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# Computational Study of Savonius Vertical Axis Wind Turbine (VAWT) for Different Overlap Ratios

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## ABSTRACT

*Wind energy alone can fulfill most of the energy requirement of the world by its efficient conversion in to energy. Savonius wind turbine is the simplest type of vertical axis rotor that has a relatively low efficiency. Operation of the Savonius wind turbine is based on the difference of the drag force on its semi-spherical blades, depending on whether the wind is striking the convex or the concave part of the blades. Savonius wind turbine is being used in various countries around the world due to the simplistic design, cheap technology for construction, and a good starting torque independent of wind direction at low wind speeds. Due to its simple design and low construction cost, its rotor is mainly used for water pumping as well as wind power on small scale. The main goal of the current research work presented in the paper is to investigate the aerodynamic performance of Savonius wind turbine. The different set of designs of rotor blades with different overlap ratios are examined for their aerodynamic behavior at different Reynolds numbers.*

*3-Dimensional CAD models of three blade Savonius wind turbine rotor models with and without overlap ratio have been designed in ANSYS. Moving mesh and fluid flow simulation have been developed in CFD software FLUENT. Numerical investigation was also performed to determine torque and power coefficients using FLUENT to analyse aerodynamic characteristics of these models. The paper presents contours of pressure distribution around the Savonius turbine rotor models and calculates drag coefficients. For several values of Reynolds number, the Pressure contours, velocity contours and torque coefficient are presented. Calculation of the numerical power coefficient and torque coefficient of models is also discussed. The paper recommends the relevant applications and the utility of different designs of Savonius* *wind turbine with an aim to obtain max power and torque coefficients.*

***Keywords:—****Savonius wind turbine, Vertical axis wind turbine, Power Coefficient, Overlap ratio.*

## I. INTRODUCTION

Wind energy has the potential to resolve the power demand of the entire world if it can be converted into electricity efficiently. Wind is going to be the most popular alternative energy source; because of its availability throughout place and time. As a pollution free and sustainable source, wind is getting importance in energy policy too. The disadvantages are its lower efficiency and high installation cost. But the ultimate cost would be lowered if it operates continuously and small scale turbines can be installed in any corner of the world.

## II. LITERATURE REVIEW

Wind turbine aerodynamics must be designed for optimal output to exploit the wind energy in a specific location. The problem remains both challenging and crucial. Much research has been conducted on Savonius rotors with two semi-cylindrical blades and S-shaped rotors with various flow parameters. Ramesh K and Pravin M. Ghanegaonkar[1] analysed turbine power of hybrid turbine with combination of 3 Savonius and 3 aerofoil is quite good at wind speed range 2-8 m/s compared to other combinations. Savonius turbine with three blades performs better at low wind speed than two and four blades Savonius turbine. Aerodynamic characteristics of turbine depends mostly on geometry of the turbine. Yingkang Du [2] has proved that the rotors with end plates show a much better performance than the rotors with bar connection, the structure of rotors has a big influence on the efficiency. A. Sanusi, S. Soeparman, S. Wahyudi and Lilis Yuliati's[5] research includes the use of shaft linking the end plates can decrease the performance of turbine due to the influence of inertia and the change of ratio overlap. Zulfa ferdous, Md. Quamrul Islam and M. Ali[4] suggested that the value of maximum power coefficient is higher for higher Reynolds number. As the Reynolds number increases, the value of maximum power coefficient is shifted towards the higher tip speed ratio.

## III. VERTICAL AXIS WIND TURBINES

VAWT may be more appropriate than HAWT in small scale. VAWTs are suitable for electricity generation in the conditions where traditional HAWTs are unable to give reasonable efficiencies such as low wind velocities and turbulent wind flows. The quiet behavior is more attractive for highly populated places. The cost of complex structure of HAWT blades is higher than simpler VAWT blades. Such type of rotor can be installed in remote places, away from the main distribution lines and places where large wind farms cannot be installed due to environmental concerns.

### *3.1. Savonius Rotor:*

The operation of Savonius rotor depends on the difference of drag force when the wind strikes the concave and convex part of the semi-spherical blades. The flow energy utilization of Savonius rotor is lower than that of Darrieus rotor. Hence such type of turbine is generally not used for high-power applications and usually used for wind velocimetry applications. The greatest advantage of a Savonius rotor is its ability to self-start in contrast to other 'Lift type' VAWT.

### *3.2. Performance of Savonius turbines*

The Savonius rotor is very robust, simple to construct and is characterized by a high starting torque. It has many advantages, including a simple design, and the ability to operate in any wind direction, though it has a low aerodynamic efficiency.

