Marine and Hydrokinetic [MHK] Technology: Background Information

Marine and Hydrokinetics Distributed and Alternate Applications Forum
November 2017
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Glossary


International Electrotechnical Commission (IEC) TC114 Marine Energy Terminology

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>kW</td>
<td>Kilowatt – Rate of energy transfer. Average use rate of U.S. household.</td>
</tr>
<tr>
<td>kWh</td>
<td>Kilowatt hour – Amount of energy transferred. One kilowatt for one hour. Equivalent to electric heater running for one hour.</td>
</tr>
<tr>
<td>WEC</td>
<td>Wave Energy Converter</td>
</tr>
<tr>
<td>CEC</td>
<td>Current Energy Converter</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>Availability</td>
<td>Percentage of time energy device is operational and able to convert energy.</td>
</tr>
</tbody>
</table>
## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROV</td>
<td>Remotely Operated Vehicle</td>
</tr>
<tr>
<td>UUV</td>
<td>Unmanned Underwater Vehicle (DoD)</td>
</tr>
<tr>
<td>AUV</td>
<td>Autonomous Underwater Vehicle</td>
</tr>
<tr>
<td>Electrolysis</td>
<td>The process of using electricity to split water into hydrogen and oxygen. This reaction takes place in an electrolyzer.</td>
</tr>
<tr>
<td>EEZ</td>
<td>Exclusive Economic Zone. Extends no more than 200 nautical miles from the territorial sea baseline and is adjacent to the 12 nautical mile territorial sea of the United States, including any other territory or possession over which the United States exercises sovereignty. Within the EEZ, the United States has: Sovereign rights for the purpose of exploring, exploiting, conserving, and managing natural resources, whether living or nonliving, of the seabed and subsoil and the superjacent waters and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents, and winds.</td>
</tr>
<tr>
<td>Reverse Osmosis</td>
<td>The movement of freshwater through a semipermeable membrane when pressure is applied to a solution (such as seawater) on one side of it.</td>
</tr>
<tr>
<td>Array</td>
<td>An arrangement of similar devices. In ocean energy devices, this means a number of similar devices arranged into a single group to provide a combined energy output. Also known as a &quot;farm.&quot;</td>
</tr>
<tr>
<td>Bathymetry</td>
<td>The measurement of water depth and the shape of seabed — often as shown on a map of the sea or hydrographical chart.</td>
</tr>
<tr>
<td>Term</td>
<td>Description</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Availability</strong></td>
<td>The degree to which a system is free from degradation or interruption in its output, resulting from component failures, maintenance, or operational scheduling. Availability is often expressed as an annual percentage derived from the following equation: Availability = Time available for operation / Total time in period.</td>
</tr>
<tr>
<td><strong>Capacity Factor</strong></td>
<td>Same as load factor or full load factor. The ratio of the mean generation to the peak generation on a renewable energy generator. Either expressed in percentage (referring to a reference time period) or in equivalent full load hours per year.</td>
</tr>
<tr>
<td><strong>Conversion Efficiency</strong></td>
<td>The conversion efficiency ($\eta$) of a device is the proportion of energy converted to a useful form (e.g., electricity) compared to the total energy available to the device.</td>
</tr>
<tr>
<td><strong>Installed Capacity</strong></td>
<td>The installed capacity of a device is the total power that the device can produce when operating correctly and at full power output. Traditionally, this is the installed capacity of the electrical generator in a device. Installed capacity is usually measured in kilowatts (kW) or megawatts (MW).</td>
</tr>
<tr>
<td><strong>Power-Take-Off (PTO)</strong></td>
<td>A system incorporated to a renewable energy device that allows energy from the physical motions of the device to be converted to a useful form, such as electricity.</td>
</tr>
<tr>
<td><strong>Survivability</strong></td>
<td>A measure of a device's ability to remain intact and operational in extreme environmental conditions.</td>
</tr>
</tbody>
</table>
Tidal range is very predictable, although it can be modified by local weather conditions. The worldwide theoretical power of tidal energy, including tidal currents, has been estimated at around 1,200 TWh/year.

