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Technical Review of Companies able to Support the Education and Naval Installations' Renewable Energy Goals through the use of Tidal and Hydro-Kinetic Energy Devices

Lt. George Tyler Fischer, U.S. Navy

Raised in Dayton, Ohio, Lieutenant Fischer entered Officer Candidate School in October 2009. After receiving his commission in 2010, he was designated as a Civil Engineer Corps Officer. Lieutenant Fischer's first tour was with Naval Mobile Construction Battalion THREE, serving as the Intelligence Officer and Detachment OIC during deployment operations supporting CJTF-HOA in humanitarian and civic assistance missions. In 2012, Lieutenant Fischer was assigned to Naval Base Ventura County (NBVC) as the Assistant Public Works Officer and Assistant Officer in Charge of San Nicolas island. During his assignment to NBVC, Lieutenant Fischer supported Naval Air Warfare Center Weapons Division (NAWC-WD) and several other installation tenants by managing reliable utility and facility operations as well as overseeing facility and airfield service contracts. In 2014, Lieutenant Fischer began his overseas tour with Naval Facilities Engineering Command (NAVFAC), Far East. He served as the Facility Support Contract Manager (FSCM) for Public Works Yokosuka and was then reassigned as the Assistant Operations Officer and Command Managed Equal Opportunity Officer for NAVFAC Far East. He managed facility and utility contracts for over 55 tenant commands across seven Naval and two Marine Corps Installations. Lieutenant Fischer holds a bachelor's degree in Civil and Environmental Engineering from the University of Dayton. His personal decorations include the Navy and Marine Corps Commendation Medal (3 awards), unit, and campaign awards. He is an active member of the Society of American Military Engineers and American Society of Civil Engineers.

Lieutenant Fischer is currently assigned to NROTC University of Florida as a Civil and Costal Engineering graduate student.

Dr. Fazil T. Najafi, University of Florida

Dr. Fazil T. Najafi

For more than forty years, Dr. Fazil T. Najafi has worked in government, industry and education. He earned a BSCE in 1963 from the American College of Engineering, in his place of birth, Kabul, Afghanistan, and since then came to the United States with a Fulbright scholarship earning his MS in civil engineering in 1972 and a Ph.D. degree in transportation in 1977. His experience in industry includes work as a highway, structural, mechanical, and consultant engineer and construction manager for government groups and private companies. Najafi went on to teaching, first becoming an assistant professor at Villanova University, Pennsylvania in 1977, a visiting professor at George Mason University, and then to the University of Florida, Department of Civil Engineering, where he advanced to associate professor in 1991 and then full professor in 2000 in the Department of Civil and Coastal Engineering. He has received numerous awards including a scholarship award (Fulbright), teaching awards, best paper awards, community service awards, and admission as an Eminent Engineer into Tau Beta Pi. His research on passive radon-resistant new residential building construction was adapted in HB1647 building code of Florida Legislature. Najafi is a member of numerous professional societies and has served on many committees and programs, and continuously attends and presents refereed papers at international, national, and local professional meetings and conferences. Lastly, Najafi attends courses, seminars and workshops, and has developed courses, videos and software packages during his career. His areas of specialization include transportation planning and management, legal aspects, construction contract administration, and public works.

Technical Review of Companies able to Support the Education and Naval Installations' Renewable Energy Goals through the use of Tidal and Hydro Kinetic Energy Devices

Abstract

Tidal Energy uses the earth's gravitational interactions with the sun and moon to convert hydraulic energy into usable electric power for various uses. The orbital and rotational effects of the sun and moon create tidal patterns which may be reasonably predicted as opposed to other forms of renewable energy. The energy available can be measured by the difference in tide heights or velocities depending on the application of the tidal device. Today's challenges focus on overcoming the minimum energy necessary to effectively power the turbines, initial project costs, meeting peak load demands, and low impacts to the environment.

The United States Navy is currently on a tenacious path to explore energy saving technology that could be used in isolated and remote locations as well as various climate conditions to supplement the Navy's power generation requirements. Executive Orders 13693 and 13514 mandate the reduction of energy intensity coupled with the reduction of greenhouse gas emissions of approximately 28% by Fiscal year 2020 from a year 2008 baseline. The purpose of this research is to conduct a technical review of companies capable of supporting the Navy's global goal in reduction of greenhouse gases for future Research, Development, Testing, and Evaluation or financed energy type contracts. The methodology for technical review will include examining the company's corporate experience, past performance, environmental compliance, permitting, and the ability to operate internationally. The study of the Technical Review of Companies able to Support the Education and Naval Installations' Renewable Energy Goals through the use of Tidal and Hydro Kinetic Energy Devices would fit the call in the graduate division and it is consistent with the division objectives. Furthermore, the study is relevant to the ASEE division's mission and the scope is interdisciplinary including design, development and research. The research paper was a term project for a public works engineering and management class that is offered each fall semester. This makes it relevant to the theme of the ASEE Graduate Studies Division.

