CFD Analysis of a Twisted Savonius Turbine

Md. Imtiaj Hassan, Tariq Iqbal, Nahidul Khan, Michael Hinchey, Vlastimil Masek

Memorial University of Newfoundland
St. John's, NL, A1B 3X5, Canada

Abstract- **This paper presents Computational Fluid Dynamics (CFD) analysis of a Twisted Savonius rotor. Simulations were performed in a CFD software Flow-3D, using Reynold's Averaged Navier-Stokes Equations (RANSE) solver with structured rectangular mesh. The proposed rotor has 180° twist with two endplates and no central shaft. Expected performance of the twisted Savonius rotor has been determined, this includes starting characteristics, static torque and rotational speed of the turbine. Simulation results show better performance of twisted Savonius rotor as compared to the other conventional Savonius rotors. Designed twisted rotor will be used in a small seafloor power generation system.**

Index Terms—Twisted Savonius Turbine, Tip Speed Ratio, Power Coefficient, Torque Coefficient

I. INTRODUCTION

In this work, software Flow-3D has been used as a Computational Fluid Dynamics (CFD). By using this software package the twisted Savonius rotor has been analyzed from fluid dynamics point of view. By investigating the dynamic behavior of liquids and gases Flow-3D provides flow simulation solutions. It also specializes 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. For this work, the turbine rotation can be observed in real time including the transient state.

II. TWISTED SAVONIUS ROTOR

The concept of the Savonius rotor was based on the principle developed by Flettner. Savonius used a rotor that was formed by cutting the Flettner cylinder into two halves along the central plane and then moving the two semi cylindrical surfaces sideways along the cutting plane so that the cross-section resembled the letter 'S'[1,2]. In case of twisted Savonius the cross section resembles also like two half circle but it moves a certain degree in every step for certain cross sectional width. In this work, a twisted Savonius rotor is analyzed which has a half pitch twist along its' vertical axis.

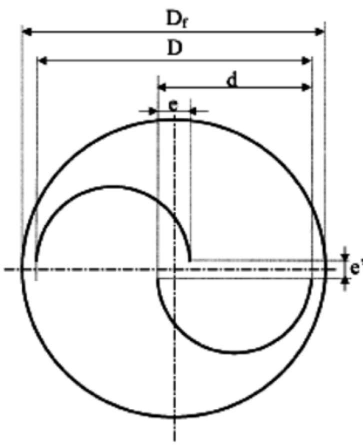

Figure 1. Top view of twisted Savonius Rotor

Figure 1 shows the top view of the twisted Savonius rotor which is exactly the top view of conventional Savonius rotor.

The power coefficient Cp of a turbine is:

$$Cp = P/(2A\rho V^3) \tag{1}$$

Where, P is the output power (W)
ρ is the density of water (kg/m^3)
A is the swept area of rotor (m^2)
V is the speed of water (m/s)

In case of twisted Savonius rotor the swept area is

$$A = H \times D \tag{2}$$

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

The coefficient of torque C_t [3] is given by

$$C_t = 4T/(\rho V^2 D^2 H) \tag{3}$$

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

$$\lambda = U/V \tag{4}$$

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

$$A = H/D \tag{5}$$

The overlap ratio is represented by

$$\beta = e/d \qquad (6)$$

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

In this work, two end plates have been used. There is no central shaft in the turbine but small shafts have been used in two edges to hook it up. The edges of the buckets are circular. The turbine has a height of 0.32m and a diameter of 0.2286m. The overlap ratio of the turbine to simulate is 35%. Figure 2 shows the CAD diagram with half pitch turn.

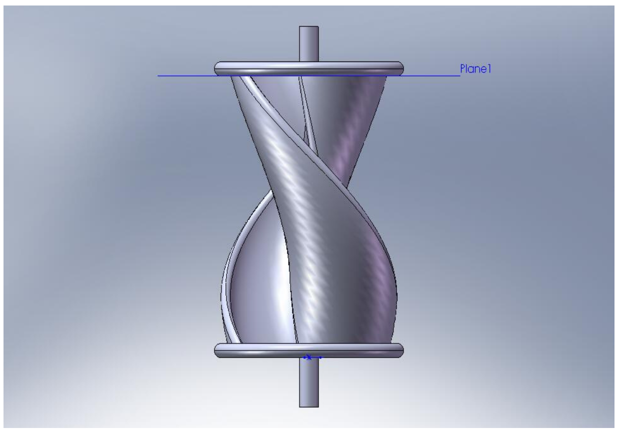

Figure 2. Half pitch turn twisted Savonius turbine

III. MESHING GEOMETRY AND BOUNDARY CONDITIONS

Twisted rotor is the same rotor like Savonius but it has twist along its vertical axis. Actually this twisted profile is not same along vertical axis rather it changes in every step and has a certain amount of along vertical axis through the whole body. Basically this twisted profile is responsible for its' better performance compare to the conventional Savonius rotor. Figure 3 represents 3D view of the turbine when STL file of the CAD drawing is imported into the mesh in Flow-3D software package.

