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Revision History

Rev. Num.	EC Num.	Description	Prep.	Date	Chck.	Date	Appr.	Date
01		Initial draft	RNT	20200123	JD, MW	20200207		
02		Draft based on JD and NH input re commissioning, and MW input on P&D cable installation	RNT	20200207	JME	20200216		
03		Accepted Edits from JME review	RNT	20200219				

CONTENTS

1 INTRODUCTION

The purpose of the Open Water Deployment Report is to provide an overview of the installation of the ORPC RivGen 2.0 Power System in Igiugig, AK, in 2019, beginning with the transportation of the system to Igiugig and ending with the deployment of the device to the Kvichak River bottom.

This report fulfills deliverable 14.1 for Igiugig Village Council's Department of Energy award DE-EE0007348.

2 OVERVIEW

The primary steps for RivGen® Power System installation were the following:

1. System transportation to Igiugig, AK
2. Re-assembly of the RivGen device (including mechanical brake and turbines)
3. Installation of the RivGen shore station
4. Installation of terrestrial power and data cables
5. Mooring System installation
6. RivGen device installation and deployment
7. Installation of submerged power and data cables
8. Environmental monitoring tests
9. Initial commissioning

3 REFERENCE INFORMATION

3.1 RivGen Power System Overview

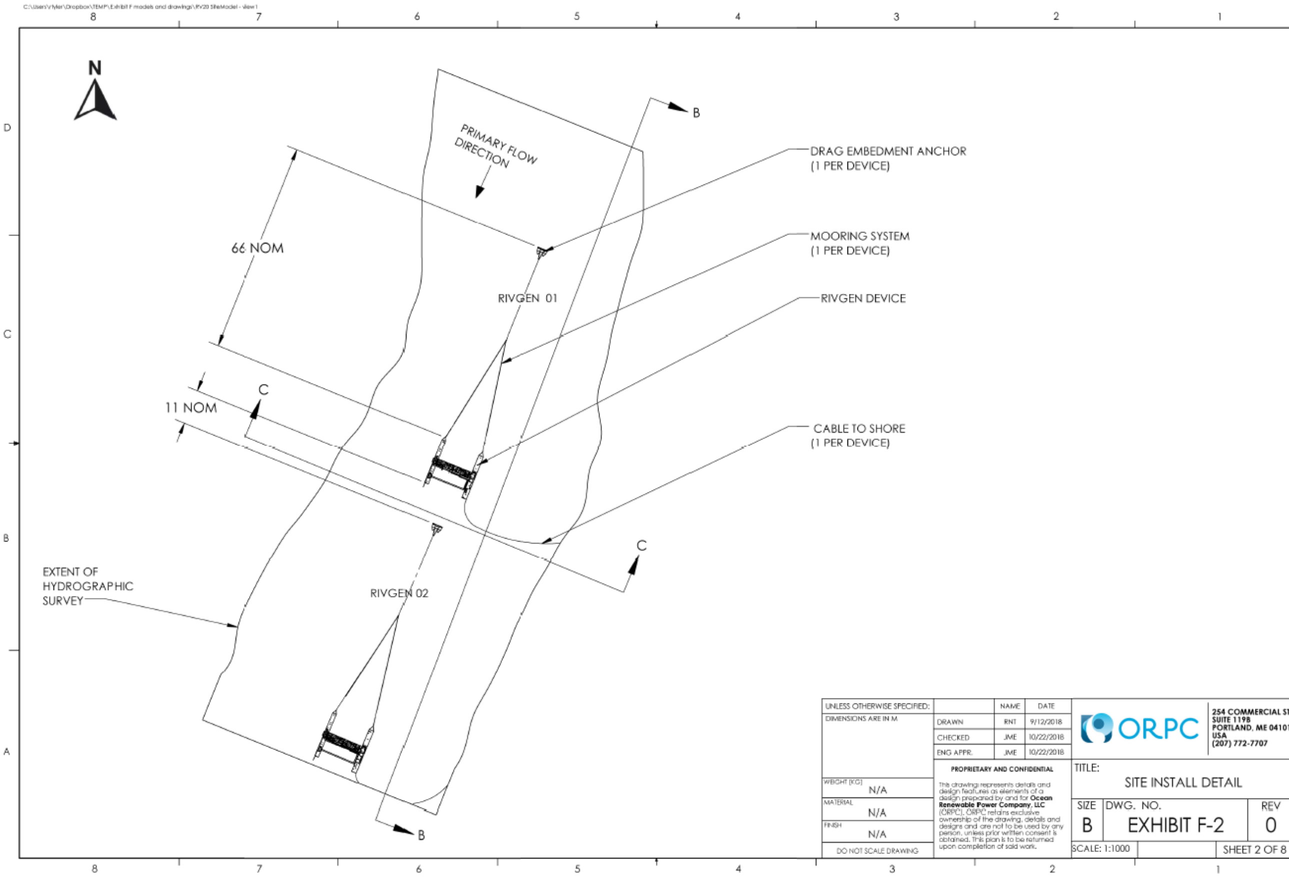

Figure 1. RivGen Power System overview. Only RivGen 01 was deployed in 2019. RivGen 02 will be deployed in 2021.

