University Marine Energy Research Community

2023 Conference

4-6 October | Durham, NH, USA

Bridge Support Structure for Horizontal Axis Tidal Turbines Parametric Study

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Abstract

Many island countries are heavily dependent on diesel fuel for electricity, which contributes to harmful emissions and high electricity costs in these locations. Archipelagos create channel opportunities that produce higher current velocity potential that can be utilized. In the Caribbean archipelago, we focused on a site in the US Virgin Islands which was selected through satellite images and confirmed using USCROMS current mapping. In this paper, a novel bridge-like support structure for horizontal axis tidal turbines (HATTs) is being proposed that can better utilize surface current velocities within a channel and create a more efficient operation and maintenance (OPEX) process. This design is based on NREL's RM 4 current energy converter and optimized to better suit known issues that lead to the failure of tidal energy in these locations. In isolated locations like archipelagoes, the extraction and maintenance of these devices will be extremely costly and inefficient leading to these devices not being economically viable. With a bridge-like structure that has HATTs attached, allows for easier access for OPEX and opportunity for local labor without the need for special large-scale devices. With current speeds being depth dependent, these HATTs can be launched at varying depths that would be most effective for each location. We use Solidworks to develop the model of the structural design. An actuator disk model will be utilized in determining the loads on the structure as a function of number of turbines, depth, and current speeds. This study confirms that this structural design can support several tidal turbine devices under varying conditions. This design is shown to be more efficient for archipelagos in utilizing higher current potential and allowing easier access for operation and maintenance of the HATT devices.

Keywords: Tidal Energy; Renewable Energy; Optimization; Tidal Turbines

1. Introduction

According to IRENA, ocean energy has a current resource potential from 20,000 TWh to 80,000 TWh of electricity per year. [1] While there are many devices that can harness this energy, horizontal axis tidal turbines [HATTs] work by converting the current kinetic energy into electricity. [2] This kinetic energy potential can be generated from tidal currents, ocean currents, and even wind-driven currents. There are many advantages to utilizing ocean energy, especially in island communities where access to natural resources and cost of living is high. Although there is such potential, ocean energy continues to be one of the least used renewable energy technologies as a result

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of site-specific requirements, high initial cost of construction, and high operation and maintenance costs. [3] Therefore, to utilize this resource, especially in islands that can benefit most from these technologies, optimization of the design must be done to improve the operation and maintenance methods. In archipelagos, islands are often near each other, creating unique channel opportunities with increased current speeds. A preliminary design of a bridge-like structure that can support the loads of these turbines is being developed that will take advantage of the proximity of these islets and utilize the high current potential found as you get closer to the surface of the water. This design will also allow for easier access to the turbines for operation and maintenance and eliminate the need of special equipment often necessary for the installation and removal of these devices when maintaining them. [4] Therefore, local communities will have more opportunity for local labor when developing these larger systems to support island-wide grid support.

2. Methodology

2.1 Technical Site Analysis

This analysis was done for two channels in the US Virgin Islands off the east side of St. Thomas. This location was determined through tidal analysis done using the US Caribbean Regional Ocean Modeling System (USCROMS) to determine a location in the upper Caribbean region which may hold the highest tidal current potential. [5] *Figure 1* shows that in the south-east side of St. Thomas shows extremely high tidal current potential and therefore, channels in that region will give the highest current opportunity. This model also provided current velocity at both locations measured at the sea floor. Through field data, current speeds closer to the surface were measured to be 4 times that of the sea floor. The data from the model was multiplied by a factor of 4 to account for the speeds the turbines will be operating corresponding to the depth. *Figure 2* shows the current velocity (m/s) in channel 2 over the course of a full year. This location has a mean current velocity of 1.42 m/s and a max velocity of 3.6 m/s which is adequate for HATT use. [6] The structure will be designed for site 2 which is ~150 meters from St. Thomas to the corresponding islet.

