Ocean Engineering 137 (2017) 59–67

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Experimental and numerical study of a vertical axis tidal turbine performance

Shahram Derakhshan*, Mohammadreza Ashoori, Amirhosein Salemi

School of Mechanical Engineering, Iran University of Science & Technology, Narmak, 16846 Tehran, Iran

ARTICLE INFO

Keywords:
Tidal turbine
Power coefficient
Duct
Farm performance factor

ABSTRACT

In the present study, a vertical axis tidal turbine with movable blades was investigated using experimental and numerical methods. A laboratory model of this turbine type nominated as Hunter turbine was manufactured and tested in an established test rig. In the next step, 3D steady Reynolds-Averaged Navier-Stokes (RANS) equations were solved by CFD using k-ω turbulence model to predict turbine's performance. The numerical results were verified by the experimental data. In addition, effects of duct, neighbor turbines distance and layout on the power coefficient were investigated. The results showed that the power coefficient of a turbine in the present of ducts with area ratios of 0.1–0.26 increased from 0.14 to 0.29. It was also observed that in a four-turbine farm, the output power is maximum for a distance of 13*D* (diameter of turbine) between neighbor turbines and area ratio of 0.26. For this case, the farm's performance factor is 0.944.

1. Introduction

Recently, due to the growing concerns about pollution from energy sources that come from fossil fuels such as oil, coal and natural gas, there have been some reasonable effective efforts in international agreements and national energy action plans, such as EU 2009 Renewable Energy Directive to increase the use of renewable energy (Blunden and Bahaj (2007); World Energy Assessment (WEA) (2000)). Clean energies are going to be important by considering environmental limitations such as greenhouse gases and earth warming problem. Off grid renewable energies such as solar energy, wind power energy, hydro energy, and biomass energy are the main alternative to overcome the mentioned problems. Unfortunately, renewable energies are not always economical in comparison with the conventional energies. Therefore, designing the low-cost machines with higher efficiencies is a hot topic for researchers and engineers (Derakhshan and Kasaeian, 2013). Marine energy, also known as ocean energy and marine hydrokinetic energy including tidal and wave powers, is a relatively new sector of renewable energy. The theoretical annual potential is equivalent to 4–18 million tones oil equivalent (toe per year). International development of marine energy are currently doing by advanced technologies such as wave energy converters in open coastal areas with significant waves, tidal turbines placed in coastal and estuarine areas, stream turbines in fast-moving rivers, ocean current turbines in areas of strong marine currents and ocean thermal energy converters in deep tropical waters (Smith, 2007).

Some researchers have worked on applying advanced technologies to convert available hydro potentials in water systems (Fecarotta et al., 2016, 2015; Carravetta et al., 2014a, 2013, 2014b; Vieira and Ramos, 2008) by pumps used as turbines (Derakhshan and Nourbakhsh, 2008a, 2008b; Yang et al., 2012). In addition, micro-hydro turbines were applied to recover rivers flow potential vastly (Derakhshan and Kasaeian, 2013; Bozorgi et al., 2013; Derakhshan and Mostafavi, 2011; Yassi and Hashemloo, 2010; Sammartano et al., 2013; Reihani et al., 2014). For ocean wave energy, sea- wave generators used for wave energy recovery (Buccino et al., 2012; Vicinanza et al., 2011).

Tidal turbines are interested in coastal area with reasonable tides. Two types of turbines are usually implied to produce the energy from tides: Horizontal axis and vertical axis (Bryden and Couch, 2006; Garrett and Cummins, 2007; Khan et al., 2009). One of the axial turbines with movable blades named as Hunter turbine was investigated by Yang and Lawn (Yang and Lawn, 2011, 2013). They analyzed the performance of this turbine in a stand-alone application comparing with fix blades turbines. They reported that this turbine is more efficient than conventional vertical fixed blades turbines.

Vennell (Vennell, 2012) and Li (Li, 2014) considered the performance factor of tidal turbines in a farm. Garret and Cummins (Garrett and Cummins, 2007) studied the maximum output power of a channel from an oceanography point of view by treating the turbine as a black box and the channel as a two dimensional flow with lateral boundary. Whelan et al. Whelan et al. (2009) studied the maximum output power of a channel by treating the channel as a two dimensional flow with vertical boundary.