How Tidal Energy Works

Tidal Energy uses the earth's gravitational interactions with the sun and moon to convert hydraulic energy into usable electric power for various uses. The orbital and rotational effects of the sun and moon create tidal patterns which may be reasonably predicted as opposed to other forms of renewable ocean energy. The energy available can be measured by the difference in tide heights. The National Oceanic and Atmospheric Administration (NOAA) summarized tidal patterns in three categories. Figure 1 illustrates those typical tidal patterns. [5]

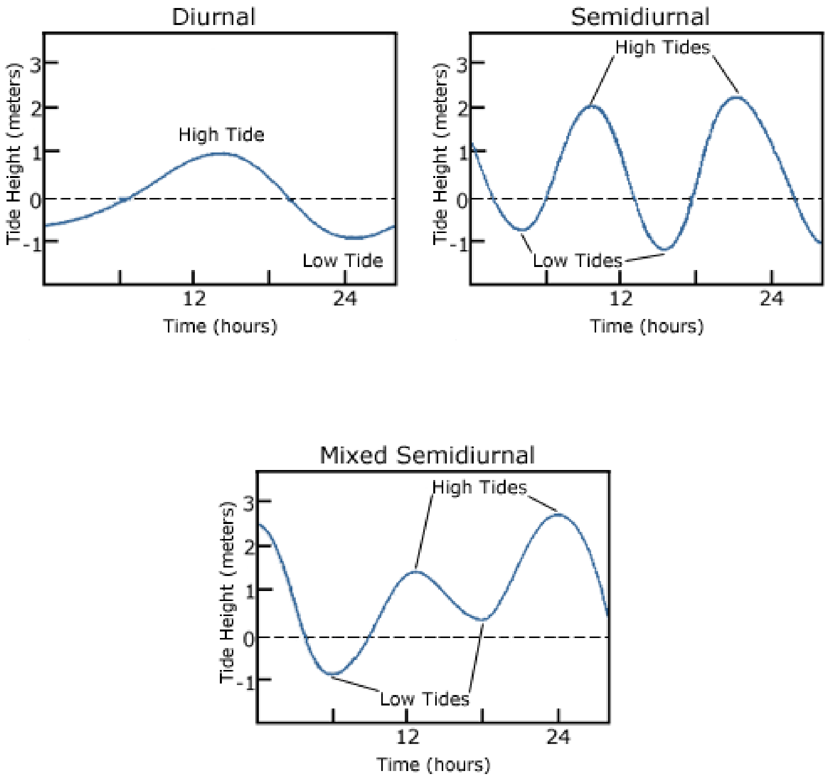


Figure 1: Typical Tidal Patterns

Diurnal tide has one high tide and one low tide every 24 hours and can be observed in many areas within the Gulf of Mexico. Semidiurnal has two high tides and two low tides every 24 hours and can be observed along the eastern coast of North America. Mixed Semidiurnal tides also experience two high tides and two low tides every 24 hours, however; the amplitude of high are low tides are dependent on the lunar cycle. Semidiurnal tides can be observed along many areas on the western coast of North America. [5]

As an estimate for the energy available, a simple energy equations derived from Newton's Law can be used. The total energy available is the sum of the potential and kinetic energy. The potential energy can be calculated by: E = ½ x (cross sectional area of the device) x (density of the body of water) x (acceleration due to gravity) x (difference in tidal height)^2. While the density and acceleration due to gravity are mostly fixed constants, the difference in tidal height and cross sectional area of the device are the main focus of an engineer's challenge to harness the potential energy. To calculate the kinetic energy: E = ½ (mass of object) x (velocity)^2. The mass of the object (or device used) is dependent on the engineer's design. To maximize the kinetic energy, engineers examine hydraulic mapping of ocean currents, searching for suitable sites with rapid moving currents. More complex equations based on empirical data are currently being developed by engineers and scientists across the United States, Europe, and Asia. In the subsequent sections of this research the different types of tidal and marine hydro kinetic energy devices will be examined for their various uses in different geographic regions[5].

Conventional Tidal Energy Devices

Tidal Barrages

Tidal barrages are very similar to hydraulic dams constructed on inland river streams. The barrage generates power from the difference in hydraulic head energy between high and low tides. Barrages are often constructed in the vicinity of a river or tidal estuary to maximize the available hydraulic head energy from the tidal effects. Figure 2 illustrates a cross-sectional view of a typical barrage. [12]

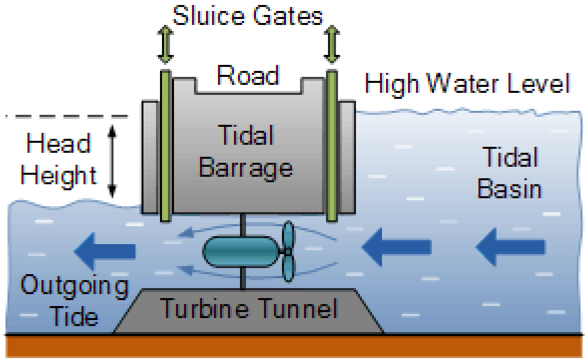
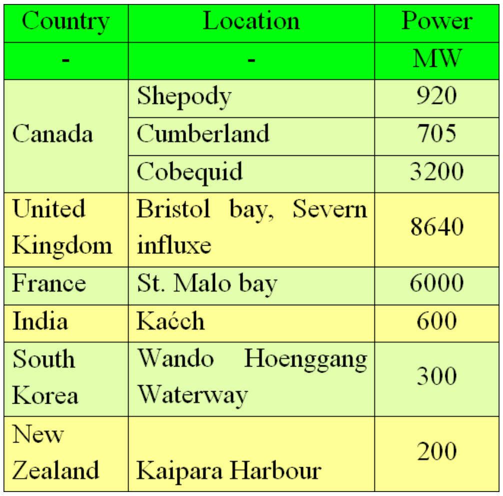


