PUBLIC TECHNICAL REPORT
BUDGET PERIOD 1 ADVANCED TIDGEN® POWER SYSTEM
DE:EE0007820

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1 Purpose

This document presents the technical progress made during Budget Period 1 (BP1) by ORPC and its partners for the Advanced TidGen® Power System Project, DE- EE0007820. The document presents a non-confidential version of the Continuation Application that was submitted to demonstrate that ORPC has met the criteria for approval to begin Budget Period 2 (BP2), as defined by the U.S. Department of Energy (DOE):

- Progress toward achieving the goals as stated including the Metric Table (Table 1) in the project's Statement of Project Objectives (SOPO), currently at MOD 0004
- Completeness in meeting BP1 milestones and deliverables
- Status of any critical NEPA compliance/holds/permits for BP2 activities
- Adequate recognition, classification, and mitigation of risk as demonstrated through an updated risk register
- Reasonableness and justification of ability to meet scope, budget and schedule of future budget periods

1.1 Project Objectives

The following are the major Project objectives, to be achieved through three Budget Periods: to design the Advanced TidGen® 2.0 Power System, perform subsystem and system verification testing in Cobscook Bay, Maine, and install and operate the device in Western Passage, Maine, for a 12-month validation period.

1. **Produce a full-scale design** integrating targeted advanced technologies optimized for subsea operation with improved performance achieved by the addition of fairings and optimized turbine hydrodynamics
2. **Increase reliability of the structures** and reduce production cost, through a composites optimization and accelerated life test program for materials, joint design and structures that balances hydrodynamic gains with fatigue performance, to achieve a service life of 20 years
3. **Implement ORPC's Buoyant Tension Mooring System (BTMS)** for commercial sites. The ease of deployment and retrieval of the prototype system will significantly reduce O&M costs over the TidGen® baseline.
4. **Implement ORPC's advanced control strategy** at full scale to achieve sustained maximum power output at all times in a tidal site
5. **Follow a certification protocol** for the Advanced TidGen® Power System. This process will qualify the advanced system at TRL 8 at project end.
6. **Verify system design by subsystem tests and a two-month integrated, system deployment** in Cobscook Bay, validating performance gains and verifying functionality in low velocity.
7. **Validate the commercial design by a 12-month test in Western Passage**, Maine, verifying system performance and LCOE reduction in high velocity
8. **Implement focused environmental monitoring** for the determination of realistic and quantifiable risk thresholds

With the conclusion of BP1, ORPC will have completed the first phase of the project. The project is on target to meet all the project objectives:

- ORPC has completed the engineering design of the TidGen® 2.0 system, which incorporates all targeted technology integration, including turbine hydrodynamic improvements with integrated fairings, the adapted BTMS, advanced control system for maximum power output in turbulent conditions in a tidal site, and reliability improvements to the power take-off system.
- The composite optimization program has made significant strides towards characterizing critical failure mechanisms in subsea composite operation, developing an NDI technique capable of fully mapping manufacturing defects throughout the laminate structure in turbine foils, and determining an accelerated life testing strategy to compare two resin systems towards achieving a component life greater than 20 years.
- ORPC has worked with DNV GL to meet all requirements for achieving a Statement of Feasibility for Technology Qualification, expected to be received by end of BP1, and for having passed the Design Basis Review, the first two steps towards prototype certification.
- University of Maine (Z) and ORPC have worked with the Adaptive Management Team to identify cost effective monitoring strategies and a quantitative method to baseline and describe the potential impact on relevant fish and mammal behavior.
- As of the Critical Design Review, ORPC's LCOE predictions for the Advanced TidGen® Power System are $0.72/kWh, showing significant progress from the LCOE baseline ($13.58/kWh) and bettering the project target of $0.80/kWh (Figures 1 &2).

In February 2018, the SOPO was formally modified to MOD 0004 as a no-cost-time-extension that reflects a risk-mitigation approach to subsystem and system testing. The current schedule has BP1 from November 2017 through June 2018; BP2 from July 2018 to August 2020; BP3 from September 2020 to December 2021. This document refines all milestone and deliverable dates to match the approved timeline, with the only exception being a one-month longer duration for BP2 and a subsequent shift of BP3 start and end dates. This is detailed later in this document.

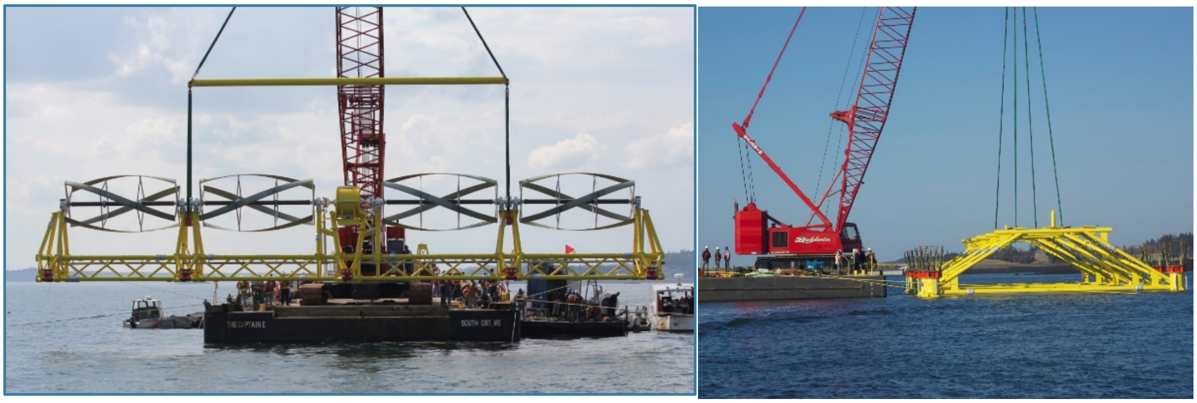


Figure 1. Baseline TidGen® 1.0 (left), deployed over a several weeks period in 2012 with a piled bottom support frame (right). The device produced nearly 85 kW of on-device power at a rated flow speed of 2.25 m/s and had a normalized LCOE of $13.58 kW/h for the DOE reference site distribution at Admiralty Inlet (186,000 MWh array).

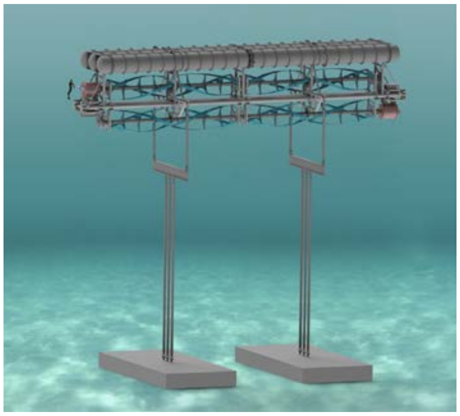


Figure 2. Advanced TidGen® 2.0 Power System as of the Critical Design Review in December 2017. The system is 34.6 m x 8.2 m x 6.4 m with an on-device output of 250 kW at a rated flow speed of 2.25 m/s. It can be deployed within a tidal cycle. The projected LCOE of $0.72/kWh meets the project target of $0.80/kWh.

1.2 Completed Project Metrics Table

Table 1. Metrics Table. Values are based on a DOE reference site distribution in Puget Sound for an array producing a plant AEP of 136,000 MWh. Quantities in this table are defined in the MHK cost and performance template, which is included in the award package.

Single Device Performance Parameters				
	Baseline System	Targeted System	Improved System	Units
Rated Capacity	0.15	0.3	0.5	MW
Availability	79.0%	92.0%	92.0%	
Transmission Losses	14%	11%	11%	
Theoretical AEP	209	592	633	MWh/year
AEP	142	487	520	MWh/year
Capacity Factor	11%	19%	12%	
Average Electrical Power	0.016	0.056	0.059	MW
Array Performance Parameters				
	Baseline System	Improved System	Improved System	Units
Number of Devices	998	288	269	
Array Efficiency	96%	97%	97%	
Array Rated Capacity	149.7	86.4	134.5	MW
Array AEP	1.36E+05	1.36E+05	1.36E+05	MWh/year
Array Capacity Factor	10%	18%	12%	
Cost Parameters (from Cost Breakdown Structure)				
	Baseline System	Improved System	Improved System	Unit
Single Device CAPEX	11,468,676	9,866,432	9,469,850	$
Single Device OPEX	2,896,809	93,917	148,422	$/year
Array CAPEX	4,217,235,234	758,670,777	567,014,916	$
Array OPEX	1,373,953,424	27,047,966	39,959,207	$/year
LCOE Calculations				
	Baseline System	Improved System	Improved System	Unit
Single Device LCOE	29192.46	2381.34	2250.12	$/MWh
Array LCOE	13479.10	801.22	742.37	$/MWh

1.3 Milestones Status

Table 2. BP1 Design Milestones

#	**Milestone**	**Milestone Status**
1.1	Preliminary hydrodynamic design completed, with CFD models achieving 35% relative increase over baseline turbine performance.	*Completed and meets requirement.* Hydrodynamic efficiency of the new turbine is a 29% efficiency improvement, with a power production increase at rated velocity (2.25 m/s) from a baseline near 85 kW to 250 kW, an improvement of more than 294%.
2.1	Characterization testing of composite material sets completed, with selected composite structure delivering > 20 component life.	*Completed and meets requirement.* Optimization program is on track with material sets selected for turbine design. Have determined a critical failure mode of resin-carbon fiber disbondment. Have developed NDI technique capable of fully mapping manufacturing defects throughout the laminate structure in turbine foils. turbine inspections.
3.1	Mooring system and anchor design completed, with models demonstrating achievement of performance criteria identified during the design process, including stability during installation, operations and retrieval, mitigation strategies covering critical risks such as wave loading, debris, and cable loading and dynamics.	*Completed and meets requirement.* Mooring system and anchor design completed, , supporting analytical models, and subsystem FMEA.
4.1	Preliminary control system and SCADA design for tidal system operation completed, with control system models supporting capability to maintain maximum power point operation through tidal and turbulence ranges.	*Completed and meets requirement.* Control and SCADA system designed with advanced control system.
6.1	DNV-GL will have completed a Design Basis Review of the system design per requirements outlined in standards DNVGL-SE-0163 and DNVGL-ST-0164 toward Prototype Certification.	*Partially Completed, on track to meet requirement by end of BP1.* ORPC has completed the Design Basis Review with the DNV GL (activity 2.4), which is done in parallel with the Technology Qualification (activity 2.3). ORPC received DNV GL letter stating that we are on track to complete Technology Qualification to receive the Statement of Feasibility.

