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THE EFFECTS OF RIVER AND DEBRIS DIVERSION STRUCTURE GENERATED TURBULENCE ON THE OCEANA RIVER ENERGY CONVERTER

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INTRODUCTION

During summer 2014, the Alaska Hydrokinetic Energy Research Center (AHERC) and OCEANA Energy Company (OCEANA) conducted performance tests on OCEANA's river energy converter (REC) at the Tanana River Test Site (TRTS). OCEANA's REC was deployed from AHERC's test barge moored immediately downstream from AHERC's research debris diversion platform (RDDP), which was moored to a midstream buoy attached to an embedment anchor (Figure 1).

FIGURE 1. AHERC TEST BARGE WITH OCEANA REC ON DECK MOORED BEHIND THE RDDP WITH A DEBRIS OBJECT FLOATING BY.

RECs operating on large uncontrolled rivers can be subject to impacts from woody debris that can cause damage, result in unsustainable operating and maintenance costs and create safety hazards [1, 2]. To reduce the risk of debris impacts on RECs deployed from floating platforms the AHERC developed the RDDP and demonstrated its effectiveness at the TRTS in Nenana, Alaska [1].

A concern of placing a REC downstream from the RDDP is that turbulence generated by flow around and under the RDDP might adversely affect the power performance of the REC. To examine the influence of RDDP generated turbulence on OCEANA turbine performance the power output of the turbine was determined at 14.5, 50m and 100m downstream from the RDDP. The 14.5 m downstream distance was the default position of the turbine during most of the performance testing.

RDDP DESIGN AND OPERATION

The RDDP is a "V" shape with and interior angle of 50 degrees and its apex facing upstream. A freely rotating cylinder of approximately 1m diameter with a low-friction surface is mounted forward of the apex (debris sweep). Debris that impacts the debris sweep is typically deflected with the result that it slides downstream along the pontoon surface. Debris is thus diverted away from the downstream region behind the RDDP. Numerous direct impact tests with debris and debris impacts during extended deployments have demonstrated the RDDP's effectiveness at deflecting debris away from the region immediately downstream from the RDDP [1]. Maximum protection of the test barge from debris occurs when the barge is tethered by a bridle to a spreader bar attached across the rear of the RDDP pontoons (Figure 2). This mooring arrangement prevents large inertia debris objects from causing the RDDP to rotate about its forward mooring point. The bridle tethered barge and RDDP move as a unit. The combined mass of the barge/RDDP system reduces the rotation of the RDDP/barge unit and ensures that the barge remains behind the RDDP when rotation does occur.

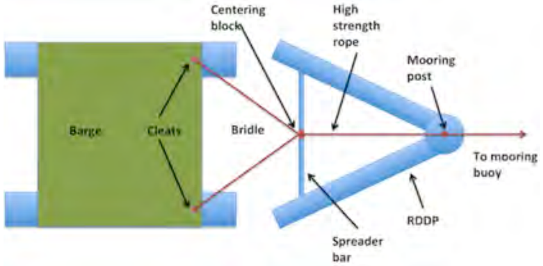

FIGURE 2. MOORING CONFIGURATION OF THE TEST BARGE AND RDDP.

RIVER AND RDDP GENERATED TURBULENCE

Rivers are inherently turbulent due to constant changes in water flow direction caused by variable bathymetry, river bends, riverbank projections into the flow and other sources. Energetic eddies with diameters on the order of, or larger than, the ~2 m diameter turbine have been observed that cause a reduction in the mean flow velocity [3] that can reduce a REC's power production. Large diameter energetic eddies that can influence the flow velocity are common at the TRTS (Figure 3).

Turbulence results from water upwelling under the front of the RDDP, water diverted around the RDDP and from vortices formed at the ends of the pontoons (Figure 4).

THE EFFECT OF RIVER AND RDDP GENERATED TURBULENCE ON THE OCEANA TURBINE PERFORMANCE

Prior to testing at the TRTS, the OCEANA turbine was tested at the Navy's Carderock tow tank. These tests demonstrated that in low Reynolds number conditions, the OCEANA turbine generated a constant power output at a set velocity. In contrast, tests at the TRTS produced variable power output consistent with water flow fluctuations associated with turbulence (Figure 5).

To determine if turbulence from the RDDP influences turbine performance the turbine was operated at a downstream distance of 14.5 m, 50 m and 100 m from the RDDP. Power from the OCEANA turbine was fed into a load bank and the turbine power output for the three locations downstream from the RDDP are shown in Figure 5. The difference in power at locations of 14.5 and 50 m compared to the power 100 m downstream of the RDDP is shown in Table 1.

FIGURE 3. VORTEX EDDY (~3-M DIAMETER) MOVING DOWNSTREAM AT THE TRTS VIEWED FROM THE FRONT OF THE RDDP.

