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9 Community-Scale Isolated Power Systems

Powering the Blue Economy: Exploring Opportunities for Marine Renewable Energy in Maritime Markets

April 2019

9. Isolated Power Systems: Community Microgrids

Key Findings

- Many remote communities are currently powered by diesel generation, and some with wind. Although diesel fuel is energy dense and provides on-demand power, it presents operational and logistical challenges. For example, many remote communities in Alaska depend on a few bulk fuel deliveries each year that are susceptible to supply chain disruptions and fuel price volatility.

- The cost range of diesel-generated power for most of the remote Alaska communities varies from $0.50 to over $1 per kilowatt-hour (kWh). For larger and less remote locations, costs are less, in the $0.19–$0.37 per kWh range (Alaska Energy Authority 2016b).

- Remote communities typically have microgrid power systems from 200 kW to 5 megawatts (MW), with high reliability being a key objective. First adopters are environmentally conscious resorts, small villages, and military bases.

- Marine energy technologies, operating individually or in conjunction with other generating sources, could help mitigate reliance on diesel fuel. For communities nearby rivers, reliable power can be produced from river current generators in sufficient capacity to offset a small community's entire load during the summer.

Opportunity Summary

There are hundreds of isolated communities in the United States, primarily in Alaska and island territories, that have microgrid power systems from 200 kW to 5 MW, according to studies completed by the National Renewable Energy Laboratory. Nearly all are currently dependent on diesel generators for some or all of their power. The energy cost is higher than the national average, sometimes more than $1/kWh, and it varies with the price of oil. The reason the cost is high is largely because of supply chain logistics. Transporting diesel is difficult, expensive, and, in many cases, requires extensive storage capacity.

Remote and isolated communities are not the only groups that suffer from high fuel costs. The U.S. Department of Defense (DOD) operates dozens of bases in similar regions and they are facing significant pressure to "…dramatically change energy consumption at an installation or joint base, implement renewable energy technologies, and generate and store energy to improve supply resilience for critical loads…" (Energy Resilience & Conservation Investment Program 2018). The DOD also has numerous forward-operating bases that are often more remote from fuel sources and operate with higher cost profiles (Defense Science Board 2016). For the DOD, transporting diesel fuel to forward-operating bases and remote operating adds additional risk to military personnel that must deliver the fuel. Isolated resorts are another category of microgrid consumer, such as fishing resorts in Alaska. In both Alaska and the warmer island regions, there is a growing ecoresort sector and some of them are remote. They all have the same incentives as the isolated communities for reducing or replacing diesel generation of power, and the ecoresorts have the added incentive of needing to maintain a green footprint as much as possible, while continuing to provide the amenities expected by tourists.

Most of these isolated communities have access to harvestable marine energy resources: wave energy or tidal current for coastal and island communities and river current for inland locations (Alaska Energy Authority 2016a; Kilcher and Thresher 2016; Kilcher et al. 2016; Figure 9.1). The desire to reduce energy costs and keep remote communities viable has motivated subsidized energy for many communities. Alaska provides support to all remote communities to reduce electric utility prices for residential users to a rate that is close to the larger grid-connected communities. This practice gives the state an incentive to support the development and use of renewable technologies that have no fuel cost and the state support could provide an impetus for marine energy deployment as costs decrease over time.

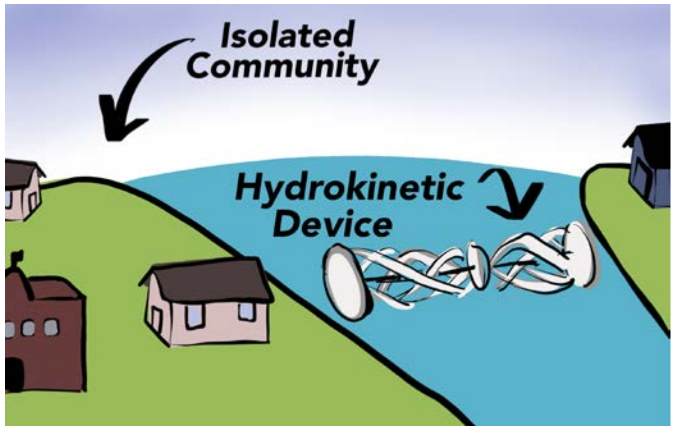

Figure 9.1. Hydrokinetic energy application overview for isolated communities. *Image courtesy of Molly Grear, Pacific Northwest National Laboratory*

