NUMERICAL STUDY OF HELICAL SAVONIUS WIND TURBINE.

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Abstract:

In present study a helical Savonius wind Turbine is studied in a 3-dimensional flow domain with the help of a simulation Software with main focus on value of static torque coefficient of a helical Savonius wind turbine. A 3D model of helical Savonius turbine with 90^0 twist and without shaft is developed and simulation is carried with the help of Ansys Fluent solver. The numerical results were obtained by solving incompressible steady flow equations with the help of k-ε Realizable turbulence model. Static pressures on turbine blades are obtained and Static torque Coefficient is calculated at different rotor positions. The simulation results are compared with experimental results available in literature. It is observed through numerical study that at certain rotor positions the value of Cts is negative. Further efforts are made to find out the reasons for the negative values of Cts. The above study was done at different wind velocities and results are presented.

Keywords- Static torque Coefficient, vertical axis wind turbine, CFD.

1. INTRODUCTION

A helical Savonius turbine is a modification of conventional Savonius turbine which will have a certain twist angle. In present study a helical Savonius wind turbine with 90^0 twist without shaft and having end plates is subjected to static test numerically with the help of a 3- dimensional model with the help of Ansys Fluent solver version 16. Static tests on helical Savonius wind turbine are conducted at different wind speeds and static torque coefficient values are calculated at different rotor angles. The static torque coefficient is one of the important parameter in the study of a Vertical Axis Wind Turbine (VAWT). Hence in present study main focus is on measuring static torque coefficient of a Helical Savonius Wind Turbine at different rotor positions. Further in present study the reasons for the negative static torque coefficient values at some of rotor positions are studied. The similar studies have been conducted experimentally by earlier researchers Kamoji et.al.[1], these experimental results are compared with numerical results obtained in the present study.

Helical Savonius rotors could provide positive coefficient of static torque [2] Kamoji et. al. A Helix can be defined as a curve generated by a marker moving vertically at a constant velocity on a rotating cylinder. The blade retains its semi-circular cross-section from the bottom (0^0) to the top (90^0). Combination of two such blades is called as a helical Savonius rotor. U.K Saha and Jaya Rajkumar [8] also studied twisted three bladed Savonius rotor with a twist angle of 15 degree. Kamoji et.al [2] carried out experimental investigation of overlap ratio (0.0, 0.1 and 0.16), aspect ratio (0.88, 0.93 and 1.17) and Reynolds number for a 90^0 twist, shaft-less helical rotor at Reynolds numbers of 120,000 and 150,000 on coefficient of power, coefficient of torque and coefficient of static torque.

Keum Soo Jeon et.al [3] studied the effect of end plates on the performance of helical wind turbine. It was observed that Cp value increases with increase in area of end plates. [4] U.K.Saha and M Jaya Rajkumar conducted wind tunnel experiments on twisted Savonius turbine and they found that twisted blade with a 15^0 shows a maximum of Cp. Keum Soo Jeon et. al. [5] studied the effects of end plates and various shapes on performance of helical Savounius wind turbine. They found that power co-efficient increased by 36% due to use of both end plates. Tong Zhou & Dietmar Rempfer [6] numerically explored the non-linear two-dimensional unsteady flow over a conventional Savonius-type rotor and a Bach-type rotor, and developed a simulation method for predicting their aerodynamic performance. Konrad Kacprzak et. al. [9] conducted 2D flow study with Ansys CFX. Most importantly they examined elliptically shaped blades and found that this type of blade can improve the performance of VAWT. M.H. Nasef et. al. [8] conducted experimental and 2D numerical on a Savonius rotor. They studied the effect of different overlap ratios on the aerodynamic performance of Savonius rotors. Sukanta Roy and Ujjwal K. Saha [7] conducted unsteady 2D computational study, the effect of overlap ratio was studied, a realizable k-ε turbulence model with enhanced wall treatment was used in their study. It was found that an overlap ratio of 0.2 eliminates negative torque. A combined experimental and numerical study was conducted by Jae-Hoon Lee [11].

2. DATA REDUCTION & SYMBOLS

$SFA1 = SPA1 * AA1$ $\quad SFA2 = SPA2 * AA2$

$SFR1 = SPR1 * AR1$ $\quad SFR2 = SPR2 * AR2$

$TFA = SFA1 + SFA2$ $\quad TFR = SFR1 + SFR2$

$ESF = TFA - TFR$ $\quad Ts = ESF * R$

$Cts = 4Ts/\rho\, U^2 D^2 H$

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	

3. NUMERICAL STUDY

3.1 GEOMETRIC MODEL & MESHING.

The geometry of Helical Savonius Turbine was modeled in Ansys design Modeler as shown in fig 2(a). 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 $2x10^{-3}$ is provided on blades. Meshed model is shown in fig. 2 (b).

