Alaska Field Testing of a BladeRunner Energy Hydrokinetic Turbine

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***Keywords*—hydrokinetic turbine, field testing, debris.**

I. Introduction

Alaska is home to over 100 remote riverine communities that are largely served by diesel microgrids. Wind, solar PV, and battery storage technologies have made significant inroads in many grids, displacing diesel and lessening the local environmental impact of electricity generation. However, the high variability of wind and solar resources creates technical complexity when penetration levels become significant. On Alaska's two largest rivers, the Yukon and Kuskokwim, most communities have total electrical loads of a few hundred kW while multiple MW of steady river power flows by continuously during the open water season from early May to late September. The potential for hydrokinetic energy systems to harness this resource is of significant interest to these communities and their electrical utilities.

A. Alaska Hydrokinetic Background

In 2013 and 2014, vertical axis turbines rated at 5kW and 25kW were deployed in the communities of Ruby and Eagle Alaska, respectively [1], [2]. While both turbines successfully produced power, both efforts were discontinued due to damage incurred from interaction with woody debris present in the river. From this experience, the Alaska Center for Energy and Power (ACEP), an applied research group at the University of Alaska Fairbanks, initiated a research program devoted to studying solutions to deploying hydrokinetic technologies in Alaska[3]–[8]. As part of this effort, the Tanana River Test Site (TRTS) was established in Nenana, AK, to provide an accessible and pre-permitted location to perform hydrokinetic turbine testing and study debris interactions and other parameters key to economic implementation of riverine hydrokinetic energy in Alaska.

B. BladeRunner Energy Hydrokinetic Turbine

BladeRunner Energy (BRE) is a hydrokinetic turbine developer in Bend, Oregon. BladeRunner's turbine design utilizes a minimally constrained submerged axial-flow rotor connected to a floating generator housing via a torsional cable. The torsional cable carries the drag load of the rotor and transmits the torque to the generator driveline. This design enables the rotor to translate, pitch, and yaw to absorb debris impacts, deflect around large debris, and shed small debris. A schematic of the BRE turbine architecture is shown in Fig. 1.

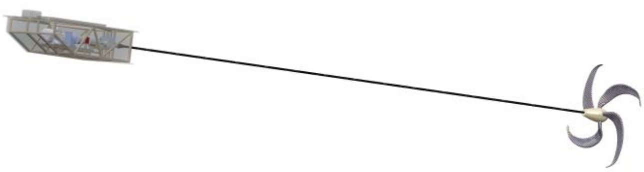

Fig. 1. Schematic of BladeRunner Energy hydrokinetic turbine architecture.

Under the US Department of Energy's ARPA-e SHARKS program, BladeRunner Energy and UAF have embarked on a multi-year effort to iterate BladeRunner's turbine technology and field test it at TRTS. This paper summarizes findings and results of field testing a BRE system with 1.57 m diameter rotor and a rated output of 3.0 kw at 2.0 m/s.

II. Methods

C. Tanana River Test Site

The Tanana River Test Site (TRTS) is located in Nenana, AK approximately 55 road miles southwest of the University of Alaska Fairbanks (UAF) campus in Fairbanks, AK. The test site comprises a pre-permitted stretch of the Tanana River that flows roughly south to north. Open water runs May to September, with main channel depth averaging 8 meters and surface velocities typically near 2 m/s and ranging from 1.3 m/s in spring and fall to up to 3 m/s during high water events. A satellite view of the Nenana area with the TRTS location circled is shown in Fig. 2.

Fig. 2. Satellite view of Nenana, AK with TRTS stretch of the Tanana River circled.

The test site infrastructure consists of multiple floating assets installed in series from a single mooring line connected to a permanent drag embedment anchor, as shown from an overhead view in Fig. 3. The research debris diverter platform is often deployed to deflect surface debris during testing, however the testing described in this paper was performed with no debris diverter in place. Turbines are deployed from the floating research barge, which also houses all data collection and power dissipation equipment. Directly downstream of the research barge is the inclined plane fish trap, which samples for fish downstream of deployed turbines and findings are reported to Alaska Department of Fish and Game.

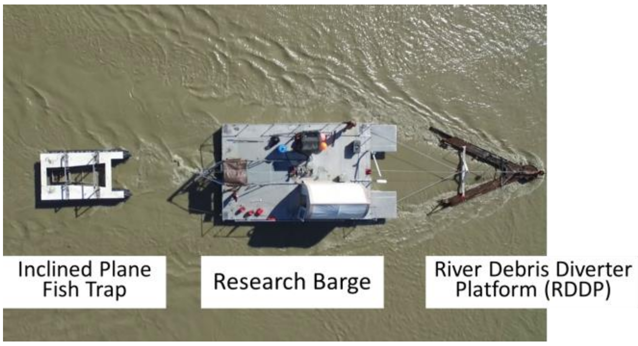

Fig. 3. Overhead view of TRTS floating infrastructure.

