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Preface to Special Topic: Marine Renewable Energy

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INTRODUCTION

Marine renewable energy (MRE) is generated from waves, currents, tides, and thermal resources in the ocean. MRE has been identified as a potential commercial-scale source of renewable energy. This special topic presents a compilation of works selected from the 3rd IAHR Europe Congress, held in Porto, Portugal, in 2014. It covers different subjects relevant to MRE, including resource assessment, marine energy sector policies, energy source comparisons based on levelized cost, proof-of-concept and new-technology development for wave and tidal energy exploitation, and assessment of possible interference between wave energy converters (WECs).

MARINE RENEWABLE ENERGY

Marine renewable energy produced from various sources has the potential to become a key contributor to global energy needs, not only because of issues and problems often related to the use of fossil fuels (e.g., environmental pollution, climate change, security in energy supply, price volatility in the international markets, and near-future depletion of resources) but also because of the vast and yet almost untapped energy resources available in the oceans and the long-lasting availability of those resources. Estimates of the theoretical potential of renewable energy resources in the oceans follow:

- Waves: 32 000 TW h/yr;[1]
- Tidal range and tidal currents: 22 000 TW h/yr;[2]
- Ocean currents: 6000 TW h/yr;[3]
- Salinity gradients: 30 000 TW h/yr;[4]
- Temperature gradients/ocean thermal energy conversion: 61 300 TW h/yr.[5]

Although resource estimates may vary with the source, it is clear that, at approximately 151 300 TW h/yr, the theoretical potential for ocean energy technologies is very significant. However, although the theoretical potential for MRE production is high, the technical potential is less because of the limitations of currently proven technologies. Presently, it is impossible to assess MRE technical potentials accurately because they depend on future technology developments. In addition, most MRE technologies are either the subject of significant R&D efforts or in the pre-commercial or demonstration stages of development, with tidal barrages possibly being the most well-known exception.

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If other energy sources that use the marine environment or space are included, namely, offshore wind energy with a technical potential of 192 800 TW h/yr,[6] potential MRE production increases significantly to amounts well above present world electricity consumption, which was estimated to be 18 900 TW h/yr in 2012,[7] and the total primary energy supply, which was estimated to be 155 500 TW h/yr in 2012.[7] Including the offshore solar energy resource and marine biomass farming for production of biofuels from seaweed and/or algae adds even more potential renewable energy that could be produced from the oceans.

This special topic is focused on production of energy from wave and tidal currents action. These sources still present significant challenges in terms of R&D and practical engineering solutions given the harsh marine environment; however, efforts to advance them to commercial viability steadily continue.

As mentioned previously, oceans contain a large and almost untapped amount of renewable energy, which could make an important contribution to the future energy mix. For this potential to be realized, it is imperative that the resources be characterized, not only at the global scale but also at national and regional scales. This type of resource characterization is needed to guide selection of the most appropriate installation sites and assessment of potential energy production using a certain technology, which would be required to determine if a plan is economically viable or not. Iuppa *et al.*[8] analyzed the potential energy that could be produced by 10 different kinds of WECs installed at three selected sites located west of Sicily, Italy. This kind of analysis is very important because, as in other technologies, energy productivity has to be high enough to ensure economic payback in a reasonable number of years.

Iuppa *et al.*[8] also reported that, to guarantee investments in appropriate conversion technologies, national and local governments must be aware of the energy potential of their maritime areas. In fact, in many countries worldwide, policies are being developed and implemented to create favorable conditions for investments and to increase the share of renewable energy in the energy mix. However, a proper regulatory framework is still needed in several countries to facilitate the development of the marine energy sector and to include them in the energy mix with a relevant share. Vazquez *et al.*[9] refer to the lack of concrete government plans and relevant legislation for the exploitation of marine resources in Spain and also suggest policy measures that could promote the growth of the marine renewable sector in that country.

Indeed, most ocean energy technologies are at an early stage of development and are not yet cost competitive with the traditional and well-established energy production technologies. The levelized cost of energy (LCoE) often is used to compare different electricity generation approaches on an equivalent basis. The LCoE is the ratio of total lifetime expenses versus total expected outcomes, expressed in terms of the present equivalent value (including discount rates), representing the cost at which electricity must be generated to reach the breakeven point over the lifetime of the project. Astariz *et al.*[10] reported that the LCoE values of wave (325€/MW h), tidal (190€/MW h), and offshore wind (165€/MW h) energy are approximately three to five times more than those of conventional energy sources, which highlights the importance of increasing public funding to attract investors either in the R&D stages of the technologies or through feed-in tariffs and subsidies. Those high LCoE values are expected to decrease significantly in the future as a result of investment in R&D, which will continuously advance the technology toward commercial viability.