If marine energy technology costs become significantly lower than diesel costs, and competitive with solar photovoltaics (PV) and wind, the technologies could improve the financial viability of remote communities by reducing dependency on the state subsidy that is at risk. Cost and availability of PV and wind varies depending on the resource (annual and seasonal), and the logistics for installation and maintenance. If further cost reduction allows costs to fall below the subsidized rate, the cost of living would be further reduced and allow more money to circulate in the local economy. With lower and stable energy prices, the risk barrier for developing new business enterprises is reduced.

Application

Description of Application

In remote communities, bases, and resorts, electric power is essential for lighting, water pumping, and running services, such as waste water treatment. As show in Figure 9.2, many remote communities are currently powered by diesel generation, some with a wind turbine. Although diesel fuel is power dense and allows for on-demand power, it presents operational and logistical challenges. Inland river, northern, northwestern, and western region communities in Alaska depend on a few bulk deliveries by barge when weather conditions permit. Sometimes fuel must be flown in if supplies run short. Although barge delivery of fuel to remote locations is expensive, air freight is far more expensive (Alaska Energy Authority 2016a). In Bethel, Alaska, the last barge of fall tops off the tanks, leaving the community with almost 13 million gallons of fuel to use over the next 8 months or so (Demer 2016). When stored for long periods of time, diesel grows mold and requires additional treatment before use, which adds to the cost of storage.

Figure 9.2. Wind generators with oil storage tanks in foreground. *Image by Ian Baring-Gould, National Renewable Energy Laboratory 16097*

Marine energy technologies, operating individually or in combination with other local renewables, could provide critical electrical generation, replacing current day dependence on diesel fuel. For riverine communities, the first level of development that could provide operational experience is river current generators that provide sufficient daily energy to offset a small community's entire load during the summer. Igiugig, Alaska, has been exploring the utilization of a river current generator that provides about half of the community's power. A community generating all its energy in this way would only need enough storage to respond to the variations in load because the river current generator provides continuous power. These communities cannot use small hydro as an alternative because of the size of the rivers and spring ice flow that make dams not a feasible answer for a small community.

For some coastal communities, developing a tidal current system is similar to developing a river current system (but slightly more challenging because of corrosion and varying current velocity and direction). Tidal currents, while predictable, vary hour by hour and day to day. Greater storage capacity is needed to transfer energy produced during peak tidal flow to the slack tide period and to respond to load variation during the day. There are also variations in the tidal range and current (spring and neap tides) that depend on the alignment of the sun and moon, and the system must be designed to compensate for that with additional storage or other forms of generation. Tidal generation has locations where ice will be less of an impact than it is for interior rivers and northern Bering Sea locations, specifically in the Gulf of Alaska and Aleutian Islands. The Bering Sea freezes over, and many locations in the Bering Sea and Arctic Ocean could be impacted; however, the phenomena of frazil ice and breakup seen in river current applications are not present. Frazil ice is a phenomenon in which the water reaches freezing temperature and forms ice crystals but is too turbulent to freeze solid. The icy river is slushy on top and very abrasive. Therefore, operating tidal current generators under the ice is feasible. Doing maintenance during ice-covered times of the year might not be economically viable or even possible.

