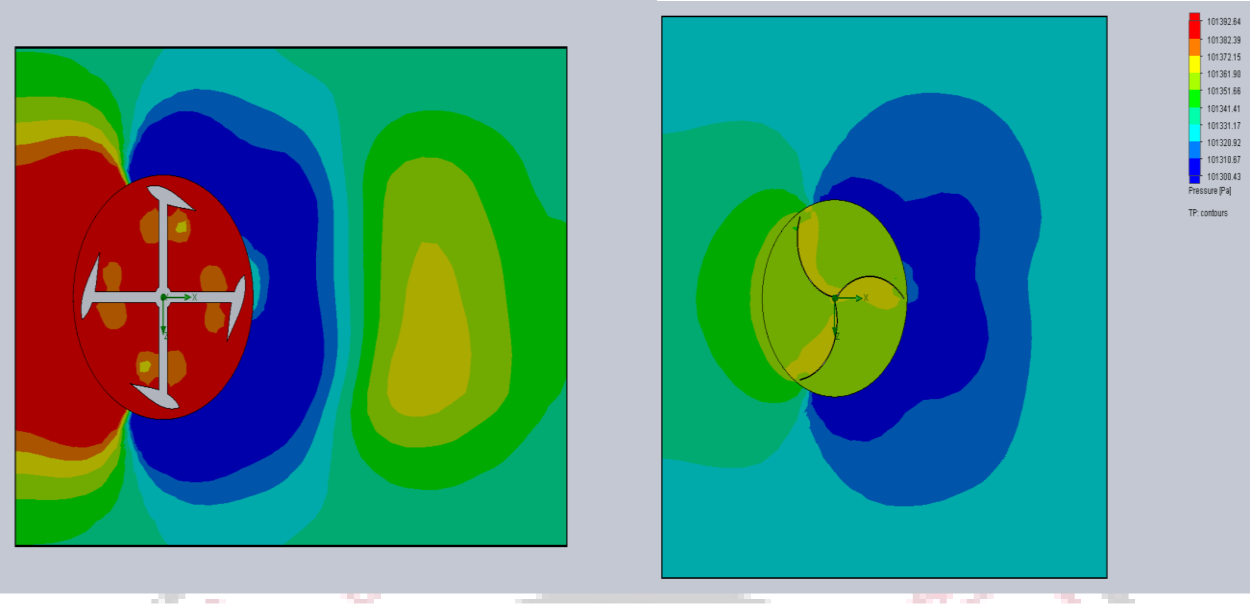

Figure 10: Pressure Contour along the section parallel to Top Plane at v= 12 m/s

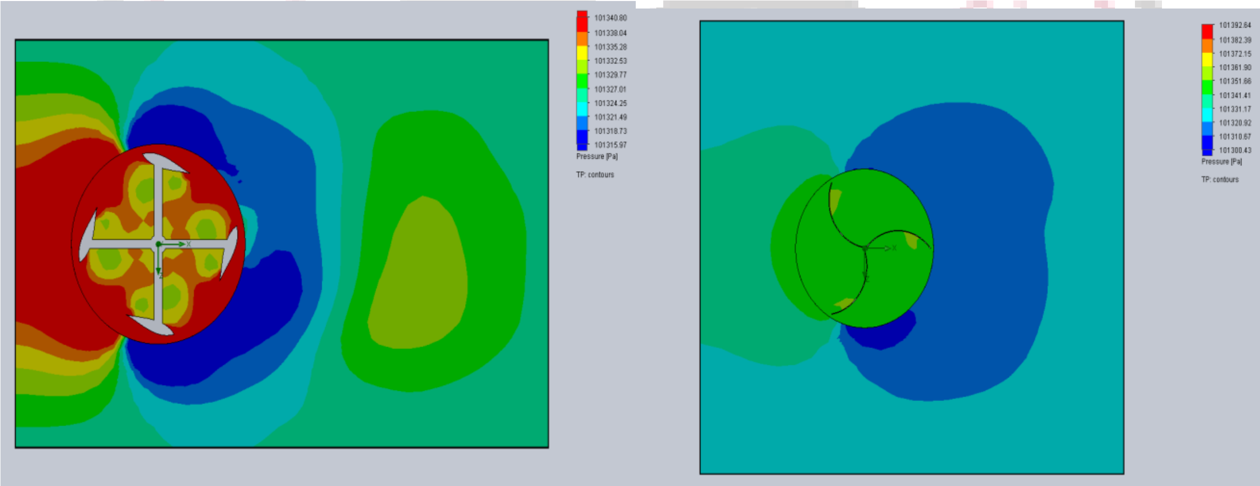

Figure 11: Pressure Contour along the section parallel to Top Plane at v= 10 m/s

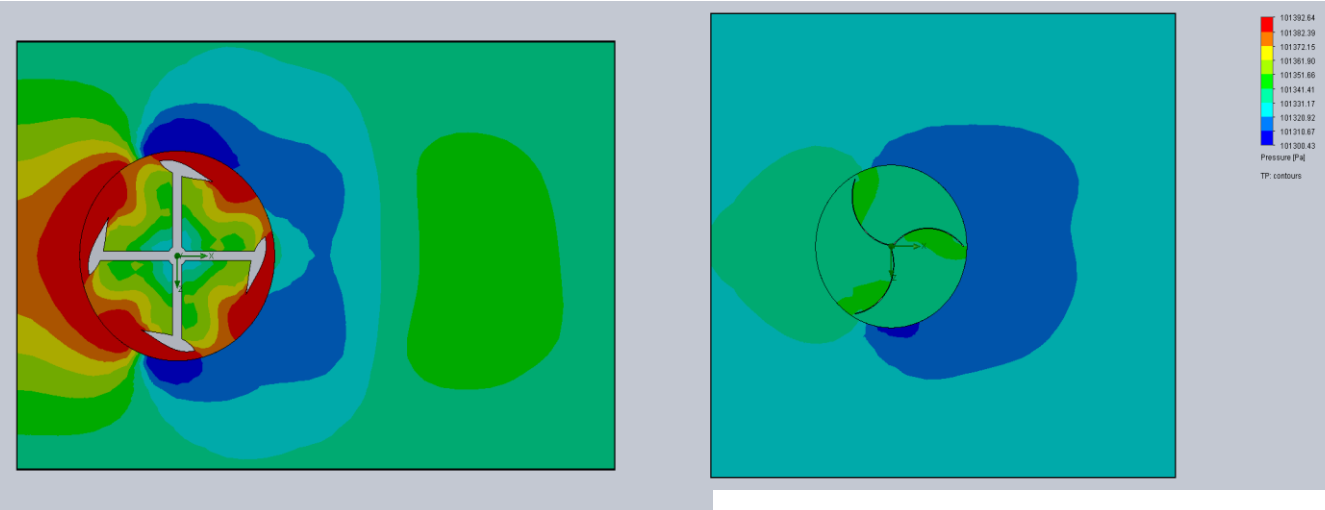

Figure 12: Pressure Contour along the section parallel to Top Plane at v= 8 m/s

- **Velocity Contour comparison of Savonius and Darrieus wind turbine at 10 rad/s**

All the results are converge after 850 iterations Parameters of the goals with average value are given in the table. Pressure counter and the velocity counter cut plots along the section parallel to top plane of the rotour is taken. Pressure counter gives how the pressure varies inside the flow domain along this plane. velocity counter along with the vector directions are also plot of the same plane

