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Performance Analysis of a Conventional Savonius Wind Turbine

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ABSTRACT

In present simulation study, the performance of a conventional Savonius wind turbine is studied with respect to static torque coefficient (Cts.). Simulation study is carried out with the help of Ansys Fluent software. The results obtained after conducting simulation study, are then compared with the experimental results obtained by Kamoji et. al [3] and the results show that Conventional Savonius rotor shows negative Cts. at various rotor angular positions. It is observed in present study and earlier studies, by other researchers that there is a sharp decreasing trend of Cts. values. In present study the reasons for negative Cts. value is also studied.

Keywords: Static torque Coefficient, vertical axis wind turbine and CFD

Nomenclature

Φ - Rotor Angular Position	D - Diameter of Rotor
Do - Diameter of End Plate	H - Height of Rotor
R - Blade Radius	Re - Reynold's Number
ρ - Density of Air	U - Free stream velocity of wind
AA1 - Area of advancing surface of blade1.	AA2 - Area of advancing surface of blade2
AR1 - Area of returning surface of blade1	AR2 - Area of returning surface of blade2
SPA1 - Static pressure on advancing surface of blade1	SPA2 - Static pressure on advancing surface of blade2
SPR1 - Static pressure on returning surface of blade1	SPR2 - Static pressure on returning surface of blade1
SFA1 - Static Force on advancing surface of blade1	SFA2 - Static Force on advancing surface of blade2
SFR1 - Static Force on returning surface of blade1	SFR2 - Static Force on returning surface of blade1
TFA - Total force on Advancing blade surfaces	TFR - Total force on Returning blade surfaces
ESF - Effective static force on Turbine shaft	Ts - Static torque.
Cts -Static Torque Coefficient	

1. INTRODUCTION

A Savonius wind turbine is known to be one of the simplest types of wind turbine with a very simple construction having very less number of parts and has low maintenance. The most important feature of a Savonius turbine is that it is omni-directional. The Savonius rotor was developed by Sigurd Savonius in 1920s [1], since then many researchers are contributing for its development. Efforts are being made for improving its aerodynamic performance and other characteristics. In present study a single stage conventional Savonius rotor with zero overlap and without central shaft is considered, since the performance is better with these configurations [5] [6] [7]. One of the important parameters the static tourque coefficient (Cts.), is considered for simulation study and the values of Cts. are computed at different rotor angles. Static tests on Savonius wind turbine are usually conducted at a particular wind speed and Cts. values are calculated. The values of Cts. are expected to be positive at all rotor positions which indicates that turbine starts operating at each rotor angular position independently from its rest position, at a particular wind speed under study. On the other hand, a negative value of Cts. at certain rotor angular position indicates that the turbine may not start operating from its rest position at these rotor angular positions independently from its rest position, at a particular wind speed under study. A positive Cts. at all rotor positions is essential for the practical application of any Vertical Axis Wind Turbine.

Static torque coefficient calculations have been performed experimentally and numerically by many researchers. Kamoji et al. [5] studied the conventional Savonius wind turbine and in their study, they found that negative static torque coefficient is observed for rotors they studied, from a rotor angle of 135^0 to 165^0 and from 315^0 to 345^0. Thus, for almost a 1/6th (60^0) of a cycle, rotor would not start at wind velocities corresponding to Reynolds numbers up to 150,000, with no load on the rotor. J. Kumbernuss et al. [6] conducted experimental study on single and double stage Savonius turbines with main focus on overlap ratios and different phase shift angles. In their study they found that for a single stage Savonius turbine with zero overlap there is a negative value of Cts. but with overlap ratio of 0.16 and 0.32 there is only positive torque. Also a number of researchers conducted numerical study on different forms of Savonius rotors, Tong Zhou et al. [8] conducted numerical study of conventional and Bach-type rotors and found that Bach-type rotor performs well and mainly the flow field was studied. Sukanta Roy et al. [9] carried out computational study of conventional Savonius rotor with respect to Cts. and found that there is negative Cts. at lower wind speeds and at overlap ratios less than 0.2. At wind velocity of 10.44m/s and overlap ratio 0.2 the values of Cts. are positive at all rotor positions. M.H. Nasef et al. [10] conducted experimental and numerical study on conventional Savonius rotor and their result of Cts. values are negative for all Reynold's numbers at rotor position of 160^0. Konrad Kacprzak et al. [11] conducted numerical study of conventional Savonius rotor and Bach-type rotor, their results with respect to Cts. show that there are positive values of Cts. at all rotor positions for all the rotors they studied. However, from graph it can be seen that for some rotor positions 75^0 to 115^0 and 265^0 to 285^0 the values of Cts. are very close to zero. Yan-Fei Wang [12] conducted numerical study on 3D lotus shaped wind turbines and tested different forms of rotors. M. Zemoum et. al conducted review of work related to performance of Savonius wind turbine.