Figure 2: Typical Cross Section of a Tidal Barrage

The sluice gates are designed and operated based on the tidal pattern observed in the estuary. This is known as a bi-directional tidal barrage scheme. The sluice gates will raise and fall according to the tidal patterns (outgoing and incoming) and the turbines are designed to rotate in order to capture bi-directional flow patterns. For mono-directional or Ebb system, the sluice gates are designed to capture the outgoing tidal flow pattern and the turbine is fixed. Two-way schemes often produce more total power output, however; the Ebb systems are more efficient in terms of cost times power efficiency per unit turbine ($\text{Efficiency}_{\text{total}} = (\text{Energy}_{\text{in}} \times \text{Cost}) / (\text{Energy}_{\text{out}} \times \text{number of turbines})$) because bi-directional turbines are generally more expensive and provide less energy or power output. There are no active barrages in the United States, however; devices can be found in Canada, UK, France, India, South Korea, and New Zealand. Table 1 below shows the locations and power output for active devices. [8]

Table 1: Active Barrage Devices as of 2011



Country	Location	Power
-	-	MW
Canada	Shepody	920
	Cumberland	705
	Cobequid	3200
United Kingdom	Bristol bay, Severn influxe	8640
France	St. Malo bay	6000
India	Kaćch	600
South Korea	Wando Hoenggang Waterway	300
New Zealand	Kaipara Harbour	200

Tidal Turbines

Tidal turbines operate in a similar fashion to wind turbines. Unlike the typical three blade design of a wind turbine, tidal turbines are currently being designed in a variety of blade patterns, ranging from a helical pattern to a typical jet fan turbine pattern. The location of these devices can range from the ocean floor to just below the surface of the water to capture wave action. The turbines can operate as stand-alone units or collectively as an array. Tidal turbine projects are largely in the developmental and planning stages, however; there are some completed projects with promising results. The world's first commercial 1.2MW turbine developed by Marine Current Turbines (MCT) was installed in Strangford Lough, United Kingdom in 2007. The device serves as a prototype to collect data on the environmental impact and record energy output information. A small scale turbine project in Eastport, Maine was completed in 2012. Through additional phases of constructions the project is expected to expand to a network of turbines and produce enough power to supply power to 1,200 homes. [1]

Tidal Fences

A tidal fence is another device used to harness tidal energy and can be classified as hybrid of tidal barrages and tidal turbines. Tidal fences are mainly designed for areas of fast moving ocean currents near channels between two or more land masses. The energy harnessed is kinetic and largely depends on the velocity of water moving through a cross sectional area of a channel. Unlike the tidal barrages, tidal fences do not retain water through a reservoir system, making these devices more environmentally friendly, however; these devices can alter fish and other large marine animal migratory patterns. Figure 3 illustrates a typical construction of a tidal fence configuration. [7]

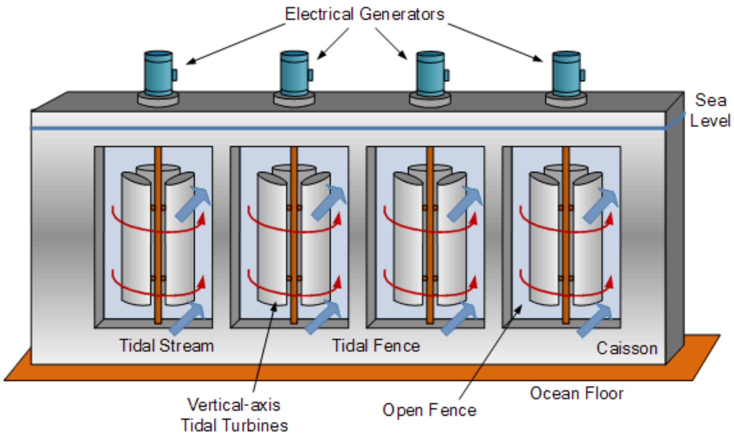


Figure 3: Typical Tidal Fence

The electrical generators, wiring, and cabling are often kept above the high tide mark to prevent corrosion, creating an advantage in maintenance and repair operations. Although tidal fences are less efficient than barrages, the design requires less material (concrete and steel) for the caisson and saves on operations and maintenance costs. Tidal fences are largely in the developmental and planning stages. Engineers and scientists are currently developing theoretic models that will allow manufacturers to design the turbine blades based on the flow patterns in specific geographic areas. Promising large scale projects have been identified in Great Britain and Yantai, China. [7]

Tidal turbines, barrages, and fences each have common challenges that engineers are currently working to overcome. The subsequent sections of this research will focus on minimum elevation or velocity head required, project costs, meeting peak demand loads, and the potential environmental impacts.