The wave energy map has been shaded to enhance the wave power flux between 15 and 75 KW/m, which is the likely operational range of wave energy converters. The worldwide theoretical potential of wave power has been calculated as 29,500 TWh/year.

https://www.ocean-energy-systems.org/news/oes-vision-for-international-deployment-of-ocean-energy/
The U.S. Has Significant, Distributed MHK Resources

Ocean Wave
2640 TWh per year

Tidal Current
445 TWh per year

Ocean Current
200 TWh per year

River Current
1381 TWh per year

International Organizations Guide Sector and Technology Development and Outline Progress

International Energy Agency: Ocean Energy Systems
- Established 2001
- 25 member countries
- https://www.ocean-energy-systems.org/index.php

International Electrotechnical Commission
- Founded 2008
- 15 participating member countries and 11 observer
- 8 Technical Specifications published
- http://www.tc114.us/
A Range of Different Wave Energy Technology Types Are Presently In Development: Some Examples Below

[Diagram showing various wave energy technologies]

Different Current (Tidal, Ocean, River) Energy Technology Types Are also in Development: Some Examples Below

Source: Renewable Electricity Futures Study NREL TP-6A20-52409-2
(https://www.nrel.gov/docs/fy12osti/52409-2.pdf)
Cost Are Presently High for Utility Application


<table>
<thead>
<tr>
<th>Deployment Stage</th>
<th>Variable</th>
<th>Wave Min</th>
<th>Wave Max¹</th>
<th>Tidal Min</th>
<th>Tidal Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>First array / First Project²</td>
<td>Project Capacity (MW)</td>
<td>1</td>
<td>3³</td>
<td>0.3</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>CAPEX ($/kW)</td>
<td>4000</td>
<td>18100</td>
<td>5100</td>
<td>14600</td>
</tr>
<tr>
<td></td>
<td>OPEX ($/kW per year)</td>
<td>140</td>
<td>1500</td>
<td>160</td>
<td>1160</td>
</tr>
<tr>
<td>Second array/ Second Project</td>
<td>Project Capacity (MW)</td>
<td>1</td>
<td>10</td>
<td>0.5</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>CAPEX ($/kW)</td>
<td>3600</td>
<td>15300</td>
<td>4300</td>
<td>8700</td>
</tr>
<tr>
<td></td>
<td>OPEX ($/kW per year)</td>
<td>100</td>
<td>500</td>
<td>150</td>
<td>530</td>
</tr>
<tr>
<td></td>
<td>Availability (%)</td>
<td>85%</td>
<td>98%</td>
<td>85%</td>
<td>98%</td>
</tr>
<tr>
<td></td>
<td>Capacity Factor (%)</td>
<td>30%</td>
<td>35%</td>
<td>35%</td>
<td>42%</td>
</tr>
<tr>
<td></td>
<td>LCOE ($/MWh)</td>
<td>210</td>
<td>670</td>
<td>210</td>
<td>470</td>
</tr>
<tr>
<td>First Commercial-scale Project</td>
<td>Project Capacity (MW)</td>
<td>2</td>
<td>75</td>
<td>3</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>CAPEX ($/kW)</td>
<td>2700</td>
<td>9100</td>
<td>3300</td>
<td>5600</td>
</tr>
<tr>
<td></td>
<td>OPEX ($/kW per year)</td>
<td>70</td>
<td>380</td>
<td>90</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Availability (%)</td>
<td>95%</td>
<td>98%</td>
<td>92%</td>
<td>98%</td>
</tr>
<tr>
<td></td>
<td>Capacity Factor (%)</td>
<td>35%</td>
<td>40%</td>
<td>35%</td>
<td>40%</td>
</tr>
<tr>
<td></td>
<td>LCOE ($/MWh)</td>
<td>120</td>
<td>470</td>
<td>130</td>
<td>280</td>
</tr>
</tbody>
</table>

Note:
LCOE for deployed energy systems typically range from 40-100 $/MWh and up to 250 $/MWh for diesel systems


Significant Cost Reductions Are Targeted in Wave Energy

**Figure 19:** Wave LCOE Percentage Breakdown by Cost Centre Values at Current Stage of Deployment (Left) and the Commercial Target (Right) [Note: the area of the chart represents the LCOE].

