Renewable and Sustainable Energy Reviews 15 (2011) 5013–5020

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

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

Development of offshore wind power in China

Jinjin Chen*

Department of Asian and International Studies, City University of Hong Kong, Hong Kong, China

ARTICLE INFO

Article history:
Received 25 December 2010
Received in revised form 15 April 2011
Accepted 5 July 2011
Available online 16 September 2011

Keywords:
Offshore wind power
China

ABSTRACT

China has strived to develop new and renewable energy resources to meet its energy demands due to issues of pollution, sustainability, and climate change related to the consumption of fossil fuels. Offshore wind power development in coastal China has attracted more and more attention because it can not only utilize the abundant natural resources but also relieve power constraint in coastal China. This paper studies the development of offshore wind power in China, providing information including the wind resources in China's coastal areas, policies promulgated by the central government to favor the sound development of offshore wind power, regional planning and progress of offshore wind power, R&D of offshore wind power technology and theory, as well as the pilot projects set up in Shanghai and Jiangsu. In addition, challenges related to offshore wind power development are depicted, and recommendations are provided.

Contents

1. Introduction 5013
2. Wind resources in coastal China 5014
3. Policies related to offshore wind power development 5014
4. Regional planning and progress 5016
5. R&D of offshore wind power technology and theory 5017
   5.1. Offshore wind power technology 5017
   5.2. Non-grid-connected wind power generation theory 5017
6. Establishment of offshore wind farms in China 5017
   6.1. Shanghai 5017
   6.2. Jiangsu 5018
7. Challenges of offshore wind power development in China 5018
8. Conclusions 5019
   Acknowledgement 5019
   References 5019

1. Introduction

Energy demand due to the rapid economic growth has made energy issue become a priority in the governmental agenda in China. China's energy supply has heavily relied on fossil fuels, especially the coal. However, due to issues of pollution, sustainability, and climate change related to the consumption of fossil fuels, China has tried its best to divert its energy supply from traditional energy resources, such as fossil fuels, to new energy resources, including nuclear power and renewable energy, such as hydro, wind and solar power. Among the new energy resources, wind power has gradually become more attracted due to the following reasons. First, wind power is safer compared with the nuclear power. Second, the development cost of wind power is cheaper compared with solar energy. Third, wind power technology is more mature compared with biomass. Fourth, wind power has larger industrial scale compared with ocean energy [1]. China has favorable natural conditions for the utilization of wind power. Since China's first pilot onshore wind power farm established in Shandong Province in 1986 [2], onshore wind power has developed rapidly, mainly in north China [3,4]. In recent years, onshore wind power development in China is relatively mature and the attention has gradually shifted from onshore to offshore wind power development. Compared with onshore wind farms, offshore wind farms do not have to

* Tel.: +852 34423784.
E-mail address: mmily2010@gmail.com

1364-0321/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2011.07.053

occupy large land resources. China has a long coastal line with abundant wind energy resources. Coastal areas, such as coastal mudflats and inshore zones, possess good conditions for wind power development [5]. A preliminary estimate indicates that the potential installed capacity is approximately 200 GW at the height of 50 m above the sea level in the inshore areas within the water depth of 5–25 m [6]. Regions along the coastal line in eastern China have faster economic growth than regions in western China thus coastal China is the major electricity demand region. If large-scale offshore wind farms can be built along China's coastal areas, long-distance electricity transmission from western to eastern China is no longer necessary. To fully utilize the advantage of clean natural resources in eastern China can relieve the electricity constraint in coastal areas as well as effectively tackling climate change [5]. According to the development plan, China is going to build 5 GW installation capacity during the 12th Five-Year Plan (2011-2015), and wind power construction in China will enter a new stage of comprehensive development of both onshore and offshore wind power [7].

2. Wind resources in coastal China

According to the data from China Meteorological Administration, offshore wind power resources reach over 750 GW, much more than the potential hydro power resources of 378 GW [8,9]. Fig. 1 shows 50 m wind map in coastal China.

