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Tidal stream energy in China

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Abstract

In the recent decades, many efforts have been made by the coastal scientists and engineers for the explosion of tidal stream energy in China, as tidal stream energy is considered as one of most promising resources of marine renewable energy. Meanwhile, tidal stream energy is easy for predication and its utilization has less harm to the environment. The tidal stream energy in China could theoretically supply more than 8.2 GW, and most of them come from Zhoushan Islands, Zhejiang Province. The government of China largely invests the explosion of tidal stream energy in these years, and a significant progress has been achieved in this area. Tidal stream turbines are especially designed to improve the utilization efficiency of tidal stream energy with low impact on marine environment, and some demonstration projects of tidal stream energy are currently under plan along the coast. This study is to provide a comprehensive overview of tidal stream energy in China, including the potential assessment of energy resource, development history (achievement and difficulties) of tidal stream turbines, progress and challenges of the undergoing demonstration project, and future plan and suggestions for developing tidal stream farm in China.

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Keyword: tidal stream energy; overview; energy resource; converter

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1. Introduction

Marine energy is one of the most promising renewable (Bahaj, 2011; Charliew, 2008; Johnstone, 2006), among which Tidal energy gains its population by its regularity and predictability. Tidal energy can be predicted with high accuracy in both short and long terms, and therefore the power output of a certain tidal plant at a given location can also be accurately forecasted. There are two different ways to harness the tidal energy, a tidal barrage system so as to impound water and then use its potential energy (Xia, 2010a,b) and by using the tidal stream itself to drive the tidal energy converters (Carballo, 2009; Blunden, 2006; Bahaj, 2004). The tidal stream energy has two advantages over the tidal barrage system, i.e. lower environmental cost and lower capital investment, which are both due to the non-utilization of the barrage. Relative to the wind energy, the power density available for marine current energy converters will generally be much higher than that for wind energy converters at appropriately rated speeds for both technologies – a result of the much higher density of water (Bahaj, 2003). The challenge for the tidal stream energy is in terms of enhancing the reliability and stability of the energy converters.

China is one of the most active economy across the world. The rapid growth of the industry and people's increasing demand for environment protection has laid pressure on China. China borders four marginal seas of the Pacific, i.e. the Bohai sea, the Yellow sea, the East China Sea and the South China Sea. These areas are rich in islands and channels where the maximum tidal current velocity could exceed 2 m/s which are thought to be the acceptable electricity-generating speed for tidal current turbines. This provides great probability to harness the tidal stream energy. Actions are taken from both the government and the academy side. The Renewable Energy Law went into effect on 1st January, followed by the middle and long term development program of the renewable energy which was published in 2007. The Harbin Engineering University has started the research on the vertical axis tidal turbine device since 1980s. Scholars from the Zhengjiang University, Ocean University of China, the NorthEast Normal Univerisity and Hohai University also show their dedicated enthusiasm to the development of tidal current energy. The purpose of this study is to give an overview of the distribution and assessment of tidal current as well as the present stage of development of tidal current turbine technology in China.

2. Tidal energy resources

Tidal energy is the energy dissipated by tidal movements, which derives directly from the gravitational and centrifugal forces between the earth, moon and sun (Owen, 2008). Most of the tides occur twice one lunar day due to the gravitational attraction exerted by the moon upon the earth and the centrifugal force of the rotation of the moon-earth system. This is called the semi-diurnal tide. The moon orbits the earth every 29.5 days, known as the lunar cycle, causing the tides vary in size between spring tides and neap tides. Spring tides occur when the sun and moon line up with the earth, whether pulling on the same side of the earth or on opposite side, resulting in very high spring tides. Neap tides occur when the sun and moon are at 90 degrees to each other, resulting in low neap tides (Rourke, 2010; Charliew, 2003; Clark, 2007). In parallel with the water level rising and falling, the tidal current moves in and out as flood and ebb currents, which is the tidal stream energy harnessing aims at.