2 Preliminary IO&M, Testing, and Fabrication Plans

2.1 IO&M

In 2012, the first TidGen® device was installed in Cobscook Bay utilizing a piled foundation, which required extensive, costly geotechnical survey and on-water effort on the order of several weeks to install the system (Figure 1). The Advanced TidGen® 2.0 Power System has adapted the Buoyant Tensioned Mooring System (BTMS) that reduces on-water deployment time to within a tidal cycle (Figure 2). The device has been designed to match the resources typically available in remote regions, such as Igiugig, Alaska, which are the immediate commercial market for ORPC's technology.

The system has been designed to meet requirements throughout the entire lifecycle concept of operations, detailed in Table 3.

Table 3. TidGen 2.0 Concept of Operations Overview

#	ConOps Phase	High Level Description
1	Component Fabrication, QA/QC, Shipping	Project development and site characterization, project specific design modifications, component fabrication and verification, subsystem validation (including system alignment), system shipping.
2	Subsystem Integration & Land Based Testing	On-site system receiving, assembly, and final pre-installation system validation tests. Modular shipping components can be lifted with standard lifting equipment and integrated using specialized assembly jig.
3	Deployment	Mooring system installation using specialized deployment barge. P&D cable installation. Transition of device from the staging location to water. Device towing and connection to mooring system.
4	Commissioning	Initial system start-up, operational checks, completion of training for local personnel, and system hand-off.
5	Normal (Deployed) Operations	In water operations and power production, monitoring, and data collection.
6	Annual (routine) Maintenance	Routine in-situ inspections of the device and mooring system using submersible inspection equipment.
7	5 yr (routine) Maintenance	Device removal to laydown area using specialized deployment barge system. On land device inspections and component replacement. Re-deployment following initial deployment procedures.
8	Unplanned Shutdown/ Maintenance	This mode includes troubleshooting for any unexpected operational conditions as well as possible device retrieval and repairs.
9	Decommissioning/ Removal	Following the completion of the project life, this step includes device retrieval, device removal, and the removal of P&D cables and the mooring system. This step represents the completion of on-water operations.
10	Disassembly & Disposal	This step includes on-site disassembly, component shipping out of the project location, and disposal/reconditioning of all Sub-Systems and components.

The strategy for onsite build and installation is as follows:

- The TGU device will be fully assembled, aligned and tested in a manufacturing facility.
- The device will be disassembled into modular sections suitable for transportation using commonly used shipping containers or standard flatbed trailers. Modular sections will maintain turbine, drivetrain, generator and chassis alignment in such a manner to minimize onsite reassembly resource and labor requirements.

- Onsite assembly of the device will utilize equipment typically available in remote regions. ORPC has assumed equipment is limited to a 20t crane, CAT 966 loader, CAT 330 excavator or equivalent, with sections limited to 10,000 kg based on preliminary discussions with a shipper in northern Quebec regarding likely available equipment for shipping and transportation.
- Onsite assembly and maintenance of the device will not require technically skilled labor, and maintenance strategies will be limited to inspections and unit replacements.
- Onsite marine vessel power limit, for tug of system and anchors to deployment site, is equal to 250 Hp (total net power).

For the launch and deployment of the power system, the anchors will be built nearshore by either pumping a slurry into a containment structure and frame, or by dropping smaller modular concrete or iron slurry into the frame. The TGU will be launched on roller bags, similar to what is done in the shipping industry, on top of its assembly frame. The TGU will be oriented for assembly with divers to the mooring system, with the aid of the deployment rig, mirroring the operations performed for the OCGen® mooring project in 2014.

A major goal of BP2 will be to de-risk these operations during deployment subsystem testing and then the system verification installation in Cobscook Bay, which is a low-energy resource site. ORPC will verify tooling and validate supply chain, assembly, operations and maintenance procedures.

2.2 Development Test Plan

BP2 will entail subsystem testing focused on refining design models and risk mitigation, ending with a full system verification installation in Cobscook Bay. The test program will be based on a sequential approach that addresses conservative design factors based on DNV GL standards to reduce likely overdesign in the system.

In 2018, efforts will primarily focus on composite development and production of the first turbine assembly, targeting barge testing for performance and drag loads. Composite analysis will refine characterization models for the selected material sets and begin an accelerated life testing program focused on high stress areas of the turbines. Loading results from turbine testing will inform cumulative damage models to quantify anticipated component life of the composite turbines. Results will also hone-in our assumptions to reduce both structure and weight, particularly for anchor requirements. Post-test inspection data will be compared to characterization testing results prior to production of the full system set of turbines.

Primary activities in 2019 will focus on model-scale anchor evaluation in Western Passage and deployment system testing. Anchor holding efficiency estimates will be derived from the model-scale testing, which will be used as well to reduce conservative design assumptions and overall anchor weight. The results will inform full-system anchor design as well as the test mooring requirements for the deployment system testing. The deployment system testing will target critical operational risks, such as near-shore anchor construction, connections between the mooring system and TidGen® turbine generator unit (TGU) – the device without the mooring system and electrical transmission infrastructure). In terms of operational safety and risks, testing priorities are development and verification of assembly, launch and deployment procedures.

DNV GL will be utilizing testing activities and full system integration to complete several steps in the certification process, including final design assessments, manufacturing and transportation assessments, and full system test plan certification.

The following overviews development test activities for the DOE Advanced TidGen® Project.

2.2.1 Turbine load / performance testing

- **Components under test:** Turbine and fairing structure. The turbine will be the first build of the TidGen® 2.0 turbine.
- **Description:** This test includes a single full-sized turbine mounted in a controlled environment (on a test barge) to measure single turbine loads. The test barge will be subject to a range of inflow velocities which will also be measured. The test set-up is similar to previous ORPC tests with load cells added to a holding frame as the primary measurement instruments. (Figure 3.)
- **Objectives:** A performance curve will be generated and drag loads will be measured to reduce conservative design assumptions primarily for the mooring system requirements, especially for anchor holding capacity. CFD models will be refined. As part of the composite development effort, the turbine will be inspected before and after operation to assess any degradation of the composite structure, particularly for the impact of manufacturing defects under operational loading.
- **Key risks:** Integrity and performance of first composite turbine build; sensor/instrumentation package for load measurements.
- **Schedule:** Testing is targeted for Q4 2018 through Q1 2019.
- **Facilities, equipment & resources:** Barge testing will occur off the coast of Maine, in either Cobscook Bay or Castine, Maine. Equipment includes a test barge used by ORPC in prior projects for similar test purposes and power electronics / load for controlling the generator torque and dissipating power.

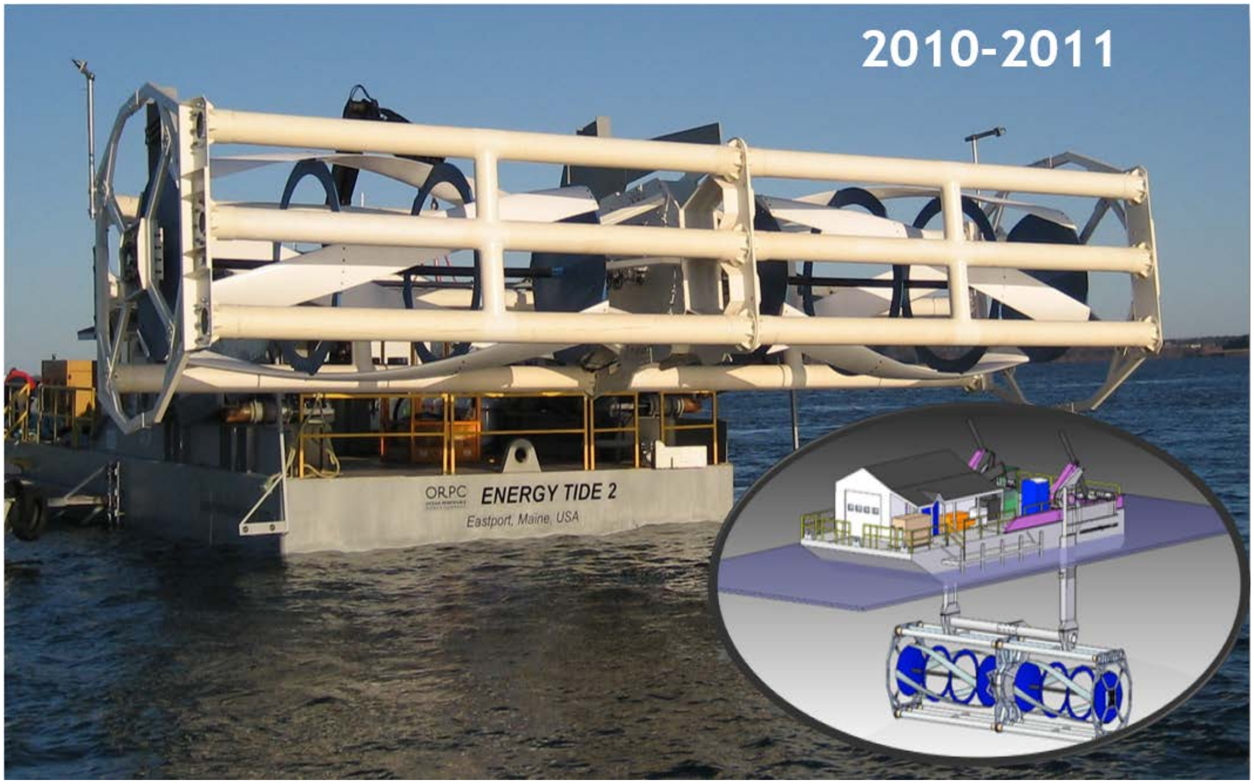


Figure 3. The turbine performance testing of the Advanced TidGen® turbines will be performed in a barge tow test similar to several tests performed by ORPC on earlier turbine designs.