Tidal Energy Challenges

As a general practice, some devices will require minimum elevation or velocity head energies to spin the turbine blades. For a tidal barrage to be effective, a minimum of five meters (16 feet) of elevation head energy is required. For tidal fences, there are no known minimum requirements for the velocity head; however, research has suggested a 30 kilometers or greater tidal fence along a dam or bridge more is required to achieve economic viability. For tidal turbines, velocities are dependent on the blade design and typically require velocities of 1m/s or greater to generate effective electrical power. [3,4]

Another tidal energy obstacle is the high initial project cost. For large scale projects, the costs are usually $10 million USD or greater. Based on published data from the Bay of Fundy (located in Eastport, Maine) turbine project it is possible to calculate the simple payback for this project:

$$\$\ 21{,}000{,}000 = \frac{\$(0.215)\quad(1{,}200\ \text{Homes})\quad(10932\ \text{kW*Hr})\quad(12\ \text{Hrs})\quad \mathbf{(\ X\ )Yrs}}{\underset{\uparrow}{\underset{\boxed{\text{Maine's electricity rate}}}{\text{kW*Hr}}}\qquad\underset{\uparrow}{\underset{\boxed{\text{Average annual household power consumption according to EIA.GOV}^{13}}}{(\ \text{Homes})}}\qquad\underset{\uparrow}{\underset{\boxed{\text{Device operating time}}}{(24\text{Hrs})}}}$$

Solving for "X" equates to a simple project payback of approximately 15 years. This means, that the tidal device must operate consistently for a period of 15 years before the investors can start seeing returns or profit. There are also additional risks to the investors not included in this equation. First, Maine's electricity rate was assumed to be fixed during the lifespan of the project. If the electrical rate decreases, this could mean a longer payback period. Also, the operations and maintenance costs were not factored into this equation which would extend the payback period. Finally, since tidal turbine technology is progressing, a more efficient turbine design could possibly be commercially available before the payback period has ended. Investors could be left with a risky business decision to invest now at a 15-20 year payback or wait an additional three to five years for the technology to develop in effort to increase profits from a shorter payback period.[1]

Another challenge to utilizing tidal energy as a renewable source is meeting peak electric demand loads. Often tidal patterns do not synchronize with peak load demands of commercial and residential consumption. To exam this issue further, a tidal chart (figure 4) was generated by NOAA for the Point Loma, California region. In this case, turbines would produce the least amount of power during the low tides at approximately 6am and 7pm. These times also coincide with the average peak demand times, creating the need for large capacitors to store the energy. The larger the tidal offset is, the greater the capacitance is required to supply continuous power.[5]

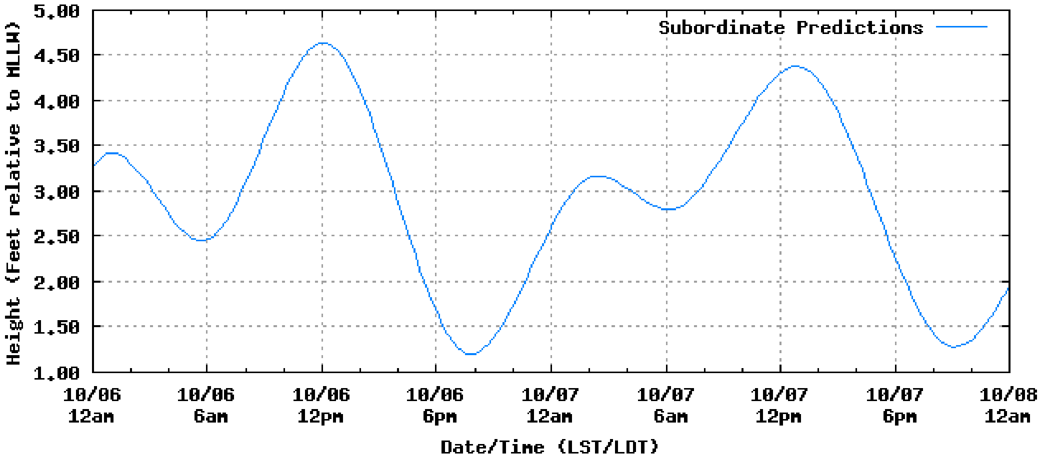


Figure 4: Tidal Graph of Point Loma, California from 10/6/2016 to 10/7/2017

The environmental and geographical challenges can also be difficult to overcome. One environmental issue is the risk towards marine life and organisms coming into contact with the turbine blade. Marine migratory behavior is often highly concentrated in estuaries, which are also ideal locations for tidal barrages and fences. Another environmental risk is disturbing migratory bird patterns. The Migratory bird act of 1918 made it illegal in the US and other nations to disturb the natural flight patterns of certain species of birds. This becomes problematic for tidal barrages and fences due to the portion of the concrete and steel protruding from the waterline and creating unnatural perching areas for migratory birds. Degrading water quality and the disturbing areas of sedimentation basins must also be taken into consideration. Finally, there are also concerns about the long term effects of the acoustical output and electromagnetic field from tidal turbines and the impact to marine life. [12]

US Navy and Tidal Energy

Due to its coastal operating climate, tidal and hydro kinetic energy device are perfect candidates for assisting the U.S. Navy in their goals to increase electrical grid stability and reduce greenhouse gas emissions. Executive Orders 13693 and 13514 sets the goal towards reduction of energy intensity coupled with the reduction of greenhouse gas emissions of approximately 28% by Fiscal year 2020 from a year 2008 baseline. Green house gas emissions can be reduced by reducing the demand and/or reducing the operating time of fossil fueled powered electric generators. Reducing the demand is not always a viable solution for some Naval Installations due to increases in personnel and operating equipment. However; reducing greenhouse gases by utilizing renewable energy devices as the primary means of electric generation and utilizing fossil fueled generators as supplementary devices to support peak demand loads, has shown substantial promise. The subsequent sections of this research will provide an analytical review of Verdant Power and Ocean Renewable Power Company and their experiences with conventional tidal energy projects. Additionally, further research will examine technological developments in non-conventional and hydro kinetic energy devices currently being tested by Oscilla Power and Vortex Hydro Energy.

