Performance of a Quarter-Pitch Twisted Savonius Turbine

Md. Imtiaj Hassan, Nahidul Khan

***Abstract*—The paper presents Computational Fluid Dynamics analysis of a quarter pitch twisted Savonius turbine. The turbine has been simulated using a CFD software package Flow 3D developed by Flow science. The simulation has been done using Reynold's Averaged Navier-Stokes Equations (RANSE) solver with structured rectangular mesh. The proposed rotor consists of no central shaft and has an overlap ratio of 0.35 with two end plates. Turbine rotates around z axis in the reference plane with six degree of freedom. The turbine is simulated for a constant current speed and a set of variable torques. The simulation result shows that the turbine can achieve more than 7% efficiency and can be used as a marine current turbine.**

***Index Terms*— Power coefficient, Tip Speed Ratio, Navier-Stokes Equations.**

I. Introduction

EVERYTHING in this universe has got energy because of its position either potential or kinetic energy. Water in the ocean is always moving in certain directions and can be used as a great source of energy. Vertical Axis Water Turbine has been chosen to serve the purpose of generating power as it has many advantages. Savonius is one of the vertical axis rotor and can be constructed by two semi circular buckets, so it has 'S shaped' cross sectional area [1-3]. The conception of Savonius rotor is based on the principle developed by Flettner [1]. In this work, experiments have been done on a quarter pitch twisted Savonius rotor. Basically, this is same rotor like Savonius but it has got a twist along its vertical axis. It is a drag type device which has a high starting torque.

The work states the Computational Fluid Dynamics (CFD) analysis of a quarter pitch twisted Savonius turbine. Flow 3D developed by Flow Science Inc. and has been used to do the CFD analysis of the rotor. Flow 3D gives simulation results by investigating dynamic behavior of fluids. It is well tested in the solution of time-dependent (transient), free-surface problems in one, two and three dimensions and models confined flows and steady-state problems. No special additional modules for meshing or post-processing are needed. An integrated graphical user interface ties everything together, from problem setup to post-processing. It gives a magnificent visualization of the simulation results. Simulations have been done using Reynold's Averaged Navier-Stokes Equations (RANSE) solver [4] with structured rectangular mesh to get results of characteristics of a quarter pitch twisted Savonius rotor.

II. Design Aspects

Savonius rotor can be made by using two half cylinders. In case of twisted Savonius, the geometry is complex and three dimensional. It requires complex machinery to build twisted Savonius. Basically, the Savonius and twisted Savonius both of them have same cross sectional area but twisted one changes the direction of its body for a certain degree for a certain width depending upon the total twist along vertical axis. It has same design aspects like conventional Savonius rotor. Fig. 1 shows the top view of twisted Savonius rotor.

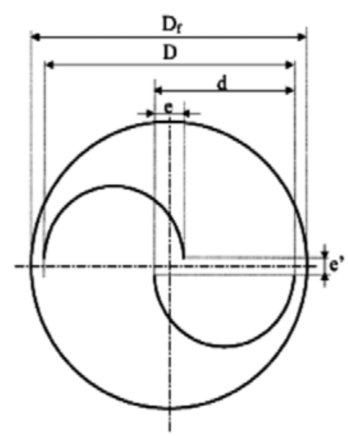

Fig. 1. Top view of Twisted Savonius rotor.

If a turbine is placed in the water then power available in the water is

$$P_{available} = 0.5\rho A V^3 \quad (1)$$

Where, $P_{available}$ is Power available in water (Watts)
ρ is Density of water (kg/m3)
A is the swept area of Twisted Savonius rotor (m^2)
V is Speed of water (m/s)

If C_p is the power coefficient of the twisted Savonius turbine then power captured by the turbine is

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$$P=P_{available} \times C_p \tag{2}$$

$$C_p=P/P_{available} \tag{3}$$

In case of twisted Savonius rotor the swept area is

$$A= H\times D \tag{4}$$

Where, H is the height of the turbine
D is the diameter of the turbine

The tip peripheral velocity of the rotor U = ωr (ω is the angular velocity of rotor and r is the radius of the rotor). The velocity coefficient of the turbine is defined as:

$$TSR=\lambda=\omega R/V \tag{5}$$

Sometimes it is called Tip Speed Ratio (TSR).