2.2.2 Anchor-holding capacity validation

- **Components under test:** Model-scale gravity anchors.
- **Description:** Pull tests on scaled anchors (1 metric ton) at the deployment site will measure frictional forces between gravity anchors and bottom. Skirts and other potential modifications will be assessed. Several "pulls" will be performed around the deployment area. Primary measurements will be anchor position and applied mooring line loads. (Figure 4.)
- **Objectives:** Anchor efficiency measurements will be used to reduce conservative design assumptions. The effect of skirts or other modifications will be assessed for effectiveness. The results will inform final anchor design, as well as the deployment subsystem testing to occur later in the year.
- **Key risks:** Bottom profile/interface uncertainty; sensor/instrumentation package for load measurements.
- **Schedule:** Testing is targeted Q1 to Q2 2019.
- **Facilities, equipment and resources:** Testing will occur at the deployment site area identified in Western Passage, off the coast of Eastport, Maine. Equipment includes a test barge and/or large boat with a crane capable of managing metric ton anchors.

Figure 4. Anchor pull testing will be performed off a boat capable of deploying a 1 metric ton anchor, with instrumentation capable of determining pull loads for holding capacity estimates.

2.2.3 System deployment and retrieval testing

- **Components under test:** Subsystem testing of buoyancy pod, bridle interface with mooring system, mooring system and anchor.
- **Description:** The testing will assess and verify the deployment and mooring system design including critical operations from onsite assembly, near shore assembly, transit, and deployment offshore. A section of the buoyancy pod will utilize the bridle and mooring system rigging to smaller scale anchors. The test well replicate ORPC's prior deployment of the 2014 OCGen® buoyant tensioned mooring system project sponsored by the U.S. Dept. of Energy. A deployment rig with external equipment, such as winches and float bags, will be assessed for safety and functionality, as well as the connecting and detachment of anchors in critical operations during deployment and retrieval. The system will be moored over a short duration to verify dynamic stability and predicted movements of the system throughout a tidal cycle.
- **Objectives:** The test will verify the bridle and mooring system interface design, and of attachment and detachment methods. Critical operations will be verified for anchor deployment, system launch, and on-water operations of external equipment. Tooling requirements for full system deployment will be finalized.
- **Key risks:** New component interfaces, offshore attachment/detachment operations, bridle functionality throughout tidal cycle, test anchor holding capacity.
- **Schedule:** Testing will be performed in Q3 2019.
- **Facilities, equipment, and resources:** The test will require a deployment site with launch ramp and required crane for test system assembly and launch, either in Cobscook Bay or Western Passage. A tug and barge outfitted with winches will be used for transit and offshore deployment and retrieval.

2.2.4 Composite structural testing and accelerated life testing

- **Components under test:** Composite coupons of candidate material sets, critical high stress structural sections of the turbine (foil/strut joint)
- **Description:** Static and dynamic (fatigue) testing will be performed on carbon fiber/glass fiber epoxy laminates, for further characterization of failure mechanisms of saturated composites

under representative loading. Water uptake and diffusion rates will be analyzed. The impact of typical manufacturing defects on material degradation will be characterized, particularly with respect to water uptake, stress concentrations and static and dynamic failure. A second phase of testing will be an extensive accelerated life program for the finalized turbine composites towards development of component life models, to be performed in parallel with on-water system installations. (Figure 5).

- **Objectives:** Testing will inform final composite designs of the second through eighth TidGen® turbines, along with inspection of the first turbine after its performance testing. Cumulative damage models will be developed, for utilization and validation for eventual full-system deployments.
- **Key risks:** Durability of composite material sets determined from accelerated life testing; inadequate manufacturing quality or process control methods; inability to get statistically significant results
- **Schedule:** Testing will occur over an extended duration, from Q3 2018 through Q2 2020.
- **Facilities, equipment and resources:** Coupons will be produced by the turbine manufacturer and tested at laboratory facilities at CERL (Composites Engineering Research Laboratory) and Montana State University.

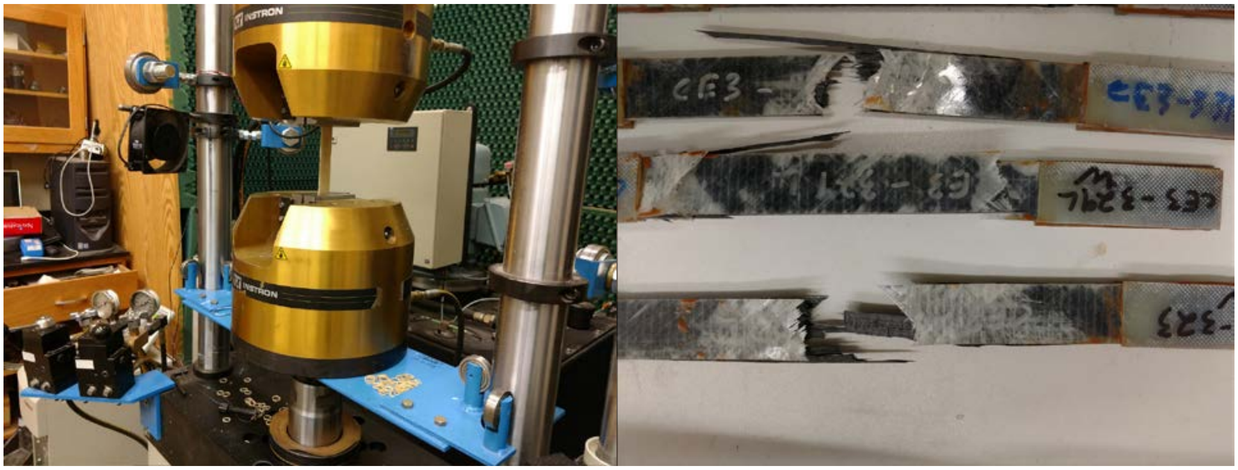


Figure 5. Coupon testing performed at Montana State University in BP1. Static and dynamic (fatigue) tension testing were performed as a preliminary evaluation of composite material sets in both dry and saturated (aged) states. Efforts in BP2 will focus on two material sets for comprehensive characterization of failure in accelerated life testing.

2.2.5 Composite turbine joint testing

- **Components under test:** Candidate joint geometries of foil to strut connection
- **Description:** Structural testing will be performed prior to and during the first turbine build to evaluate structural integrity and fatigue performance.
- **Objectives:** Determine the best joint geometry in terms of durability for the composite turbine from a selection determined by ORPC and the manufacturer.
- **Key risks:** Primary risks are schedule and manufacturer’s resources to perform sufficient testing for evaluation prior to the first turbine build; results of test may require an additional turbine to be built to replace the first one for the final system integration.
- **Schedule:** Q3 through Q4 2018

- **Facilities, equipment and resources:** Testing will be performed either at the manufacturer's facility.

2.2.6 Testing in BP3

After the development testing in BP2, ORPC will refine the system design. Full system procurement and integration will take place in BP3. The full TidGen® system will first be deployed in Cobscook Bay, a lower flow resource, where ORPC had previously deployed its first-generation system in 2013. The system will be verified throughout the concept of operations, from supply chain through onsite assembly, deployment, operations and retrieval. The mooring system will be adapted for Cobscook Bay's shallower depths and seabed type. Following the verification testing, the system may be modified to address any functionality and/or reliability issues. Then the mooring system will be reconfigured for the full system 12-month validation installation in Western Passage. The Cobscook Bay deployment will occur in Q3 2020. The Western Passage deployment will occur from Q2 2021 through Q2 2022.

2.3 System Fabrication Plan

ORPC will contract with suppliers in BP2 to fabricate components, supply components and subassemblies, integrate and the TidGen® system. In early BP2, ORPC will bid out the supply chain activity. A marine contractor will final assemble the system and perform shakedown verification testing at an indoor facility in Maine. The same contractor will breakdown, transport, and onsite assemble the system in Eastport, Maine. The contractor will then launch and deploy the system for both Cobscook Bay and Western Passage installations. All work will be done with ORPC oversight.

Prior supply chain activity, at the component and subsystem level, will be contracted out separately by ORPC or subcontracted out by the marine contractor. Turbines, generators, and commercial-off-the-shelf (COTS) equipment will be shipped to the final assembly facility for final integration.

Figure 6 overviews the build of the system in relation to testing and task number, through the end of subsystem development testing. Figure 7 continues with system verification testing to be performed in Cobscook Bay. Figure 8 continues through the Western Passage validation testing.