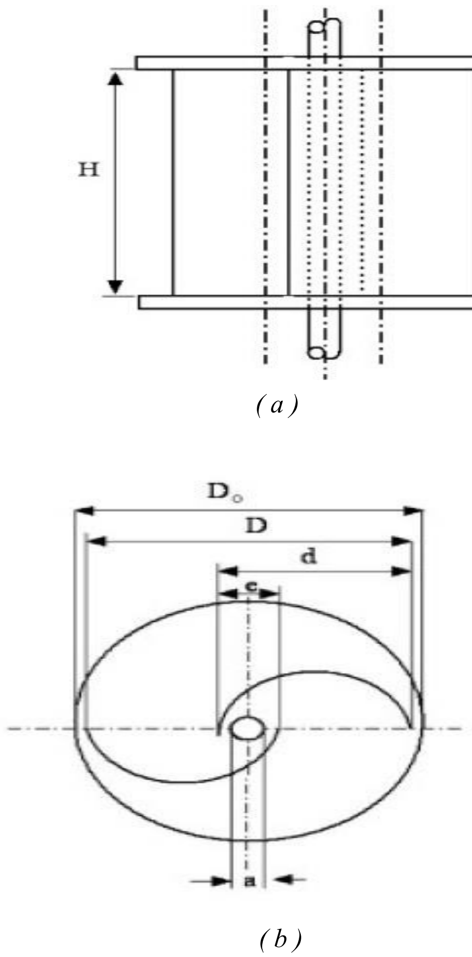



*Figure 3.1: Front (a) and Top (b) views of savonious turbine rotor*

### *3.2.(a). Aspect ratio (α):*

It is the ratio of the height of the turbine blade to the diameter of the rotor given by,

$$\alpha = \frac{H}{D}$$

where H and D are the rotor height and the rotor diameter respectively.

### *3.2.(b). Overlap ratio (β):*

It is the ratio of the radius of the shaft (a/2) at the centre subtracted from the half of the overlap distance between the blades (e/2) to the diameter of the blade(d) given by,

$$\beta = \frac{\frac{e}{2} - \frac{a}{2}}{d}$$

where β is the overlap ratio and e is the overlap length.

The air at velocity U produces mechanical torque T, and mechanical power P on a turbine. By defining the swept area (As) for the Savonius rotor as the height H multiplied by diameter d,

Swept Area $A_s$ = H×d

Mechanical power P = ω T

the torque coefficient ($C_q$) is given by,

$$C_q = \frac{T}{\frac{1}{4}\rho A D V^2}.$$

and the power coefficient ($C_p$) is given as,

$$C_p = \frac{P}{\frac{1}{2}\rho A V^3} = \frac{T\omega}{\frac{1}{2}\rho A V^3} = C_q \times \lambda.$$

### *3.2.(c). Tip Speed Ratio (TSR)*

$$TSR = \lambda = \frac{Vtip}{V} = \frac{\omega R}{V}$$

The tip speed ratio λ or TSR is defined as the ratio between the rotational speed of the tip of the blade and the actual velocity of the wind such as, Where $V_{tip}$ (m/s) is rotor tip speed and λ is the angular velocity of rotor in rad/s.

## IV. PROBLEM DEFINITION

The present study is to investigate the aerodynamic characteristics of three bladed Savonius wind turbines in order to contribute in the performance improvement of vertical axis wind turbine (VAWT). As previous research suggests that design of turbine blades may responsible for the efficiency improvement of savonious wind turbine. It influences the modification of the rotor blade with different overlap ratios and to examine aerodynamic behaviour of savonious wind turbine models at different Reynolds numbers. The present analysis may give answers for appropriate conditions where wind turbine to give max power and torque coefficients.

## V. RESEARCH METHODOLOGY

The research objective is to find the highly efficient Vertical Axis Wind Turbine by studying the aerodynamic characteristics of the blades of Savonius rotor. In the present work, aerodynamic characteristics of a three bladed Savonius vertical axis wind turbine (VAWT) with different overlap ratios are investigated. The computational investigation was done using ANSYS. The mesh was generated with ANSYS and basic investigation was run on FLUENT to determine the aerodynamic coefficients; such as power and torque coefficients.

### *5.1. Three Bladed Savonius rotor Models*

To observe the effect of overlap ratio (ratio between the distance of the two adjacent blades and rotor diameter) and Reynolds number on the aerodynamic characteristics of the Savonius rotor, three different rotor models with and without overlap ratio were designed. Dimentions of models are taken from study conducted by Khandakar Niaz Morshed [3].

### *5.1.(a). Savonius Rotor Model 1*

The three bladed Savonius rotor model called Model 1 with no overlap between adjacent blades was designed. The model was made of three semi-cylindrical blades of diameter, d = 127 mm, and height, H = 300 mm. The central shaft was removed from the turbine model. The blades were 120° apart from each other and the overall rotor diameter was D = 248 mm for the Model 1. Triangular mesh with 49102 nodes and 250755 elements is generated.

