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# Numerical Investigation on Aerodynamic Performance of Helical Savonius Rotor Inspired by Natural Shapes

**Pramodkumar M. Bagade[1]*, Preeti P. Bagade[2], Ashish Chaudhari[3], Prabhat Ranjan[4], Samartha Shirke[5] and Chetankumar Sedani[6]**

[1]*Bhivarabai Sawant College of Engineering and Research, Pune – 411041, Maharashtra, India; pramodbagade@gmail.com*

[2]*Padmabhooshan Vasantdada Patil Institute of Technology, Pune – 411021, Maharashtra, India; preetibagade10@gmail.com*

[3]*Jayawantrao Sawant College of Engineering, Pune – 411028, Maharashtra, India; ashish.Chaudhari@moderncoe.edu.in*

[4]*Shrimati Kashibai Navale College of Engineering, Pune – 411041, India; prabhatiitism@gmail.com, prabhatmech14@gmail.com*

[5]*Modern College of Engineering, Pune – 411 005, Maharashtra, India; shirkesam30@gmail.com,*

[6]*Indira College of Engineering and Management, Pune – 410 506, Maharashtra, India; cmsedani@gmail.com*

## Abstract

*There have been extensive studies conducted on Horizontal Axis Wind Turbines (HAWT) at relatively moderate to high wind speed regions. However, such detailed investigations for Vertical Axis Wind Turbines (VAWT), specifically for low wind speed terrains are amply reported. This motivates us to conduct research to explore possibilities in improving performance of VAWT in low wind speed terrains, which is attempted in the present work. This is required due to the fact that most of regions do not have sufficient extractable wind energy due to low speeds. VAWTs can perform at such low wind speed, but are less efficient. Improving efficiency of VAWT will solve the purpose. Hence, the present study is aimed at finding the performance characteristics of VAWT for low Wind speed configurations. Various parameters affecting power generation are investigated. Numerical analyses on various configurations are conducted to study the effects of twist angle, free stream velocity, number of blades. Computational results obtained have been in good agreement with the established results for semi-circular Savonius rotor profile. The results suggest that for low wind speed terrains, there is a need to explore the combination of lift and drag type of profiles, which could be used for the utilization of available wind power. Hence, naturally inspired shapes (profiles) were investigated for the possible solution of combined lift and drag type wind turbines at low speeds. The blade shape for such combined lift and drag type wind turbine were deduced from the available literature. It is well established that the naturally inspired shapes as noted in sea conch follow golden ratio in its contours. The present study provides an insight on the characteristic curves of VAWT for low wind speed terrains, effects of various geometric and flow parameters suitable for low wind speed terrains.*

**Keywords:** *CFD, Helical, Savonius Rotor, Nature Inspired Shapes for VAWT, VAWT*

**Author for correspondence*

## 1.0 Introduction

Vertical Axis Wind Turbines (VAWT) are one of the most suitable aerodynamic devices for power extraction in the low wind speed terrains. The necessity for adequate efforts in improving its efficiency lies in the fact that not all regions have sufficient extractable wind energy zone. One of the most important features of the VAWTs is that they can perform at such low wind speed. Horizontal Axis Wind Turbines (HAWT) on other hand need a sufficient free stream velocity to start up. VAWTs have conventional two configurations *viz:* lift-type and drag-type. It has been a hot topic for researchers to improve its aerodynamics efficiency for both the configurations. Due to its suitability in low wind speed terrains, it is a suitable device, particularly in urban environments. Also it provides necessary aesthetics to houses and open gardens, other advantages being simplicity in construction, cost effective, and omnidirectional, when it comes to operation.