The evaluation of the tidal energy resource is the first step to harvest the tidal energy. Four national surveys of the tidal currents energy have been conducted since the middle of the last century. It was due to 1958 that the first exploitation of tidal energy was carried out, followed by numerous small tidal barrage power plants. Unfortunately most of the plants failed due to the inappropriate design and operation (Wang, 2009). The second survey started in 1978 organized by State Oceanic Administration and Ministry of Resources and Electric Power. The investigation and design institutes in nine coastal provinces are involved in this survey. 156 bays and 33 estuaries were investigated in terms of its tidal energy (Wang, 1989). The third survey, which was accounted for tidal stream energy, tidal potential energy and wave energy, was performed in 1986. In 2004, the Investigation and Assessment of China Offshore Resources, namely 908 Special, was organized by the State Oceanic Administration of China. This survey was featured by the comprehensiveness in terms of ocean renewable energy resources.

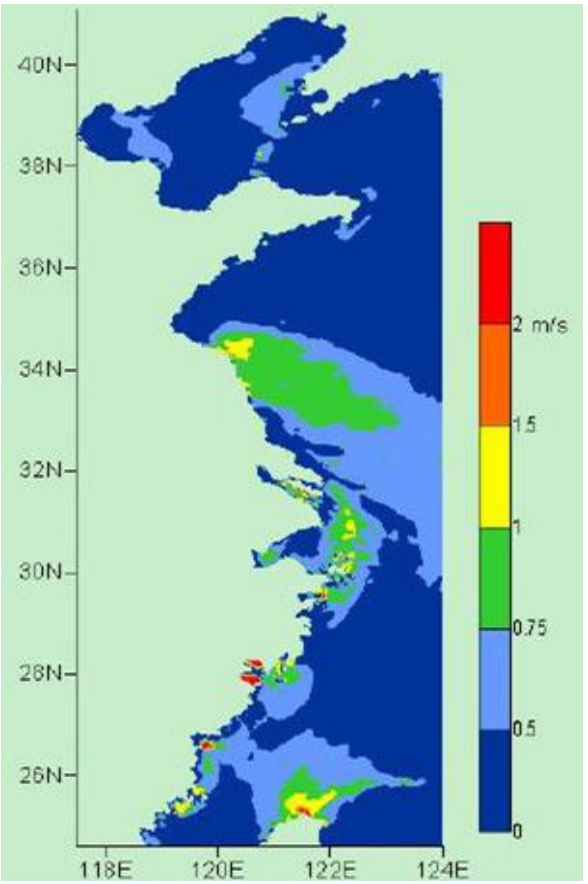

Fig. 1 Depth-averaged current velocity in Bohai Sea and East China Sea.

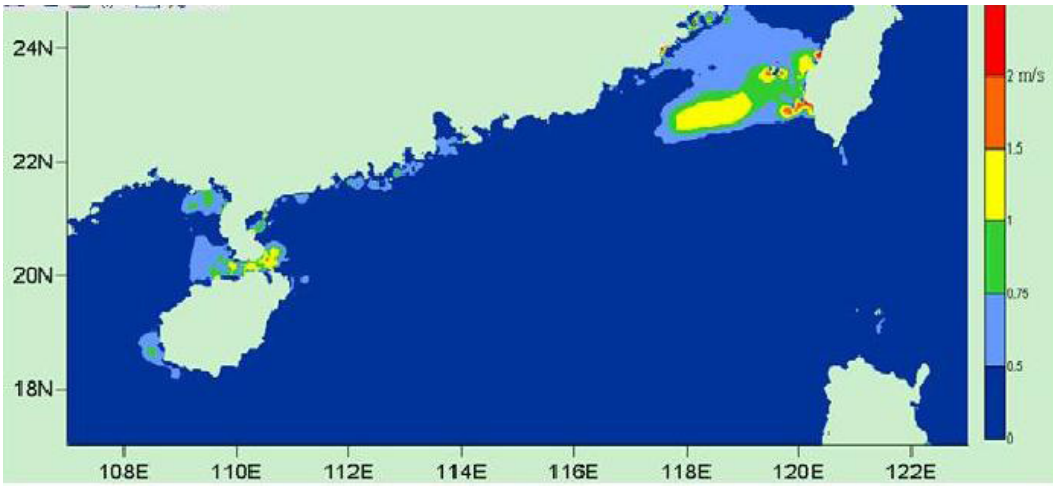

Fig. 2 Depth-averaged current velocity in South China Sea.

