International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 7 (2017) pp. 1178-1181

Computational Hydrodynamic Analysis of Horizontal-Axis Hydrokinetic Turbine With and without Diffuser

Cristian Cardona-Mancilla[1], Jorge Andrés Sierra del Río[1] and Diego Andrés Hincapié Zuluaga[1]

[1]Facultad de Ingeniería, Departamento de Mecatrónica y Electromecánica, Instituto Tecnológico Metropolitano (ITM). Calle 73 No. 76A – 354, Medellín (Colombia).

Abstract

A computational fluid dynamic analysis of a horizontal-axis hydrokinetic turbine with and without diffuser was performed. A turbine was designed with three blades and 0.75 meters of radius for an output power around 1 HP with water velocity of 1.5 m s^{-1}. A NREL S822 hydrodynamic profile was used for designing the blades and the diffuser. The model was discretized with tetrahedral elements and subsequently and the hydrodynamics of the system was simulated using ANSYS CFX V17.0® module using transient arrangements. The simulations were performed with a k-ε turbulence model, the effect of angular velocity (0 to 300 RPM with steps of 10 RPM) on the output power was analyzed, and the velocity profiles were evaluated for both models (with and without diffuser). The maximum output power reached by the turbine with and without diffuser was of 880 W at 180 RPM and 846 W at 200 RPM, respectively. From the simulations, boundary layer detachment and recirculation of fluid downstream of both turbines were observed. Turbine without diffuser showed higher energy losses compared to the model with diffuser.

Key words: boundary layer detachment, CFD, distributed generation, kinetic energy, output power, renewable energy.

INTRODUCTION

Turbines are essentials parts in power energy plants. These devices are used to transform the kinetic energy from renewable sources into mechanical energy. Hydrokinetic turbines are preferred because the construction of dams, or tunnels for engine rooms is not required. This reduces their effect on the ecosystem since during their operation and consequently, water sources are not modified [1].

Efficiency of horizontal-axis hydrokinetic turbines has been studied by some authors. Shahsavarifard et al., (2015) analyzed the effect of the shroud in the performance of this type of turbine and they found that, the proposed shroud increased 91 % the power generated. Gaden and Bibeau, (2010) simulated computationally a rotor with a diffuser reaching 3.1 time more power with relation to the turbine without diffuser.

In this work a computational simulation was done to evaluate the hydrodynamic conditions of a horizontal-axis hydrokinetic turbine. Simulations were done to evaluate the effect of the angle of attack of the blade and a diffuser on the output power of the turbine.

METHODOLOGY

Tridimensional models of the horizontal-axis hydrokinetic turbine with and without diffuser were modelled in NX10.0® software. The angle of attack of the blade was modified from 5, 10, 20, 30 up to 90 degrees for the turbine without diffuser. The turbine was designed with three blades and 0.75 meters of radius for an output power from 1 HP. A NREL S822 hydrodynamic profile was used for the blades and the diffuser. One-third of the fluid volume of the hydrokinetic turbine without diffuser was generated in simulations. The model was simplified geometrically to reduce the computational cost. However, the turbine with diffuser was not simplified given its geometric complexity. The fluid volume of the horizontal-axis hydrokinetic turbine with and without diffuser was composed of a rotary and steady volume according to the studies of Chica et al., 2015, and Schleicher et al., 2013). They are shown in Figure 1 (a) and b, respectively.

Fluid volumes were export to ANSYS V17.0® software. The meshing process was performed using a tetrahedral mesh with a relevance of 100 (software parameter) using a proximity and curvature algorithm. Sizing mesh property was set at 1 millimeter in the output profile of the blades because boundary layer detachment and fluid instabilities were observed in that area. The study of mesh independence was done for both tridimensional models. The number of elements was 10'193,443 and 20'963,979 for hydrokinetic turbine with and without diffuser, respectively. Computational Fluid Dynamic analysis (CFD) was performed by transient simulation. The simulations were done during 6 s and 4 s for the model of the turbine with

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 7 (2017) pp. 1178-1181

and without diffuser, respectively. The diffuser generates higher velocity gradients on the vicinities of the turbine, therefore, a longer time of simulation is necessary to obtain a uniform behavior and a fully developed flow. Time steps of 0.01 s were used for the analysis. The working fluid was water at ambient temperature and double precision was used to reduce numerical errors, and k-ε turbulence model according to the studies of Chica et al., (2015), and Gaden and Bibeau, (2010). Figure 2 shows a design of experiment by blocks of the hydrodynamic analysis. This diagram was divided in two stages and it presents the input and output parameters used for the simulations.

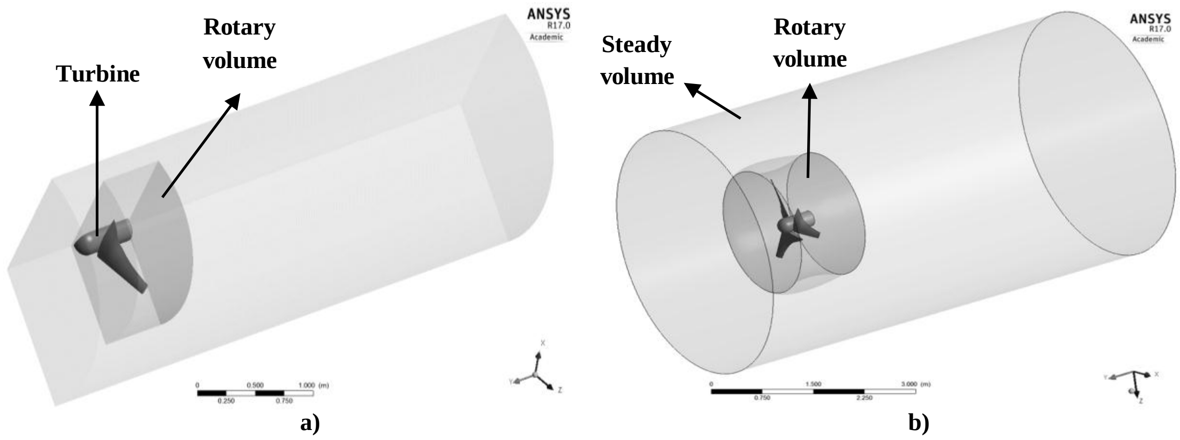

Figure 1. Fluid volume of horizontal-axis hydrokinetic turbine: (a) without diffuser and (b) with diffuser. Own source.

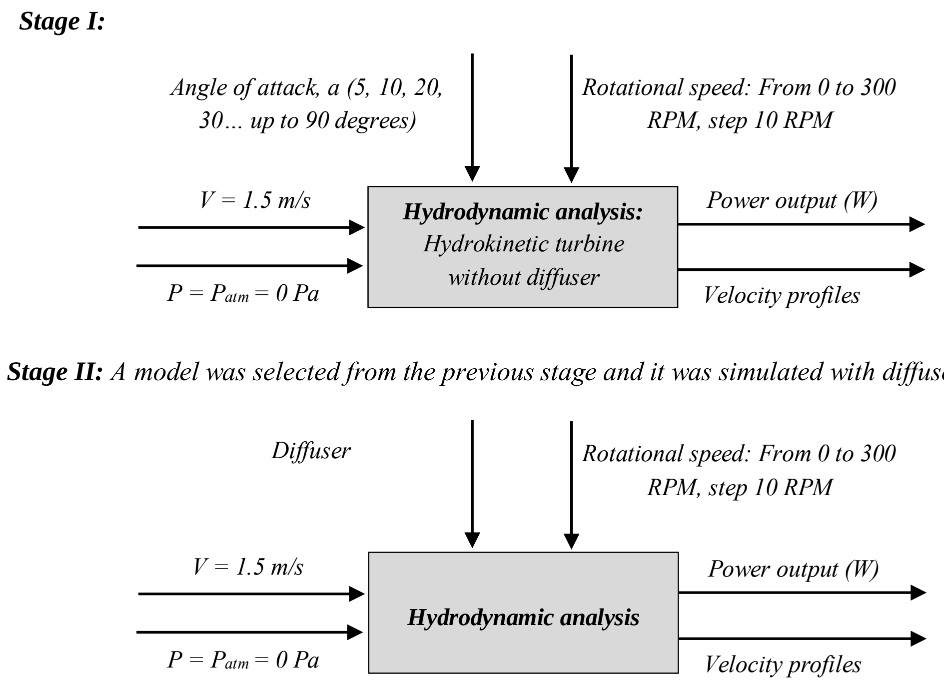

Figure 2. Design of experiment by blocks of the hydrodynamic analysis. Own source.

RESULTS

Figure 3. shows the output power in Watts and the angular velocity (RPM) from 0 to 300 RPM, with steps of 10 RPM. The curves drawn with continuous lines represent the results obtained for the hydrokinetic turbine without diffuser with different angles of attack. The dotted line corresponds to the result obtained for the turbine with diffuser with an angle of attack of 5 degrees. The results showed a parabolic shape. The output power tends to decrease when the angle of attack increase from 5 to 60 degrees and to increase for angles from 70 to 90 degrees. In the case of the turbine without diffuser, the best behavior in terms of generated power is presented using five (5) degrees of angle of attack, reaching a maximum output power of 846 W to 200 RPM. The maximum output power reached by the turbine with diffuser was of 880 W to 180 RPM. It is equivalent to an increase of the output power of 3.9 % compared to the previous result of the turbine without diffuser. This increment can be considered insignificant compared with the results obtained by Shahsavarifard et al., (2015) and Gaden and Bibeau, (2010).

