ACHIEVING COST REDUCTION IN THE MRE INDUSTRY; INTEGRATED DESIGN AND O&M EFFORTS AT RITE

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INTRODUCTION

As the first tidal device developer to deploy an array of grid-connected tidal turbines at its Roosevelt Island Tidal Energy (RITE) Project[1], in New York, NY, Verdant Power has continued to address the issues associated with commercial expansion to MW-scale array projects.

The installation, operation and maintenance (IO&M) component of the project economics becomes increasingly important as arrays grow to commercial scale, driving the Levelized Cost of Energy (LCOE). The Verdant approach to technology advancement has been to demonstrate cost-effective solutions at the 5m-rotor diameter scale at a highly accessible tidal site. Simultaneously, environmental compatibility has been confirmed. These efforts are leading to device, system, and ultimately array, performance certification, and scaling to larger turbine rotor sizes.

In 2016 Verdant Power began work on a potentially [2] 3-year DOE project: *"Integrated Development and Comprehensive IO&M Testing at RITE of a KHPS TriFrame Mount*," with the objective to conduct an integrated design process to develop, build, install, and operate a TriFrame™ (TF) mounting structure supporting three Verdant Power Gen5 Kinetic Hydropower System (KHPS) turbines at RITE. Figure 1 shows the TF oriented in the tidal flow. This arrangement allows for close placement of three turbines without a negative impact on turbine performance in either flow direction.

This full-scale, open-water project will also include a complete maintenance cycle. Project goals include 1) advancing the TF design from the Technology Readiness Level (TRL[3]) 3 to TRL 8 2) optimizing the TF design for Capital Expense (CAPEX) and Operational Expense (OPEX), specifically, reducing the time and cost of on-water work (OWW), for installation and maintenance while 3) meeting structural performance requirements, 4) meeting regulatory and environmental requirements, and 5) providing a path for scale-up.

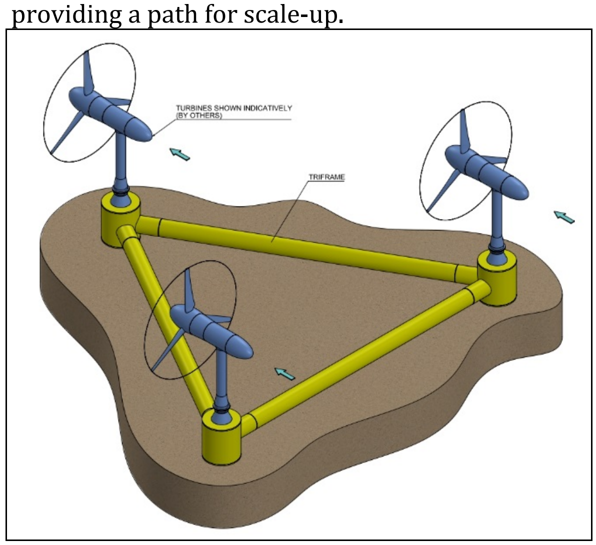

FIGURE 1. TF WITH 5M GEN5 TURBINES FOR RITE [PRELIMINARY PRODUCT DOE 7349]

This paper presents the results of the Budget Period 1 effort, in the context of scale up of

[1] See www.theriteproject.com; FERC P-12611 (2012)
[2] DE-EE0007349 is awarded in three Budget Periods (BP); this work reflects BP-1.

[3]The widely-used framework in which TRL 1-3 is proof of concept, TRL 4-6 is lab and scaled deployment, TRL 7-8 is full-scale pre-commercial deployment, and TRL 9 is commercial.

devices and arrays to achieve the needed LCOE reduction objectives. It builds on the DOE 7349 work as Verdant looks to develop a viable US-based export market, and with policy and incentives, grow this industry within the US at commercial scale. Verdant's strategy of stepwise advancement on CAPEX and OPEX array issues at RITE is aimed at achieving insight into the LCOE of commercial projects.