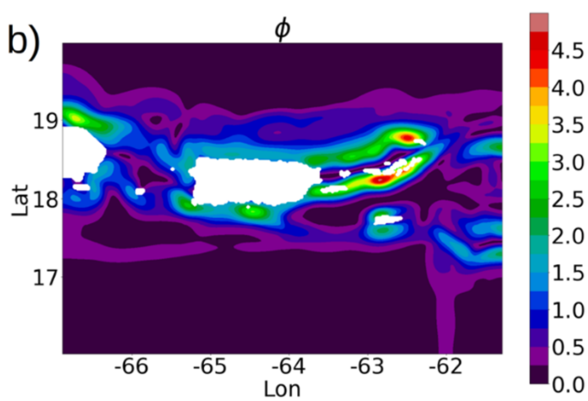


Figure 1: Map of the upper Caribbean region showing the magnitude of the tidal parameter. Higher tidal parameter corresponds to a higher current potential (Mukherjee et al.)

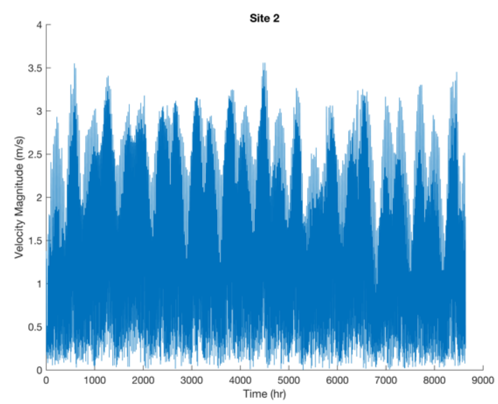


Figure 2: Hourly data for the velocity over a full year at site 2. At the sea surface the current speeds are shown to be over 4x these speeds at these sites.

2.2 Technical Design

This research is on the optimization of NREL's RM4 ocean current turbine model as shown in *Figure 3*. The original design is a moored glider with four axial-flow rotors attached to a 120 meter long "wing". Each rotor in the original design has a rotor diameter of 33 meters and a power electronics housing unit in the center of the structure as well. [7][8] In our preliminary design, we have a 150-meter-long bridge that spans from the tip of St. Thomas to an

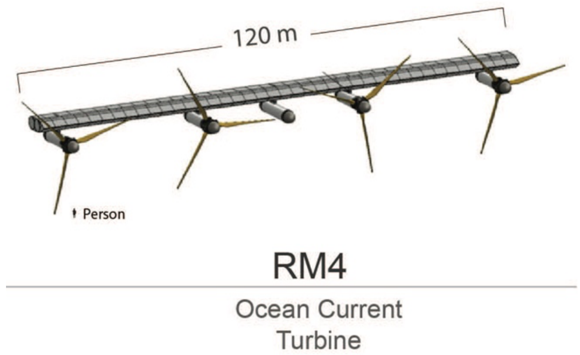


Figure 3: NREL's RM4 ocean current turbine concept. It has a 120-meter wing with 4 rotos spanning 33 meters each.

islet known as site 2 and is ascended 5 meters above the water. This is a fully steel preliminary design and initially assumes a simple rectangular beam as the bridge. The turbines are attached to steel rectangular columns and are 20 meters from the bridge to the rotor hub. The diameter of each rotor is 15 meters and the spacing between each turbine hub is 2D – so 30 meters from rotor hub to rotor hub. A total of 4 turbines is expected to be supported by the structure. An actuator disk model is used for this design to get the expected power for the system and the loads on the structure. The loads acting on the structure is determined using the SAP2000 modeling software. Refer to *Table 2* for the moment and shear force on the structure.
More details on the structure and turbine parameters used for these equations can be found in *Table 1*.