D. Prototype Turbine

BladeRunner Energy designed and fabricated the rotor blades, hub, and nacelle while UAF designed and utilized local fabricators to build and assemble the generator housing. The torsional cable was procured from a commercial vendor to custom specifications.

The generator housing is constructed with the generator and gearbox offset from the housing centerline to counter the torque from the rotor. The rotor blades incorporate a spiral leading edge to improve debris shedding. The rotor hub is fitted with adjustable ballast chambers and testing explored the effect of various ballast configurations on rotor depth and pitch during operation. A photograph of the rotor on the deck of the Research Barge is shown in Fig. 4. When deployed, the rotor and torsional cable are fully submerged, with the generator housing stable on the water surface with a single mooring line, as shown in the photograph in Fig. 5. A gantry system is used to deploy the BRE system from the Research Barge, however alternative deployment methods are anticipated for commercial deployments.

Fig. 4. BladeRunner Energy hydrokinetic turbine prototype on TRTS barge between deployments.

Fig. 5. BladeRunner Energy hydrokinetic turbine deployed at TRTS.

E. Instrumentation

The Research Barge provides a platform for various data collection instrumentation, summarized in Table 1. An acoustic doppler current profiler (ADCP) is mounted on the upstream end of the barge to measure the 3-dimensional water velocites in the river current. Due to the unique BRE topology, it is not possible to locate the ADCP close to the rotor, resulting in a significant time shift between the ADCP measured velocity and the velocity incident on the rotor, v. A correlation script is run to time-shift the ADCP velocity to best corelate velocity and rotor mechanical power.

Rotor depth is measured using a static pressure logger installed in the nacelle and rotor pitch is recorded using a 3-axis accelerometer aligned with the rotational axis of the rotor.

Mechanical power is measured using an inline torque, T, and speed, ω, transducer installed in the generator housing between the input shaft and the power take-off driveline. A 3-phase permanent magnet generator is used to convert mechanical rotational power into electrical power, and the AC output of the generator is connected to a diode bridge rectifier and DC load bank. The DC load bank is digitally controlled, enabling variable loading on the generator to control the torque-speed operating point of the rotor.

TABLE I
INSTRUMENTED VALUES DURING FIELD TESTING

Measurement	Instrumentation	Unit
Streamwise water velocity	Acoustic Doppler Current Profiler (ADCP)	m/s
Drag load on mooring	Inline load cell	N
Torque at input shaft	Rotating torque sensor	N-m
Input shaft velocity	Shaft speed sensor	rpm
Rotor pressure depth	Static pressure logger in nacelle	Pa
Rotor pitch	3-axis accelerometer in nacelle	m/s^2
Generator housing pitch and roll	3-axis accelerometer on housing	m/s^2
DC output voltage	DC Voltage transducer	VDC
DC output current	DC Current transducer	A
Gearbox temperature	K-type thermocouple	C

III. RESULTS

The BRE system was tested in various configurations during two week-long testing campaigns in June and August 2023. The primary independent variables were rotor density, center-of-mass location, and tip speed ratio (TSR). Density and center-of-mass were controlled by changing ballast configurations in the rotor nacelle. TSR was controlled by varying the electrical resistance of the load bank. In total, over 40 hours of instrumented operation were completed during the 2023 field testing efforts. Presented here are the nominal mechanical power performance values for one configuration of interest based on approximately 70 minutes of data collected during testing on August 17, 2023.

The rotor under test had a diameter of 1.54m for a swept area, A, of 1.86 m^2. A 60-second moving average filter was applied to the streamwise water velocity at the rotor depth and the calculated mechanical shaft power, and the filtered data are plotted in Fig. 6. River testing provide a narrow range of velocities, so to project power performance across a range of flow velocities, a projected power curve is plotted based on the average coefficient of performance, C_p, observed over the testing window. During this testing window TSR ranged from 3.87 to 4.34 and rotor C_p averaged 0.422. The projected power curve is based on these values according to (1). The water density, ρ, is assumed to be 998 kg/m^3.

$$P_{mech} = T\omega = \frac{1}{2} C_p \rho A v^3 \quad (1)$$

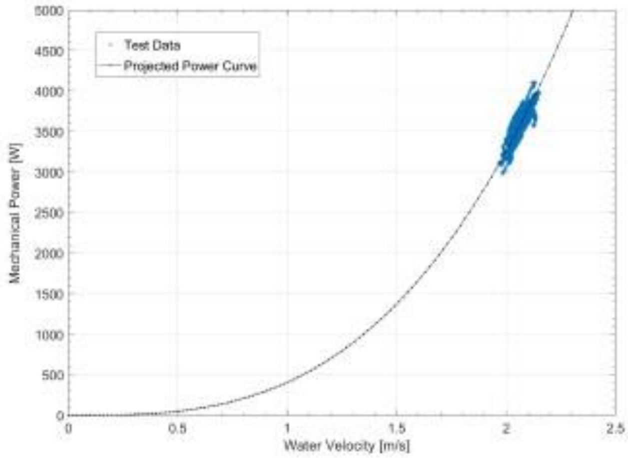

Fig. 6. Mechanical power versus rotor depth flow velocity, with projected power curve.