Coastal communities with a wave energy converter (WEC) resource must account for variability in their system designs, but wave energy resource variability is not as sudden as PV or wind energy variability, along with inherent seasonal reductions in solar irradiance at higher latitudes (National Renewable Energy Laboratory undated). The variability implicit in the typical wave period is on the order of a few seconds, and these variations are smoothed out in the collection of WECs in a farm. Although the wave height varies, the embodied energy in the usable vertical column has less cyclic variability. The wave resource is predictable in most locations a couple of days in advance, so managing complementary generation sources can be planned. The available energy varies throughout the year and through periods of stormy and calm weather, so a WEC farm may not be a good solo candidate for a 100% renewable system. However, in combination with solar PV, which is good in the summer in the Gulf of Alaska and many places with a winter wave resource, a hybrid WEC and PV farm with storage could be designed to provide all the energy for many days in the year. Areas where the seas freeze over are not viable during the ice-covered period even if the WEC device is bottom mounted because the ice suppresses the waves. Ice cover is diminishing in the Bering Sea and some villages are being eroded out of existence because of the lack of an ice barrier during winter storms; therefore, the latitude limits for WEC devices in the Bering Seas appear to be shifting.

For DOD, the energy resiliency afforded by having on-site/near-site renewable energy generation (tidal or wave) enhances operations, and any reduction in transported fuel adds to the value proposition of marine energy technologies. Bases always have backup generation on-site for necessary resilience, so the focus will be integrating marine energy generation with existing power sources and/or backup generation to establish effective microgrid capability. The requirements for marine energy technologies will be the same for all generation capabilities (i.e., to ensure that reliable, quality power is available continuously to accomplish DOD missions).

Power Requirements

Remote communities typically have microgrid power systems from 200 kW to 5 MW, with high reliability being a key objective. Remote resorts will span the spectrum from a few kilowatts to megawatts and, in some cases, are part of an isolated community grid. Remote DOD bases will have electric power needs comparable to remote villages, though load size will generally be at the upper end of the load spectrum and bases will often have greater fuel storage capacity.

Markets

Description of Markets

By definition, isolated communities are not connected to a major utility grid. These communities are isolated either by water (islands) or being remote from population centers (for example, more than 300 communities in interior and coastal Alaska). In this chapter, we will only discuss communities with a load less than 5 MW that are not connected to a major regional grid. Utilities with a load greater than 5 MW have scale advantages that can lower their costs. These utilities also have larger populations that correlate with better transport connections.

Isolated U.S. communities with a load less than 5 MW have a combined market of more than 70 MW, which is $350 million in marine energy technologies installed cost (assuming $5 per Watt installed). The U.S. market includes approximately 175 to 300 small communities in Alaska, the two smaller Hawaiian islands of Lanai and Molokai, a couple of dozen islands mostly off the coast of Maine, four inhabited islands in the Northern Mariana Islands, and some islands in American Samoa (Kilcher and Thresher 2016). Other major island territories, such as Guam, have larger utilities and are not covered in this report.

There is a growing number of remote and ecotourist resorts. Some are included in the power systems of isolated communities and some are independent. No database of remote resorts and their electrical loads has been identified.

DOD operates numerous Pacific Island facilities in the Marshall Islands, Guam, and Okinawa, as well as Diego Garcia in the Indian Ocean. Some of these bases will have loads larger than the 5-MW target, but the basic market and benefits of marine energy technologies will still apply. DOD has nine bases in Alaska; about half are coastal and could benefit from marine energy technologies.

The international market is much larger, comprised of thousands of small island and remote coastal communities. Indonesia alone has 13,000 rural communities without utility power services (GE Reports Staff 2017). Therefore, a competitive marine energy system could have a large global market space to develop.