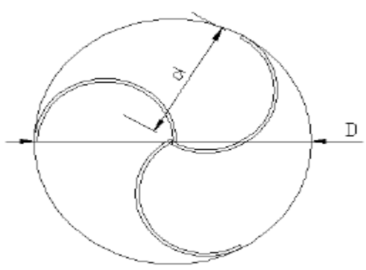



*Figure 5.1: Top view of Model 1*

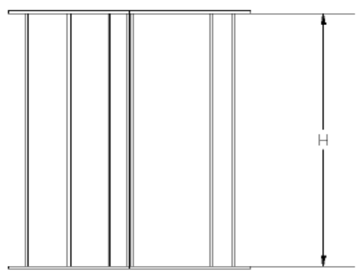



*Figure 5.2: Front view of Model 1*

### *5.1.(b). Savonius Rotor Model 2*

Savonius rotor Model 2 with overlap distance between adjacent blades, a = 25 mm, was designed. The model was made of three semi-cylindrical blades of diameter, d = 127 mm, and height, H = 300 mm. Overall rotor diameter was D = 216 mm for the Model 2. Overlap ratio for Model 2 was 0.12. Triangular mesh with 45552 nodes 234688 elements is generated.

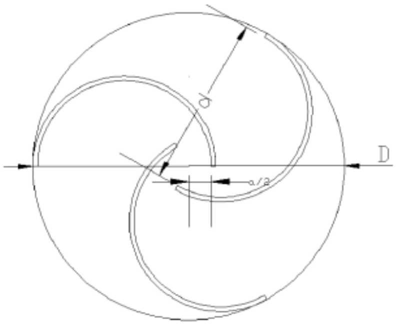



*Figure 5.3: Top view of Model 2*

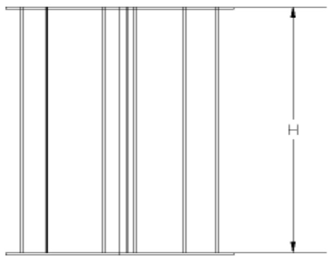



*Figure 5.4: Front view of Model*

### 5.1.(c). Savonius Rotor Model 3

Savonius rotor Model 3 with overlap distance between adjacent blades, a = 50 mm, was designed. The model was made of three semi-cylindrical blades of diameter, d = 127 mm, and height, H = 300 mm. The blades were 120 mm apart from each other and the overall rotor diameter was D = 192 mm for the Model 3. Overlap ratio for Model 3 was 0.26. Triangular mesh with 44190 nodes and 226939 elements is generated.

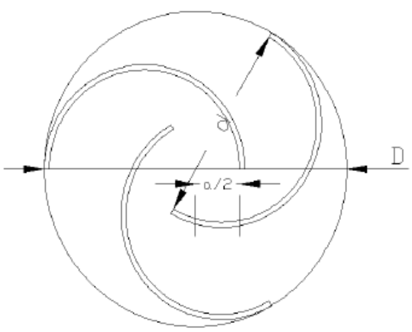



*Figure 5.5: Top view of Model 3*

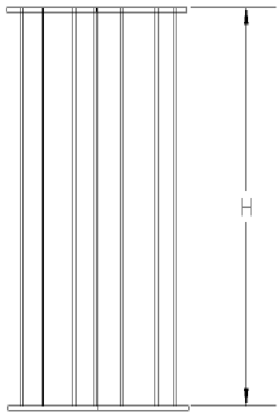



*Figure 5.6: Front view of Model 3*

## 5.2. Selection of Model

### 5.2.1 Procedure

The k-ε turbulence model was used for the computational flow simulation around the Savonius rotor models with different overlap ratios. Commercially available software FLUENT was used to solve the turbulent flow field and for mesh generation around the rotor models. The simulation provides the pressure and velocity values at all nodal points of flow domain around the rotating blades. The pressure-velocity coupling is achieved using the well- known SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) method. Turbulent kinetic energy (k) and turbulent dissipation rate (ε) second order upwind scheme was chosen for the momentum equation solution. Boundary conditions are the left side is open with inlet free stream velocity, and the right side is open with an atmospheric pressure outlet. Inlet air velocity was considered as 9 m/s, 8 m/s, and 7 m/s, air density was considered 1.225 kg/ m3. The blades were considered as stationary walls and their rotational velocity was provided from the rpm measured during the experiment.