3.2 Assembly Site Overview

Figure 2. ORPC RivGen device assembly site, overview

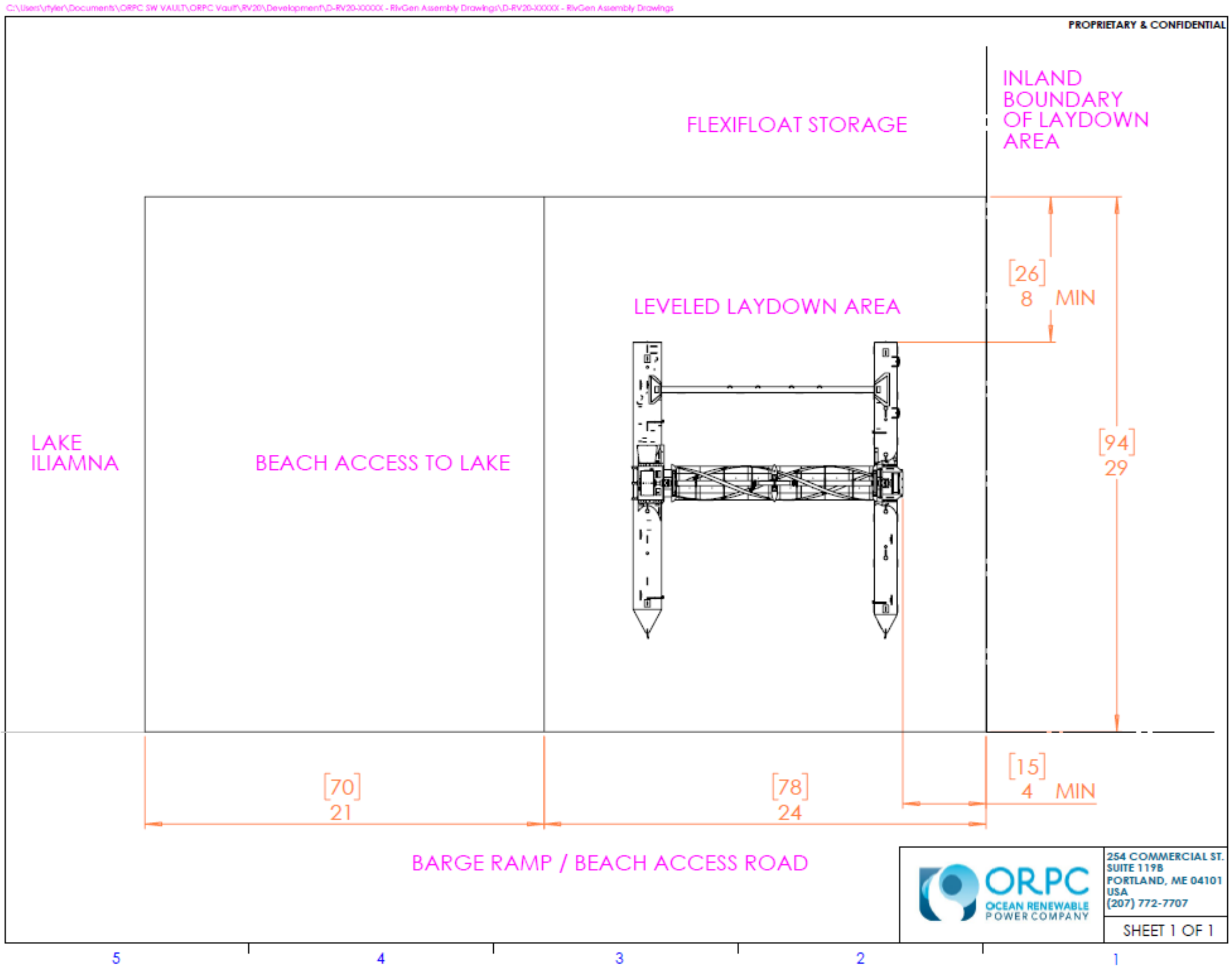

Figure 3. ORPC RivGen device assembly site, detail

3.3 Deployment Site Overview

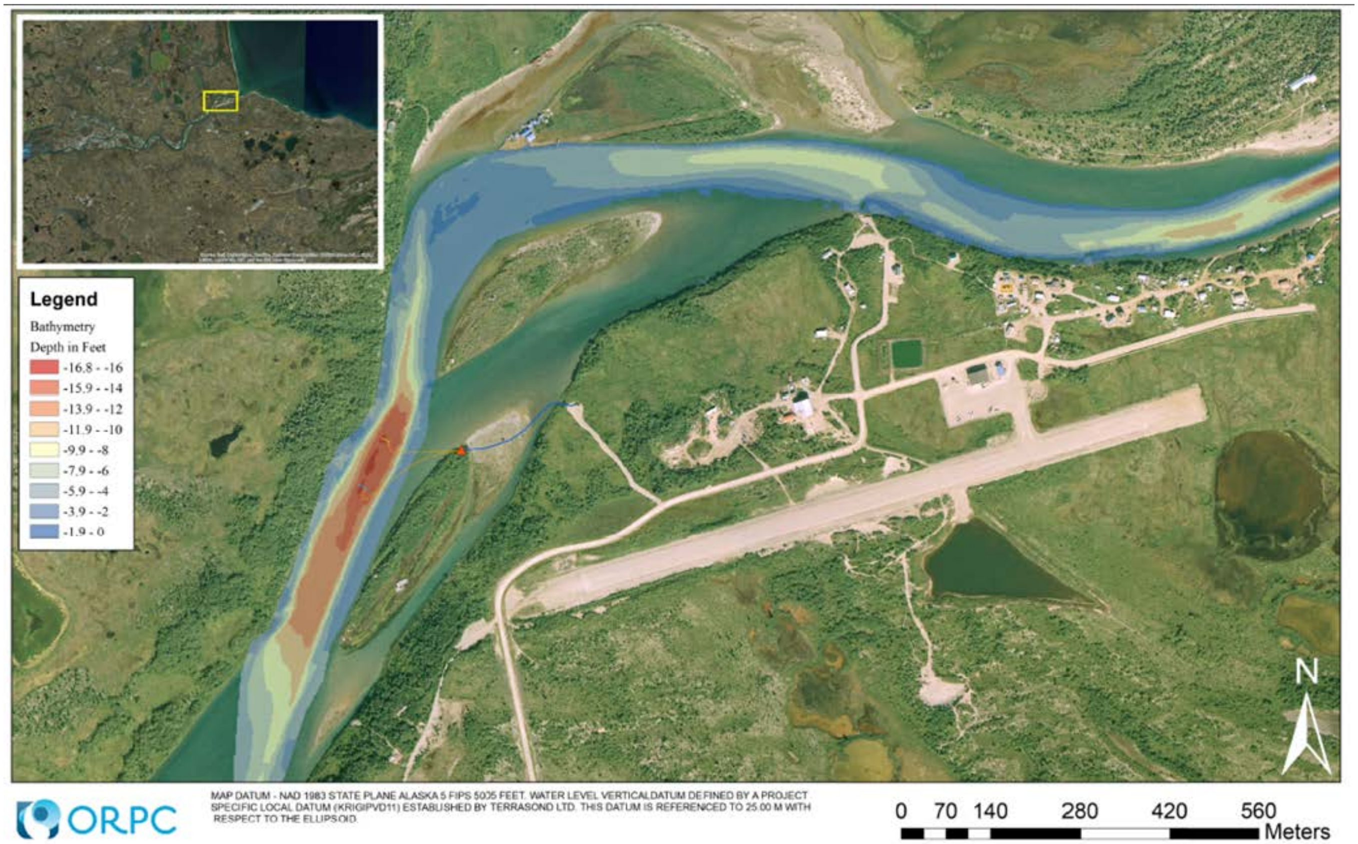

Figure 4. RivGen deployment site, overview

3.4 Installation Equipment Overview

Heavy equipment and operators were supplied by Iliamna Lake Contractors (ILC). Marine vessels were operated and provided by the Igiugig Village Council (IVC).

Table 1. Heavy equipment utilized in the installation

Item		Qty	Supplier	Primary Uses
CAT 966 Loader		1	ILC	- Device assembly - Shore station assembly
CAT 330 Excavator		1	ILC	- Device assembly - Terrestrial power and data cable installation - Mooring system installation
CAT 325		1	ILC	- Device launching
Chuylen Push Boat		1	IVC	- Mooring system installation - Device installation - Device deployment - Power and data cable installation
Tri-hull Work Skiff		1	IVC	- Device installation - Power and data cable installation
Seine Skiff		1	IVC	- Device installation
Safety Skiff		1	IVC	- Mooring system installation - Device installation - Device deployment - Power and data cable installation

3.5 RivGen Installation Test Plans and Documentation

- PS-RV20-10595 - Site Safety Plan – Igiugig, 2019
- PI-RV20-10538 - RivGen Device Onsite Assembly - Igiugig
- PI-RV20-10539 - Shore Based PE Installation - Igiugig
- PI-RV20-10584 - Mooring Anchor Install
- PI-RV20-10540 - RivGen PD Cable Installation - Igiugig
- PI-RV20-10541 - RivGen Device Deployment - Igiugig
- PF-RV20-10616 - RivGen Lockout Tagout (LOTO) Procedures – Igiugig
- PT-RV20-10583 - RivGen Pre-Deployment Validation Tests – Igiugig
- PI-RV20-10575 - Commissioning Procedure - Igiugig

4 RESULTS

4.1 System Transportation

Following subsystem integration tests in Brunswick, ME, the RivGen device components were shipped via three 53ft flatbed trailers along with one smaller trailer for the generator to Homer, AK. The remaining components, which were not assembled in Brunswick, were shipped directly to Homer from various vendors. These included the mechanical brake, shore station, mooring system, and power and data cables. Once in Homer, the components were transloaded and consolidated onto four approximately 40ft flatbed trailers for the shipment to Igiugig (Figure 5).

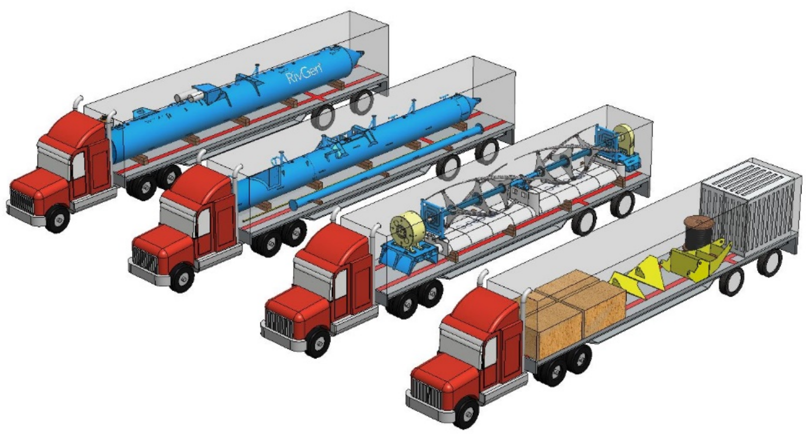

Figure 5. Planned shipping arrangement for the RivGen Power System

The shipment left Homer on June 4, 2019 and arrived in Igiugig via barge across Lake Iliamna on June 6 where Iliamna Lake Contractors (ILC) off loaded the trailers and staged the system equipment for assembly (Figure 6). Note that the trip from Homer to Igiugig often takes approximately three weeks.

Figure 6. Offloading the RivGen Power System at Igiugig

Due to delays in manufacturing, the turbines did not arrive in Homer in time to make this main shipment. Instead, they arrived in Igiugig on July 6.

4.2 RivGen Device Assembly

Preparations for device assembly began on June 14 with the leveling and compacting of the sand in the lay-down area (Figure 7). Once staged, the device assembly took place in three main phases: (1) re-assembly of the device components previously assembled in Maine, (2) installation, alignment, and testing the mechanical brake, and (3) installation of the turbines.

4.2.1 Re-assembly of device components

Once prepped, the structural components were staged, and full device assembly began on June 19. Initial re-assembly, which included all structural components, generator, mechanical brake dry fit, safety walkways, and on-device cable and hose routing took approximately two days to complete.

Although the initial re-assembly went quickly, several small integration tasks continued to occupy time throughout the next two weeks. These tasks included: addition of final coating decals, integration of generator and mechanical brake flow shields, deployment rigging, final abrasion protection for all cables and hoses, final instrumentation installation and checks, and installation of generator cable routing guide.

Figure 7. Re-assembly of the RivGen device major structural components

4.2.2 Mechanical brake installation

On June 22, ORPC contracted Tern-Tech of Anchorage, AK, to validate the alignment of the components of the power take off system. They focused on the alignment of the mechanical brake, which had not previously been installed due to delays in manufacturing. Prior to Tern-Tech's arrival, ORPC and ILC implemented several low-cost alignment techniques, including straight edges and tensioned strings. Although these techniques were not sufficient for a final alignment, they significantly reduced the time required by Tern-Tech. After only a half day, Tern-Tech was able to validate that the alignment was within 0.050 in.; alignment of the other driveline components was also re-checked with the equipment and time on hand. Once the alignment was verified, the mechanical brake was set in place using Chockfast (Figure 8). All other driveline components were completed with Chockfast during initial system integration in Brunswick, ME.

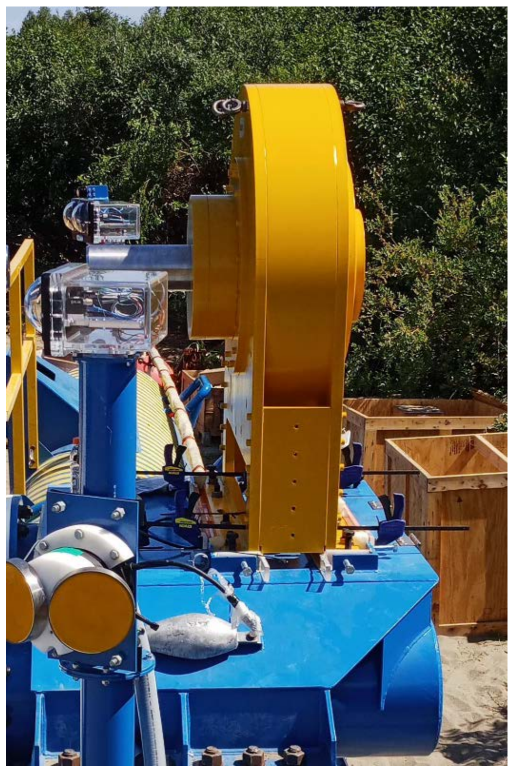

Figure 8. Installation of Chockfast between the mechanical brake and the chassis

In addition to installing and aligning the mechanical brake, the instrumentation signals and controls communications were validated. As this was the first time ORPC had used the component, this process took several days. Once communications to the mechanical brake hydraulic pressure unit (HPU) were validated, the HPU was installed onto the RivGen device and hydraulic and instrumentation connections were routed between the HPU and the mechanical brake.