The variability of marine renewable resources at different time scales and the harsh marine environment are important issues that must be overcome through the continuous development of existing concepts and design of new, cost-effective technologies. Unlike most other renewable energy resources, in which a limited number of technologies (sometimes only one) are technically and economically feasible, it is expected that several technologies will co-exist to harvest wave energy, with each technology suitable for specific conditions such as water depth, the marine environment, seabed characteristics, distance from the shoreline, and integration into multifunctional structures. Falcão[11] refers to approximately 100 different projects at different levels of development and states that the number is not expected to decrease in the future, as new concepts tend to replace those that are abandoned.

The Inertial Sea WEC (ISWEC)[12] and CECO[13] are two WECs that are based on different working principles and are in different stages of development. Whereas Cagninei *et al.*[12] developed an adaptive control strategy to maximize the wave power absorption of ISWEC and performed a productivity analysis of a full-scale unit for the sea of Pantelleria, Italy, using a numerical model, Rosa-Santos *et al.*[13] present the experimental proof-of-concept of CECO, which is a new WEC designed to absorb simultaneously the kinetic and potential energy of incident waves. ISWEC uses the inertia of a large mass to guarantee the reaction needed from the power take-off (reacting body device), while CECO transforms into electricity the mechanical energy associated to the oblique motion of two lateral mobile floating modules, which follow the sea wave motion in relation to a fixed central element. While CECO is supposed to be able to absorb both components of the wave energy simultaneously, ISWEC harvests wave power without exposing any sensitive mechanical part to the harsh maritime environment.

The commercial exploitation of some MRE sources (e.g., waves) in utility-scale projects requires the installation of a large number of devices in an array (i.e., a farm or park) to take advantage of economies-of-scale and obtain a more uniform power output. However, hydrodynamic interactions between the WECs affect the global production of the array, which may be smaller or larger than the sum of the power produced by the equivalent number of isolated WECs. Because of the lack of data in that respect, Troch *et al.*[14] tested experimentally a setup of 25 individual heaving WECs with different arrangements (this is the largest setup of its kind worldwide) to analyze intra-array interactions. The data obtained, as mentioned by the authors, are useful for validating numerical models but also gives important insight to the geometrical design of WEC arrays (i.e., the arrangement of units within the array) and its effect on the coastline.

The response of ocean water to the tidal range results in currents that are modified by the seabed bathymetry, particularly near coastlines. The amount of energy harvested by tidal energy converters has a significant impact on the commercial viability of a project; therefore, it is important to characterize tidal currents at the location of interest and subsequently accurately predict electricity production, which depends on the performance of the tidal energy converter. In this regard, Adcock *et al.*[15] carried out a numerical study of an idealized headland and presented general conclusions regarding the tidal resource assessment and the design of tidal farms at those sites. His conclusions concern the variation of the maximum absorbed power with the number of turbine rows, lengths of turbine rows, and the blockage ratio of the turbines (the fraction of the water column they take up). The general qualitative trends could be useful in analyzing real locations.

Technologies needed to extract the kinetic energy from tidal, river, or ocean currents are under development, with probably more than 50 tidal current devices at the proof-of-concept or prototype-development stages.[1] Ruopp *et al.*[16] assessed the performance of a prototype tidal current turbine based on data from acoustic Doppler current measurements and actual turbine production measurements. The prototype has been tested in South Korea. A computational fluid dynamics model was calibrated with the measured data, and additional numerical simulations were performed to predict tidal currents in magnitude and direction at the area of interest at any time. The expected electricity production obtained with turbine performance curves was compared with actual field measurements during the operation of the scaled demonstrator. The analysis showed that numerical models can play a key role in project planning for detailed site selection, being capable of capturing even local flow characteristics and vortices and allowing the estimation of the financial revenue for the entire project lifecycle, reducing investment risks.[16] In spite of the work already carried out, large-scale installation, operation, and maintenance costs of tidal and ocean current energy converters have not yet been determined.[1]

FINAL REMARKS AND INSIGHTS

- Presently there is no convergence on a single design for WECs. A range of possibilities exist for energy extraction, each one based on different working principles. A single design is unlikely, in contrast with wind turbine generators.

- It is of paramount importance to bring the LCoEs of MRE production down further to levels that can compete with traditional energy sources on an equal footing (without incentives). Multifunctional floating platforms, in which energy harvesting is not seen as the only investment goal but as one of the purposes, could be an alternative approach.
- Hybrid energy converters that allow harvesting two or more renewable sources at the same time and under the same structure, instead of isolated ones, would allow important synergies (e.g., sharing the structure and other components) and savings.[17]
- Further investment and political support for the industry are required as well as assessments of the commercial potential of the technologies and their ecological impacts. A long-term strategic approach should be adopted.[9]
- A better knowledge of the expected operation and maintenance costs of the technologies developed to harvest the MREs is needed.

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