Marine Energy: The Key for the Development of Sustainable Energy Supply

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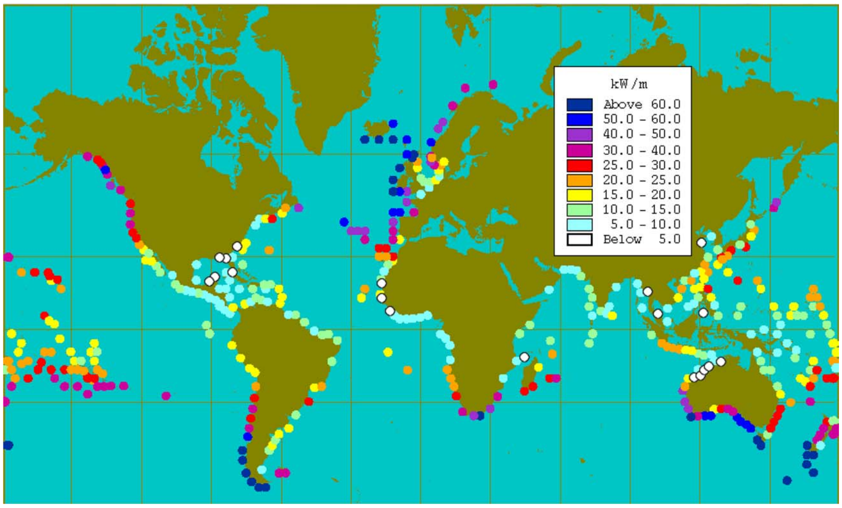

I. WORLDWIDE DEVELOPMENT OF MARINE ENERGY

Marine energy generation technologies include offshore wind, wave, and tidal energy generation, which are considered to be the fundamental renewable generation technologies for the long-term aim to reduce our climate's CO_2 emissions. Hence, marine energy is the key to develop future sustainable energy supply.

In March 2009, the European Wind Energy Association (EWEA) increased its 2020 target to 230-GW wind power capacity, including 40-GW offshore wind. EWEA's target is 150 GW by 2030. In May 2008, the U.S. Department of Energy (DOE) released the report: "20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply." This report has investigated the wind energy providing 20% of United States electricity, and it found that more than 300 GW of wind energy capacity would need to be installed, while 54 GW of wind energy capacity would be offshore. With its large land mass and long coastline, China has very rich wind resources. With assuming 10%–20% of the total amount of sea surface being used for offshore development, the total offshore wind capacity would be 100–200 GW.

The ocean occupies 70% of the surface of the earth, and it contains enormous amount of energy, such as tidal energy, wave energy, wave stream energy, etc., which are all renewable energy. The global wave power potential is shown in the opening graphic. It has been estimated that the global wave power potential is around 1000–10 000 GW, which is the same order of magnitude as world electrical energy consumption.

According to the World Offshore Renewable Energy Report 2002–2007, released by the U.K. Department of Trade and Industry (DTI), it has been suggested that 3000 GW of tidal energy is estimated to be available where less than 3% is located in areas suitable for power generation. Tidal current energy is therefore very site specific, and has the distinct advantage of being highly predictable in comparison to some other forms of renewable energy sources such as wind and solar. This makes tidal energy development more attractive.

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II. TECHNOLOGIES AND SOLUTIONS

A. Marine Energy Generation and Control

Marine energy generation systems include offshore wind, wave, and tidal energy generation. The wave and tidal generation can be broadly categorized into: 1) tidal barrage, 2) ocean wave, 3) tidal current, 4) ocean thermal, and 5) salinity gradient.

With the development of wind turbine technologies, the size and capacity of wind turbines becomes bigger and bigger. For instance, now the largest wind turbine of its next-generation dedicated offshore wind farms can ensure the lowest possible cost of energy, has a capacity of 7 MW, and has a rotor diameter of 164 m. According to a report from the European Union (EU)-funded project, 20-MW wind turbines are feasible. The project explored the design limits of up-scaling wind turbines to 20 MW and it has been found that they would have rotor diameters of around 250 m, compared to some 120 m on today's 5-MW turbines. It is believed that such turbines could be a solution for expanding Europe's offshore wind energy capacity and would be providing several times more electricity at lower costs than today's turbines. It is anticipated that the 20-MW turbines will be used within ten years. Now wind turbine control technology is available to provide similar frequency and voltage control as conventional synchronous machines in thermal and hydro plants. The control can be achieved by using power electronic control of variable speed machines such as doubly fed induction generators (DFIGs), or induction or synchronous machines with full back-to-back converters. Due to the fast response of power electronic converters, improved stability performance can be achieved as well. A lot of R&D work has been done in the area but more work is expected to make future wind turbines more flexible and adaptable to system operating conditions.

