

COMPUTATIONAL ANALYSIS ON SAVONIOUS VERTICAL AXIS WIND TURBINE TO ENHANCE THE PERFORMANCE

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ABSTRACT: Savonius wind turbine is the simplest type of vertical axis rotor that has a relatively low Efficiency, but can operate throughout the year even with wind speed as low as 4 to 5 m/s. Operation of the Savonius wind turbine is based on the difference of the drag force on its semi-cylindrical blades, depending on whether the wind is striking the convex or the concave part of the blades. This turbine is being used in various countries around the world due to the simplistic design, ordinary workmanship for construction, and has a good starting torque along with independency towards wind direction at low wind speeds. The main goal of this current research is to investigate the aerodynamic performance of Savonius wind turbine. The numerical study conducted in this paper aims to investigate the effect of number of blades on the performance of the model of Savonius type wind turbine. Numerical investigation on 2, 3, and 4 blades wind turbines has been carried out using ANSYS FLUENT 15.0 to show torque and power coefficient related with wind speed on different tip speed ratios. The results of study showed that number of blades influence the performance of wind turbine. Savonius model with three blades has the best performance at Tip speed ratio 1.0 when compared to other blades. Moreover, significant improvement was observed in the torque and power coefficients on all the three blades as the free-stream velocity increases.

INTRODUCTION

The continuous improvement of this world is based on technological advancement. And the technological advancement is directly related to the utilization of energy. The demand of energy is creeping up every day due to increase of population, industrial and agricultural advancement. But the conventional energy sources are becoming limited which is ultimately making them more expensive. In addition to this, everyone is concerned about global climate change. This whole scenario is pushing the world to find the alternative sources of energy.

Literature Review

Researchers have been conducting lots of experiments on HAWT, because of its high efficiency. In some way, researchers have been trying their best to find the best from Darrieus rotor. Meanwhile, significant numbers of researchers have been working to improve the aerodynamic characteristics of Savonius turbine. These researches are numerical and theoretical prediction for flow around the wind turbines and from that it varies from research laboratories to full scale simulation.

Savonius and Darrieus Type Wind Turbine

The Savonius wind turbine was first used by a Finnish Engineer S. J. Savonius in 1931(Savonius 1931). The design of his rotor was S-shaped with two semi-circular buckets with small overlap. At that time this rotor was successfully used as an ocean current meter. In 1931, G. J. M. Darrieus in France patented another VAWT named Darrieus vertical axis rotor. This type of rotor was not self-starting.

Reviews on Savonius Rotor

The optimum output from the wind energy is the key objective of the investigation and different aerodynamic shapes of the blades are designed to verify the outcome. Numerous investigations had been carried out in the past to study the performance characteristics of Savonius rotor. These investigations included wind tunnel tests, field experiments and numerical studies.

Changing the Overlap Ratio of Blade

The performance of two bladed Savonius turbine with five overlaps of 16.2%, 20%, 25%, 30% & 35% were investigated. Among them 16.2% overlap condition showed maximum power extraction.

Changing the Shape of Blade

(Qasim et al. 2011) worked with impeller scoop-frame type with movable vanes wind turbine VAWT. The objective was to maximize the drag factor by closing the vanes on convex shape and open when air hit the concave part. Due to movement of vanes for and against of wind, a higher drag factor had worked on the impeller scoop-frame type with movable vanes, and had higher efficiency than flat vanes.(Manzoor et al. 2008) experimented on Savonius rotor to compare the performance of twisted blade.

Changing the Stage

(Ghosh, et al. 2009) have experimented Single- and three-stage modified Savonius rotors, which are extensively tested in front of an open jet wind tunnel. With the increase in the Reynolds number both the single- and three-stage rotors shows higher coefficient of power. The three-stage rotor showed positive and uniform coefficient of static torque. Here the number of blade also had some effect.