Power Options

The established source of power generation in isolated communities is primarily diesel generators. Any new generation must be competitive with diesel-generated power. Although diesel fuel is inexpensive today, the price has been much higher in the past. Even at today's prices, the cost range of diesel-generated power for most of the remote Alaska communities is more than $0.50 and sometimes exceeds $1 per kWh (Alaska Energy Authority 2016a). For larger and less remote locations, costs can be in the $0.19−$0.37/kWh range, with higher costs associated with degree of remoteness and seasonal limits to access. Diesel generation is flexible and set up to follow load, with technology and controls that are familiar and reliable. Any new generation must be integrated with the existing diesel system.

Over the past 20 years, an increasing number of community grids in Alaska have incorporated wind energy. There are 27 communities with wind installations in rural Alaska (Alaska Energy Authority 2016b). In Wales, Alaska, two 60-kW wind generators can provide up to 150% penetration. In other words, the wind generators can produce 1.5 times the electric load. They have a battery system and heat loads to balance the utility system while making use of excess electricity generation. For high-latitude locations, wind is the established competitor for diesel replacement. The installed cost of wind generators in remote locations (especially Alaska) is high (up to four times the cost of continental U.S. installations), and maintenance is very challenging because cranes are not available. Because of logistics constraints and grid size, installed wind generators are smaller than typical utility wind generators, which means they are more expensive and offer fewer options. So wind installations are vulnerable to competition from marine energy technologies if they can reduce project cost and demonstrate reliability.

For midlatitude and tropical communities, the number of solar PV installations is increasing rapidly with the decline in the cost of PV and storage. Islands off the coast of Maine are reducing energy loads with energy efficiency programs and by adding large ground-mounted PV systems and battery energy storage systems. The coastal islands off Maine are a good fit for PV because of having peak summer loads from tourism that align with peak summer performance from PV. This niche market will likely be filled in the short term by PV and storage before marine energy technologies are available at competitive prices. However, marine energy provides power at night and could complement PV.

For DOD, the competition in these markets will be diesel, PV, wind, and storage, but with greater emphasis on the reliability and resiliency that marine energy technologies offer; cost will be an important but secondary factor.

Geographic Relevance

U.S. markets include coastal and interior Alaska, islands off the coast of Maine, smaller Hawaiian Islands, and smaller territorial islands. Remote resorts are present, from Bering Sea fishing lodges to Caribbean diving retreats. DOD has bases in Alaska, Puerto Rico, the Bahamas, U.S. Virgin Islands, Cuba, and other remote areas. The interior Alaska communities have river current potential, and the coastal and island communities usually have wave and tidal current resources. High-latitude locations with winter ice covering most rivers will only be generating power during half the year unless river/tidal generators are developed for use under the ice. Even if generators are developed that can operate under the ice, they must be able to survive the annual freeze and break up. The freezing in some rivers includes formation of fazil ice and during breakup, the ice, which is several feet thick, breaks into chunks that can be larger than a bus and can pile up, even forming temporary dams.

In high-latitude locations like Alaska, electrical power consumption is greatest in the winter and lowest in the summer. Although much of the heating load is provided by burning diesel directly and diesel's thermal efficiencies are much higher than its electrical efficiencies, the electric load is significant, a result of 20 or more hours of daily dark. The river currents are high in the summer and low in the winter; even if the challenge of operating in an ice-covered river can be overcome, there is a resource-seasonal mismatch to the load. This means that river current generation will usually need to be complemented with other generation technologies in the Alaska market. The only reason that river current is a valuable consideration is that it produces steady and consistent power, which means a higher energy delivery per installed kilowatt and minimal integration needs, such as storage. The wave energy resource in the Gulf of Alaska is higher in the winter, so the seasonal distribution of wave energy correlates well with the energy consumption pattern of the communities. For tropical island locations, electricity use is less seasonal.

Marine Energy Potential Value Proposition

Marine energy technologies offer price certainty, relief from transport logistics, and reduced pollution risk. Marine energy devices do not have a fuel cost and are therefore not subject to the energy cost variations that diesel generators have as a result of oil market volatility. Although currently more expensive than other renewable energy technologies, marine energy devices typically have less variability in the short and long terms, making integration into hybrid systems easier (as well as diminishing storage or demand response requirements). Marine energy as a part of a mix of generation resources creates a more reliable system because a single point of failure or change in resource has less impact on the system.