The aspect ratio represents the height of the rotor relatively to its diameter.

$$A=H/D \tag{6}$$

The overlap ratio is represented by

$$B=e/d \tag{7}$$

Where, e is the overlap portion of the two buckets
d is the diameter of one of the buckets.

The paper represents the CFD study for a quarter pitch twisted Savonius rotor has been done. Fig. 2 shows the CAD drawings of the twisted Savonius rotor for the simulation.

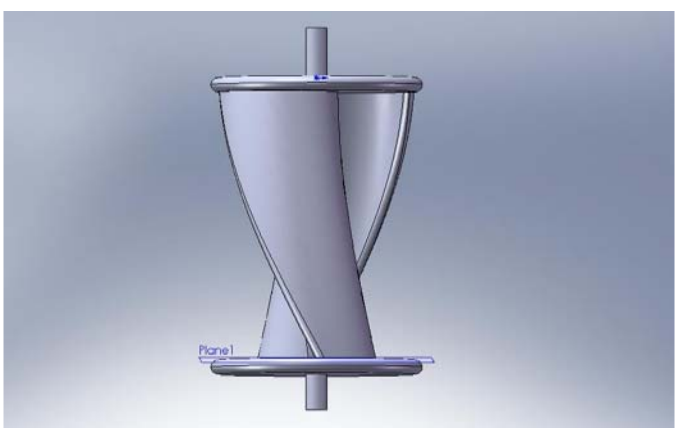

Fig. 2. Quarter pitch twisted Savonius turbine.

The turbine is made up of two semi circular twisted buckets with no shaft and has an overlap ratio of 0.35. The turbine has a height of 0.32m and a diameter of 0.2286m.

III. Mesh Blocks

The drawing of the twisted Savonius has been done using Solid Works. The Mesh has been set up in Flow 3D in which the STL file generated from Solid Works has been imported. Two mesh blocks have been considered for simulation of quarter pitch twisted Savonius shown in Fig. 3.

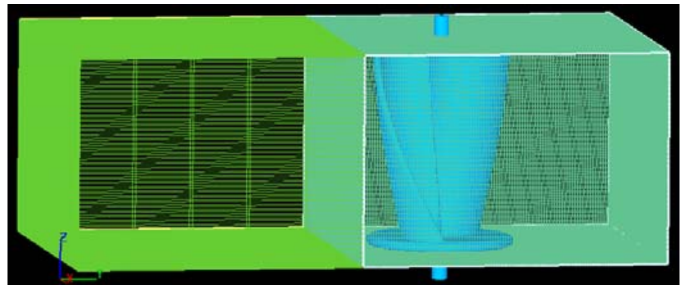

Fig. 3. Turbine imported in the mesh block.

The first mesh block is coarser compared to the second one as it contains no moving body. Second mesh block is made finer because of the twisted Savonius.

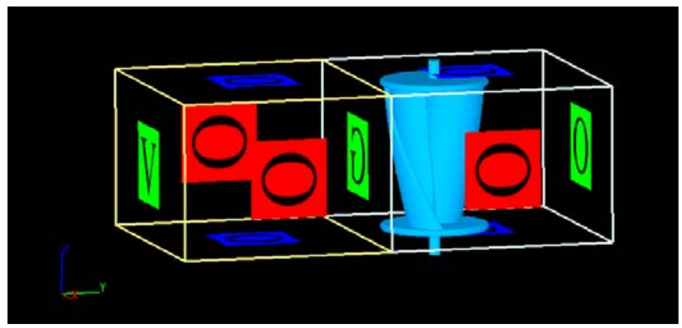

Fig. 4. Boundary conditions for turbine simulation.

The resolution of the mesh is adjusted by means of trial and error. The boundary conditions are shown in Fig. 4 for simulation of twisted Savonius turbine. The velocity of water flow has been assigned in negative Y boundary of first block. First block's positive Y boundary and second block's negative Y boundary have been overlapped grid over lay has been assigned here. All other boundaries have been assigned out flow to mimic the seabed condition.

