ORPC
OCEAN RENEWABLE
POWER COMPANY

U.S. DEPARTMENT OF ENERGY
TIDGEN® POWER SYSTEM COMMERCIALIZATION PROJECT
DE-EE0003647

FINAL TECHNICAL REPORT

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DOE Award Number: **DE-EE0003647**
Recipient: **ORPC Maine, LLC**
Project Title: **TidGen® Power System Commercialization Project**
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1. EXECUTIVE SUMMARY

ORPC Maine, LLC, a wholly-owned subsidiary of Ocean Renewable Power Company, LLC (collectively ORPC), submits this Final Technical Report for the TidGen® Power System Commercialization Project (Project), partially funded by the U.S. Department of Energy (DE-EE0003647). The Project was built and operated in compliance with the Federal Energy Regulatory Commission (FERC) pilot project license (P-12711) and other permits and approvals needed for the Project. This report documents the methodologies, activities and results of the various phases of the Project, including design, engineering, procurement, assembly, installation, operation, licensing, environmental monitoring, retrieval, maintenance and repair. The Project represents a significant achievement for the renewable energy portfolio of the U.S. in general, and for the U.S. marine hydrokinetic (MHK) industry in particular.

The stated Project goal was to advance, demonstrate and accelerate deployment and commercialization of ORPC's tidal-current based hydrokinetic power generation system, including the energy extraction and conversion technology, associated power electronics, and interconnection equipment capable of reliably delivering electricity to the domestic power grid.

ORPC achieved this goal by designing, building and operating the TidGen® Power System in 2012 and becoming the first federally licensed hydrokinetic tidal energy project to deliver electricity to a power grid under a power purchase agreement in North America. Located in Cobscook Bay between Eastport and Lubec, Maine, the TidGen® Power System was connected to the Bangor Hydro Electric utility grid at an on-shore station in North Lubec on September 13, 2012. ORPC obtained a FERC pilot project license for the Project on February 12, 2012 and the first Maine Department of Environmental Protection General Permit issued for a tidal energy project on January 31, 2012. In addition, ORPC entered into a 20-year agreement with Bangor Hydro Electric Company on January 1, 2013 for up to 5 megawatts at a price of $215/MWh, escalating at 2.0% per year.

Research Adds to the Understanding of Marine Hydrokinetics

The Project significantly expanded the understanding of MHK by documenting in detail the technical, operational and environmental aspects of siting, designing, building, installing, operating and maintaining a complete MHK power system. ORPC collected a significant amount of data on overall system and individual component performance, including identification of needed improvements. In addition, ORPC acquired actual cost data on fabrication, assembly, installation, operation, monitoring, retrieval and maintenance of a FERC-licensed MHK tidal energy facility. ORPC also developed innovative technologies and methodologies to collect environmental monitoring data. In managing the challenging conditions of new technology installed in the underwater marine environment, ORPC has also become an industry leader in the development and implementation of the adaptive management approach for environmental compliance, including using it as a mechanism for license modifications. Finally, study data on fish, birds and marine mammals collected by ORPC and researchers at the University of Maine (UMaine) School of Marine Sciences, the Center for Ecological Research and the New England Aquarium have shown that no adverse interactions have occurred between marine life and the TidGen® Power System.

Technical Effectiveness and Economic Feasibility of the Methods Demonstrated

ORPC demonstrated the technical effectiveness of the TidGen® Power System. With the knowledge gained on the Project as a basis, ORPC is now working to increase reliability and extraction efficiency and reduce costs – the very same challenge that every new technology faces and the challenge that has, or is being, overcome with wind and solar technologies. ORPC has learned from these other renewable energy industries so overcoming the reliability, efficiency and cost challenges will be done in a more expedient and effective manner. ORPC anticipates a continual and significant lowering of the cost of energy within the next couple of years. An example of the types of cost savings that are achievable is the innovative installation and retrieval techniques developed towards the end of the Project that reduced the cost of these operations by two-thirds.

Public Benefit

From the day it was founded, ORPC has been committed to bringing a project's economic benefits to the local and regional level. In Maine, the Project created local jobs and brought other benefits to economically depressed areas in the state, while supporting Maine's renewable energy goals. During the period of the Project, ORPC spent more than $21 million on the Project and other related activities, which includes $10 million from the U.S. Department of Energy (DOE). This boosted the Maine economy by spreading this spending in 13 of the state's 16 counties and creating or retaining more than 100 jobs statewide. This includes approximately $5 million spent in the Eastport/ Lubec area alone, which has provided employment for over three dozen contractors, as well as spending on local goods, services and academic resources.

The Project brought significant educational benefits to the State of Maine through ORPC's partnership with UMaine. In addition to triggering an increase in research and development (R&D) spending, it has created numerous opportunities for Maine students, educators and researchers, as well as helping UMaine strengthen its multi-institution research and development program that links marine science and engineering in pursuit of ocean energy excellence.

The Project also allowed ORPC to be the catalyst in establishing and sustaining the supply chain that is needed for a successful tidal energy industry to flourish. This effort has led to new and expanded services in manufacturing, fabrication and assembly; creation of deep water deployment, maintenance and retrieval services; and expansion and formation of new technical support services such as site assessment and design services, underwater geotechnical services, underwater cable installation services, and environmental monitoring services.

With the completion of this Project, ORPC is now poised to significantly advance the design of the TidGen® Power System and to build and commercialize this tidal power generation system based on best-in-the-world technology, making it ready for tidal power projects in Maine, Alaska and elsewhere around the world.

2. COMPARISON OF ACTUAL ACCOMPLISHMENTS WITH GOALS AND OBJECTIVES

The goal of the TidGen® Power System Commercialization Project (Project), as stated in the Statement of Project Objectives, was:

> To advance, demonstrate and accelerate deployment and commercialization of ORPC's tidal-current based hydrokinetic power generation system, including the energy extraction and conversion technology, associated power electronics, and interconnection equipment capable of reliably delivering electricity to the domestic power grid.

The Project objectives were as follows:

- To design, build, install and monitor a commercial-scale, grid-connected TidGen® Power System below the ocean surface
- To gather critical technical, operational, cost performance and environmental data for one of the most advanced tidal energy systems in the world
- To significantly advance the technology commercialization, operational and environment goals of the tidal energy industry

Table 1 shows a comparison of the Project objectives with the actual accomplishments.

Table 1. ***Comparison of project objectives with actual accomplishments***

OBJECTIVES	ACTUAL ACCOMPLISHMENTS	VARIANCES
To design, build, install and monitor a commercial-scale, grid-connected TidGen® Power System below the ocean surface	ORPC designed, built, installed and operated the first hydrokinetic tidal power project (TidGen® 001) to be connected to an electric utility power grid anywhere in the Americas (North, Central and South America).	Objective modified, reducing the number of grid-connected TidGen® devices from five to three (03/20/ 2013) Objective modified, reducing the number of grid-connected TidGen® devices to one (09/18/2013)
To gather critical technical, operational, cost performance and environmental data for one of the most advanced tidal energy systems in the world	ORPC collected a significant amount of data and has gained invaluable expertise, hands-on experience and critical insight into: • Technical aspects of siting, designing, constructing, installing and operating MHK turbines • Overall system and individual component performance, including identification of needed improvements • Costing data on fabrication,	No variances.

Table 1. *Comparison of project objectives with actual accomplishments*		
OBJECTIVES	**ACTUAL ACCOMPLISHMENTS**	**VARIANCES**
	assembly, installation, operation, monitoring, retrieval and maintenance of a FERC-licensed MHK tidal energy facility • Development of several retrieval techniques, each significantly reducing costs associated with retrieval and deployment. • Environmental monitoring plans, equipment, protocols and data collection and analysis related to installation and operation of an MHK facility	
To significantly advance the technology commercialization, operational and environment goals of the tidal energy industry	ORPC has become an internationally recognized leader in the development and implementation of MHK energy technology and projects, and has moved to the forefront of the U.S. MHK industry. This project has led to the first construction of an MHK project under a FERC license in the U.S., and an acceptance of MHK technology at multiple levels of federal and state regulatory agencies, as well as electric utilities. ORPC has negotiated and executed the first long term (20 year) power purchase agreement, utility interconnection contract, and Renewable Energy Credit sales contract for an MHK project in the U.S. ORPC applied for and received the first U.S. Treasury Rebate for an MHK project. ORPC with technical partners has developed innovative methodologies and technologies to identify and	No variances.

Table 1. ***Comparison of project objectives with actual accomplishments***		
OBJECTIVES	**ACTUAL ACCOMPLISHMENTS**	**VARIANCES**
	monitor environmental interactions with our tidal device. Examples include the drifting noise measurement system used to characterize pre- and post-deployment noise and the bottom mounted side looking split beam sonar to monitoring fisheries interaction with the turbine. ORPC submitted the first ever annual environmental report for a tidal energy project under our FERC pilot project license. The report was reviewed in detail and approved by all regulatory agencies. The report stated that there were no known adverse environmental impacts from the project. The TidGen® device made the cover of the June 2013 issue of Popular Science and was featured in many of media outlets, including PBS News Hour, New York Times and other newspapers and magazines around the world, greatly increasing world awareness of tidal energy. ORPC was named one of "World's Top Ten Most Innovative Companies in Energy" by Fast Company, 2013. ORPC was awarded the 2013 Annual Tibbetts Awards from the U.S. Small Business Administration, in recognition of our unique contributions as a "Model of Excellence" for the Small Business Innovation Research (SBIR) Program ORPC is now poised to significantly advance the design of the TidGen® Power System and to build and	

Table 1. ***Comparison of project objectives with actual accomplishments***		
OBJECTIVES	**ACTUAL ACCOMPLISHMENTS**	**VARIANCES**
	commercialize this tidal power generation system based on best-in-the-world technology and to develop and build tidal power projects in Maine, Alaska and elsewhere around the world.	

3. SUMMARY OF PROJECT ACTIVITIES

Project activities are summarized in Table 2 showing the Project tasks.

Table 2. ***Summary of project activities by task***

TASK	TASK DESCRIPTION
	PHASE I: Single-device TidGen® Power System
1	Engineering & design
2	Procurement, manufacture & assembly
3	Installation of bottom support frame
	PHASE II
4	Installation & start up
5	Grid Interconnection
6	Initial testing of the first unit
7	Operation of TidGen® Power System
8.0	Retrieval & Maintenance
8.1	First retrieval
8.2	Second retrieval
9.0	Evaluate & Report

Task 1: Engineering & Design

Resource Assessment

Original Hypotheses

ORPC used empirical and literature data to estimate the hydraulic energy intensity of the proposed deployment area. Field and modeling studies on the hydrodynamic conditions of Cobscook Bay, in particular tidally-driven water movements, were performed in the 1990s. More recently, Danya Xu of the University of Maine worked on numerical modeling and theoretical investigations to study the dispersion mechanisms in coastal areas and tidal basins around the Gulf of Maine, and in particular Cobscook Bay (Lagrangian study of particle transport processes in the coastal Gulf of Maine, University of Maine, 2008). The principle objective of Xu's modeling of Cobscook Bay was to characterize the tidal circulation and to identify water exchange mechanisms in Cobscook Bay. Unlike previous models of Cobscook Bay, Xu added inputs to the model to account for the shoreline, topography, and intertidal zone of the bay with the goal of producing a model that would demonstrate small-scale circulation features. Xu developed a three-dimensional, high-resolution, and barotropic finite element model, referred to herein as the Quoddy Circulation model, with drying/wetting processes to simulate the time-dependent, three-dimensional circulation. The model prediction was validated by data gathered from the observed sea level, direct current measurements, and drifter trajectories. ORPC analyzed the flow velocity data generated by the Quoddy Circulation model and generated maps of the energy intensity in the Quoddy region and in the proposed deployment area.

Approaches Used

ORPC has analyzed the flow velocity data generated by the Quoddy Circulation model and has created maps of the energy intensity in the Quoddy region and in the Deployment Area. The plots of energy intensity show that there are significant hydrokinetic energy resources at the proposed deployment site. The results of this modeling effort were used to identify areas to be surveyed using acoustic Doppler current profiler (ADCP) deployments. OPRC made several deployments of bottom-mounted ADCPs for the purpose of measuring water flow speeds through the water column at various locations within the proposed deployment area. The ADCP deployments were made at different periods of the lunar cycle and for differing lengths of time. ADCP deployment locations and dates of deployments are given below in Table 3. Figure 1 shows the locations of the ADCP deployments used for site assessment.

Table 3. ***Cobscook Bay ADCP deployment history***

Deployment Name	ADCP Deployment Location	ADCP Deployment Date	ADCP Deployment Duration
Upper Cobscook	44°54'35.28"N, 67° 2'44.28"W	3-31-2010	30 days
ADCP Center	44°54'37.86"N, 67° 2'43.62"W	5-11-2010	58 days
ADCP SE	44°54'32.70"N, 67° 2'40.38"W	6-16-2010	7 days
ADCP SW	44°54'34.32"N, 67° 2'48.24"W	6-2-2010	7 days
ADCP NW	44°54'40.20"N, 67° 2'46.68"W	5-19-2010	7 days
ADCP NE	44°54'37.86"N, 67° 2'38.34"W	6-24-2010	7 days
ADCP South	44°54'31.68"N, 67° 2'45.00"W	7-1-2010	7 days

The equipment used to collect the current profile information included a 600 kilohertz (kHz) and a 300 kHz Teledyne RDI ADCP. These units were mounted on trawl-resistant DS2 bottom mounts manufactured by Flotation Technologies. The DS2 bottom mounts are molded plastic filled with concrete to create a trawl-resistant base and protection for the gimbal-mounted ADCPs. Both ADCPs were configured using a six-minute ensemble (ping) period and one-meter depth bin.

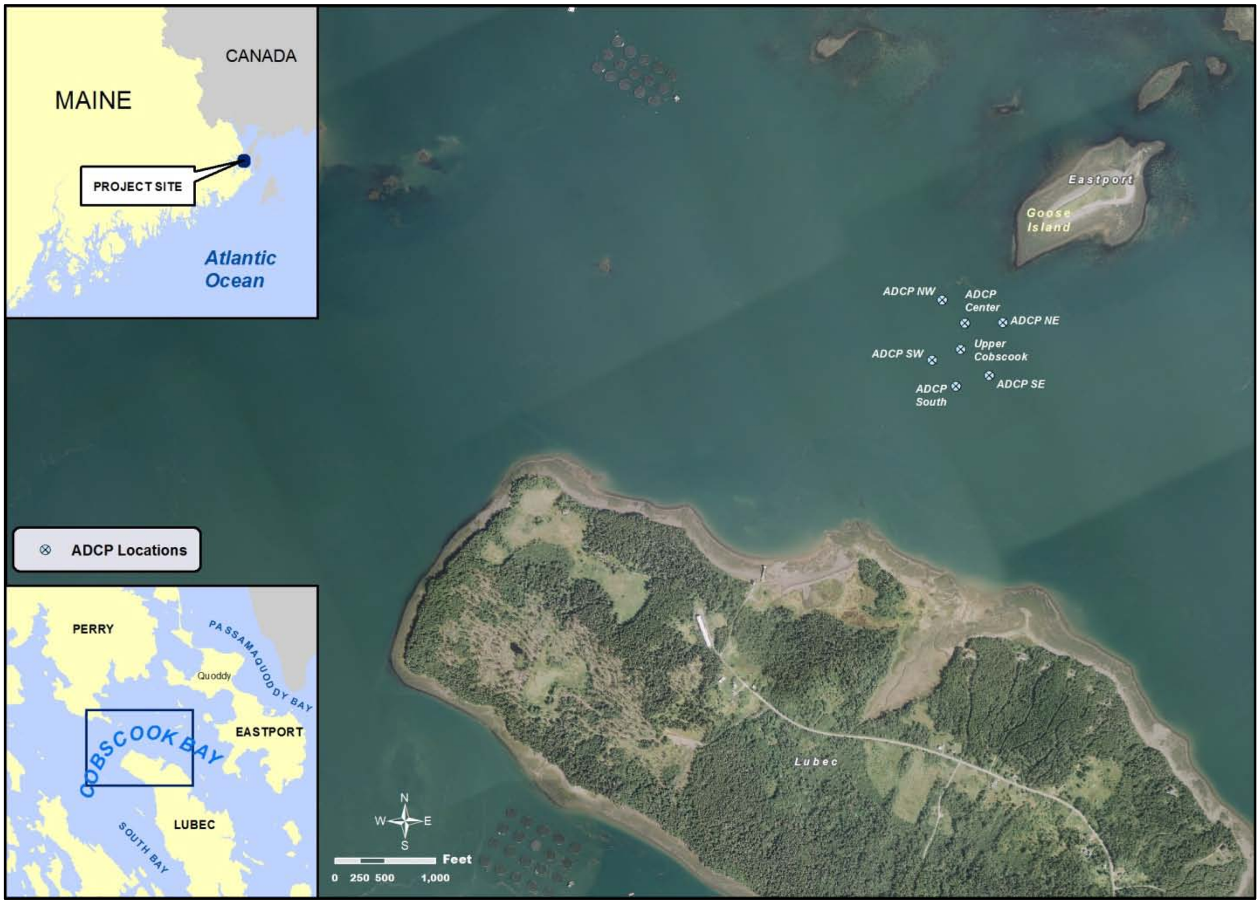

Figure 1. ADCP deployment locations in Cobscook Bay, Maine. These deployments were used to provide a resource assessment for the project site.

Using methods developed by the University of Washington, it is possible to extract tidal harmonic components from ADCP data.[1] This allows direct comparison of ADCP data sets from different time periods. Data from the Upper Cobscook ADCP deployment was analyzed using the methods developed by University of Washington. This analysis technique also allows for long term prediction of the tidal flow speeds and extrapolation of the flow speed data to be performed from a limited data set.