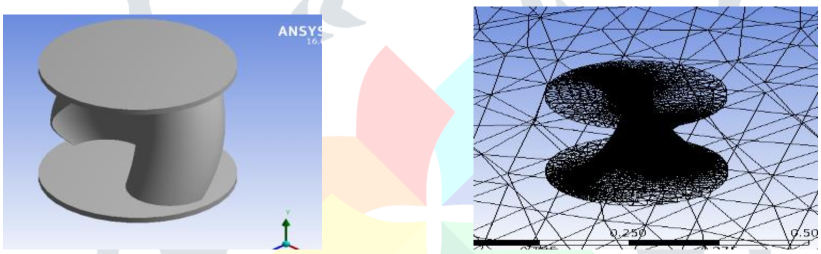

Fig. 2 (a) Geometry Model Fig. 2 (b). Meshed Geometry

3.2 MESH INDEPENDENCE STUDY

Details of mesh are shown in fig. 2 (b), grid independence study is carried out and any variation in the values of static torque co-efficient with variation in mesh size is studied. The grid independence is studied with 2.6 x 10^5 nodes and 1.4 x 10^6 elements up to 5.2 x 10^5 nodes and 2.8 x 10^6 elements. At a composition of 3.1 x 10^5 nodes and 1.7 x 10^6 elements onwards a constant value of static torque coefficient 0.04965 was observed. The grid independence study results are shown in fig. 3.

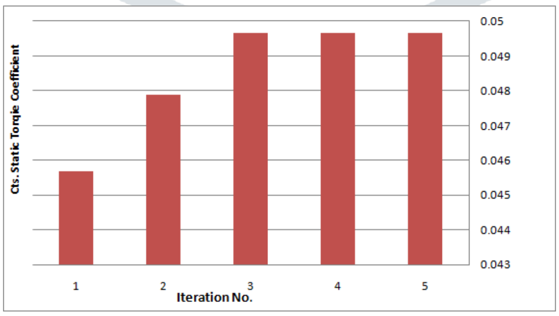

Fig. No. 3 Grid Independence Study Results

3.3 DOMAIN SIZE

Domain size is used from a related research paper by Yan-Fei Wang 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 down stream distance is increased to 15D in order to avoid vortex formation. All dimensions are derived from diameter of rotor. The details are shown in fig. 4.

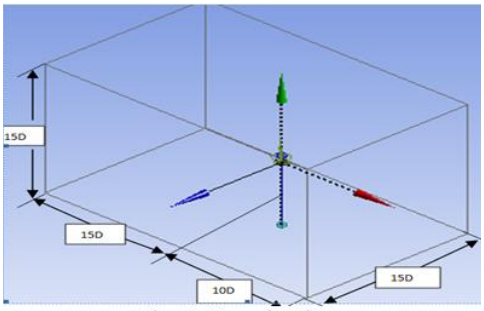

Fig. 4. Domain Size.

3.4 NUMERICAL SCHEME

A careful selection of turbulence model based on past research, resulted in selecting **r**ealizable k-ε turbulence model with 5% turbulence intensity and turbulence viscosity ratio 10 is used. Near wall treatment is kept as standard wall function. In case of boundary Conditions inlet velocity inlet.4 m/s and for outlet, a pressure outlet with atmospheric Pressure condition is used. Further, for wall a stationary wall treatment with no slip condition is used.

3.5 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 the curves of the conservation equations. During calculations of conservation equations average static pressure was monitored on blade surfaces. 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 and X-Y plots.

4. Study of Physics of flow with respect to negative value of Cts.

Calculation of static torque co-efficient values indicates that at rotor angles 30^0, $45^{0,}$ 210^0 and 225^0 the static torque coefficient value is negative. The average static pressure on returning a blades surface is higher than the average static pressure on advancing blades surfaces. The physics of flow responsible for this can be explained with X-Y plots for those rotor angles as shown in fig. 5 & 6. As observed from fig.4 the sum of average static pressures on advancing blades 3.014 Pa is less than average static pressure on returning blades 4.54 Pa. Similarly at rotor position $\phi = 45^0$ from fig.5 the sum of average static pressures on advancing blades 3.55 Pa is less than average static pressure on returning blades 4.74 Pa. Due to this reason, the effective static torque (Ts) is negative and subsequently the static torque coefficient becomes negative.