- The power equation is used to determine the expected power from the turbine.

$$P = \frac{\frac{1}{2} C_p \rho A v^3}{10^3}\ (kW) \tag{1}$$

- The thrust force is the axial force applied to the turbine from the current.

$$T = \frac{\frac{1}{2} C_T \rho A v^2}{10^3}\ (kN) \tag{2}$$

Table 1
Equation Parameters

Sea Water Density	ρ	1025 $\frac{kg}{m^3}$
Turbine Rotor Radius	r	7.5 m
Current Speed	v (mean)	1.4 m/s
Power Coefficient	C_p	16/27
Thrust Coefficient	C_T	8/9

3. Results

The equations above were calculated using the data taken from USCROMS to determine the annual power output of each turbine and the thrust. Being that the data is a measurement of the current speed for a full year, the sum of the power for each data point was used to determine the annual energy output. *Figure 4* shows the annual energy production for each turbine for sites 3 and 4. Based on our design, this value can be multiplied by 4 rotors to get an approximate annual energy output of 10,500 MWh of electricity. Assuming this power is fully used to replace diesel generation, diesel use on island would be reduced by 8.6%.

Our preliminary design can be seen in Figure 5, where each end of the bridge would connect to the shorelines of the islands. This structure would be designed to withstand the weight of the structure, the turbines, maintenance employees, and the forces acting on the structure from the

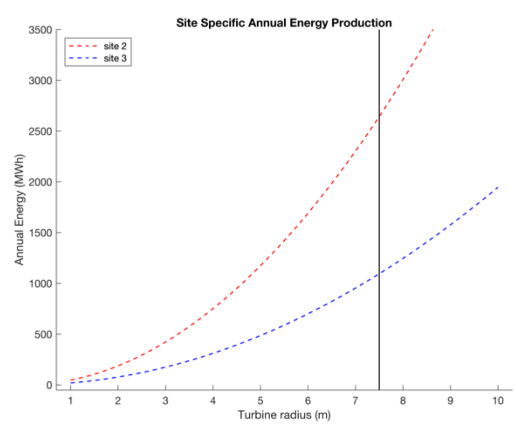


Figure 4: Annual energy production for varying rotor diameters applied to both sites.

thrust of the turbines. The mean of the thrust was inputted in SAP2000 to determine the shear stress and bending moment on the structure in *Figure 6*. This thrust value is 213 kN. See *Table 2* for forces acting on structure.