So, the problem identified in present study is that, a Conventional rotor is suffering from negative Cts. values at some rotor angular positions. The main objective of present study is to identify the accurate rotor angular positions with negative Cts. value, and then to conduct some analysis to find out the reasons for these negative values.

2. PROCEDURE OF NUMERICAL STUDY

2.1 Geometry Models and Meshing

The geometry of Conventional Savonius rotor is modeled in Ansys design Modeler. Meshing is done in Ansys ICEM CFD. A fine mesh is used through entire domain and a face sizing with element size of the order 0.002 is provided on blades. Geometric model and meshed model are shown in Figure 2.1.

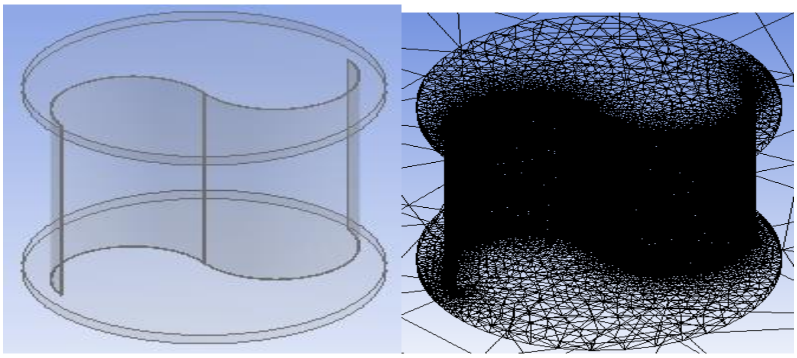

Figure 2.1 Conventional rotor Model and mesh

2.2 Mesh Independence Study

Grid independence study is carried out and any variation in the values of Cts. with variation in mesh size is studied. The grid independence is studied with 2.6 x 105 nodes and 1.4 x 106 elements up to 5.2 x 105 nodes and 2.8 x 106 elements. At a composition of 3.1 x 105 nodes and 1.7 x 106 elements onwards a constant value of Cts. 0.049 was observed. The grid independence study results are shown in Figure 2.2.

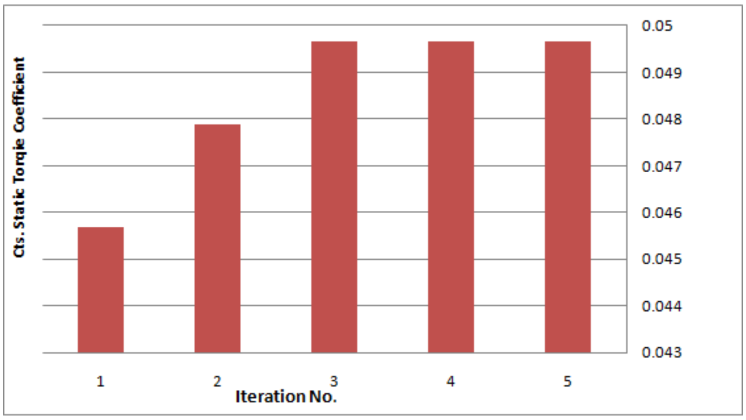

Fig. 2.2 Grid Independence Study Results

2.3 Domain Size

Domain size is used from a related research paper by Mc.Tavish et.al. [13]. the cross section of domain is maintained the same as 15 X 15 rotor diameter times. The lengths in the direction of flow are varied. The distance from inlet to the center of rotor is kept 10D and the downstream distance is increased to 15D in order to avoid vortex formation. All dimensions are derived from diameter of rotor.