SUMMARY

Many research papers, published in leading international journals regarding the improvement of Savonius Turbine performance were collected and the important findings are critically reviewed. Several techniques were incorporated by researchers for improving the efficiency and self-starting capability of the Savonius rotor. It has been reviewed that, the performance of the wind rotors will be examined based on the variation of the dynamic torque and power coefficient with respect to Tip Speed Ratio for a constant Reynolds number.

There is an immense potential, scope and opportunities for the researchers to investigate and predict the performance of various Savonius rotor configurations, numerically and experimentally, by employing different procedures. The main objectives of this study are: To improve the performance of the Savonius Wind Turbine by blade profile modifications.

Diameter of the Rotors	0.15 m
Height of the Rotors	0.13 m
Aspect Ratio	0.7
Frontal Projected area	0.019125 m ²
Blade Overlap Gap Distance	0.0225 m
Blade Separation Gap Distance	0 m
Blade Thickness	0.002 m

Geometrical parameter of the Rotor under study

The geometry of the blade profile is defined by spline curves connected through a set of three coordinates or characteristics points. The aim of this project is to analyze the blade configuration of the Savonius rotor with the help of CFD and relatively determine the performance. Due to this, the geometrical parameter of the rotor is retained to the same values. By doing so, we determine the influence of blade profile modification on the rotor performance.

SLIDING MESH MODEL

Several solution strategies exist when there are moving parts or zones in the fluid solution domain. Fluent has a unique capability of moving cell zones, which serves as a powerful tool in solving the problems involving moving parts like wind turbines. Fluent also provides three different approaches in analysing these kinds of fluid domains. They are,

1. The multiple reference frame (MRF) model
2. The mixing plane model and
3. The sliding mesh model

Both MRF and mixing plane model assume that the flow field is steady and accounts for the rotating - stationary domain interaction by approximate means. On the other hand, sliding mesh model considers the flow field to be unsteady and models the interaction with complete reliability.

Modelling the fluid domain

The modelling was done in the Gambit 2.4.6. The sliding mesh model requires two cell zones interfaced to slide relative to one another along the interface. Two such zones were modelled - one stationary and one rotating zone.

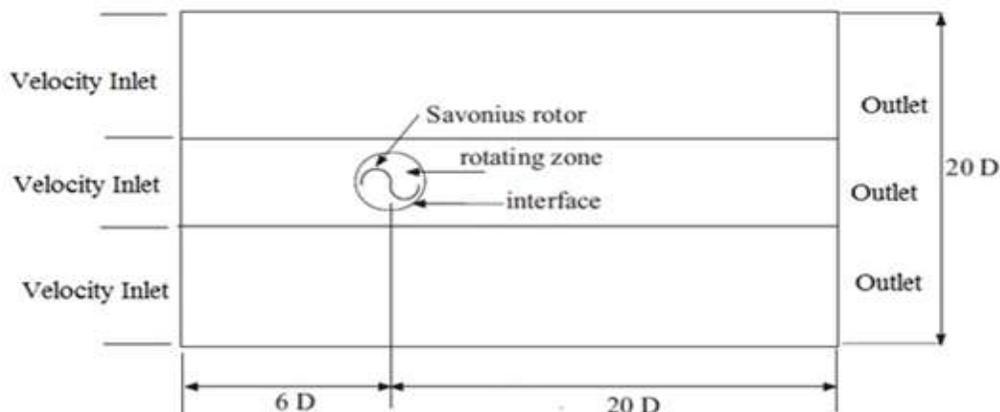
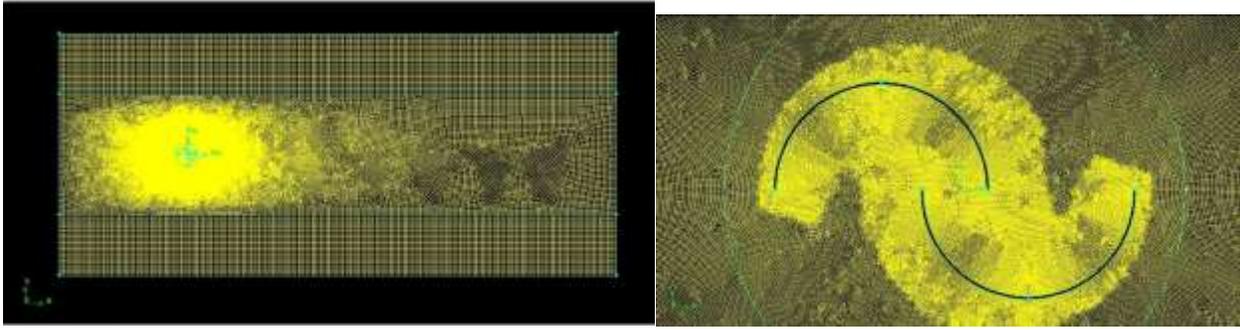