* Corresponding author.
E-mail address: shderakhshan@iust.ac.ir (S. Derakhshan).

http://dx.doi.org/10.1016/j.oceaneng.2017.03.047
Received 4 March 2016; Received in revised form 9 January 2017; Accepted 24 March 2017
0029-8018/

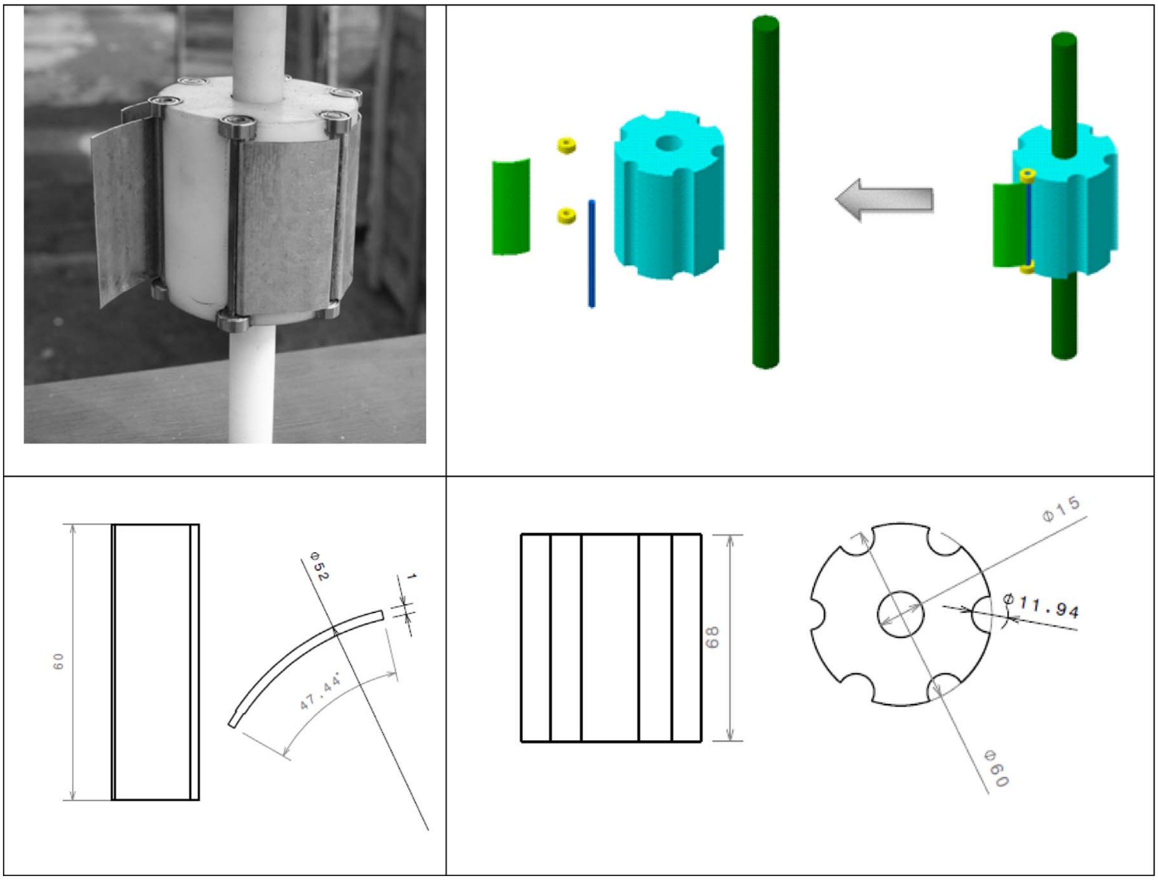

Fig. 1. Laboratory model of vertical axis tidal turbine.

Fig. 2. Turbine position in open channel test rig.

In the present study, a model of Hunter turbine was carefully manufactured to test in an established test rig in laboratory of IUST. The turbine had six movable blades hinged around a cylinder with aspect ratio of 1.0. Measured data was used to verify the numerical simulation data done by flow solver. This verified numerical model was applied to consider the effects of the duct and the farm (multi-tidal turbines) on the performance of the turbine. Finally, results was considered and discussed.

2. Case study

The model of vertical axis tidal turbine with six movable blades around a cylindrical casing with an aspect ratio of 1.0 was selected to analyse experimentally and numerically. The turbine includes a long main shaft, six small shafts for blades installation, a cylindrical body and six blades. Fig. 1 illustrates the model of this turbine. The diameter and the height of this turbine were 0.6 m.

3. Experimental setup

A complete open test rig was constructed in laboratory for testing the model of turbine. Fig. 2 shows the turbine's position in an open channel. Water flow was provided by a centrifugal pump type KSB-100-250. Using pump's characteristic curve, after measuring the pump head using barometer (ranged 0–1.0 bar), the flow discharge was obtained. Using the value of discharge, the velocity of flow has been determined. To measure the power, after obtaining the rotational speed by a laser tachometer, the shaft torque was measured by a dynamometer.

Using measured data, the flow coefficient was obtained using:

$$C_f = \frac{\omega R_c}{U} \tag{1}$$

where ω is the angular velocity, U is the flow velocity and R_c is the distance between the drum axis and the center of the blade chord when the blade is completely opended. And the power coefficient of turbine was derived by: