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Development and the environmental impact analysis of tidal current energy turbines in China

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Abstract. Chinese government pays more attentions to renewable energies (RE) in the context of increasing energy demand and climate change problems. As a promising RE, the utilization of marine renewable energy (MRE) is engaging in the world, including the wave energy and tidal current energy mainly. At the same time, the tidal current energy resources in China are abundant. Thus, the utilization of tidal current energy becomes an inevitable choice for China to meet the challenge of global climate change. The Renewable Energy Law (amendment) and “Twelfth Five-Year” Plan of Renewable Energy Development (2011-2015) were released in recent years in China, the tidal current energy are successfully implemented in China, including the R&D and pilot projects. After the summary of the status of tidal current energy converters in recent years in China, especially the devices being in the open sea test. The environmental impact study in China is also introduced in order to offer reference for the environmental impact assessment of tidal current power generation.

1. Introduction

China is confronted with the problem of an increasing energy demand, large dependence on fossil fuel imports and climate change. For this reason, China has set the target to achieve a 15% renewable energy implementation in the year 2020. Chinese government has committed that the carbon emission per unit of GDP in 2020 would decrease by 40-45% relative to 2005 levels, which would rely on the utilization of renewable energies (RE) to a great extent. As a prospective RE, the development and utilization of Marine Renewable Energy (MRE) is engaging in the world in recent years. Chinese government has funded the development of MRE since 1980s, including the wave energy converters and the tidal current energy converters mainly.

Tidal current generation is a form of hydropower that converts the energy of tides into the electricity. For the reason that tidal forces are periodic variation in gravitational attraction exerted by the celestial bodies to create corresponding motions or currents in the oceans, which reflects the changing positions of the Moon and Sun relative to the Earth, the magnitude and character of tidal current energy utilization is relatively predictable and stable, which is a very important factor for the commercial operation of power station [1]. The main form for tidal current energy utilization is the tidal turbine, including horizontal-axis turbine and vertical-axis turbine mainly.

1.1. History of tidal current energy turbines development

At the same time, the tidal current energy resources in China are abundant. Thus, the utilization of tidal current energy becomes an inevitable choice for China to meet the challenge of global climate change. The Harbin Engineering University (HEU), Ocean University of China (OUC), Zhejiang



University (ZJU) and Northeast Normal University (NNU) have started the development of MRE turbines. The 70 kW floating vertical-axis turbine (Wanxiang-I, by HEU), 40 kW bottom fixed vertical-axis turbine (Wanxiang-II, by HEU), 5 kW horizontal-axis turbine (by NNU) and 25 kW horizontal-axis turbine (by ZJU) were developed ten years ago to demonstrate the principle of tidal current energy generating [2].

1.2. Opportunities and supporting initiatives

In 2008, the State Oceanic Administration (SOA) was entitled to perform the new functions of administration, utilization and development of ocean energy from the States of Council of China. In 2010, the Renewable Energy Law of the People's Republic of China (Amendment) enforced outlines a policy to accelerate and promote the development of renewable energy projects. According to the "Law of renewable energy", Ministry of Finance (MOF) and SOA released the "Interim measurements of marine renewable energy special funds" to support MRE research, including pilot demonstration projects used in isolated islands, pilot demonstration grid-connected projects, technologies industrialization, R&D [3]. In 2010, SOA established the Administrative Centre for Marine Renewable Energy to coordinate and manage the special funding programme for marine renewable energy. Now, the special fund program for MRE (SFPMRE) has entered the forth round and has supported more than 80 projects with a total funding of \$120 million. Other main public funding mechanisms include the Technology Support Plan of Ministry of Science and Technology (MOST), Technology Innovation Plan of CAS, etc.

Under the support of "Twelfth Five-Year" Plan of Renewable Energy Development (2011-2015) and the above funds, more and more organizations are engaging the development of MRE devices in China. Meanwhile, the environmental impact of tidal current energy turbines and the tidal current energy test site planning are emerging in China.

2. Status of tidal current energy technology

2.1. ZJU development



Figure 1. ZJU 60 kW turbine in test (self-lighting).

ZJU turbine (60 kW) is a semi-direct-drive horizontal-axis turbine (Figure 1), which was co-sponsored by the 1st round of SFPMRE and National High-tech R&D Program (863 Program). The ZJU turbine has been deployed near Zhairuoshan Island for sea trial since May 2014. During the sea trial, the maximum output power has reached 31.5kW and the conversion efficiency is 0.371. Until Apr 2017, the turbine has generated over 25 MWh of electricity. Now, Guodian United Power Technology Co. has initiated the developing of a new 300 kW turbine based on ZJU turbine. Additionally, a 120 kW turbine by ZJU has been also deployed, with accumulative power generation of more than 13 MWh.

2.2. HEU development

Based on Wanxiang-I 70 kW floating vertical-axis turbine and 40 kW Wanxiang-II bottom fixed vertical-axis turbine developed in 1996 and 2002 respectively, HEU subsequently developed the Haineng-I, Haineng-II, Haineng-III tidal current energy turbines.

2.2.1. Haiming I 10 kW horizontal axis tidal turbine. As the most common means of extracting power from marine currents, the horizontal axis turbines are somewhat similar in design to those used for wind power. Under the support of first round of SFPMPRE, the developed Haiming I consists of a turbine with a horizontal-axis of rotation, aligned parallel to the current flow, the power take off mechanism involving a generator coupled to the turbine's shaft to produce electricity directly.

The diameter of the turbine is 2m, the dimension is 9.0×7.5×6.5m and the weight is 20t, with a 2m/s rated speed. Haiming I was deployed for sea trial in Xiaomentou strait, Zhejiang province in Sep 2011. During the 6 months trial, accumulated electricity generated is 12,000 kWh. The efficiency of Haiming I is tested to be about 35%.

2.2.2. Haineng I 300 kW vertical axis turbine. Vertical-axis turbines have fallen out of use in the wind power industry, however, for the advantages that vertical-axis turbines work well with fluid flows from any direction and the larger cross-sectional turbine area in shallow water than is possible with horizontal axis turbines, the technology is in use still. In the support of the National Key Technology R&D Program, the Haineng I vertical axis tidal current energy turbine (2×150 kW) was developed and tested (Figure 2). The turbine consists of a ship-shaped pontoon carrier, turbine, mooring system, generator and control system. The turbine is housed in the carrier, which is anchored to blocks to hold the turbine. The turbine has two rotors with output port connecting to the hydraulic pressure system to drive the generator.



Figure 2. Haineng I 300 kW turbine in test.

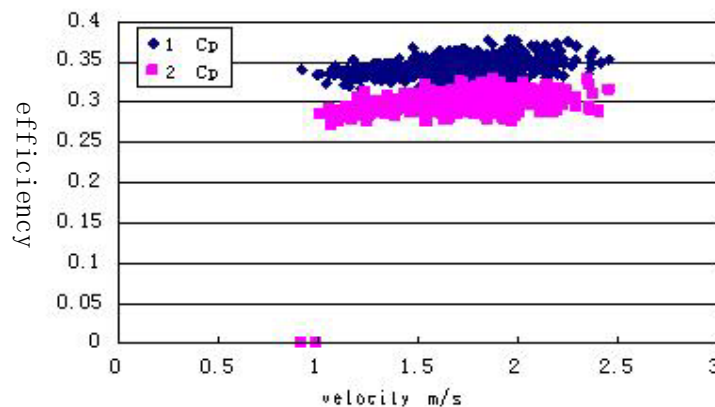


Figure 3. The operation record for efficiency of the two turbines in Mar 2013.

The turbine carrier is a catamaran-type with 24×14×3m dimension, the diameter of the turbine is 4 meter, with 1.2m/s of cut-in speed and 2.5m/s of cut-out speed (Figure 3). The deployed depth is

between 15 and 50 meters. In Jul 2012, Haineng I was deployed in Guishan Channel, Zhejiang Province for the first time and continued to be tested there in Aug 2013.

2.2.3. Haineng II 200 kW horizontal axis turbine. The horizontal axis tidal current energy *turbine* (2×100 kW) was supported by the first round of SFPMRE. The *turbine* has a H-shaped carrier with a platform in the middle, which is anchored in two points. The turbine has two rotors.

The floating turbine was assembled in Jun 2013 for sea trial. After the in-situ modulation, the turbine would be planned to be deployed in Zhaitang Island, Shandong province in 2014. The diameter of the turbine is 12 meter, with 0.6m/s of cut-in speed and 2m/s of cut-out speed.

2.2.4. Haineng III 600 kW vertical axis turbine. The vertical-axis tidal current energy *turbine* (2×300 kW) was supported by the first round of SFPMRE, the floating *turbine* was deployed in Daishan, Zhejiang province for sea trial (Figure 4). The diameter of the turbine is 6 meter, with 1.2m/s of cut-in speed and 3.5m/s of cut-out speed.



Figure 4. Haineng III 600 kW turbine in test.