## VI. Results and Discussion

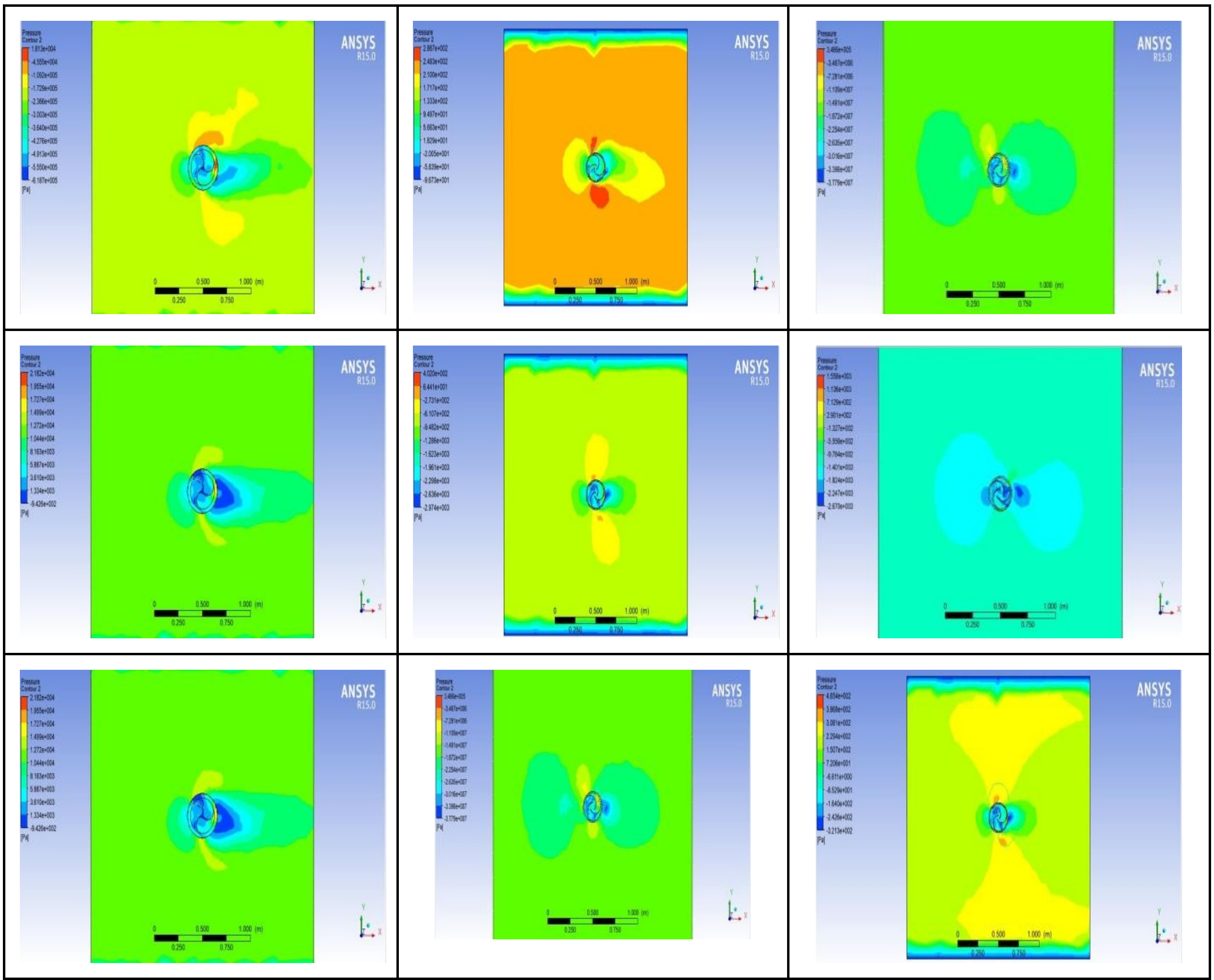
### *6.1. Results*

#### *6.1.1. Pressure Contours for Three Models at Three Velocities*

Pressure contours generated from numerical simulation of three models for three different velocities are shown in figure 6.1. The negative pressure is creating pressure difference between concave and convex surface that eventually rotates the turbine blades.

#### *6.1.2. Velocity Contours for Three Models at Three Different velocities*

Contours of velocity magnitude for Savonius rotor Model 1, model 2 and model 3 at velocities 7 m/s, 8m/s, 9m/s are shown in Figure 6.2. Once the wind strikes the turbine blades the velocity starts to decrease at the trailing edge of the Savonius wind turbine model but after some distance travel stars to regain the velocity. From these figures it can be seen that with the increase of overlap ratio the lower velocity region shorten after the trailing edge and come closer to the turbine blades.




