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Experimental and Numerical Study of a Vertical Axis Tidal Current Turbine

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ABSTRACT: Tidal energy is one of the renewable energy sources, typically harvested through tidal turbines. Tidal turbines are classified as either vertical or horizontal turbines based on their rotation axis. The present investigation concerns parameters that affect flow hydrodynamics in a vertical-axis tidal turbine. A 1:20 Hunter turbine model was manufactured and investigated in a laboratory followed by transient solution Computational Fluid Dynamics simulations. The simulations were carried out for both rigid lid surfaces and free surface assumptions while SST k-ω turbulence model was used for both cases and volume of fluid method was employed for the free surface model. Simulations results verified by Empirical data which showed a good agreement. The power coefficient reached 0.23 at the best case scenario and the maximum power coefficient occurs at a flow coefficient between 0.4 and 0.43 for all investigated flows. Furthermore, the free surface simulations showed that the flow deflection on the turbine region leads to a greater torque exerted on the turbine blade. While the maximum mean torque coefficient for the rigid lid cases is 0.18, for the free surface cases the said coefficient reaches 0.4 showing a 120 percent increase. Additionally, the free surface cases power coefficient increased by 10 percent

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1- Introduction

The optimal place for setting up tidal turbines is in narrow straits and capes with extremely high current velocities. Most existing vertical axis turbines can be adapted to tidal currents. Numerous studies have been conducted on vertical axis wind and tidal turbines field in recent years. For instance, in one study the near-wake of a vertical-axis cross-flow turbine was modeled numerically [1]. Akbari and Abdolahifar [2] investigated the performance of hybrid Darrieus-Savonius wind turbines.

The turbine investigated in the present paper is called Hunter turbine with six flapping blades hinged on a drum. A flow visualization experiment was conducted followed by a Computational Fluid Dynamics (CFD) analysis in 2D and 3D steady state to investigate the Hunter turbine [3, 4]. Derakhshan et al. [5] analyzed the effects of the duct and various arrays in the farm on Hunter turbine performance in steady state analysis. The current research aims to investigate further the turbulent flow effects on the turbine blades during the opening and closing process in time, in which the free surface effects are taken into account.

2- Experimental Setup

In this study, a 1:20 Hunter turbine model is built and examined in a rectangular open channel in fluid mechanics lab in Iran University of Science and Technology (IUST).

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The schematic view of the experimental setup is illustrated in Fig. 1. To conduct an accurate non-dimensional analysis, the flow was characterized by two non-dimensional numbers. Froude number based on turbine height, and the depth to turbine height ratio are defined as:

$$Fr_L = \frac{U}{\sqrt{gL_t}} \tag{1}$$

$$D_L = \frac{D_t}{L_t} \tag{2}$$

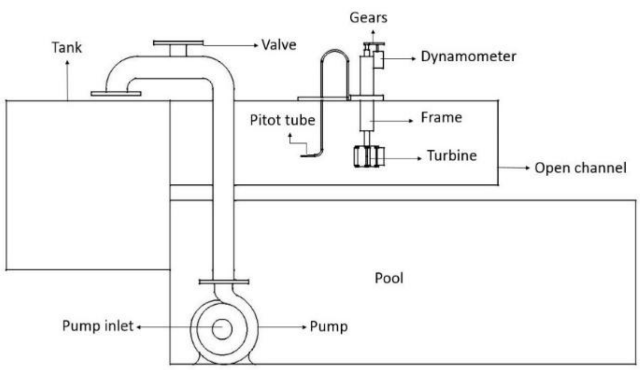

Fig. 1. Schematic side view of the experimental setup

In this study, the non-dimensional characteristics of the flows are shown in Table 1:

In which, U is the flow velocity, g stands for gravitational

Table 1. Non-dimensional characteristics of flows

Q (l/s)	L_t (cm)	D_t (cm)	$U\left(\frac{m}{s}\right)$	$D_L=\frac{D_t}{L_t}$	$Fr_L=\frac{U}{\sqrt{gL_t}}$
8.1		6	0.56	1	0.730
10.5	6	8	0.60	1.333	0.782
15		11.5	0.66	1.917	0.860

acceleration, L_t shows the turbine height and D_t represents the turbine depth from the flow surface.

3- Numerical Setup

The turbine was dynamically modeled through a 3D transient simulation using CFD software, Autodesk CFD 2017. Turbulence was modeled using k-ω SST which is a two-equation model. The free surface solver is based on the Volume of Fluid (VOF) approach. The grids were refined, so that the value of Y^+ near the solid walls was assured to be less than 1 (Fig. 2). For dynamic modeling of the flapping blades, we used the software masking mesh approach to model the interaction between the fluid and the moving blades. The flapping blades motion is a function of displacements around both the drum and the blade hinge axes. Ultimately, appropriate boundary conditions were applied to the computational domain.