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[1] University of Washington (2010). B.L. Polagye, J. Epler, and J. Thomson (2010). *Limits to the predictability of tidal current energy*. Paper presented at MTS/IEEE Oceans 2010 Conference, held in Seattle, WA, 23-25 September, 2010. Retrieved from http://faculty.washington.edu/jmt3rd/Polagye%20et%20al%20-%20Oceans2010%20-%20prediction.pdf.

Modeling efforts for the Cobscook Bay site have been continued by Sandia National Lab (SNL) under a Cooperative and Research Development Agreement (CRADA) agreement with ORPC. SNL have provided results for the whole of Cobscook Bay and for a smaller inset area within Cobscook Bay surrounding the ORPC site. Flow assessment with and without turbines installed have shown no significant change to the flow conditions.[2]

Problems Encountered

There were no significant problems encountered in the collection of flow data at the proposed sites.

Departure from Planned Methodology

A greater effort than expected was required to analyze the ADCP data and to make comparisons between the ADCP data and the circulation model. ADCP results are naturally obtained for different time periods (the period of deployment of the instrument). It was not clear how best to compare flow measurements from different deployments. The method of harmonics presented above allows for direct comparison of ADCP measurements from different deployment and also for comparison of measurements with model results obtained for differing time periods.

Assessment of Impact on the Project Results

The Project results were unaffected by departures from the planned methodology.

Foundation Design

Original Hypotheses

ORPC reviewed publically available information related to site bathymetry and bottom conditions, primarily from National Oceanic and Atmospheric Administration (NOAA) charts and other literature available for the area. While significant amounts of data were available related to the benthos, the data were inconclusive as to the nature of the substrate. Prior geophysical investigations had suggested that the bottom was acoustically hard and reflective. Experience at other tidal power sites suggested that the bottom would consist of cobble and ledge outcroppings as it was expected that tidal scouring would remove any sediments. The most recent surficial geologic map produced by U.S. Geological Survey shows that both soft, compressible glaciomarine clay deposits and glacial till soils are prevalent in the vicinity of the site. Surficial bedrock outcrops are also mapped just south of the site.

ORPC assumed that the bottom would be hard and would be capable of bearing the weight of a TidGen® turbine generator unit (TGU). The foundation was initially conceived as contacting the seafloor at four separate locations with friction between the TGU and the seafloor providing the required lateral resistance to drag loads and weight of the structure providing resistance to overturning (Figure 2).

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[2] Nelson, K., Jones, C., & Roberts, J. (2013). MHK Array Placement Analysis: SNL-EFDS Model Application at Cobscook Bay, Maine, FY13 Q3 Water Power Report, June 30, 2013.

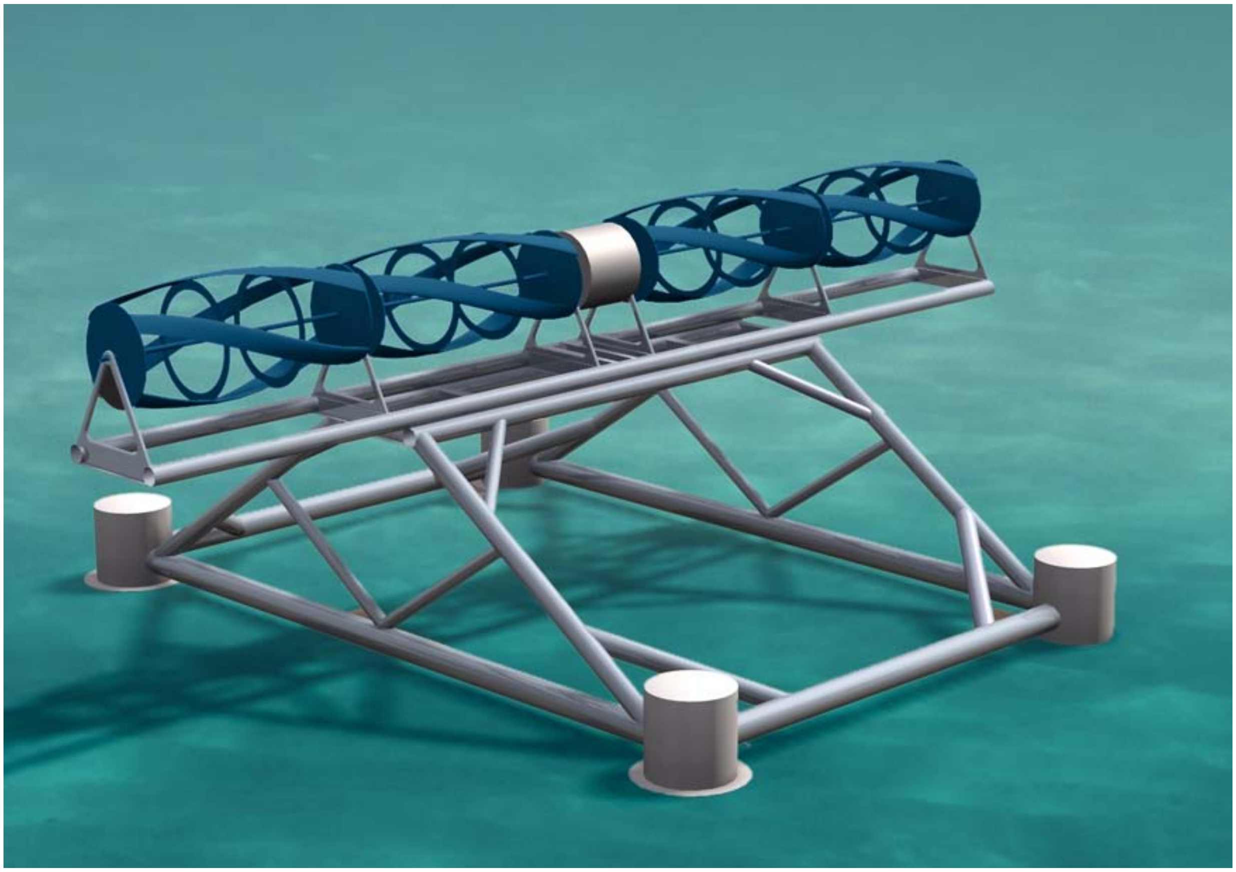

Figure 2. Original bottom support frame and foundation concepts for TidGen® device

Approaches Used

To provide the necessary information for design of the bottom support frame interface with the seabed, ORPC conducted a geotechnical investigation in the deployment area. To assess the geophysical properties of the site, ORPC performed a focused multi-beam bathymetric and geophysical survey from November 16 to 19, 2010. CR Environmental acquired hydrographic and geophysical data by simultaneous deployment of a multiband echo sounder, a sub-bottom compressed high intensity radar pulse (CHIRP) profiling system, and a marine magnetometer. Towed high resolution side scan sonar data was collected separately to aid substrate characterization. Images and data collected from this effort are presented in a report prepared by CR Environmental, Inc. entitled “Focused Bathymetric and Geophysical Survey – Upper Cobscook Bay.”

Estimates of sediment thickness were obtained which showed that the potential for significant sediment thickness existed at the proposed deployment sites. These estimates were generated using the acoustic backscatter data from the multi-beam side scan sonar survey. The dominant surficial substrate classes and the sediment thicknesses are presented in the geophysical report (Figure 3).

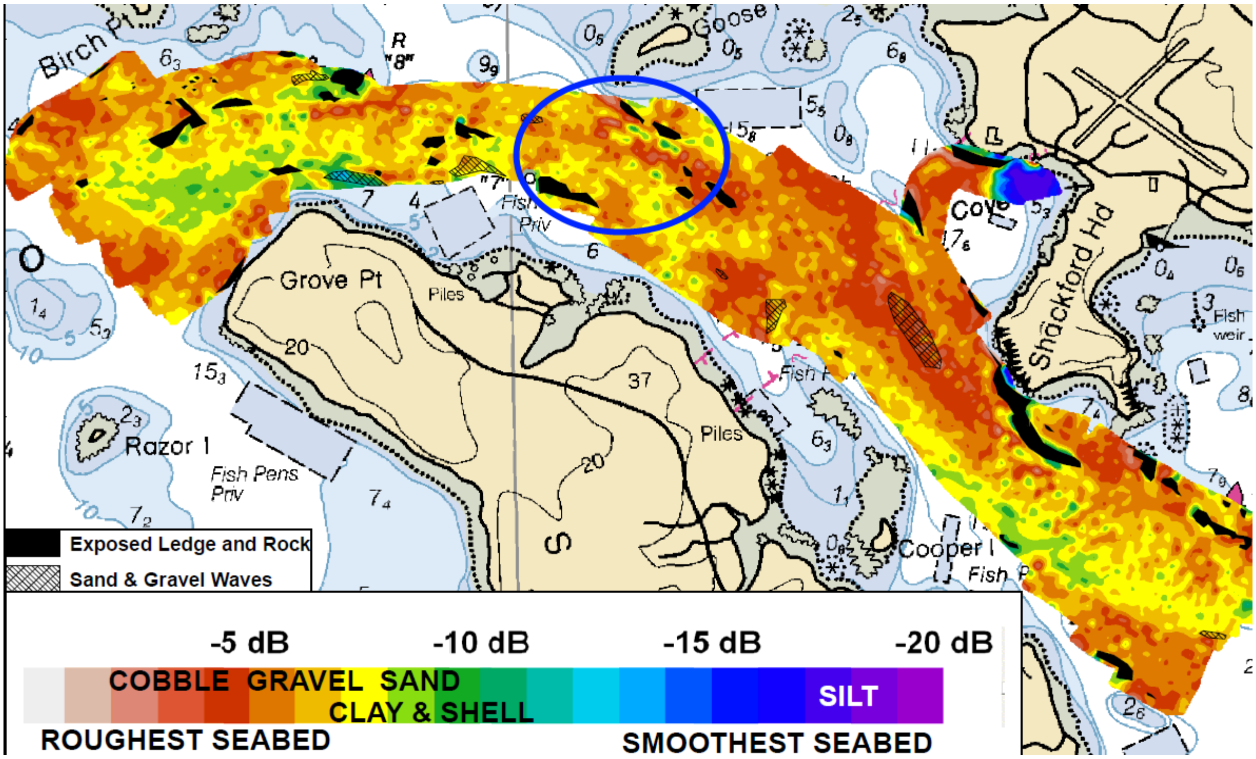

Figure 3. Surficial substrate classes in Cobscook Bay. The project area is circled. Figure was generated by processing backscatter data from multi-beam sonar data sets. A stronger acoustic reflection is generated by harder bottoms.

Soil samples obtained in test borings were typically collected at the mudline and at various intervals thereafter using either a 1-3/8-in ID split-spoon sampler or an open end rod sampler consisting of a 3 in., ID 5-ft-long piece of steel casing. The split-spoon sampler was driven with a 140 lb hammer dropped from a height of 30 in. The number of hammer blows required to advance the split-spoon sampler through each 6 in. interval was recorded and is provided on the test boring logs. The Standard Penetration Test N-value is defined as the total number of blows required to advance the sampler through the middle 12 in. of the 24 in. sampling interval. The open end rod sampler was driven with a 300 lb hammer dropped from a height of 24 in., as indicated on the test boring logs included in Attachment E to this document.

In-situ vane shear tests were conducted in several test borings within the marine deposit (encountered in all of the test borings). Peak and remolded shear strength values within the marine deposit based on in-situ vane shear test data are indicated on the test boring logs and are summarized in the geotechnical report that is included as Attachment E to this document.

Rock core samples were obtained in several of the test borings by advancing a 2 in. ID NQ-II wireline core barrel into the bedrock. The samples were obtained so that laboratory tests could be conducted to assess strength characteristics of the bedrock for use in TidGen® device foundation design analyses.

In addition to test borings at the deployment site three test borings were conducted along the proposed conveyance cable alignment (HA11-1, HA11-2 and HA11-3). The cable conveyance borings were advanced to depths ranging from 14.3 to 28.0 ft below mudline using PW-size (5 in. ID) and/or HW-size (4 in. ID) steel casing. Split-spoon soil samples were collected in all of the cable conveyance borings. Undisturbed soil samples were obtained and in-situ vane shear tests were conducted in test boring HA11-2. Bedrock was not cored in the cable conveyance borings.

Four test borings were conducted at proposed turbine location GT1 (HA11-4, HA11-5, HA11-6 and HA11-10). Borings were advanced to depths ranging from 19.5 to 54.8 ft below mudline using PW-size (5 in. ID), HW-size (4 in. ID) and NW-size (3 in. ID) steel casing. Split-spoon and/or open end rod soil samples were collected in all of the borings at turbine location GT1. Undisturbed tube samples were obtained in borings HA11-5 and HA11-10. In-situ vane shear tests were conducted in borings HA11-5, HA11-6 and HA11-10. Bedrock was cored in all of the test borings at turbine location GT1.

Problems Encountered

Geotechnical data showed that a more robust foundation than the initially planned gravity base would be required. The Presumpscot clay sediment layer at this site has relatively low shear strength. The design of the foundation required to support the TidGen® TGU and bottom support frame required several iterations to finalize the foundation design. The final design of the foundation design consists of a pile bent arrangement consisting of ten piles, each with a 3 ft diameter and a 1 in. wall thickness. Each pile rests on bedrock. The lateral loads applied to the TidGen® device by the water flow were the determining loads in this foundation design. Piles needed to be driven to bedrock to support the weight of the TGU and bottom support frame.

For the initial design concept the use of suction caissons was considered. Geotechnical engineering calculations using data collected from the geotechnical campaign predicted that large diameter caissons would rotate in the clay and cause failure as the reversing loads caused the caisson to scoop the clay. To prevent soil scoop it was necessary to reduce the stiffness of the caisson to better comply with the stiffness of the marine clay. The design criteria selected by the geotechnical consultants was that the weight of the structure had to be supported on bedrock, and that at the contact point on the bedrock there would be no relative motion between the bedrock and the foundation. These criteria led to an iterative design process which ultimately led to the selection of ten piles of 30 in. diameter and ½ in. wall thickness. These piles are driven to bedrock and so support the weight of the entire structure. The stiffness of the pile is consistent with the clay stiffness such that the clay and pile move together under the reversing tidal loads. The maximum expected movement of the pile at the mudline is estimated at ½ in. (Figure 4).

The recommended pile installation technique involved pile vibratory hammer and diesel impact hammer operations. ORPC consulted with U.S. Army Corps of Engineers (USACE) and National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA NMFS) Protected Resource Division and developed an installation plan for the foundation to protect endangered species from acoustic noise issues under the Marine Mammal Protection Act (MMPA). NOAA NMFS determined that the potential sound levels of pile driving could emit sound levels that could damage young salmon if the pile driving occurred during smolting season, April 10 through November 7, but not during other times of the year. This restricted period resulted in only a brief window between license issuance on February

27 to April 10, 2012, to complete the pile driving required for completion of the installation of the bottom support frame.

Departure from Planned Methodology

The original foundation design required modification due to geotechnical considerations. The number of fixture points on the seafloor increased from an original estimate of four to a final ten pile arrangement.

Assessment of Impact on the Project Results

The issues encountered in collecting geotechnical data and the changes required in the foundation design led to additional unexpected expenses for the project. The technical effects were minimal.

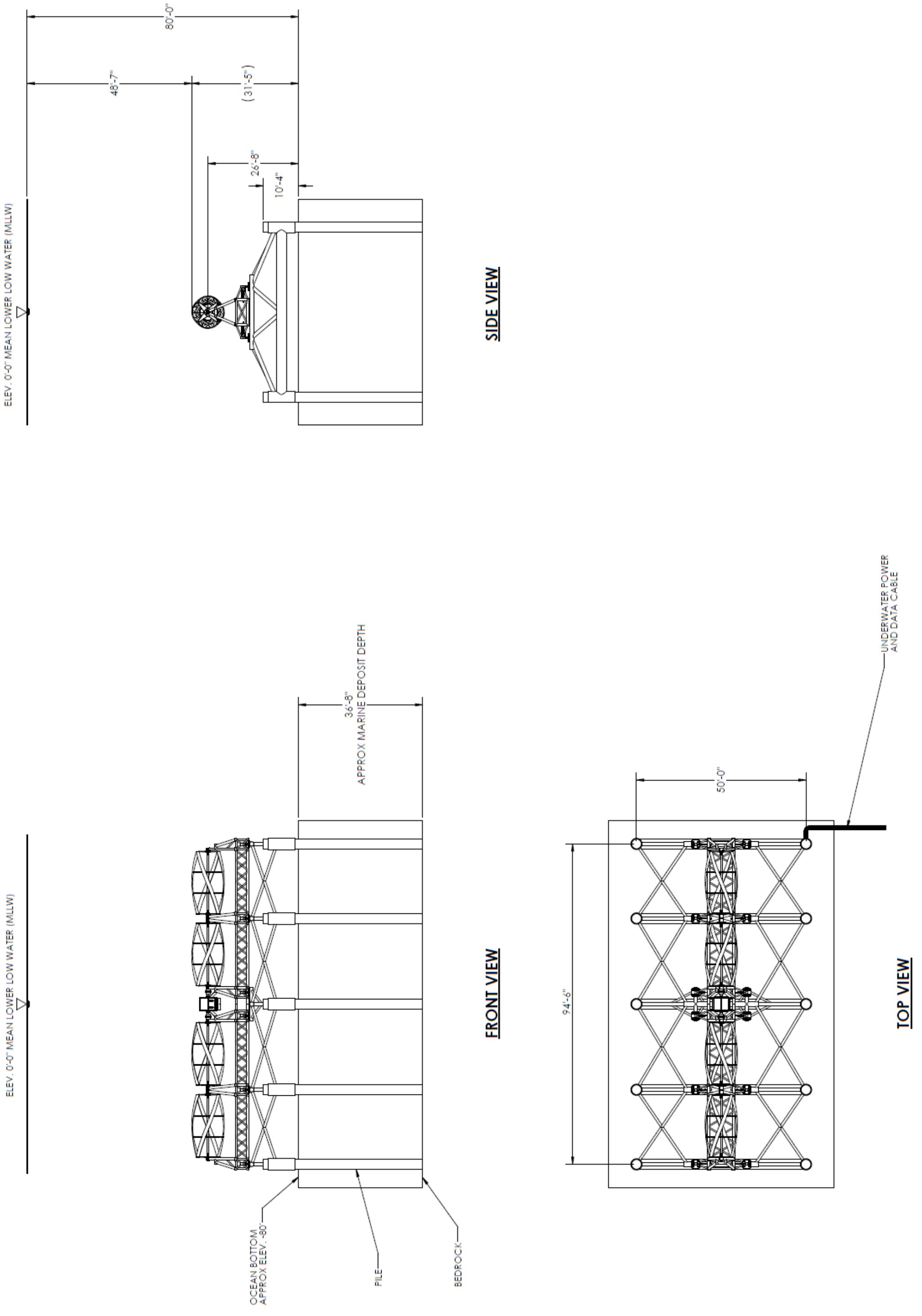

Figure 4. General arrangement drawing for TidGen® 001

Turbine Design

Original Hypotheses

ORPC advanced the turbine design through the Prototype TGU Demonstration Project (TGU Demo Project) off the coast of Eastport, Maine, from 2007 to 2008. The TGU Demo Project included the engineering, fabrication, assembly, deployment and testing of a prototype TGU that was approximately one-third the physical size of the TidGen® TGU. Specific data was recorded during continuous TGU performance in tidal flows while the testing barge was moored in Western Passage, Maine from April 18 to 24, 2008. Testing proved the TGU's technical viability as well as its ability to operate unattended and to self-start in reversing tidal flows. Through the successful completion of the TGU Demo Project, ORPC became the first company to generate electricity from Bay of Fundy tidal currents without the use of dams or impoundments.