*(a)* *(b)* *(c)*

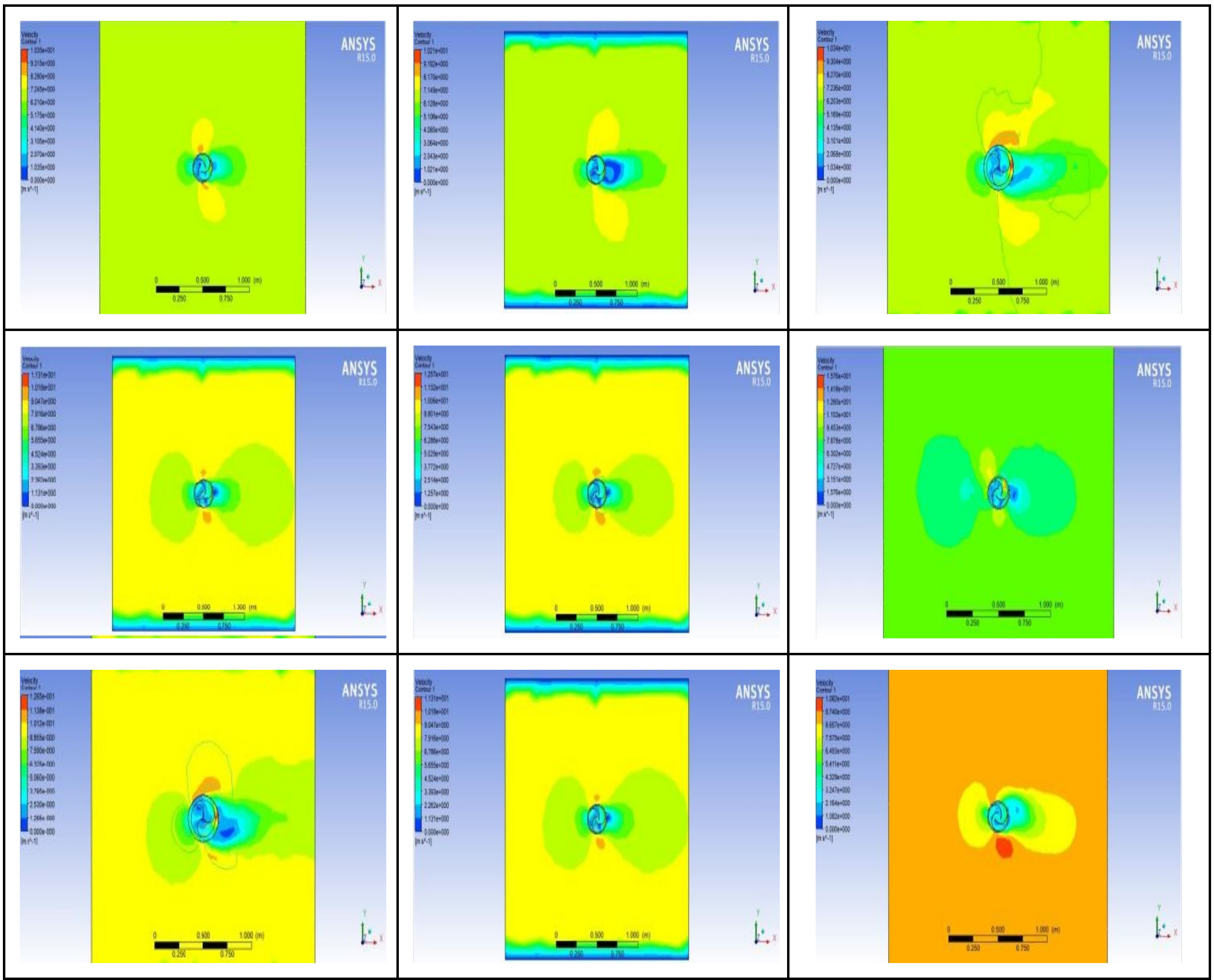
*Figure 6.1 Pressure Contour around Savonius rotor (a) model 1, (b) model 2, (c) model 3 at three different speeds.*

### *6.2. Torque and Power Coefficient Variation for Three Individual Savonius VAWT Models:*

Torque and power coefficients of Savonius wind turbine models were calculated for three different velocities. Torque coefficient was calculated for combined blade effect at every 30° interval 0° to 360° of turbine models.

Three velocities for Model 1 were 7 m/s (Reynolds number =1.22×105), 8m/s (Reynolds number =1.37×105) and

9m/s (Reynolds number=1.61×105 ). For every velocity the values of torque coefficient increase from 0° to 30° and then start to decrease at 150°. The same pattern repeats for the blade angle from 150° to 240° and from 240° to 330°. There was negative torque coefficient is observed at for 8 m/s at 1500 for model 1. It is desired to remove the negative torque for all rotor positions. The model shows better torque coefficient for wind speed 9 m/s (Reynolds number 1.61×105). From the figure for model 2, it can be seen that the torque coefficient increases from 0° to 60° and decreases at 90° again increases at 1200. There was negative torque coefficient is observed for 9 m/s at 2100 for the present model. The same pattern repeats for the



