Renewable and Sustainable Energy Reviews 76 (2017) 701–716

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Comparison study of tidal stream and wave energy technology development between China and some Western Countries

Yijin Liu[a,b,c], Ye Li[a,b,c,d,*], Fenglan He[a,b,c], Haifeng Wang[e]

[a] State Key Laboratory of Ocean Engineering, School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, 800 Dongchuan Rd., Shanghai 200240, PR China
[b] Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Shanghai Jiao Tong University, Shanghai 200240, China
[c] Multi-function Towing Tank, Shanghai Jiao Tong University, Shanghai 200240, China
[d] China Strategy Institute of Ocean Engineering, Shanghai 20040, China
[e] National Ocean Technology Center, Tianjin 300112, PR China

ARTICLE INFO

Keywords:
Tidal stream energy
Wave energy
Technology development
Policy incentives

ABSTRACT

During the last decade, tidal stream and wave energy technologies have made significant progress. A number of large-scale prototypes have been deployed around the world. In this article, the recent development in some western countries and China is presented. Taken as the representatives from European and American continent, UK, Portugal and US are chosen to compare with China in resource assessment, research & development, and policy aspects. With an analysis of similarities and differences, the major elements that have great effect on development of ocean energy industry are concluded, and some suggestions are given to improve the development of tidal stream and wave energy technology.

1. Introduction

As human society and economy is under a rapid development, the demands for energy resources are getting more and more increased nowadays. However, our excessive consumption on traditional fossil fuels brings serious environment pollution and great pressure of energy crisis. To achieve the sustainable development, an increasing number of countries start to transfer their focus on renewable energy [1]. Compared with the other renewable energy, the potential of ocean energy is giant. It is estimated that global resources are over 30,000 TWh/year theoretically [2].

The boom of developing of ocean energy technology has been lasting for decades. Especially, tidal stream and wave energy have been identified as technology with the potential to offer a significant contribution for most countries with ocean resource in the medium to long term. Based on a recent assessment result, the potential resource of tidal stream and wave energy in China are about 8.33 GW and 7.7 GW respectively [3], which would be a substantial amount of energy for the town and countryside on coastal area and isolated islands. It is a complicated and challenged national strategic goal to develop tidal stream and wave energy industry, with a necessity of a comprehensive framework to support. In this aspect, many western countries have accumulated a lot of experience. On the other hand, we have also explored on this way for so many years. Therefore, this article provides a comparison study of tidal stream and wave energy technology development between China and some western countries.

2. Recent development in some western countries

The exploration on ocean energy has been keeping since a notable article in Nature by Stephen Salter in 1974 [4]. To date, having the oldest ocean energy industry, vast tidal stream and wave energy resource, Europe became a pioneer in recent development [5]. In the most abundant region– European Atlantic Arc [6], a combination of policy accelerator and market condition makes this region become one of the world's most-promising areas. There are six countries, including Denmark, France, Ireland and Portugal, Spain and UK. Compared with European countries, those on American continent are relatively later in this field. They realized the potential of ocean energy but also the importance of environment guidelines [7]. With a developed industry system and a series of stimulations, they have made a rapid growth on capturing the benefit of these resources. Currently, it is taken as one of the most potential area in the near to medium [8].

2.1. Deployment

Since the beginning of the century, tidal stream technology and wave energy technology development has started to ramp up. Fig. 1 and

* Corresponding author.
E-mail address: ye.li@sjtu.edu.cn (Y. Li).

http://dx.doi.org/10.1016/j.rser.2017.03.049
Received 5 February 2016; Received in revised form 17 February 2017; Accepted 8 March 2017

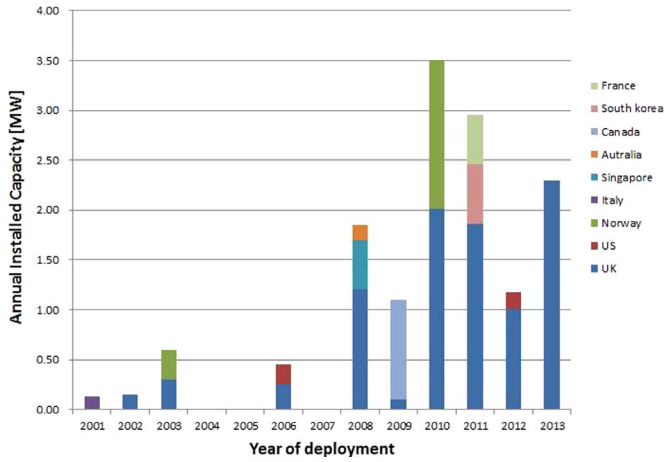

Fig. 1. Distribution of large-scale tidal stream prototype deployments. Data obtained from IRENA 2014 [10].

