

# Marine Energy Technology

By XIAO-PING ZHANG

*Guest Editor*

PINGLIANG ZENG

*Associate Editor*

The potential for marine energy to make contributions to mitigating the impact of climate change is expected to increase significantly in the longer term. Marine energy generation technologies, including offshore wind, wave, tidal, marine current, and ocean thermal energy generation, which are considered essential to meet long-term aim of reducing CO<sub>2</sub> emissions, have experienced rapid development and significant progresses over the past few years. This special issue provides a timely and comprehensive review of recent progresses, applications, and challenges spurred by the marine energy generation and transmission technology developments. It is intended for a broad audience interested in gaining comprehensive understanding of technical issues and opportunities that may exist in this important emerging field.

## I. INTRODUCTION

The ocean occupies 70% of the surface of Earth, and it contains enormous amount of renewable energy, such as tidal energy, wave energy, wave stream energy, etc. It has been estimated that the global wave power potential is around 1000–10 000 GW, which is of the same order of magnitude as current world electrical power consumption. According to the World Offshore Renewable Energy Report 2002–2007, released by the U.K. Department of Trade and Industry (DTI), the potential of tidal energy is estimated at 3000 GW with less than 3% being located in areas suitable for power generation. Tidal current energy is 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.

According to the International Energy Agency's (IEA's) Medium scenario (IEA Blue Map), the installed capacity of wave generation would be 46 GW while that of tidal generation would reach 13 GW by 2050. It is estimated that

under the Medium scenario the global market turnover in 2050 could grow to c.£3 billion in wave and £1 billion in tidal.

The potential of offshore wind power generation capacity is enormous. For instance, the total offshore wind generation capacity in Europe could be seven times that of Europe's power demand, and that in the United States four times over its energy demand. At the end of June 30, 2012, a total of 4620 MW of offshore wind power generation has been installed globally, which represents about 2% of total installed wind power capacity. However, this is expected to rise exponentially over the next few years and could reach 80 GW by 2020, according to some ambitious projections, with three quarters of this in Europe. Currently, around 6 GW of offshore wind is under construction in Europe, 17 GW has been consented, and a further 114 GW planned. It is expected that a total of 16.2 GW of offshore wind capacity would be installed in Europe over the next four years where the majority of these are in the North Sea. The United Kingdom alone is expected to install 18 GW of offshore wind by 2020 according to the U.K. Government Roadmap, while the Crown Estate's ambitious figures show that the installed offshore wind capacity in the United Kingdom could reach some 32 GW by 2022. However, along with the worldwide development of offshore wind power generation, it

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has been recognized that offshore generation technology is relatively new, hence there would be significant opportunities and scope for cost reduction, technical innovations, and revolutionary developments.

This special issue provides a timely and comprehensive review of recent progresses, applications, and challenges spurred by the marine energy generation and transmission developments including marine energy generation technologies; marine energy grid integration and control; smart integration of different types of marine energy sources; energy storage application for dealing with the intermittency of renewable energy; the risk of environment impacts; and marine energy development policy and strategy. It is intended for broad audience interested in getting insight into the technical issues of marine energy technology and hence stimulating R&D activities in this important emerging field.

## II. TOPICS AND PAPERS

The papers in this special issue cover three broad areas: marine energy generation technologies, system integration and transmission technologies, and environmental impacts and considerations.

The first group of papers is devoted to marine energy generation technologies and their developments, including scaled development of a novel wave energy converter, overview of the technology developments and testing facilities, and review of offshore wind generation technologies.

The second group reviews technologies and techniques for system integration of marine energy as well as marine energy transmission, including innovative energy storage concept and technology, power conditioning technique to integrate the AWS into the power grid, and the application of the energy storage in smoothing the output power, smart integrated network for offshore wind and ocean energy, transmission network security assessments as well as system security for a meshed HVDC grid.

The last group of papers surveys representative work that demonstrates the impacts of marine energy generation on environment as well as resource development considering environmental factors. We present a brief summary of papers in each of these three categories in the following section.

### A. Marine Energy Generation Technologies

In the paper entitled “Scaled development of a novel wave energy converter including numerical analysis and high-resolution tank testing,” by Brekken *et al.*, numerical analysis and scaled wave tank testing are presented on the recent scaled development of a novel point absorber wave energy converter (WEC) developed by Columbia Power Technologies. Four hydrodynamic modeling tools are employed to evaluate and optimize the performance of the WEC. This paper concludes with the development of a 1 : 7 scale WEC and associated field testing.