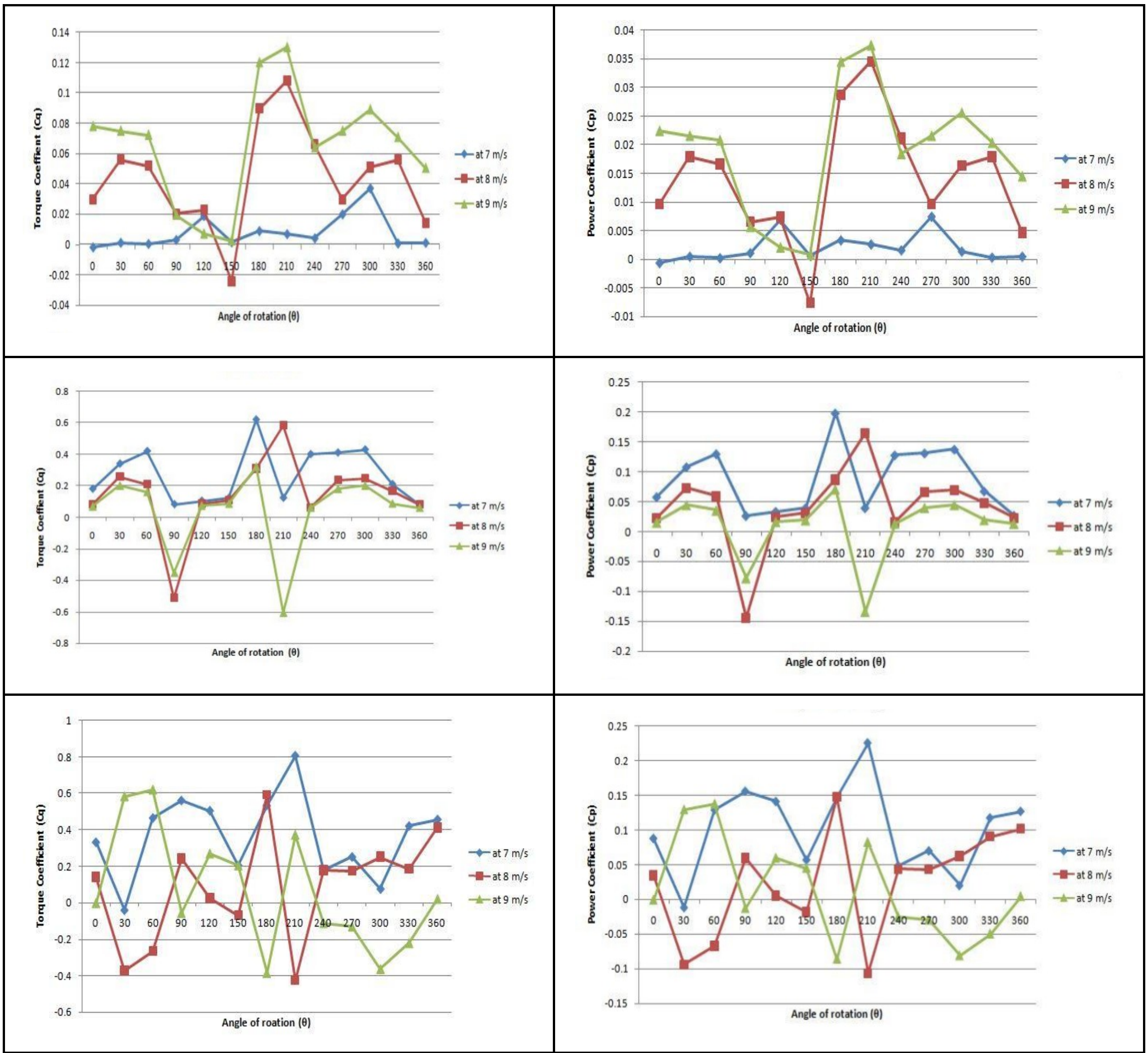
*(a)* *(b)* *(c)*

*Figure 6.2 Velocity Contour around Savonius rotor (a) model 1, (b) model 2, (c) model 3 at three different speeds.*

blade angel from 150° to 210° and from 240° to 330°. The model shows better torque coefficient for wind speed 7 m/s (Reynolds number 1.06×105). For Model 3, there was negative torque coefficient is observed at 8 m/s at 300 and 2100 for the model. The model shows better torque coefficient for wind speed 7 m/s (Reynolds number 9.44×105 ).

### *6.3. Torque Coefficient and Power Coefficient Variation at Three Different Wind Speeds:*

Figure 6.3 shows power coefficient (Cp) variation with angle of rotation (θ) from 0° to 360° for Model 1. Trends of the plots are similar for velocities 8 m/s and 9 m/s (Re = 1.61×105 and 1.37×105). Power coefficient was negative at 150° for 8 m/s. For the model, better power coefficient variation occurred at 9 m/s (Re =1.61×105).