In mid-2009, ORPC commenced the design phase of the Beta Pre-Commercial TidGen® Power System Project (Beta TidGen® Project). This project improved and expanded on the prototype TGU's design to create a complete commercial-scale hydrokinetic power system, the Beta Pre-Commercial TidGen® Power System (Beta TidGen® System). In early March 2010, ORPC launched the Beta TidGen® System—the largest ocean energy device ever deployed in United States waters—in Cobscook Bay, adjacent to Eastport and Lubec, Maine. ORPC fully commissioned the system in early August and continued testing through mid-December 2010.

Additionally, through the Beta TidGen® Project, ORPC contracted with the USCG to charge battery banks and provide supplemental electrical service to the USCG shore power installation at its dock on the Eastport, Maine waterfront. This was the first use of tidal generated electricity by a federal agency.

Additional validation of the turbine design was also demonstrated by significant research, tow tank testing and analysis done in conjunction with several research institutes and consultants, supported in part by DOE's STTR program (DE-SC0003622). The goal of these various research tracks was to develop and validate analytical models used for turbine performance and blade loading. No TidGen® turbine scale models were tested.

ORPC expected that based on this previous experience with turbine performance mapping and structural design that the company would select the TidGen® turbine parameters based on previously developed Multiple Streamtube Models, and confirm selection of these parameters using two-dimensional (2D) Computational Fluid Dynamic (CFD) models. In parallel with the design effort ORPC would confirm expected performance using three-dimensional (3D) CFD models. For structural design ORPC assumed that the company would use finite element models of the composite structure using a design flow speed in excess of that encountered in the field to account for unknowns of turbulence intensity and potential inaccuracies in blade loading models which are inherent in multiple streamtube models modeling tools.

Approaches Used

Computational performance models of the turbine began with Multiple Streamtube Models (MSM) which allow for selection of the turbine foil solidity, chord, and tip speed ratio. The MSM model predicts the Coefficient of Performance for the turbine as a function of Tip Speed Ratio and also provides a prediction for blade loading.

Multiple Streamtube Models

The primary modeling tool to predict turbine performance and loadings is the MSM developed by various authors.[3,4,5] Turbine flow area is divided into streamtubes and aerodynamic forces on the blade elements are calculated for each streamtube. An axial drag force is determined for each streamtube. This axial drag force is also calculated using the momentum based actuator disk theory developed by Glauert.[6] The effective stream velocity at the turbine blade is iterated until calculations of drag force from both methods produce equal results. The amount by which the free-stream velocity is modified is the *axial induction factor, a*.

$$V_{axial} = (1-a)\cdot V_{free\_stream}$$

The vector addition of the axial velocity and the blade velocity gives the relative velocity for calculation of the aerodynamic forces.

Glauert's theory works for values of induction factor less than 0.5, but additional correlations are required above a=0.5. These are provided by Buhl.[7]

This version of the multiple streamtube model makes the assumption that turbine performance is symmetric about the centerline perpendicular to the flow direction, i.e. that forces predicted for the range [0,π] are the same as the forces that exist from [π,2π]. In other words, the model assumes that the forces acting on the foils on the upstream and downstream sides of the turbine are equal. This is shown in the above plot as a repeat of the loading. While this is clearly not true these models are claimed to be accurate for the prediction of blade forces.

Vortex Models

An alternative approach to modeling the turbine is to track vortex generation and shedding from the rotating foils. This approach provides an alternative estimate for foil loads. ORPC worked with UMaine to develop vortex lifting line codes to predict the performance of cross-flow turbines. This work was in process during the TidGen® turbine design effort and results below are the interim results obtained for blade loading, which were expected to be more accurate than the loads predicted by the MSM approach.

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[3] The Darrieus Turbine: a performance prediction model using multiple streamtubes, James H. Strickland, SAND75-0431, Sandia Labs, Energy Report.

[4] Wind Turbine Design, with emphasis on Darrieus Concept, Ion Paraschivoiu, Polytechnic International Press, 2002.

[5] Streamtube Theory, A new approach, R.N. Laoulache, University of Massachusetts, Dartmouth, 2008.

[6] The elements of aerofoil and airscrew theory, H. Glauert, Cambridge Science Classics, 1999.

[7] A new empirical relationship between thrust coefficient and induction factor for the turbulent windmill state, Marshall L. Buhl, Jr. NREL/TP-500-36834, August 2005

2D Computational Fluid Dynamic Simulations

2D CFD work was performed for ORPC by the Applied Research Laboratory (ARL) at The University of Pennsylvania using (RANS) codes, particularly OVERFLOW. The Spalart- Almaras turbulence model was used. Chord length and radius had been established by the MSM, and setting these parameters as fixed ARL analyzed the behavior of different foil profiles and trailing edge combinations.

3D CFD modeling of the TidGen® turbine was performed by ARL. A mirror section of the assembly consisting of two turbines, each with opposite helical twist, and a half section of the generator were modeled using OVERFLOW. Neither the TGU chassis structure, nor the bottom support frame is directly modeled as this would add a much higher level of complexity to the model and would significantly increase computational time. Meshing and overset assembly required four to five days to complete. The full suite of 3 moving body and 2 static simulations required approximately 300,000 hours**.**

A unique field output is computed by Helius-MCT™ that allows the user to visualize the locations of failed elements and the damage state of the elements. Since the model uses layered elements, each element contains multiple integration points in the thickness (stacking) direction that allow for the composite stacking sequence to be properly represented. This means that a single element contains some combination of failed and unfailed integration points. Thus, for example, a green element does not mean that all integration points have matrix failure. Rather it means that at least one integration point in the element has failure. Such plots are referred to as envelope plots.

Problems Encountered

Multiple Streamtube Model

The MSM models are known to be relatively accurate in terms of predicting maximum Coefficient of Performance and associated Tip Speed Ratio but are known to under predict blade loading. This was known and accounted for in the design phase. Blade loading calculations were performed at a reference speed of 4 m/s as opposed to the expected site speeds of 3 m/s.

Vortex Models

The vortex models used during the TidGen® turbine design process had not been validated against tow tank data at that time. Further tow tank testing and analytical model development have shown that the versions of vortex models used were missing the effects of several key physical phenomenon including dynamic stall and flow curvature effects. Furthermore recent developments have identified additional physical mechanisms which have traditionally been ignored in vortex lifting line codes.[8]

2D CFD Models

The selection of a turbulence model for the 2D CFD work was a substantial effort. Different turbulence models provided significantly different results for efficiency and blade loads.

3D CFD Models

3D models consumed a large amount of computational effort to provide a limited set of results.

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[8] Urbina, R. (2013). A Dynamic Stall Model for Modeling Cross-Flow Turbines Using Lifting-Line Vortex Methods. Submitted for publication to AIAA Journal.

Structural Modeling

Initial models of the turbine showed deflections under load that exceeded expectations. Additional structure was required in the form of tensioned spokes connecting the turbine foils to the turbine shaft to increase the stiffness of the structure and reduce foil deflection in operation.

Departure from Planned Methodology

Multiple Streamtube Modeling

No departure from planned methodology.

Vortex Modeling

No departure from planned methodology.

2D CFD

No departure from planned methodology.

3D CFD

No departure from planned methodology.

Structural

A second design iteration was required in order to accommodate the available processes and techniques at the turbine manufacturer. Laminate schedules were adjusted and processes changed in order to facilitate manufacture in a manner compatible with available machinery and skill sets. In retrospect, this is a natural outcome of the design-for-manufacture process in that the feedback from the manufacturer needs to be included in the design. This critical step was omitted from the original plan.

Assessment of Impact on the Project Results

Multiple Streamtube Modeling

No departure from planned methodology.

Vortex Modeling

No departure from planned methodology.

2D CFD

No departure from planned methodology.

3D CFD

No departure from planned methodology.

Structural

No departure from planned methodology.

Generator Design

Original Hypotheses

ORPC selected an underwater permanent magnet generator and electrical case in the TGU that would be built by a company with existing, proprietary designs. The design was originally developed for oil and natural gas drill rigs exposed to arctic, desert, offshore, and tropical environments while subjected to constant shock and vibration. This company's generators had been subjected to in-house and third-party environmental and qualification tests. In addition, ORPC had successfully tested a generator built by this company in its Beta Tidal Energy System in 2010. The proposed TGU's generator weighed approximately 17,500 lb, had a housing constructed of steel, and was designed for a 20-year life expectancy.

The architecture of the generator and associated turbine load controls was based on the premise that DC transmission would form the backbone of an array of tidal turbines. DC transmission is believed to offer several advantages, primarily the ability to connect power outputs from multiple TGUs without the need to synchronize operation of each TGU. DC transmission also offers the potential for high voltage transmission which increases efficiency and reduces capital costs of the cable. Based on these findings it was decided that control of the TGU be accomplished locally at the generator, which requires separate power electronics mounted on the TGU subsea.

The generator technology selected was an air filled permanent magnet machine. This necessitated dynamic shaft seals on the generator shaft.

Approaches Used

Comprehensive Power Inc (CPI) manages product development in a stage gate manner which provides the opportunity to review at critical junctures to review the design. ORPC and CPI engaged in a coordinated effort to define the specifications for the generator and controls. These specifications were approved by ORPC at a Preliminary Design Review for the Project. The details of the design were further developed by CPI and were approved at the Detail Design Review in May of 2011. CPI continued to refine the design and begin construction of the generator and control electronics, followed by construction and then testing of the generator and controls systems.

The TGU's generator is a rugged, submersible three-phase permanent magnet AC generator that includes internal power conditioning electronics, which produce DC power. In permanent magnet machines, the voltage generated is directly proportional to the rotational speed and the electrical current is directly proportional to the applied torque. As flow speed begins to increase at the start of a tidal cycle, the rotational speed of the turbine and the voltage produced by the generator increase. The frequency of the electrical current is directly proportional to the rotational speed of the generator. The torque produced by the turbine is converted into electrical current in the generator.

As power is generated, the temperature of the generator increases. Changes in the temperature of the generator stator windings slightly change the electrical properties of the machine. Heat is removed from the stator coils by the flow of seawater over the generator case. Lip and cartridge seals prevent seawater from penetrating into the generator.

Double cartridge seals were selected for the dynamic shaft seals.

The turbine converts kinetic energy of water flowing in currents from 0 to 3 m/s into rotational motion and delivers that energy through a shaft into the stub shaft of the permanent magnet generator. The turbine is an ORPC proprietary ADCF turbine with multiple twisted foils attached by spokes to the shaft about which the turbine rotates.

The rotational speed of the turbine is maintained at the required set point by application of a controllable load on the generator provided by the power electronics in the electronics case. The TGU is operated so that a load intersection exists between the torque curves and the load line provided by the generator and power electronics.

Problems Encountered

No problems were encountered at the design stage of the project. During the manufacturing and testing of the system, issues became apparent and changes to the functionality needed to be made to account for manufacturing defects in the machine.

Departure from Planned Methodology

Departures from the planned methodology were in construction and testing of the generator rather than in design. The departures are outlined above under Problems Encountered. The main departure was the reassignment of transmission cable polarity such that instead of a grounded external power cable, the voltage level in the cable was negative and capable of reaching -450VDC.

Assessment of Impact on the Project Results

The departures from the planned design with respect to polarity of the power cable led to many issues with commissioning of the system. The negative outer cable for the system radiated electromagnetic interference onto an adjacent data cable. The corrupted data streams led to an inability to communicate with the generator controls. These issues were addressed by rewiring of shore side station components and instrumentation bottle components, but with some loss of functionality.

TGU Chassis Design

Original Hypotheses

The TGU chassis functions to support the driveline for the turbines and generator and to provide a connection between these and the bottom support frame. The original intention behind the design of the TGU chassis was to provide a modular support structure for the TGU that would allow the turbines and generator to be removed and deployed as a separate unit from the foundation and bottom support structure.

The TGU chassis is required to provide enough stiffness to the turbine and generator under operating conditions such that deflection at the bearing supports is small.

The connections points between the TGU and the bottom support frame are mounted on the TGU chassis and will be discussed later in this document.

Approaches Used

A space frame was adopted as the basis design of the TGU chassis. This was primarily driven by the requirement to minimize weight and to maximize structural stiffness. Tubular sections were selected as these are less subject to corrosion subsea than other structural members.

A LRFD approach was initially considered, however the API RP2A WSD recommended practice in Section 3.1.1 specifically states that the AISC LRFD code is not recommended for the design of offshore platforms, and recommends the AISC ASD code be used. Therefore the AISC ASD code was used with substitutions as required by the API RP2A WSD recommended practice.

Some special considerations were used in this particular design approach. A load factor of 1.7 was applied to all live loads to account for the uncertainty associated with the loads applied to the turbines by the tidal currents. This uncertainty arises due to 1) the lack of sufficient information to characterize both the mean flow and turbulent intensity at the TidGen® site and 2) loads computed from CFD studies that have not been sufficiently validated.

Table 4 itemizes the criteria for assessing failure. A global deflection criterion for the bearing supports was maintained in order to minimize driveline misalignment. Also, members were checked for Vortex Induced Oscillations (VIO) and compared with the structural fundamental frequencies to assess the likelihood of Vortex Induced Motions (VIM).

Table 4. *Criteria for assessing failure*

Failure Check	Criterion	Evaluation Method
Unity Check	$UC < 0.9$	AISC ASD Combined Stress
Bearing Support Deflection	$\delta < 0.25''$	RISA3D Static Analysis
Vortex Induced Oscillations (VIO)	$V_R < 3$	DNV RP-C205
Vibration Modes and VIM	$\lambda_1 > \lambda_{VIO}$	RISA3D Modal Analysis

Sixteen different load cases were assessed for the chassis design, including considerations of how the chassis would perform in the event that not all connections to the bottom support frame were made (Figure 5 and Figure 6).

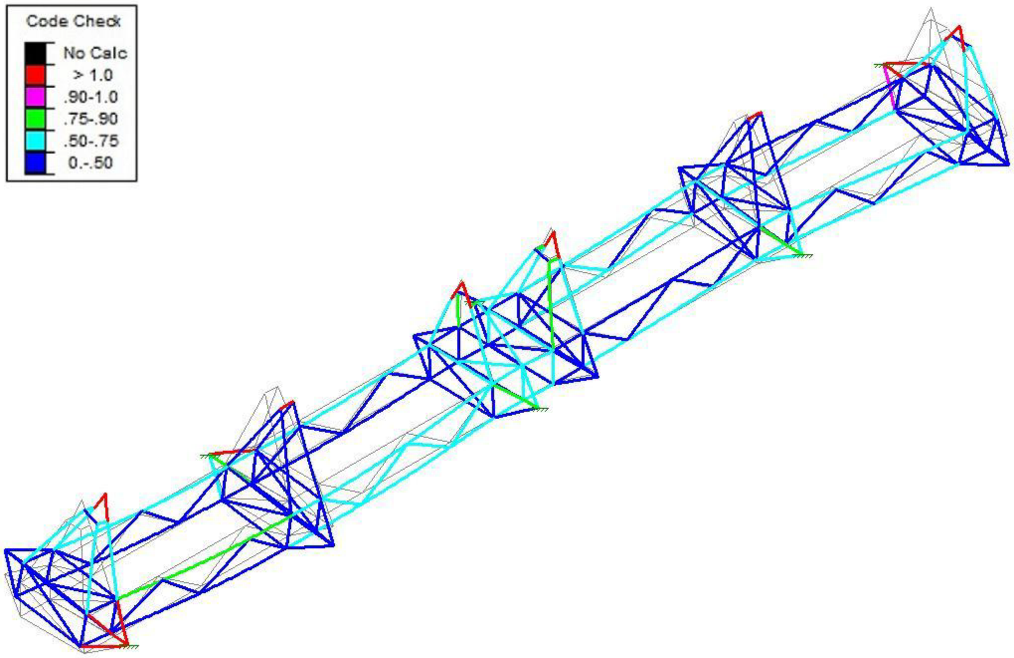

Figure 5. LC16B Deflected Shape, Scale=40, UCmax=0.84. Turbines are free spinning, with maximum drag, TSR = 3.5, V = 3m/s. One connection between the TGU and bottom support frame at each of the supports has been removed in this model to estimate the effects of improper connectivity.