*Figure from International Energy Agency Ocean Energy Systems 2016 Report: "International Levelised Cost of Energy (LCOE) for Ocean Energy Technologies." https://www.ocean-energy-systems.org/*
Significant Cost Reductions Are Targeted in Tidal Energy

Figure 9: Tidal LCOE Percentage Breakdown by Cost Centre Values at Current Stage of Deployment (Left) and the Commercial Target (Right) [Note: the area of the chart represents the LCOE]

Figure from International Energy Agency Ocean Energy Systems 2016 Report: "International Levelised Cost of Energy (LCOE) for Ocean Energy Technologies." https://www.ocean-energy-systems.org/
DOE Has Outlined MHK Status, Challenges, and Opportunities in the Quadrennial Technology Review

- Section 4.2.9 Marine and Hydrokinetic Power Technology

The 2015 Quadrennial Technology Review (QTR 2015) examines the most promising research, development, demonstration, and deployment (RDD&D) opportunities across energy technologies to effectively address the nation's energy needs.

Specifically, this analysis identifies the important technology RDD&D opportunities across energy supply and end use in working toward a clean energy economy in the United States. The insight gained from this analysis provides essential information for decision makers as they develop funding decisions, approaches to public-private partnerships, and other strategic actions over the next five years.
Present MHK R&D Efforts

- **Performance**
  - Drive and empower innovation
  - Verify and optimize power performance and quality
  - Identify opportunities and approaches for improvement

- **Reliability**
  - Assess and improve system and component reliability
  - Identify areas and approaches for O&M focus and cost reduction

- **Capex**
  - Drive down capital costs
  - Validate structural and dynamic models
  - Collaborate with industry to refine designs

- **Risk / Risk Perception**
  - Decrease real risks and risk perception
  - Characterize grid and grid fault response
  - Verify systems operate as designed — ready for deployment
  - Device certification testing

- **Deployment**
  - Early application assessment
  - Grid response, services, and power market value
  - Market barrier and opportunity assessment
  - Project feasibility assessment
Lack of Impacts Observed Globally Summarized in Recent Report

U.S. Wave At-Sea Validation and Optimization Site in Development: PMEC SETS

Images from Oregon State University

http://nnmrec.oregonstate.edu/facilities/pmec-sets

Umbrella organization for wave, current, in-river academic & scientific research

Umbrella organization for all marine renewable energy test facilities at partner institutions
Provides three grid connected berths (30/60/80 m depth; 1 to 2 km offshore)

For technical evaluation and environmental impact assessment studies of in-water WEC devices

http://hinmrec.hnei.hawaii.edu/nmrec-test-sites/wave-energy-test-site/
Examples of Tidal Current Validation Sites in Operation

- UAK, Fairbanks/NNMR
- EC Tidal Test Site, AK
- FORCE, Bay of Fundy, CAN
- Bourne Tidal Test Site, MA
- EMEC, UK
Remote Installation and Operation and Maintenance Considerations

1. Vessels and Harbors
2. System Access
3. Mechanical and Electrical Service Expertise

Verdant Power, NY

MBARI, CA

Houston Ship Repair
Vessels and Harbors

Vessels
- Needed for site selection, installation, and maintenance – minor and major
- Smaller deployments will likely utilize existing vessel fleet regionally – project/design constraint
- Larger deployments could utilize larger vessels from more distant ports at significantly greater expense
- Rates and availability fluctuate significantly for larger vessels (competing with other industries, e.g., oil and gas)

Harbors
- Air and water draft limitations
- Cranes and lift capacity constraints
- Docks and berths
- Existing nearby fabrication and manufacture
- Sufficient assembly and service areas
- Relevant ocean operations services
System Access Considerations

- Distance from relevant port
- Seabed conditions and depths
- Weather windows
- Environmental constraints (e.g., migratory mammals)
- Service paradigm and plan
- Acceptability of down time/availability
Mechanical and Electrical Service Expertise

- Early deployments will have customized engineering, equipment, controls, and construction with little uniformity or commonality among systems
- Limited local technical skills for installation and maintenance
- Constrained by adequate infrastructure and available equipment and tools
- The more remote, the more limited and expensive access
- Therefore, highly reliable systems are desired!