The availability and reliability of marine energy varies by resource: river current has an integration advantage because of the near-continuous power generation, and tidal current is predictable and available for most of every day. The short periods of no tidal current generation couple well with energy storage technology. Average wave energy can be forecasted days in advance and varies on a slower timescale (when averaged over multiple devices) than wind energy and solar PV. In remote applications, the logistics costs and resource variation will have a major impact on the competitive advantage and value of the marine energy technologies in complex hybrid systems.

Like all renewable energy, if marine energy technologies begin to comprise a large share of the generation in a small utility (have high penetration), maintaining grid stability could be challenging. In a diesel generator grid system, the diesel generators are typically operated in the range of 50% to 80% of their capacity. The inertia of the rotating engine generator provides stability to short-lived disruptions, such as a shorted feeder. The reserve "head room" in generating capacity supports meeting sudden load increases within seconds. At low penetration levels of variable-generation sources, such as marine energy and other renewables, the variability of the generation is a minor addition to the load variation. The diesel generators can still provide the needed response to compensate. The lower and slower variation of marine energy technologies could increase the level of penetration before additional storage or demand response is required.

As variable-generation penetration levels increase, there is less diesel generation capacity on the system and therefore less ability to rapidly increase or decrease power to maintain stability. It is not possible to have unloaded diesel generators running on standby. A diesel generator must be loaded to a minimum of 40% or 50% to avoid accelerated degradation. The penetration levels for variable generation are limited in a diesel hybrid system by the need to operate the diesel generators within their acceptable operating range while still maintaining the ability to respond to the largest combined variation in load and variable-generation sources (Power and Water Corporation 2013). Inexpensive storage could eliminate the penetration limits imposed by diesel generators and allow for greater flexibility when using all variable-generation sources including marine energy up to and including 100% penetration.

Beyond this penetration level, storage or demand response is required (Defense Advanced Research Projects Agency undated). With river and tidal current generators, the short-term variation is minimal and does not add to load variation; therefore, higher penetration will be possible with current generators than with wind or PV. If the cost of river current generators decreases enough, these generation sources could be managed like a diesel generator in that they could be run at less than maximum output, so they provide reserve capacity to handle load variation. The value and cost compared to adding storage and demand response require a complex system analysis.

Some configurations of WEC devices need to be large (about 1 MW) to be efficient and therefore may not fit into a community grid of much less than a megawatt. They will be more difficult to integrate in any isolated community microgrid. Other types of WECs scale well and can be built in the 100-kW range or even smaller.

Path Forward

The advantage of this market for developing marine energy technologies is that the cost of generated electricity is high; therefore, the cost and performance requirements of marine energy technology must meet are less difficult than the general utility market. Although it will be more expensive to install and maintain marine energy devices in remote locations, all competitors have similar or greater challenges. For instance, in permafrost areas, heavy construction is planned for when the ground is frozen and installing a wind generator requires moving a crane to the site by barge in the summer. The crane remains over the winter; it cannot be returned until the river opens the following spring. There are river current demonstration projects in several locations, including Igiuggig and Eagle in Alaska. Tidal current and wave projects have been proposed in Alaska.

Devices using river or tidal current to produce power need more prototype demonstrations to show effectiveness and improve reliability, ease of deployment, and understanding of servicing requirements. Better approaches to avoiding damage from debris need to be developed and tested for river and tidal current installations. The feasibility of operating current devices under the ice must be studied to identify the benefit and cost reduction of year-round production. River systems in Alaska are mostly frozen for approximately half of the year. Although most river current devices being tested in Alaska are floating devices, bottom-mounted devices are being tested in other locations. A bottom-mounted device in a deep location would be less vulnerable to ice and would be exposed to less floating debris. Little published technical study is available on the formation of frazil ice and ice breakup phenomena (Figure 9.3). So even if a current generator can operate under the ice, there may be additional challenges during the transitions from ice-covered to free of ice in spring and back to ice-covered in the fall.