It is reported that when the maximum velocity exceeds 2 m/s, 20000 kWh can be generated per unit square meters (Black & Veatch Consulting, 2004). Based on the earlier survey, the theoretical value of mean power for China tidal stream energy is 8.2 GW, among which the East China Sea, the Yellow Sea, the South China Sea accounts for 6.45 GW, 1.35 GW and 0.4 GW, or 78.6%, 16.5% and 4.9% of the total output power, respectively. Liaoning province, Shandong province, Zhejiang province, Fujian province, Taiwan are all rich in tidal stream energy resources, where the energy flux density varies from 10 kW/$m^2$to 30 kW/m^2, extremely large Jintan channel, Guishan channel, Xihou channel in the Zhoushan archipelago.

The field data was used to calculate the energy resource around Zhoushan, which yielded a value of 64300 kW. Wang (2009) used the Farm method and the Flux method to evaluate the tidal stream energy in Gaoting channel and Guanmen channel. According to different method, the results vary from 4.67 MW to 5.31 MW for Gaoting channel, from 7.92 MW to 9.73 MW for Guanmen channel.

Numerical results showed that the maximum flow exceeded 2.5 m/s in spring tide and more than 2.3 m/s in neap tide for Chenshantou Shandong province. It yielded an average energy density of 0.7 Kw/m^2. The tidal energy in Jiaozhou bay was also studied by POM model, the maximum velocity was around 2m/s with a great potential to harness the tidal stream energy. The extractable energy is expected to be 3.2MW.

There are many islands and channels in Bohai Bay, such as the Laotieshan channel, Qinshan channel, where the maximum current speed ranges from 3.6 m/s to 4.2 m/s. The channels here are featured by its wideness and shallowness, which is favored by the turbine installation and operation. It is reported that the average energy density is more than 500 W/m^2.

In Xiamen bay, the Jinmen northeast channel has the largest tidal current with the maximum velocity of 2.2 m/s and average velocity of 1.6m/s.

3. Tidal energy converters

Harbin Engineering University (HEU) triggered their research on vertical tidal turbine in 1980s. Numerous laboratory experiments has been carried out, these experiments aim at 1) analyze the relation between the power coefficient and several parameters including the tip speed ratio, chord length, diameter of the turbine etc. 2) provide reference for the prototype design. Following these experiments, “WanXiang I”, “WangXiang II” and “Hai Neng I” were installed and tested around Daishan waters Zhejiang province (see Figure 3). “WanXiang I” is a floating tidal stream power station based on the cycloid type controllable-pitch vertical axis turbine with a rated power of 70 kW. “WangXiang II” is a seabed-mounted tidal power station with a rated power of 40 kW. “Hai Neng I” has a rated power of 300 kW (Jing, 2014).

Zhejiang University (ZJU) investigated a horizontal axis turbine, a sea trial of 5 kW horizontal-axis turbine which was tested in April 2006, followed by a 25kW device tested in May 2009. The latter one generated a peak power of 30 kW at a water speed of 2.4m/s (Li, 2008). It has good self-starting characteristics and can start rotating at 1.37m/s (see Figure 4). The results suggest that the total system efficiency is around 25% (Ma, 2010; Liu, 2011).

Ocean University of China (OUC) started studies of tidal current energy with a grant from the “863” Programme in 2006. They also focused on the vertical-axis turbine, which is featured by the flexible vanes. This novel design has some advantages such as light weighted, simple structure and easy maintaining. The laboratory experiments indicated that the flexible vanes have some elegant performance. In 2008, the first demonstration system, a floating, moored platform that holds a fexible vane turbine with a rated power of 5kW was tested around Zhaitang Island Channel Shandong province (see Figure 5). The test gives out the expected results.

Northeast Normal University (NENU) developed a horizontal-axis turbine supported by National High Technology Research and Development Program (“863” Program). A 2 kW device was tested in the coastal area of Qingdao (Zhu, 2012), as shown in Fig. 6.

