HYDROKINETICS SEEKS TO BRING GIGAWATTS OF UNTAPPED WATER POWER INTO THE GRID.

BY MARK CRAWFORD
According to Pike Research’s January 2012 report, *Hydrokinetic and Ocean Energy Renewable Power Generation*, the U.S. still has plenty of untapped hydropower resources—enough to “generate from 85,000 to 95,000 more megawatts, with 23,000 MW available by 2025.”

The upside potential for “technically recoverable wave energy alone could provide about 25 percent of U.S. electricity demand,” said Christopher Mahoney, director of communications for the Electric Power Research Institute in Charlotte, N.C.

This kind of notice is starting to bring the technology of hydrokinetics out from the shadows of wind turbines and solar panels.

Hydrokinetics studies how kinetic energy is generated by the natural movement of water—surface waves, tidal currents, and rivers, streams, and ocean currents—and how to convert that energy to electricity. Hydrokinetic devices are placed directly in the flow and generate energy only from the power of the moving water; no dam or diversion structure is required to increase hydraulic head to drive a turbine.

Hydrokinetics is a rapidly developing field where both big companies and startups can compete equally in engineering and design.

“Various approaches to harvesting ocean wave energies have been developed that focus on maximizing wave-energy capture, maximizing the output of the electromechanical power conversion process, and optimizing the overall system performance from a cost, reliability, and value proposition standpoint,” said Gregory Lennon, director of business development-utility scale for Ocean Power Technologies, a Pennington, N.J., wave-power technology firm. “Significant focus has also been given to solutions that are grid-connect-ready, as well as the ones that serve as autonomous power sources for localized loads.”

Designs for hydrokinetic devices continue to evolve. Many are buoy-like and float on the ocean surface, like Ocean Power’s PowerBuoy. Wave movement creates a mechanical stroking within the device that is converted via a sophisticated power take-off to drive an electrical generator. The electricity is transmitted to shore by an underwater power cable.

Ocean Power recently partnered with Lockheed Martin to develop a 19-megawatt wave-energy project in Australia—one of the largest wave-energy projects announced to date.

Other devices consist of cylinders connected by hydraulic joints that also float on the surface. Wave motion drives internal hydraulic motors that produce electricity. An innovative invention by Aquamarine Power, a wave-energy company in Scotland, is a wave-powered pump with a large, hinged flap that pushes high pressure water to drive an onshore hydroelectric turbine.

The most popular hydrokinetic device is the turbine. The basic technology is well-known and comes in a variety of sizes and shapes and can be anchored underwater. Turbines also work well in tidal environments and tend to be lower cost than wave-energy recovery. As a result, tidal projects comprise over 90 percent of today’s total marine kinetic capacity—and that is driving advanced research in tidal turbine design.

Tidal turbines are very similar to wind turbines in that they convert a directional flow of energy into rotational mechanical energy. They work in river currents as well as in tides. Because these turbines are installed underwater, which is much denser than air, hydrokinetic turbines provide much more power than wind turbines at relatively low water current speeds. They can also be modular in design and stacked in different arrays, de-
pending on the characteristics of the site.

NEW TURBINE PROJECTS

Ocean Renewable Power Co. placed the first of several planned turbine generator units in Cobscook Bay, Maine, in late summer 2012. It was the first grid-connected tidal energy project (that is, not involving a dam) in the Americas.

The unit began sending electricity to the grid in September. The TidGen turbine device has a peak output of 180 kilowatts and can provide enough electricity annually to power 25 to 30 homes. Built primarily with composite materials, the turbines resist corrosion, require no lubricants, and emit no discharge into the surrounding water. Two additional units will be installed in the fall of 2013; combined, the three-device power system will generate enough electricity to power 75 to 100 homes.

“Given the benefits that developing local tidal energy resources will have for the state of Maine, the utility commission approved a power purchase agreement at a significant premium to conventional pow-
er sources,” said Brian Polagye, research assistant professor of mechanical engineering and co-director of the Northwest National Marine Renewable Energy Center at the University of Washington-Seattle. “Similarly favorable interconnection agreements have been put in place in Nova Scotia and Scotland, creating a powerful market ‘pull’ mechanism to accelerate the industry.”