In BP2:

- The first turbine will be constructed in 2018 as part of Task 9 in parallel with further composite testing, per Task 8, for refinement of failure mechanism characterization and life estimates. ORPC has engaged several potential turbine manufacturers, to be decided on by the end of BP1. Performance testing of the first turbine will yield more accurate loading estimates for reduction of overdesign, as well as provide via inspection additional information for composite characterization. These will inform design and manufacturing process modifications, and production of the second through eighth turbines will take place in 2019 by the same turbine manufacturer.
- Anchor model-scale testing will occur in early 2019, with results informing final anchor design. Deployment system testing will occur in summer of 2019; ORPC will target reuse of any purchased auxiliary equipment required for deployment and, to the extent possible, components of the test rig for later system installations.
- Environmental monitoring equipment will have been purchased and developed through prior survey activity conducted throughout BP2. The equipment is external to the device and will be

deployed for monitoring during the deployment subsystem testing, and later during the Cobscook Bay deployment.

In BP3:

- The Cobscook Bay system installation occurs in early 2020, as part of Task 15. The entire system must be purchased and integrated for this test.
- Western Passage site will also be prepped prior to BP3 activity, including the power and data cable installation as part of Task 16. The onshore substation will be transported and installed at the WP site.
- Also, in Task 16, the mooring chains will be replaced, and the system reconfigured for the deeper site at Western Passage.
- Environmental monitoring equipment will be transported and redeployed for the system validation testing in Western Passage.

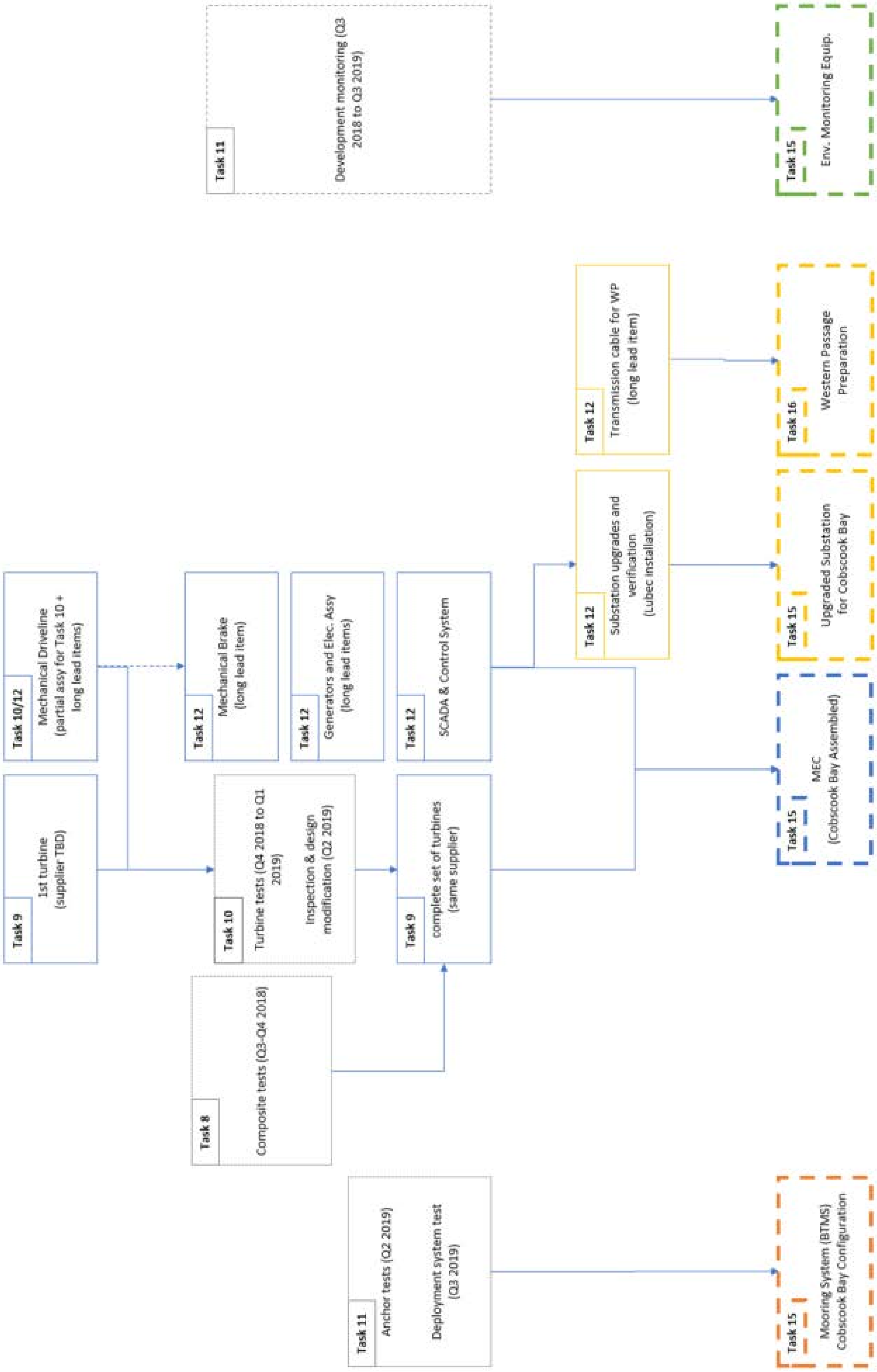


Figure 6. System fabrication plan for the Advanced TidGen® through completion of subsystem testing (dashed lines indicate BP3 Task 15 for the subsequent Cobscook Bay deployment).

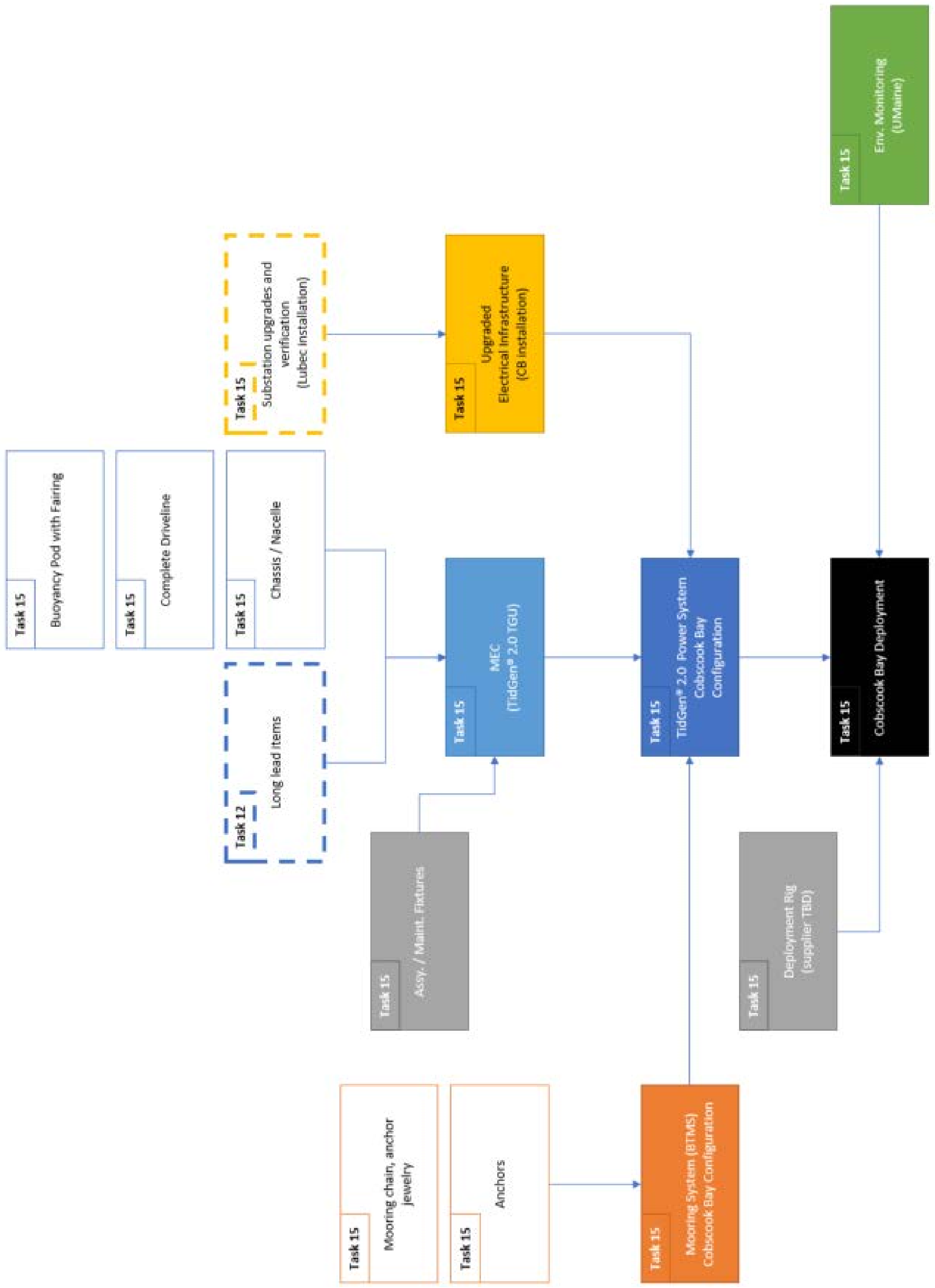


Figure 7. System fabrication plan for the Advanced TidGen® from subsystem testing through the Cobscook Bay deployment.