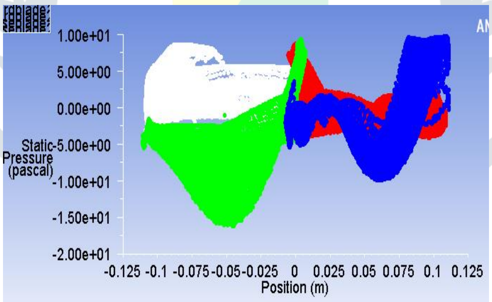

Fig. 5. Average Static pressures on blades at rotor angle $\phi = 30^0$

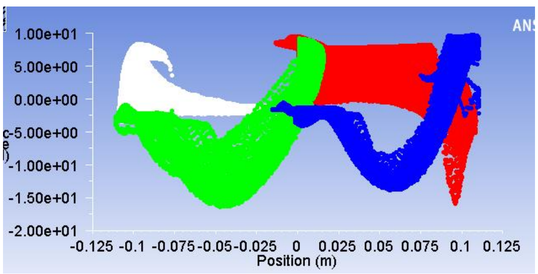

Fig. 6. Average Static pressures on blades at rotor angle $\phi = 45^0$

5. RESULTS AND DISCUSSION:

The results obtained are presented in fig. 7, reveal that there are negative values of static torque coefficient at rotor positions 30^0, 45^0, 210^0 and 225^0. The 3D numerical results are compared with experimental results obtained by Kamoji et.al [1] as shown in fig 7. The experimental results show that there is a negative value of static torque co-efficient at rotor position 75^0 with the value of Cts is -0.01.

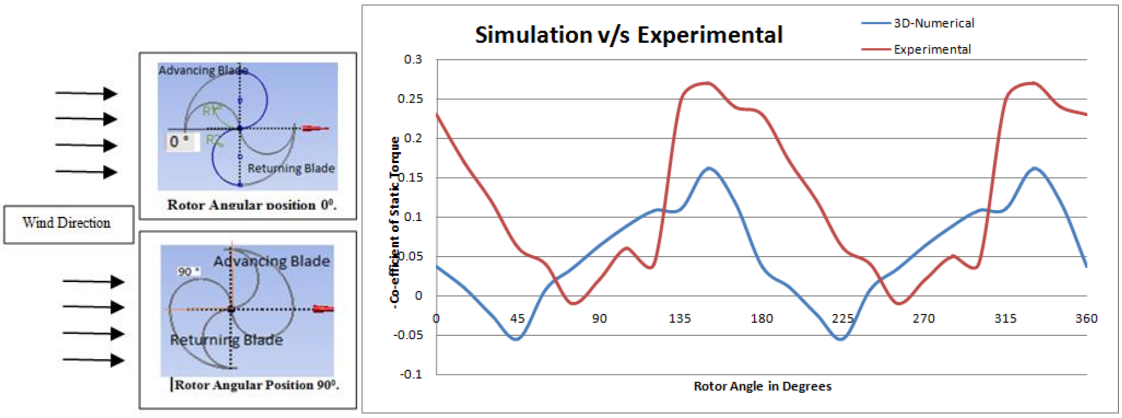

Fig 7: Plot of Cts values obtained by experimental by Kamoji et.al. and 3D numerical study

6. CONCLUSION.

In Present study the efforts have been made to identify the rotor positions at which the value of static torque coefficient is negative and provide an explanation for the reasons for negative value of Cts. To address this problem a 3D numerical study is conducted and static pressures, torques and static torque coefficient values are calculated. It is then concluded that there are negative values of static torque coefficient -0.0242 and -0.0548 at rotor positions 30^0 and 210^0 & 45^0 and 225^0 respectively. Also with the help of X-Y plots shown in figs. 5 & 6 explanation is provided for the possible reasons for the negative values of Cts. The information obtained will help to further modifications in the design of the turbine, also the values of Cts at other rotor positions shown in table 1 is going to provide an insight into those values which are very close to zero line in fig. 7. These Cts values are shown as shaded in table no. 1. It can be concluded that four more values of Cts at rotor positions $0^{0,}$ 15^0, 60^0 & 75^0 apart from 30^0 & 45^0 are having very low Cts values.

Φ	0^0	15^0	30^0	45^0	60^0	75^0	90^0	105^0	120^0	135^0	150^0	165^0
Cts	0.012	0.04	-0.05	-0.17	0.012	0.04	0.14	0.22	0.29	0.28	0.2	0.15

Table No.1 Values of Cts at respective rotor angles Φ

7. Future Scope

A Helical Savonius wind turbine is showing positive static torque coefficient at maximum number of rotor positions. In future study, efforts can be made to eliminate the negative static torque coefficient and improving the overall value of static torque coefficient at all rotor positions. Suitable modifications in the design of helical Savonius wind turbine are required for improving performance and ensuring practical application in a large scale.

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