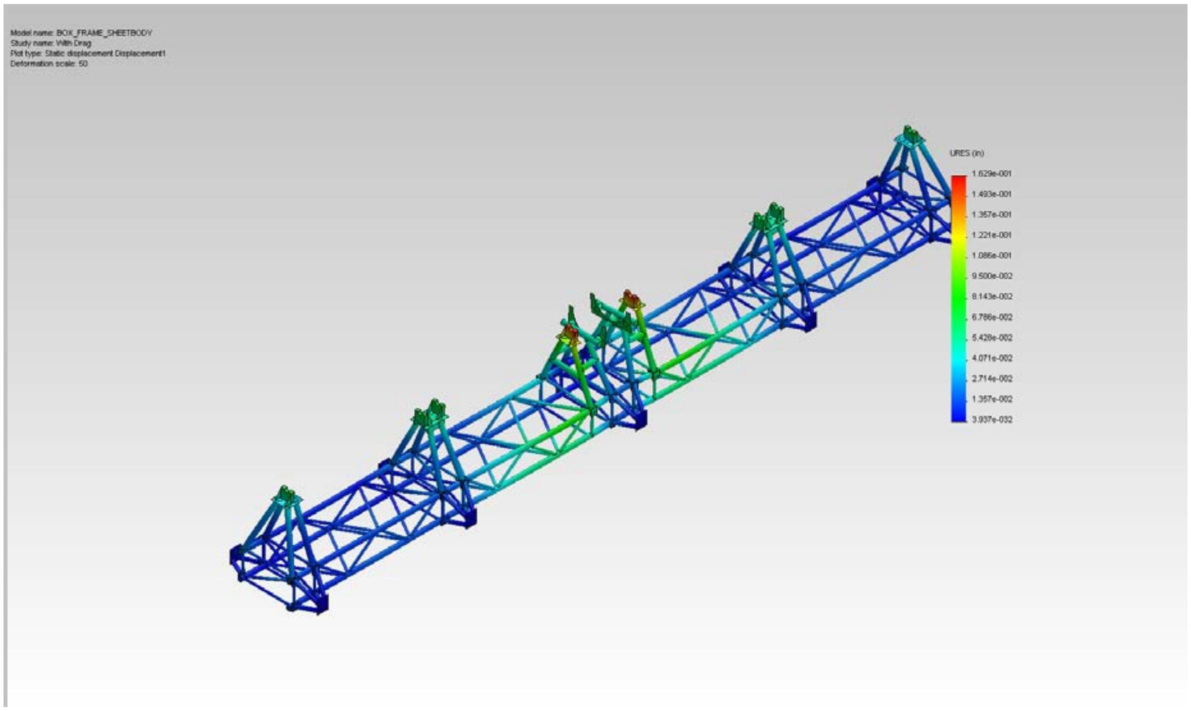

Figure 6. Displacement of TGU bearing mounts under the operational loads.

Problems Encountered

No significant problems were encountered. Achieving a design driveline deflection of ¼ in. in the presence of multiple confounding factors (stiffness of soil, stiffness of bottom support frame and TGU, and various failure cases to be assessed) proved a time consuming process.

Departure from Planned Methodology

There were no departures from the planned methodology.

Assessment of Impact on the Project Results

No impact.

TGU Driveline

The TGU driveline consists of various components necessary to support the turbines and to connect them to the generator. Primary components are bearings and couplings.

Original Hypotheses

Based on prior experience with the Beta TGU, ORPC selected the same bearing materials and driveline arrangement previously used.

Approaches Used

The approach used was consistent with the design of previous generations of TGUs.

Tolerances for the driveline and turbine assembly were selected and allowances determined for each of the subassemblies. Alignment tolerances for the turbine end shafts were determined at this stage. Alignment tolerances for the bore of the bearings in the assembly were determined at this stage. In addition, overall length tolerances were established for each of the assemblies and components.

An alignment process is necessary to ensure that proper centerline position and axial positions are achieved. A laser alignment process was used with targets located at the bearing locations of the driveline.

Problems Encountered

Alignment of the driveline in the field was more sensitive than anticipated and required additional effort to complete. The tolerances required for the driveline bore alignments are tight relative to the deflections of the TGU chassis structure.

No issues were detected with any of the couplings.

Departure from Planned Methodology

Alignment data was difficult to assess in real time.

Assessment of Impact on the Project Results

Increase in the bearing friction values led to larger than expected power dissipation and increased wear rate on the bearings.

Bottom Support Frame Design

The bottom support frame is the structure that supports the TidGen® TGU on the seafloor and which in turn connects to the foundation.

Original Hypotheses

As explained above (foundation section) the original concept for the bottom support frame consisted of a tubular steel structure which would connect the TGU to a foundation consisting of four foundation footers. The design intent was for this structure to be assembled on site, and installed on the seafloor to await attachment of the TGU.

Approaches Used

Since the bottom support frame acts as a connection between the foundation piles and the TGU the design process for the bottom support frame is closely interwoven with that of both the TGU and foundation. As the foundation system developed and changed from a four pile system, and then to eight, and finally to ten piles, the bottom support frame design also changed. Once the design of the foundation was finalized, final design of the bottom support frame commenced.

Loads on the bottom support frame were developed using API methods for assessing drag loads on tubular structural elements. Sizing calculations for the bottom support frame were conducted using RISA3D models. To better understand the behavior of the entire assembly, these RISA3D models also included geometry representing the TGU chassis and geometry representing the foundation piles. Support properties for the piles were adjusted to mimic the behavior of the foundations soils. Multiple load cases were investigated, including cases where several of the foundation piles were not fully engaged with surrounding soils.

Problems Encountered

Geotechnical investigation of the soil properties revealed that the marine clays underlying the site did not possess sufficient shear strength to support the lateral loads on the system with only four footers.

Departure from Planned Methodology

The unexpectedly low shear stress for the foundation soils led to multiple iterations in the design of bottom support frame.

Assessment of Impact on the Project Results

Re-engineering of the bottom support frame led to multiple redesigns, which in turn led to higher than expected design costs for this portion of the project.

TGU/Bottom Support Frame Connection

A connection mechanism is required to transfer loads from the TGU to the bottom support frame.

Original Hypotheses

Bolts would be used to attach the TGU to the bottom support frame, with the nature and design details of the bolting system to be developed as a better understanding of the loads, installation routines and diver capabilities were obtained.

Approaches Used

The attachment problem was broken up into several stages of operations. First when the TGU is approaching the bottom support frame there needs to be a coarse guiding mechanism to align the two assemblies. This is achieved by two guide pins on the bottom support frame mating with two funnel receptors on the TGU.

Problems Encountered

No issues were encountered.

Departure from Planned Methodology

There was no departure from the planned methodology.

Assessment of Impact on the Project Results

There were no impacts.

Lifting & Handling

Original Hypotheses

ORPC engaged a general contractor (GC) to assemble, deploy and retrieve the bottom support frame, cable and other project components. It was planned that the GC would engineer all lifts and any handling operations.

Approaches Used

It became clear in early discussions of the lifting and handling operations that the GC would need significant engineering support to properly design the lifting and handling operations simply because they did not fully understand all of the systems and the design restraints and did not have access to all the finite element models which ORPC had developed. ORPC provided engineering support for the lifting and handling and transportation operations for the bottom support frame and the TGU. For the various operations and transportation cases, ORPC developed designs and criteria for safe and proper handling of the components. This was done primarily through finite element methods and by following recommended practices (Figure 7 and Figure 8).

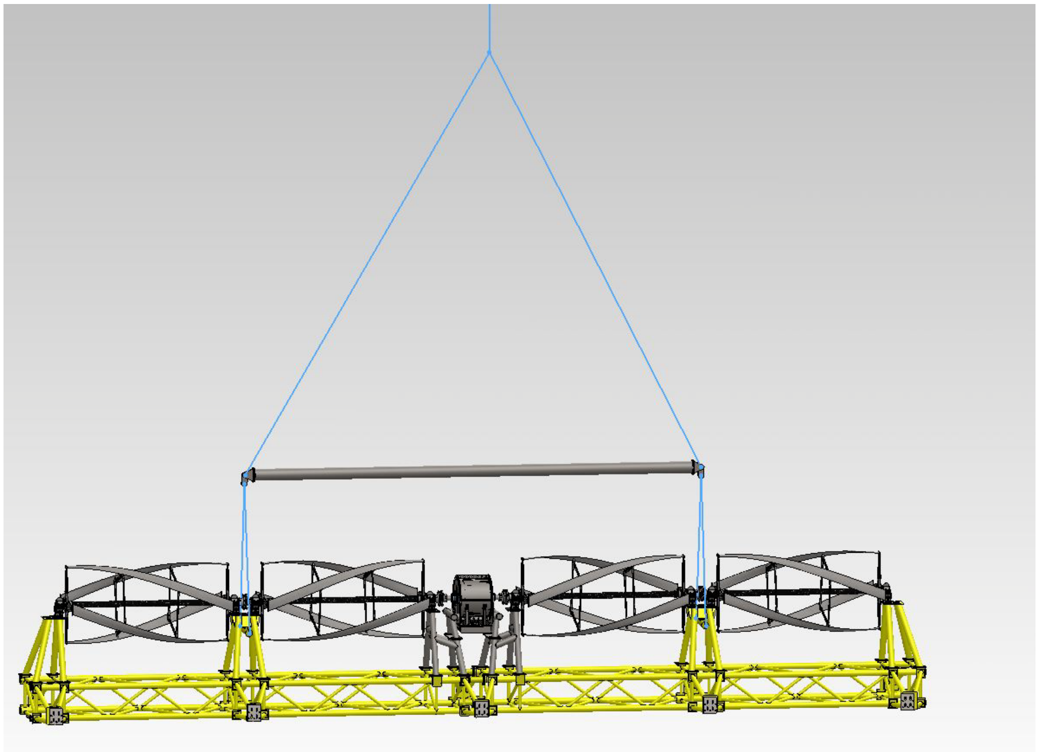

Figure 7. Spreader bar design for Lifting & Handling of TGU

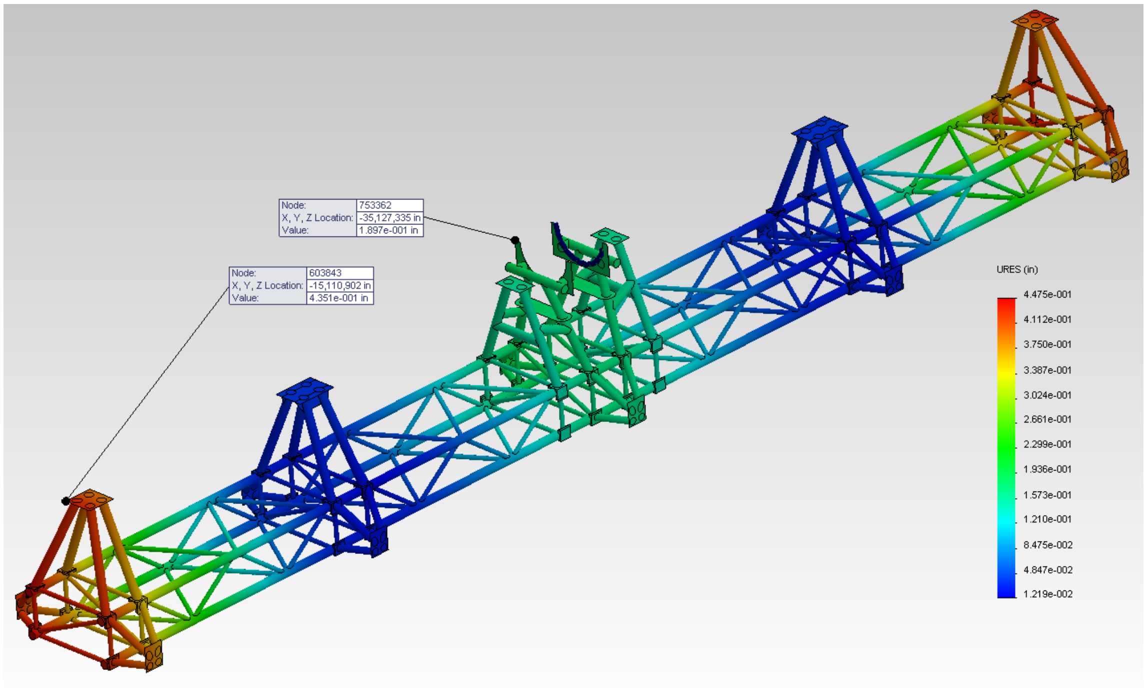

Figure 8. Deflection calculations for TGU under spreader bar

Problems Encountered

The additional effort required to engineer the lifting and handling operations had not been planned for early in the project. Consequently this was an additional piece of work which needed to be performed. Since this was recognized relatively late, this work became a critical path . The root problem was unclear communication of expectations between ORPC and the GC as to responsibilities for lifting and handling operations.

Departure from Planned Methodology

ORPC planned the lifting and handling operations.

Assessment of Impact on the Project Results

This additional piece of work needed to be performed and since this was recognized relatively late the work became a critical path adding cost to the project.

Deployment and Retrieval Systems

Original Hypotheses

Deployment and retrieval of the project components would be completed from a four point moored barge equipped with a tractor crane. Positioning of the subsea assets would be accomplished by winching the barge to the correct location as determined by a GPS system mounted on the crane tip. Hardhat divers would visually monitor subsea operations and provide audio and video feeds to the surface to help coordinate activities.

Approaches Used

The moored barge was used for deployment of the bottom support frame, for pile driving operations and for multiple deployments and retrievals of the TGU. This approach proved successful and was fully capable of operating in relatively protected Cobscook Bay. Hardhat divers successfully performed all operations required of them.

Problems Encountered

The cost of stationing the barge and crane on site was high.

Departure from Planned Methodology

ORPC determined that alternative means of retrieval and deployment of the TGU needed to be developed to reduce project costs. Several different approaches to retrieval schemes were investigated. Two different types of schemes were planned in detail. The first of these was an air-bag retrieval system which was developed to recover the TGU. This system was planned out in detail but not reduced to practice. The second approach involved the development of a catamaran retrieval system utilizing commonly available pin barges with added superstructure. Lifting was implemented by deck winches. The elements of this system are modular and can be made readily available at Project sites.

The system was successful in retrieving the TGU (Figure 9). The catamaran system did not need to be moored in place to complete the pick operation, and was positioned by two independently operating work boats, each equipped with feedback on the catamaran position relative to the TGU.

Figure 9. Catamaran TGU retrieval system.

Assessment of Impact on the Project Results

The economics of TGU retrieval and deployment were improved due to the advancement in retrieval and deployment techniques.

Project Design

Original Hypotheses

The Project consists of multiple elements in addition to the TGU itself. Power and data cables, a shore station, grid interconnection and environmental monitoring equipment were also installed. These Project elements were planned and licensed as part of the FERC license process.

Approaches Used

DC power cables and data run from the TGU to an electrical consolidation unit (the puck) located adjacent to the bottom support frame. From the puck, these cables run to the shore station, located approximately 3600 ft from the bottom support frame. There are DC to AC inverters within the On-shore Station which transform the DC power from the TGU to 480V three phase AC power. Transformers and a recloser complete the grid connection. Also included in the shore station is the SCADA system where operations are monitored and data recorded.

Fisheries monitoring equipment is located several hundred feet from the TGU. A Simrad split beam sonar camera is mounted atop a tower and is pointed in front of the TGU. Power and data cables from the Simrad system run to the puck where they are consolidated with the power and data cables running to the shore station. The Simrad data is monitored and collected at the shore station.

The cables from the puck to the shore station were all encased in HPDE pipe and were all intended to be buried when laid. A shear plow was used to cut a trench in the seafloor. However, only approximately half of the cable run was successfully buried, as the plow tended to skip over sections of the bottom.

Problems Encountered

Cable laying was performed using barge and tug assets and a shear plough.

Departure from Planned Methodology

The cable was not fully buried as planned. Additional dive work was required to pin the cable in place.

Assessment of Impact on the Project Results

Costs associated with additional dive work required to pin the power and data cables in place were not part of the original budget estimates.

Corruption of the data due to electromagnetic noise led to delays in commissioning the system.

Federal Energy Regulatory Commission Licensing

Original Hypotheses

ORPC was aware that the FERC pilot project licensing process and the State of Maine General Permit process would require a high level of description of the Project's technical details as well as comprehensive environmental monitoring plans for both pre-deployment and post-deployment operations. FERC and the State of Maine executed a Memorandum of Understanding (MOU) to coordinate and streamline procedures and schedules for review and approval of tidal energy projects off the coast of Maine in 2009. Federal resource agencies, however, were challenged by statutory mandates that restricted their ability to accelerate the FERC pilot project license process. Fortunately, the MOU served as a catalyst to promote cross agency collaboration and provide a basis for an adaptive management approach to environmental monitoring. Also, FERC and DOE became cooperating agencies to minimize duplication in the FERC and DOE NEPA review process.

Approaches Used

Given the complexity of the FERC pilot license and state general permit processes, ORPC needed to organize a structured, project management approach. This included the expansion of internal project development staff by hiring personnel with environmental regulatory expertise, the creation of a team of technical advisors, the hiring of UMaine and private sector scientists, and selective and strategic use of outside consultants. ORPC maintained close contact with the various resource agencies throughout the consultation period and led productive public meetings at the local level. By managing the consultation and public outreach process internally, and using in-house resources for most of the drafting and assembly of the license application, ORPC reduced the company's overall cost of licensing compared to original approaches.

Problems Encountered

Agency Inexperience with the Federal Pilot License Process

The cost and level of effort associated with licensing this Project was not proportional to the Project size and power output. This was due in part to the first-time nature of the pilot license process and that resource agencies had more experience assessing large hydropower projects using a dam than small projects using marine hydrokinetic devices.