Table 1. OCEANA turbine power output and percentage difference from the 100 m downstream measurement location. Bold values indicate statistically significant differences.

Distance from RDDP	Power (W)	Percent difference from 100 m location
14.5	1399	**-8.3%**
50	1522	-0.3%
100	1526	-

FIGURE 4. DOWNSTREAM VIEW OF TURBULENCE GENERATED FROM THE RDDP.

The results shown in Figure 5 indicate that natural turbulence from the river produced voltage fluctuations of about 150 W at a downstream distance of 100m. This is about 1% of the mean power at 100 m. The results of Figure 5 and Table 1 indicate that turbulence generated by the RDDP may have reduced the mean power output of the OCEANA turbine by about 8.3%.

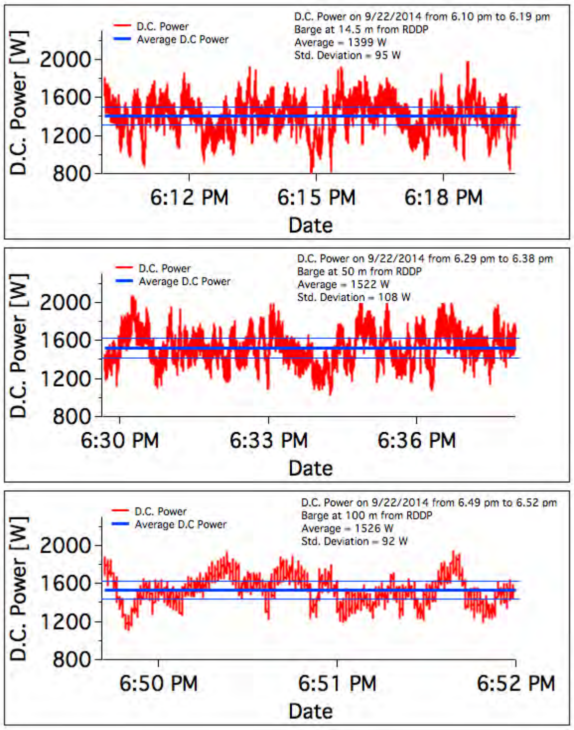

FIGURE 5. POWER OUTPUT FROM THE OCEANA TURBINE AT DOWNSTREAM DISTANCES OF 14.5 M, 50 M, AND 100 M FROM THE RDDP. THE THIN BLUE LINES INDICATE +/- 2 STD DEVIATIONS.

During testing a 1200 kHz TRDI acoustic Doppler current profiler sampling at ~1 Hz was mounted on the bow of the barge (the exact sample rate depends on the depth). Mean velocities measured by the ADCP show no significant differences in current velocity between the three locations. Thus the differences observed in the power output of the OCEANA REC must be due to other factors not captured by the ADCP measurements.

Note since the ADCP was sampling at f~1 Hz, the ADCP is only capable of sampling turbulence with frequencies <0.5f (0.5 Hz). Using Taylor's frozen turbulence hypothesis and assuming mean velocities, U~O(1.65 m s^{-1}) this means the ADCP only accurately samples eddies with wavelengths, $\lambda > 3.30$ m ($\lambda = U/0.5f$).

We hypothesize that differences in turbulence wavelength not captured by the ADCP measurements are responsible for the measured differences in REC power output. This hypothesis is supported by visual observations of the flow near the RDDP. Eddies just behind the RDDP are visibly smaller than eddies outside of the RDDP's wake (e.g. Figure 4). Eddy size far downstream from the RDDP appears to revert to the eddy size distribution characteristic of the undisturbed river.

Note, numerical model results obtained with the CCHE2D package show no difference in velocity magnitude, specific discharge or in the ratio between average turbulence kinetic energy and turbulence kinetic energy at the three locations behind the RDDP where measurements were taken [4]. While the CCHE2D results do not account for the presence of the RDDP, we find no evidence in these model results to indicate that along-stream differences in REC power output can be attributed to naturally occurring variations in river hydrodynamics. We thus conclude that it is highly likely that changes in turbulence size due to the presence of the RDDP are responsible for the variation in REC power output.

CONCLUSIONS

AHERC's RDDP effectively protects floating platforms used to deploy river energy converters from surface woody debris. Power output from the OCEANA turbine is essentially constant in the absence of turbulence. Turbulence generated by water displaced by the RDDP appears to have resulted in a reduction in OCEANA power output by about 8% at a distance of 14.5 m downstream from the RDDP. OCEANA's REC power output was not affected by RDDP turbulence at 50 m and 100 m downstream from the RDDP. Thus RDDP generated turbulence influences appear to dissipate rapidly with downstream distance.

ACKNOWLEDGEMENTS

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