Figure 4.1 – Two-dimensional computational domain



Mesh pattern in the domain of computation using Gambit

The rotating zone consists of the turbine blade. The diameter of the rotating zone is twice that of the rotor diameter. The size was chosen because the vortex structures that are close to the rotor are solved in the rotating frame of reference. The rotating zone is surrounded by a stationary zone as shown in Figure 4.1. Meshing is done in the Gambit 2.4.6. The simulation domain consists of two parts and two bodies. The simulation domain is to be meshed into two cell zones. The edges and faces are named appropriately for easy identification. Meshing is done by Adaptive Mesh refinement. Since, the simulation domain is a two dimensional domain, a structured Quad Mesh is done.

The number of cell zones is two and the number of face zone is twelve. The simulation of a Savonius wind turbine using sliding mesh model is a transient problem. However for the analysis of static torque coefficient the problem may be assumed as a steady state problem. The inlet boundary condition is given as the free stream velocity calculated from the Reynolds Number while the outlet boundary condition is given as a pressure boundary condition and is equated to the atmospheric pressure. The analysis was at a very low speed and hence incompressibility conditions were assumed. The rotor blades were designated as smooth walls with no slip condition.

Cell zone conditions

The cell zone condition for the rotating zone should be set to Mesh motion. The rotational velocity of the mesh should be specified which can be calculated from the tip speed ratio. No motion is set to the stationary cell zone.

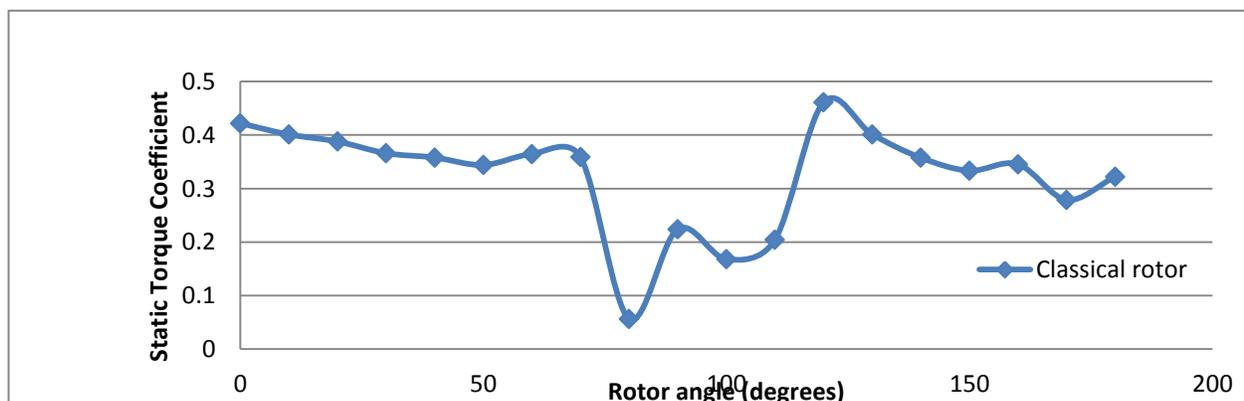
Turbulence Modelling

$k - \omega$ SST model is a two equation eddy-viscosity model well suited for viscous sub layer. Its two variables are turbulent kinetic energy and specific rate of dissipation. The suitability of $k - \omega$ SST model is because of its high boundary layer accuracy. SST models are less sensitive to free stream conditions outside the boundary layer. Shear stress limiter avoids over prediction of turbulence kinetic energy near stagnation points.