Final Pilot License Application

Additionally, ORPC had expected to complete the site permitting process and receive a FERC license prior to the installation of the TidGen® Power System. However, due to lack of precedence related to hydrokinetic licensing, it was difficult to predict how lengthy the actual FERC application document would be. Nevertheless, the application, more than 4,000 pages in length, was submitted on September 1, 2011, and the license was issued on February 27, 2012. In addition, ORPC received all required approvals and licenses from regulatory agencies, including a Maine General Permit, Maine Department of Conservation submerged lands lease, National Environmental Policy Act Finding of No Significant Impact (NEPA FONSI) and Incidental Harassment Authorization (IHA) from NOAA NMFS Office of Protected Resources prior to initiating construction. Significantly, the U.S. Army Corps of Engineers abdicated their jurisdiction noting their oversight was unnecessary given FERC's involvement.

Restricted Installation Periods

Late in the FERC licensing process, restricted dates for pile driving activities associated with the foundation installation were mandated. NOAA NMFS Protected Resource Division determined that the potential sound levels of pile driving could emit sound levels that could damage young salmon if the pile driving occurred during smolting season, April 10 through November 7, but not during other times of the year. This restricted period resulted in only a brief window between license issuance on February 27 to April 10, 2012, to complete the pile driving required for completion of the installation of the bottom support frame. Despite the pressure on scheduling created by introducing the restricted period so late in the process, pile driving was completed before the April 10 deadline, and environmental monitoring demonstrated minimal impact to the environment. Sound readings taken during the pile driving activities demonstrated that source levels for both the vibratory and impacts hammers were below the levels that would trigger restrictive dates.

Departure from Planned Methodology

The time, expense and effort involved in addressing the restricted installation dates were the most significant departure from planned methodology.

Assessment of Impact on the Project Results

The project became the first in-water operation of tidal energy power system authorized under FERC's pilot license and the State of Maine's general permit. The successful licensing helped more clearly identify the permitting path for marine hydrokinetic projects, increased agency knowledge about tidal energy technology and environmental monitoring technology and techniques, and strengthened ORPC's project development expertise

Task 2: Procurement, Manufacture & Assembly

Original Hypotheses

The Project, as proposed, was based on the TidGen® Power System being assembled at an on-shore location in close proximity to the Project site in Cobscook Bay. ORPC would secure this staging area through a lease or a lease-to-purchase option. Components of the TidGen® Power System would be brought to this staging area for final assembly. Once assembled and inspected, a marine service provider would move major subsystems of the Power System to the deployment location.

The TidGen® Power System would be comprised of two major subsystems: an ORPC TGU and a bottom support frame. Ancillary components, both underwater and onshore, would complete the Power System. The TGU assembly would include a generator, turbines, and structural framework for mechanical alignment. The bottom support frame would include a framework to support the TGU off the seabed in an optimal orientation for the tidal conditions.

ORPC would engage a skilled manufacturer to manufacture the proprietary cross flow turbines for the TidGen® Power System. The turbines were to be manufactured using composite materials and manufacturing technology, which had a well established and successful track record in the marine environment. ORPC had garnered extensive insight of turbine design and manufacture during its prototype and pre-commercial beta programs. This knowledge would be coupled with advanced composite techniques to manufacture quality turbines for the power system.

The proposed manufacture of the turbines was a specialized process for unique hydrofoil design. The composite components used in the TGU structural framework had more standardized pieces. The same composite manufacturer who fabricated the composite components for the TGU structural framework, or another qualified manufacturer, would be engaged for the less specialized pieces.

To facilitate close monitoring of turbine quality and other composite components for the TidGen® Power System, ORPC planned to work with local governments and economic developers of the deployment location to catalyze manufacturing use of unoccupied local infrastructure. Once fabricated, the composite components would be moved to the shore side staging area for final assembly into a TidGen® Power System.

The generator used in the TGU is specialized underwater equipment; experienced manufacturers were limited in number. The generator would be fabricated offsite of the general deployment location, and transported to the final staging area to be installed in the TGU.

With the generator, turbines, and structural frame at the staging area, the final onshore assembly of the TGU structure would be completed. Once the generator and turbines were set in the framework, the alignment of the TGU components were then integrated through field adjustment of the inline bearings and couplings.

The Project proposed that the bottom support frame and associated components would be fabricated with standard steel structural materials. Underwater design to support TGU had been advanced through ORPC's prototype and beta projects. Design features for supporting devices on the seabed had been well established in existing marine industries, and would be employed in positioning the bottom support frame at the deployment location.

Although components of the bottom support frame may be fabricated at remote shops, the final fabrication and primary assembly of the bottom support frame would take place at the shore side staging area. Manufacturers experienced in steel fabrication in the marine environment were established in the local area of the deployment location.

Approaches Used

Maine has a skilled labor force in boat building and marine services, including manufacturing, fabrication, assembly, and engineering services. ORPC's approach was to use these services to the fullest extent possible for procurement, manufacture and assembly.

TGU Procurements

- Turbines
  A bid package was created and released to sixteen potential composite manufacturing vendors in May 2011. ORPC received six proposals and went through a detailed evaluation of all proposals received. This internal review process led to the selection of four vendors to visit and review in great detail their ability to manufacture the turbines. After these visits were conducted, a vendor to manufacture and supply the turbine sets was chosen.

- Generator
  ORPC selected the generator company that manufactured the generator for the Beta TidGen® Project. Continuance with this company had attractive time and cost savings, as well as facilitation of manufacturing improvements.

- TGU Chassis
  A competitive drawing bid package was issued for the TGU chassis. Two fabricators based in Maine were able to bid on the work; one other wanted to bid on the work, but did not have the room in their schedule for the work. Shop visits were held and based on the received bids and these site visits, a local company was selected as vendor. The chassis is a structure approximately 102 ft long by 16 ft wide by 17 ft high, and is constructed of steel tubular members. The TGU chassis was delivered to Eastport on June 26, 2012 (Figure 10).

- Miscellaneous Items
  Bid packages were released to vendors for other significant TGU procurements, such as the power electronics and SCADA. Selections were made after an internal review process.

Bottom Support Frame Procurement

Due to the level of review that was performed for the TGU chassis, the same fabricator was also selected for the bottom support frame. This allowed for consistency between the two items. Another crucial benefit of using the same fabricator was maintaining the quality of the mating portions between the TGU chassis and the bottom support frame.

Assembly & Deployment

- General Contractor
  ORPC contracted a local construction company to serve as construction manager for the Project. The company was responsible for on-location assembly and deployment of equipment into Cobscook Bay.

Utility Upgrade

- Bangor Hydro Electric Upgrade
  In compliance with separate interconnect and construction agreements executed between ORPC and Bangor Hydro Electric Company on April 26, 2012, a 3.3-mile distribution system upgrade was completed along North Lubec Road, Lubec, ME. This upgrade included the installation of ~78,000 ft of new 336 AAC power line and ancillary line equipment including bypass switches, reclosers, meters, cutouts and grounding mats. In addition, rebuild materials including poles, framing and guys/anchors, were placed.

- FairPoint Communications Upgrade
  ORPC worked with FairPoint Communications to properly outfit the newly built On-shore Station at the end of North Lubec Road, which served as ORPC's power conditioning, environmental and systems monitoring and utility interconnection point. ORPC was required to install new telephone service as a result of the approximately 3.5 miles of wire and pole upgrades completed along the North Lubec Road in 2012 by Bangor Hydro Electric Company.

Figure 10. The assembled TGU chassis delivered to Eastport, Maine, June 26, 2012.

Problems Encountered

The procurement schedule for the bottom support frame had to be advanced to meet the FERC imposed restricted period on pile driving, requiring that the pile driving be completed no later than April 9.

To stay on schedule the bottom support frame was installed before the TGU was fabricated and constructed, which meant the bottom support frame and TGU were not dry mated prior to installation. The inability to perform this dry mate resulted in the need to properly and accurately survey the bottom support frame and the TGU prior to installation of each component. This was performed adequately;

however additional risk of the assemblies not mating properly was created by the imposition of the restricted pile driving window.

Departure from Planned Methodology

There were no material departures from ORPC's planned procedures for procurement, manufacture and assembly.

Assessment of Impact on the Project Results

Problems encountered in Task 2 had an impact on the Project. The schedule slipped and costs increased primarily due to the first-of-a-kind nature of the system components and unforeseen events such as poor subsurface conditions and the restrictive period. There was also increased risk caused by having to accelerate the pilings installation due to the window of time allowed for installation. These risks were successfully mitigated by rigorous planning, practice sessions and coordination among all of the subcontractors.

Task 3: Installation of Bottom Support Frame

Original Hypotheses

The installation of the bottom support frame proposed the placement of ten piles into the seabed using a driving template as well as pile driving equipment located on a moored barge. Temporary moorings would be used to hold the barge in position for these operations. Subsea construction would begin with the setting of the template, followed by the placing and driving of the individual piles. After the piles were driven, they would be surveyed for elevation from the surface to allow for positioning and installation of subsequent fixtures and components, and would be cut to final dimension if necessary.

Once the foundation was installed, the template would be removed, and receiving fixtures for the bottom support frame would be installed. Next, the bottom support frame would be installed by aligning it with the foundation piles and lowering it into place on top of them. Once positioned on the lower receiving fixtures, the bottom support frame must be able to withstand the force of the maximum tidal current experienced at the site. To accomplish this, a set number of supporting piles would be needed to be immediately engaged with the bottom support frame in order to provide the necessary uplift resistance. Once the bottom support frame has been initially stabilized, it would be thoroughly affixed to the foundation during subsequent operations.

It was anticipated that the installation of the bottom support frame would require only a heavy crane and marine barge. Minimal diver intervention was planned.

Approaches Used

General Contractor

A well qualified Maine General Contractor was selected to serve as the construction manager for the TidGen® project and, under ORPC's overall management, was responsible for Task 3, the installation of the bottom support frame.

Design of Installation
The installation of the bottom support frame was designed and submitted to ORPC by the General Contractor on March 5, 2012. ORPC submitted the Bottom Support Frame Deployment Plan to FERC on March 6, 2012.

Bottom Support Frame Installation
The design of the bottom support frame was completed, released for fabrication, manufactured and delivered to the Project site in Eastport. The frame sections were assembled in Eastport and surveyed to ensure that critical dimensions and tolerances were satisfactory. Final assembly of the bottom support frame was completed on March 16, 2012 (Figure 11 and Figure 12).

Figure 11. Final assembly of the bottom support frame, March 16, 2012.

The bottom support frame for the first TidGen® device was installed onto the seabed on March 20, 2012 using a crane on a barge that was secured into position using a four point tensioned mooring system very similar to the one used successfully for the geotechnical borings. The deployed bottom support frame then acted as a template for the driving of piles to secure the bottom support frame in place.

Figure 12. Bottom support frame deployment, March 20, 2012.

Pile Installation
Pile driving staging activities commenced on March 24, 2012, with several dry runs. Some weather delays occurred with wind speeds of up to 30 knots over several days. Of the 10 piles driven, 9 were driven greater than the design depth, pile 1 was driven to 0.7 ft short of design. All piles met refusal. Pile driving activities were completed by April 8, 2012. The pile driving activities were conducted using the same barge and crane used for the bottom support frame installation.

Two technologies were used for the pile installation process; a vibratory and a diesel impact hammer. Due to the depth of water, a 100-ft follower was used between the pile and each hammer type. The follower, using a flanged connection, was attached to the pile on deck in a receiver attached to the barge and lowered to the appropriate pile sleeve on the bottom support frame. Hardhat divers, with full audio and video capabilities, were used to help guide the pile into pile sleeve on the bottom support frame. Once the pile was in the correct spot the diver would return topside before the pile was driven.

Due to limitations of deploying structures in high velocity tidal currents, pile-driving operations only occurred during an approximate 1-hour period centered on slack tide. Water depths were approximately 105 ft and 85 ft at high and low slack water respectively.

Once lowered to the seafloor, most piles sunk approximately 10 ft into the marine clay under their own weight. Each pile was then driven to refusal using the vibratory hammer. During a subsequent slack water period, three piles were driven further into glacial till or to bedrock using the impact hammer. However, operation of the impact hammer provided minimal additional embedment, so its use was discontinued after March 31, 2012. Following the hammer operations each pile was unbolted from the follower and hammer assembly underwater by hardhat divers. Figure 13 shows the vibratory hammer assembly.

Figure 13. Vibratory hammer operations, April 1, 2012.

Connection of Friction Collars
Friction collars, which were attached to the bottom support frame prior to deployment were tightened to the piles from April 11 through April 19, 2012. Final adjustments to the bottom support frame were made by April 19, 2012.

Problems Encountered

There were several problems encountered during the installation of the bottom support frame: (1) the pile driving operation took several attempts before the contractor learned the proper timing and technique, (2) an excessive amount of dive time was required to connect the friction collar, adding additional costs to the Project, and (3) the bottom support frame was installed before the TGU was constructed, therefore, the components were not dry fit. Even though the TGU and bottom support frame were not dry fit on land, the two pieces fit together without an issue when the TGU was deployed. This was due to much time being taken to survey the bottom support frame once it was assembled and making adjustments to the TGU chassis as needed.

Departure from Planned Methodology

ORPC had planned on driving every pile using the vibratory hammer and then “proving” it to refusal with the impact hammer. However, initial results of this methodology indicated minimal further penetration with the impact hammer, so remaining piles were driven solely with the vibratory hammer (which also has less risk from an acoustic standpoint).

ORPC originally thought that the company would use a Remotely Operated Vehicle (ROV) to assist with underwater operations of the installation. But demonstrations showed of the ROV had issues with holding station and maneuverability in water speeds of over 1 knot. ORPC opted for divers.

Assessment of Impact on the Project Results

Pile driving activities were conducted between March 24 and April 8, 2012 in accordance with regulatory concerns related to Atlantic salmon occurrence as required by our FERC license and source levels dictated by the IHA. Results of the monitoring during pile driving activities demonstrated minimal impact to the environment. Source levels measured during impact and vibratory pile driving were below the thresholds of concern for Atlantic salmon. Measured Level A and B isopleths ranges, thresholds for marine mammal harassment, were significantly smaller than the conservative ranges included in the IHA. In addition, responses to pile driving noise by birds and harbor seals were minimal, with sightings of each occurring in the vicinity of the project area both before and after pile driving. Harbor seals, or more likely a single harbor seal, returned to the project site on multiple days of pile driving.

Task 4: Installation and Start-up

Original Hypotheses

The proposed installation would be comprised of placing the TGU on a floating platform to be moved to the deployment location and lowered to the bottom support frame using a heavy lift crane. Guide cables would be used to orientate and direct the TGU to the bottom support frame. These operations would be conducted at slack neap tides. A series of locking connections would be actuated by a remotely operated vehicle (ROV), mounted with a torque tool to connect the TGU to the bottom support frame. Sensing equipment to monitor and provide feedback on environmental resources, mechanical integrity, and electrical characteristics for the TidGen® Power System would be installed on both the TGU and the bottom support frame shore-side. Final connection, calibration, and positioning would be completed once the TGU is attached to the bottom support frame.

It was assumed that installation costs would not be significant compared with capital costs of the equipment. In addition, it was expected that multiple issues associated with controls and data acquisition would be encountered.

Approaches Used

Shore Cable Termination Anchor Installation

A Cable Installation Plan was submitted by the contractor on May 23, 2012 (revised July 11, 2012). ORPC installed a Shore Cable Termination Anchor (SCTA) approximately 25 ft from the TidGen® 001 (Figure 14). This was the first component of the cable system to be laid during cable deployment. The SCTA is held in place by a gravity base and resists lateral drag loading by friction between the base and the sea floor. The unit is 4 ft high and 6 ft in diameter. With concrete ballast the unit weights approximately 7,500 lb.

Figure 14. Shore cable termination anchor

Cable Installation

The subsea power and data (P&D) cables were deployed on the seafloor on July 13 (subsea) and 14 (intertidal), 2012. Installation was by means of a shear plow in submerged portions of the cable route and by an excavator with a narrow width (8 to 10 in.) bucket in the intertidal zone (Figure 15). ORPC received permission from NOAA NMFS in compliance with our FERC license to use the shear plow in the intertidal zone on March 19, 2012.

Figure 15. Shear plow used for cable installation (July 13, 2012)

The subsea cable termination anchor and a deployment reel containing the P&D cable were loaded onto a barge equipped with a crane. The P&D cable was secured to the shore cable termination anchor while on the barge. The barge transported the cable and subsea cable termination anchor to the deployment area (Figure 16).

Installation began with the barge moored at the offshore cable terminus where the shore cable termination anchor was deployed. The deployment barge was then moved along the cable transects, dispensing cable from the deployment reel as it advanced. Once the cable was laid along the seabed, the barge was stopped and the shore-side cable end was transferred to shore for completion of the on-shore cable run. Following the laying of the outboard cable transect, the cable was secured by divers with anchors embedded into the cobble substrate.

The cable burial in the intertidal zone was performed at low tide using a rubber tired backhoe using a narrow width bucket to minimize environmental disturbance. The backhoe dug a trench from MLLW to the On-shore Station, a distance of approximately 675 ft. The excavator reached the intertidal area from an existing road. The cable was set in the trench through the intertidal area and covered with the excavated material. Trenching continued to the On-shore Station located approximately 400 ft from the MHW line.

This installation of subsea cables in high current environments was an experimental application of the shear plow technology. Our efforts to completely bury the cable bundle were hindered by larger cobbles encountered in a few areas of the cable deployment. ORPC addressed portions of the route where the cables were not adequately covered using driven staples.

Figure 16. Data Cable As-built Map, Cobscook Bay Tidal Energy Project

Installation of TGU

The TidGen® TGU 001was placed on a floating platform consisting of pin barges, moved to the deployment location and lowered onto the bottom support frame on August 14, 2012 (Figure 17 and Figure 18). The operation was performed using the same barge and crane used for the bottom support frame installation and pile driving. Guide cables were used to orientate and direct the TGU to the bottom support frame. These operations were conducted at slack neap tides. A series of locking connections were actuated by divers, equipped with a torque tool to connect the TGU to the bottom support frame. Final connection, calibration, and positioning were completed after the TGU was attached to the bottom support frame.