Verdant Power

Corporate Leadership

Verdant Power’s headquarters is based out of New York, New York. Their corporate leadership is comprised of a Chief Executive Officer (CEO), two co-founders, a Chief Technology Officer (CTO), a Roosevelt Island Tidal Energy (RITE) Project Manager, and a Director of Technology Performance. Their CEO (John Banigan) has extensive experience in international investing and banking as well as consummating foreign-based joint ventures. The company’s co-founders (Ron Smith and Trey Taylor) have collective experience in manufacturing consulting, working with US and UK based utilities companies, and leadership in ocean renewable energy organizations. Ron Smith is a retired Naval Intelligence Officer. Their Chief Technology Officer (Dean Corren) has extensive experience in research and design. He is also the innovator the Kinetic Hydropower System (KHPS) design. Their RITE manager (Mary Ann Adonizio) addresses regulatory licensing and permitting requirements as well as environmental risk management services for renewable energy projects. The Director of Technology Performance (Jonathan Colby) has experience in turbine blade design, hydrodynamic modeling, as well as environmental monitoring of native fish and bird species.

Overall, Verdant Power’s corporate leadership has demonstrated vast experience in financial management, marine turbine modeling and design, and environmental monitoring and permitting. [14]

Completed Projects and Projects in Development:

RITE Project

Located on the strait that connects Long Island South with the Atlantic Ocean, the RITE project generates energy from the natural tidal currents of the East River. The tidal patterns are dynamic in this region and produce two high tides and two low tides per day. Although the variance between the tide heights is only five feet, the tidal pattern produces peak velocities at approximately 2.1m/s, four times per day as shown in figure 5. [10]

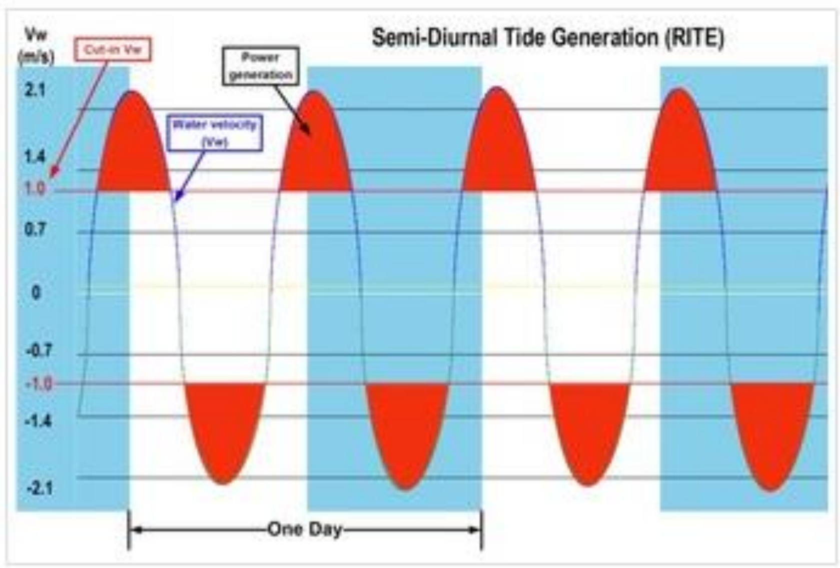


Figure 5: Tidal Graph of New York, New York

The project commenced its first of three phases in January of 2002. Phase one of the project consisted of testing, evaluation, and monitoring to in order to determine the proper KHPS technology to produce the most power, while minimizing the impact to the environment. Phase two consisted of installing six KHPS generation 4 type turbines, a dynamometry turbine, and five generator turbines from 2006-2008. A total of 70MWh were delivered over a period of 9,000 operating hours (77% electrical generation rate) to two commercial customers. Verdant Power used this data in their application for the first Federal Energy Regulatory Commission (FERC) license. During phase three of the project, Verdant was granted the first-ever commercial license for a permanent tidal energy project. Verdant also conducted a finite element analysis on one of the turbine blades that fractured during the second phase. The analyses lead to a change in turbine blade material design with higher strength properties. The third phase will install up to 30 turbines providing up to one MW of power. [14]

Technology

Verdant Power is primarily experienced in the KHPS turbine that operates in both rives and oceans. The design is a three-blade turbine that will rotate along the vertical axis to capture bi-directional flow patterns. With the financial support from the Department of Energy (DOE), and other support from the National Renewable Energy Laboratories, and the University of Minnesota's St. Anthony's Falls Laboratory, Verdant Power was able to design and test composite blades (improving from the generation 4 model) as well as optimize the new rotor design. Figure 6 illustrates the dimensional comparison between the generation 4 and generation 5 turbines. Both generation 4 and 5 designs includes patented technologies. [14]