2.3. LHD development

LHD Corp. has been developing the modular vertical axis turbines since 2009. In Mar 2016, the first platform to host 3.4 MW turbines was towed and fixed in Xiushan channel. In July 2016, two 300kW and two 200kW vertical axis turbines were deployed for demonstration (Figure 5). The 1 MW project was gridded in 26th Aug, the other turbines of phase 1B project (2.4 MW) and phase 2 project (4.1 MW) would be deployed in the following two years. The accumulative power generation reached 200 MWh till Sep 2017.



Figure 5. LHD 1MW turbines gridded in demonstration.

3. Tidal current energy test site

In the support of the special fund program for MRE, NOTC is preparing to build Chinese small scale ocean energy device (for wave energy and tidal current energy) test site in Shandong Province. The first berth for tidal current energy is 20m depth and about 300m offshore, and the designed capacity is 300 kW. The pilot project was initiated in Aug. 2012, and the planning and the marine environmental effect assessment have been accomplished. But the offshore consent of local government is difficult for the conflict of sea area usage [4].

According to the planning of Chinese ocean energy test site, a full scale tidal current energy test site would be built in Zhejiang Province. The 1 MW tidal current energy test site locates in Zhoushan Islands (Zhejiang) sea area, including 3 test berths. The site selection and in situ observation will continue until the end of 2016.

4. Environmental impact analysis

Although the tidal current energy is relatively clean, the utilization still has some environmental impact. In order to provide reference for the environmental impact assessment of tidal current power generation, some studies has been made [5].

4.1. Identification of potential environmental impact of tidal current energy turbines

Though the technology development of tidal current energy is still in the beginning, more and more developers and governors are concerned about the environmental impact of tidal current energy turbines. The first step to assess the environmental impact of tidal current energy turbines is identification of the affected factors [6]. The study shows that the factors would be affected by the installation and decommission of turbines, such as tidal current, sediment, water quality, marine mammal, etc (Table 1).

Table 1. Identification of potential environmental impact of tidal current energy turbines.

<i>affected factors</i>	<i>sources of effect</i>
<i>tidal current</i>	power extraction, blades and supporting structure, installation, operation and decommission of turbines
<i>sediment</i>	power extraction, installation , operation and decommission of turbines
<i>water quality</i>	installation, operation and decommission of turbines, emergency
<i>marine mammal</i>	blades and supporting structure, noise, installation, operation and decommission of turbines, emergency
<i>sea birds</i>	blades and supporting structure, noise, installation, operation and decommission of turbines, emergency
<i>fish</i>	blades and supporting structure, noise, installation, operation and decommission of turbines
<i>benthic animal</i>	blades and supporting structure, installation, operation and decommission of turbines, emergency
<i>social economy</i>	blades and supporting structure, installation, operation and decommission of turbines

4.2. Monitoring of environmental impact of tidal current energy turbines

Some case studies has shown that the monitoring of environmental impact of tidal current energy turbines is feasible, usually has a duration of more than one year. Before the construction of Chinese small scale ocean energy device test site, the priority of monitoring has included the content of chlorophyll, noise, current and so on [7]. The experience acquired by the case study includes that the monitoring must be specific enough to detect the expected impacts, the monitoring must be broad

enough to detect large unexpected impact, and strong political support is needed for tidal energy projects.

4.3. *Environmental impact assessment index system of tidal current energy turbines*

The confirmation principle includes pertinent, operational, scientific and independent. An environmental impact assessment index system for tidal current power generation was proposed, which contains environmental biological and socioeconomic factors (Table 2).

Table 2. Environmental impact assessment index system of tidal current energy turbines.

assessment content		assessment index	assessment element
environmental factor	oceanography	tidal current	direction, velocity, tidal level
		wave condition	wave height, velocity
		suspending coast	content
		sediment type	coastal type
		sediment composition	granularity
Biological factor	water quality	physical index	distribution
		chemical index	heavy metal
		biology index	pH, T, C, DO
Biological factor	noise	environmental noise	COD, hydrocarbon, heavy metal
	phytoplankton	primary productivity	bacteria
	benthic	biomass	noise level
	organism/fish/marine mammal/birds	biodiversity	chlorophyll
socioeconomic factor	fishing		Pielou index
	shipping		Shannon-wiener index
	tourism		fishing area
	employment		sea-route area
			number of tourist
			increased employment

5. Conclusions

Generally speaking, the MRE technologies are still in the demonstration phase in China. Thus, there are not enough cases in operation to validate the environmental impact assessment index system for both the tidal current energy turbines and wave energy converters.

China strives to build a MRE industry in order to achieve a competitive advantage in this area. Under the support of four rounds of special fund program, more and more MRE technologies have entered the large scale prototype sea trials phase.

In order for Chinese government to achieve the initial targets, the development of MRE technologies, especially the tidal current energy converting technologies will continue in next five years until the prosperity of MRE industry [8].

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