IV. Simulation Results

In the simulation the current speed of the flow has been set up at 1 m/s. The rotational speed of the rotor goes through a transition state then it reaches the steady state within few seconds. Flow 3D can generate an excellent visualization of the simulation results. The simulation allows us to visualize the rotation of the rotor both in 2D and 3D in terms of real time.

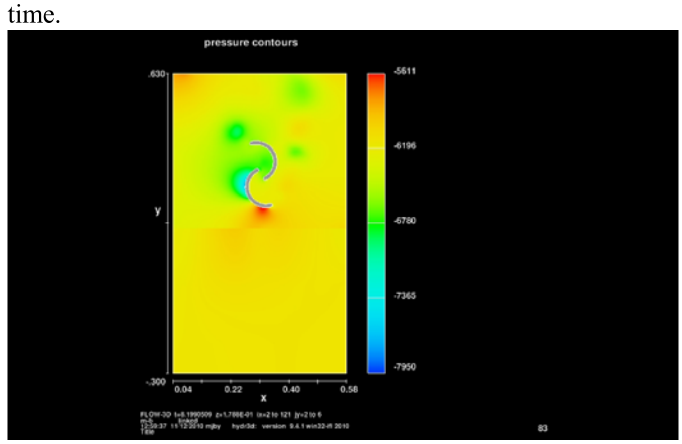

Fig. 5. At time frame t=8.199 sec.

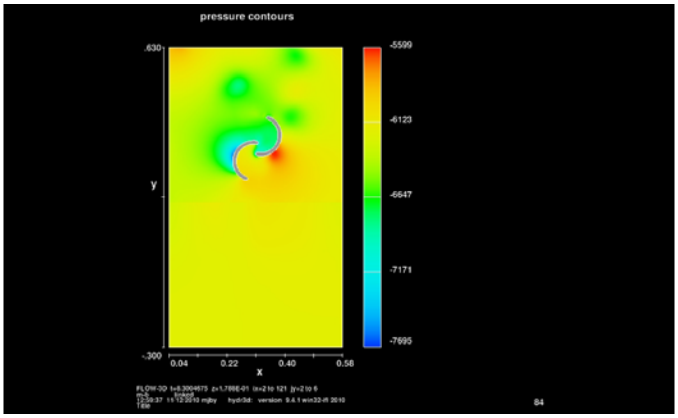

Fig. 6. At time frame t=8.3 sec.

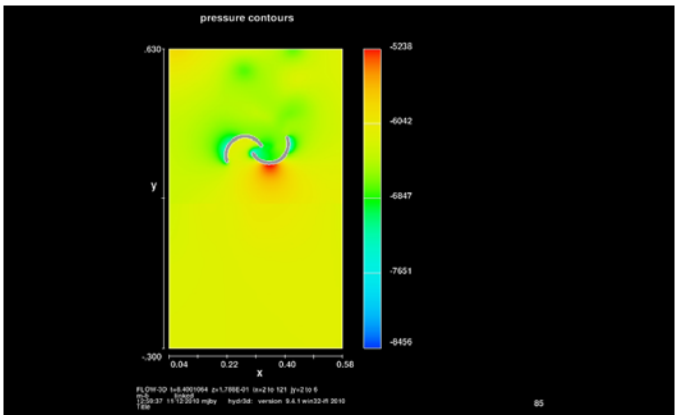

Fig. 7. At time frame t=8.4 sec.

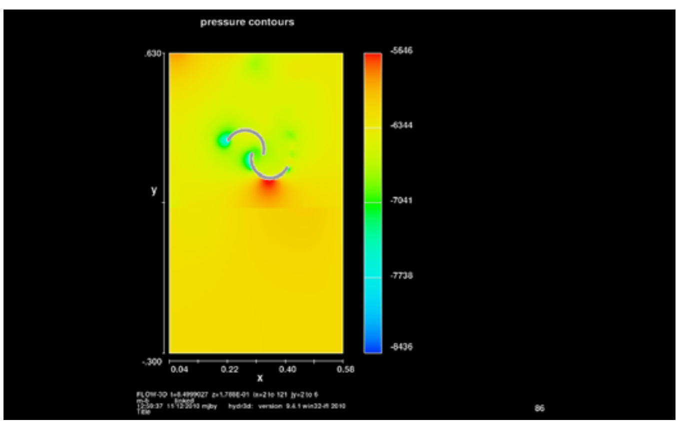

Fig. 8. At time frame t=8.499 sec.