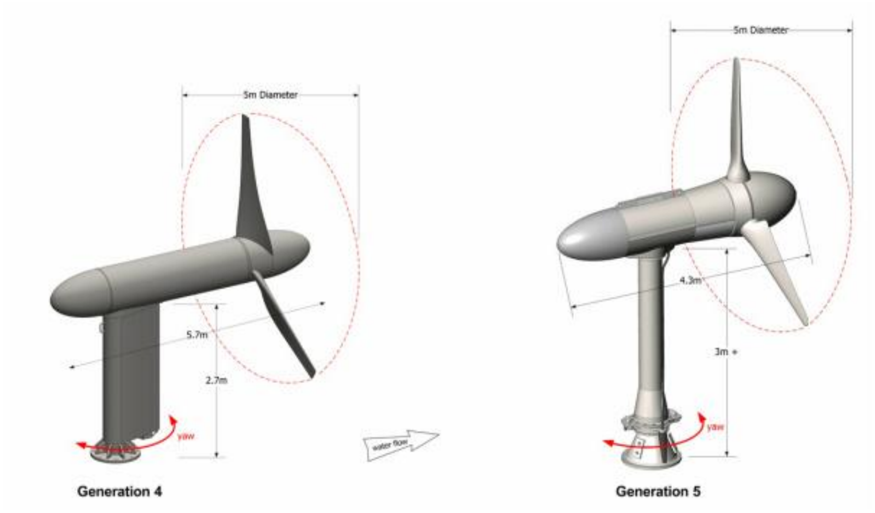


Figure 6: KHPS Turbine comparison.

Ocean Renewable Power Company

Corporate Leadership

Ocean Renewable Power Company's (ORPC) headquarters is based out of Portland, Maine. They also have partnerships with other subsidiaries such as the ORPC Nova Scotia Ltd. Their senior management is composed of a President and CEO as well as three Vice Presidents. Their President and CEO (Christopher Sauer) has vast experience in cogeneration and adverse environmental impact reduction technologies. His work in environmental impact reduction technologies includes biomass-based activated carbon and mercury removal technology. He is a registered Professional Engineer in the state of Colorado. ORPC's Vice President and President of project development (John Ferland) has experience in environmental permitting and project licensing. He is a founder of an oil spill response company and a consulting firm for biofuel, hydrogen, solar, and tidal power. ORPC's Vice President and Chief Technology Officer (Jarlath McEntee) has experience in proprietary technology development and management in the Federal Energy Regulatory Commission. ORPC's Vice President and Finance Manager (Abbey Manders) has experience in management and financing in tidal energy and the corporate restaurant business. [9]

Completed Projects and Projects in Development

Bay of Fundy (Eastport, Maine) Project

Eastport, Maine is located on northeastern boarder between the United States and Canada. The area is well known to have an active tidal range of approximately 15 -17feet (see figure 7) which translates to current velocities of 1-5m/s in the Bay of Fundy. The project began in early 2011.[5]

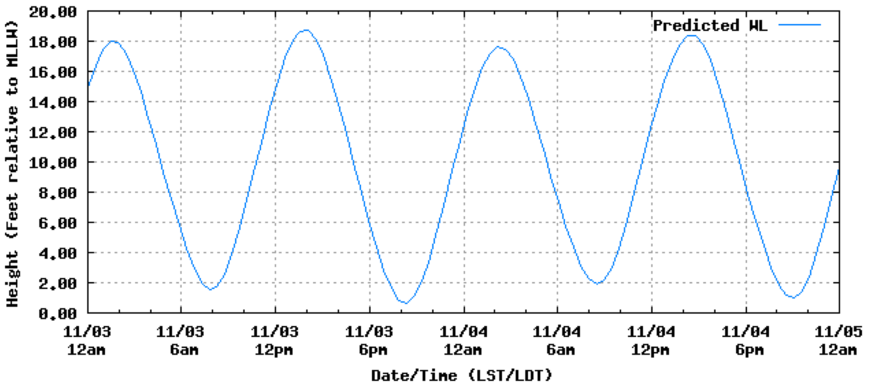


Figure 7: Tidal graph for Eastport, Maine

ORPC used their “TidGen” turbine generator technology in a pilot study. The TidGen turbine design has the capacity to power approximately 25 residential homes. In September of 2012, ORPC became the first company in the United States to generate electricity to the general power grid. In January of 2013, ORPC and the project were the first to establish a long term power purchasing agreement with the Bangor Hydro Electric Company. ORPC is planning to expand the project to an array of turbines that would power approximately 1,200 residential homes. The project is projected to cost $21 million at its completion.[9]

Cook Inlet, Alaska Project

Inside the Cook Inlet, (located in Alaska) are extremely active tidal ranges. The tidal ranges represent an enormous potential for developing tidal energy projects. The Alaska Energy Authority (AEA) and NOAA estimate the state of Alaska has 90% of the tidal power potential compared to the rest of the United States. ORPC and Homer Electric established a collaborative effort that began in 2010. ORPC’s “Beta TidGen” 150kW turbine was used during the pilot study. In early 2012, ORPC received an FERC license and general permit for the Environmental Assessment having concluded a Finding of No Significant Impact (FONSI). ORPC is assessing the potential to install an array of turbines that would produce up to 5 MW of power.[9]

Technology

ORPC is primarily experienced in project development of the TidGen turbine unit. For this particular design, the blades are shaped in a helical formation and rotate about a horizontal axis. The unit can secured to the ocean floor using is fixed bottom support frame, or a buoyant tensioned mooring system. The buoyant tension mooring system allows the turbine to be placed at a depth most conducive to rapid flow conditions. The turbine can also be deployed at depths up to hundreds of feet. At certain conditions, the TidGen turbine unit can produce as much as 600kW. Additionally, up to four turbine units can be stacked using a single buoyant tension mooring system. In an array configuration, the turbines are connected to an underwater power consolidation module, which is then connected to a power station using a single underwater power cable. [9]