Oil was then added to the HPU and the mechanical brake sump void, and leak tests of the sump volume were conducted by applying a vacuum to the sump chamber and measuring changes over time. These tests verified that the instrumentation signals and shaft seals were not leaking.

The brake controls were validated by actuating the installed brake and HPU through the SCADA system prior to completing device assembly. This was done by releasing the brake, rotating the shaft by hand using a strap wrench, then engaging the brake and confirming that rotation was no longer possible. Although this was effective for validating communications, it did not provide a sufficient test for confirming the braking time. During the fall maintenance event, this technique was altered to allow for a longer lever arm for rotating the brake shaft. The additional torque that this provided allowed for clear comparisons for how adjustment of the HPU's flow control valve resulted in greater braking speed.

4.2.3 Turbine installation

The turbines arrived in Igiugig on July 6. Prior to installing the turbines, they were visually inspected, and fit tests between the turbine shaft and ETP couplings which connects the turbines to the driveline were conducted. Unfortunately, these tests revealed that the turbine shafts were not able to fit on the ETP coupling. After careful inspection and measurements with an inside hole micrometer, it was confirmed that the turbine shaft inner dimensions did not meet the specified tolerances (Figure 9). It appeared that this may have been a result of machining the shaft inserts prior to welding, which lead to shaft deformation. It was for this reason that the fabrication drawings specified machining to be done *after* welding.

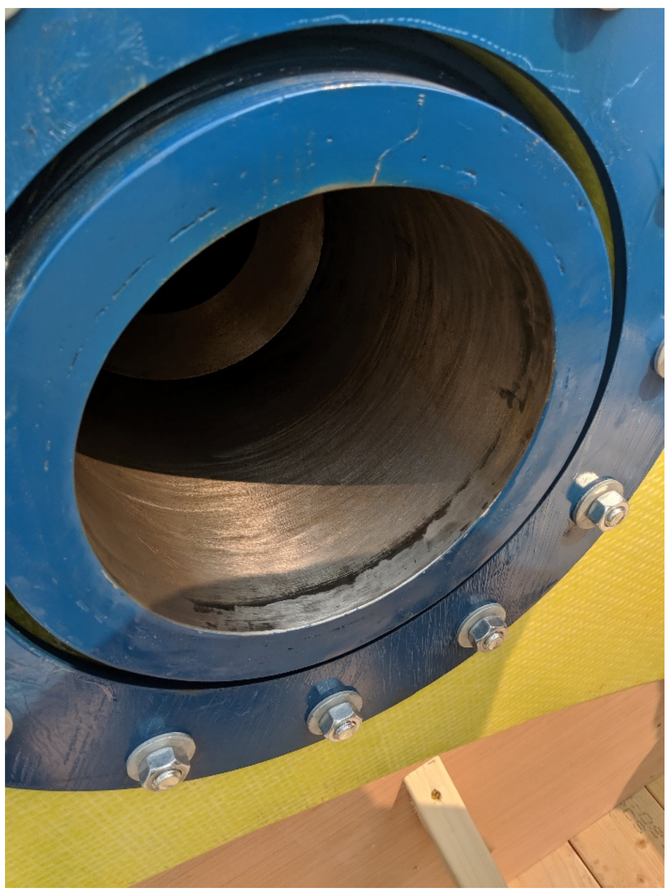

Figure 9. Example of a turbine shaft ID as received. Measurements and visual inspection indicated shaft ID did not meet fabrication specifications.

Over the course of the next week, a number of different techniques were used to correct the shaft ID. Ultimately, a cylinder hone was used to slowly remove small amounts of material from the inside of the shaft and bring the shaft into tolerance (Figure 10). This process took several days.

Figure 10. To correct tolerance issues on the turbine shaft ID a cylinder hone was used.

Once the shafts were corrected and the ETP couplings were confirmed to fit into the turbines, the turbines were installed onto the RivGen device. This was done by lifting each turbine using an excavator and sliding it onto the elevated mid-stanchion (Figure 11). Once each turbine was in place on the mid-stanchion, the turbine was lowered onto temporary stands and the end stanchions were installed by sliding their stub-shafts into the outside of turbine (Figure 12). This process took approximately one day, and on July 17, the turbines were both installed and the RivGen device assembly was complete.

Figure 11. Installation of the first RivGen turbine onto the mid-stanchion

Figure 12. Installation of the end stanchion onto the second turbine

4.3 RivGen shore station installation

Although the shore station components arrived in Igiugig along with the majority of the RivGen Power System on June 4, the actual wiring of the shore station occurred in Igiugig following the component arrival. This took approximately a month to accomplish and was proceeded by necessary repairs to the shore station to help ensure it was weather-proof. Part of this effort included integration with the SCADA system. As components were installed communications and controls of the components were verified. Despite the significant SCADA integration tests conducted in Maine as part of the initial system integration tests, this process took significant effort and lasted though system installation.

As part of the effort to confirm communications between the shore station and RivGen device, the shore station was moved to the device laydown area and connected to the device via the full submarine power and data cable (Figure 13). This test confirmed communications between the shore station and the on-device SCADA modules—Sensory Interconnection Module (SIM) and Shore-Power Interconnect (SPI). In addition, communications with all the major instrumentation were confirmed, light-dark tests confirmed signals from the environmental cameras were being received, and the mechanical brake was actuated.

Once communications between the shore station and the RivGen device were confirmed, the shore station was moved from the lay-down area to its installed position. The initial installation was completed on July 21. And the connection to the grid and terrestrial cables was completed on July 24.

Although the shore station was officially installed, component wiring and subsystem testing continued until August 5.

Figure 13. The shore station was moved to its installed location.

4.4 Installation of Terrestrial Power and Data (P&D) Cables and Junction Box

4.4.1 Junction box installation

The junction box was installed on July 10 (Figure 14). This was done by mounting the junction box to a well casing, which was piled into the ground with one of excavators used for trenching the cable on the island. The junction box was mounted later with some pipe clamps and Unistrut.

Figure 14. Junction box mounting pole installation

4.4.2 Terrestrial P&D cable installation

To protect the cables and reduce the impact on the community, the terrestrial P&D cables from the junction box to the shore station were buried (Figures 15 and 16). After ORPC marked the cable route based on GPS markers along the planned route, ILC dug an approximately 3ft deep trench for the cables. Two power cables, two data cables, and a fiber optic cable, were then laid into the trench and buried. The installation of the terrestrial cables took approximately three days.

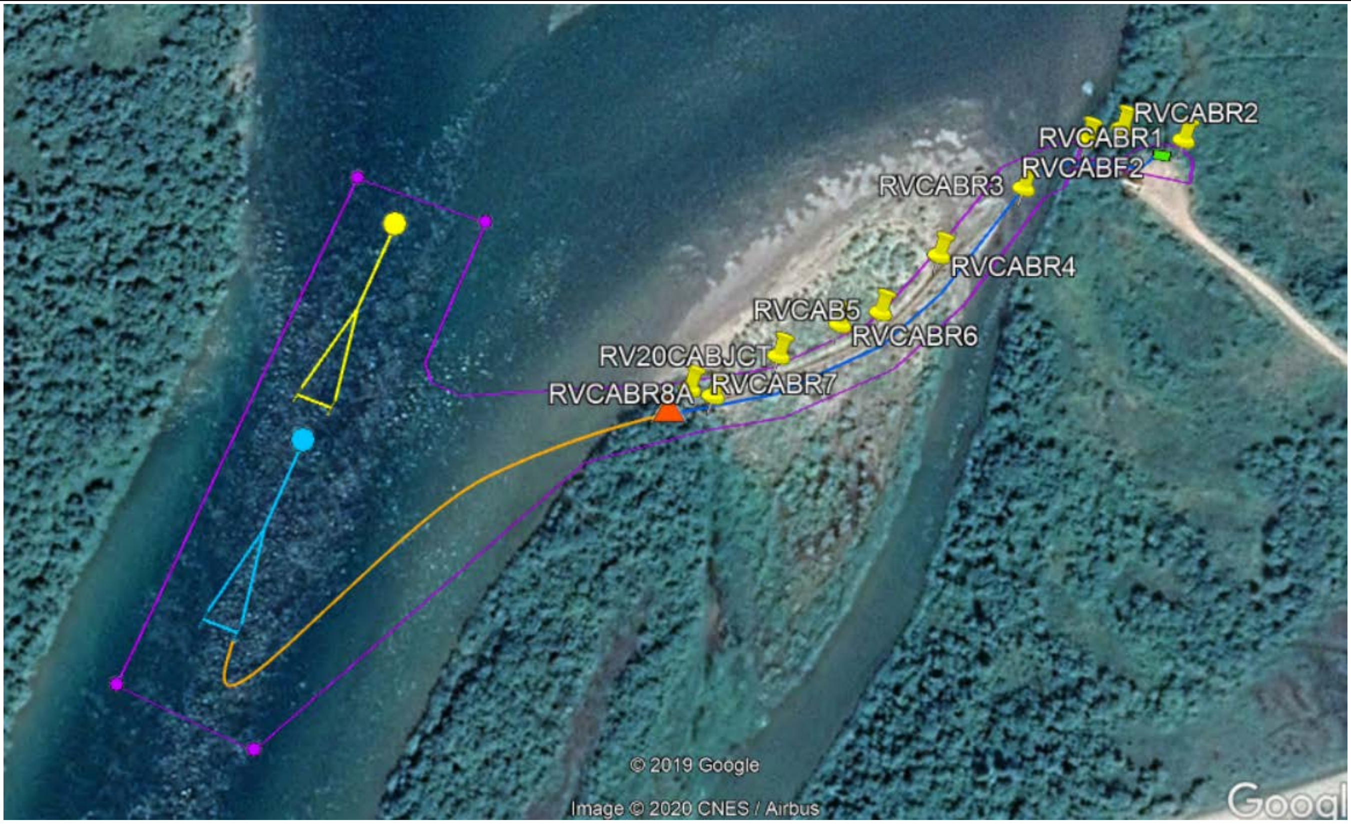

Figure 15. Installed cable GPS markers (pins) relative to planned route and Federal Energy Regulatory Commission (FERC) boundary