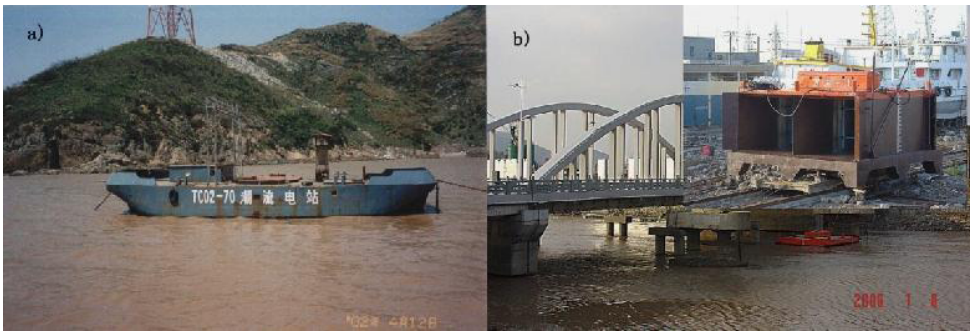

Fig. 3 a) “WangXiang I” tidal power station b) “WangXiang II” tidal power station

Fig 4 ZJU horizontal-axis turbine

Fig 5 OUC flexible van turbine

Fig. 6 NENU horizontal-axis turbine.

4. Tidal energy demonstration project

A number of demonstration projects are under plan. Two tidal stream devices are installed in parallel with the Daishan Wind Farm project in 2011. The two devices are horizontal-axis turbines with the rated power of 60kW and 100kW. Another two tidal stream energy converters are installed with Pingtan Daliandao Wind Farm project. The devices are horizontal-axis turbines with rated power of 100kW. While these two cases are stand-alone projects, the national tidal stream energy test center is also on its coming path, at the stage of preliminary design and investment. The preliminary site was selected between Putou Island and Hulu Island of Zhengjiang province. The water depth of this tidal channel is around 30~70 m. The installed capacity will be more than 1MW from an array of tidal stream turbines.

5. Challenges and advices

China's energy consumption is increasing quickly in the last decade. Statistics shows that the total commercial primary energy consumption was 2247 Million ton of coal equivalent (Mtce) in 2005, about 62% above 2000 levels, or an average of 10.15% per year (China National Development and Reform Commission, 2007). The fossil fuel accounts for the majority of the energy supply. Unfortunately the fossil fuel is non-renewable and emits greenhouse gases which is the primary cause of climate change. To meet the energy demand and reduce the heavy dependence on fossil fuel, the tidal stream energy provides one of the solutions. But to be honest, the present status of tidal stream energy is far from extracting in a large scale in China. Research and development on tidal current energy is urgently needed in terms of:

- Assessment of the tidal energy should be updated. The previous assessment missed some of the ideal locations such as the Zhaitang island where the OUC device was tested. These sites may have a large amount of energy in potential. The renewed evaluation of the national tidal stream energy resource should cover all the coastal and remote bays, channels and islands using the more accurate assessing methodology.
- The extractable tidal stream energy is remote from land. The environment in these areas is harsh, and the reliability of the tidal stream device is of great concern.
- Novel tidal current turbines should be developed. Since the first prototype turbine was tested in 2002, the rated power of the devices is of the order of 100 kW, which is far from commercial utilization.
- International cooperation could enhance the development of tidal turbine device in China. The Europe starts a base, i.e. the European Marine Energy Centre, for worldwide institutes and universities to test and develop their ocean renewable devices including tidal stream energy.

- Support from the government should be emphasized regarding the funding, policy and regulations. Tidal stream energy is present at its infant stage. It is not economically competitive with the traditional fossil fuel. But accounts for its various attractive features, viz. high power density, predictability, abundant energy in potential, it will certainly play a significant role in future energy consumption.

Besides the above mentioned items, there are certainly other issues including the cost effectiveness, environmental impact that should be addressed before any definite conclusion can be drawn.

6. Conclusions

More and more people have recognized the importance of the renewable energy, the vast coastal and offshore areas contributes one of renewable resources, i.e. the tidal stream energy, to the entire energy consumption. This paper presents the distribution of China tidal resource, the status of the tidal turbines and the tidal stream demonstration project. China has an excellent tidal current energy resource with a capacity of approximate 8.2 GW. As the number of institution and researchers involved in the tidal stream energy increased, people can expect that the vast amount of energy could be utilized in the future.

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Reference

Bahaj A.S., Myer L.E. Fundamentals applicable to the utilizationof marine current turbines for energy production. Renewable Energy 2003;36: 121-132.

Bahaj A.S., Myers L.E. Analytical estimates of the energy yield potential from the Alderney Race (Channel Islands) using marine current energy converters. Renewable Energy 2004;29:1931-1945.

Bahaj, A.S. Generating electricity from the oceans. Renewable and Sustainable Energy Reviews 2011; 15:3399-3416.

Black & Veatch Consulting, Ltd. UK, Europe, and global tidal energy resource assessment. Marine Energy Challenge Report NO. 107799/D/2100/05/1[R]. London: Carbon Trust, 2004.

Blunden L.S., Bahaj A.S. Initialevaluation of tidal sream energy resources at Portland Bill, UK. Renewable Energy 2006;31:121-132.

Carballo R, Iglesias G, Castro A. Numerical model evaluation of tidal stream energy resources in the Ria de Muros (NW Spain). Renewable Energy 2009; 34:1517-1524.

Charlier H.R. Sustainable co-generation from the tides: A review. Renewable and Sustainable Energy Reviews, 2003, 7: 187-213.

Charlier R.H., Finkl C.W. Ocean energy: tide and tidal power. Springer; 2008.

China National Development and Reform Commission. The 11th Five-Year Plan on Energy Development; April 2007, pp.1-19.

Clark, R.H. Elements of Tidal-Electric Engineering. IEEE PRESS. 2007.

Li, W., Lin, Y.G., Liu, H.W., Ma, S. Research on horizontal-axis marine current turbine. In: 1st national symposium on ocean energy in Hangzhou. 2008. P.81-90.

Liu, H.W., Ma, S., Li, W., Gu, H.G., Lin, Y.G. and Sun, X.J., A review on the development of tidal current energy in China. Renewable and Sustainable Energy Reviews. 2011, 15: 1141-1146.

Jing F.M., Sheng, Q.H. and Zhang, L. Experimental research on tidal current vertical axis turbine with variable-pitch blades. Ocean Engineering, 2014, 88: 228-241.

Johnstone C.M., Nielsen K, Lewis T, Sarmento A, LeMONIS g. EC FPVI coordinated action on ocean energy: a European platform for sharing technical information and research outcomes in wave and tidal energy systems. Renewable Energy 2006; 31:191-196.

Ma, S., Li, W., Liu, H.W. and Lin, Y.G. A 25kW stand-along Horiztonal Axis Tidal Current Turbine. Automation of Electric Power Systems. 2010(14), 34: 18-22

Owen A, Trevor ML. Tidal current energy: origins and challenges. In: Future energy. Oxford: Elsevier; 2008. Pp. 111-128.

Rourke O. F., Boyle, F. and Reynolds A. Tidal energy update 2009, Applied Energy, 2010, 87:398-409.

Wang, C.K., Lu, W., Analysis methods and Reserves Evaluation of Ocean Energy Resources. Ocean Press. Beijing: 2009.

Wang, C.K., Lu D.C., Division of marine resources in China. State Oceanic Administration, Ministry of Resources and Electric Power; 1989.

Xia, J.Q., Falconer, R.A. and Lin, B.L., Hydrodynamic impact of a tidal barrage in the Severn Estuary, UK. Renewable energy, 2010.35: 1455-1468.

Xia, J.Q., Falconer, R.A., Lin, B.L., Impact of different operating modes for a Severn Barrage on the tidal power and flood inundation in the Severn Estuary, UK. Applied energy, 2010.

Zhu, W.Q., Xu, M.Q. and Zhang, X.M., Study on the key technologies of horizontal axis surface tidal current generating. Acta Energiae Solaris Sinica, 2012, 33: 1067-1072.