1- TriFrame Innovative Design

The TriFrame mount designed in BP1 has several key innovations:

- Integrated design process to coordinate CAPEX and OPEX reductions
- Universal, scalable mount design for structural stability and long term (20-year) life
- Scalability

The TF was designed in a cycle of iterative design stages that closely integrates the structural design with that of the operational activities: deployment, installation, and O&M. The CAPEX and OPEX contributing factors must be addressed in concert in order to successfully optimize overall LCOE.

At the 5m turbine diameter scale, the TF allows single-operation installation of three turbines. For O&M, it can allow a rapid and cost-efficient Retrieve & Replace (R&R) operation, minimizing both the time and cost of OWW, the major driver of CAPEX and LCOE.

The TF is a triangular welded tubular steel structure with identical vertex assemblies connected by arms. Each vertex assembly consists of a leg, stub arms, a top surface for mounting a turbine pylon, and at the bottom, a foot that is specifically suited to the site. The shape and ballasting of the TF "hybrid" design contribute to its ability to hold the turbines securely in the flow, resisting thrust, torque, overturning, and sliding loads from the turbines in the reversing flows.

To reduce the time on-water, and to eliminate complicated leveling systems operating underwater, the TF is pre-leveled based on high resolution bathymetry data collected before deployment.

Based on sub-centimeter bathymetry data collected in November, 2015, Verdant determines a specific location for the TF and the length of each leg is sized to match with the elevation of its foot location. See Figure 2 which includes the final TF location superimposed over the high-resolution (hi-res) bathymetry data.

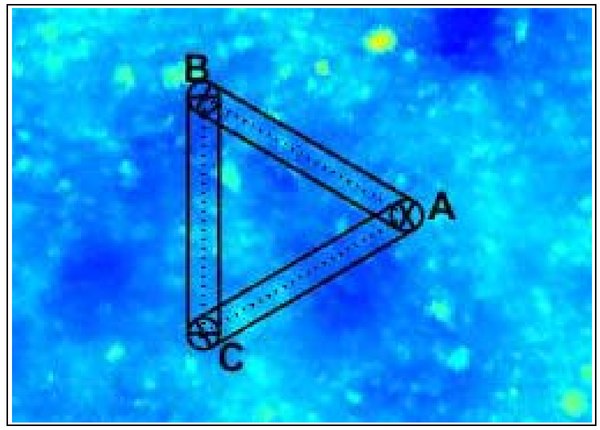

FIGURE 2. HI-RES BATHYMETRY OF TF PLACEMENT [PRELIMINARY PRODUCT DOE 7349]

The TF foot areas and arm paths are analyzed and selected to ensure adequate clearance from any obstructions such as boulders. Further, as shown in Figure 3, the micro-sitting details of each foot landing place can be evaluated for slope and obstructions, such as significant rocks, that might impact sliding and stability. For all positioning analyses, a conservative 0.5m placement error in all directions is used.

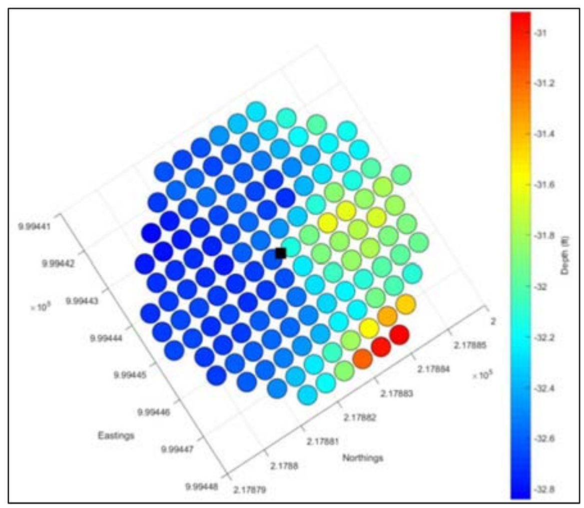

FIGURE 3. HI-RES BATHYMETRY DETAIL OF TF FOOT PLACEMENT [PRELIMINARY PRODUCT DOE 7349]

To ensure that the deployment location conditions haven't changed significantly since the characterization in 2015, Verdant will perform an updated high-resolution bathymetry campaign shortly before the TF deployment.