Solution

The pressure velocity coupling, is based on the SIMPLE (Semi Implicit Method for Pressure Linked Equations) algorithm. The transient formulation is based on First Order Implicit. The solution initialization values are computed from the inlet boundary conditions. The Coefficient of Moment is monitored by the force monitors and the value for each and every time step is written and stored in a separate text document. A relationship between the time step and the Coefficient of moment is plotted. When the calculation is run, this graph is simultaneously monitored until a periodicity is achieved. Then the average moment coefficient in one particular cycle is calculated. The findings for rotor blade configuration at different tip speed ratios are tabulated and then compared graphically. The classical rotor blade configuration was analysed using ANSYS Fluent 15.0 in order to estimate the performance of the Savonius rotor. The performance characteristic of a Savonius turbine is defined by the dynamic torque and power coefficient variations with respect to the Tip Speed Ratio (TSR) under a constant free stream condition. The power output of the turbine is calculated from the aerodynamic power coefficient. In addition to this, the static torque coefficient at different rotor angles for the same free stream condition was also estimated. The assessment was performed to interpret the self-starting capability of the rotors at different angular positions. This chapter presents the results obtained during the computational studies and compares the performance of the Savonius rotor under different operating conditions like tip speed ratio.

Variation in Static torque coefficient for Classical Rotor

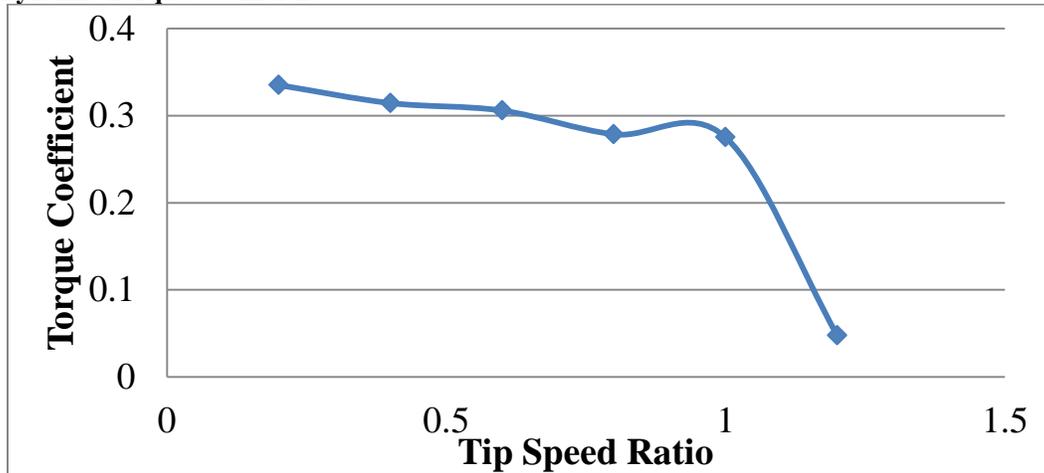


DYNAMIC TORQUE AND POWER COEFFICIENTS

The performance of the Savonius rotor is a measure of the capability of the rotor to harvest power from the wind. The power coefficient is the fractional measure of the amount of energy possessed by the wind that has been collected by the turbine. The torque coefficient is a measure of the load carrying capability of the turbine. Both of these performance parameters depends on various other geometrical and flow parameters. Among them, the Tip Speed Ratio is an important factor.

TSR	C_t (Torque Coefficient)
0.2	0.3351
0.4	0.31443
0.6	0.30585
0.8	0.27855
1.0	0.2751032
1.2	0.047586

Effect of TSR on the Dynamic Torque Coefficient



Variation of Dynamic Torque Coefficient with respect to the Tip Speed Ratio (TSR)

From the above expression it's evident that C_p is a function of TSR. Therefore, the variation of C_p with respect to the TSR has been calculated based on equation 5.7 for classical rotor and the results have been plotted.