ORPC is currently developing its OCGen turbine unit that is similar to the TidGen design with variations to the design that allow the device to capture deep water unidirectional and continuous flow. These flow patterns are located 15 miles off the eastern coast of Florida. ORPC plans to test a prototype of this technology by 2020. [9]

Oscilla Power

Oscialla Power is currently developing its patented Triton wave energy converter (WEC). This device consists of surface float connected to a heave plate by three flexible tension cables. Moving waves and ocean currents will cause the surface plate to move in a pitch and roll motion. This kinetic energy is transferred to mechanical energy through the flexible tension cables. The energy is then transmitted to independent linear power trains, comprised of a linear hydraulic load transfer mechanism and a solid-state magnetostrictive. Oscilla Power conducted a series of tests to optimize the mass ratio of the float to heave plate. Additionally, the flexible tension cables were optimized by using finite-element analysis software. Figure 8 is an illustration of the Triton WEC currently being developed. [11]

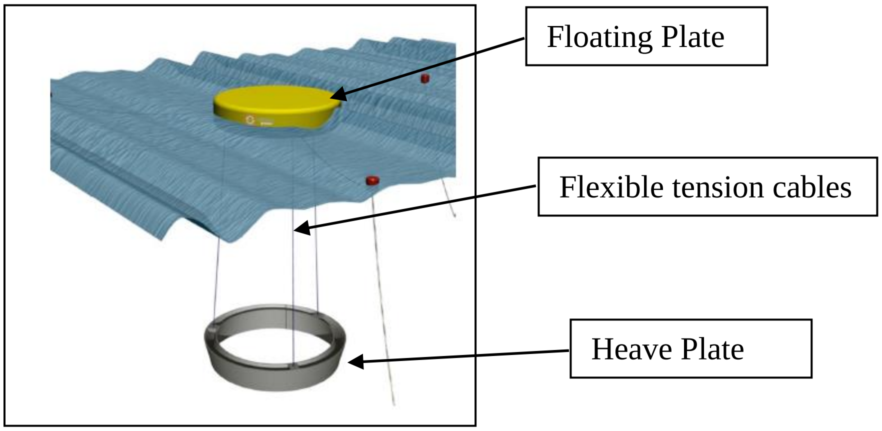


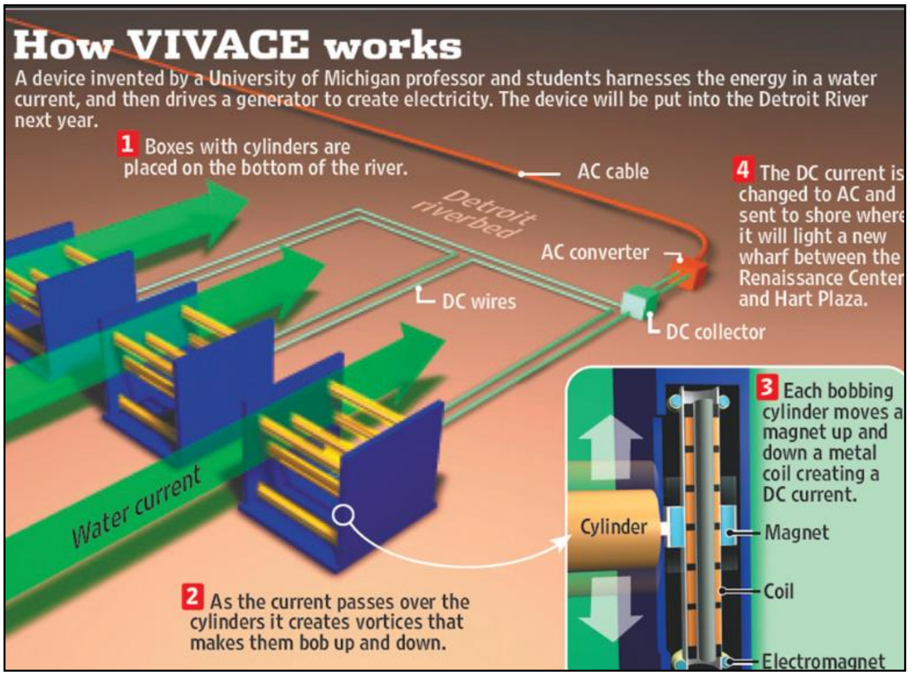
Figure 8: Triton WEC device

A half scale model of this device was fabricated in Seattle, Washington and then deployed at the Isle of Shoals, New Hampshire in 2014. The Triton WEC has several advantages when compared to conventional turbine technology. First, the device transmits power through the floating plate, greatly reducing external movement that could potentially impact marine life. Secondly, the device is constructed from common commercial products such as steel, plastic, and copper.

Finally, there are low capital and low operations and maintenance costs associated with this technology. [11]

Vortex Hydro Energy

The Vortex Hydro Energy uses a phenomenon known as vortex induced vibrations (VIV) to convert the hydrokinetic energy to electricity. The patented VIVACE converter uses horizontal cylinders (instead of typical turbine blades) that will move perpendicular to supporting columns. The movement of these cylinders is caused by a vortex created through moving water. As the water mass passes through the cylinder, a downward force pushes the cylinder in a downward direction. Shortly after the water mass passes, a spiral effect is created to force the cylinder to move vertically. On both sides of the vertical columns, magnets move up and down a coil system creating direct current. The direct current is converted to alternating current for commercial applications. Large scale testing of this device was completed in 2010. Figure 9 is a graphical representation of how the system works. [2]



How VIVACE works

A device invented by a University of Michigan professor and students harnesses the energy in a water current, and then drives a generator to create electricity. The device will be put into the Detroit River next year.