Figure 16. Terrestrial P&D cable installation

4.5 Mooring System Installation

4.5.1 Installation testing

The RivGen 2.0 mooring system is primarily comprised of a single drag embedment anchor and a single anchor chain, connected to two mooring lines. Although like previous RivGen mooring systems, the installation of the drag embedment anchor was not previously done in Igiugig. Prior to installation of the mooring system in the river, several test installations were conducted in the lake and near-shore areas (Figure 17).

The installation was completed by lowering the anchor off the Flexi-float barge using the CAT 330 Excavator while the push boat held the barge in position. The initial installation plan called for this to be completed by the excavator holding the anchor by the anchor chain using a customized chain hook. This resulted in the anchor being lifted vertically above the deck of the barge before being lowered into the water. Due to the reach of the excavator, depth of the water, and length of the anchor, the excavator could not fully deploy the anchor in a single lift, and so a second chain hook was fixed to the barge such that “bights” could be taken to lower the anchor into the water. On July 12, this technique was tested in Lake Iliamna. It quickly became apparent that while the process of attaching and removing chain hooks was possible in the lake, in the river it might be dangerous for personnel and would likely result in anchor “fluttering,” which could cause damage to equipment or personnel. As a result, an alternative picking method using the excavator bucket to lift the chain was also tested. This also proved ineffective and unsafe, and led to a near-miss when the equipment operator accidentally released the chain and anchor onto the deck of the barge. This initial testing proved that a new technique would need to be devised and that lifting the anchor from the chain in a “vertical lift” was likely not possible given the limitations of the excavator and the depth of the river. In addition, lifting from the anchor chain created challenges with chain management. Lifting from the chain meant that two lengths of chain were elevated, one to the anchor and a second to the barge deck. Due to the size and weight of the chain to the deck, it was clear that controlling the deployment of the chain could become an issue.

Figure 17. Preliminary anchor lifting/deployment test

Based on the lake trials, it was determined that lifting from the chain was not advisable and lifting the anchor such that it was suspended horizontally was preferred to a vertical lift. Based on these lessons, a new technique for deploying the anchor was developed which utilized a separate lifting bridal comprised of wire rope (Figure 18). Due to high winds and waves on the lake, testing of this modified deployment technique was conducted in the Kvichak River near shore with the barge tethered to the shore. To further reduce risks, the initial lifting and deployment tests were conducted with the anchor chain removed from the anchor. A progression of tests was conducted with each test building on the previous test by deploying the anchor deeper into the current and eventually re-attaching the anchor chain to the anchor. Included in these were tests of the excavator's ability to quickly release the anchor if needed. This emergency contingency was critical for a safe deployment. These tests indicated that the refined method for deploying the anchor was not only effective but could be safely conducted. In addition, the tests showed that the anchor handled well in the river and would "self-correct" its orientation as it was lowered.

Figure 18: Anchor installation tests using modified install approach

4.5.2 Final installation

Following the successful sequence of anchor deployment tests, the full mooring system was installed in the river on July 14. The system installation was conducted using the modified anchor lifting technique with the excavator lowering the anchor over the side of the barge into position. Once the anchor was installed and its position and orientation confirmed, the barge moved downstream allowing the anchor chain and installation mooring lines to pay out.

Once the anchor was on the riverbed, it needed to be set. This was done by pulling on the anchor to allow it to embed into the river. To improve the angle of the pull, the scope of the line was increased by putting two 100ft mooring lines in series and connecting one end of these installation lines to the anchor chain and the other to the barge via a load cell link.

Ideally, the anchor would be set by applying the full design load of 28,000lbs (125kN) for 30minutes. Given the equipment available, this was considered unlikely to be possible. Although the setting began by applying the drag load of the barge and push vessel only, this was quickly added to by the push boat pulling in reverse and the excavator placing its bucket in the water to further increase drag. With this full load applied, the average load recorded on the load cell was ~5000lbs, although peak loads of 8500lbs were recorded when the excavator “paddled” with the bucket. Although these loads were higher than expected, they were still well below the anticipated maximum loads. Later inspections confirmed that the anchor had only partially embedded. This, however, was expected, and the risks associated with not being able to apply the full load had been considered and accepted. As a result, the anchor was considered fully installed following this test.

With the anchor installation complete, the temporary installation mooring lines were removed, and the final mooring lines and marking buoys were installed (Figure 19). This was done following the planned procedures and went smoothly.

Final inspections of the mooring system included GPS measurements of the anchor locations and estimated device location, based on the end of the mooring lines. These confirmed the installed location met specifications (Figure 20).

Figure 19. Installed mooring system

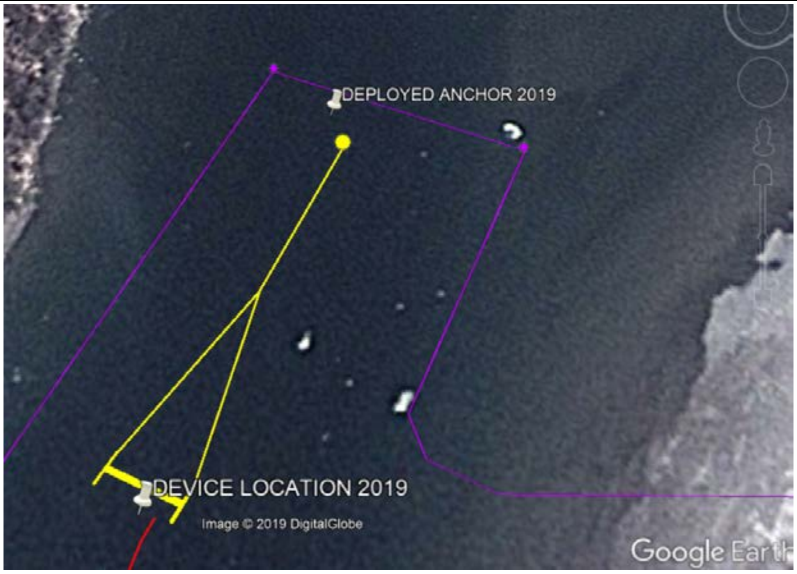

Figure 20. Measured final anchor position and estimated device position following anchor setting

4.6 RivGen Device Installation and Deployment

4.6.1 Launching the device

On July 18, the RivGen device was moved from the laydown site to Lake Iliamna (Figure 21). This process involved first rotating the device 90deg so it was oriented with the aft end towards the lake, then pulling and pushing the device to the water. This was performed using the CAT 330 and CAT 325 excavators. The tow excavators moved the device by lifting on the fore and aft ends lifting padeyes on each pontoon and then walking the excavators. Although rotating the device was a slow process due to the slope of the beach near the laydown site, the entire process went smoothly and took approximately an hour.

Figure 21. Launch of the RivGen device

Once the device was moved to the edge of the water, the Chuylen push boat was connected to the downstream pipe of the device. The was done using four attachment lines between the bow of the Chulyen and the downstream pipe as well as a spring line between the Chulyen and each pontoon. Once attached, the push boat and excavators launched the device by pulling and pushing it off the beach.

4.6.2 Installation and deployment lake tests

The first in-water validation test for the device was the test of its ability to be pushed at speed and maneuvered by the push boat (Figure 22). During the test, the push boat operated at the maximum sustainable RPM of 2100 while an average speed of 5.9knts was measured using two GPSs. This speed was considered acceptable for moving the RivGen device up and down river, as was the maneuverability of the device.

Figure 22. In-water validation tow test in Lake Iliamna

Following the tow test, the RivGen device was installed on a temporary anchor that had previously been installed in the water near the laydown site. Although this location was more shallow than desired, it was selected due to its proximity to the lay-down area, and it was considered adequate for the primary intent of the test, which was to validate the actuation of the deployment and retrieval systems. The connection to the temporary anchor proved challenging, due to the competing forces of a small current near the mouth of the river and high cross winds. Once connected to the temporary anchor, the first deployment test was conducted using a side pivot launch (SPL) technique to submerge the RivGen device to the bottom. This deployment took approximately 1.5hrs and allowed the device to overnight on the lake bottom.

The initial SPL deployment was followed by an aft-first retrieval and a bow-down deployment. These techniques both proved successful in the shallow lake water, although a number of refinements to the handling of the umbilical were made to reduce potential risks that could arise once operations moved to the river.