2.4 Simulation Set-up and Boundary Conditions

A Steady pressure-based simulation strategy is adapted with boundary conditions as velocity inlet and pressure outlet and wall function as stationary wall with no slip condition. Realizable k-ε (Kinetic energy- dissipation rate) turbulence model is used with 5% turbulence intensity and turbulence viscosity ratio as 10. Near wall treatment is kept as standard wall function. The boundary conditions for rotor have been selected so as to facilitate the comparison between experimental and numerical results.

2.5 Solution Methods

A pressure based absolute velocity formulation steady solver is used with SIMPLE scheme for pressure -

velocity coupling and least square cell based scheme for gradient. The turbine model is placed inside calculation domain at different rotor positions from 0^0 to 165^0 with a step of 15^0. At each rotor position, the simulation is run till convergence is achieved or till there is a constant nature of curves of the conservation equations. During calculations of conservation equations average static pressure was monitored on blade surfaces and final value of average static pressure on blade surfaces is used for further calculations in an excel spread sheet. The final results are expressed in the form of graphs, X-Y plots and pressure contours on blade surfaces.

2.6 Formulae and Calculation of static torque coefficient

The following formulae are used for calculation of static torque coefficient.

$$SFA1 = SPA1 * AA1 \quad SFA2 = SPA2 * AA2 \quad ------ \quad (1)$$

$$SFR1 = SPR1 * AR1 \quad SFR2 = SPR2 * AR2 \quad ------ \quad (2)$$

$$TFA = SFA1 + SFA2 \quad TFR = SFR1 + SFR2 \quad ------ \quad (3)$$

$$ESF = TFA - TFR \quad Ts = ESF * R \quad ------ \quad (4)$$

$$Cts = 4Ts/\rho\, U^2 D^2 H \quad ------ \quad (5)$$

Substitute the values in the equation (5), we get the value of Cts is as follows, for rotor position 30^0 and at a wind velocity of 6.96 m/s is shown below.

$$Cts = (4 \text{ X } 0.0172) / 1.1 \text{ X } (6.96)^2 \text{ X } (0.22)^2 \text{ X } (0.21)^2 \text{ X } 0.21$$

$$Cts = 0.1349$$

3. RESULTS AND DISCUSSION

3.1 Comparison of 3D Numerical Results with Experimental Results

The 3D numerical results obtained, are compared with experimental results available in literature [3] and are as shown in Fig.3.1. The experimental results for conventional Savonius rotor in a half cycle show that there are negative values of Cts. at rotor position 75^0 & 255^0. The Cts. according to 3D numerical study results in a half cycle shows negative Cts. at rotor positions 60^0, 75^0, 90^0,105^0 and the values of Cts. at these rotor positions are -0.0371, -0.1396, -0.145 & -0.0376 respectively.

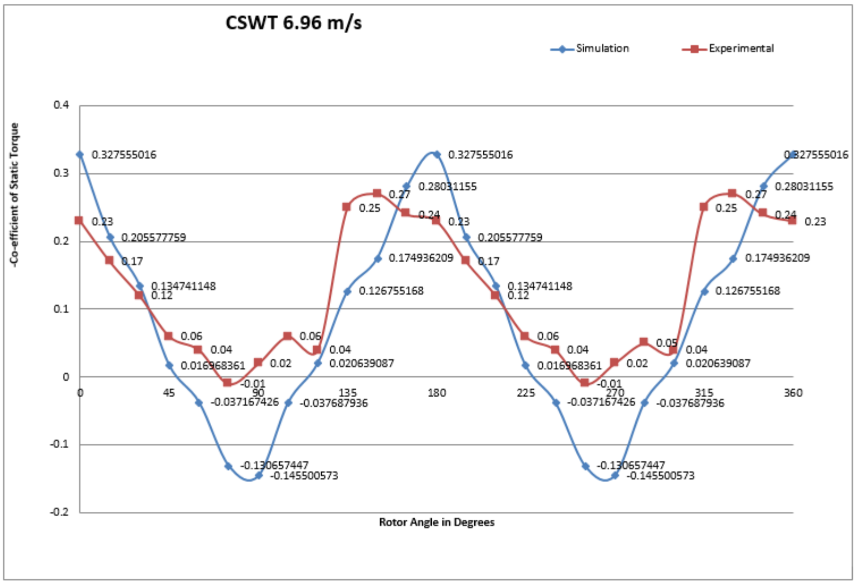

Figure 3.1 Conventional Rotor (U=6.96m/s)