1 Boxes with cylinders are placed on the bottom of the river.

2 As the current passes over the cylinders it creates vortices that makes them bob up and down.

3 Each bobbing cylinder moves a magnet up and down a metal coil creating a DC current.

4 The DC current is changed to AC and sent to shore where it will light a new wharf between the Renaissance Center and Hart Plaza.

Figure 9: VIVACE technology

Similar to the Triton WEC, the VIVACE has several advantages when compared to conventional turbine technology. First, the cylinders can generate electric power through slower moving currents ranging from 1-2m/s. Secondly, the curved surface and slow oscillations of the moving cylinders greatly reduces the potential injury to marine life. Finally, the cylinders move in unison with the current, causing less potential for fouling and eccentric forces that would cause the devices to fail. [2]

Conclusion

Although the basic knowledge of tidal and hydro kinetic energy has been known since the last century, the research, development, and full scale testing have skyrocketed in the past decade. Tidal and marine hydro kinetic energy is a largely new and untapped market capable of continuing its exponential growth and research in the next decade. Companies such as Verdant Power and Ocean Renewable Power Company have demonstrated their potential to provide substantial and reliable power generation on a commercial scale. Additionally, breakthroughs in non-conventional turbine power such as the Triton WEC and the VIVACE converter have provided insight on how these devices can be used in environmentally sensitive areas, demonstrating negligible impact to marine life. Collectively and independently, the companies and their corporate technologies mentioned in this research, provide the U.S. Navy with an opportunity to meet or exceed the goals outlined in Executive Orders 13693 and 13514. Furthermore, at its current growth rate, future developments may provide the U.S. Navy with the opportunity of achieving the ultimate goal of a zero-net energy infrastructure, in which federal buildings are supplied with 100% renewable energy, by the year 2030. The study is relevant to the ASEE graduate division's mission and it can be incorporated in any relevant engineering graduate level course. The study can also be linked to a renewable graduate level courses. Furthermore, it can be incorporated to interdisciplinary research leading to a degree of Master of Science in engineering.

1. Ailworth, Erin. "In Maine, a US First in Tidal Energy; Commercial Project Dedicated." *The Boston Globe (Boston, MA)*. 25 July 2012.

2. Bernitsas M.M., Raghavan K., Ben-Simon Y., Garcia E. M. H., "VIVACE (Vortex Induced Vibration Aquatic Clean Energy): A New Concept in Generation of Clean and Renewable Energy from Fluid Flow", OMAE 2006; and Journal of Offshore Mechanics and Arctic Engineering, ASME Transactions, Nov. 2008, Vol. 130, No. 4, pp. 041101-15

3. Draper S., G. L. Borthwick, and G. T. Houlsby. "Energy Potential of a Tidal Fence Deployed near a Coastal Headland." *Philosophical Transactions of the Royal Society* 14 Jan. 2013: 1-16.

4. Knoppers, R: "Thirty kilometers of electricity" NRC Handelsblad. 16 January 1999.

5. "NOAA's National Ocean Service: Tide Cycle Variations." *US Department of Commerce, National Oceanic and Atmospheric Administration*. National Oceanic and Atmospheric Administration, https://tidesandcurrents.noaa.gov/tide_predictions.html Accessed Sept. 15, 2016.

6. "Ocean Renewable Power Company, LLC." *Ocean Renewable Power Company, LLC*. http://www.orpc.co/content.aspx?p=h3jCHHn6gcg%3d Accessed Nov. 17, 2016.

7. "Ocean Tidal Fences Harnessing the Power in the Tides." *Alternative Energy Tutorials*. http://www.alternative-energy-tutorials.com/tidal-energy/tidal-stream.html Accessed Sept. 26, 2016.

8. Olek, Blazej. *Renewable Energy Resources. Comparative Analysis and the Web Presentation*. Tech. Electrical, Electronic, Computer and Control Engineering, Technical University of Lodz. 1-130.

9. "ORPC Drops Cook Inlet Tidal Project License." *Tidal Energy Today*. http://www.orpc.co/ Accessed Nov. 3, 2016.

10. "RITE Project." *Verdant Power*. http://www.verdantpower.com/rite-project.html Accessed Nov. 17, 2016.

11. Rosenberg, Brian J., and Timothy R. Mundon. *Numerical and Physical Modeling of a flexibly-connected Two-body Wave Energy Converter*. Rep. Oscilla Power, 2016. 1-4.

12. "Tidal Barrage and Tidal Barrage Energy Devices." *Alternative Energy Tutorials*. http://www.alternative-energy-tutorials.com/tidal-energy/tidal-barrage.html Accessed Sept. 22, 2016.

13. United States. The White House Council on Environmental Quality. Office of Federal Sustainability. *Implementing Instructions for Executive Order 13693 Planning for Federal Sustainability in the Next Decade*. Print.

14. "Verdant Power." *Verdant Power*. http://www.verdantpower.com/ Accessed Nov. 17, 2016.