The final retrieval test used the secondary umbilical. The pop-up buoy (PUB) was released from the Chulyen and gathered by the work skiff. Although generally successful, the coiling of the secondary umbilical within the PUB resulted in some hose entanglement, which led to a modified coiling technique and the addition of light tensile “break-away” lines within the PUB to attempt to prevent the buoyancy of the hoses from out-pacing the buoyancy of the PUB upon release. With the secondary umbilical retrieved an “all chambers” evacuation was attempted. The test proved that this was not a viable option. Although stability did not appear to be an issue, the bow chambers rose to the surface first. This resulted in the water inside the chambers moving to the aft end of each chamber and away from the riser tube of the pontoon chambers, which prevented full evacuation and did not allow the device to fully surface. As a result, it was determined that the only viable retrieval techniques are SPL or an aft-first retrieval (Figure 23).

Figure 23. Retrieval attempt using secondary buoyancy system and "all chambers" evacuation, which resulted in "bow up" orientation that prevented full retrieval, highlighting the risk of an “all chambers” evacuation

Following lake testing, the final draft measurements were taken of the RivGen device on the surface of the lake. These measurements confirmed both the weight of the RivGen device and the predicted draft. The device was then removed from the temporary anchor and pulled partially up the beach. The submarine P&D Cable was re-attached to the device so final communications tests could be performed and the on-device batteries could charge prior to moving the device down-river (Figure 24).

Figure 24. RivGen device following still water deployment and retrieval tests

4.6.3 In-river installation

On July 20, the RivGen device was installed on the mooring system (Figure 25). This used the technique previously developed during RivGen 1.0 and 1.F deployments, which involved two work skiffs separating the mooring lines while the push boat moved the RivGen device into position between them. The work skiffs then made the connections to the mooring lines. This operation was successfully completed according to plan.

Immediately following the connection to the mooring system; there was, however, a near-miss incident when a Bristol Bay trawler which was moving upriver inexplicably veered course into the area directly upstream of the mooring RivGen device. Although the currents nearly pushed the vessel into the RivGen device, the vessel captain was able to recover and make his way upriver. While no harm was done to either the vessel or the RivGen, this highlighted a known concern associated with operations in the river. To mitigate risks, ORPC and IVC had placed a dedicated safety vessel on the river to warn the public of the risks and advice vessels where to safely travel. Despite this, the captain of this vessel ignored the warnings and directions and instead placed his vessel directly into the most dangerous location in the deployment area.

Figure 25. Installed RivGen device on its mooring system

4.6.4 In-river deployment and retrieval tests

The first deployment and retrieval tests were conducted following the installation of the RivGen device onto the mooring system and without the P&D Cables attached to the device (Figures 26). This was done to mitigate risks associated with anchor slippage during deployment. It was anticipated that the highest loads on the mooring system would be during deployment. If the anchor was going to slip downstream, the first deployment was considered the most likely moment for this. Without the P&D cables connected, anchor slippage was not considered likely to result in damage to the RivGen device.

The initial deployment and retrieval were conducted using the SPL technique with the starboard (generator) pontoon being submerged first and the port pontoon being raised first. Both deployment and retrieval took approximately 1.5hrs, the device remained stable and under control throughout, and no anchor slippage was detected.

Figure 26. Side pivot launch in-river deployment test

Figure 27. End pivot launch (bow down) deployment attempt

Once the submerged P&D cables were deployed (7), the in-river deployment and retrieval tests commenced. There tests repeated the tests conducted in the lake; however, with the P&D cable connected data was able to be collected throughout. The tests conducted were SPL deployment and retrieval, bow-down deployment, Aft first retrieval, and a secondary umbilical SPL retrieval.

All of these were successful except for the bow-down deployment (Figure 27). In the deeper water of the river, with the bow down, the water in the partially filled aft pontoon chambers covered the air vacuum pipe prior to sufficient filling to sink the aft end. As a result, the bow was able to fully submerge; however, the aft end was not. This was due to the layout of the pontoon’s internal plumbing. Once the cause of the issue was identified, the partially deployed device was retrieved without issue.

During the secondary buoyancy system retrieval test, the system was retrieved using a small compressor on a river skiff (instead of the larger deployment vessel). Although some of the same line handling issues witnessed in the lake remained present, this test not only proved the efficacy of the secondary buoyancy system, it also showed the possibility of using smaller vessels for deployments and retrievals.

Throughout the deployment and retrieval tests device pitch and roll data along with mooring line load cell data was collected. Although one of the mooring line load cells lost its functionality, the measured loads aligned well with predicted loads.

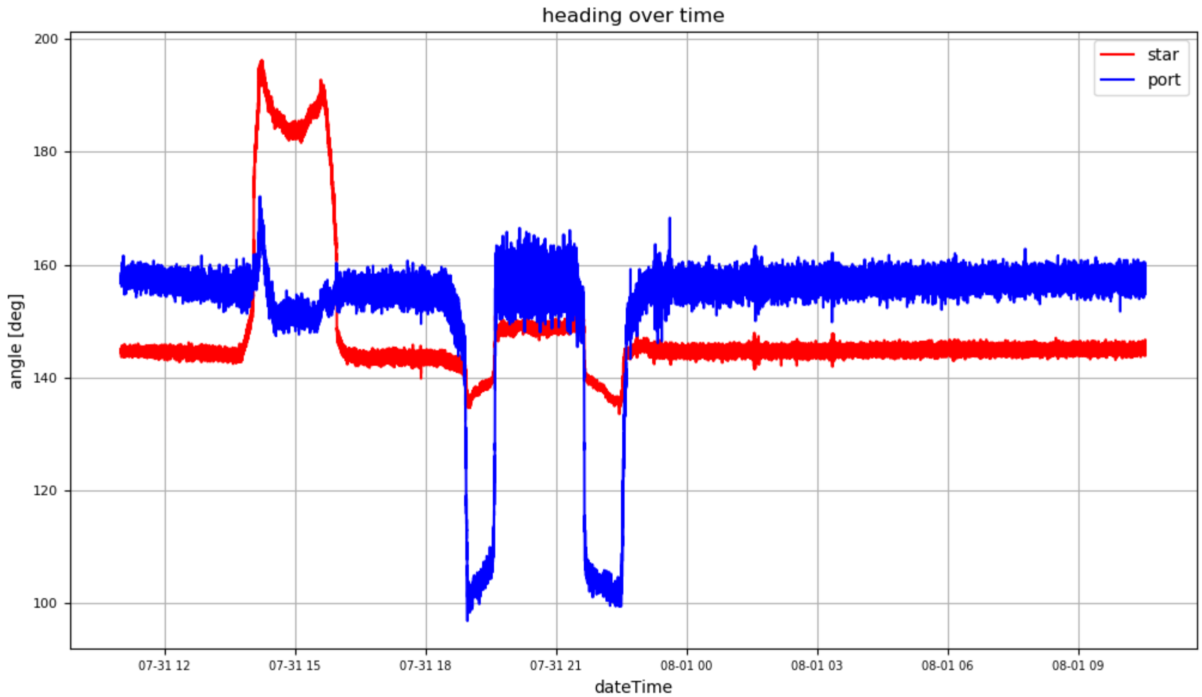

Figure 28. AWAC heading measurements during deployment tests. First peak represents the attempted bow-down deployment. The second peak represents the side pivot launch deployment. Note: AWAC measurements are skewed due to 25deg (starboard) and 40deg(port) offsets of AWACs for velocity measurements.

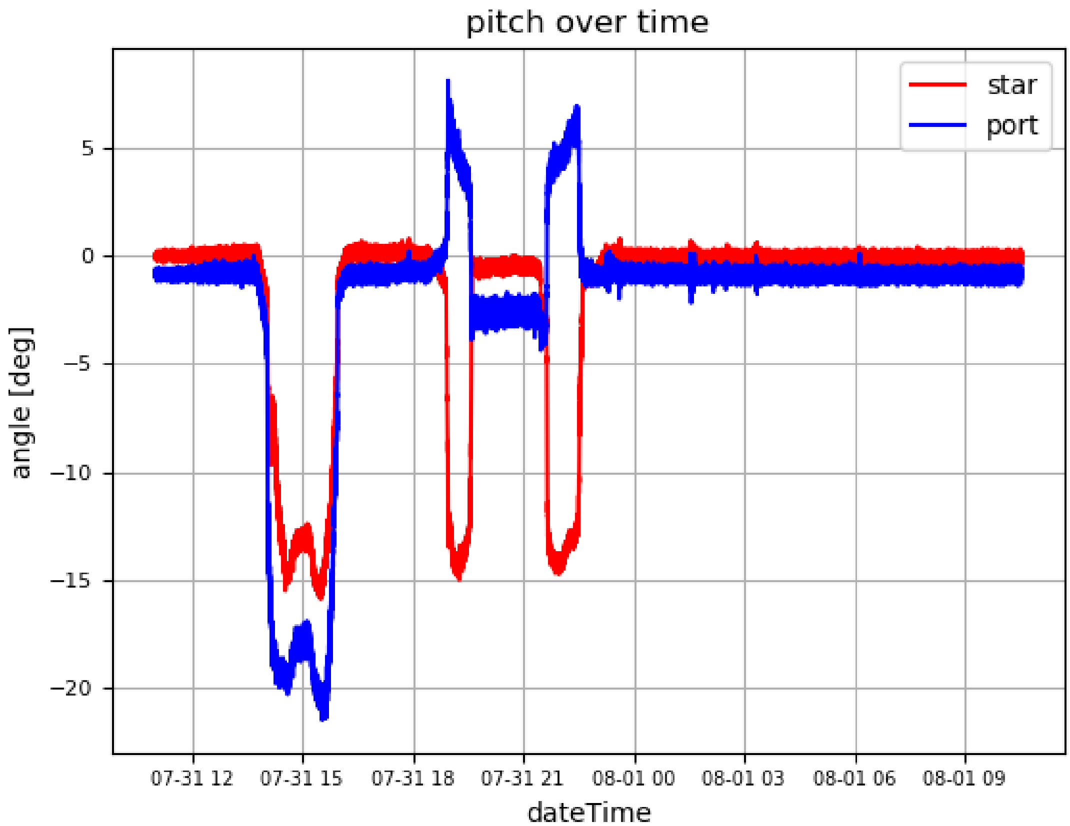

Figure 29: AWAC pitch measurements during deployment tests. First peak represents the attempted bow-down deployment. The second peak represents the side pivot launch deployment. Note: AWAC measurements are skewed due to 25deg (starboard) and 40deg (port) offsets of AWACs for velocity measurements.

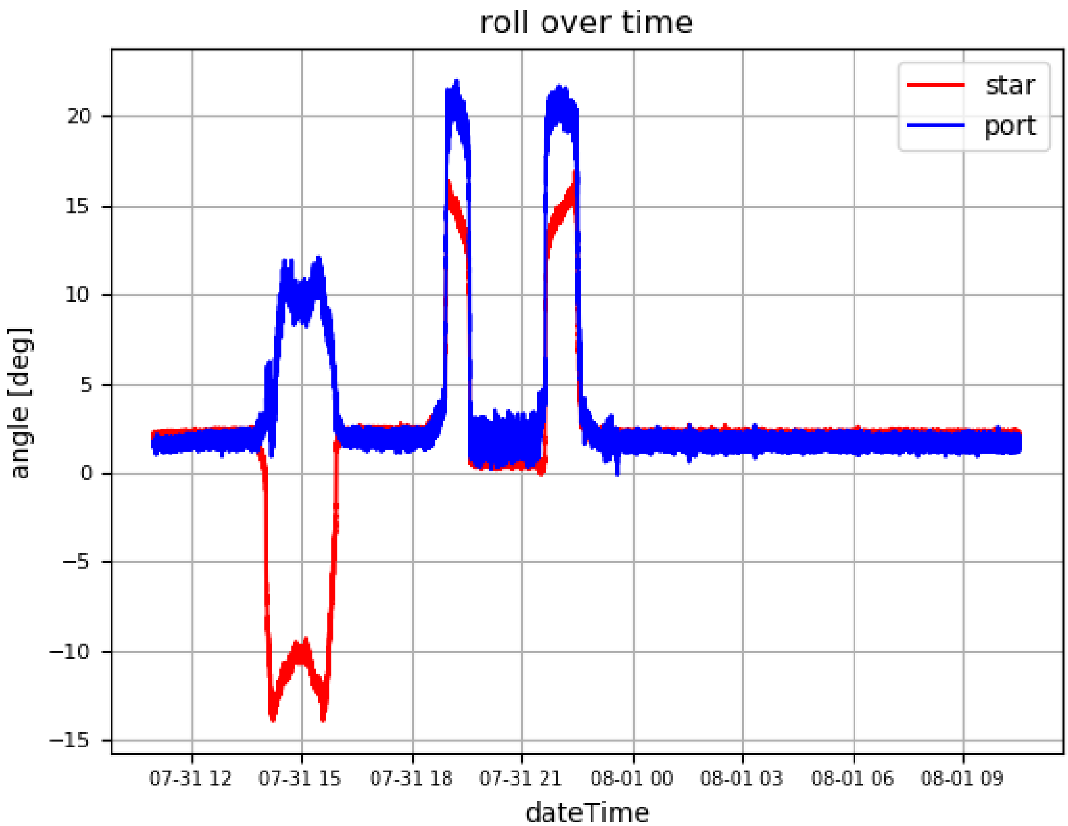

Figure 30: AWAC roll measurements during deployment tests. First peak represents the attempted bow-down deployment. The second peak represents the side pivot launch deployment. Note: AWAC measurements are skewed due to 25deg (starboard) and 40deg (port) offsets of AWACs for velocity measurements.

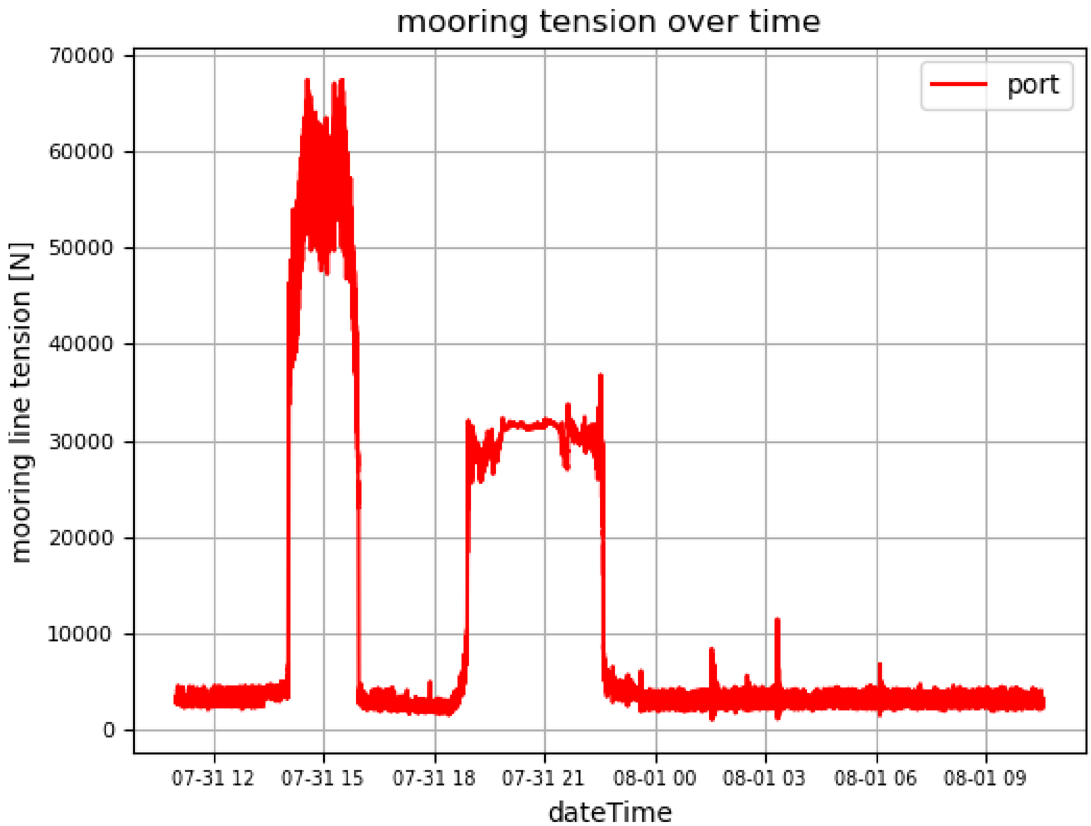

Figure 31: Mooring line tension during deployment tests. First peak represents the attempted bow-down deployment. The second peak represents the side pivot launch deployment. Predicted deployment loads at Igiugig for a *single* mooring line were 62kN, compared to the 67kN measured in the end pivot launch configuration. Based on numerical modeling conducted using OrcaFlex and Proteus modeling tools, it is expected that mooring line loads during a side pivot launch would be approximately half of those during an end pivot launch. Note that predicted loads do not include load factors and are far less than the mooring line design loads of 325kN

4.7 Installation of Submerged P&D Cables

4.7.1 Staging the cables

On July 22, the full length of P&D cable was unspooled and flaked out onto the barge at the beach laydown area. The cable was staged with the device end at the port bow of the barge and 225ft from that end the ductile iron piping began and continued until all 250 sections were attached. Once all the pipe sections were attached, bolts were placed every 10 sections to keep the protective pipe section together. “Cut away” tag lines were then added at multiple bight locations to prevent all of the cable from going overboard during installation.

4.7.2 Installation

Cable installation began on July 23 by bringing the barge with the staged cable down the river to the device (Figures 32 and 33). Once the barge pulled up next to the device the cable grips on the device end of the cable were attached to the device on the surface and the connectors were temporarily secured. Once the cable was attached and all deck personnel were in safe locations, the barge began to move across the river channel towards the junction box. As the cable was pulled overboard the tag lines were cut trying to keep an even layout of the cable on the riverbed. About 20ft from shore and about 100ft from the junction box the barge ran aground, and the operation paused.

The deployment operation resulted in a smaller catenary than expected and as a result more cable and ductile iron pipe remained than was needed to reach the junction box, with the barge secured in the shallow water 50 sections of the ductile iron pipe were removed. As haul block was anchored to the island and with a winch secured to the deck of the barge the remaining cable was pulled from the barge to the junction box.