3.2 Study of X-Y Plots

X-Y plots are studied to reveal the reasons for negative Cts. values at certain rotor positions. The graph shown in Figure 3.2 indicates that at rotor angles 60^0, 75^0, 90^0, 105^0 and at U=6.96 m/s the Cts. values are negative. The reasons for these negative Cts. values can be understood from the Table 3.1. The average static pressure on returning blade surface is higher than the average static pressure on advancing blade surfaces. The physics of flow responsible for negative Cts. value can be explained with X-Y plots for rotor positions 105^0 & 285^0 which are having negative Cts. values. As observed in Fig. 3.2 and by obtained computed data the sum of average static pressures on advancing blades surfaces is 7.64 Pa which is less than the average static pressure on returning blade surfaces 19.584 Pa. Due to this, the effective pressure on the turbine blades is -11.944 Pa, which is the reason for negative value of Cts..

Table 3.1 Variation of static pressure with respect to blade positions

Blade	**Color**	**Static Pressure (Pa)**	**Average St. Pressure (Pa)**	**Effective St. Pressure**
Forward Blade 1	White	5.8764	(5.8764+1.76882) = 7.64	(7.64 – 19.584) = **-11.944 Pa**
Forward Blade 2	Red	1.76882		
Returning Blade 1	Green	7.949	(7.949+11.635) = 19.584	
Returning Blade 2	Blue	11.635		

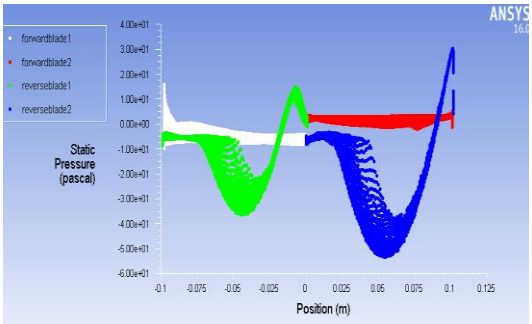

Figure 3.2 Effect of static pressure with position

3.3 Study of Pressure Contours

Pressure contours on blade surfaces are studied with respect to negative value of Cts. considering as an illustration, for a Conventional Savonius rotor, at a rotor position of 105^0 , calculation of Cts. values indicates that the Cts. values are negative. The pressure contours on blade surfaces are shown in Figure 3.3. Here the pressure contours on blades surfaces show that a large amount of positive pressure acting on forward blade 2, visible as a red completely red color. This is applying sufficient amount of pressure in the direction opposite to the direction of rotation of the turbine, so as to oppose the rotation of turbine. This negative pressure in the direction opposite to the rotation is causing a negative torque and hence a negative value of static torque coefficient is obtained.

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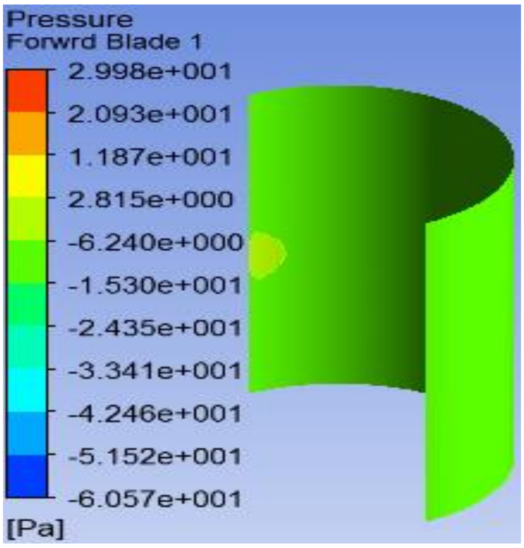
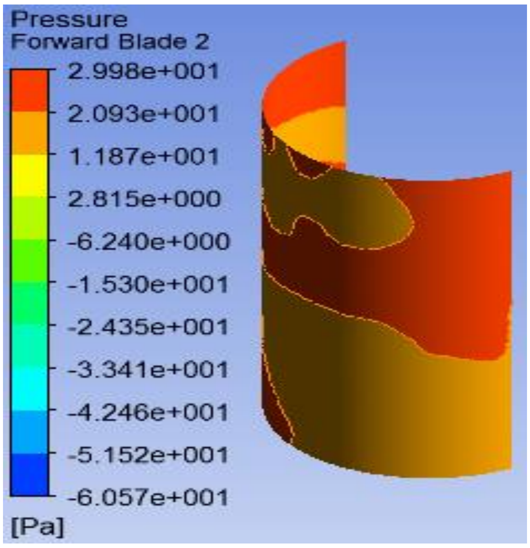
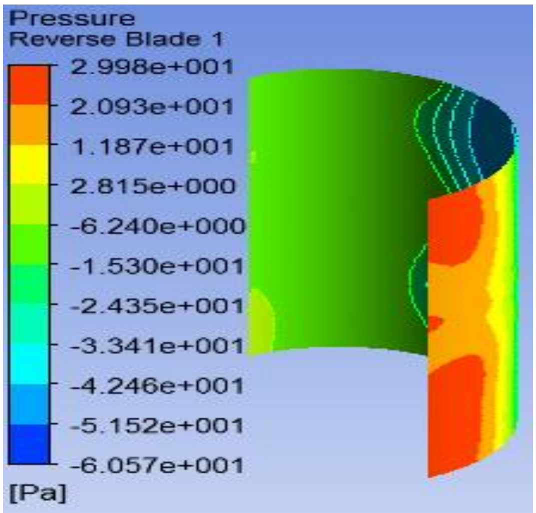