Figure 17. ORPC's TidGen® TGU awaiting installation in Eastport/Lubec, Maine, July 24, 2012. (Photo courtesy of Jeffrey Hains)

Figure 18. Installation of the first TidGen® TGU in Cobscook Bay, Maine, August 14, 2012

Simrad Installation

Sensing equipment to monitor and provide feedback on environmental resources, mechanical integrity, and electrical characteristics for the TidGen® Power System was installed on a split beam echosounder imaging system manufactured by Simrad in August 2012. A "tower" composed of steel trusses and attached to a concrete gravity foundation, was required to position the echosounder (Figure 19). The Simrad tower was mounted at a distance of 200 ft from the TGU, and elevated 20 ft above the seabed to provide an adequate field of view in the vicinity of the TGU on August 20, 2012. Connectivity was finalized and confirmed on August 25, 2012, and calibration exercises occurred on August 27-31, 2012.

Figure 19. Simrad environmental monitoring observation tower

On-shore Station Construction

On-shore Station construction activities began in Lubec, Maine on March 26, 2012 by the general contractor. The erosion control silt fence was installed, trees and brush were removed and the area was prepped for construction. The On-shore Station was installed on May 20, 2012 (Figure 20).

The On-shore Station is located off of North Lubec Road in Lubec, Maine and housed the power inverters and the Supervisory Control and Data Acquisition (SCADA) system. An existing road is used to reach the On-Shore Station. ORPC has installed two 20 ft by 8 ft containers that serve as the On-shore Station for the Project. The On-shore Station is located approximately 400 ft from the shore. A fence surrounds the On-shore Station with dimensions of 30 ft by 30 ft. Gravel was used in the yard surround the On-shore Station and extends outside of the perimeter fence for a total impacted area of 1,300 square ft. A 100-gallon propane tank and gas generator are located within the fenced area outside of the modular buildings. A concrete vault with dimensions of approximately 6 ft by 6 ft is located outside of the fenced area, and the grid connection transformer is positioned on the pad.

Power is delivered to the On-shore Station via the underwater P&D cable at 800 V DC. The power is converted to three-phase AC at a frequency of 60 Hertz (Hz) and 480 V using a SatCon power inverter to synchronize to the electrical grid. A 1,000 kilovolt-ampere (kVA) rated step-up transformer boosts the voltage to grid levels.

Figure 20. On-shore Station, Lubec, Maine.

Connection of TGU
Power and data cables were installed from On-shore Station to vault at high tide line. Bangor Hydro Electric completed the transmission line upgrade on June 1, 2012.

Start Up of System
Bangor Hydro Electric has been very supportive of our efforts and the system was put online and power generated on September 13, 2012.

Problems Encountered

Our efforts to completely bury the cable bundle into the ocean floor were hindered by large cobbles encountered in a few areas of the cable deployment. ORPC wanted to minimize movement of unburied sections of cables, which could damage the cables and potentially the benthic community. ORPC addressed portions of the route where the cables were not adequately covered using driven staples.

Working windows for tides were tighter than anticipated and require good coordination between divers and barge crew.

There were data issues related to electrical noise caused by generator construction.

Departure from Planned Methodology

ORPC originally thought that the company would use a Remotely Operated Vehicle (ROV) to assist with underwater operations of the installation. But demonstrations showed of the ROV had issues with holding station and maneuverability in water speeds of over 1 knot. ORPC opted for divers.

Assessment of Impact on the Project Results

No serious construction difficulties were encountered.

Task 5: Grid Connection

Original Hypotheses

The Project proposed that the TidGen® TGU would be connected to shore through a combined underwater power and fiber optic control cable, which would interconnect with the Bangor Hydro Electric Company power grid. Power generated by the TidGen® TGU would be rectified by a boost converter on the TGU to 13 kV DC. This medium voltage DC power would be transmitted to shore via a submarine transmission cable. The power would then be stepped down to 600 V DC and connected to a commercially available grid tie inverter system, which would connect to the local utility grid. The boost converter would control TGU operation by loading and unloading the generator, to keep the turbine at the desired maximum power point for any given water flow speed. Closed loop control is implemented using multiple acoustic flow speed sensors as the free stream water speed input signal. The TidGen® Power System would be monitored from a shore station, which would have the capability to start, stop, emergency stop, and monitor the TidGen® Power System. Data, video, and instrumentation readings would be transmitted by fiber optic cable bundled with the power transmission line.

It was expected that multiple issues associated with controls and data acquisition would be encountered.

Approaches Used

An underwater power cable delivered electricity generated by the Project to an On-shore Station in Lubec, Maine, where it was power-conditioned and connected to the Bangor Hydro Electric Company power grid on September 13, 2012. Bangor Hydro issued the Permission to Operate: Certificate of Completion on September 25, 2012.

Problems Encountered

There were no problems encountered with the grid connection.

Departure from Planned Methodology

There were no departures from the planned methodology.

Assessment of Impact on the Project Results

There were no impacts from the grid connection.

Task 6: Initial Testing of the First Unit

Original Hypotheses

Detailed testing of the TidGen® Power System, including all device components and subsystems and initial operations, would be monitored from the On-shore Station, which would have the capability to start, stop, and monitor the TidGen® Power System. Data, video, and instrumentation readings would be transmitted by data cable bundled with the power transmission line. All major system components would be instrumented and monitored for performance and environmental/ecological study, with data collected to validate Project progress.

Based on previous experience with cross-flow turbines, it was expected that multiple issues primarily associated with controls and data acquisition would be encountered.

System checks were conducted during the first six weeks of operations, with primary focus on the grid connection systems, instrumentation on the TGU and the environmental monitoring equipment. Several modifications were required to the SatCon inverter firmware to properly implement the automated grid connection sequence and grid protection. These changes were witnessed and approved by the grid utility, Bangor Hydro Electric Company.

Approaches Used

Detailed testing and monitoring of the nearby environment, as well as all device components and subsystems and initial operations began after the September 13, 2012 start-up. The TidGen® Power System was monitored from the On-shore Station, which had the capability to start, stop, and monitor the TidGen® Power System. Data and instrumentation readings were transmitted by data cable bundled with the power transmission line. All major system components were instrumented and monitored for operational characteristics and environmental/ecological study, with data collected to document and validate Project performance.

A mapping of the control parameters was carried out and initial control parameters selected. An initial assessment of the performance of the unit was conducted, and the data was processed.

Problems Encountered

The Simrad fisheries monitoring equipment, however, was especially sensitive to disturbance on its power feed. Data from the Simrad showed signs of electromagnetic noise when the generator was operating in boost mode. ORPC added more line filters to other elements of the system, but this did not eliminate the issue.

In addition to the Simrad data problems, there were issues with the water speed sensors deployed with the TGU. A Nortek Aquadopp unit was not functional, and a Valeport flow sensor with the TGU was providing confused data. After retrieval of the system, ORPC discovered that divers had inadvertently rotated a SubCon connector and made a connection to the incorrect terminals. This was rectified, and upon redeployment, the water speed sensors provided consistent flow data.

Departure from Planned Methodology

There were no departures from the planned methodology.

Assessment of Impact on the Project Results

The installation and operation of the TidGen® TGU 001 in 2012 was a significant accomplishment for ORPC and the marine hydrokinetic industry. Despite technical issues with the system, ORPC considered that given the innovative technology and challenging, dynamic site conditions, performance issues were to be expected.

Task 7: Operation of initial TidGen® Power System

Original Hypotheses

The TidGen® Power System design philosophy promoted system characteristics that would highlight the interdependence of maintenance, reliability, performance, and environmental factors. The philosophy had been employed during ORPC's prototype and beta pre-commercial projects. Using system modularity that incorporated robust ocean-tested components, this philosophy would minimize operational and maintenance costs while meeting performance criteria. The philosophy would be integrated early in the TidGen® Power System program, and ORPC would assign a Technical Manager to oversee the operations and maintenance (O&M) from the commencement of operations through the project lifecycle.

ORPC would adopt an O&M Plan for the TidGen® Power System. The O&M Plan would schedule periodic inspections, service activities based on operation reports, and pre-planned component replacements. The design philosophy would facilitate insertion of component upgrades as the technology advanced. Normally, personnel would monitor operations remotely from an ORPC Operations Center. Remote monitoring systems would signal appropriate intervention action prior to system degradation or failure.

ORPC would monitor operation performance parameters and indicators for system component integrity. The data from the TidGen® Power System would be transferred to shore for display and evaluation by both software and personnel. Some response actions may be initiated automatically as feedback to reduce personnel monitoring and improve the level of unattended operation.

ORPC would prepare a series of operations reports for performance assessment. Environmental appraisal would be included in these assessments. These reports would be maintained at the Operations Center. There were two basic reports – a periodic summary of the operating performance parameters and an inspection report. The data for the reports would be generated and recorded automatically, other than those parameters for which visual observation were practical. Reports would be prepared per periodic frequency required with daily, weekly, monthly, quarterly, and annual reports as pertinent.

Operation training would be specific for the TidGen® Power System including component manufacturer-supplied training. The Technical Manager, in collaboration with the engineering team, would institute a project-training program to support project performance, personnel health and safety, and environmental harmony.

An operations material and spare parts inventory would be maintained at the Operations Center. Inventory would be set to avoid significant impact on availability, operations, and sustainability. Use rate, operational scenarios and equipment reliability drove sparing requirements.

The O&M Plan outlined the periodic inspection and replacement activities. The Plan was to complement Original Equipment Manufacturer (OEM) manuals and documentation. ORPC would employ the 'repair by replacement' policy. The material and spares inventory supported this policy. System design would enhance mechanical component, electronics, and control gear replacement using standardized equipment to ease exchange. Component and modular replacement would minimize downtime and maintenance activity.

Certain maintenance procedures on the TidGen® Power System components would be conducted in situ. Other activities would require removal of a Power System component to shore. Generator or turbine module replacement could be an example for shore-side maintenance. Overall maintenance was managed by condition-based data to support planned maintenance. Scheduled activities were augmented by corrective maintenance when data indicated intervention.

ORPC maintenance philosophy was designed to minimize site visits and activity on the water and at the shore station. ORPC would have marine vessels available under charter for on-water activity. Vessels chartered were required to have demonstrated capability, including safety and environmental compliance adherence, for the task at hand. The On-shore Station would be accessed by vehicle.

The Technical Manager would generate timely maintenance reports, and maintain such reports at the Operations Center.

The Technical Manager would institute a maintenance training program, as well as a materials and spares inventory.

Maintenance is dynamic; operation experience would determine the actual schedule. The Project was designed so that the TidGen® Power System would operate for a full year to provide an initial technical and environmental evaluation period. Operation and maintenance would focus on this single system. At the end of Year One, components of the Power System would be fully evaluated for wear and reliability of subsystems. As the Project evolved, the O&M program would evolve to meet the implementation.

Approaches Used

Inspection of the TGU by divers showed some mechanical issues with the turbine which required retrieval and repair of the TGU. Upon re-deployment, an electrical issue with the generator brake occurred which again required retrieval, repair and redeployment. The TGU was redeployed on February 26, 2013.

Environmental Monitoring

In compliance with ORPC's FERC pilot project license, ORPC continued environmental monitoring of the TidGen® Power System, including hydroacoustics for fisheries interaction, benthic surveys of the cable route, ADCP measurements of the flow field, bird and marine mammal observations and acoustic monitoring. ORPC submitted its 2012 Environmental Monitoring Report for the Cobscook Bay Tidal Energy Project to FERC on March 26, 2013.[9] The report represents a significant achievement for the

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[9] The entire Environmental Monitoring Report is included in the Data List as part of this Final Technical Report.

Project and the Adaptive Management Plan. As the first annual environmental monitoring report in North America for an operational tidal energy device, it documents how knowledge was obtained and utilized for the installation and operation of ORPC's TidGen™ Power System and the interaction of the system with the marine environment.

Adaptive Management Plan
ORPC developed an Adaptive Management Plan as required by the FERC pilot project license. Federal and state resource agencies participated with ORPC on the Adaptive Management Team (AMT) and provided oversight on the Plan. The Plan was an integral part of ORPC's implementation of the Project and provided a strategy for evaluating monitoring data and making informed, science-based decisions to modify monitoring as necessary. The Plan was designed to be modified within the Project timeline and acknowledged that elements of the Plan, such as key environmental uncertainties, applied studies and institutional structure, may evolve over time. ORPC thanked the resource agency members of the AMT for their guidance and collaboration in helping to make the Plan a success.

Acoustic Monitoring
ORPC's acoustic consultant, Scientific Solutions, Inc. (SSI), developed a NOAA-sanctioned methodology using a drifting spar buoy for pre-deployment acoustic monitoring at the high velocity deployment site. SSI conducted acoustic monitoring using the same methodology and equipment during Phase I pile driving in March and April 2012. Results confirmed that pile driving source levels were within acceptable ranges, provided that sound absorption devices were used and best practices were implemented. Acoustic monitoring around the installed TidGen™ device was completed in April 2013.

Benthic and Biofouling Monitoring
MER Associates review of ORPC's November 9, 2013 benthic survey of the cable route concluded that exposed sections of the cable were causing minimal disturbance to the seabed and were not adversely impacting the surrounding habitat or benthic epifauna. In addition, the buried portion of the cable was stationary and was not expected to cause any disturbance impacts. Unburied sections of the cable were pinned in position and were not observed to have moved. ORPC is continuing to improve methods and quality of data collected for the benthic survey. Review of the dive video and visual inspection following retrievals of the TidGen® indicate minimal biofouling of the TidGen® device.

Fisheries and Marine Life Interaction Monitoring
UMaine continued performing fisheries surveys in 2012 using a vessel mounted down-looking sonar to determine total water column fish biomass at both the installation and control sites. Survey results indicated that March had the lowest fish biomass and May had the highest. In addition, UMaine continued trawl and intertidal surveys in the Cobscook Bay to provide species verification and characterize the fish community.

ORPC installed a seabed-mounted side-looking sonar on an environmental monitoring tower to monitor marine life interaction with the TidGen® device. UMaine analyzed an acoustic data subset from the system and detected a total of 13,643 fish tracks; 3,191 of these were detected during flood tides and 10,452 detected during ebb tides. UMaine's analysis resulted in a determination of fish target strength (relative size), density, and direction of movement in the vicinity of the TidGen® device.

Hydraulic Monitoring

Sandia National Laboratories utilized their SNL-EFDC model to simulate flow in Cobscook Bay, which reproduces available data sets for three water-level locations and an ADCP measurement. The modeling results demonstrated that there would be no significant changes in tidal range, flow rate, or velocity upon operation of five ORPC tidal energy devices. Tidal changes of less than 10 millimeters of tidal height were predicted in some local areas. Scour monitoring performed to-date indicated that there was no significant change in seabed elevation around the ten foundation piles, except at pile #6, where the bottom support frame skirt was embedded upon deployment.

Marine Mammal Monitoring Plan

ORPC collaborated with Dr. Moira Brown, senior scientist at the New England Aquarium, to design and implement a plan to minimize marine mammal exposure to noise-generating activities during pile driving. This plan resulted in an observer training program, and established requirements regarding observer equipment needed, observation methods, data collection, management and reporting protocols. Dr. Brown trained ORPC staff and qualified candidates from the local community who performed observation during pile driving, as well as during deployment and retrieval activities and incidental sightings. Marine mammal observations made by trained personnel in 2012, including during periods of construction, operation, and maintenance, did not indicate changes in marine mammal presence or behavior. There is no evidence of any marine mammal strikes with system components during deployment, retrieval or operation.

Bird Monitoring Plan

The Center for Ecological Research (CER) conducted monthly surveys at the TidGen® deployment site in North Lubec, Maine between November 2011 and May 2012 to monitor wintering seabirds and waterfowl. Preliminary results from November and December 2012, following the initial installation, show the same general number of seabirds as was observed in the previous two winters. In addition, CER conducted surveys during the pile driving period and found that the responses of seabirds to the vibratory hammer noises were generally minimal or of short duration. No obvious seabird response was observed during brief periods when the louder diesel impact hammer was operated.

Performance Testing of TidGen® 001

A summary of performance of the first ORPC TidGen® TGU based on operational data collected between April 3, 2013 and April 17, 2013 is given below. Figure 21 illustrates tide heights during the test period. Figure 22 and Table 5 shows the locations of the ADCP deployments.