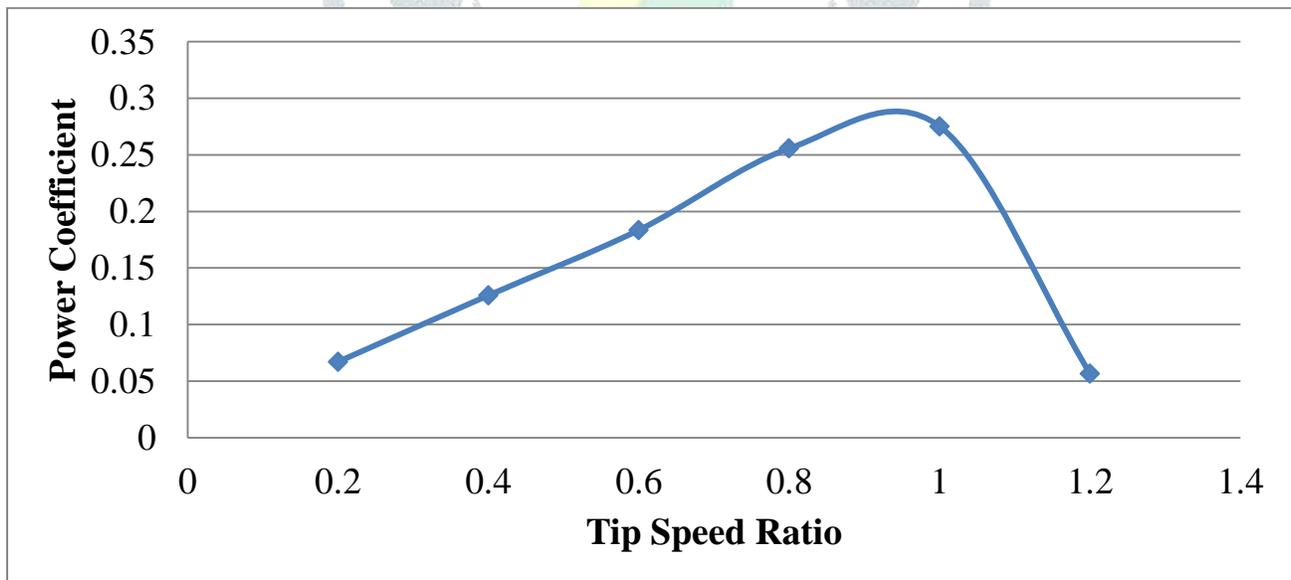
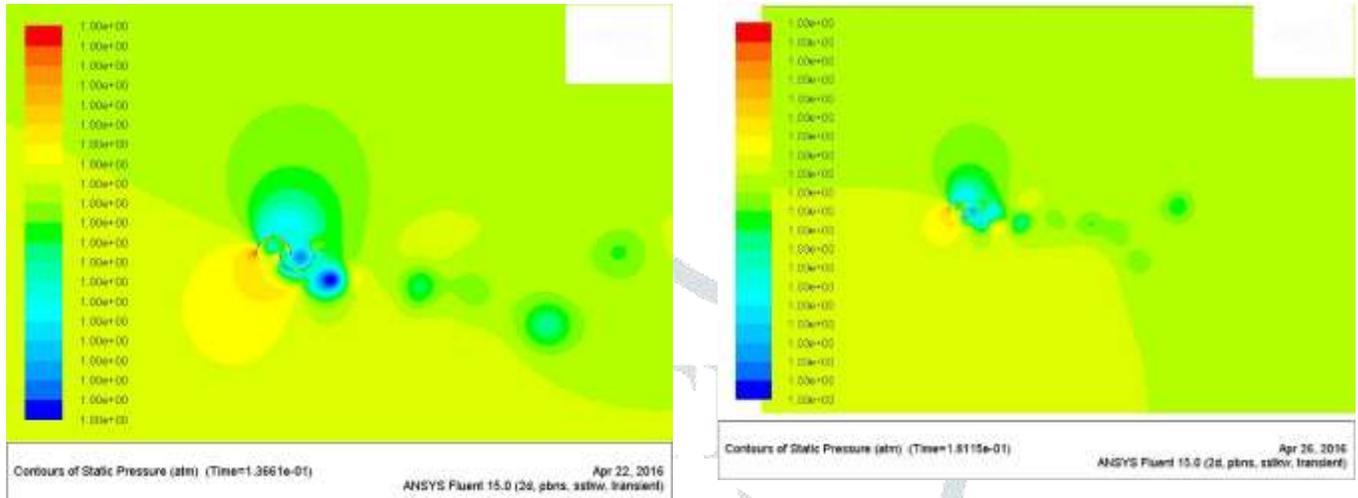