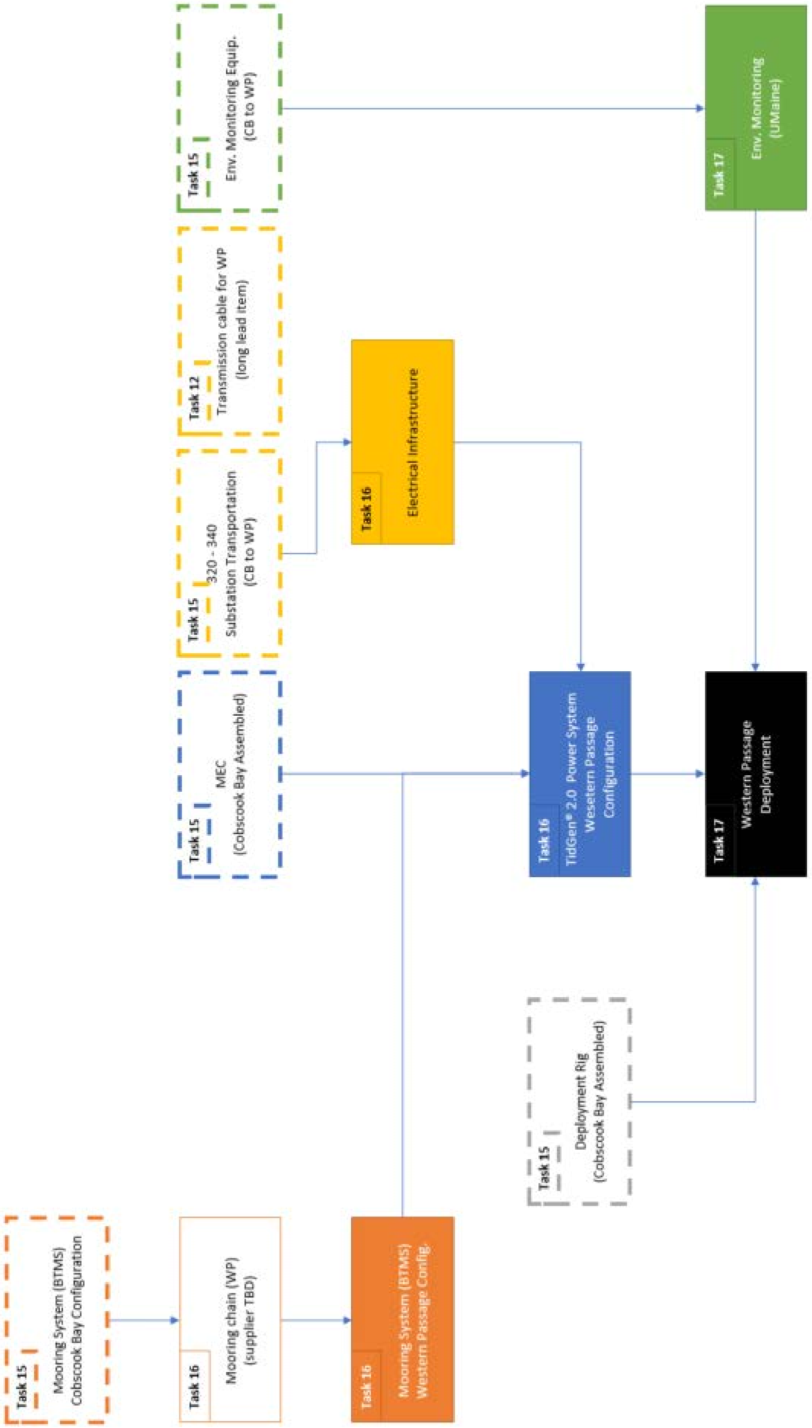


Figure 8. System fabrication plan for the Advanced TidGen® after the Cobscook Bay verification deployment through the Western Passage validation installation.

3 Description of advanced technology and final system design

3.1 Turbine, Task 1 Advanced Hydrodynamic Design

For a more complete detail analysis of the turbine design, refer to deliverable D1.2: *Technical report with final design, supporting CFD analysis, structural analysis, and development plan* of the Advanced TidGen Power System project.

3.1.1 Final Design Overview

Upon completion of budget period one for Task 1 of the Advanced TidGen Power System project, a final turbine design was produced. The first build will consist of building one turbine for evaluation followed by a second build of the remaining seven turbines.

This CDR turbine design was produced with project contractor, Blusource Energy Inc., whom ORPC relied on for some design decisions. These decisions included making the foil half the length of the turbine and adding a flange to the ends of each foil section, so the foils could be bolted axially to the struts. The foil section center joint consists of a bolted saddle which clamps the foils to the struts. The turbine is connected to the shaft by means of a bolted flange that is welded to the shaft. Doubler plates are utilized for this joint.

3.1.2 Supporting CFD Analysis

During the design phase of the turbine development for Task 1 many 2D computation fluid dynamic (CFD) analysis were carried out. Once the turbine was defined during the Critical Design Review (CDR) a final 2D CFD analysis including a buoyancy pod, a representative center nacelle and two counter rotating turbines was conducted.

ORPC have developed a post processing tool (LExCoSS) to convert 2D CFD into quasi 3D data by extrapolating the 2D loads along the span and helical twist. This process has proven valuable as full 3D CFD analysis is computationally intensive, costly and time consuming.

Raw 2D data gave a high max Cp because no losses were accounted for. Post-processing with LExCoSS dropped the max Cp to an average that was relatively 29 percent better than baseline performance, which is a reasonable estimate of the final turbine performance given the advanced design features.

3.1.3 Development Plan

ORPC have engaged manufacturers to quote the turbine build aspect of this project and have received feedback on the manufacturability of the CDR turbine design. Two key areas are targeted for design refinement based on manufacturers input. Firstly, the foil/strut joint design.

The joint to connect the foil to the strut has been designed with a bolted saddle connection. It is understood that this design is not hydrodynamically efficient and the manufacturers have suggested potential structural improvements that also promise better hydrodynamics.

Secondly, the cost of incorporating varying geometry of the foil profile is less than previously anticipated so we can use this to increase the hydrodynamic performance of a turbine. Spanwise variations can take advantage of varying lift and drag predictions, and thicker sections can strategically relieve high strain areas.

Along with turbine design refinement, ORPC also intends to perform barge testing of a single turbine for many reasons.

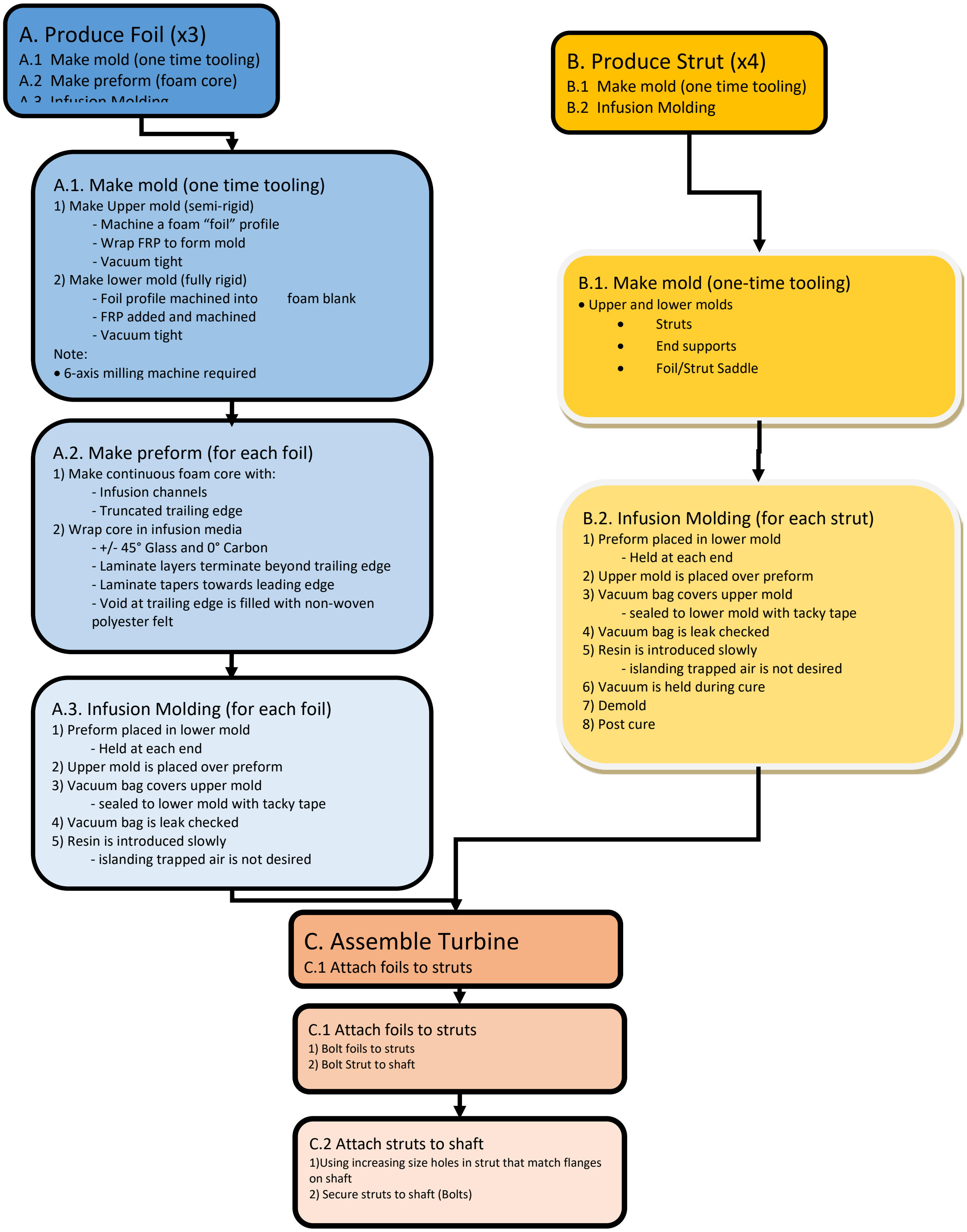
1) Hydrodynamic performance predictions.
   ORPC is aware that CFD analysis are not validated with performance measurements so it is important to characterize the turbine performance with a subsystem test of a single turbine. This testing will give a realistic Cp - TSR curve that can be used to accurately calculate Annual Energy Production (AEP) and Levelized Cost of Energy (LCOE).
2) Turbine Load Predictions.
   To-date all the loads applied to the turbines are calculated with 2D CFD and are anticipated to be conservative. For this reason, ORPC intend to measure the turbine loads and use that information to refine the affected components of the system, namely the mooring system. The Advanced TidGen Power System uses a buoyant tension mooring system with large gravity anchors which prove to be a challenging engineering problem. The updated turbine loads will allow ORPC to design an appropriately sized anchor and buoyancy pod reducing cost and deployment difficulty.
3) Turbine Durability. As part of BP2, ORPC will work with CERL and the turbine manufacturer for preliminary structural testing of the turbine joints, and more complete evaluation during accelerated life testing as part of Task 8.

