

The development of marine renewable energy in China: prospects, challenges and recommendations

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Abstract. In this paper, resources distribution and technology status of tidal energy, wave energy, tidal current energy, ocean thermal energy and salinity gradient energy in China is reviewed, and assessment and advices are given for each category. By analysis, we believe that marine renewable energy is a necessary addition to existent renewable energy to meet the energy demand of the areas and islands where traditional forms of energy are not applicable and it is of great importance in adjusting energy structure of China. This paper describes the potential of marine renewable energy in China, and explores the possible role in future energy systems. As the paper discusses, building on these initiatives, and ‘realizing’ the accelerated development of marine energy, presents a number of challenges. This paper describes a scenario for the accelerated development of marine renewable energy in China from now to 2030. Finally, this paper provides recommendations for future development of marine renewable energy in China.

1. Introduction

Facing great pressure of economic growth and energy crisis, China pays much attention to the renewable energy. Beginning in 2006, China experienced a rapid growth in its renewable energy resource. This growth was greatly enabled by the renewable energy policy framework created by its landmark Renewable Energy Law, passed in 2005 and amended in 2009. To promote the development and utilization of MRE, the Chinese government has established the largest special funding project in history for tapping MRE, the Special Funds for Marine Renewable Energy (SFMRE). The project mainly focuses on the construction of self-sufficient island power generation demonstration systems and grid-connected demonstration power stations, industrial demonstration of key technologies, research and development of new technologies, and the public service system. From 2010 to 2017, special funds of \$160 million were invested to support more than 107 projects.

2. Overview of marine renewable energy in China

2.1. Tidal range energy

China has been exploiting tidal energy since the 1970s and has attained numerous mature technologies. Several tidal power plants have been developed, such as the Jiangxia Tidal Power Plant (3900 kW), which has been in operation for 3 decades (Figure 1). In August 2012, Jiangxia Tidal Power Plant began the upgrading project sponsored by the third round of special fund programme for MRE. One of the six existing turbines will be improved from 500 kW to 700 kW to increase 200,000 kWh annual power output. With the support of SFPMRE, the upgrading project (#1 turbine upgrade) was



completed in August 2015; the installed capacity of Jiangxia Plant has increased to 4,100 kW. The new turbine(#1) has been generated electricity of 954,000 kWh until October 2016. China has mastered its capabilities of designing and manufacturing large-capacity and low-head tidal turbines. Currently, tidal power prefeasibility studies are underway in Rushan (40,000 kW) of Shandong Province and Bachimen (30,000 kW) and Maluan Bay (24,000 kW) of Fujian Province, with the support of the SFMRE. Meanwhile, some high-efficiency and eco-friendly technologies are also being developed.



Figure 1. Jiangxia tidal power plant.

2.2. Tidal stream energy

Since the 1990s, several tidal current technologies have been developed, most of which are funded by SFMRE. Now, the largest installed capacity of single turbine has reached 300 kW.

Zhejiang University (ZJU): ZJU turbines (60 kW/120 kW) are semi-direct drive floating H-axis turbines. The ZJU turbines have been deployed near Zhairuoshan Island for sea trial since May 2014; the amount of electricity generated has accumulated to more than 23,00 kWh till October 2016, with the maximum instantaneous output power of 118 kW and the conversion efficiency of 0.371. MOST inspected and concluded the project on 27 October 2015. A new 300 kW turbine based on ZJU turbines will be assembled and tested in 2018 by Guodian United Power Technology Co. and ZJU(Figure 2).

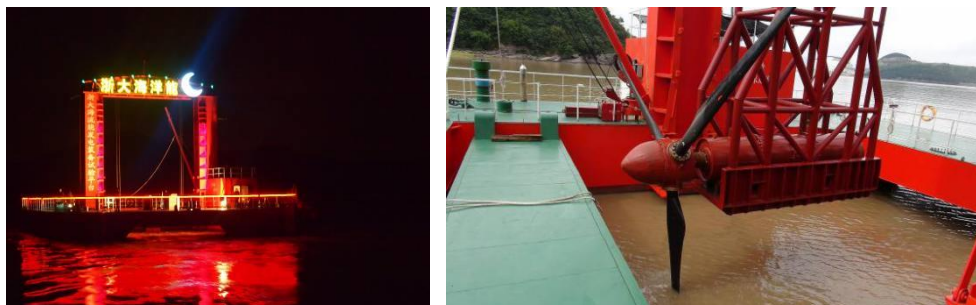


Figure 2. 60kW tidal stream turbine, Zhejiang University.

Zhejiang Zhoushan LHD New Energy Corporation Limited (LHD): LHD L-1000 turbines are fixed V-axis turbines, with cut-in speed of 0.7 m/s and cut-out speed of 4m/s. The modular turbines have been assembled and deployed on Xiushan Island in August 2016. In August, Hangzhou United Energy Co. Ltd. installed two of their turbines in the platform (#1 turbine: 400 kW, #2 turbine: 600 kW), and connected them to the grid. To date, the power generation has accumulated to more than 170,000 kWh(Figure 3).



Figure 3. LHD tidal stream turbine, Zhoushan United Energy Co. Ltd.