Wind energy resources in the coastal areas of China are classified into two categories [6]:

(1) Wind-energy abundant belt in the coastal areas and their related islands: Coastal areas and their related islands include 10-km-broad coastal areas of Hainan, Guangxi, Guangdong, Fujian, Zhejiang, Shanghai, Jiangsu and Shandong, with annual wind power density above 200 W/m^2, and wind power density contour is parallel with the coastline.
(2) Inshore wind-energy abundant areas: Coastal areas in eastern China have vast sea areas within the sea water depth of 5-20 m, although the capacity of technically exploitable inshore wind energy resources in practice is much smaller than on land due to the constraints of sea function division including ship route, harbor, and aquaculture. However, areas in Guangdong, Fujian, Jiangsu and Shandong have abundant inshore wind energy resources which are close to centers of major electricity demand, thus inshore wind power can become key clean energy for the future development of these areas.

Wind farms are classified into onshore and offshore wind farms by the National Energy Administration. Offshore wind farms include mudflat wind farms in the intertidal and subtidal zones, inshore wind farms, and deep-sea wind farms. Detailed classifications are as follows [6]:

(1) Onshore wind farms, refer to those established on land and in supratidal mudflat areas above the average high tidal line in coastlands, including those established on islands with permanent residents.
(2) Mudflat wind farms in the intertidal and subtidal zones, refer to those established in sea areas below the average high tidal line in an up to 5-m water depth at the theoretically lowest water level in the coastal areas.
(3) Inshore wind farms, refer to those established in the sea areas of 5–50-m water depth below the theoretically lowest water level, including those established on islands without permanent residents and reefs within the corresponding sea areas.
(4) Deep-sea wind farms, refer to those established in the sea areas with a water depth of 50 m or more below the theoretically lowest water level, including those established on islands without permanent residents and reefs within the corresponding sea areas.

3. Policies related to offshore wind power development

In 2005, the National Development and Reform Commission (NDRC) issued *Directory of Renewable Energy Industry Development* in which research projects of inshore wind power technology were listed as priorities supported by the state [11]. Projects related to inshore wind power technology were listed in Table 1. It indicates that compared with inland wind power industry which has already reached preliminary stage of commercial scale, inshore wind power industry still focuses on technological R&D.

In August 2007, the *Mid- and Long-Term Development Plan of Renewable Energy* was issued. It proposed to build one or two pilot projects of 100 MW-scale offshore wind farms by 2010 and establish 1000 MW-scale offshore wind farms by 2020 [12]. In 2007, the *11th Five-Year Plan of Renewable Energy Development* was issued by the NDRC. The plan proposed to strengthen the research on technology of developing offshore wind power, carry out preliminary preparation for exploration and evaluation of offshore wind power, and pilot demonstration projects, and establish one or two pilot projects of 100 MW-scale offshore wind farms, so as to accumulate experience for the development of large-scale offshore wind farms. In the plan, coastal areas which are suitable for wind farm development are classified into two major categories: key areas and general areas [13]. Table 2 shows regional layout of wind power projects of key and general areas.

On January 15, 2009, the National Energy Administration held the *Seminar on the Development of Offshore Wind Power and Construction of Coastal Large-scale Wind Power Bases*. Related departments at the central and local levels, scientific research institutes, companies and organizations took part in the seminar. The chief of the National Energy Administration indicated that to promote the initial work for offshore wind power development, several tasks need to be done in recent periods, including choosing several sites which are fit for the development, completing utilization plans of land and sea areas and environmental impact assessment, improving wind measurement and resource evaluation, and determining enterprises for the development and investment of offshore wind power [14].

In addition, the chief of the National Energy Administration of the NDRC indicated that related departments would carry out the deployment of offshore wind power plan and construction. The plan will focus on three main aspects. First is to formulate an administrative regulation. The national administrative procedures of onshore wind power are relatively thorough and normative while offshore wind power is at the initial stage. Offshore projects involve regulatory departments different from those of onshore wind power projects thus new procedures need to be established and authorities and administrative permission of various departments need to be clearly defined. Second is to make a regional plan. China has a long coastline. Some regions are fit for harbor development while some are fit for offshore wind power development. Therefore, coastal areas which are fit for offshore wind power development should be identified and functions among coastal areas should be clear defined. Third is to deal with technological difficulties of offshore wind power. Compared with onshore wind power, the operating environment of offshore wind power is more complex with higher demand for technology and more difficulties in construction. According to the pilot demonstration projects, the current difficulties are construction, offshore wind power