3.2 Turbine, Task 2 Composite Optimization for Durability

ORPC worked with three partners, CERL, MSU and BluSource Energy, to develop the turbines for the Advanced TidGen® system. This work was done in parallel with the effort in Task 1, and as stated above, ORPC has engaged potential manufacturers for design refinement towards cost reduction and better structural performance based on improved manufacturing quality and joint strength.

The following overviews the composite design as produced for the Critical Design Review (CDR). The composite layup was designed by Blusource Energy, Inc. and consists of +/- 45 E-Glass interlayered with two layers of unidirectional carbon fiber. The biaxial E-glass transmits shear loads on the foil while the unidirectional carbon adds stiffness to limit deflections and strains.

Production of the turbine will incorporate process control measures developed as part of Task 2. Figure 9 illustrates the fabrication process for the composite turbine.



A. Produce Foil (x3)
A.1 Make mold (one time tooling)
A.2 Make preform (foam core)
A.3 Infusion Molding

A.1. Make mold (one time tooling)
1) Make Upper mold (semi-rigid)
  - Machine a foam “foil” profile
  - Wrap FRP to form mold
  - Vacuum tight
2) Make lower mold (fully rigid)
  - Foil profile machined into foam blank
  - FRP added and machined
  - Vacuum tight
Note:
- 6-axis milling machine required

A.2. Make preform (for each foil)
1) Make continuous foam core with:
  - Infusion channels
  - Truncated trailing edge
2) Wrap core in infusion media
  - +/- 45° Glass and 0° Carbon
  - Laminate layers terminate beyond trailing edge
  - Laminate tapers towards leading edge
  - Void at trailing edge is filled with non-woven polyester felt

A.3. Infusion Molding (for each foil)
1) Preform placed in lower mold
  - Held at each end
2) Upper mold is placed over preform
3) Vacuum bag covers upper mold
  - sealed to lower mold with tacky tape
4) Vacuum bag is leak checked
5) Resin is introduced slowly
  - islanding trapped air is not desired

B. Produce Strut (x4)
B.1 Make mold (one time tooling)
B.2 Infusion Molding

B.1. Make mold (one-time tooling)
- Upper and lower molds
  - Struts
  - End supports
  - Foil/Strut Saddle

B.2. Infusion Molding (for each strut)
1) Preform placed in lower mold
  - Held at each end
2) Upper mold is placed over preform
3) Vacuum bag covers upper mold
  - sealed to lower mold with tacky tape
4) Vacuum bag is leak checked
5) Resin is introduced slowly
  - islanding trapped air is not desired
6) Vacuum is held during cure
7) Demold
8) Post cure

C. Assemble Turbine
C.1 Attach foils to struts

C.1 Attach foils to struts
1) Bolt foils to struts
2) Bolt Strut to shaft

C.2 Attach struts to shaft
1)Using increasing size holes in strut that match flanges on shaft
2) Secure struts to shaft (Bolts)

Figure 9. Process map for production of the Advanced TidGen® turbines.

3.3 Task 3 and Task 7, System Design

3.3.1 TidGen® System Overview

The TidGen® System is comprised of four major subsystems: the TidGen® Device (MEC), the buoyant tension mooring system (BTMS), the power and data (P&D) cables, and the onshore power electronics substation.

The TidGen® device consists of an upper and lower TGU comprised of four cross-flow turbines and a permanent magnet generator connected via a mechanical driveline. The TGU are held in place by a structural chassis and lateral buoyancy pod. The buoyancy pod provides enough buoyancy for the system to operate suspended in the water column while being held beneath the water surface by a tension mooring system.

Design Load Cases (DLC) Overview

As part of the overall design effort critical load cases were determined following DNV guidelines, development of concept of operations, and preliminary failure modes and effect analysis (FMEA).

Turbine Load Overview

A primary aspect of system loadings is the hydrodynamic lift, drag, and axial loads generated by the turbines. In many cases these loads represent the highest loads experienced by the TidGen® Power System. The determination of TidGen® loads was primarily developed through the use of computational fluid dynamics (CFD).

Characteristic Velocity Profile

To enable device designs independent of specific site velocity characteristics, a generic “characteristic” velocity profile was developed for the TidGen® system design. This velocity curve utilized scaled harmonic coefficients and added random turbulence such that the resulting velocity distribution was conservative when compared to measured data from multiple ORPC sites. Velocity distributions for long range site forecasts were developed from using harmonic constituents derived from site data. These distributions were also compared to the characteristic velocity distribution.

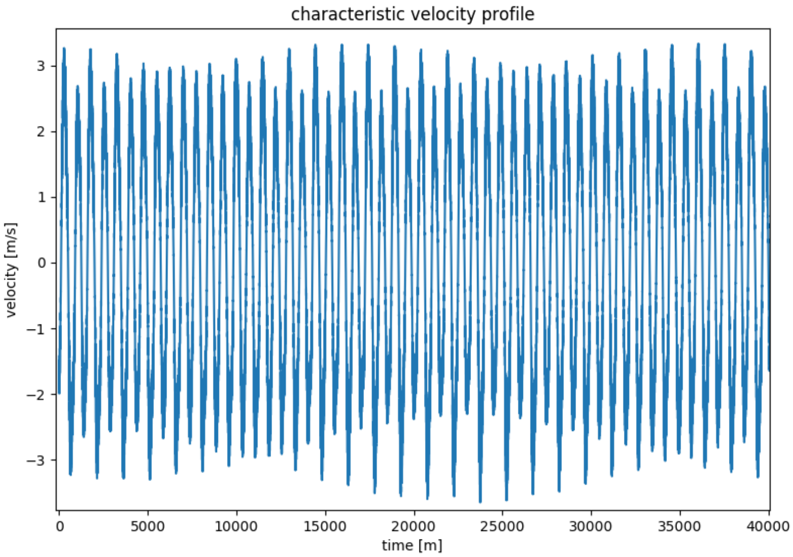


Figure 10. Characteristic design tidal profile

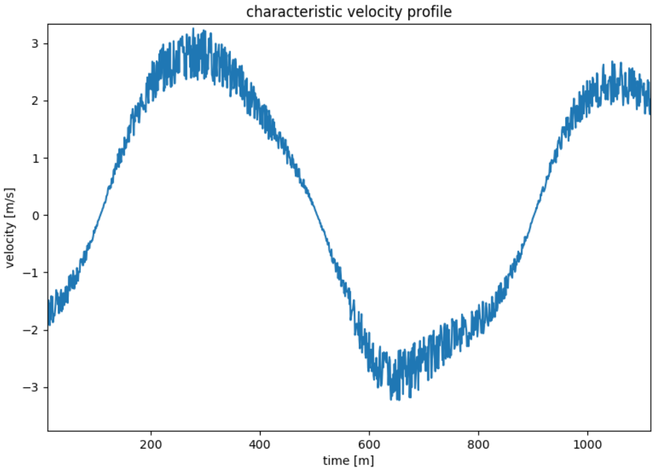


Figure 11. Characteristic velocity profile turbulence

3.3.2 Driveline Design

Refinement of driveline components, analysis tools, and methodology has continued. The focus of recent efforts has been to finalize design, determine costs, and ensure final designs meet performance and cost goals. A critical design review was performed to review all components, a summary is discussed below.

A thorough fatigue analysis was performed on all driveline components to ensure adequate strength and suitability for purpose, utilizing DNV-GL standards. The analysis required full system FEA modeling to establish limits of deflection and derive anticipated loading through system flexure, operational loading, and typical manufacturing tolerances. The current driveline design was determined to be adequate and able to withstand continuous operational loads for the life of the device.

Interconnection of turbine sections require flexible couplings for transfer of torque from discrete driveline sections. System flexure for driveline tolerances, both angular and concentric, was reviewed for suitability of chosen couplings and deemed to be acceptable.

The generator to drivetrain connection requires a large, keyless shaft coupling. A suitable solution was found that integrates a flexible coupling, keyless shaft coupling, and a methodology for ensuring corrosion protection for the life of the connection device.

Results from the PTO driveline testing empirically derived misalignment limits of deflection for bearings and overall system flexure. Further analysis was performed on the overall system to determine flexure and misalignment during operation.

The PTO test assumed symmetrical deflection and the driveline design effort also assumed this attribute, the design requires symmetrical loading to function properly. Modifications are necessary to accommodate non-symmetrical flexure. Specifically, the mid-bearing housing would exceed alignment capabilities with non-symmetrical loading. A modification of the original design will allow for a self-aligning capability of the bearings, in a similar concept to the end stanchions, and reduce the potential for edge-loading and damage to the PCD bearings. The radial bearings are suspended in an elastomer ring and will align with the flexure of the shaft to eliminate edge loading.

The suitability of flexible couplings for interconnection of drivetrain components was reviewed for suitability of chosen components. The generator to drivetrain connection requires a large, keyless shaft coupling. A suitable solution was found that integrates a flexible coupling, keyless shaft coupling, and a methodology for ensuring corrosion protection for the life of the device.