2.3. Wave energy

Since the 1980s, several wave technologies have been developed in China. Wave converters have been developed with installed capacities ranging from 30 to 100 kW. Among these, the BD102C series wave devices for navigation light power supply have been successfully commercialized and exported.

Guangzhou Institute of Energy Conversion (GIEC) of Chinese Academy of Sciences (CAS): By April 2014, Sharp Eagle I (10 kW) floating wave energy converter had been running near Wanshan Island for nearly 6000 hours accumulatively, with the total conversion efficiency of 16.76%. Based on Sharp Eagle I, China Shipping Industry Co. and GIEC jointly developed a 100 kW Sharp Eagle Wanshan converter, the new converter has been deployed for test since November 2015 (Figure 4).



Figure 4. “Wanshan” wave converter, GIEC, CAS.

Zhejiang Ocean University (ZJOU): Haiyuan I (10 kW) is a floating converter with 3 oscillating buoys, and had been deployed for sea trial on Zhoushan Islands for more than 165 days till May 2014. The total efficiency is about 16.4%. The project was concluded in May 2015.

Jimei University (JMU): Jida I (10 kW) is a floating wave energy converter composed of 10 oscillating buoys, has been deployed near Xiaodeng Island for sea trial for more than 5000 hours till April 2015. The maximum output power is 3.6kW, with the total efficiency (synergy with wind turbine) of 15%. The project was concluded in October 2015.

2.4. Ocean thermal energy

In China, the research and development of 2.4. Ocean Thermal Energy Converters (OTEC) technology is still at the theoretical stage. With the support of the National Key Technologies R&D Program, the First Institute of Oceanography of the SOA has developed a 15kW OTEC prototype

system. Research regarding the OTEC as a power supplier for marine observation apparatus is also conducted with the support of the SFMRE.

2.5. Salinity gradient and marine biomass energy

Research and development in these fields in China are also at the early stage. Currently, seven projects involving marine microalgae technologies sponsored by the SFMRE are under development.

3. Accelerated development of marine renewable energy

3.1. Marine renewable energy research challenges and priorities in China

- **Immature Technologies:** Due to the shortage of investments in early years, the foundation of research and development of MRE technologies in China is weak, and China must overcome some difficulties to narrow the gap with more advanced technologies at the international level, in the aspects of efficiency, reliability, and levels of industrialization and demonstration[1].
- **Complicated Conditions for Development:** In general, the resource density of marine renewable energy in China is quite low, especially wave energy resources. Some negative factors must be solved, such as difficulties in exploitation, typhoon-prone measure, harsh working conditions, and prominent contradictions in the use of sea areas.
- **Low-Level Application of New Technologies:** In China's ocean energy industry, technological innovations are quite limited and are basically at the academic level. In addition to the poor industrial application of new marine renewable energy technologies, China has not established a comprehensive mechanism to promote the effective collaboration of the academic, research, application, and industry sectors. The lack of a public service platform for the development and utilization of marine renewable energy restricts the development and industrialization of marine renewable energy technologies in China[2].

3.2. Marine renewable energy support policy in China

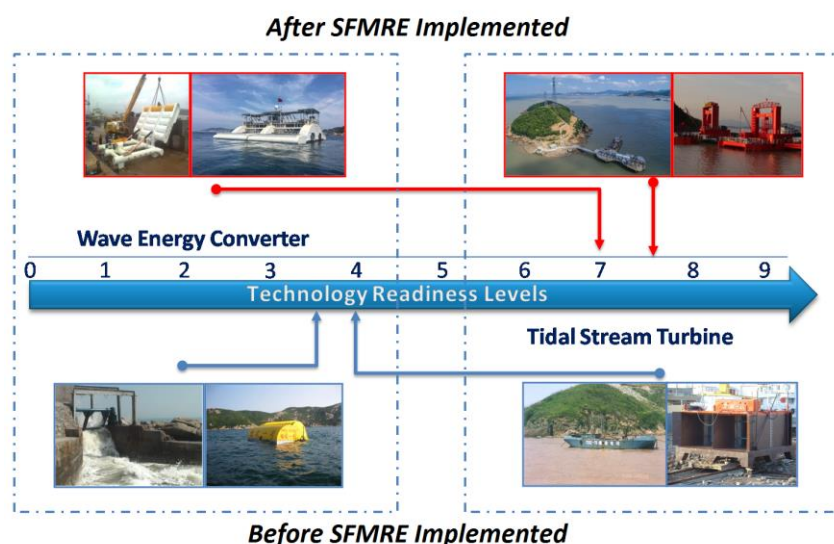


Figure 5. Marine renewable energy technology's level of technological maturity in China.

To promote the development and utilization of MRE, the Chinese government has established the largest special funding project in history for tapping MRE, the Special Funds for Marine Renewable

Energy (SFMRE), with the highest amount of funds issued by the Ministry of Finance (MOF) and the State Oceanic Administration(SOA). The project mainly focuses on the construction of self-sufficient island power generation demonstration systems and grid-connected demonstration power stations, industrial demonstration of key technologies, research and development of new technologies, and the public service system(Figure 5). From 2010 to 2017, special funds of \$160 million were invested to support more than 107 projects[3].