| (a) | (b) |
|---|---|

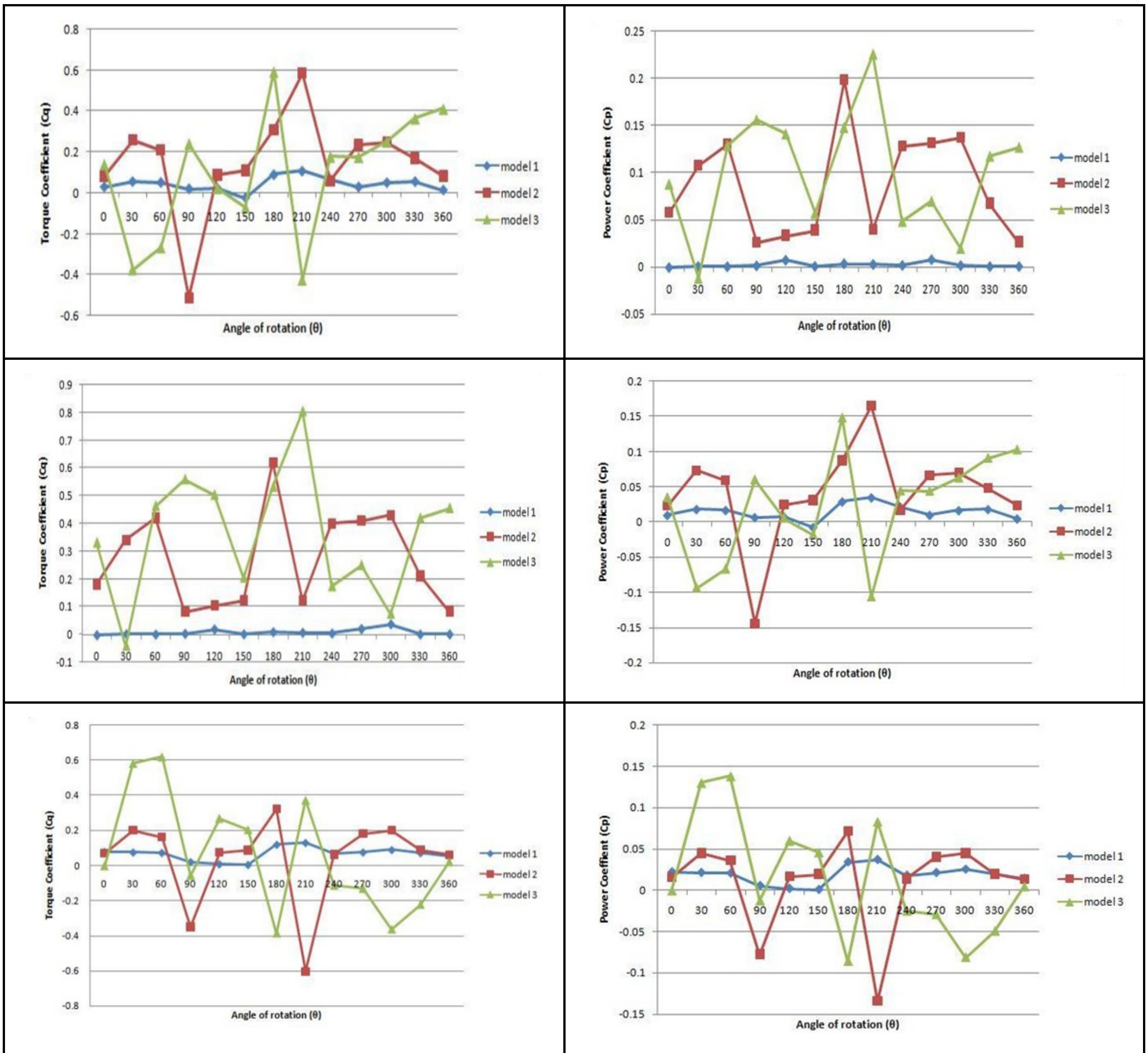
*Figure 6.3 : (a) Torque Coefficient (Cq) versus Angle of Rotation (θ), (b) Power Coefficient (Cq versus Angle of Rotation (θ) for Model 1, Model 2, Model 3 at three different speeds*

For model 2, better power coefficient variation occurred at 7 m/s. Model 3 shows negative power coefficients at 8 m/s and 9 m/s at some angle of rotations. For model 3, better power coefficient variation occurred at 7 m/s.

Figure 6.4 : ( a ) Torque Coefficient (Cq) versus Angle of Rotation (θ), (b) : Power Coefficient (Cq) versus Angle ofRotation (θ) at wind speed of 7 m/s, 8m/s, 9m/s for three models.

### 6.4. ***Torque*** Coefficient ***(Cq) for different Reynolds numbers***

Figure 6.5 shows the numerically calculated torque coefficient (Cq) variation with different Reynolds number (Re) for three different models. With the increase of Reynolds number torque coefficient slightly increases for all three models and decreases




| *(a)* | *(b)* |
|---|---|

*Figure 6.4 : ( a ) Torque Coefficient (Cq) versus Angle of Rotation (θ), (b) : Power Coefficient (Cq) versus Angle of Rotation (θ) at wind speed of 7 m/s, 8m/s, 9m/s for three models.*

except for model 1. Model 2 gives better torque coefficient compared to other two models.