The TF design is inherently general-purpose, and adaptable to different sites and scales. In addition to accommodating the loads of a given resource, the key unique physical element is the foot interface to the site bottom. In the case of RITE, the bottom is essentially bare bedrock (gneiss), so the feet use spikes with pressures adequate to engage the rock to provide the required bidirectional sliding resistance. Figure 4 is a diagram of a RITE foot. Other foot designs will suit other bottom constituents.

Avoiding post-installation securing operations, especially by divers, is key to minimizing on-water work for IO&M, and thus CAPEX, OPEX, and LCOE.

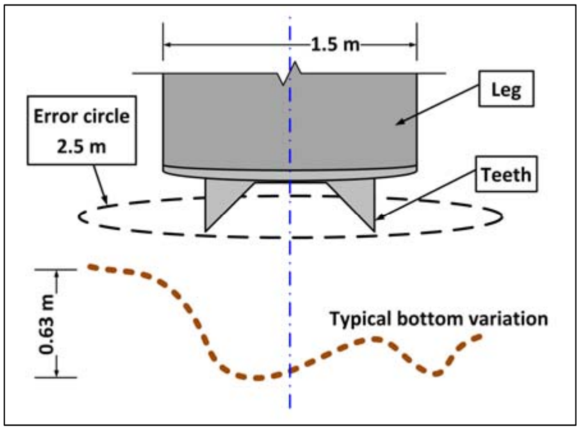

FIGURE 4. RITE SITE TRIFRAME FOOT DIAGRAM [PRELIMINARY PRODUCT DOE 7349]

The TF is scalable to accommodate larger turbine sizes in deeper water. The CAPEX and OPEX advantages are applicable at the increased loads along with the ability to create site-efficient arrays. Some structure and operations aspects will change at increased scale. For example, ballasting of the structure is flexible to suit the resource and site requirements. Also, with larger turbines, most IO&M operations will involve individual turbines.

2- Tools to reduce Risk and On-Water Work Cost

To accomplish the efficient IO&M procedures, two specific tools were incorporated into the overall system design:

1. TriFrame Positioning System (TFPS)

In order to accomplish the precise placement installation. The TFPS, shown in Figure 5, allows the TF to be placed on the bottom in the position and orientation selected from the geo-referenced bathymetry with better than 0.5m accuracy. Once placed properly, the TF is correctly oriented within specification in azimuth and level for all three turbines.

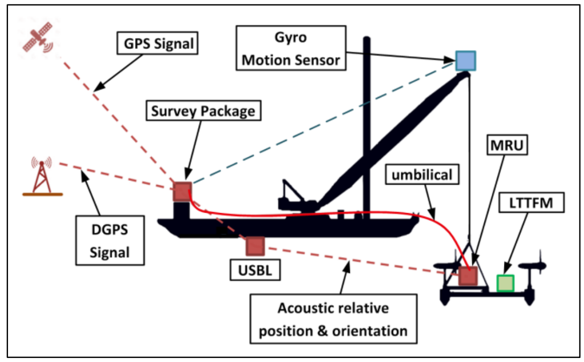

FIGURE 5. SCHEMATIC DIAGRAM OF THE TRIFRAME POSITIONING SYSTEM (TFPS) [PRELIMINARY PRODUCT DOE 7349]

2. Lifting and Retrieval System (LARS).

The second tool needed for rapid and efficient on-water operations is a permanent reusable lifting rig known as a LARS. This rig safely lifts the TF with three turbines under all conditions. It quickly engages and releases the TF using three hydraulic latches controlled from the crane barge. For retrieval operations it also carries instrumentation that allows it to be rapidly re-oriented to the TF and re-latched for lifting. The LARS is shown lifting the TF in Figure 6.