Figure 9.3. Ice breakup on the Yukon River in Alaska. *With permission from yukonriverbreakup.com*

Wave devices need prototype testing to determine the effectiveness of the various WEC configurations that have been designed. Some are bottom mounted and some float, and researchers must determine which will be better for this market and environment. Some scale and others (especially floating point absorbers) may not scale well because of resonant wave period response requirements. The survival of WEC devices in this environment needs to be demonstrated. The successful devices then need to be installed in demonstration projects that will allow financial, installation, and operation procedures and costs to be developed and validated. The ability to maintain WEC devices in a location like the Gulf of Alaska, which has high energy waves for long periods, especially in the winter, must be demonstrated. The smaller the maximum wave height for safe maintenance, the more reliable the WEC device must be to be viable. A bottom-mounted flapping WEC has been proposed for Yakutat on the Gulf of Alaska. This type of WEC scales well and can be deployed in the size range that fits Yakutat's small load. That project has not been funded.

All types of marine energy devices need better integration management controls for microgrids so developers can incorporate marine energy technologies as pilot projects without designing a new control system for each installation. These controls need to be simple and reliable. They need to integrate easily into existing diesel systems that are transitioning to complex integrated systems that have multiple generation options, along with load control and storage assets. The integrated energy cost, including installation and operation, must be lower than imported diesel generation (in many areas less than $0.50/kWh). Depending on the marine energy device type and configuration, it may or may not have inertia (resistance to rapid changes in frequency) like the diesel generators have because of their spinning mass being electrically directly coupled to the grid. Technology for synthetic inertia in generation connected through inverters has been developed and commercially deployed with large wind power plants in Quebec, Canada.

Potential Partners

This market can serve as a development step for marine energy technologies in that it provides a niche with high energy costs so it is easier to be competitive. The customers have relatively small power requirements that may make projects easier to finance for the early high-risk demonstrations of the technology. There are financial hurdles unique to these small applications, such as the cost of developing feasibility studies being high per dollar of project and finding financing sources for small projects that are using new technology. The U.S. Department of Energy has an Office of Indian Energy Policy that periodically releases funding opportunities to help tribal governments and communities develop local energy resources.

Planning and financing early projects in Alaska will require cooperation between the state government and the local utility. Both have a financial stake in the energy system. The state provides a fuel subsidy for power generation in high-cost remote communities. The drawback is that because the state pays approximately half of the cost of electricity in these remote communities, if it does not provide much of the capital cost for a renewable energy system, then there is less incentive for the small local utility to fund a project. Remote resorts do not get subsidies, so they have the full incentive to offset fuel cost and many have an ecotourist branding to maintain so reducing or eliminating diesel use supports their branding.

Although DOD requires extremely high reliability for their bases and operations, the agency also offers testing and validation programs that help move technologies toward market readiness. DOD has several programs in technology and energy development that target different technology readiness levels and can be effective partners in new technology development, including the Defense Advanced Research Projects Agency, which is focused on making pivotal investments in breakthrough technologies for national security; the Environmental Security Technology Certification Program,[14] and the Strategic Environmental Research and Development Program,[15] which targets prototype test projects and early market entrance projects; and the Energy Resilience and Conservation Investment Program,[16] which targets commercially viable energy technologies that enhance base energy, security, and resilience.

[14] https://serdp-estcp.org/About-SERDP-and-ESTCP/About-ESTCP

[15] https://serdp-estcp.org/About-SERDP-and-ESTCP/About-SERDP

[16] http://www.hnc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/490653/energy-division-energy-conservation-investment-program-ecip-validation/

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