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Field performance assessment of a hydrokinetic turbine

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ABSTRACT

A cross-flow hydrokinetic turbine with a projected area (product of blade span and rotor diameter) of 0.7 m^2 is evaluated in open-water tow trials at three inflow speeds ranging from 1.0 m/s to 2.1 m/s. Measurements of the inflow velocity, the rotor mechanical power, and electrical power output of a complete power take-off (PTO) system are utilized to determine the rotor hydrodynamic efficiency (maximum of 17%) and total system efficiency (maximum of 9%). A lab-based dynamometry method yields individual component and total PTO efficiencies, shown to have high variability and strong influence on total system efficiency. The method of tow-testing is found effective, and when combined with PTO characterization, steady-state performance can be inferred solely from inflow velocity and turbine rotation rate.

1. Introduction

Development of hydrokinetic turbines used for electricity generation involves advancing systems through technology readiness and performance levels to commercialization [1,2]. Field testing of scaled prototypes is a critical phase of development following laboratory experimentation and addresses two potential limitations under laboratory conditions. First, a turbine's hydrodynamic performance and thrust can be augmented in confined flow (such as a recirculating laboratory flume

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Nomenclature

Abbreviations

A	rotor projected area
ADV	acoustic Doppler velocimeter
c	blade chord length
C_P	coefficient of performance
D	turbine diameter
H	turbine span/height
$\tilde{I}$	generator current, dynamometry
I	generator current
IMU	inertial measurement unit
I_U	turbulence intensity
K_V	generator voltage constant
N	number of blades
N_B	gearbox ratio
P_e	electrical power
P_k	kinetic power
PTO	power take-off
r	turbine radius
R	resistive load
t	blade thickness
U_∞	undisturbed upstream water velocity
$\tilde{V}$	generator voltage, dynamometry
V	generator voltage
z	submergence of rotor
η_B	gearbox efficiency
η_G	generator efficiency
η_L	electrical efficiency
η_S	total system efficiency
θ	helical pitch angle
λ	tip-speed ratio
ρ	density
σ	solidity
σ_U	standard deviation
φ	helical sweep angle
$\tilde{\tau}_{hss}$	high-speed shaft torque, dynamometry
τ_{hss}	high-speed shaft torque
τ_{lss}	low-speed shaft torque
$\tilde{\omega}_{hss}$	high-speed shaft rotation rate, dynamometry
ω_{hss}	high-speed shaft rotation rate
ω_{lss}	low-speed shaft rotation rate

or tow tank) due to increased mass flux through the turbine and accelerated flow around the turbine, resulting in a higher pressure drop across the rotor [3]. Second, below a critical Reynolds number, where the lift and drag coefficients of hydrofoils depend on current velocity, rotor performance also depends on current velocity [4–6]. Because hydrofoils in a cross-flow turbine (rotation axis perpendicular to direction of flow) undergo dynamic stall as a consequence of large changes in the angle of attack, a critical Reynolds number cannot be accurately determined from static foil data [7]. In a laboratory setting, it can be difficult to achieve Reynolds independence due to limitations on maximum velocity in experimental facilities and the aforementioned consequences of flow confinement as model size increases.