From construction and operation point of view, VAWTs do not need any yaw mechanisms and other advantage is that their generators can be positioned either near the blades or close to the ground. These features make them easily accessible and maintenance is low. Despite the fact that not all VAWTs are self-starting, the starting velocity is low, as compared to HAWTs[3]. There have been conventionally two types of WAVTs: the Darrieus and the Savonius types. Aerodynamically, two forces, which govern the overall performance of any wind turbine are the lift and the drag force. When the velocity of wind on the lee ward side is higher than the windward side, a force is generated, which is responsible for turbine rotation[1]. In the present research, a combined lift and drag type VAWT is being reported, which is based on the blade profiles inspired by natural shapes.

## 2.0 Background and Literature Review

There has been a considerable amount of research going in the field, specifically to enhance the efficiency of the wind turbine. Many researchers have contributed through their numerical and experimental investigations for the same. Rosario Lanzafame *et al.,*[1] numerically investigated performance of wind turbines with respect to operating characteristics such as Cp, TSR, and other geometric configurations. The authors developed a 2D CFD model of H-Darrieus wind turbine in ANSYS solver to predict wind turbine performances and optimize its geometry for 3D analysis. In order to exploit superior offshore wind resources in deep water regions utilizing an advanced aerodynamic modeling method, Brian Hand *et al.,*[2] presented the conceptual architecture of VAWT. According to their investigation, the torque/power generated by the turbine was affected by the solidity of the turbine, the number of blades, and the blade aspect ratio. Wannan Wu *et al.,*[3] exhibited pressure distribution for a tip speed ratio of 1 and reported lift and drag coefficient for various angles of attack. They pointed out that deflection causes the lift and drag ratio to increase. The authors performed air-drop testing of a canopy with the leading-edge incision and the trailing-edge deflection. For single and double layer of blades, Zheng Li *et al.,*[4] examined torque characteristics at various Tip Speed Ratios (TSR). The work focused on a drag type VAWT that is intended for usage in small-scale wind energy systems. Cory Seidel *et al.,*[6] applied a biological technique for blade profile design and analyzed using the shape of maple and samara seeds, whereas Seralathan, S. *et al.,*[5] tested the performance of overlap batch type rotor with standard basic Savonius rotor. For the purpose of designing VAWTs, Javier Blanco *et al.,*[7] reported power coefficient against the angular location for several Fibonacci series curves. The rotor blades in this study were designed using an organic shape, and the shape was mathematically analyzed. Another study by A. Zakaria *et al.,*[8] looked into how the 180$^{\circ}$ twist helical Savonius rotor performed depending on the time step and time increment. Numerous numerical investigations of the effectiveness of VAWTs have contributed to the domain's expertise[9-15].

The majority of the research focused on the turbine's operational features. Likewise, a number of researchers have made contributions through their experimental research[16]. M. Zemamou *et al.,*[18] reported their investigation focused at improving the *Cp* of Savonious rotor, while Arifin Sanusi *et al.,*[17] investigated combination of the circle-shaped with a concave elliptical model to improve the performance. In two new possible areas, namely far offshore and in urban and rural settings, VAWT has recently experienced resurgence in demand for wind energy harvesting.

For a deep-water floating offshore wind farm, VAWT are promising. VAWTs can be installed in wind catchers, ventilation ducts, between buildings that are integrated into urban and rural settings, and on building roofs in both. In comparison to HAWT, VAWT has a number of benefits, including omni-directionality, low noise, simplicity, inexpensive manufacture, installation, and maintenance costs, scalability, and compactness, minimal aesthetic disturbance from shadow flickering, and great bird and bat safety.

After studying the numerous efforts by researchers, it is noted that there is a need to explore possibilities to design wind turbines which can optimize lift and drag force effectively such that the net result is the higher rotation (torque) at available wind speeds. In the present research, we have reported such a possible design. The proposed design is inspired by natural shapes, such as conch. These shapes adopted by nature have potential in wind industry also.

## 3.0 Methodology

Conventional VAWTs perform poor aerodynamically than HAWTs due to their less extensive study as well as the complexity of their unstable aerodynamics. Therefore, their aerodynamic performance needs to be further enhanced in order to profit from their many advantages. The standard VAWTs are initially examined in this study, followed by a design that is suggested for greater performance at low wind speeds.