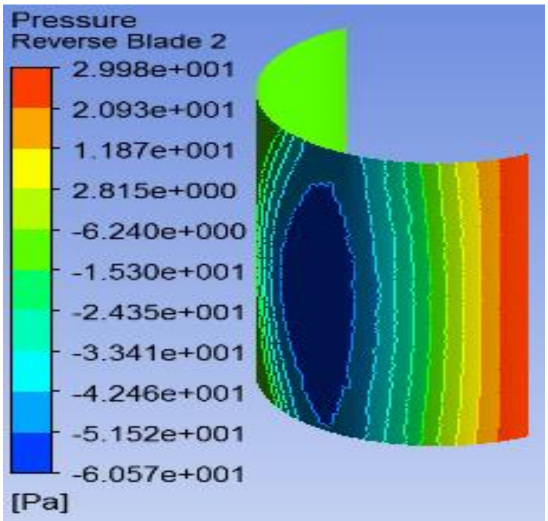
a) Pressure contour on Forward Blade 1



b) Pressure contour on Forward Blade 2



c) Pressure contour on Reverse Blade 1



d) Pressure contour on Reverse Blade 2

Figure 3.3 Pressure Contours on blades at 105^0 (6.96 m/s) position for Conventional Savonius Turbine

4. CONCLUSIONS AND FUTURE SCOPE

In present study, the main focus was on identifying the rotor positions at which the value of Cts. are negative. and provide an explanation for the reasons for negative value of Cts. through numerical study using Ansys Fluent solver. To address this problem a 3D geometrical model is modeled and tests are conducted. Static pressures, torques and Cts. values are calculated and it is then concluded that there are negative values of Cts. at various rotor positions at different wind velocities. Also, with the help of X-Y plots and pressure contours on blade surfaces, an explanation is provided for the possible reasons, for the negative values of Cts. The information obtained will help for further modifications in the design of the turbine by considering the specific rotor positions at which the values of Cts. are negative. Also the values of Cts. at other rotor positions going to provide an insight into those values which are very close to zero. The graph shows that, the values of Cts. at some rotor positions are very close to zero which indicates that the wind turbine may not start operating at these rotor positions or will have very poor starting torques.

As we know that a HAWT will have a straight line graph when plotted rotor angle v/s Cts., on the other hand, a VAWT has got a graph showing large variation of Cts. between a minimum and maximum Cts. values. As it is not possible to obtain a rotor angle v/s Cts. graph similar to HAWT, but only we can put efforts to obtain higher values of rotor angle v/s Cts. and minimize the variations. The very important conclusion of present study is that, there is a need to put maximum efforts to eliminate negative values of Cts.

Following is the summary of the conclusions are drawn from present study.

1. In future study, efforts can be made to eliminate the negative static torque coefficient and improving the overall value of Cts. at all rotor positions.
2. A suitable modification in the design of the three rotors and working on blade profiles is essential to improve aerodynamic characteristics.

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