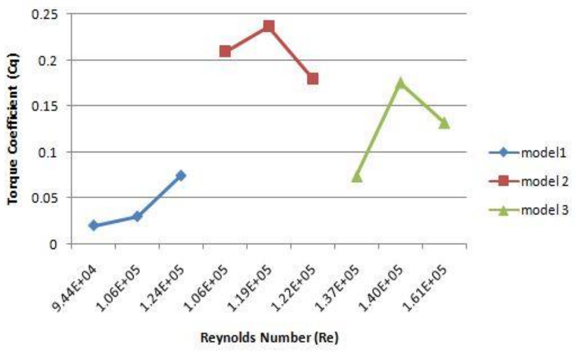



*Figure 6.5 : Torque Coefficient (Cq) versus Reynolds Number (Re) for three models*

***6.5. Power Coefficient for different tip speed ratios***

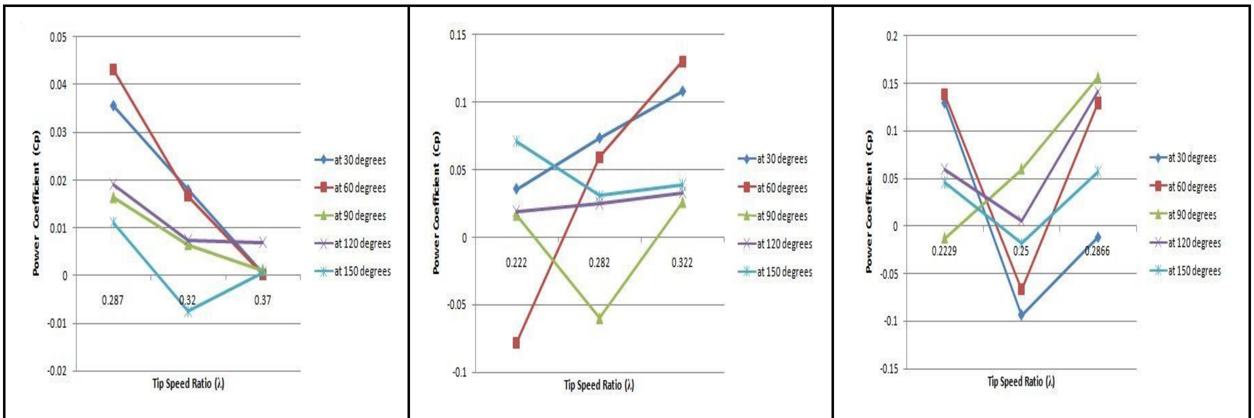
Figure 6.6 shows the comparison of numerically obtained power coefficient (Cp) of the three Savonius rotor Models with the increase of tip speed ratio (λ).power coefficient values were considered at all tip speed ratios for numerical at 30°, 60°, 90°, 1200 and 1500 were considered.

Figure shows that for model 1 power Coefficient keeps decreasing from 300 to 1500 as tip speed increases. And model 1 shows negative power coefficient at 0.32 tip speed ratio at 1500. Figure 6.6 (b) shows that for Model 2, Power Coefficient increases at all positions except for 900 at tip speed ratio of 0.282. And there is a huge increment of power coefficient at 600 angle position. Figure (c) shows that for Model 3 power coefficient follows similar pattern from 300 to 1500.

## VII. Conclusions

It can be concluded from figure 6.3 that model 1 exhibits good torque and power coefficients at high speeds like 9m/s. Model 2 and model 3 shows better power and torque coefficients at low velocities like 7m/s. Hence, it is recommended to use model 1 at higher speeds and model 2 and model 3 at lower speeds.

Model 3 is preferred at low speeds as it touches maximum power coefficient at few positions of the rotor. From figure 6.5, for model 1 with the increase of Reynolds number, torque coefficient increases. Torque coefficient of model 2 increases upto 1.19×105 and then decreases. torque coefficient of model 3 increases upto 1.40×105 and then decreases. Model 2 exhibits better torque coefficients in the range of Reynolds numbers 1.06×105 to 1.37×105. And it is suggested to use Model 2, which works better at high Reynolds numbers. Power coefficient obtained from




| (a) | (b) | (c) |
|---|---|---|

*Figure 6.6: Power Coefficient (Cp) versus Tip speed ratio (λ) for Model 1, Model 2, Model 3*

numerical method shows that it is always increasing with the increase of tip speed ratio for model 2 and model 3. And model 2 can be recommended for higher tip speed ratios.

**REFERENCES:**

[1] Ramesh K. Kavade and Pravin M. Ghanegaonkar: Design and Analysis of Vertical Axis Wind Turbine for Household Application, 2017, JOCET 2017 Vol.5(5): 353-358 ISSN: 1793-821X.

[2] Yingkang Du : An Orthogonal Savonius-Type Wind Turbine: Design And Experiments, 2016.

[3] Khandakar Niaz Morshed "Experimental and Numerical Investigations on Aerodynamic Characteristics of Savonius Wind Turbine with Various Overlap Ratios", 2013.

[4] Zulfa ferdous, Md. Quamrul Islam and M.Ali: A Comparetive Analysis Of Aerodynamic Charecteristics of A Vertical Axis Vane Type Wind Turbine Over Even and Odd Number of Blades, 2015.

[5] Arifin Sanusi, Sudjito Soeparman, Slamet Wahyudi and Lilis Yuliati:Experimental Study of Combined Blade Savonius Wind Turbine, 2016, International Journal of Renewable Energy Research,Vol. 6, No. 2,2016.

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