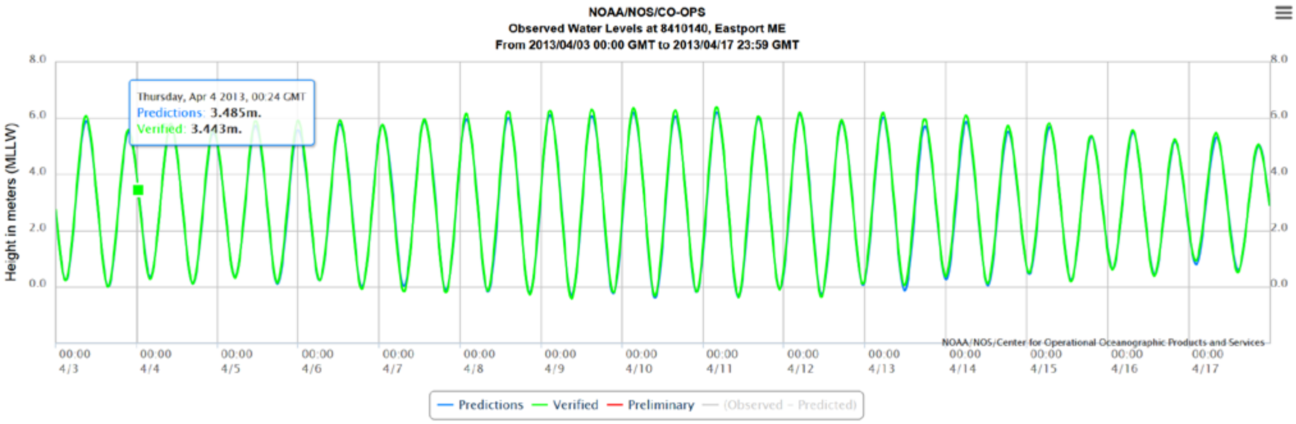
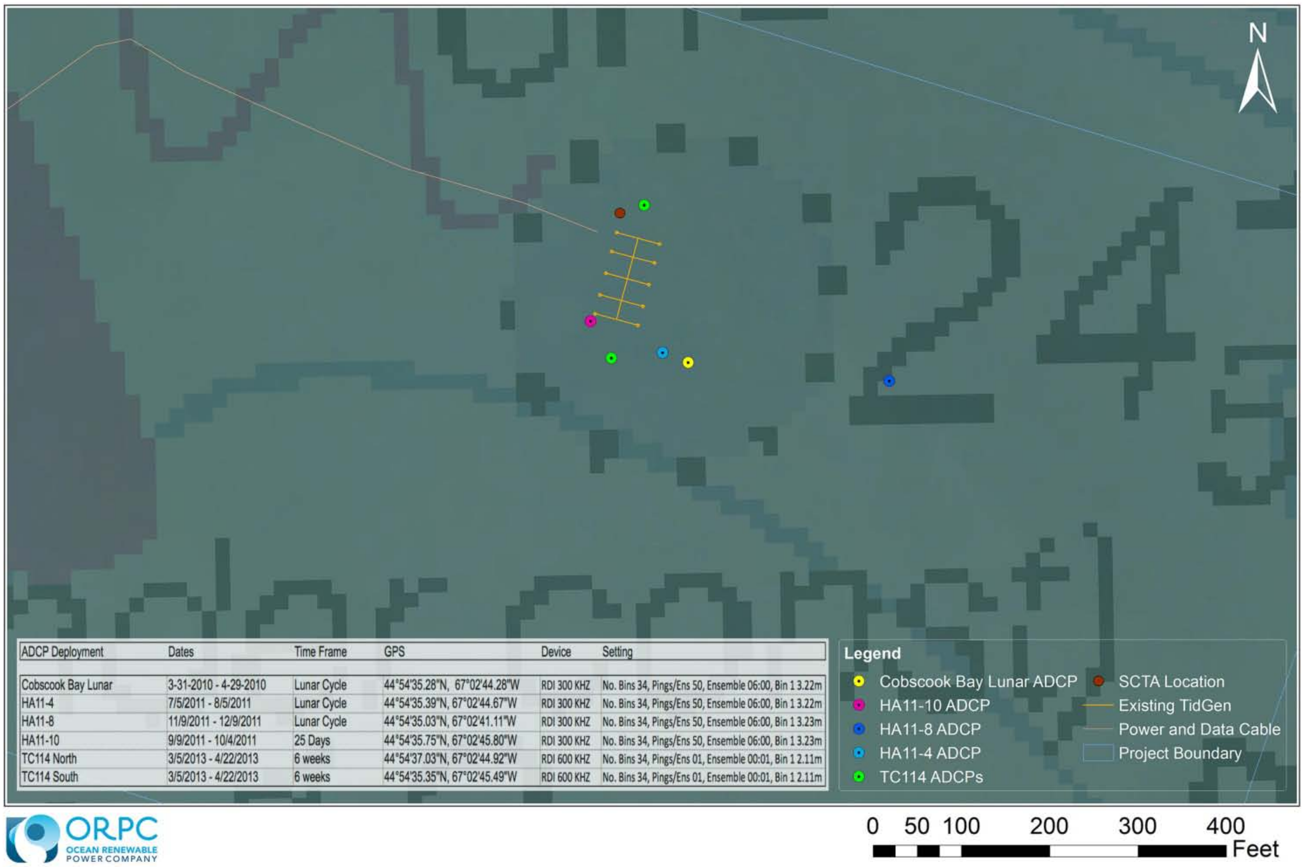


Figure 21. Water level at the TidGen® 001 test site from April 3, 2013 through April 17, 2013



ADCP Deployment	Dates	Time Frame	GPS	Device	Setting
Cobscook Bay Lunar	3-31-2010 - 4-29-2010	Lunar Cycle	44°54'35.28"N, 67°02'44.28"W	RDI 300 KHZ	No. Bins 34, Pings/Ens 50, Ensemble 06:00, Bin 1 3.22m
HA11-4	7/5/2011 - 8/5/2011	Lunar Cycle	44°54'35.39"N, 67°02'44.67"W	RDI 300 KHZ	No. Bins 34, Pings/Ens 50, Ensemble 06:00, Bin 1 3.22m
HA11-8	11/9/2011 - 12/9/2011	Lunar Cycle	44°54'35.03"N, 67°02'41.11"W	RDI 300 KHZ	No. Bins 34, Pings/Ens 50, Ensemble 06:00, Bin 1 3.23m
HA11-10	9/9/2011 - 10/4/2011	25 Days	44°54'35.75"N, 67°02'45.80"W	RDI 300 KHZ	No. Bins 34, Pings/Ens 50, Ensemble 06:00, Bin 1 3.23m
TC114 North	3/5/2013 - 4/22/2013	6 weeks	44°54'37.03"N, 67°02'44.92"W	RDI 600 KHZ	No. Bins 34, Pings/Ens 01, Ensemble 00:01, Bin 1 2.11m
TC114 South	3/5/2013 - 4/22/2013	6 weeks	44°54'35.35"N, 67°02'45.49"W	RDI 600 KHZ	No. Bins 34, Pings/Ens 01, Ensemble 00:01, Bin 1 2.11m

Figure 22. Locations of bottom mounted ADCP deployments in the vicinity of TidGen® 001 with TidGen® 001 North and TidGen® 001 South shown as "TC114 ADCPs".

Table 5. *ADCP deployments in the vicinity of TidGen® 001*

ADCP Deployment	**Dates**	**Time**	**GPS**	**Device**	**Settings**
TidGen® 001 North	3/5/2013 - 4/22/2013	49 days	44°54'37.03"N 67°02'44.92"W	RDI 614kHz	No. Bins 34, Pings/Ens 01, Ensemble 00:01, Bin 1 2.11m
TidGen® 001 South	3/5/2013 - 4/22/2013	49 days	44°54'35.35"N 67°02'45.49"W	RDI 614kHz	No. Bins 34, Pings/Ens 01, Ensemble 00:01, Bin 1 2.11m

TidGen® 001North and TidGen® 001 South were placed adjacent to the TGU in compliance with the instructions under section 8.9.1 of DTS/93/114, orientation B. The bin spacing and blanking distances relative to the turbine are shown in Figure 23.

Data for TidGen® 001 North and South are ensemble size of 1 second as per DTS/93/114.

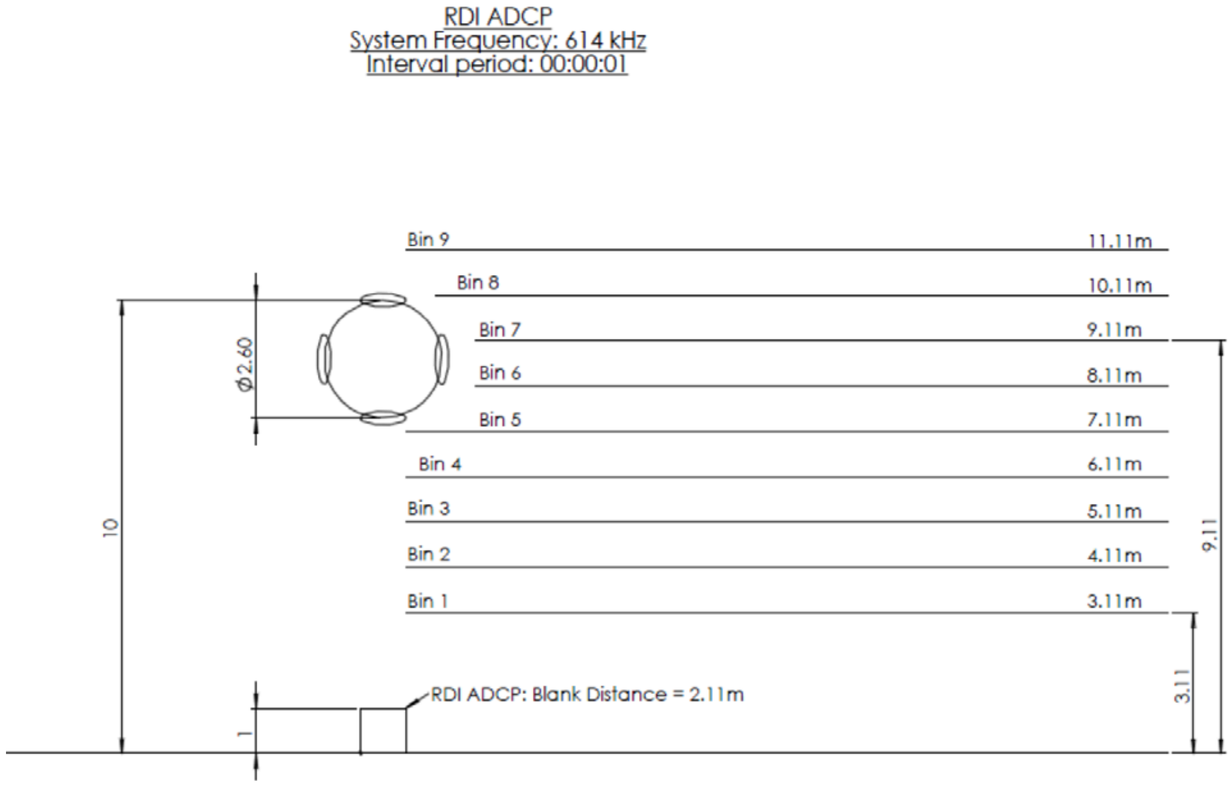


Figure 23. Bin spacing and blanking distances for TidGen® 001 North and South ADCP deployments

Installed orientation is ~ 102° true. Installed orientation of the TidGen® 001 TGU shows that the TEC is oriented with 9 degrees offset on the ebb tide and 7 degrees offset on the flood tide using data from the 14 day test period.

During the data collection period, peak water speeds ranged from about 1.3 m/s in the smallest tides, up to approximately 2.2 m/s in the largest tides. Power was generated down to a water speed of 0.7 m/s.

The IEC 114/93/DTS, *Power performance assessment of electricity producing tidal energy converters,* requires that the method of bins be used to produce a power curve for the device. Time duration for the bins is set due at 10 minutes and this has a noticeable effect on the presentation of flow data for this site. Averaging over a ten minute period removes all FSV data above 2 m/s. Data from both ADCPs are averaged for the following analyses.

The ten minute binning average results in the exclusion of flow speeds greater than 1.8m/s from the power performance curves. Figure 24 illustrates the effect that the 10 minute averaging period has on the logged flow data. The top graph shows raw ADCP data at 1 Hz showing flow speeds up to 2.3 m/s; however as the averaging periods get larger the peak flows decrease down to as low as 1.9 m/s.

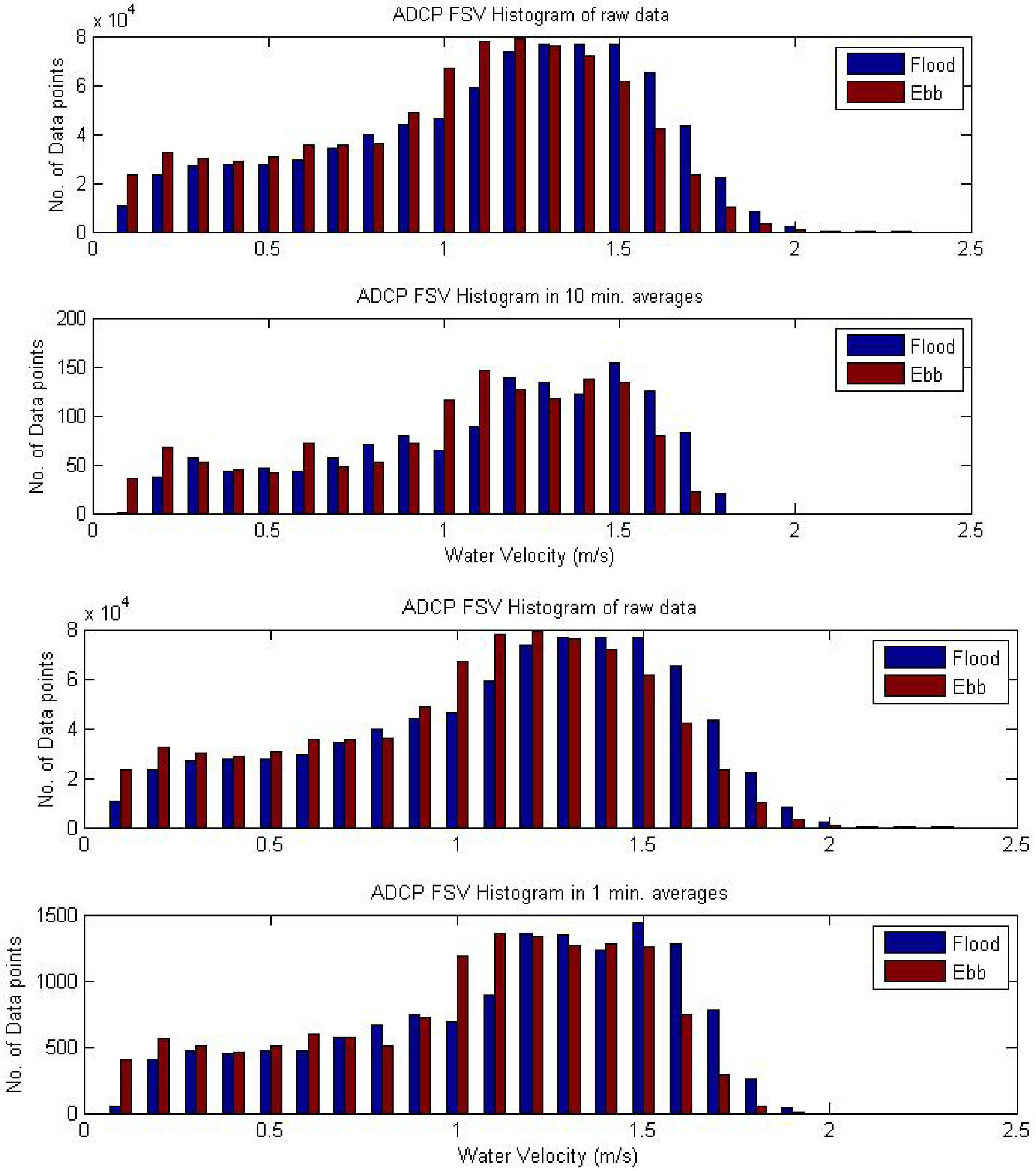


Figure 24. Water speed distribution (free stream velocity FSV) for a 10 minute binning period and for the raw 1Hz data.

The SCADA system logged power and other performance data from the TGU at intervals of 3 seconds. The deployed ADCPs had logging frequency of 1Hz and in bin heights of 1m.

TGU Performance

As per the IEC DTS/93/114, the power measured is that at the terminals of the TGU. To calculate TidGen® 001's power curve, the recorded power data at the shore was recorded and an estimate of the power loss in the subsea cable made and included in the TGU power. Line resistance to shore was measured at 0.4Ω and an I^2R losses were in turn calculated.

Cross Flow Turbine Performance

To make an estimate of the performance of the turbines alone it is necessary to account for power losses associated with the generator and its power control electronics, in addition to other losses in the driveline due to friction.

Water to Wire Performance

In addition to power losses associated with transmission from the TGU to shore there are additional power losses before power delivery to the utility grid. These are inverter inefficiencies and transformer inefficiencies.

Inverter efficiency is estimated at 95.5% at full load. Part load efficiency for the inverter will be lower than for full load but again estimates of part load efficiency are not available.

Transformer efficiency ranges from 85% to 98% depending on electrical load. For the purposes of this analysis the transformer efficiency is estimated at 93.5%.

Summary

Findings indicate that:

- Flow at the location for the TidGen® TGU is consistent with the pre-deployment ADCP studies.
- There is a variance in power density between the flood and ebb tides.
- There is measurable variance of power density across the TGU in an ebb tide.
- There is uniform power density across the TGU in a flood tide.
- The orientation of the TGU as installed is correct relative to the available resource.
- The placement of the Bottom Support Frame structure on the sea floor does not significantly affect flow at the turbine hub height.

Power curves were developed using the IEC DTS/93/114 method. Implementation of this method illustrates some concerns with the methodology:

- Binning in 10 minute averages removes the higher flow velocities from the analysis.
- Measurements of vertical shear velocity for a cross-flow turbine are not of great value as there are few bins in the vertical direction in the turbine energy extraction plane.

Operating History

The bottom support frame was fully installed with piles driven on April 8, 2013.

The TGU was deployed on August 14, 2012.

The TidGen® Power System was first connected to the grid on September 5, 2012 and was certified as grid connected by BHE on September 13, 2012.

Problems Encountered

During operation of the TidGen® TGU, several mechanical and electrical issues occurred which required retrieval and repair of the unit. Mechanical fasteners on some of the turbine components were observed to have vibrated loose. These required retightening. An electrical resistor in the generator controls failed and required replacement.

Departure from Planned Methodology

Several issues occurred during construction and operation of the TidGen® TGU which necessitated changes to the planned methodology. Retrievals of the TGU were required at more frequent intervals than planned.

Assessment of Impact on the Project Results

The issues encountered during operation of the initial unit had a profoundly negative impact on Project results. Because of the unplanned outages caused by the various issues, availability was less than planned due to these breakdowns. The significant cost increases incurred during operation and repair of the initial unit necessitated a reduction in number of additional units to be installed. And the sooner than expected retrieval of the TGU and extensive repairs needed for the generator and EC caused a significant loss of operating time. The total amount of time the unit was in operation during the Project was 734 hours.

