A. INTRODUCTION

Axial flow hydrokinetic turbines provide a method for extracting energy available in unidirectional (tide), unidirectional (tidal) and marine currents; however, a deep understanding of the wake dynamics, momentum recovery, geomorphologic effects, and ecological interaction with these hydrokinetic turbines is required to guarantee their economical and environmental viability. The St. Anthony Falls Laboratory (SAFL) at the University of Minnesota (UMN) has performed physical modeling experiments using a 1:10 scale axial flow tidal turbine in the SAFL Main Channel, a 2.75m x 1.8m open channel set-up. A sophisticated control system allows synchronous measurement of turbine power along with high resolution 3D velocity measurements within the channel. Using acoustic Doppler velocimeters (ADV), 3D velocity profile data were collected up to 15 turbine diameters downstream of the turbine location. These data provide valuable information on the wake characteristics (mean flow, turbulence, Reynolds stresses, etc.) resulting from a running axial flow hydrokinetic machine. Regions of high turbulence and their effects in the near wake region are delineated along with the velocity deficit and momentum recovery within the wake elements of the device. Synchronous ADV data shall highlight the retention characteristics of the wake and its potential impacts on the local geomorphology and hydrodynamic environment. This dataset on single hydrokinetic turbine flow characteristics is the basis for further work on the operational arrangements and performance assessment for arrays of similar hydrokinetic devices. Through this research, we aim to understand turbine wake recovery and the impacts it may have on the a) performance; b) stability and lifespan; and c) spacing requirements of nearby machines. Additionally, we begin fulfilling the need for high-resolution measurements to validate CFD models for further development.

There is growing interest by the U.S. Department of Energy (DoE) to accelerate the development of environmentally sustainable and renewable energy technologies. For these technologies to develop into economically viable solutions to meet our Nation's energy demands by producing energy at competitive prices and scales (i.e., hydrokinetic turbine technology), there is a need for high-resolution measurements to validate CFD models for further development. This research provides insights on effects of near- and far-field environments, most notably showing: Hydrokinetic technologies show promise of harvesting substantial energy to contribute towards the Nation’s energy demands. This research provides insights on effects of near- and far-field environments, most notably showing:

1. Highly turbulent zones exist in the downstream near-field environment;
2. Turbine operating conditions respond to varying scales of turbulence; and
3. Wake recovery occurs more quickly with increased mixing from turbine approach conditions; however, this is likely a result of increased mixing. This only affects near-field regions, however, and the data show a remnant of the wake beyond 10d.

B. EXPERIMENTAL SETUP

<table>
<thead>
<tr>
<th>Q, = 1.26m³/sec</th>
<th>h = 1.15m</th>
<th>%Turb = 0.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re = 200,000</td>
<td>Fr = 0.12</td>
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</table>

Figure B.1. SAFL Main Channel with instrumented Data Acquisition Carriage used to measure flow field, topography, and water surface elevation.

Figure B.2. Exploded view of the instrumented 1:10 scale model axial flow tidal turbine used for this study.

C. RESULTS

C.1. Turbine Performance

Figure C.1. Turbine power time series (top) and performance curves (bottom) (Chamorro et al.)

Figure C.2. Power spectral density of approaching velocity (blue) and turbine power output (black) for three tip-speed ratios (TSR = 2.9 (left) and 5.6 (right)) highlighting critical frequencies for turbine response. (Chamorro et al.)

Figure C.3. Turbulence intensities (r; A; B; C) at 5.5 and 10 rotor diameters downstream of the turbine (Chamorro et al.)

D. DISCUSSION

D.1. Turbine Performance

Figure D.1. Spectral coherence between turbine power and ADV measurement setup.

Figure D.2. Velocity deficit downstream of turbine with and without turbulence generating obstacles.

D.2. Flow Field

Figure D.3. Mean streamwise velocity from -2 to +15 rotor diameters along the centerplane of the turbine. (Chamorro et al.)

Figure D.4. Spectral coherence between turbine power and ADV measurement setup.

E. SUMMARY

Hydrokinetic technologies show promise of harvesting substantial energy to contribute towards the Nation’s energy demands. This research provides insights on effects of near- and far-field environments, most notably showing:

1. Highly turbulent zones exist in the downstream near-field environment;
2. Turbine operating conditions respond to varying scales of turbulence; and
3. Wake recovery occurs more quickly with increased mixing from turbine approach conditions; however, this is likely a result of increased mixing. This only affects near-field regions, however, and the data show a remnant of the wake beyond 10d.

E. ACKNOWLEDGEMENTS

F. ACKNOWLEDGEMENTS

This project was partially funded by Vodan Power and U.S. Department of Energy under Contract DE-AC05-00OR22725.

We would like to thank the contributions of the Engineering and Technical Support at St. Anthony Falls Laboratory, and especially the assistance of SAFL Engineers Chris Ellis and Jim Mullins with design and instrumentation of the turbine power system and synchronized turbine power measurements.

Figure B.3. Three acoustic Doppler velocimeters positioned at C1 (ADV-1), C2 (ADV-2) and hub center (ADV-3) and 10 rotor diameters downstream with turbine power measurements allowing for correlation between flow field and turbine performance measurements.