With the advent of various novel concepts and reported success of several deployments of wave and tidal generation technologies, the wave and tidal energy sector, especially the field of tidal current and wave energy conversion technology, has gained significant attention throughout the world. At the current state of these technologies, a range of concepts and conversion technologies are being tested either in laboratories, or in open seas. It is expected that multiunit tidal current and ocean wave farms will be constructed in the future. Tidal barrage, ocean thermal gradient technologies as well as shore-based large wave power plants will also be a part of this class of energy harvesting. The interactions between fluid motion, for instance, tidal current or wave formation, and front-end conversion unit result in primary energy transfer from the resource field to the device itself. For most tidal current devices, this is realized through blade spinning, directly coupled to the rotary electrical machines. On the other hand, wave generation devices might utilize more than one degree of freedom in capturing kinetic and/or potential energy of the ocean water. Similar to wind generation systems and most wave and tidal current devices, the input mechanical torque drives the rotary machines. While some direct drive systems do not use any intermediate stage and linear movement of the front-end, conversion unit is directly coupled to a permanent-magnet-based linear generators. In general, all marine energy systems including wind, wave, and tidal energy generation systems can be classified into the following four classes:

- induction generators where there are no power electronic converters and they are directly connected to the power grid and they consume reactive power;
- synchronous generators where there are no power electronic converters and they are directly connected to the power grid with/without transformer and they can either produce or consumes reactive power;
- full back-to-back power electronic converters as the interface between the generator and power grid where the converter at the grid side can either produce or consume reactive power;
- DFIGs with partially rated converter on the rotor side, stator connected directly to the power grid where the power grid side can either produce or consume reactive power.

Among the generation systems above, the full back-to-back power electronic converter interfaced generation systems can provide better flexible control possibilities and hence demonstrate better stability control performance and system behavior.

B. Integration of Energy Storage Into Marine Energy Generation

The increasing role of variable renewable sources, for instance wind, in the energy supply has been limited by the system active power reserve requirements. Energy storage can provide the opportunity to unlock the grid to integrate more intermittent renewable energy sources into power grids. In addition, smart integration of different renewable sources into the power grid would create opportunity to maximize fuel and emission savings. Energy storage can help address the intermittency problem inherent in wind and reduce the impact of diurnal wind patterns, when high winds/low demand occur at night which can require wind power to be curtailed or thermal power plants idled.

Integration studies have found that variable renewable generation sources such as wind, wave, and tidal generation can be incorporated into the power grid by changing operational practices to address the increased ramping requirements. At higher penetration levels, the required ramp ranges will increase, which adds additional costs and the need for fast-responding generation control resources to provide operational flexibility. Energy storage can be considered to be flexible resources to enable renewable energy integration and should be optimized over wide area in order to improve the overall system efficiency.

C. Marine Energy Grids

Normally a cluster of wind or wave generation units can form a wind or wave farm grid, then such a marine energy grid is connected with an onshore transmission grid via either an alternating current (ac) or a direct current (dc) interconnector. With the development of large-scale offshore wind farms, it has been found that in comparison to connecting each wind farm to shore by a dedicated connection, it would be more efficient to collect offshore wind energy in an offshore marine energy grid by connecting a cluster of wind or wave farms together and transmitting the wind or wave energy to shore, or directly to the main load centers. The North Sea super green grid is an example of such an offshore wind energy grid. The North Sea super green grid being considered will employ a multiterminal voltage-sourced-converter-based HVDC (VSC HVDC) configuration. The super green grid is promising to provide the opportunity to balance power generation between different energy sources, for instance, wind and hydro power, over wide areas, at different time scales. Innovative control strategies for such a super green grid are required to achieve required security and stability performance.

III. ENVIRONMENTS AND POLICY

Assessing wind resources for wind energy projects demands a level of detail and accuracy regarding the spatial and temporal variations of the wind and turbulence climate which is beyond that required for other purposes. Hence, a wide range of measurements and models need to be developed and are employed to provide assessments for initial site identification, quantifying the long-term wind resource based on short-term measurements, extrapolating the vertical wind speed profile, calculating the potential power output from each turbine and for wind farm layout to optimize power output.

The ocean has the potential to contribute significant amounts of renewable energy to the electrical grids of coastal and island nations. The renewable marine energy industry worldwide faces significant hurdles to achieving responsible development of commercial scale marine energy installations, led by the need to protect the marine environment and the organisms it supports. Regulatory agencies and stakeholders have widespread concerns about the potential effects of small- and large-scale marine energy developments; little scientific literature exists to help confirm these concerns. In this situation, environmental risk assessment techniques would be useful to measure effects of industrial processes, and assess the vulnerabilities and risk to marine animals, habitats, and ecosystems from marine energy development.

Increasing environmental concerns and reliance on energy imports have led governments to increase their investment and use of wind energy, through the construction of offshore wind farms. Because the technologies are new, there is little information on how such schemes will interact with the environment. Hence, there is need to develop methods which integrate socioeconomic evaluation of ecosystem goods and services into technology evaluation to enable a holistic assessment of the impact of renewable energy production and greenhouse gas (GHG) mitigation technologies.

It is required to take exploitation and protection of the ocean as a long-term strategic task before the sustainable development of its national economy can be achieved. In this situation, policy and strategy become important along with the development of marine energy in order to develop a sustainable energy economy. ■