3.3.3 Buoyancy Pod Design

Design Overview

The primary buoyancy pod is comprised of six main buoyancy chambers, each of which was designed following *DNVGL-RP-202 Buckling Strength of Shells* and includes ring stiffeners to prevent buckling. These buoyancy chambers are connected to one another via bolted flange connections and are faired to reduce drag by corregated fairing plate which minimizes weight while maximizing tolerance to hydrodynamic pressure variations. The Buoyancy pod sections are connected to the structural chassis by three sets of pinned connections.

Following the PDR, the buoyancy pod was increased in length to provide additional structural support and stiffness. Although this increased the overall weight of the buoyancy pod, it allowed for significant reductions in the size and weight of the central nacelle, resulting in a decrease in structural weight while simultanously increasing stiffness.

Analysis Overview

The main structural pods were desgined following *DNVGL-RP-202 Buckling Strength of Shells*. Considering that external pressure and bending momenents (due to buoyancy and structural forces) are the main forces acting on the buoyancy pod, shell buckling and panel ring buckling are considered the primary buckling modes for design. The result of this analysis was to include ring stiffeners along the length of the main tubes along with heavy ring stiffeners near the center of each tube to maintain the cylindrical shape and avoid buckling. Following the PDR, ellipsoidal heads were determined to be preferrable to stiffened plates as they greatly reduce localized stresses. These heads were designed using ASME's Boiler and Pressure Vessel Code.

Combined chassis and buoyancy pod strucutral analysis was conducted using finite element analysis (FEA) (see Chassis Design Analysis). Reaction and connection loads from the full system FEA were utilized in performing detailed FEA analysis at critcal connection joints.

Structural analysis of the fairing plate was conducted by applying an assumed hydrodynamic pressure load from the turbines to the plate.

Because the loads throughout the structure will fluctuate with turbine rotations, fatigue analysis was conducted following *DNV-RP-C203 Fatigue Design of Offshore Structures*. Allowable stress ranges for "high risk" aspects of the buoyancy pod design (joints, connections, etc.) were determined based on DNV-RP-203 and assuming high cycle fatigue. These allowable stresses were then compared to the stress ranges resulting from FEA.

Along with analysis of deployed operations, FEA was conducted on the buoyancy pod under assembly loads.

3.3.4 Structural Chassis Design

Design Overview

The primary role of the structural chassis during deployed operations is to hold the power take off system in position while providing the structural interface between the mooring system and the buoyancy pod. In order to minimize weight while maximizing stiffness, a truss frame is utilized as the primary structural backbone. This frame is segmented into shippable sections, which are connected by bolted flanges, and is covered with a fairing shell cover to improve the flow through the turbines. The main driveline supports, generator, and mechanical brake/converter assemblies, are connected to the chassis through pre-aligned bolted Chockfast interfaces. While the chassis' interfaces with the buoyancy pod and mooring systems are comprised of pinned connections.

Analysis Overview

Preliminary structural design was conducted using simplified truss models and ASIC Steel Construction Manual Vol. 14. Following the PDR, a combined structural assembly (half) model was developed for FEA. This model was used to analyze operational design load cases 5.1 – 5.13. As part of this model, connection and reaction loads were determined for each major pin connection for each design load case. These loads were then used as the basis for more detailed component analysis. In addition, chassis deflections at the driveline interfaces were determined. These deflections were an important consideration in the design of the mechanical driveline.

Using the local loads determined through the combined structural model, detailed analysis of critical chassis design features was conducted. As with the buoyancy pod, FEA was used to determine maximum stresses under bot ULS and FLS loading states. *DNV-RP-C203 Fatigue Design of Offshore Structures* was utilized to determine the maximum allowable stress ranges for "high risk" aspects each design feature. The FEA stresses were then compared to allowable fatigue values.

Because the chassis is comprised of long slender tubular sections under external pressure, bucking checks were also conducted for those elements where buckling was a concern. For the main tubular sections, conservative estimates for the maximum bending moment were used along with external pressure loads and *DNV-RP-C202 Buckling Strength of Shells* to compare the buckling strength against buckling stresses.

Similar buckling checks were performed for any Buoyancy Pod / Chassis connection tube which was determined to be under compressive loading during operations. In all cases, buckling was not found to be a primary concern.

Along with the major structural members, the fairing shell panels were analyzed for maximum stress and deflection under ULS loading, for plate buckling (using *DNV-RP-C201 Buckling Strength of Plated Structures*) and fatigue failure under a varying pressure load due to turbine rotation.

Assembly conditions were also checked using FEA with assumed assembly loads. The chassis was analyzed under conservative loading conditions which assumed the generator weight was not supported by a separate assembly jig and considered loadings that would maximize structural twist. Under these loading conditions, the structural chassis was found to have minimal deflections and acceptable maximum localized stresses.

3.3.5 Mooring System Design

The mooring system is comprised of five major components:

1. Bridle lines that connect the device to the rigid bridle. The principle purpose of the bridle lines is to attach the moorings close to the center of drag while not interfering with turbines or driveline components.
2. A rigid bridle that connects a pair of bridle lines to a primary mooring line and a pair of redundant mooring lines.
3. A primary mooring line that serves as a single point connection from the anchors to the rigid bridle. During normal operations all load is through the primary mooring line.
4. A pair of redundant mooring lines of equivalent size of the primary line however are left in an unloaded state. Should the primary mooring line fail, the redundant mooring lines take up the load preventing loss or significant damage to the device.
5. Gravity anchor, they serve to hold the device in place through the primary mooring line.

Of the mooring components, only the gravity anchor is lacking a formal design. The design of the anchor is highly specific to the bottom type at a specific site to ensure that an anchor is made to the right shape to prevent failing the soil and causing the anchor to sink and be unrecoverable. Second, the underside of a gravity anchor is typically outfitted with shear keys to add holding power, however some geotechnical work is required to ensure the keys are sized appropriately. Third, as currently design the anchors are significantly heavy due to the large drag loads on the system, it is suspected that the turbine drag is not as large as predicted in CFD however testing is required to verify. Therefore, final sizing of the anchors is delayed until verification of turbine loads is performed in the hope that the size of the anchors can be safely reduced.

Simulations for all load cases were performed for both the Cobscook Bay deployment and the Western Passage deployment site. Note that Cobscook is significantly shallower than Western Passage and this the mooring lines are quite short. During accidently limit cases (one of the mooring lines failing) this led to a higher shock load on the system even in a less energetic site. The driving load case for mooring lines is the accidental limit state where one of the bridle lines fails while the turbine is operating at peak flow, this leads to oversized mooring lines in design. ORPC investigated mooring line suppressors as a means to reduce the shock load to the lines and the chassis of the TidGen 2.0.

The final analysis did reveal a concern about having redundant lines under low to no tension. The fore redundant line is likely to collide with the primary line which introduces the possibility of tangling and premature wear increasing the likelihood of line failure in both the redundant line and primary line. The aft redundant line may also touchdown on the anchor which is another significant concern. Most mooring line corrosion and wear occurs when a line touches down on the surface. Should the redundant lines wear early then if the primary line does snap they will not perform adequately to protect the device. Three options are identified to reduce these risks. The first is to increase the separation distance between the lines, this will prevent clashing of lines. The second is add additional abrasion protection to the lines. The third option is to add additional spreader bars between the lines tying them together and keeping them a fixed distance apart. A combination of all three solutions while reduce or eliminate the risk of line failure from clashing.

ORPC is also investigating alternative anchoring methods to gravity anchors. While providing the ability to deploy and retrieve the system and anchors in one tide cycles the size of the gravity anchors substantially increase the on-land and on-water operations costs. Alternative anchoring methods, such as micropiles, would require leaving the anchors in place when the device is retrieved and thus a connector is needed in the mooring lines. Most subsea mooring connectors are designed around having an ROV performing some of the operations.

3.4 Task 4 Control System and SCADA

The following excerpts from Deliverable, D4.2 Control and SCADA System Design, which provides further design detail.

SCADA and Control System Description

The SCADA and control system of the Advanced TidGen® is separated into three areas of responsibility:

1. Control of turbine speed to maintain optimum efficiency, remain within allowable torque limits and remain below the limit of the power electronics. The “Control System” refers to this area of responsibility.
2. Supervisory control of the system including turning the system on and off, switching control system states and preparing the system for deployment and retrieval. The “SCADA system” refers to this area of responsibility.
3. Monitoring the performance and health of the system, alerting the SCADA system to any faults and logging sensor and status information for historical review. The “Condition Monitoring System” or CMS refers to this area of responsibility.

The control system operates on hardware independent of the SCADA and CMS and can manage any faults specific to the operation and health of the generator. The Advanced TidGen® operates two independent control systems, one for each row of turbines.

The SCADA and CMS operate on the same hardware. Unlike previous ORPC systems, the hardware is located on the device and can operate the device independently from the on-shore station. This allows for a controlled shutdown of the device in the event of a loss of communication or power from the shore station and continued monitoring of system health.

- **Communications Architecture**

The Advanced TidGen® will utilize a local ethernet network on the system to communicate between various enclosures, data acquisition modules and to network to the shore station. The controllers for each generator communicate over CAN-A bus and thus operate on a separate network. CAN-A is still relatively new to industrial automation and few industrial PLCs or DAQ systems can utilize the CAN bus, thus the backbone of the communication system was selected to be ethernet based.

- **Control Theory**

The control theory selected for this project was the Kω^2 – a nonlinear feedforward controller.

Previous projects focused on control approaches evaluated four types of controllers which were tested in simulation, emulation, a laboratory flume, and the field.[1] Trends in simulation were verified through experiments, which also provided the opportunity to test assumptions about turbine responsiveness and control resilience to varying scales of turbulence. The clear message was that the feedforward Kω^2 controller out-performs feedback controllers in almost all aspects and modes of evaluation. The controllers proved a substantial improvement over the baseline performance of the TidGen® turbine, in terms of energy capture.