The paper entitled “An overview of the U.K. marine energy sector,” by Lawrence *et al.*, provides a historical overview of the U.K. marine energy development, including discussion on government support policies. The authors also present two very different projects as examples of capital investment in the sector: the European Marine Energy Centre in Orkney and the forthcoming All Waters Current and Wave Test Facility in Edinburgh.

In the paper entitled “Offshore wind power generation technologies,” by Erlich *et al.*, a comprehensive overview of the current state of the technology of offshore-wind-based power generation and the technological challenges with emphasis on the electrical parts is provided. Then, the authors discuss the platform to accommodate the main and grounding transformers, the switch gear, and other assorted accessories, showing options for the transmission link from the offshore plant to the grid onshore and special grid code requirements for grid integration.

### B. System Integration and Transmission Technologies for Marine Energy

There are five articles discussing system integration and transmission technologies for marine energy.

In the paper entitled “Ocean renewable energy storage (ORES) system: Analysis of an undersea energy storage concept,” by Slocum *et al.*, an unobtrusive, safe, and economical utility-scale energy storage by taking advantage of the hydrostatic pressure at ocean depths is proposed to store energy by pumping water out of concrete spheres and later allowing it to flow back in through a turbine to generate electricity. Analysis indicates that storage can be economically feasible at depths as shallow as 200 m, with cost per megawatt hour of storage dropping until 1500 m before beginning to trend upward.

In the paper entitled “Modeling, control strategy, and power conditioning for direct-drive wave energy conversion to operate with power grid,” by Wu *et al.*, the models of the direct-drive WEC are first presented and recommendations are also proposed for their applications where an optimal control strategy, which enables AWS extracting maximum power from the irregular wave, is proposed. In order to deal with the variations of the frequency, terminal voltage, and output active power of the AWS, the power conditioner is developed to integrate the AWS into the power grid, and the application of the energy storage in smoothing the output power of the AWS is also studied.

The paper entitled “A smart integrated network for an offshore island,” by Denny and Keane, examines the potential to create an energy-independent smart network for an island community utilizing ocean and wind energy. The analysis involves the simulation of an extensive electrification of heat and transport sectors on the island and the use of renewable energy to maximize the fuel and emission savings. The authors also show the design of a smart network control algorithm to optimize the timing of

electric vehicle charging and heat pump usage to exploit available renewable energy and minimize cost.

In the paper entitled “Network security assessments for integrating large-scale tidal current and ocean wave resources into future electrical grids,” by Khan *et al.*, an insight on how the novel schemes of marine power generation can be analyzed under conventional network planning exercises using generic information is provided. Steady-state (overloading and voltage deviations/collapses), time-domain (angular stability and dynamic voltage recovery characteristics), and small-signal (eigenvalue) stability analysis are carried out for the systems with the new marine energy generation schemes. Subsequent  $N - 1$  contingencies and various suitable security criteria are used to identify the underlying network bottlenecks, especially within the coastal areas.

In the paper entitled “Power system security in a meshed North Sea HVDC grid,” by Haileselassie and Uhlen, large-scale offshore wind farms tackling the impact of wind power variation on ac grids are presented where the challenges can be properly managed by the use of meshed high voltage dc (HVDC) grids. A test scenario of a meshed North Sea HVDC grid is studied to demonstrate the potential of such a system for delivering offshore wind energy and enhancing power supply security of the ac grids. The authors show that with proper control techniques a meshed North Sea HVDC grid can mitigate the effect of wind power variation by facilitating exchange of primary and secondary re-

serves between asynchronous ac grids. In addition, with the potential of such a meshed dc grid technology, a European Union Super Transmission Grid as well as Global Power Grid Interconnections (also referred to as “Global Power Internet”<sup>1</sup>) can be implemented.

### C. Environmental Impacts and Considerations

In the paper entitled “Environmental and human dimensions of ocean renewable energy development,” by Henkel *et al.*, the authors show how the perceived risk or impact of ocean renewable energy development on coastal communities is a function not only of actual physical interactions but also depends on the regulatory environment and how potentially impacted coastal resources are valued by stakeholders. In this paper, the authors review potential environmental effects of ocean energy, identify applicable federal regulations that address potentially affected ecological components, and highlight observations about stakeholder concerns from experiences in Oregon.