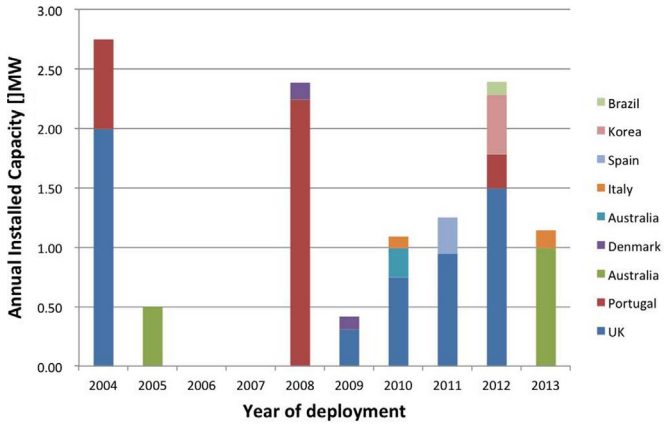

Fig. 2. Distribution of large-scale WEC prototype deployments. Data obtained from IRENA 2014 [10].

Fig. 2 show the geographic distribution of tidal stream turbine and wave energy converter deployments at a significant scale (> 100 kW capacity) respectively. Although the situation of some smaller scale (< 100 kW) deployments has not been shown up, the recent development in western countries could be illustrated in a way.

As shown in Fig. 1, the distribution is scattered in the first half of this period, but it is getting more and more concentrated in the last half. UK is largely the hub of tidal stream activity, which implies its ability to attract demonstration deployments have increased obviously. To date, there are several front-running industrial players, such as Marine Current Turbines −1.2 MW SeaGen device (Fig. 3), Andritz Hydro Hammerfest HS1000 device, Tidal Generation Limited Deep Gen device, etc.

Simultaneously, Fig. 2 shows that UK and Portugal have the vast majority of wave energy deployments. In early time, the main form of WEC is onshore like Pico Wave Energy in Portugal. With the technology development, offshore WEC technology is getting more and more popular. Contributed a lot in both UK and Portugal deployment history, Pelamis is the first full-scale prototype generated electricity into UK national grid in 2004 and the first pre-commercial array tested at the Portuguese site from 2008 to 2009. Although it called in administrators in 2014, more forms of offshore WEC are getting deployed in test centers, such as Aquamarine Power Oyster, Wave Dragon, etc.

Apart from these European countries, the deployments in others indicate the progress in American Continent, Asia and Oceania. As there is few large-scale WEC prototypes deployed in US, it is not included in Fig. 2 [9]. However, there is a great leap forward of WEC

Fig. 3. The 1.2 MW SeaGen tidal energy system (UK). Adapted from [11].

development in US recent years. A handful of developers take some small-scale (< 100 kW) sea trials. One of the top wave energy companies in US, Ocean Power Technologies (OPT), shift their focus to smaller-scale devices such as APB-350 (a 350-Watt-rated PowerBuoy) (Fig. 4).

The deployment of devices is relative to the construction of infrastructures closely. As seen from the deployment of tidal stream and wave energy device, UK and Portugal are very outstanding, which supporting infrastructures for ocean energy contributes a lot.

Currently, many counties developed testing facilities for ocean energy actively. Europe takes a large proportion of test centers in the world, such as EMEC [13] in Scotland, Wave Hub [14] in UK, Ocean Plug – Pilot Zone in Portugal [15], AMETS in Ireland, BIMEP in Spain, Lysekil in Sweden, and so on. In the American continent, there is Northwest National Marine Renewable Energy Center (US), Pacific Marine Energy Center (US), Fundy Ocean Research Center for Energy (Canada), etc [16].

As EMEC is active to the promotion of global wave and tidal power device standards under the International Electro-Technical Commission (IEC) [17], a consensus is reached to gather experiences from these test centers to form a general disciplines and standard [18]. In the aspect of power distribution system, small grid technology is developed to overcome the traditional issues [19,20].

2.2. Technology innovation

In general, document and patent activities are taken as the access to the information of technology innovation. For policy makers, it helps to assess the effectiveness of different policy and make adjustments. For institute researchers, it helps to indicate the possible break through and innovative technologies. For industrial players, it helps to perceive the potential market activity.

Fig. 4. OPT PowerBuoy wave energy generation system (US). Adapted from [12].