DIFFUSER SHAPE OPTIMIZATION FOR GEM, A TETHERED SYSTEM BASED ON TWO HORIZONTAL AXIS HYDRO TURBINES

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This paper concerns the numerical shape optimization of the diffuser of a horizontal axis hydro turbine. The turbine is part of the tethered system GEM developed for harnessing ocean current energy. The methodology consists of: a first phase in which axial symmetric analysis has been performed CFD simulating the turbine with pressure jump across actuator disk; a second phase where 3D CFD computations have been performed and compared with experiments. Results from both CFD axisymmetric model and experimental data show a significant increase for the power coefficient, while the 3D model not fully confirms this advantage.

Keywords: renewable energy, tidal current energy, hydro turbine, diffuser optimization, CFD

INTRODUCTION

Nowadays, the utilization of renewable energy is not enough to global energy requirements, but it’s certainly necessary to support the energy demand with clean energy [1]. One of the most promising fields in energy production from renewable sources is related to the intensive exploitation of marine and river currents. The ADAG (Aircraft Design & AeroFlightDynamics) research group has developed since 2003 a system named GEM, The Ocean’s Kite, to harness tidal current energy [2]. GEM working principles is shown in Figure 1: it consists of a tethered system employing two horizontal axis shrouded turbines mounted on the sides of a semi-submersible body. The first prototype has been deployed in 2012 (visit www.seapowerscrl.com). Each hydrokinetic turbine is equipped with a diffuser (or shroud) and the main goal of this work is the optimization of the diffuser shape with the aim of increasing the maximum power coefficient (C_P) while keeping at minimum the ratio of the exit area over rotor disk area.

The theoretical maximum power coefficient for a bare turbine (without a diffuser) is known as the Betz limit, and it could be exceeded if a mechanism is used to increase the flow rate through the rotor disk. This effect can be obtained by placing a diffuser (shroud) around the rotor. If the cross-section of the diffuser is shaped as an airfoil, the generated lift will give the circulation of a ring vortex. The more lift that can be achieved, the more the air will be sucked through the disk.
Similarly, Van Bussel [3] asserts that, applying the momentum theory normally used for bare turbines, power augmentation is proportional to the mass flow increase generated at the nozzle of the diffuser augmented turbine. Such mass flow augmentation can be achieved through two basic principles: increase in the diffuser exit ratio and/or by decreasing the back pressure at the exit. The power increase could results in a misleading overcoming of the Betz limit. As shown by Van Bussel this is due to an incorrect choice of the reference area. In this case the suitable reference area should be the shroud exit area. From this momentum theory, it can be seen that the achievable power is comparable with the power of a normal HAWT (Horizontal Axis Wind Turbine) having a diameter equal to the exit diameter of the diffuser. But from this momentum model it can also be seen that larger performances are possible when a substantial low back pressure level can be achieved at the diffuser exit. As shown by Tognaccini in [4] the power augmentation is proportional to the thrust exerted by the flow on the diffuser. The shroud design criteria were based on the maximization of this thrust. A high lift airfoil has been opportunely chosen, and the working angle of attack has been numerically estimated and experimentally validated by Scherillo et al. [5]. The measured power coefficient of the shrouded configuration, referred to the turbine area, is almost 0.75, and it shows an increase of about twice compared to the bare turbine characterized by a $C_P = 0.4$. When the measured power coefficient of the shrouded configuration is referred to the diffuser exit area, the increase respect to bare turbine is about 7% showing a net improvement respect to what momentum theory would suggest.

METHODOLOGY

In order to determine a new optimized shape for the hydro-turbine diffuser an automatic numerical procedure has been arranged. Its main components are: a main optimization program written in MATLAB language[1]; a genetic algorithm (based on NSGA-II [6]) used to perform optimization for a specific objective function (in this case the power coefficient referred to the diffuser exit area); a CFD library used to evaluate the objective function, namely STARCCM+ from CD-Adapco[2]; it has been used the overlapping grid, very useful in parametric study where the same airfoil is analyzed at different pitch angle; a parallel computing infrastructure (S.Co.P.E. [3] of

[1] © 1994-2014 The MathWorks, Inc., http://www.mathworks.de/products/matlab/

[2] http://www.cd-adapco.com/

[3] http://www.scope.unina.it/