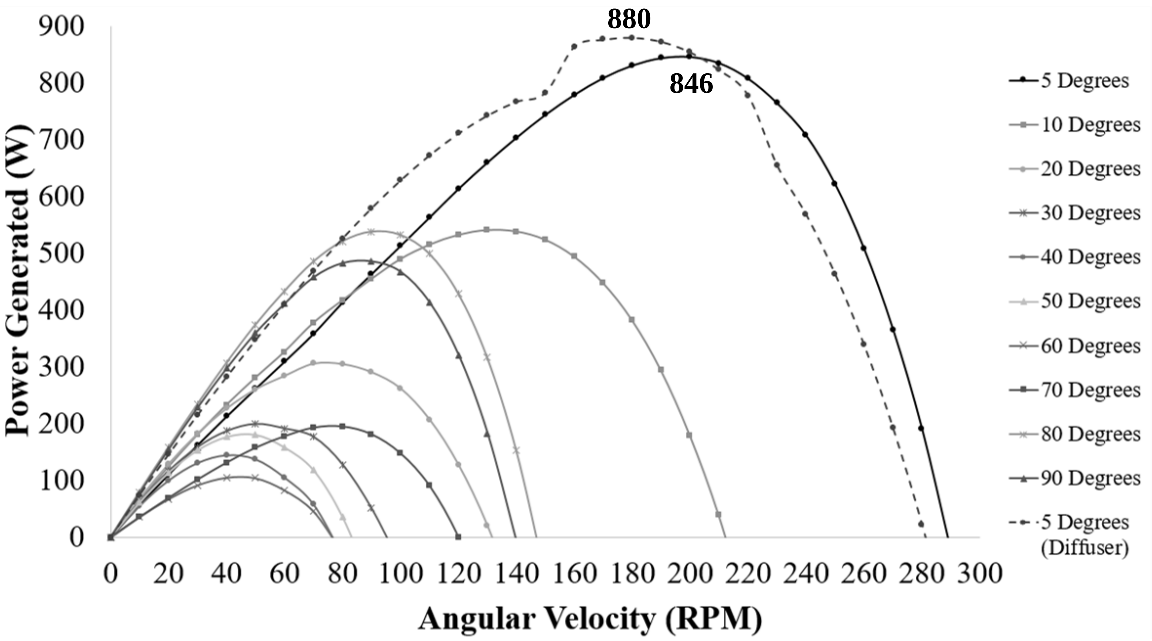

Figure 3. Power generated (W) vs angular velocity (RPM) based on the variation of 5 to 90 degrees of angle of attack of horizontal-axis hydrokinetic turbine: (a) without diffuser and (b) with diffuser. Own source.

Figure 4. shows a profile and velocity vectors on the airfoil of the hydrokinetic turbine. This contour is in the cross-section plane in the middle of the blade (a) of the turbine with (c) and without diffuser (b). Figure 4(b-c) has a color scale with values from 0 to 2.1 meters per second. Both figures showed a high speed upstream and low speed downstream of the turbine.

High speeds at the inlet and outlet areas of the airfoil are shown in the Figure 4(b-c), with values between 1.9 and 2.1 meters per second, which represents a boundary layer detachment generating energy losses. The low velocity downstream of the turbine without diffuser with values from 0 and 0.4 meters per second and a recirculating fluid in the same area were presented. This causes energy losses because an obstruction is generated in the fluid flow.

Figure 4(c) shows the boundary layer detachment decreased on the inlet and outlet areas of the airfoil profile. This behavior is obtained due to the reduction in the velocity of those areas from 1.3 to 1.7 meters per second. In addition, an increment in the speed downstream of the turbine from 0.6 to 1.0 meters per second was presented. The mentioned features reduce the energy losses compared to the results obtained for the turbine without diffuser.

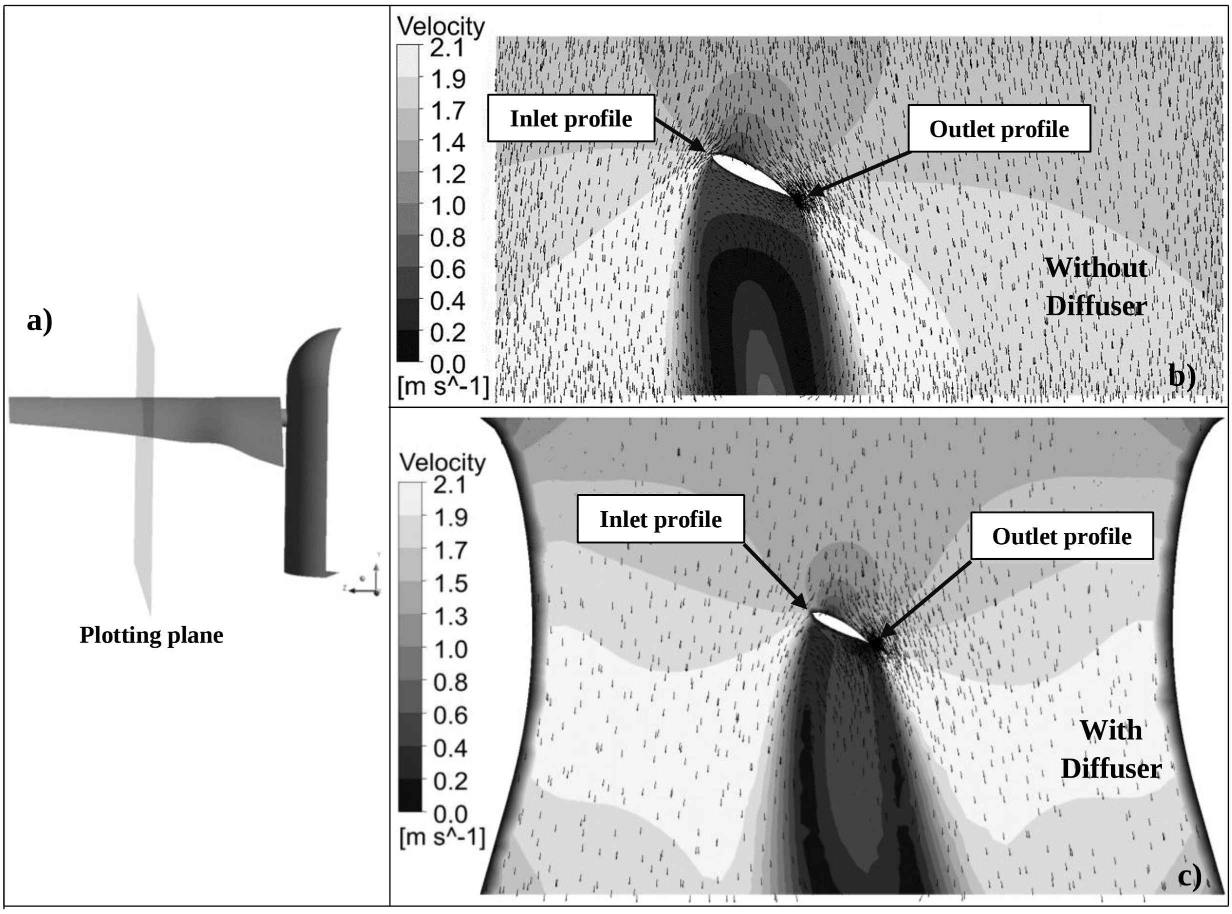

Figure 4. Velocity profiles and vectors of horizontal-axis hydrokinetic turbine: (a) plotting plane, (b) without diffuser and (c) with diffuser. Own source.

CONCLUSIONS

Hydrokinetic turbine showed the best behavior at an angle of attack of 5 degrees.

Horizontal-axis hydrokinetic turbine with and without diffuser reaching a maximum output power of 880 W to 180 RPM and 846 W to 200 RPM, respectively. The diffuser increased in a 3.9 % the output power of the turbine. The increase is considered insignificant compared to similar studies (Shahsavarifard et al., 2015) and (Gaden & Bibeau, 2010).

The recirculation and boundary layer detachment occur downstream of the turbine and they cause energy losses.

REFERENCES

[1] E. Chica, F. Perez, A. Rubio-Clemente, and S. Agudelo, “Design of a hydrokinetic turbine,” *WIT Trans. Ecol. Environ.*, vol. 195, pp. 137–148, 2015.

[2] M. Shahsavarifard, E. L. Bibeau, and V. Chatoorgoon, “Effect of shroud on the performance of horizontal axis hydrokinetic turbines,” *Ocean Eng.*, vol. 96, pp. 215–225, Mar. 2015.

[3] D. L. F. Gaden and E. L. Bibeau, “A numerical investigation into the effect of diffusers on the performance of hydro kinetic turbines using a validated momentum source turbine model,” *Renew. Energy*, vol. 35, no. 6, pp. 1152–1158, Jun. 2010.

[4] W. C. Schleicher, J. D. Riglin, Z. a Kraybill, and G. Gardner, “Design and Simulation of a Micro Hydrokinetic Turbine,” *Proc. 1st Mar. Energy Technol. Symp. METS13*, 2013.