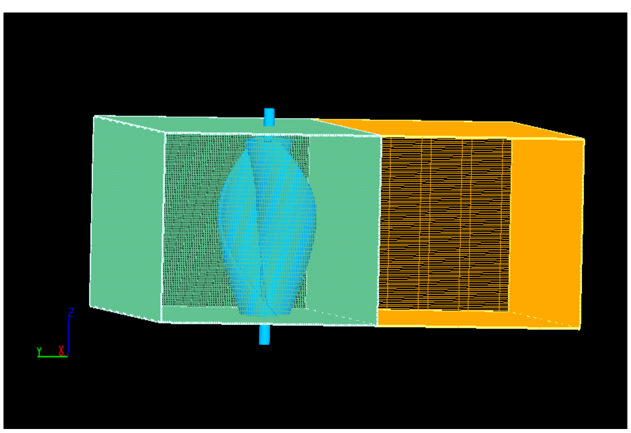

Figure 3. Turbine imported in the mesh block.

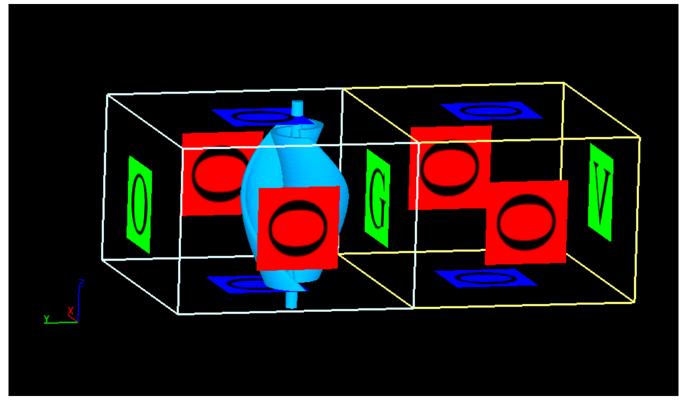

Figure 4. Boundary Conditions

The resolution of the mesh is adjusted by means of trial of error because of the hardware capability. A closer view to the boundary condition is shown in figure 4. In this work two mesh blocks have been used. Flow has been given from negative y axis. The overlap of the two mesh blocks is grid overlay. All other boundaries are assigned outflow. So, fluid comes from negative axis, hits the turbine and flows out.

IV. CFD RESULTS

The performance of the twisted Savonius has been analyzed in 1 m/s water flow. Different torque has been applied to observe the rotational speed of the turbine. The following figures show the 2D animation result of the turbine. The top views of the rotors are presented here for better understanding the rotation of the rotor. One can also determine the angular speed of the rotor also from 3D animation results.