Computational analysis has been carried out with high resolution grid *via* ANSYS software. A grid-independence study was done and here the results with the fine grid are presented. The results obtained are validated with the established experimental results of Saha *et al.,*[19]. Power coefficient calculated from simulation is then compared with experimental power coefficient. Geometry and Boundary Conditions: For the simulations, the following parameters are considered for model creation. Diameter (D) = 0.19m, Height (H) = 0.173m, Thickness (t) = 3mm, Swept area (A) = D × H = 0.0329 $m^2$. Table 1, shows the boundary conditions used during the computation. At the inlet velocity boundary condition was employed, while outflow boundary condition was enforced at the outlet on the right side as shown in Figure 1, k-ε realizable wall turbulence model was used during computations. All the computations are conducted till the convergence of $10^{-6}$ . Figure 1 show the grid generated used during the simulations and associated boundary conditions. Care has been taken to resolve the boundary layer deploying a very fine grid near the wall ($10^{-5}$).

## 4.0 Results

Figure 2(a) and 2(b) show comparison of the computational results with the experimental results of Saha *et al.*[19]. Figure 2a shows the variation of pressure coefficient for different inlet velocities for a 2-bladed Savonius rotor blade. It is observed that at V = 8 m/s, highest values

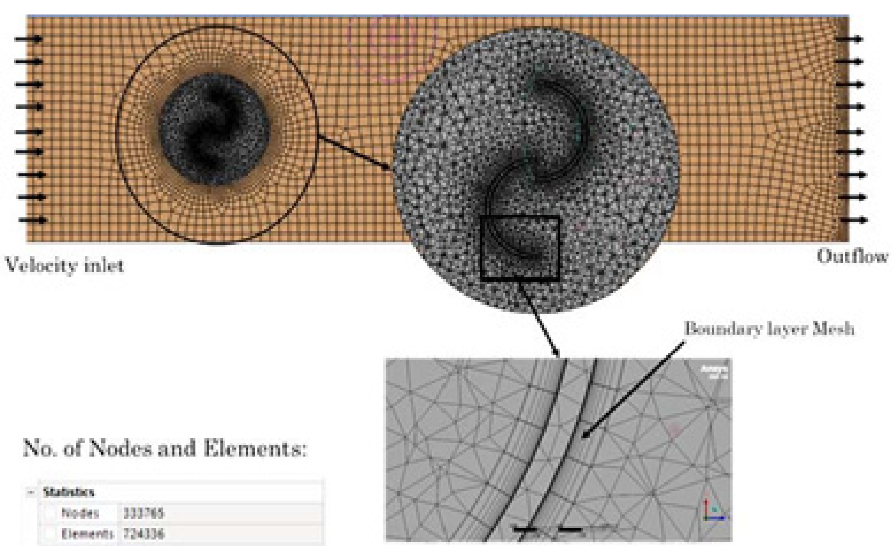
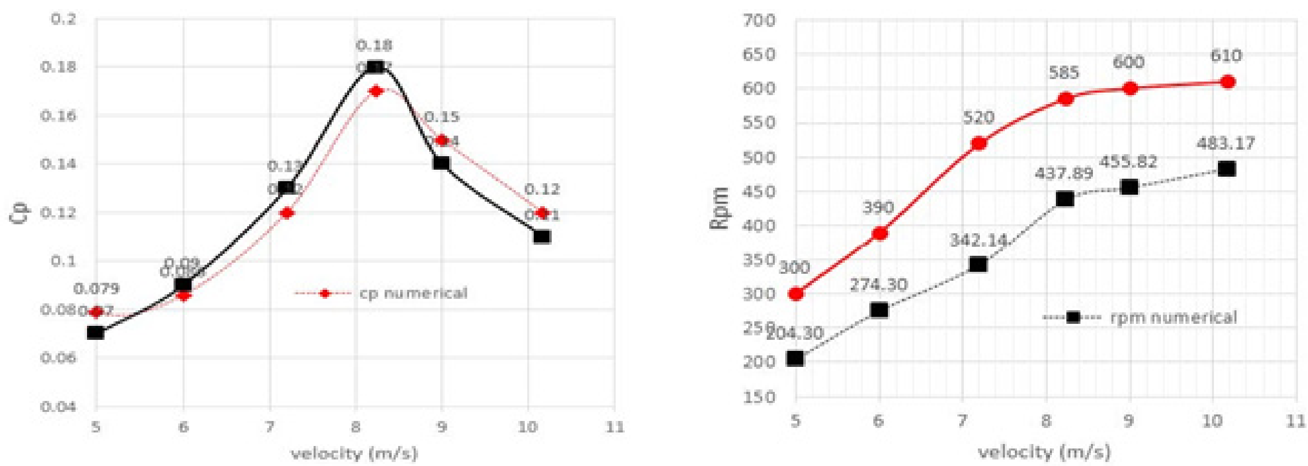