- **Theory**

Derived from the dynamic model of turbine operation, the nonlinear feedforward Kω^2 controller commands a torque,

$$\tau_c = K\omega^2 = \frac{1}{2}\rho A R^3 \frac{\eta(\lambda)}{\lambda^3}\omega^2$$

which brings the turbine to a desired operating point on its performance curve ($\eta(\lambda)$). In the case where K results in the turbine operating at peak efficiency, this optimal gain is referred to in this report as K^*. K values larger or smaller in magnitude than K^* result in operation to the "left" or "right" of the peak (slower or faster than optimal λ, respectively). Optimal performance requires a well-defined performance curve and accurate measurement of ω. Note that unlike a feedback controller, the control torque equation does not explicitly prescribe a fixed set-point. Rather it controls the turbine to a set-point based on the estimate for the plant dynamics. This controller is shown schematically in Figure 12.

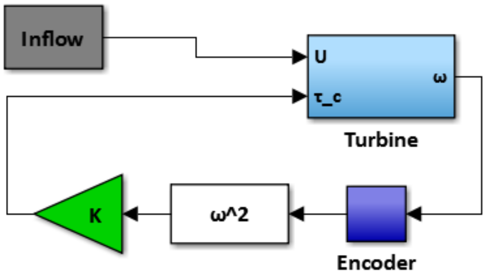


Figure 12. Kω2 controller schematic. This feedforward controller creates a torque command based on the speed of the turbine and the plant characteristic K.

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[1] EE0006397_ORPC_FINAL_TECHNICAL_REPORT

- **SCADA Design**

The SCADA system is the link between the control system and the on-shore operation. The system can run in manual, semi-automatic and automatic mode.

In manual mode, the operator has complete control of the system, capable of switching states without automatically handling faults reported by the CMS. Important status readings will be displayed to the operator, however if the readings are outside normal operating conditions, the system will not take corrective action. Manual mode is intended for use during commissioning to more readily establish baseline readings and determine the operational conditions, as well as stress testing the system. Semi-automatic mode is like manual in that the operator controls the switching of system states, however unlike manual control, the SCADA system will automatically handle any faults presented by the CMS. This may include a gentle or emergency shutdown of the system or change of control system commands to maintain integrity of the system. When an operator is present for maintenance, installation or removal the system is in semi-manual control.

Automatic mode is where the system is most likely to spend time. The SCADA system handles complete control of state switching; performing start-up and spin up of the turbines when the flow speeds reach useable levels, changing control mode between $K\omega^2$, torque limited operation, power limited operation, and shutdown as necessary. Any faults reported by the CMS will automatically be handled. In common faults, such as motor overspeed due to higher than expected current speeds, the SCADA system will automatically restart the Advanced TidGen® at the next tide cycle. Other faults such as bearing over temperature or water ingress in sealed compartments will alert operators and keep the system shutdown until operators can intervene. This last feature is required by DNVGL, any fault the triggers a shutdown will prevent a restart until the fault is cleared and an operator has restarted the system.

- **Condition Monitoring**

The condition monitoring system serves two purposes. The first is to provide a constant assessment of the health of the Advanced TidGen® while in operation. The second is to monitor performance and environmental information unnecessary to the operation of the Advanced TidGen® but useful for improving the design and functionality in the future. An instrumentation and equipment list can be found in Appendix C. The instrumentation and equipment are assigned unique identifiers according to ISA 5.1 Standards.

- **Warning and Fault Limits**

Sensors critical to the health and operation of the Advanced TidGen® are given warning and fault limits, used as indicators to the operator of abnormal behavior. Warnings are used as indication that a part of the system is entering an uncommon operational state. Warnings do not indicate a failure is occurring or imminent on their own, only to raise awareness and begin careful attention to all other systems. Faults are conditional limits that, when exceed the SCADA system must respond immediately, such as a shutdown of the system if a leak is detected in a compartment.

Most warning and fault limits cannot be determined before initial deployment. During the commissioning phase, the Advanced TidGen® will be operated at lower power outputs, with faults set low to both ensure the SCADA system is handling faults and to gain experience in what the steady state operational conditions are. In this phase, the SCADA system is typically left in a manual or semi-automatic mode and has constant operator attention making note of system parameters. Once defined, the system can be left in automatic control safely.

- **Data Logging and Backup**

A critical component to the CMS is logging and backup of sensors and control system parameters. The system must handle many inputs with varying levels of importance and sampling frequencies and keep a record of them backed up in multiple locations in the event of a failure anywhere along the network line.

Depending on the current and previous state of the system, the data logging procedure is different. Those procedures and conditions are as follows:

- **Rolling Log**: A continuous log of the last hour of system status and intersystem communications is kept. This log is continually overwritten, stored locally and not logged unless some condition requires it.
- **Power Production Operation**: When the system is operating normally and actively producing power, system health and status information is logged at most every minute. Voltage and current are monitored at each generator, converter, and before and after the transmission line. Leak sensors are not logged.
- **Shutdown Operation**: When the system is shutdown, such as between tide cycles, system position and environmental conditions are logged. Power systems and leaks systems are not logged.
- **On Fault**: When a fault in the system is detected, the rolling log is immediately backed up locally and to the shore station. The system then enters a high data rate logging of all power production and rolling log parameters until the system has successfully shutdown.
- **On Shore Connection Loss**: When the Advanced TidGen® loses connection to the shore station, the On Fault logging begins. Once complete standard Rolling Log and Shutdown Operation logs are suspended and a low power, low rate log is initiated. Only critical system parameters are recorded. This is to preserve adequate storage space for logs on the device, until re-connection or recovery is performed and to minimize the power draw of the system, ensuring the longest period of operational time while connection to the shore is lost.

The logs are kept in three separate locations. The first is locally on the device, where at least the last 24 hours of operations is kept. These logs are automatically backed-up by the shore-station every 6 hours. Depending on the shore-station storage capacity, months to years of historical data is kept. Each day, the logs are backed-up to an offsite location accessible by ORPC for monitoring and review.

It is important to differentiate between monitoring and logging. All sensors on the Advanced TidGen® are actively monitored by the CMS. Monitored sensors are sampled at the program clock frequency, typically faster than 10Hz. This information is also displayed to the operator at the shore station in real time. Logged data is kept for historical review and must be stored. Sensors such as leak detection, enclosure pressure and temperature, oil pressure and humidity do not change frequently and do not provide any useful information historically, therefore are not logged, but actively monitored.

- **Development Path and Subsystem Testing**

The development of the control system is largely independent of the Advanced TidGen® design and development path. The remaining development of the SCADA and Control system is as follows:

1. Identification of any outstanding sensors not yet defined.
2. Internal layout of electronics enclosures and associated wiring diagrams
3. Subsea cable specification
4. Software development of the PLC code
5. Interface testing with vendor equipment such as the converter and brake
6. User Interface development for the PLC code

The last phase of the development takes place after final assembly of the system and before installation. A system integration test will checkout all sensors are reading properly and that the generators and brakes operate successfully.

ORPC is currently developing the next generation RivGen®, schedule for deployment a year before the first installation of the Advanced TidGen®. In the interest of keeping components and design common between products, the RivGen® will utilize the same SCADA and control system architecture as the Advanced TidGen® despite being a significantly smaller device. As a part of the development and testing of the SCADA and control system, ORPC will install the system on the RivGen® and perform software development and testing early. The core software and user interface will be able to be copied directly to the TidGen® system. Doubling as a test system, the RivGen® does not use the same converter electronics and generator as the TidGen®, however the driveline, enclosures and environmental monitoring are all sufficiently similar that determination of warning and fault limits for the TidGen® can start with that of the RivGen®. In all, the development of the RivGen® SCADA and control system will significantly reduce the development time and risk of the Advanced TidGen®.

4 Status of any Critical NEPA Compliance/Licenses/Permits for BP2 activities

Below is an overview of status. Document, D-TD20-10186 BP1: Task 5 Report – Environmental Approach, details the permitting status and activities for the next budget period.

4.1 NEPA

ORPC and UMaine previously received acceptance from NOAA and NEPA approval from DOE for a Biological Assessment (BA) for 2017 field activities to test passive acoustic monitoring devices and fish hydroacoustic surveys. Hydroacoustic surveys are now proposed to start in May/June 2018. Because a BA environmental monitoring testing has already been completed ORPC does not anticipate a new BA will be needed for 2018. However, due to proposed 2018 field activities occurring during periods when more marine mammals are anticipated consultation with NOAA will occur to determine what modifications to the existing BA might be necessary. ORPC has schedule a meeting with NOAA and UMaine on May 2, 2018 for this purpose.

In addition to a modification to the existing BA for environmental monitoring activities, ORPC anticipates a BA will be required for BP2 in-water subsystem and full system testing starting in late 2018 and continuing until early 2020. Specific activities to be covered under this BA will include, but may not be limited to, the following:

- Barge test of a single turbine in Cobscook Bay (Q4 2018 to Q1 2019)
- Anchor tests (Q1/2 2019)
- System deployment and retrieval test in Western Passage (Q3 2019)

4.2 FERC License

During Budget Period 3, verification of the system performance will include a two-month in water deployment at ORPC's Cobscook Bay Tidal Energy Project site, for which ORPC holds a Federal Energy Regulatory Commission (FERC) pilot project license for the Cobscook Bay Tidal Energy Project site (P-12711.005). ORPC anticipates a modification to the FERC license to incorporate the Advanced TidGen® device at the Cobscook Bay site.

4.3 Permits

ORPC's current Submerged Land Lease from the State of Maine will expire in February 2020. An extension will be requested to align with the term of the FERC Pilot License which will expire in 2022.