In New York City’s East River, another tidal deployment is under way—Verdant Power’s 1,050 kW Roosevelt Island Tidal Energy Project will generate electricity from turbine generator units mounted on the riverbed. This kinetic hydropower system will capture energy from both ebb and flood directions by yawing with the changing tide, using a passive system with a downstream rotor.

“We have a three-blade downstream axial flow rotor and use the nose cone to orientate the turbine to the water current,” said Verdant Power’s president, Trey Taylor. “So with the East River tides, the turbine can turn around to get the ebb and flood tides.”

The turbines are positioned in an offset arrangement. “We inadvertently came to that conclusion as we were looking at existing wind turbine modeling to determine how to space turbines,” Taylor said. “If you take a percentage of energy out, you need to allow enough distance for the water current to restore itself before you take another percentage of energy out. Otherwise it will take the path of least resistance, and the water current will start to move around the turbines.”

OTHER ENGINEERING CHALLENGES

Engineers must take into consideration the interface between the various stages of power conversion—for example, the conversion of pneumatic power created by the oscillation of a water column to mechanical power by turning the turbine, which is then converted to electrical power by the generator, drive, and transformer.

“The ability of mechanical, electrical, controls, and production engineering to think in a holistic fashion in such a way as to understand the inter-dependability of these aspects of the design process is critical to achieve a truly optimized system solution,” Lennon of Ocean Power said. “For instance, designing a power take-off system requires cutting-edge mechanical expertise that accounts for various mechanical stress sources and loads—such as wave force, assembly and interface requirements, electromechanical forces and torques, and cabling and electromagnetic interference—to maximize overall system efficiency.”

For both tidal and wave converters, machine speeds tend to be quite low, particularly compared to wind turbines. Consequently, device components experience very high torques near rated power, which will only increase as devices scale up.

“Developing reliable and highly efficient drivetrains is a significant engineering challenge for the marine renewable sector,” said Polagye at University of Washington. “Similarly, control algorithms to optimize power production will be constrained between the realities of structural loads and the benefits of cap-
turing the power from turbulent ‘gusts’ in the tidal sector, and large waves in the wave sector. This represents a structural-fluids-control problem that has not yet been fully explored.”

Oceanlinx, an international wave-energy company based in Sydney, Australia, has designed several innovative turbines, including its patented airWAVE turbine that generates electricity under variable flow conditions. The Australian government recently awarded the company a multi-million-dollar grant to grid-connect the world’s first 1 MW-capacity, single-wave energy converter unit.

‘O’cean waves are random and combinations of small and large waves generally travel in wave groups,” said Sean Barrett, technical wave resource and project analyst with Oceanlinx, “Therefore the excitation of a wave-energy converter can go from periods of low excitation to excitation up to the rated capacity of the electrical equipment. Successful control and management of this variable energy flow, and its compliance with the stringent requirements of grid operators, will lead to low electricity production costs and successful device development.”

Making this happen requires having a wave-energy team comprising various experts. For example, Barrett noted, naval architects and structural engineers are required for the design of the structure, and mechanical and electrical engineers are required for the power take-off mechanisms.

“Then this team needs people who understand wave-energy input, the environmental consequences or benefits of such devices, and have the expertise on how to navigate the bureaucracy surrounding permitting and consenting issues,” Barrett said. “The right management structure also has to be in place to ensure that projects are delivered on time and within budget, attract new investment, and go from a design concept to a commercial product.”

**ON THE HORIZON**

According to Lennon at Ocean Power, considerable research and development are being conducted on three aspects of hydrokinetics technology:

- Optimization of the devices to maximize their capture of wave energy.
- Overall electromechanical system design.
- Development of control approaches to maximize power output under a variety of sea states.

“Creative control algorithms are also being sought to maximize the effects of...