**Figure 1.** Grid generated for the simulation and boundary conditions.




(a) $C_p$ vs. Velocity (b) rpm achieved for different $V_\infty$

**Figure 2.** Comparison of computational results with the experimental results of Saha[19] for a Savonius rotor with end places.

of $c_p$ are recorded, while in Figure 2b, one can note that after this velocity of 8m/s, there is insignificant rise in the RPM of the turbine for this configuration. It is noted that the present results are in good agreement with the experiments. For a semi-circular blade profile of VAWT, pressure coefficient recorded with computation is 0.18, while for the same inlet $V$ = 8.23 m/s, experiments shows a $Cp$ =0.17.

**Table 1.** Boundary conditions applied at various locations

| Location | Boundary Condition |
|---|---|
| Inlet (Left) | Velocity inlet |
| Outlet (Right) | outflow |
| Top, sides, bottom, turbine surface | No-slip Wall |

## 4.1 Effect of Number of Blades

Effects of number of blades has been studied for semi-circular blade profiles. Figure 3 and 4 show the torque and power generated for different inlet velocities for multi-bladed Savonius rotor. It is noted that 2-bladed configuration performs the best as compared to a 3 and 4-bladed configuration. However, the deviation from the theoretical power is also noted for all the configurations. This deviation being the least for a 2-bladed configuration.

## 4.2 Effect of Eccentricity

In this section, we discuss the effects of eccentricity on the performance of the VAWT. The eccentricity is defined as

