ARTICLE IN PRESS

Renewable Energy xxx (2016) 1–14

Contents lists available at ScienceDirect

Renewable Energy

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

Economic feasibility of tidal stream and wave power in post-Fukushima Japan

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ARTICLE INFO

Article history:
Received 30 April 2016
Received in revised form
18 June 2016
Accepted 21 June 2016
Available online xxx

Keywords:
Japan
Tidal current
Wave
Cost
Electricity price
Capacity factor

ABSTRACT

Since the Fukushima nuclear disaster of 2011, Japan has relied on imported fossil fuels for electricity generation, but is quickly increasing its share of renewable energy sources. Recent development has been in biomass, geothermal, wind, and solar PV, though little attention has been given to the potential of marine energy resources. The present paper carries out an analysis of the economic viability of this resource using real wave and tidal current data. The results show that marine energy technologies could be cost-effective at several locations in Japan, and can pragmatically add reliable and predictable power to the energy generation mix. Deployed in straits with strong tidal flows near large population centers in western Japan, SeaGen and Verdant-type tidal turbines are shown to operate at costs far below the current price of electricity in the country. In northern Japan, the Aquabuoy, Pelamis, WaveDragon, and Guarda-type Oscillating Water Column Wave Energy Converters show costs near the current price of electricity. Even though Aquabuoy and Pelamis are now defunct, it is likely that in the future new generation wave energy converters would be able to produce electricity at even lower costs and further enhance the practicality of developing wave power in northern Japan.

1. Introduction

Immediately prior to the March 11, 2011 Great East Japan Earthquake and Tsunami and the subsequent nuclear disaster in Fukushima, nuclear power made up 27% of Japan's domestic power generation [1]. The online nuclear generating capacity in March 2011 was 47.5 GW, and nuclear energy generated 288 TWh of power in 2010 [2]. After the 2011 Fukushima disaster, all nuclear generating plants in Japan were shut down (2 out of 17 locations, Satsuma-Sendai and Takahama, resumed operation on September 2015 and January 2016, respectively [3]), and the gap in energy was filled by increasing imports of natural gas, oil, and coal, as well as conservation measures to reduce demand. In 2014, the total energy generated was 1025 TWh, with 32.9% coming from coal, 40.3% from natural gas, 11.1% from oil, 8.5% from conventional hydropower, and 7.2% from renewable sources, which included biomass and waste (4.1%), solar (2.3%), wind (0.5%), and geothermal (0.3%) [2].

As Japan is an island country, its marine resources are abundant. However, it suffers from a lack of hydrocarbon natural resources, making it one of the world's largest importers of natural gas, oil, and coal [1]. Beginning during the OPEC embargo and oil crisis of 1973, Japan made the development of nuclear power a national priority to achieve energy stability and independence [2]. However, the 2011 Fukushima disaster threw the country back into a heavy reliance on imported energy. Currently, the ruling political party (Liberal Democrats, or LDP) has made seismic safety evaluation, modernization, and restarting of Japan's nuclear plants a priority to regain energy independence and reduce carbon dioxide emissions, but this has ignited a fierce debate within the nation, with the abolition of nuclear power becoming a campaign platform of opposition political parties and citizens' groups. In the summer of 2012, Tokyo was the stage of massive weekly anti-nuclear demonstrations, the largest since protests against the Vietnam War that took place in the 1960's. In this sense, a recent opinion poll revealed that 70% of people in Japan opt for a nuclear phase out, with 60% approving the decommissioning of all units before 2030 [4].

As a result of this, it is clear that there is a need for the country to further diversify its electricity generation mix if it aims to achieve

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http://dx.doi.org/10.1016/j.renene.2016.06.049
0960-1481/

the commitments made as part of the United Nations Convention on Climate Change (UNFCCC) Paris Agreement in 2015 to reduce greenhouse gas emissions, given the difficulty to restart many of the nuclear reactors. This paper will attempt to show that Japan's marine energy resources favor the development of tidal stream and wave energy extraction infrastructure. We apply the tested performance data of turbines developed in the US and Europe to particularly energetic sites around Japan and show that development of these resources can economically make a dent in the energy gap of post-Fukushima Japan. Results show that tidal power resources are distributed around southern and western Japan, while wave resources cover northern Japan (Takahashi and Adachi [5] and Okawa et al. [6] found a similar trend in their resource assessments). Existing tidal turbine technology could generate grid power in western Japan at costs below market power prices, while well-developed Wave Energy Converters deployed in the northern part of the country could be competitive with fossil fuels in some locations.

The paper is structured as follows: Section 2 of this paper covers the development of renewable resources in Japan thus far. Section 3 describes the performance of the major tidal stream and wave energy converter technology that has been field tested and proven in the US and Europe. Section 4 details the tidal and wave resource present in Japan, and the amount of energy that could be produced by the installation of such tidal and wave power generation units. Section 5 discusses the economic costs and feasibility of the proposed infrastructure, and the practical contribution that marine renewable resources can make to the country's power mix. Finally, section 6 comments on the policy implications of marine renewable energy development in Japan.