Figure 32. P&D cable installation

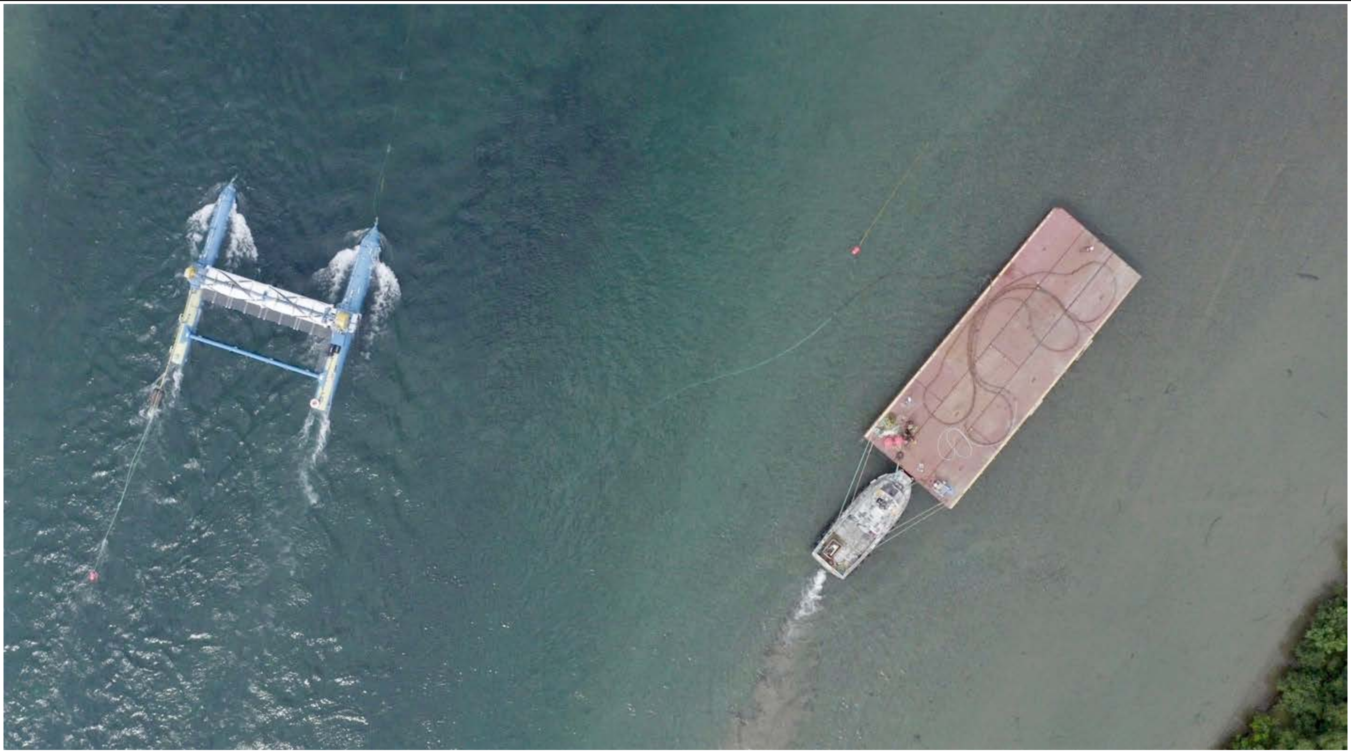

Figure 33. P&D cable installation, moving the barge towards the come-ashore

4.7.3 Fiber optics damage and repair

Although the submerged P&D cable had connectors on the RivGen device side of the cable the shore-side of the cable did not include connectors as the connections between the submarine and terrestrial cables would be made in the junction box by certified electricians. This meant that the fiber optic terminations were exposed to potential damage during handling (Figure 34). This was immediately identified as a concern and attempts were made to protect the exposed fibers. Unfortunately, these efforts were only partially successful as two of the fibers were damaged during cable installation. These damaged fibers were repaired by a fiber optic tech prior to completing initial commissioning.

Figure 34. Exposed Fibers (the four fiber terminations above the main cables with the exposed fibers extended below the main cable) at the submarine P&D cable shore-side termination

4.8 Environmental Monitoring Tests

The environmental monitoring system was tested as part of the initial validation tests with a biologist from the University of Alaska Fairbanks (UAF) onsite to review images from the cameras. This review confirmed that the quality, resolution, and orientation was acceptable for the monitoring effort (Figure 35). This was further validated during subsequent tests which included lowering fishing lures into the camera's field of view to confirm that objects the size of salmon smolt could be adequately detected.

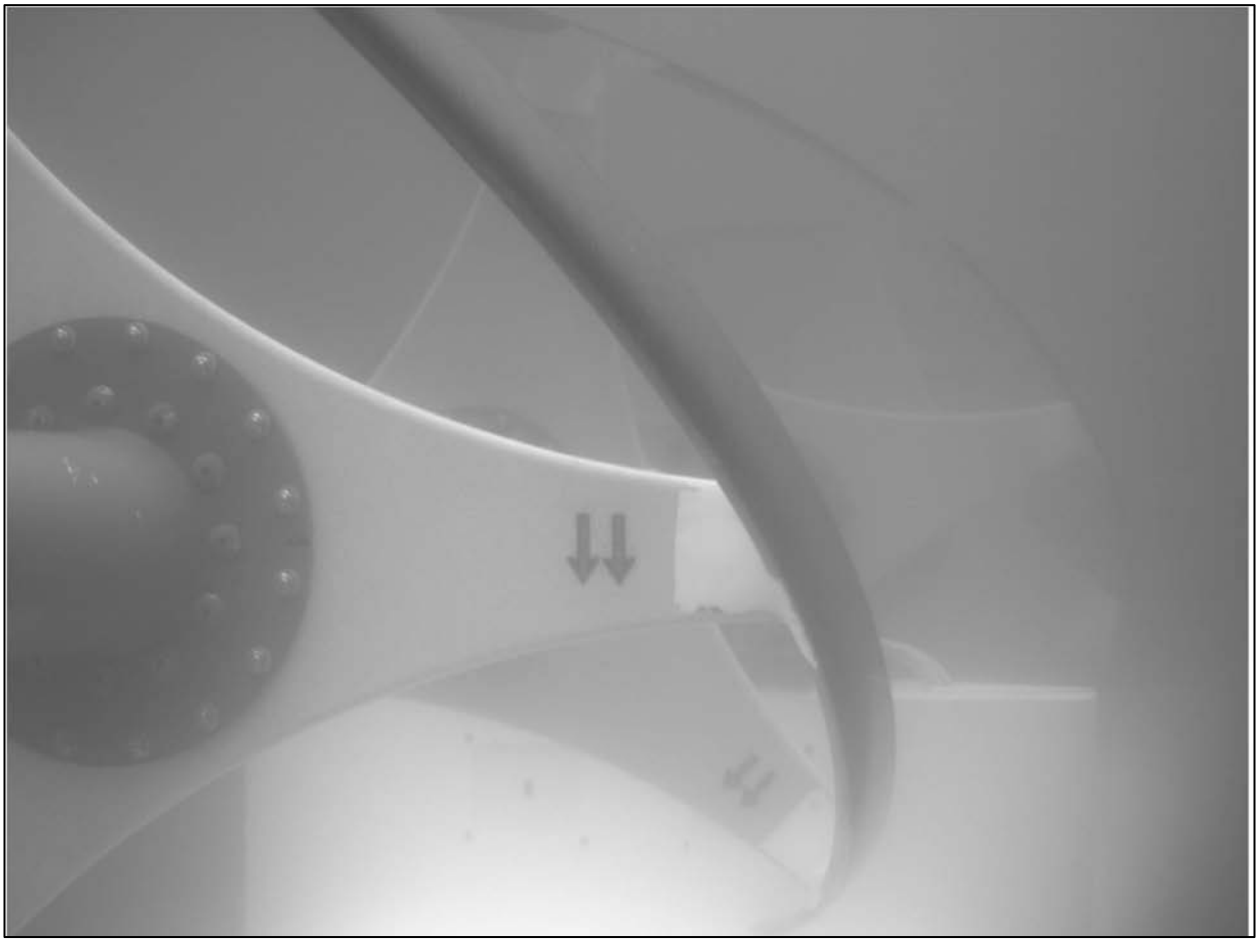

Figure 35. RivGen turbines as viewed from the downstream environmental monitoring cameras

Figure 36. Environmental monitoring validation tests. A fishing lure (circled in red) is the approximate size of a salmon smolt.

Along with validating the cameras, the collection software, StereoVision, was tested. Unfortunately, issues arose with this software working on the full camera network. As a result, the cameras native software, SpinView, was used to capture images. While this could perform adequate recordings, it could only record one camera at a time and challenges with storing the images in the correct format arose.

4.9 Initial System Commissioning

Initial system commissioning included final set up of all system communications, data logging, validation of device and shore station instrumentation measurements, device power production through a resistive load bank, and finally grid connection. This process took longer than expected due to issues encountered along the way. The initial commissioning period lasted from August 1 to August 18. On August 18 during the initial attempts at grid connection, the RivGen experienced a foil failure (see *RF-RV20-10752 – Turbine Joint Failure Overview – Aug. 2019*). Details on the subsequent turbine retrofit, maintenance events, and final commissioning are found in *RF-RV20-10735 – Open Water Operations and Maintenance Report*.

4.9.1 Device communications and instrumentation validation

Although communications to the device had been tested during initial system integration tests and again during on-site assembly, these communications had not been tested through the full-length cables. This additional cable length did not appear to create an issue during initial tests; however, a number of device instruments were found to be not functional. These included: one of the mooring line load cells, one of the mid-stanchion bearing temperature sensors, the shallow water ice profiler (SWIP), the generator search coil, and the generator bearing accelerometer. These instruments were considered not vital to the overall system functionality, and despite their loss, it was decided to proceed with system commissioning. Attempts to repair missing data streams were made during the pre-winter planned maintenance (see *RF-RV20-10735*).

Despite communications with the device being validated, on August 5, while performing the initial operational tests through the secondary load, communications with the SIM and SPI were lost. Camera video was still maintained however, indicating that the cables were still in-tact, and the SIM was not fatally damaged. Eventually, communications were re-established by transitioning from a data connection over DSL cable to one over the fiber optic cables. Although DSL communications is still available as a back-up if the connection via fiber optics is lost, the interference created by the operations of the generator and VFD will continue to impact the reliability of DSL communications.

4.9.2 Internet connections and power plant communications

In addition to the communications with the RivGen device, communications needed to be established between the RivGen shore station and the Igiugig Power Plant and between the Shore Station and the internet as this would allow for off-site monitoring and controls of the system. The original plan was to use a network extender to connect the RivGen shore station to Igiugig's cell tower. Although this had been successfully tested during initial wiring of the shore station, this proved ineffective once the shore station was moved to its installation site. This appears to be the result of the lower elevation of the installation site resulting in a loss of line-of-sight communications with the cell tower. Numerous attempts were made to resolve this issue including the elevating the antenna at the shore station with makeshift towers on the top of the shore station. Eventually, connection to the internet was achieved via a 900MHz radio connection to the power plant. Although this has been effective, it may be able to be improved by moving the receiver on the power plant to reduce possible interference from the electrical equipment and metal roof of the power plant. This radio connection also provided the communications to the Igiugig Power Plant, which allowed load information on the diesel generators to be transferred to the shore station. This information was critical in determining the allowable RivGen power output in order to ensure the load on the diesel generators does not fall below the minimum threshold for sustained operations.