Additionally, to minimize the risk of OWW delays and cost overruns due to weather, vessel availability and operational inefficiencies, Verdant has partnered with Mojo Maritime. Mojo has developed a sophisticated tool MERMAID (Marine Economic Risk Management Aid) that organizes and evaluates these on-water actions and their risks for the MRE industry. The detailed TF deployment, installation, and R&R OWW sequences have been preliminarily evaluated using MERMAID, for logic, accuracy and risk mitigation. Storyboarding of the sequences (Figure 6) is useful for preparing for the OWW as well as identifying risks and time and cost consequences.

<u>Importance of Risk Management</u>

In accordance with the evolving NREL MHK Technology Development Risk Management Framework [4], Verdant implemented TRL-specific risk management for the TF development.

With supporting reviews by NREL, Verdant developed a project-specific Risk Register which itemizes the critical project risks and includes an evaluation of initial risk severities and probabilities, the product of which is the risk priority number (RPN). Based on a number of risk responses, including mitigation, Verdant minimized the residual RPNs and identified risk-specific contingency plans. These will be refined and finalized if the DOE decides that the project will proceed.

FIGURE 6. RITE MERMAID STORY BOARD [PRELIMINARY PRODUCT DOE 7349]

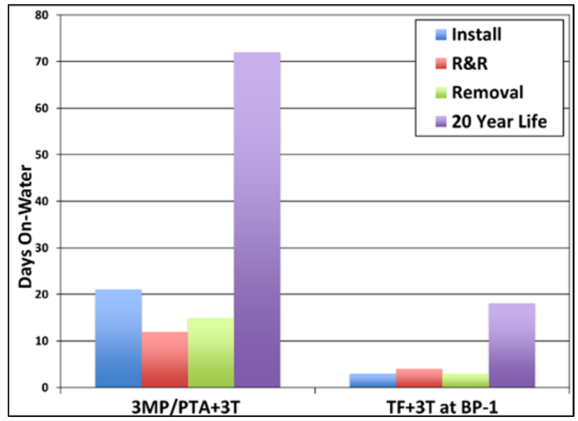

FIGURE 7. OWW DAYS METRIC REDUCTION AT RITE [PRELIMINARY PRODUCT DOE 7349]

3- Measuring Performance and LCOE

As outlined in a previous Verdant Power METS paper [5] the development of International Standards and Technical Specifications, and their support of certification, is critical to the success of the marine energy industry, reducing risk and increasing stakeholder confidence. Specifically, the tidal energy power performance Technical Specification (TS), IEC/TS 62600-200 [6] will be followed in the next phase of this project to collect and process both power and velocity data, including the deployment of current profilers, in order to produce a power curve and calculate the overall device and system efficiency for full-scale tidal energy converters in other sites and as a basis for meaningful comparisons with other devices and installations.

<u>Project metrics on the path to LCOE</u>

During this first phase of the DOE project, several key metrics were targeted for improvement and are projected to be achieved during the RITE project. The first, days of on-water work (OWW), is shown in Figure 7, comparing the baseline (left) RITE Gen4 experience of a monopile mount and pile-top adapter (MP/PTA) (2005-2009) with the current TF and 3 Turbines (TF+3T) project (right). The TF+3T clearly shows the significant reduction in OWW days. The reduction in total project lifecycle effort (installation, three Retrieve and Replace cycles over 20 years and a removal) is dramatic – from over 70 days to under 20 days (a 70% reduction) in time of vessels active on the water.

Similarly, in terms of the other key metrics, reducing LCOE and increasing Annual Energy Production (AEP), the project is expected to achieve significant improvements in over the baseline as shown in Figure 8.

This reduction is significant in the context of the evaluation of this project, and is generally in line with the DOE 2017 baseline expectation for tidal current (0.58 $/kW-hr) [9]. However, this project, at 5m scale, and the resulting LCOE, is only at the beginning of the pathway to achieving TRL/ TPL at 7-8-9, defined as competitive with other renewable energy. Additional reductions in LCOE are expected during BP-2 and BP-3, assuming continued funding.