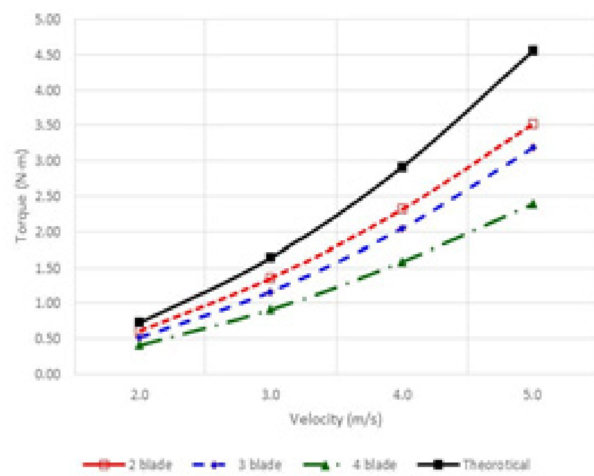



**Figure 3.** Torque generated by the VAWT at different inlet velocities for different number of blades.

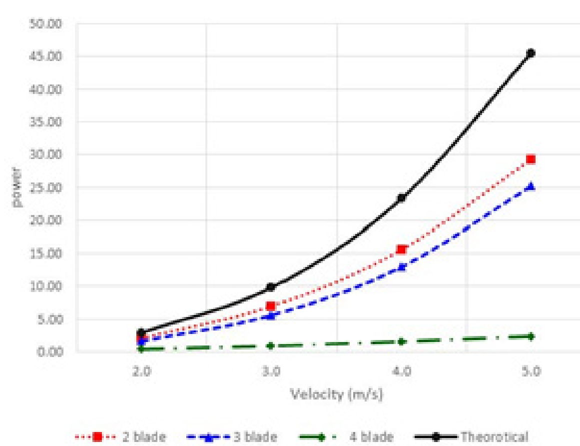



**Figure 4.** Power generated by the VAWT at different inlet velocities for different number of blades.

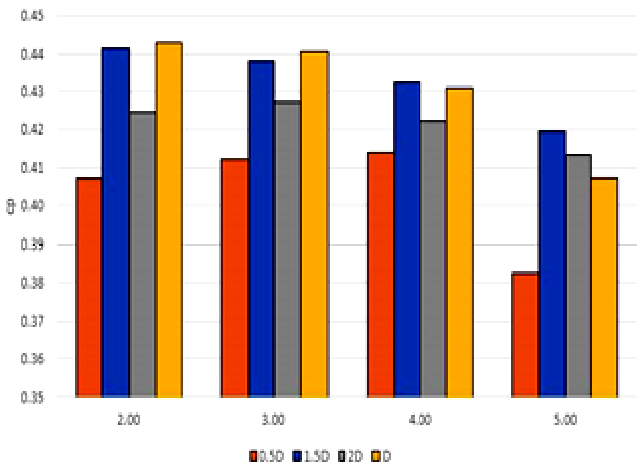



**Figure 5.** Coefficient of pressure for different eccentricities of blade profiles at different inlet velocities.

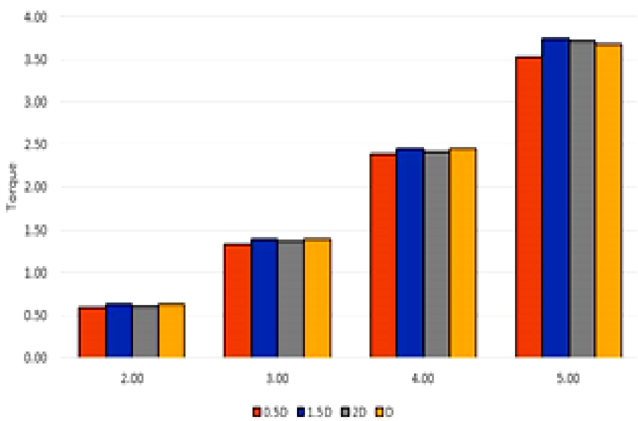



**Figure 6.** Torque for different eccentricities of blade profiles at different inlet velocities.

per explanation given in [16]. Figure 5 and 6 show *Cp* on the blades and the torque generated for different eccentricities at various inlet velocities respectively. It is noted that the performance of the 2-bladed profiles with eccentricity, *e* =1D and 1.5D is the best, as compared to others. This is noted for all the velocities investigated. Also from Figure 6 it is noted that eccentricity should be more than D for higher torque generation.

## 4.3 Design of Wind Turbine Blades Inspired By Nature

Because of their intricate structures, one may initially assume that the growth of plants and animals is governed by extremely complex laws. The seashells and snails are prime instances of this. Any of the numerous varieties of seashells may be described and produced using a very basic model. For creating the VAWT blade geometry in this case, we have modified the following process. For the reasons listed below, we have decided to follow this profile. Based on the preceding investigation, we came to the conclusion that twisted blades travel at higher speeds than traditional semi-circular ones. The Fibonacci series curve is the best curve we found for obtaining the best helical or twisted shape. The Fibonacci Series' ideal example is a seashell. There have been studies to computations generate such shell shape geometries. The geometry is formed using the following equations

