Numerical prediction and optimization of the performance of axial-flow hydrokinetic turbine in an array

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Long Abstract

Introduction

Hydrokinetic turbine utilizes kinetic energy of flowing water from rivers and seas and converts into this energy into useful mechanical power. The efficiency of this type of "net-zero head" turbine is lower than that of a conventional high head hydraulic turbine; but it is more suited from the perspective of minimum adverse effect on environment and population displacement. This has led to a growth in activities in this research topic in recent times. [1].

This type of turbine can be axial-flow or cross-flow, depending on the orientation of the shaft with respect to the water current. Axial-flow hydrokinetic turbine, the focus of present work, has an axis of the shaft parallel to the incoming flow while cross-flow turbine has axis perpendicular to the flow. Former is more efficient than the later type of turbine but suffers from the problem of high sensitivity to the direction of the incoming flow [2]. For tidal applications, with bi-directional flow, cross-flow turbine may be more suited; while for river application with a reasonable same direction of flow, axial-flow turbine is favorable. Design and performance prediction of axial-flow hydrokinetic turbine forms the focus of the present work.

1. Methods

In one of our earlier works [3], we had designed and predicted the performance of the axial-flow hydrokinetic turbine with S822 airfoil recommended by Anyi and Kirke [4]. In the present work, we advance that study by carrying out experiments with the axial-flow hydrokinetic turbine designed and the numerical results are compared with the experimental finding.

Though this technology is an emerging alternative, yet it suffers from low energy conversion coefficient. Thus, akin to wind farms, it may be more desirable to install an array of these turbines rather than a single turbine. However, this nascent technology faces uncertainties and challenges not only for extracting more energy per unit of rotor swept area, but also to extract the maximum energy when such turbines are coupled together at a particular site for power extraction. Hence the present work focuses on numerically determine turbine configurations in an array that will yield the best performance. The methodology adopted is outlined as follows:

i. Numerical simulations are first conducted to predict the performance of a single turbine to produce an electrical power output of 200m/s with an incoming water speed of 1m/s.
ii. Numerical results are compared with the experimental data.
iii. Performance of the turbine is improved by making suitable change in the geometry of the turbine (blade stacking and hub shapes).
iv. An array of turbines (with variable in-line and transverse separating distances) are considered.
v. The idea is to optimize these geometrical patterns (arrays) in which in-line and transverse spacing play critical role in deciding the overall performance — parameterized in terms of three functions

(power density, power loss due to wake, and area utilization). Power density is defined as the ratio of the total power offered by the coupled turbines to the array area. The turbines in an array, that extends from one side of a channel or river to the other side, experience a fixed blockage effect as a result of the adjacent turbines. This blockage effect is characterized here as the loss due to the wake created at the rear end of the former turbine, when the later enters the wake regime of the former one. Hence this loss is accounted as a function of the in-line and transverse spacing between the adjacent turbines. The area utilization factor, the third function, is taken as the ratio of the actual area utilized by the patterns to the total available area. A multi-objective optimization is formulated to characterize the above three performance parameters as the function of in-line spacing and transverse spacing that provide the maximum power density and area utilization factor, with the minimum power loss. A pareto-front obtained offers a logical and acceptable trade-off between these functions.

References

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