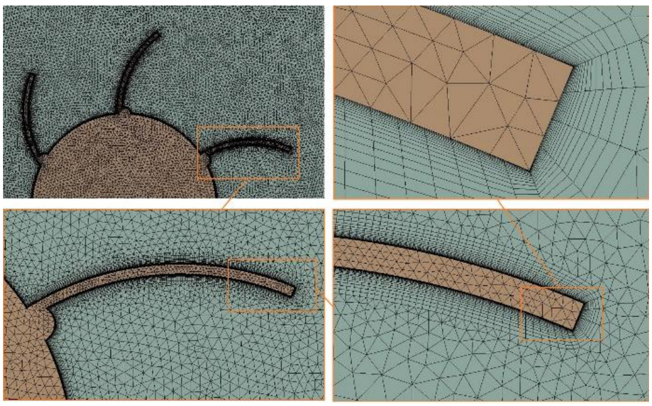

Fig. 2. Fine mesh around the complex geometry

4- Results and Discussion

Using measured data, the flow coefficient and the power coefficient of the turbine can be obtained using:

$$\varphi=\frac{\omega R_C}{U} \tag{3}$$

$$C_{Pow}=\frac{\omega \sum T_i}{0.5\rho A U^3} \tag{4}$$

Fig. 3 shows the power coefficient plot versus flow coefficient in three blockage ratio cases. The power coefficient curve for the turbine has a bell-like shape. Second, the blockage ratio has a significant effect on power production such that at 0.32 blockage ratio, the maximum C_Pow was 0.132, but it decreased to 0.084 and 0.048 at blockage ratios of 0.26 and 0.2, respectively. Higher blockage ratios resulted in higher power coefficients. This phenomenon is particularly evident in ranges close to maximum power coefficients, resulting in much higher power coefficients.

Fig. 4 depicts power coefficient curves against flow coefficients for all simulated domains. Experimental values are shown alongside the power coefficient curves obtained from the simulations for validation purposes.

CFD results showed good agreement with the corresponding experimental values. A maximum of 5% deviation was observed between CFD and the experimental data which occurred at a flow coefficient of 0.48. Maximum power coefficient was observed between 0.4 and 0.43 flow coefficients for three investigated flows. As it is obvious, power coefficients for free surface cases were much higher than rigid-lid ones due to the presence of the flow elevation head applying a greater force on the turbine. However, specific relevancy between optimum flow coefficient and non-dimensional numbers which characterize the flows was not captured. Power coefficient increased by a simultaneous increment of depth to height ratio and height based Froude number.

The torque exerted on the turbine originated from two phenomena: first, the flow elevation difference at the turbine region, second, a significant pressure drop behind turbine due to the flow separation which led to a sudden velocity drop at downstream, consequently forming flow wake region and

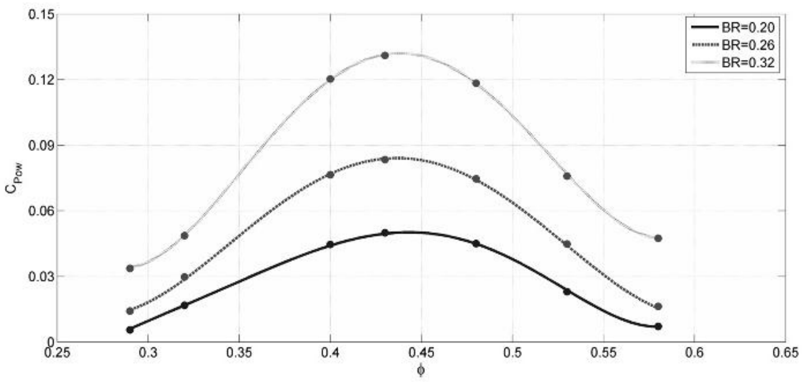

Fig. 3. Power coefficient versus flow coefficient for RL cases.

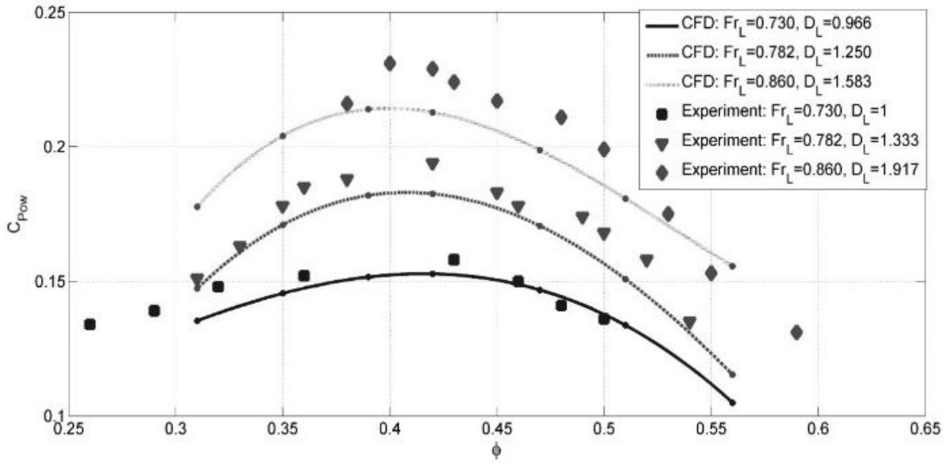

Fig. 4. Power coefficient versus flow coefficient curves-FS cases.

a notable pressure drop between upstream and downstream. This phenomenon synthesizes with additional pressure on the blade pressure side due to flow elevation head.

5- Conclusions

A Hunter turbine with six blades was experimentally and numerically investigated in open-channel flow. Experimental results demonstrated that maximum power occurred at flow coefficients between 0.4 and 0.43. At the optimum flow coefficient, the power coefficient reached to 0.23. The simultaneous increase in both turbine height based Froude number and depth to height ratio resulted in higher power coefficient and efficiency.

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