$$x(\theta) = A\sin(\beta)\cos(\theta)e^{\theta\cot(\alpha)} \quad (1)$$

$$y(\theta) = A\sin(\beta)\sin(\theta)e^{\theta\cot(\alpha)} \quad (2)$$

$$z(\theta) = -A\cos(\beta)e^{\theta\cot(\alpha)} \quad (3)$$

where, A = the distance between the starting point of curve and the origin, θ = the angle made by the curve with X axis, α = the angle between Z-axis and the line from aperture local origin to XYZ origin and β = angle made by the line tangent to the curve with Z axis. Owing to the constraints of low wind velocities, one needs to explore the blade profiles for VAWTs, which performs better as such low wind speeds. The analysis of above natural inspired vertical axis wind turbine is done for

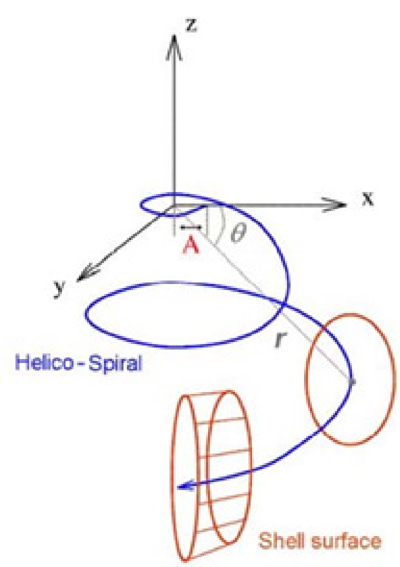



**Figure 7.** Profile created for a VAWT blade profile using Fibonacci curve equations.

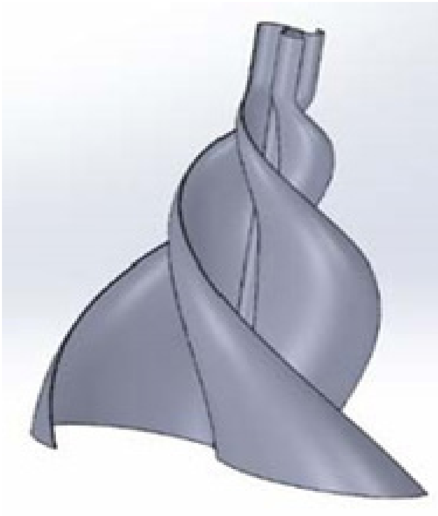


**Figure 8.** CAD model of nature inspired shape of VAWT blades.

the velocities 1.5m/s, 1.8 m/s, 2m/s, 3m/s and 4m/s resp. Table 2, shows the performance in terms of $c_p$ and RPM for one of wind turbines as shown in Figure 7. The curve thus obtained is used for modelling the blade profiles (as shown in Figure 8). Due care has been taken to avoid any clashing of surfaces during modelling.

Figure 9 and 10 shows the performance of the VAWT, in terms of pressure coefficient and RPM recorded for very low wind speeds. It is noted that, this configuration performs much better as compared to conventional Savonius rotor.

**Table 2.** Comparison of Conventional Savonius and nature inspired VAWT turbine

| Velocity (m/s) | Nature inspired | | Conventional Savonius | |
|---|---|---|---|---|
| | *Cp* | *rpm* | *Cp* | *rpm* |
| 3 | 0.136 | 139.546 | 0.103 | 134.282 |
| 4 | 0.176 | 202.513 | 0.108 | 181.850 |

Figure 11 shows comparison of experimental results with the numerical results for a nature inspired VAWT (NI-VAWT) blade profile configuration. For this computation, a 3-bladed NI-VAWT was adopted. We note that for increasing velocities, the increase in the *Cp* is consistent, as recorded for a conventional Savonius blade. However, the drag forces recorded are far higher than the former one. Figure 12 shows the time history