Figure 5.3 – Variation of Aerodynamic Power Coefficient with respect to the Tip Speed Ratio (TSR)

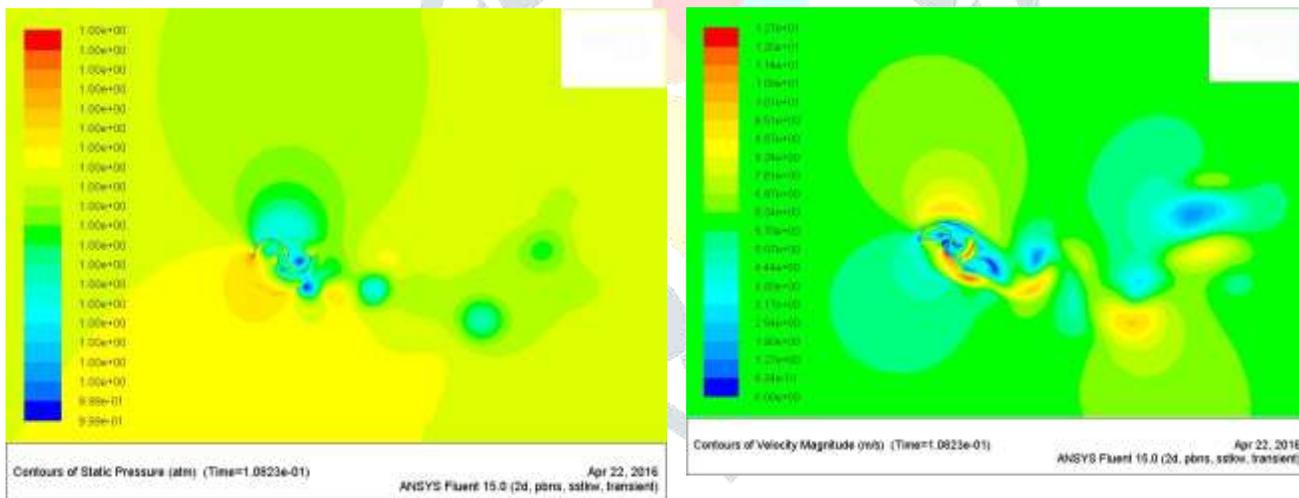
TSR	C_p (Power Coefficient)
0.2	0.067036
0.4	0.12577208

0.6	0.1835
0.8	0.25564
1.0	0.2751032
1.2	0.0566

Effect of TSR on the Aerodynamic Power Coefficient



Pressure contour for Classical rotor at TSR= 1.0 Pressure contour for Classical rotor TSR=0.8



CONCLUSION

The analysis work was successfully done using the commercially available CFD package. The present study focuses on the numerical analyses on Classical or Conventional rotor. The performance characteristics like the dynamic torque coefficient and the aerodynamic torque coefficient are examined and the results were compared. The static torque coefficient of classical rotor blades at different rotor angles has been computationally determined. The results show that Rotor is free from negative torque coefficients. Also the maximum value of C_{st} is observed in the range of 120-140 degrees while the minimum value of C_{st} is observed in the range of 65-75 degrees.

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