2. Renewable power development in Japan

Regarding renewables, Japan currently has a limited diffusion of solar, wind and geothermal systems, as discussed in section 1. However, there are plans to expand these sources, as detailed by the Energy and Environment Council and METI's 2010 Strategic Energy Plan [7,8]. In July 2012, the government approved a Feed-In Tariff (FIT) system, which establishes a premium price for renewable electricity suppliers [9]. However, marine renewables such as ocean thermal energy, wave energy, and tidal stream energy were not initially included in the system, but are supposed to be included when the technologies have matured enough to allow practical utilization.

2.1. Wind, geothermal, solar, and biomass

As of March 2016, JWPA [10] reports that 2143 wind turbines were installed in Japan, with a total capacity of 3167 MW. In FY2013, wind power produced 5.2 TWh of electricity [11]. Between 2011 and 2012, Japan's domestic shipments of solar modules rose by 171% [12], generating 14 TWh of electricity in FY2013 [11]. By 2030, cumulative solar installed capacity is predicted to go up from 7.4 GW (by the end of 2012) to 100 GW [13]. Much of this uptake in solar is due to individuals installing solar panels on top of their houses. Numerous housing magazines in Japan advertise the potential profits that can be derived from government incentives. However, the Feed-in-tariff for solar power dropped from 40 JPY/kWh in 2012 to 27 JPY/kWh in 2015, discouraging investors from prioritizing solar energy alone [14]. Another major source of renewable energy in Japan is biomass, which in FY2013 generated 12.5 TWh of electricity [11].

Being a volcanic country, Japan has a substantial geothermal production capacity, estimated at 23 GW, the third largest in the world [15]. However, installed capacity is only 540 MW, producing 2.6 TWh of energy in FY2013 [11]. This is largely the result of what's viewed as a competition for geothermal resources by the country's traditional and powerful onsen (hot spring) spa industry [16].

2.2. Ocean thermal energy conversion (OTEC)

Currently, the only fully functioning OTEC plant in Japan, with a rated capacity of 100 kW, is located in Okinawa Prefecture [17], as in this subtropical location seawater is stratified strongly enough for OTEC technology to function effectively. An in-depth analysis of OTEC devices is outside the scope of the present paper, as its potential is more relevant to tropical islands than the major urban centers located on Japan's four main islands.

2.3. Tide

Though barrage and lagoon type power plants, which harness the difference in potential energy generated by large tidal ranges, are effective at generating grid-connected power in Korea, Europe, and North America [18], the only site in Japan with potential for this type of power generation is the Ariake Sea, which has a maximum tidal range of 4.9 m [19]. However, concerns over fishery resources and water quality [20] are likely to prevent development of a barrage at this location. Furthermore, the massive infrastructure investments required for construction of new barrages [21], and their potential environmental impacts, have led to resistance against this technology in other countries such as the UK [22].

Even though barrage-type tidal power is not practical in Japan, tidal stream power has significant potential (see section 4 below). Since the 1980's, Japanese universities have conducted significant efforts to develop tidal stream power converters. Grid-connected field installations have not yet begun, but a technology proving site modeled on the European Marine Energy Center is planned [23]. Kondo et al. [24] estimate the total power in tidal currents within Japan is 25 GW on average, which is over half of Japan's pre-2011 developed nuclear power capacity. Even though only a small percentage of this power can hope to be harnessed, the existence of the resource, if developed, will be a boon for the country's energy economy.

2.4. Wave

Japan began as one of the leaders in field testing of technology to harness useable power from ocean waves via Oscillating Water Column (OWC) wave energy converters (WECs). From the 1970's to 1980's, Japanese researchers developed the "Kaimei" (1976–1986) and its successor, the "Mighty Whale" (1987–2004), a barge with OWC WEC's meant to be anchored near and provide power to remote villages [25]. Closer to shore, OWC WECs were constructed in the concrete caisson breakwaters of ports in Sakata, Kujukuri, Niigata, and Sanze [26], with the port of Sakata continuing to function as a testing ground for improving OWC technology [19]. Kondo et al. [24] estimate the wave power incident along the 5000 m coastline of the entire country to be between 36 GW and 50 GW. This alone is on the order of Japan's pre-2011 nuclear power generation capacity. In deeper water, Kondo et al. [27] estimate the wave power incident along the entire perimeter of Japan's 200 nautical mile territorial waters is 180 GW. As with tidal stream power discussed in section 2.3, only a small portion of this energy can practically be harnessed. However, the power that could be made available harnessing both tidal currents and waves could contribute to close a significant proportion of Japan's post-2011 domestic energy gap.

Please cite this article in press as: J.D. Bricker, et al., Economic feasibility of tidal stream and wave power in post-Fukushima Japan, Renewable Energy (2016), http://dx.doi.org/10.1016/j.renene.2016.06.049