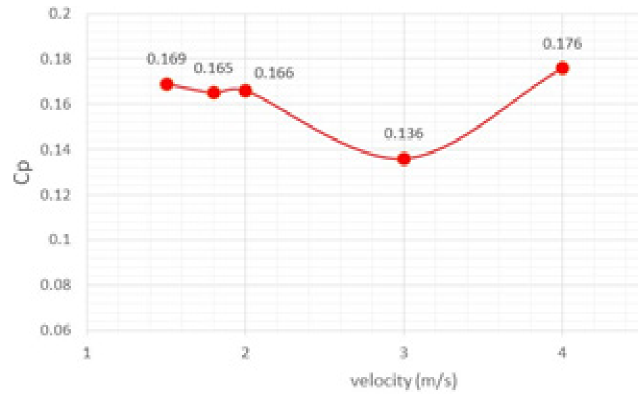



**Figure 9.** Pressure coefficient recorded for a nature inspired VAWT blade profile at low wind speeds.

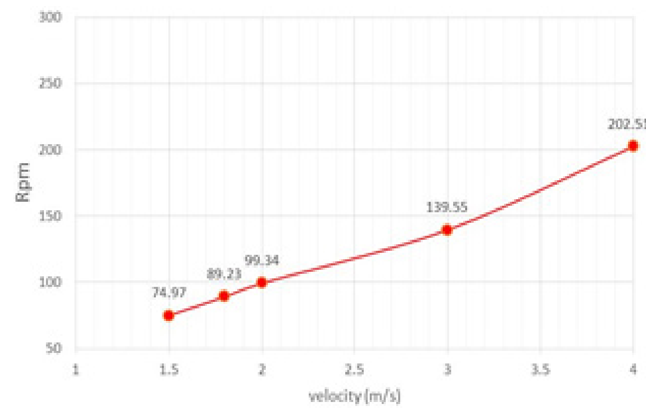



**Figure 10.** RPM recorded for a nature inspired VAWT blade profile at low wind speeds.

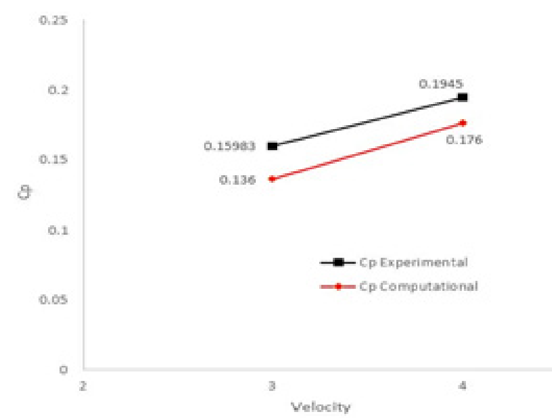



**Figure 11.** Comparison of computational results of nature in-spired VAWT blade profile with the experiments[19].

of the torque generated for the 3-bladed NI-VAWT. It is noted that after about a minute of operation, even at a low

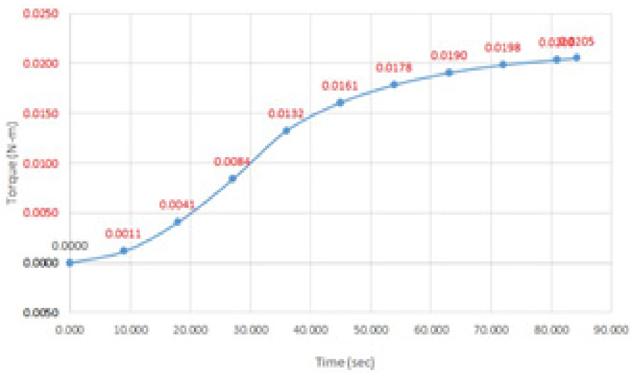



**Figure 12.** Time history of Torque generated for a nature inspired VAWT blade profile at V = 4m/s.

observe that there is huge aerodynamic unsteadiness in such flows. The wake region, indicative of pulsating feature may add to this unsteadiness. Further re-search is required to optimize these shapes to improve the aerodynamic performance.