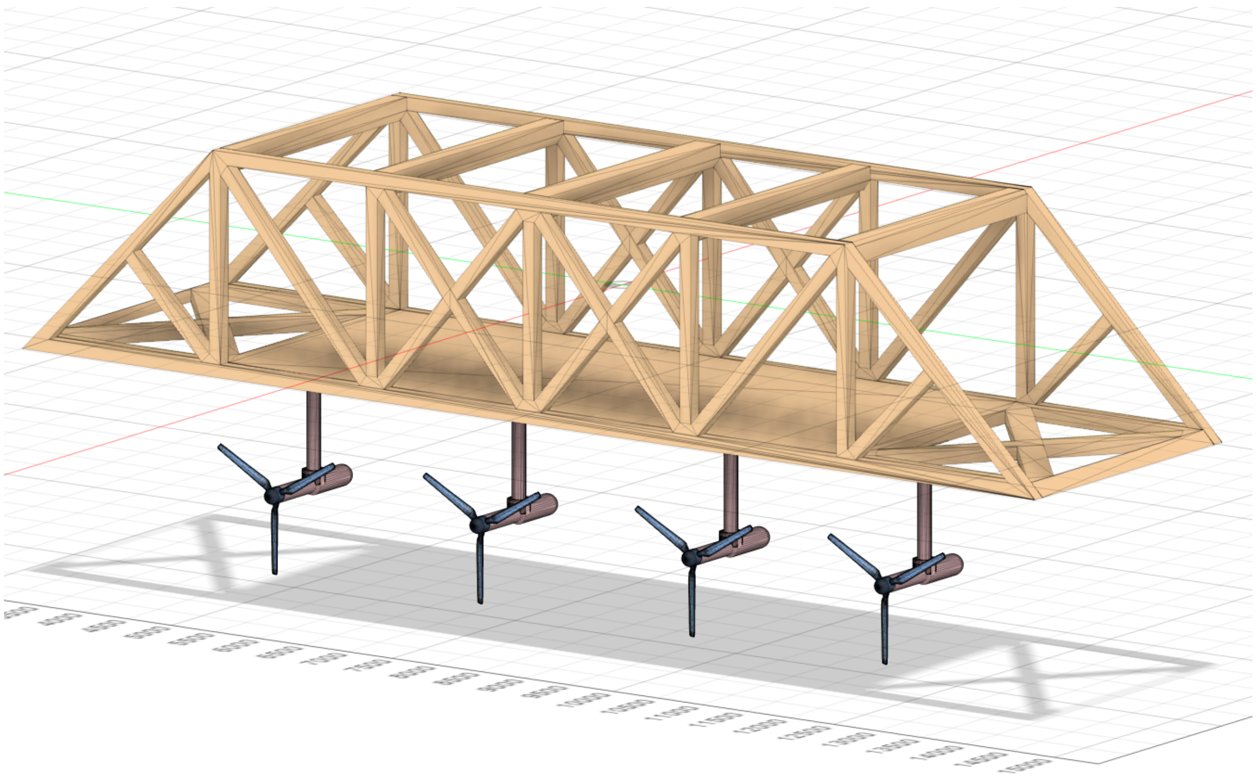
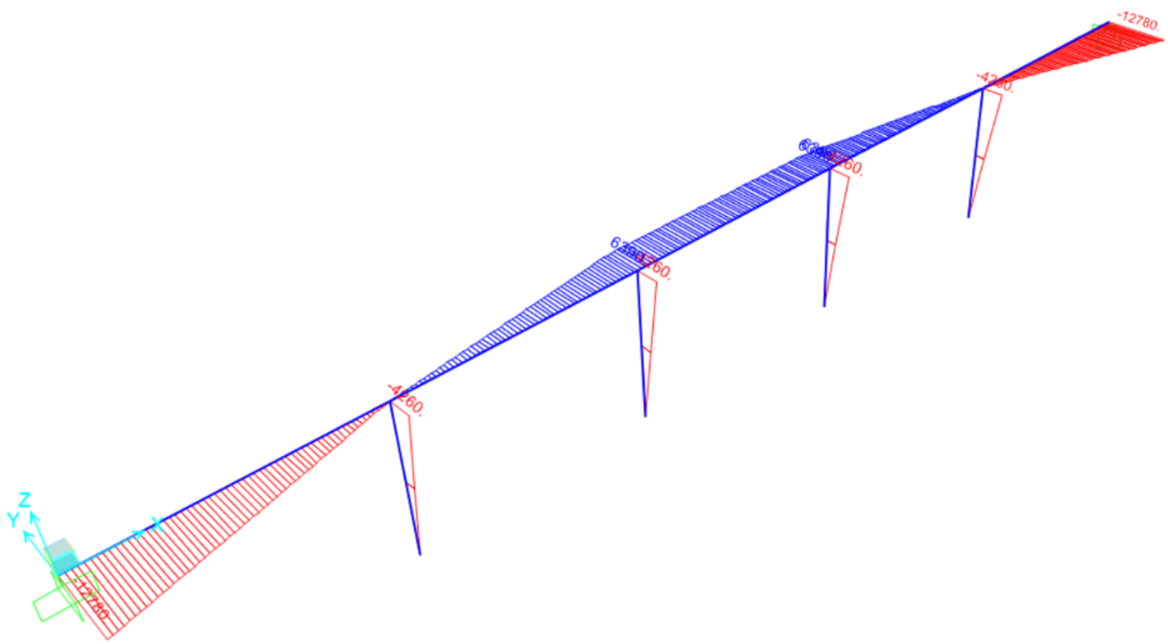


Figure 5: The preliminary turbine bridge design developed in Fusion360. This is a truss bridge structure with 4 turbines hanging below the sea surface. The truss bridge is 150m in length and the turbines are 20 meters from bridge connection to turbine hub. Each turbine is 15 meters in diameter.