4.9.3 Shore station instrumentation and power electronics controls

Along with external communications, interfacing with the instrumentation and power electronics components within the shore station continued to be refined throughout initial commissioning. This was primarily centered on final programing of the variable frequency drive (VFD) and the SMA inverters. By August 17, the communications between these components and the SCADA system were finalized and both the VFD and SMA were considered ready for grid connection.

On August 8, while attempting to test the connection between the VFD, the SMA and the grid, in order to test the ability of the VFD to motor the RivGen generator, a short in the shore station was created due to the on-shore braking circuit being engaged. This resulted in a temporary brown-out for the grid, due to a rapid current demand on the Igiugig power plant. Although the shore station had breakers to prevent this, they were higher rated then the ones in the Igiugig power plant which meant that the power plant breakers actuated first. Although this brown out only lasted a few seconds, it highlighted a flaw in the wiring design of the shore station. This was corrected by removing the VFD connection to grid power as motoring the RivGen generator was not required for operation (due to the self-start ability of the turbines, see 4.9.4 Secondary load operations). Alternatively, if motoring the generator is required, this could be remedied by altering startup procedure to release the brake prior to engaging grid connection to the VFD. The RivGen device was not electrically connected to the shore station during this event and was not affected.

4.9.4 Secondary load operations

On August 5, the RivGen brakes were released, and power production operations began. Initial operations were conducted with the RivGen only connected to a secondary resistive load, so that no RivGen power could be put onto the grid until the system was fully characterized.

The first planned test was to release the mechanical and electrical brakes and to see if the turbines would "self-start." If the turbines self-started, this would allow for the removal of the VFD-grid connection as the VFD would not be required to "kick-start" the generator. Once the turbines fully started, the next test would be to reduce the turbine speed by gradually modifying the resistance level of the secondary resistive load. In this way, the primary braking mechanism (the secondary load) would be validated. Additional braking tests and a full system power generation characterization were to follow these initial validation tests.

Upon release of the mechanical and electrical brakes, the turbines successfully self-started and freewheeled at approximately 75RPM. This was a big success as it was an early indication of the hydrodynamic capabilities of the turbines. Following this initial "take off" the secondary load resistances were slowly reduced in order to draw more power into the secondary load and eventually stall the turbines. At the second highest resistance level (21.7Ohm) there was a failure in the secondary load relay cabinet. This failure resulted in the turbines returning to freewheel until the on-device electrical brake was engaged to bring the turbines to stall.

An investigation into the failure revealed a lack of thermal paste on the back of the contactor switches in the secondary load branch switching cabinet, combined with the sharing of contactor heat sinks likely resulted in the overheating of the switches. Once one of the switches failed, this resulted in a cascading failure. Based on these findings and the nature of the failure, the entire contactor/relay cabinet was replaced. This included replacing the original solid-state relay switches with higher capacity mechanical switches that do not require heat sinks.

On August 12, the secondary load relay cabinet was replaced, and on August 14, the secondary load was tested using a local generator. This method for testing was selected as it allowed for secondary load validation without requiring rotating turbines and while mitigating any issues that could result from grid connection.

These tests proved successful, and on August 15, the RivGen turbine brakes were again released and the RivGen system was successfully operated through the refined secondary load. These tests indicated clear increases in performance of the system. Not only did the RivGen 2.0 Power System produce more power than the RivGen 1.F, but the measured power was approximately 20 percent higher than the predicted power output. Although operations through the secondary load results in power production data at discrete set points (Figure 37 and Figure 38) the complete power vs. tip speed ratio (TSR) was determined based on these secondary load points (Figure 38).

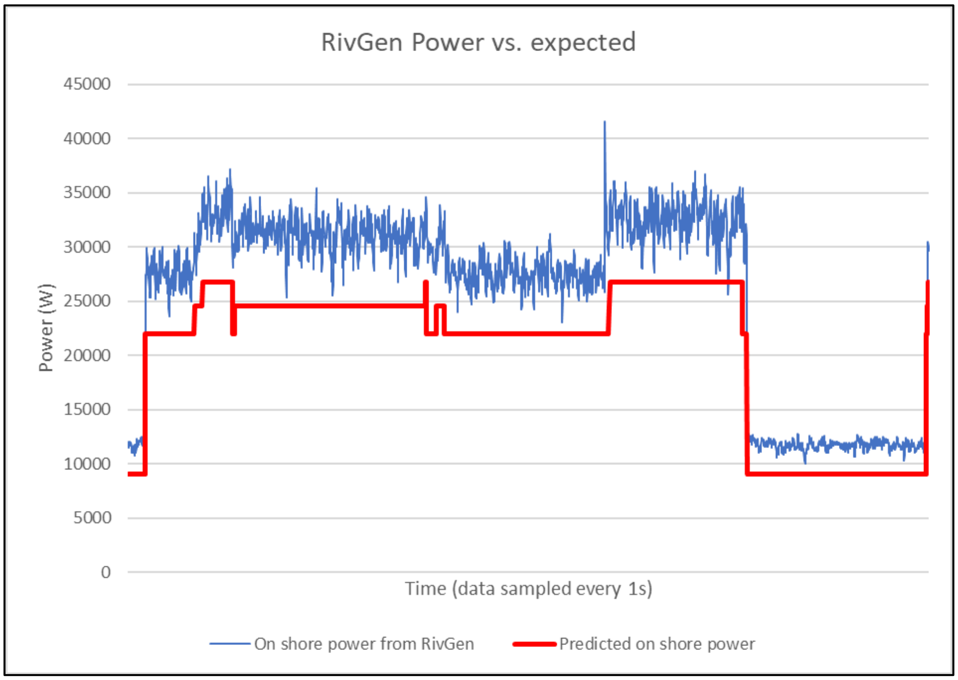

Figure 37. Actual vs. predicted power from the RivGen Power System during secondary load performance tests

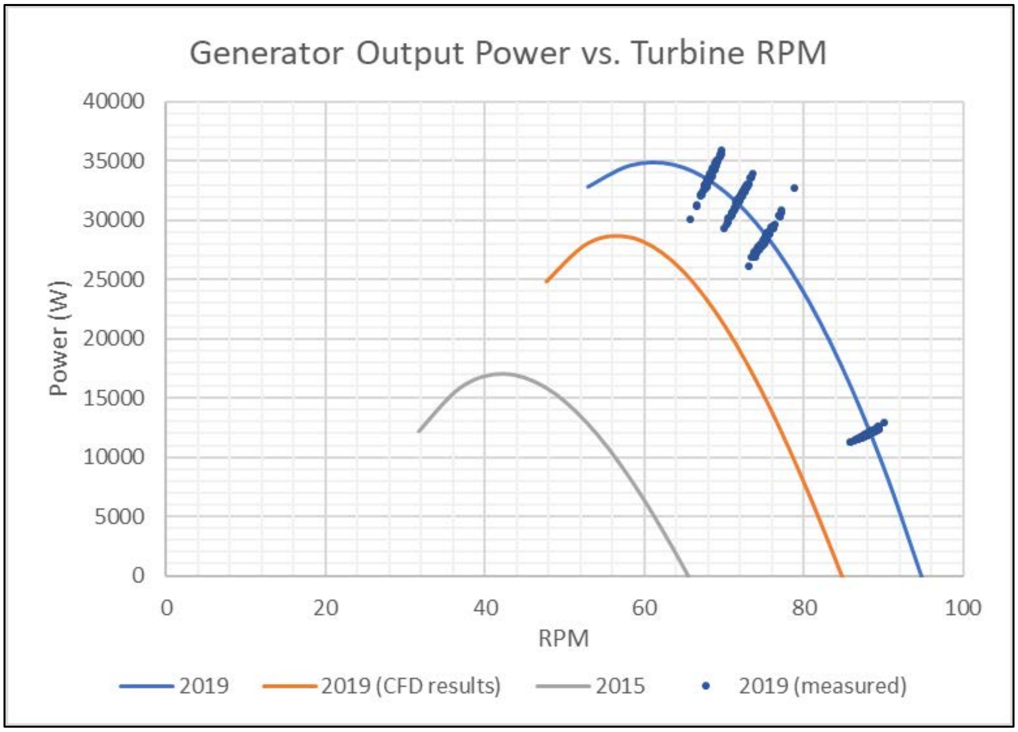

Figure 38. Preliminary power output of the RivGen 2.0 compared to the RivGen 1.F and predicted power for a common (2.1m/s) water speed

4.9.5 Grid connection

Following successful operations into the secondary load and initial power system characterization, the next step was to begin placing power onto the Igiugig grid. On August 17, this process began by applying DC voltage to the SMA inverters via passive rectification on the VFD. Once connected, the VFD would be turned on to provide active rectification while applying a low torque demand from the generator. This would allow the inverters to fully connect and begin placing power onto the grid.

Unfortunately, during the initial start-up of the turbines prior to beginning the grid-connection tests, the turbines unexpectedly stalled. Review of the environmental monitoring cameras revealed that at least one of the turbine foils had detached from its struts. Subsequent inspections revealed that three of the six foils had been dislodged.

As a result of the turbine failure, the initially commissioning was halted until the RivGen device could be removed, repaired, and re-installed. These maintenance operations and subsequent completion of commissioning are found in *RF-RV20-10735 – Open Water Operations and Maintenance Report.*