IV. DISCUSSION & CONCLUSION

Field testing does not provide precise control of velocity as can be achieved in flume or tow tank testing, limiting the scope and rigor of quantitative analysis. The data presented here on field testing validate the performance of the turbine in a narrow velocity range under real world effects of turbulence and debris. The turbine was operated across a range of resistive loading conditions, however the rotor efficiency versus tip speed ratio (TSR) data has been held proprietary by BRE.

The more valuable outcomes of field testing are often the qualitative results. In this case, the BRE turbine operated for more than 40 hours in a real Alaska riverine environment with no stoppages due to debris, sediments, or other environmental complications. One significant debris impact with a large floating tree was observed, with the rotor translating upward out of the water with the tree passing underneath with no entanglement. On two occasions, woody debris was manually collected and deliberately introduced upstream of the rotor, but no adverse effects were realized. This level of debris resilience is a first in UAF's experience testing turbines at TRTS and is highly encouraging for future development.

ACKNOWLEDGEMENTS

"The information, data, or work presented herein was funded in part by the Advanced Research Projects Agency-

Energy (ARPA-E), U.S. Department of Energy, under Award Number DE-AR0001444. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

REFERENCES

[1] J. Johnson and D. Pride, "River, Tidal, and Ocean Current Hydrokinetic Energy Technologies: Status and Future Opportunities in Alaska," 2010. [Online]. Available: https://www.researchgate.net/publication/265156371_River_Tidal_and_Ocean_Current_Hydrokinetic_Energy_Technologies_Status_and_Future_Opportunities_in_Alaska

[2] J. VanZwieten *et al.*, "In-Stream Hydrokinetic Power: Review and Appraisal," *J. Energy Eng.*, vol. 141, no. 3, p. 04014024, Sep. 2015, doi: 10.1061/(ASCE)EY.1943-7897.0000197.

[3] P. Duvoy and H. Toniolo, "HYDROKAL: A module for in-stream hydrokinetic resource assessment," *Comput. Geosci.*, vol. 39, pp. 171–181, Feb. 2012, doi: 10.1016/j.cageo.2011.06.016.

[4] H. Toniolo, P. Duvoy, S. Vanlesberg, and J. Johnson, "Modelling and field measurements in support of the hydrokinetic resource assessment for the Tanana river at Nenana, Alaska," *Proc. Inst. Mech. Eng. Part J. Power Energy*, vol. 224, no. 8, pp. 1127–1139, 2010, doi: 10.1243/09576509JPE1017.

[5] J. B. Johnson *et al.*, "Surface Debris Characterization and Mitigation Strategies and Their Impact on the Operation of River Energy Conversion Devices on the Tanana River at Nenana, Alaska," University of Alaska - Fairbanks, Nenana, AK, 2015. [Online]. Available: https://tethys.pnnl.gov/publications/surface-debris-characterization-mitigation-strategies-their-impact-operation-river

[6] J. Johnson, J. Schmid, J. Kasper, A. Seitz, and P. Duvoy, "Protection of In-River Hydrokinetic Power-Generating Devices from Surface Debris in Alaskan Rivers," University of Alaska - Fairbanks, 2014. Accessed: Aug. 22, 2022. [Online]. Available: https://tethys-engineering.pnnl.gov/publications/protection-river-hydrokinetic-power-generating-devices-surface-debris-alaskan-rivers

[7] J. Johnson, J. Kasper, N. Hansen, P. Duvoy, and J. Schmid, "THE EFFECTS OF RIVER AND DEBRIS DIVERSION STRUCTURE GENERATED TURBULENCE ON THE OCEANA RIVER ENERGY CONVERTER," in *Proceedings of the 3rd Marine Energy Technology Symposium*, Washington, D.C., 2015, p. 4. [Online]. Available: https://www.uaf.edu/acep/files/media/Johnson_et_al_2015_METS.pdf

[8] J. L. Kasper, J. B. Johnson, P. X. Duvoy, N. Konefal, and J. Schmid, "A Review of Debris Detection Methods," Northwest National Marine Renewable Energy Center, Alaska, 2015. [Online]. Available: https://tethys-engineering.pnnl.gov/sites/default/files/publications/kasperetal2015.pdf