**NEW TECHNOLOGY IS REVOLUTIONIZING THE ENERGY INDUSTRY, BUT A LOT OF IT IS UNFAMILIAR.** For instance, a recent survey of more than 400 engineers conducted by ASME found 75 percent had little or no familiarity with hydrokinetic power.

This month, the Society is launching the ASME Energy Forum, a multimedia series that will offer expert perspective and dialogue on the emerging technologies that are reshaping the 21st century energy industry—everything from renewables and fuel cells to unconventional natural gas production. The first event, a webinar exploring hydrokinetics power featuring industry leaders, is on February 14.

To join in the conversation, go to http://go.asme.org/EnergyForum.

**12 GW MORE**

In April 2012 the U.S. Department of Energy released a renewable energy resource assessment detailing the potential for developing electric power generation at existing dams across the U.S. that aren’t currently equipped to produce power. Without building any new dams, these sites could be retrofitted with hydrokinetic turbines to produce up to 12 gigawatts—enough energy to power over four million households. Most of this hydrokinetic potential occurs at lock-and-dam facilities on the Ohio, Mississippi, Alabama, and Arkansas rivers.

The U.S. Economic Development Administration in 2010 awarded Tulane University a $3 million grant to help build RiverSphere, a center of excellence that will promote the development of hydrokinetic technologies using one of New Orleans’ greatest natural resources—the Mississippi River. This research center and incubator will focus on water sustainability and renewable energy and include floating barges on which private companies can test turbine prototypes using river currents.

“The data gathered in testing the potential impacts of these hydrokinetic technologies will play a key role in determining how they can be deployed in the most environmentally sensitive way while generating as much electricity as possible,” said Keith Brannon, assistant director of public relations at Tulane University.

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WAVE HELLO The PowerBuoy is designed to convert ocean wave energy into electrical power for utility-scale grid-connected applications.

waves on the hydrokinetic system without increasing its size in such a way that cost, manufacturability, and deployment logistics become prohibitive,” Lennon said. “The task at hand is to optimize this multi-dimensional system in such a way that its power output is steady and predictable in a variety of operational environments while ensuring an attractive overall value proposition.”

He said it is important to realize that hydrokinetics is a relatively young field compared to combustion-engine technology which has, for example, gone through a century of development and improvement to achieve its current state. According to Lennon, hydrokinetics has made significant advances over the last few years.

In addition to the efforts to optimize the technology, important research is also dealing with critical aspects of site evaluation, seabed mechanics and engineering, environmental impacts, and regulatory compliance.

The Northwest National Marine Renewable Energy Center, for example, has developed a new vessel-based survey technique to characterize small-scale variations in tidal resources for optimizing the location for pilot-scale turbines. This approach represents a substantial cost-savings over the “brute-force” method of deploying a grid of Doppler profilers and provides better spatial resolution compared to traditional transect surveys.

“A surface vessel equipped with a Doppler profiler occupies a series of stations over at least four tidal ebb or flood cycles,” said Polagye. “The technique can resolve spatial variations in the tidal resource to an order of 50 meters and compares very well to the relative difference in resource that would be detected by deploying Doppler profilers at each location for 30 days or more.”

Also, using underwater noise data from tidal energy sites and models for the sound produced by tidal turbines, the center has assembled a framework for assessing the effects these sounds may have on marine life. Because both ambient noise and turbine sound vary in time, they can be described in terms of a probability (for example, at location “x” there is a “y percent” chance that marine animal “z” will detect the sound from a turbine).

“We determined that the probability of marine animals detecting sound from the project is quite low beyond one kilometer,” Polagye said. “Any environmental studies of marine mammal behavior around turbines will need to consider variations in received sound levels. For example, a marine mammal at a specific distance to a turbine may be exposed to very different received levels of sound, depending on how fast the tidal currents are running and if vessels are nearby. This type of interdisciplinary engineering and environmental analysis is at the forefront of identifying potential environmental impacts of hydrokinetics and mitigating them through engineering design.”

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