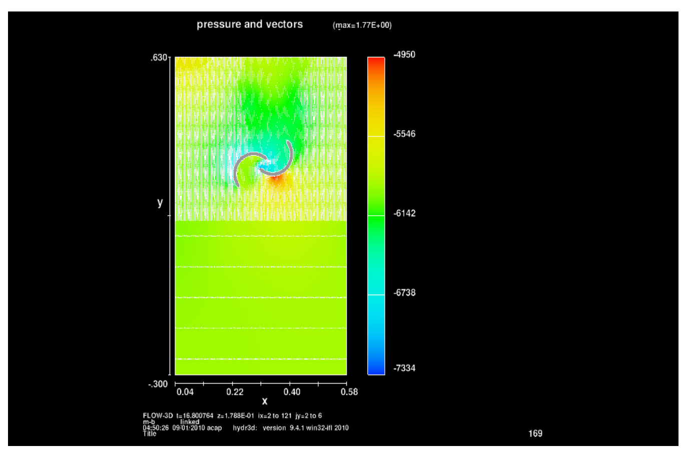

Figure 5. Simulation screen shot at Time Frame 16.8 second

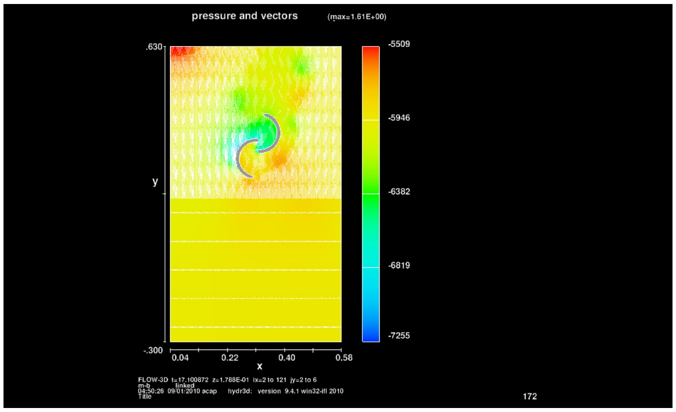

Figure 6. Simulation screen shot at Time Frame 17.1 second

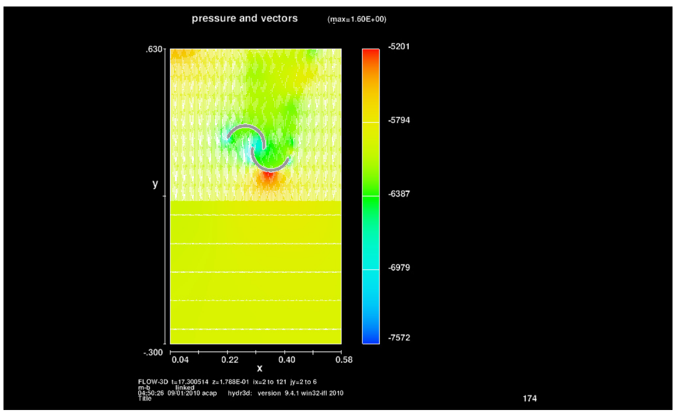

Figure 7. Simulation screen shot at Time Frame 17.3 second

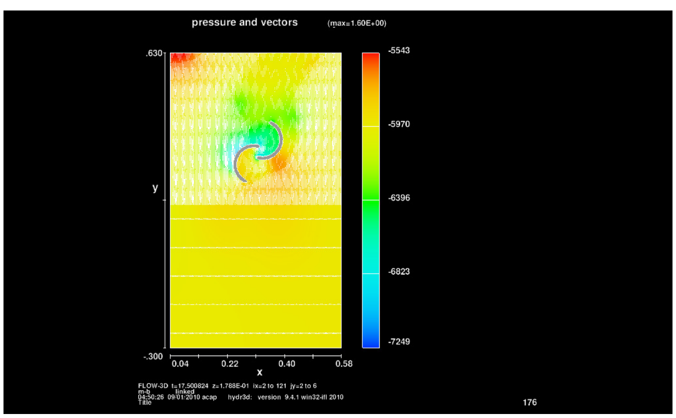

Figure 8. Simulation screen shot at Time Frame 17.5 second

In the figure 5-8 one complete revolution of the turbine is shown when it reaches a steady state condition. The revolution is shown when no torque is applied. Flow 3D gives the revolution of the turbine in real time. The torque is varied in order to determine Cp and tip speed ratio of the twisted Savonius rotor. The angular speed of the turbine is measured from the probe. The output power is obtained by multiplying torque and angular speed.

$$P = T\omega \qquad (7)$$

Where, P is Power

T is Torque, and

ω is the angular speed of the turbine

MATLAB has been used to plot characteristics of turbine obtained from CFD as shown in figure 9. Twisted Savonius gives more than 8% efficiency at the tip speed ratio 0.388. Figure 10 shows the expected torque coefficient vs. TSR curve.

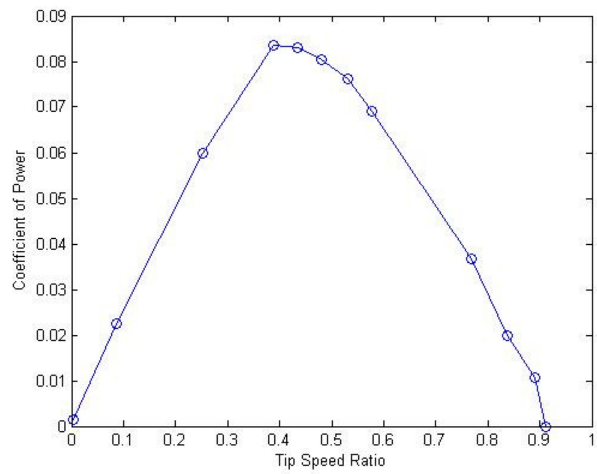

Figure 9. Cp- λ curve twisted Savonius turbine

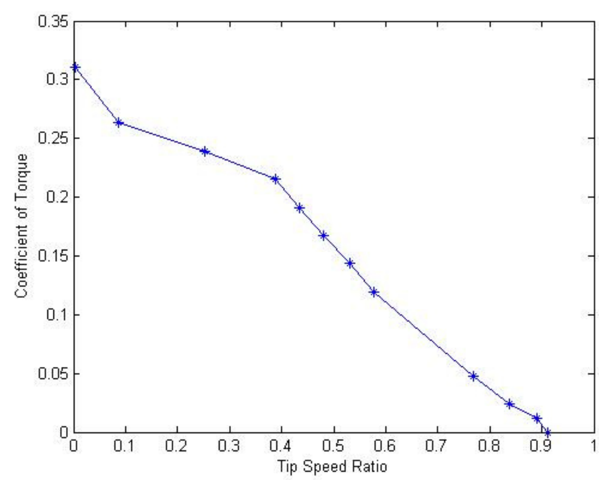

Figure 10. Ct- λ curve of twisted Savonius turbine

V. CONCLUSION

The paper shows that CFD can be used to study the behavior of water current turbine. In future the prototype will be made to compare the CFD and experimental results. The main objective is to develop a simulation model of the turbine that can replace expensive experimental setup.

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