## 5.0 Conclusions

To produce the power in domestic level and in urban areas for which the vertical axis wind turbine is a best option because of its ability to produce power at low wind speed, requires less space and cost efficient. In order to achieve these outcomes we used nature inspired geometric shape

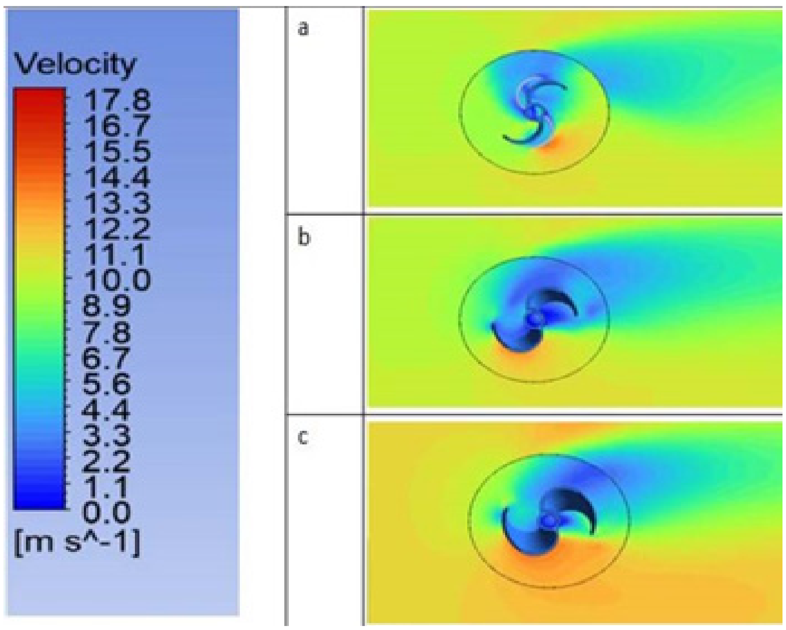



**Figure 13.** Velocity contours for nature inspired blade profile for V = 10.17m/s at (a) top, (b) middle and (c) bottom section.

velocity of $V$ = 4m/s, we can achieve a considerably higher torque, which remains almost constant with time for the given inlet velocity.

Figure 13 shows velocity contours for nature inspired blade profile for V = 10.17m/s at (a) top, (b) middle and (c) bottom section. The blade profile being convergent, as we move from bottom to top, experiences varying accelerated flow. At the bottom of the rotor, high velocity regions are noted, as compared to those at the top. This results in downward force, which in turn aids to keep the rotor intact on its mounting. It is noted for this simulation that the rpm achieved is in the range of 350-375. We

based on Fibonacci series. In rural areas power cut off is the main issue which can be solved by using our turbine because of its self-starting capacity. Though there have been many efforts for extracting as much wind energy as possible, very few efforts are seen for low wind speed terrains specifically. This is due to less efficiency of VAWTs. However, during the present investigation, it is noted that the proposed nature inspired VAWT blade profile can provide a sustainable answer to fulfil this demand. There is a need to investigate further to optimize the blade shape for the possible best efficiency, which is part of our future work.

From the present investigations, the following major observations are made.

1) Analysis of Conventional semi-circular Savonius turbine has been done and the results are in good agreement with the wind tunnel experiments of Saha[19].

2) As the number of blades increases the torque, thrust and lateral force decreases which reduces the power coefficient. To control the d/D ratio, 3-bladed turbines are preferred.

3) Eccentricity between 1D to 1.5D gives the higher efficiency. Out of the cases investigated, the best performance is noted for the turbine with 1.1D eccentricity.

4) From the results of nature inspired VAWT rotor, it is observed that these rotors attain high velocity which increases the RPM and also have high power coefficient and increases the overall efficiency approximately by 35%.

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