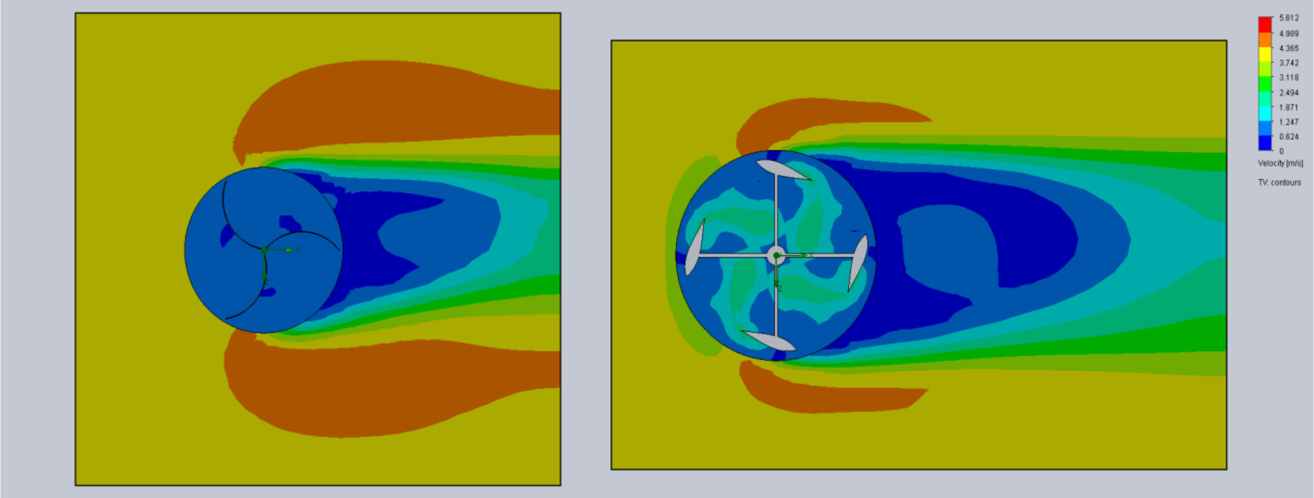

Figure 13: Velocity Contour along the section parallel to Top Plane at v= 4 m/s

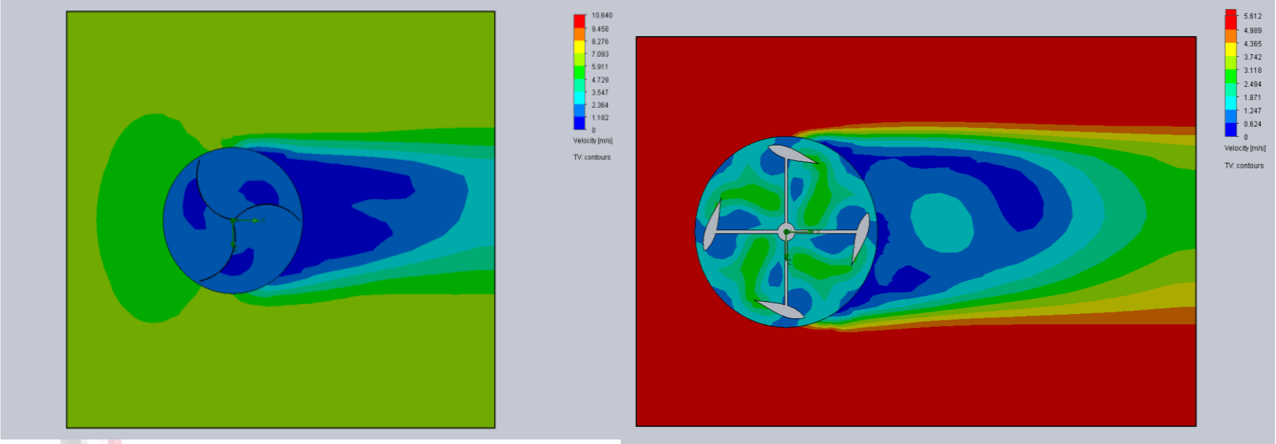

Figure 14: Velocity Contour along the section parallel to Top Plane at v= 6 m/s

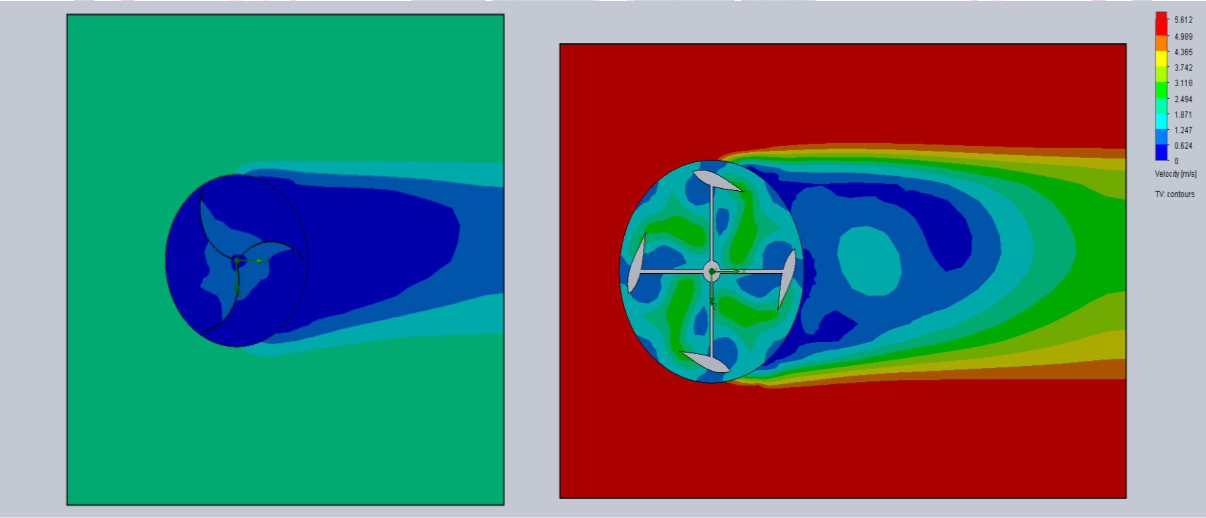

Figure 15: Velocity Contour along the section parallel to Top Plane at v= 8 m/s

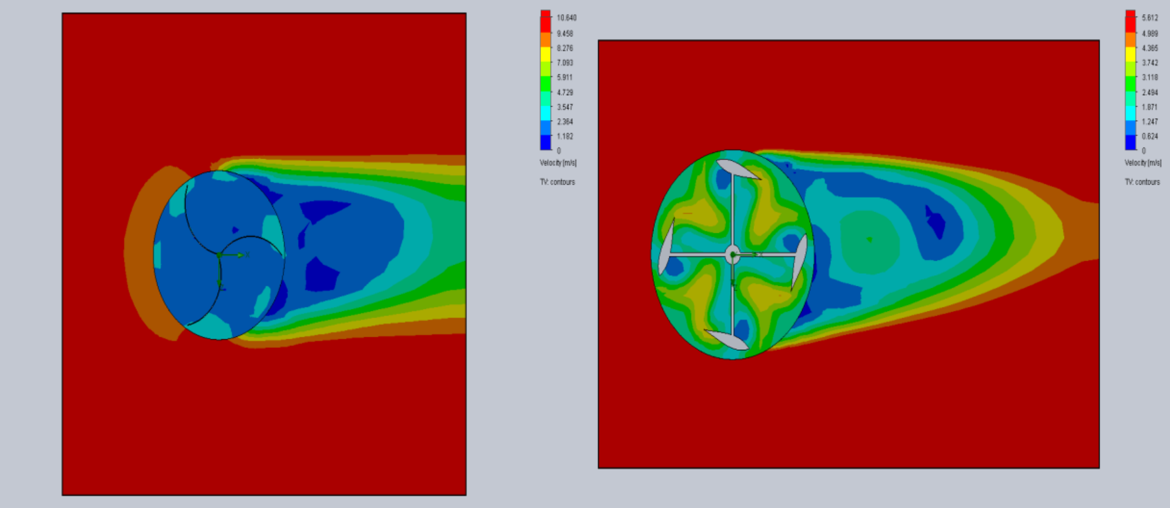

Figure 16: Velocity Contour along the section parallel to Top Plane at v= 10 m/s

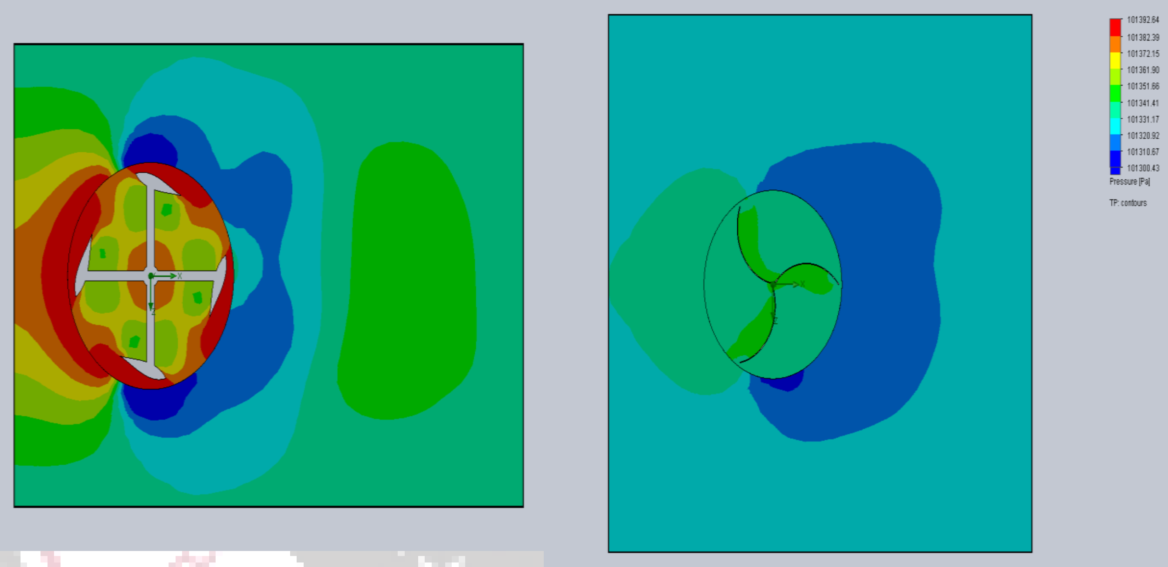