3.3. MRE Resources in China

The latest survey of MRE resources, the project of National Survey and Evaluation of Offshore Ocean Energies in China, was successfully completed in 2011. According to the survey data, the theoretical potential of MRE in China is 1580GW, and the technical potential exceeds 647 GW(Table 1).

Table 1. MRE resources in China.

Type of MRE	Potential(kW)	Available Volume(kW)	Primary Position
Tidal range	1.93×10^8	2.28×10^4	Zhejiang, Jiangsu, and Fujian Provinces
Tidal stream	8.32×10^6	1.66×10^6	Zhejiang Province
Wave	1.60×10^7	1.47×10^7	Guangdong, Fujian, Zhejiang, Hainan, and Shandong Provinces
Salinity gradient	1.13×10^8	1.13×10^7	Yangtze River basin and its southern adjacent area
Ocean thermal	3.67×10^8	2.57×10^7	South China Sea

3.4. Test sites in China

For the national small scale test site in Weihai, Shandong province, the 5 km² sea area and 30,000 m² land area were authorized in November 2014. In January 2015, to provide a foundational reference for the detailed design of the low speed tidal berth, a supplementary investigation was carried out. Additionally, a marine environmental monitoring buoy for the test site was deployed and has been in operation since May 2015[4].

For the national tidal energy full scale test site in Zhoushan Zhejiang, 3 test berths and 6 demonstration berths have been designed. In June 2015, the construction of demonstration project was initiated by China Three Gorges Corporation with the sponsorship of the new funding round by SFPMRE.

For the national wave energy full scale test site in Wanshan Guangdong, 3 test berths and 6 demonstration berths have been designed. The project feasibility study initiated in 2014 by China Southern Power Grid has been completed[5].

3.5. Strategic planning and roadmapping

According to the actualities of marine renewable energy in China and national strategic deployment, It is projected that by 2030, marine renewable energy will achieve large-scale applications, be the main energy sources in remote islands, and the MRE equipment manufacturing industry will be emerging[6].

Basing on the pre-study results, 3 steps have been proposed to advance the technology development by 2030(Figure 6).

- Phase I (to 2020): To raise the Technology Readiness Level.
- Phase II (to 2025): To apply technologies for harnessing ocean energy in remote islands.
- Phase III (to 2030): To commercialize technologies.

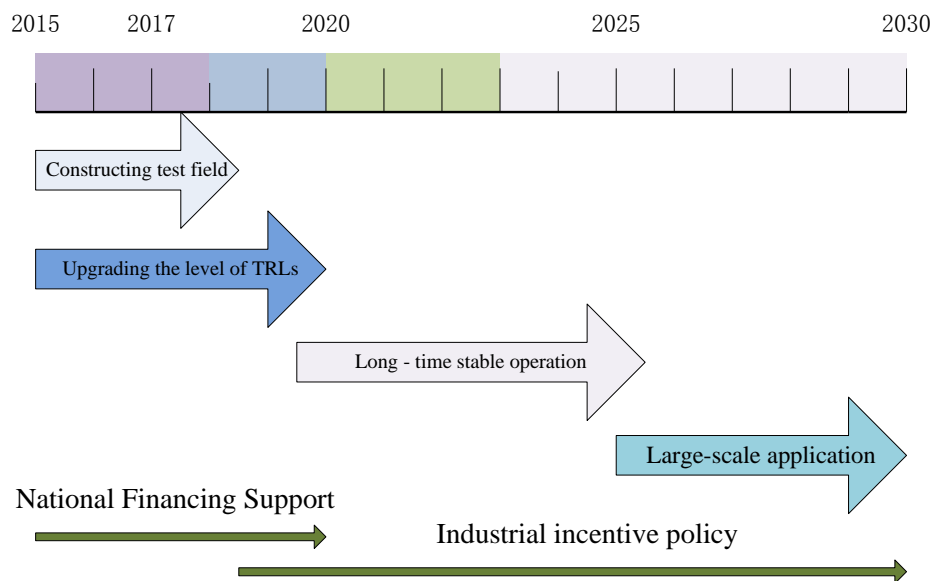


Figure 6. Development trajectory of MRE in China

4. Conclusions

Marine renewable energy is an emerging technology. There is considerable scope for marine energy accelerated development over the medium and longer terms, securing technology acceleration is far from straightforward, and faces a number of technical, institutional and policy challenges[7].

In exploring the potential benefits and challenges of marine renewable energy acceleration, this paper considered the present status of marine renewable energy technology in China, and the support policy.

Despite the technical, economic, institutional and political challenges involved, this paper presented here suggest that marine energy acceleration can contribute significantly to Chinese energy system decarbonisation. We also suggests that acceleration may offer significant benefits for supply diversity and also industry creation. In sum, technology acceleration could make a major difference to the prospects for marine renewable energy technology in the China and beyond.

Marine renewable energy technology acceleration is a multi-faceted, multi-national challenge, but it promises significant benefit both for those involved in its development, and also wider society.

Acknowledgment

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