Task 8: Retrieval & Maintenance

Subtask 8.1: First Retrieval

Original Hypotheses

The Project proposed that retrieval of the TGU for inspection and maintenance would be performed by reversing the installation sequence of operations. The locking connections will be undone by an ROV and the TGU will be lifted to the surface using a barge-mounted crane. In the event that the bottom support frame needs to be retrieved, this would be performed using barge-based heavy lift equipment.

It was assumed that the first retrieval would occur after three months of operation.

Approaches Used

The TidGen® 001 was retrieved sooner than expected because of mechanical issues identified during video inspection.

Electrical issues with the TGU electrical brake occurred upon reinstallation of the TGU. The unit was retrieved, repairs made, and then reinstalled on February 22, 2013.

Problems Encountered

The TGU was retrieved, mechanical repairs made and then reinstalled.

Departure from Planned Methodology

The locking connections were undone, however, by divers instead of an ROV.

Assessment of Impact on the Project Results

The TGU experienced sooner than expected retrieval and a loss of operating time. Due to this early retrieval, overall maintenance costs were more than expected.

Subtask 8.2: Second Retrieval

Original Hypotheses

The Project assumed that the second retrieval would occur after six months of operation.

Approaches Used

The TGU retrieval was successfully conducted in the presence of DOE HQ staff on July 15, 2013. The TGU was transported to shore, placed on blocking and lifted onto a trailer for transfer to the concrete blocking pads on July 16, 2013 (Figure 25).

Figure 25. Catamaran barge retrieval

Problems Encountered

There were no material issues encountered with the retrieval using the new catamaran system.

Departure from Planned Methodology

Due to the very high cost of the original plan for retrieval, a new system was designed, built and successfully implemented, resulting in a highly successful operation at a greatly reduced cost.

Assessment of Impact on the Project Results

The development of the new retrieval system improved the Project results by lowering costs and reducing the cost and risk of future retrievals.

Task 9: Evaluate & Report

As part of this Project, ORPC was to evaluate and report on various aspects of the technology, project development, installation, operation and maintenance, and costing. Power, energy generation and availability data are provided in prior sections.

This Final Report details the findings of the retrieval inspections and results of the analyses, including a list of TGU parts and components of concern, diagnoses of any issues and recommendations for improvements based on lessons learned, updated installation, retrieval, operation and maintenance procedures and a forecast power system operating longevity.

Capital Costs

The capital costs detailed in this Final Report Data record (Tab E4) cover this period and include installation and retrieval costs, compliance costs and other related costs for that timeframe. The amounts do not include indirect charges or management overhead charges.

Install and retrieval costs and methodologies

ORPC’s methodologies were based upon using equipment that would be readily available in most coastal areas. ORPC did not want to procure a purpose-built machine. Therefore, a barge and crane package was developed. This package was kept on site in Eastport through April 2013. At that point, ORPC developed a catamaran style barge for a final retrieval in July. The catamaran still falls into our original methodology of using equipment that would be available in most areas, as it only requires basic steel fabrication abilities to fabricate. Further information on these two methodologies can be found in the deployment / retrieval plans that are part of the data section of the report.

O&M costs

Operating costs detailed in the Final Report Data record (Tab E4) cover this period and include install and retrieval costs if applicable, compliance costs and other related costs for that timeframe. The amounts do not include indirect charges or management overhead charges.

Inspection upon retrieval process and findings

Upon retrieval of the TidGen® TGU, the system was subject to an inspection of the components of the TGU itself. Inspection of the bottom support frame, foundation piles and cable route continued on a regular basis.

Reports on the inspection processes and results are included as part of the data package provided to DOE.

Improved installation, retrieval, and O&M procedures based on lessons learned

Based on the experience gained during the multiple installation and retrieval operations for the TGU, the efficiency with which the general contractor and dive teams were able to accomplish their tasks greatly improved over the course of the project. During the initial scoping and design exercises for the deployment planning, all parties accepted that a high degree of conservatism should be built into the approach as this was the first of a kind project. As the project progressed and as a better understanding was obtained regarding all of the logistical factors involved, all parties realized that a more efficient and less costly approach to installation and retrieval was desirable. In general the costs of stationing a crane and a barge on-site full time were not supportable.

Two alternative approaches were selected and investigated further. The first approach examined was to retrieve the TGU using air bags as buoyancy components. This approach appears to have merits from a design perspective but divers and the general contractor were not supportive of this approach, primarily due to the perception that an uncontrolled ascent was a strong possibility. The second approach was to develop a catamaran lifting system which would replace the large barge and crane systems previously used. This catamaran was built using standard pin barges for the pontoons and a set of two winches for the load elements. The General Contractor practiced maneuvering the catamaran in various tidal conditions and developed sufficient handling experience so that the catamaran did not need to be moored during the final retrieval. This means of handling the TGU at sea will be utilized going forward on the TidGen® projects.

Additional changes to the Operations & Maintenance procedures occurred during the course of the project. Primarily these changes were related to cable inspection procedures and various other inspection items required by FERC as part of the license conditions. In consultation with the Adaptive Management Committee, changes in the frequency and scope of the inspections procedures were made based on lessons learned.

The initial operation of the Project in 2012 and 2013 provided an opportunity to collect and analyze environmental monitoring data throughout construction and during operation. Additionally, the Project provided insight and clarity regarding the logistical needs and challenges related to construction activities, operation and maintenance. This experience increased understanding regarding the appropriate level of environmental monitoring required. Therefore, ORPC recommended modifications to environmental monitoring based on the knowledge and experience gained including the frequency of benthic, sea and shorebird and scour monitoring surveys. These recommendations were approved by the Project's Adaptive Management Team and subsequently by FERC. FERC's Division of Dam Safety and Inspection also approved ORPC's recommendations for reduction in routine inspections and maintenance based on findings and lessons learned during these activities.

Forecast power system operating longevity

Given the difficulties found during operation of the TidGen® system, a forecast of the system operating longevity is difficult. However it is clear that some elements of the system are on their way to demonstrating their expected design life.

Shore station elements were fully functional and could achieve their design life of 15 years.

Subsea power and data cables were functional and could likely achieve their design life of 15 years in the absence of any dragging or cable damage incidents.

Foundation piles were stable and could likely achieve the design life of 15 years.

The bottom support frame was stable, functional and mechanically intact and could likely to meet its design life of 15 years.

The TGU/bottom support frame connections were fully functional and could meet their design life of 15 years.

The TGU Chassis was fully intact and could meet its design life of 15 years.

Driveline couplings were in excellent condition and could be expected to meet their design life of 15 years

Turbine bearings showed signs of wear as expected. These components could be expected to be able to achieve their design life of 2 years before requiring replacement. Bearing replacement is a planned O&M activity.

In summary, many of the subsystems were proven to be reliable, but failure in any one component could lead to system failure. Additional field testing of subcomponents and full systems is required to properly establish a mean time between failure for the entire system.

4. PRODUCTS

4.A. Publications

Publications

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Johnson, N. (2013, November). Risks, Impacts and the Role of Adaptive Management, Marine Renewables Canada Conference, Ottawa, Ontario, November 20, 2013.

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4.B. Web and Internet Sites

The following websites reflect the results of this project:

- ORPC's website: http://www.orpc.co/content.aspx?p=h3jCHHn6gcg%3d
- DOE, Office of Science, SBIR: http://science.energy.gov/sbir/highlights/2013/sbir-2013-01-e/
- Facebook: https://www.facebook.com/pages/Ocean-Renewable-Power-Co/207103839024

4.C. Networks and Collaborations

- OES Annex IV
- OES Annex V
- TC114
- Maine Tidal Power Initiative
- OREC
- Marine Renewables Canada
- E2 Tech Council
- New England Clean Energy Council

4.D. Technologies and Techniques

- ORPC has developed unique and highly effective expertise and methodologies in site assessment.

4.E. Inventions, Patent Applications, Licensing Agreements

Patent Applications

There were no new patent applications submitted under this award.

The following patent applications, filed prior to this Project, were granted:

- Submersible Turbine-Generator Unit for Ocean and Tidal Currents
    - USA (Application#11/975,581), 7,902,687, 08-Mar-2011

  - Australia, 2007309524, 30-Aug-2012
- High Efficiency Turbine and Method of Generating Power
  - New Zealand, 586210, 08-Oct-2012
  - USA (Application#11/985,971), 8,393,853,12-Mar-2013
- High Efficiency Turbine and Method of Making Same
  - USA (Application#11/985,972), 7,849,596, 14-Dec-2010
- High Efficiency Turbine and Method of Generating Power
  - USA (Application#12/414,279), 8,096,750, 17-Jan-2012

The trademark application for "TidGen," filed prior to this Project, was registered:

- USA (Application#77-837,882), 4,313,336, 02-Apr-2013

Licensing Agreements

- Federal Energy Regulatory Commission, Pilot Project License, P-12711
- Bangor Hydroelectric Company, Power Purchase Agreement
- 3Degrees Group, Inc., Renewable Energy Credits

4.F. Other Products

Educational Aids or Curricula

- Educational aid on hydrokinetic energy: *Finish Line: Grade 8 Reading for the Common Core State Standards*, Continental Press, 2011, 190-191.
- Elementary and Middle School Teaching Aid: ORPC PowerPoint presentation.
- ORPC videos on website: http://www.orpc.co/newsevents_mediacenter.aspx

6. Lessons Learned

The Project made history by being the first ocean energy project not involving a dam to deliver electricity to an electric utility power grid and obtaining a 20-year power purchase agreement anywhere in the Americas. The lessons learned in designing, building, installing, retrieving, maintaining and licensing this unique Project were numerous and extremely important for informing continued commercialization of the TidGen® Power System and for the entire MHK industry in the U.S. and abroad. For purposes of explanation, the primary lessons learned from the Project were organized by categories and described below.

Process

- Initial cost estimates were optimistic and based on limited details, and budget updates based on real time costs incurred were done too infrequently, resulting in cost overruns.
- Similar to cost estimates, initial schedules were optimistic and based on limited details, particularly with respect to methods to be used.
- Due to schedule issues, designs of some components were released for fabrication too early, resulting in design changes that led to additional costs.
- Due to mostly cost plus contracting, controlling costs of assembly, installation and retrieval were very difficult to control.
- Understanding and managing the FERC licensing process, the State of Maine permitting process and environmental monitoring requirements were essential.
- The practice of adaptive management in environmental monitoring worked well for ORPC, FERC and the participating resource agencies
- Restrictive dates for pile driving, which were imposed late in the licensing process, caused issues with scheduling.
- Planning, planning and planning, including contingency planning, was absolutely critical for success (it's not just a slogan.)

Permitting & Licensing

- Development of innovative methodologies and technologies to generate best available science is essential.
- An adaptive management process was a productive and positive procedure in managing the complexities of environmental monitoring.

Design and Engineering

- Designs relied heavily on components made of costly materials and/or costly fabrication requirements.
- The amount of engineering work required was underestimated resulting in inadequate engineering staffing at certain times during the project.
- Lack of clarity in design standards for the industry caused extra work in determining appropriate design standards to be used.
- Resource Assessment

  - The combined approach of ADCP deployment and circulation modeling was successful in locating areas of high resource and accurately assessing flow for an installed TGU

- Foundation Design
  - Design of foundations was more complex and costly than originally estimated
  - Foundations need to be finalized early in a project as changes will affect other components in the system and fundamentally affect installation approaches

- Turbine Design
  - Cross-flow turbine design is a complex multifaceted exercise which requires expertise in many areas of engineering design
  - Computational fluid dynamics tools are capable of predicting turbine performance with reasonable fidelity

- Generator & Controls Design
  - Direct drive permanent magnet generators are large and expensive for a low RPM application
  - Local rectification at the generator is feasible and provides a means of aggregating multiple TGU outputs onto a single cable
  - Grid connection using commercially off-the-shelf inverters is relatively straightforward for this application
  - Simple control schemes are robust, but do not provide maximum power point tracking capability. Heavily loading the generator can lead to multiple trips offline, reducing energy production

- TGU Chassis Design
  - Multiple structural codes are available to choose from for a subsea structure.

- Bottom Support Frame Design
  - Multiple structural codes are available to choose from for a subsea structure.

- TGU/BSF Connection
  - Simple bolting solutions between subsea components are effective, as long as the device is diver serviceable. The flexibility offered by human divers is difficult to emulate.

- Lifting & Handling
  - Lifting and Handling issues should be identified and addressed early in the design process

- Deployment & Retrieval

  - Deployment and retrieval operations accounted for a far larger fraction of the project costs than originally estimated. The large costs of having assets stationed on-site point out the need for an alternative to heavy lift barge and cranes as a means to deploy and service MHK devices.

  - The most significant lesson learned was the benefit of going from the full size barge and crane set-up to the much smaller and more cost effective catamaran barge. The procedures for both of these methods can be found in their respective plans in the data section of the report.

- Project Design
  - Many of the other elements of the project were designed, constructed and installed without issues. Burial of the transmission cable was not completed and resulted in additional costs associated with tending, monitoring and securing the cable.

Procurement and Fabrication

- Lack of clarity up-front regarding procurement responsibilities between ORPC and ORPC's General Contractor and other major vendors caused inefficiencies in the procurement process.
- Standard Operating Procedures were inadequate early in the Project. However, towards the end of the Project, ORPC instituted a much more adequate quality control process.
- Interface management issues between vendors caused some rework in the field.

Assembly

- Having an adequate on-shore facility in close proximity to the Project site for material receipt, storage, component assembly and quality control was essential.
- Having the appropriate consumables and supplies on hand needed for assembly work significantly reduced delays.

Installation, Operation, Monitoring, Retrieval and Maintenance/Repair

- Large assets such as cranes, barges and other vessels are expensive and make installation and retrieval costs infeasible.
- Divers are expensive and therefore every effort in the design phase must be taken to reduce their need.
- Weather delays are very real and uncontrollable.
- Safe operations on the water are the highest priority.
- Environmental monitoring associated with installation and operations are extensive and costly.
- The TidGen® Power System can, in fact, be easily operated and operational modes changed, even from a remote computer.

7. Plans to Address Lessons Learned

ORPC's plans to address the lessons learned on the Project are listed below in the same format as the listing of lessons learned.

Process

- ORPC significantly upgraded its capabilities and processes for developing and updating budgets and schedules, including major upgrades to back office functions to more adequately track, report and forecast costs on a frequent basis and more frequent management review of costs and schedule. ORPC will continually review these processes and procedures to look for and implement additional improvements.
- ORPC changed to a fixed price contracting policy for material, equipment and services that can reasonably be procured on a fixed price basis. The advantage of this approach was clearly demonstrated in the July retrieval of the TidGen® TGU which was done on a fixed price basis with our General Contractor at about one-third of the cost of the average retrieval cost for previous TGU retrievals.
- ORPC continued to manage and enhance its relationship with FERC and the various federal and state agencies and have set the industry standard for cooperation and streamlining through the Adaptive Management Team (AMT) for the Cobscook Bay project. ORPC was successful in obtaining approvals from the AMT for alternative methods and reduced frequency of environmental monitoring, significantly reducing the cost of monitoring not only for the Cobscook Bay project but also future projects.
- ORPC completed extensive planning for field activities for the Project and continued to improve and institutionalize the process of planning, planning and planning.
- Late in the Project and continuing into new projects being awarded to ORPC by DOE, communications between ORPC and DOE HQ had improved dramatically and projects are now reviewed on a regular and consistent basis.

Permitting & Licensing

- Continue best practices of Adaptive Management.

Design and Engineering

- As a priority in the redesign of the TidGen® Power System currently underway primarily through the new DOE projects, ORPC made cost reductions and improved reliability of the system a top priority.
- Significant progress was made in managing the estimating, budgeting and forecasting process which now allows ORPC to identify bottlenecks ahead of time so they can be avoided.
- ORPC will continue to refine its understanding of resource assessments.
- Design of foundations for MHK systems in more challenging environments was a focus area for ORPC. The company is building relationships around this area.
- ORPC continues to push towards higher fidelity CFD models of cross-flow turbines, in 2D and 3D. ORPC is engaged in multiple work scopes to improve our understanding of turbine performance.

- ORPC continues to actively participate in industry groups to develop and refine design standards and testing procedures for MHK devices and Projects.

Procurement and Fabrication

- ORPC upgraded its project controls as previously described, including a much more thorough scope definition up front, and is maximizing the use of fixed price contracts so responsibilities for procurement are now well defined.
- ORPC is in the process of instituting a more rigorous procurement process whereby materials, equipment, parts, etc. are fully specified prior to procurement and vendor QA monitoring is being improved with the goal of identifying and correcting QA and interface issues before they become field problems.

Assembly

- ORPC continues to refine and improve the on-shore facilities needed not only to assemble and install equipment, but also for operations, maintenance, spare parts and consumables storage, etc.

Installation, Operation, Monitoring, Retrieval and Maintenance/Repair

- In conjunction with the General Contractor, ORPC completely redesigned the retrieval and deployment system eliminating the need for large assets such as cranes and barges and significantly reducing costs.
- To the extent possible, diver time is being minimized in the TidGen® re-design.
- Safety remains a top priority of ORPC and is instilled in the company's culture.
- Through the re-design effort, and a major focus of the new DOE projects, the weakest links are being eliminated through significant design changes.
- As described in the fourth bullet under Process, environmental constraints are being lessened or eliminated and monitoring requirements are being reduced.
- Remote operation of TidGen® remains a high priority for ORPC.

Cost Reduction Opportunities

ORPC identified multiple opportunities to reduce cost for a TidGen® system and for associated permitting, licensing, installation and operations and maintenance costs. An outline of some of these costs reductions is given below.

- Reduced compliance and permitting costs.
    - ORPC is already experiencing some of these cost reductions in its efforts to obtain a FERC license for its Western Passage site.