Figure 17: Pressure Contour along the section parallel to Top Plane at v= 8 m/s

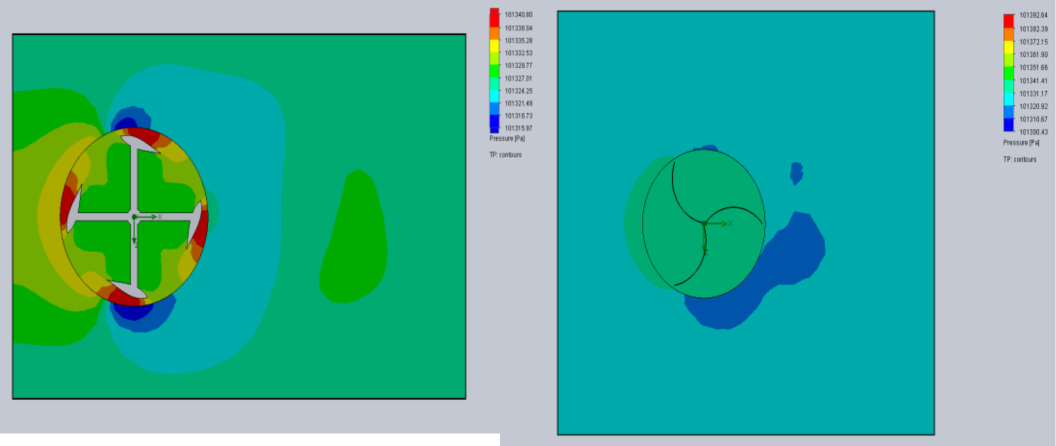

Figure 18: Pressure Contour along the section parallel to Top Plane at v= 6 m/s

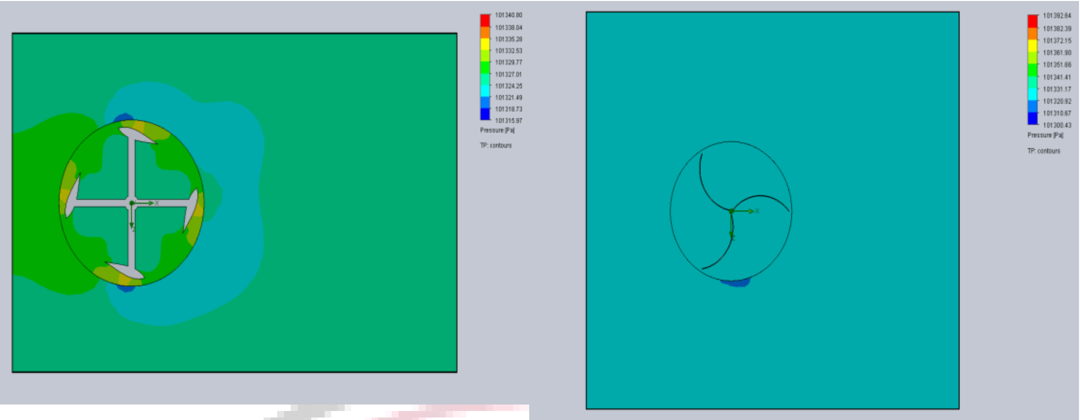

Figure 19: Pressure Contour along the section parallel to Top Plane at v= 4 m/s

- **Velocity Contour comparison of Savonius and Darrieus wind turbine at 10 rad/s**

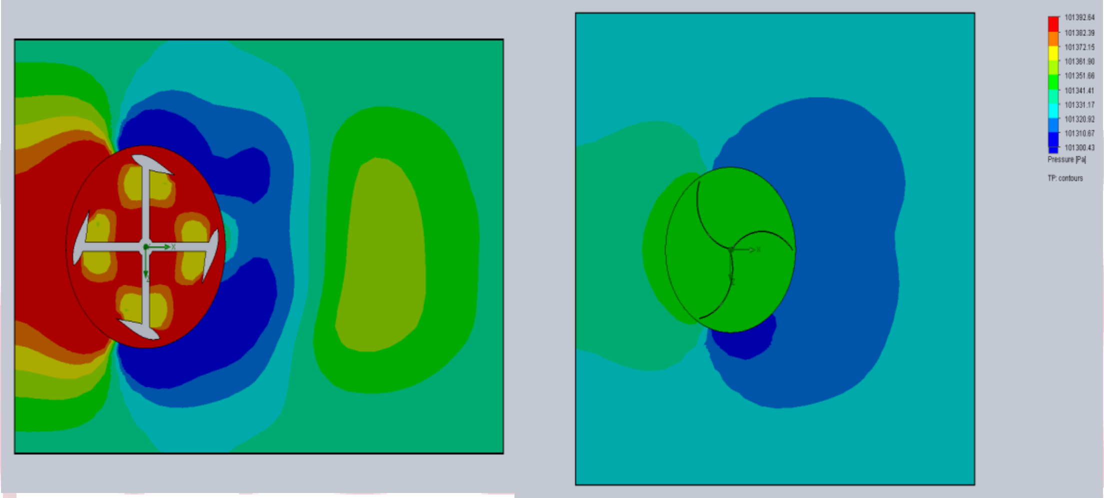

Figure 20: Pressure Contour along the section parallel to Top Plane at v= 10 m/s

V. CONCLUSION

Comparative study results on SOLIDWORKS flow simulation gives parametric tables, and contour plots of velocity and pressure along the section parallel to top plane illustrates the following

- ❖ Parametric analysis of Savonius and Darrieus Turbine with helix shape blades shows that drag force is high on darrieus turbine than savonious at low speed and decreased after 8 m/s and same trend followed at angular velocity of 10 rad/s.
- ❖ Torque of the rotor is less for Darrieus wind turbine because of aero foil cross-section of helical blade.
- ❖ Downstream velocity of the air is less for Savonius rotor than Darrieus Turbine with helix shape blades because of low dynamic pressure along the flow.
- ❖ Pressure drops around the rotating domain in downstream direction is common for both the turbines and is high for savonius at high speed.
- ❖ Values of drag force and pressure drop along the flow direction justifies that savonius rotor requires high starting torque.
- ❖ As per the Velocity profile and pressure contour inside and outside of rotor shows that Darrieus wind turbine with helical blades are more suitable.

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