In the paper entitled “The impact of offshore wind farms on marine ecosystems: A review taking an ecosystem services perspective,” by Mangi, using an ecosystem services approach, the impacts of offshore wind farms on the

ecosystem services delivered by marine environments are reviewed thoroughly. It is suggested that the development of methods which integrate socioeconomic valuation of ecosystem services into the evaluation of renewable energy devices compliments efforts in assessing the environmental impacts and should enable a holistic assessment of the impact of renewable energy production and greenhouse gas mitigation technologies on the U.K. carbon footprint.

In the paper entitled “Meteorological controls on wind turbine wakes,” by Barthelmie *et al.*, quantifying, understanding, modeling, and predicting the complex and interdependent system is critical to understanding and modeling wind farm power losses due to wakes, and to optimizing wind farm layout. The authors show how the impact of these variables on the power loss due to wakes using data from the large offshore wind farms located at Horns Rev and Nysted in Denmark can be quantified.

Last but not least, it is our pleasure to present this collection of papers on marine energy technology to the readership of the PROCEEDINGS OF THE IEEE. We would like to thank all the authors and reviewers for their invaluable contributions and efforts. We are very grateful to the managing editor J. Calder and the publication editors J. Sun and M. Meyer for their vital role through the course of this editorship. In addition, the support from the IEEE Power and Energy Society (PES) and its Marine Energy Coordinating Committee is much appreciated. ■

<sup>1</sup>X.-P. Zhang presented the concept of the “Global Power Internet,” which shows the vision of future global power grid interconnections, for the first time in the CIGRE U.K. NGN Workshop on Technologies for Smart Grids, University of Birmingham, Birmingham, U.K., June 21, 2011, and subsequently, he presented the concept in Workshops held at China EPRI and State Grid EPRI in August 2011, and many other occasions.

## ABOUT THE GUEST EDITORS

**Xiao-Ping Zhang** (Senior Member, IEEE) received the B.Eng., M.Sc., and Ph.D. degrees in electrical engineering from Southeast University, Nanjing, China, in 1988, 1990, and 1993, respectively.

He is Chair in Electrical Power Systems, and Director of the University Institute for Energy Research and Policy at the University of Birmingham, Birmingham, U.K. He worked at China State Grid EPRI on EMS/DMS advanced application software research and development between 1993 and 1998. He was visiting UMIST (now the University of Manchester) from 1998 to 1999. He was an Alexander-von-Humboldt Research Fellow with the University of Dortmund, Dortmund, Germany from 1999 to 2000, which is a lifelong honor. He was a Lecturer and then an Associate Professor at the University of Warwick, U.K., until early 2007. He is the coauthor of the monograph *Flexible AC Transmission Systems: Modeling and Control* (New York, NY, USA: Springer-Verlag, 2006 and 2012). His research interests include FACTS and HVDC, smart grid, control of renewable generation (wind, wave, and PV), integration of electric vehicles into power grids, energy storage, smart metering and wide area measurement applications, and energy economics and energy markets.

Prof. Zhang is Secretary of the IFAC Technical Committee on Power Plants and Power Systems Control. He is co-chairing the IEEE PES Working Group on Test Systems for Economic Analysis. He is the Editor of the IEEE TRANSACTIONS ON SMART GRID and the IEEE TRANSACTIONS ON POWER SYSTEMS. In addition, he has also been serving on the editorial boards of other two international journals. He is an IEEE PES Distinguished Lecturer on Wave Generation Technologies; Congestion Management and FACTS; and Voltage Stability of Unbalanced Three Phase Power Systems.



**Pingliang (Peter) Zeng** (Member, IEEE) received the B.S. degree in electrical engineering from Huazhong University of Science and Technology, Wuhan, China, in 1984 and the Ph.D. degree in electrical engineering from Strathclyde University, Glasgow, U.K., in 1990.

He is a Chartered Engineer (CEng). From 1990 to 2012, he worked in National Grid Company, U.K., as Senior Power System Engineer, Senior Commercial Analyst, Balancing Services and Incentive Scheme Forecasting Manager, System Operators Incentives and Strategy manager, and U.K. Electricity Transmission System Design Manager (South). He was closely involved in the safety and reliability evaluation of U.K. transmission network, and was responsible for the planning and design of electricity transmission systems in south England and Wales. He is currently with China Electric Power Research Institute (CEPRI), Beijing, China, as a special expert in power system planning and analysis. His main research interest includes power system planning under uncertainty, power system analysis, reliability, power economics, renewable power, optimization, and electricity market.

Prof. Zeng is a member of the Institution of Engineering and Technology (IET).