Figure 5-8 shows the real time rotation of the turbine in 2D. The RPM of the turbine can also be calculated from the angular speed curve generated by the software. The Flow 3D allows to change the applied torque. In this work, a set of torque has been applied on the turbine and the angular speed for different torque settings to determine output power of the turbine.

Power output of turbine for a certain torque setting can be expressed as:

$$P = T\omega \tag{8}$$

Where, P.is power output of the turbine in Watts
T is torque applied in N-m
ω is angular speed in rad/sec

Power co-efficient of the turbine can be calculated from equation 3.MATLAB has been used to plot the data. Cp-λ curve for quarter pitch twisted Savonius rotor is shown in Fig. 9.

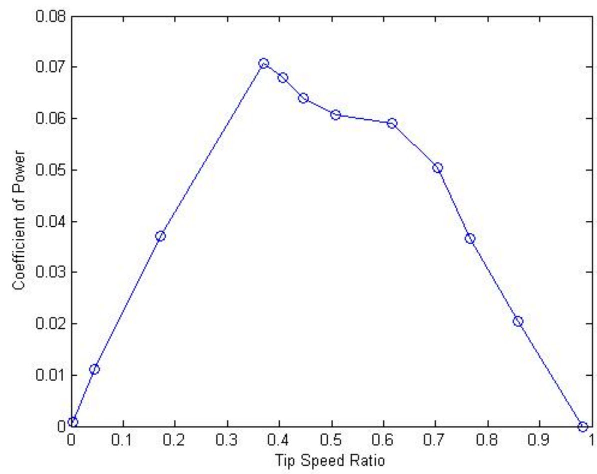

Fig. 9. Cp-λ curve of quarter pitch twisted Savonius turbine.

The simulation result shows that the quarter pitch twisted Savonius can achieve efficiency of 7% around a tip Speed ratio of 3.6.

V. Conclusion

The main objective of this work is to do the CFD study of a quarter pitch twisted Savonius turbine. The Cp-λ curve of the turbine has been generated. As these types of turbines have complex machinery because of its geometry, CFD study is a good option to characterize these kinds of turbines. It also helps to predict the characteristics of the turbine with less expense.

VI. Acknowledgment

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VII. References

[1] S. J. Savonius, The S-rotor and its applications. Mechanical Engineering Vol. 53, 1931 pp. 333–338.

[2] Khan N, M.Tariq Iqbal, Michael Hinchey, Vlastimil Masek. “Performance of Savonius Rotor as Water Current Turbine” published in Journal of Ocean Technology, Vol 4 No. 2, page 27-29, June 2009.

[3] Khan N, M. Tariq Iqbal, Michael Hinchey. “A Micro Seafloor Marine Current Energy Conversion System” presented at 18th IEEE NECEC Conference, St. Johns, NL, November, 2008.

[4] Flow 3D general Brochure

VIII. BIOGRAPHY

Md. Imtiaj Hassan was born in Bangladesh on December 4, 1986. He received B.Sc Degree in Electrical and Electronic Engineering from Islamic University of Technology, Bangladesh. Currently he is doing M. Eng. in Electrical Engineering in Memorial University of Newfoundland, Canada. He is also a research assistant in Faculty of Engineering and Applied Science in Memorial University of Newfoundland. His research interest is in Renewable Energy Sources, Water current energy conversion systems.

Md. Nahidul Khan received his B.Sc in Electrical & Electronic Engineering in 2004 from Khulna University of Engineering & Technology, Bangladesh. He came to Memorial University of Newfoundland as an M.Eng student to chase his dreams in renewable energy. He finished his Master degree from Memorial University of Newfoundland in 2008. After a successful and rewarding career in the control system, power electronics and in energy conversion systems, he had an opportunity to work as a PhD student in the School of Engineering working with the key faculty. His current research interest is to develop a novel marine current energy conversion system which is robust, cheap and more reliable than existing system.