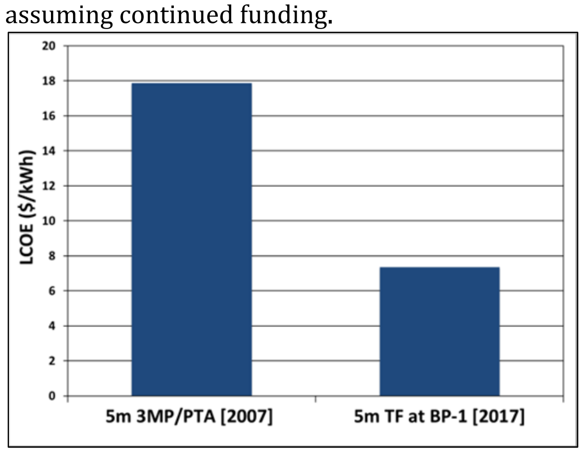

FIGURE 8. RITE REDUCTION IN LCOE [PRELIMINARY PRODUCT DOE 7349]

4- Achieving commercial LCOE

Beyond the anticipated RITE installation and R&R cycle, Verdant is working in parallel to scale up the TF and arrays with resource assessment and streamlined approaches to environmental consenting. These interconnected elements advance the MHK industry and provide the necessary design to achieve reductions in CAPEX and OPEX while increasing specific AEP to ultimately reduce LCOE.

<u>Achieving DOE's LCOE Target Strategy</u>

In December 2016, DOE issued a draft MHK Program strategy to achieve LCOE reductions [9] including reductions of "…80% compared to the 2015 baseline LCOE values for current (0.58

$/kW-hr) technology by 2030". The four-phase path of simultaneously reducing costs while increasing the number of deployments includes:

1. Foundation of Costs, Performance, Resources and Barriers Determined
2. Aggressive Technology R&D and Demonstration of Devices
3. Innovations and Demonstrations of Arrays
4. Proving Commercial Viability

The current effort at RITE falls between phases 2 and 3, but requires a significant investment to move into commercially viable array demonstrations. Two areas for achieving LCOE reductions are resource assessment and environmental streamlining. However, the true measure of achieving this target will come from the significant funding and incentive commitment — like the US government provided to the nascent wind industry for 30 years — to support these innovations and demonstrations to drive the cost of the technology to commercial levels.

Tidal Resource Assessment (RA)

With the publishing of the IEC/TS 62600-201 Tidal energy resource assessment and characterization in 2015 [2], the evaluation of the tidal energy resource has a consensus-based guideline for further investigations and should resolve discrepancies in prior RA characterizations of the RITE site [7, 8]. Verdant Power has used this TS to characterize sites globally [3].

The use of this Technical Specification, and adherence to its methodologies, is critical for the accurate and common assessment of tidal energy resources, which ultimately allows project developers, investors, and others, to make educated decisions regarding the energy generation potential. More information on TC 114 can be found at the following link: http://www.iec.ch/tc114.

Environmental Streamlining

Under an ongoing DOE project[4], and as a participant to the OES Annex IV Offshore Renewables Joint Industry Programme for Ocean Energy (ORJIP) Expert Forum on Environmental Monitoring of Tidal Turbines and Arrays, Verdant's perspective on ways to improve the advancement of commercial tidal array projects by reducing the environmental and regulatory burden includes:

1) Proportionality: Perhaps the greatest lesson learned from the RITE experience is the concept of proportionality, meaning studies and monitoring in proportion to the scale, stage, cost, duration and potential of the project to cause effects.

2) Practicality: The reality of the cost/value proposition of data collection and studies is a practical constraint, and balancing the trade-off between cost and the actual indicator levels that could cause impact is important for first arrays to be deployed.

3) Research Funding: If the nation is serious about a viable offshore renewable energy industry, resource agencies and researchers also must be funded in parallel to conduct monitoring on areas of strategic environmental importance and mutual benefit to all developers to support the renewable energy objective.

ACKNOWLEDGEMENTS

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[8] Tidal energy site resource assessment in the East River tidal strait, near Roosevelt Island, New York, New York, Renewable Energy 71, 2014

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[4] A DOE funded, Sandia Labs-led effort to understand the costs associated with licensing and compliance for MHK projects to inform strategies to reduce the levelized cost of energy (LCOE) for MHK projects.