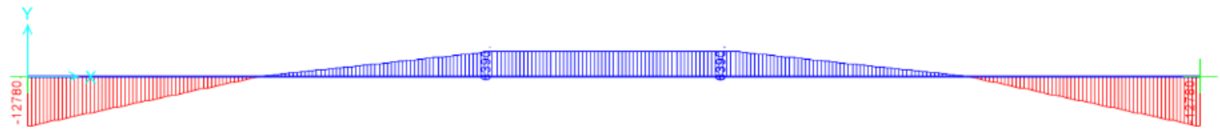


Figure 6: Bending Moment visual on the bridge structure with turbines at every 30-meter point. Structure is steel and assumed a simple rectangular design.

Table 2
Structural Parameters and Loads

Beam Length	l	150 m
Turbine Supporting Rod	z	20 m
Distance between Points	k	30 m
Bending Moment @ end points		12780 kN*m
@ mid point on beam		6390 kN*m
@ rod to beam connection		-4260 kN*m
Shear stress at ends		426 kN
Shear stress on rods		213 kN each

4. Conclusion

As the global transition to carbon net zero continues, the need to utilize ocean energy in every capacity is vital, especially for islands where access to resources and materials may be limited. Our design of a bridge support structure for horizontal axis tidal turbines is developed with the consideration of increasing efficiency through optimum turbine placement and improving operation and maintenance methods for the reduction of cost and opportunity for local labor. This design was developed through the optimization of NREL's RM4 to be applied in archipelagoes in the Caribbean wherever may have the channel opportunity. This is the preliminary design of what a structure of this scale can produce to reduce diesel use in the US Virgin Islands, but also assessing what forces are acting on the structure that will need to be addressed for future refinement. For future work, a more matured structural design for the bridge will be developed and the levelized cost of energy will be assessed to confirm the true reduction in cost this creates for this location.

Acknowledgements

Funding comes from the National Science Foundation Research Traineeship (NRT) Program Award Number 2021693. Thank you to Dr. Erin Baker and Dr. Krish Sharman for supporting this research. Thank you to Dr. Sonaljit Mukherjee for providing access to the data and research with USCROMS.

References

[1] "Ocean Energy Technologies Patents Deployment Status and Outlook," Aug. 01, 2014. https://www.irena.org/publications/2014/Aug/Ocean-Energy-Technologies-Patents-Deployment-Status-and-Outlook (accessed Jul. 31, 2023).

[2] G. S. Bir, M. J. Lawson, and Y. Li, "Structural Design of a Horizontal-Axis Tidal Current Turbine Composite Blade," in *Volume 5: Ocean Space Utilization; Ocean Renewable Energy*, Rotterdam, The Netherlands: ASMEDC, Jan. 2011, pp. 797–808. doi: 10.1115/OMAE2011-50063.

[3] C. Shetty and A. Priyam, "A review on tidal energy technologies," *Mater. Today Proc.*, vol. 56, pp. 2774–2779, Jan. 2022, doi: 10.1016/j.matpr.2021.10.020.

[4] J. Thake, "Development, installation and testing of a large-scale tidal current turbine".

[5] S. Mukherjee, D. Wilson, P. Jobsis, and S. Habtes, "Numerical modeling of internal tides and submesoscale turbulence in the US Caribbean regional ocean," *Sci. Rep.*, vol. 13, no. 1, Art. no. 1, Jan. 2023, doi: 10.1038/s41598-023-27944-2.

[6] P. Hagerman, George Brian, “Methodology for Estimating Tidal Current Energy Resources and Power Production.” Jun. 14, 2006.
[7] D. S. Jenne, “Levelized Cost of Energy Analysis of Marine and Hydrokinetic Reference Models: Preprint”.
[8] “RM4: Ocean Current Turbine | Tethys Engineering.” https://tethys-engineering.pnnl.gov/signature-projects/rm4-ocean-current-turbine (accessed Aug. 15, 2023).