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In situ near-shore wave resource assessment in the Fiji Islands

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ABSTRACT

Directional wave measurements were carried out at two different near-shore locations in the Fiji islands with the help of an underwater pressure transducer — a Directional Wave Recorder. The primary site which is located in the west of the main island in Fiji has a moderate energy potential of 9.81 kW/m at a depth of 15 m. The second site which was the focus of past wave energy measurements was also studied and the new data along with previous measurements show high energy potential at this location. This site near Kadavu Island has a near-shore energy flux of around 28.78 kW/m at a depth of 18 m. The directional spread of the waves and the nature of their occurrence are presented. Additionally, the sea states during a category 2 tropical cyclone passing about 200 km from the measurement location are discussed.

Introduction

A mix of renewable energy resources is required to change the current trend of energy production. While wind and solar are proven renewable energy resources, the availability and intensity of these resources vary greatly over the globe. The success of renewable energy will lie in its diversification. Wave energy is an upcoming energy resource that can be a strong component in the renewable energy mix. The global wave power resource in water depths of over 100 m has been estimated to be 3.7 TW (Mørk et al., 2010) while the economically exploitable resource ranges from 140 to 750 TWh/year for current designs when fully mature, and could be as high as 2000 TWh/year if the potential improvements to existing devices are achieved (Survey of Energy Resources, 2007). Estimates suggest that conversion of wave resources alone could supply a substantial part of electricity demand of several countries such as Ireland, UK, Denmark, Portugal, Spain and others. According to the total incident wave power density available to the United States of America is 2100 TWh/year (Bedard et al., 2005). In Asia, country resource assessments of wave energy estimate a high value for this resource. According to the estimation of State Oceanic Administration of the People's Republic of China, about 125 GW of wave energy is technologically available in the near-shore in China (Zhang et al., 2009). In India, wave energy potential is placed at 6 GW for around 5914 km of coastline (Raju and Ravindran, 1997).

While there can be a number of energy sources to use, it is important to choose the type of energy after a very detailed assessment of all the resources. In a study by Bağcı (2009) for the best mix for a “zero energy island”, the recommended energy mix after comparing six renewable resources was wind, solar and wave energy. As of 2010, 2 MW of wave energy capacity had been installed by the 18 member countries of the International Energy Agency (IEA) Implementing Agreement on Ocean Energy Systems (Ren21 Report, 2011). Many companies have directed their attention to wave energy. For developing island nations that have a large ratio of sea area to land area, wave energy itself may provide a suitable substitute over diesel for electricity generation. In the Fiji Islands, which has an effective EEZ bounded sea to land area ratio of 70 (Dunn et al., 2000), the deep sea wave resource on average is 26 kW/m (Barstow and Haug, 1994). Having a coastline of 1129 km, the potential for these islands stands at 29 GW. Even if 0.5% of this offshore resource is utilized, it will be enough to meet the entire nation's electricity demand. Similar opportunities exist for almost all island countries in the Oceania region. With less land area to construct utility scale wind and solar systems, wave energy is a better option for developing island nations. The capital costs of WECs are already reasonably low, and these are likely to reduce further as the industry expands and specialized industries emerge for WEC sub-components (Beatty et al., 2010). Despite the low wave power potential in some locations, it must be stressed that the population's power requirements in these islands are not very high. Near-shore wave sites with naturally low potentials are nevertheless free energy available for extraction. Another issue that plagues these island nations is sea level rise as a result of climate change. With

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higher sea levels, incident waves are larger and this presents a hazard to low lying islands. Utilization of near-shore wave energy converters will help reduce the impact of waves on the shoreline to some degree as some of the energy will be absorbed by these converters. Wave powered desalination will also prove important to many islands which do not have rivers, receive little rain and/or no other natural source of fresh water. However, before any installations in wave energy are planned or any targets are set, a detailed wave energy resource assessment must be done; this is normally followed by an environmental impact assessment and steps taken to ensure that the impact on the surrounding area as well as on the marine life is minimized. The following sections detail the characteristics of near-shore waves in the Fiji Islands and its energy potential. The near-shore data are also compared against offshore measured data available from previous measurements and the differences are discussed. The near-shore wave energy potential for the Fiji Islands is ascertained and the effects of directional spread are discussed.

Early measurements and offshore wave energy

The wave energy resource assessment program for the South Pacific was initiated by the South Pacific Applied Geoscience Commission (SOPAC) in 1987. In 1991, a Waverider buoy was deployed off the south west coast of Kadavu at a depth of 356 m. The buoy collected useful data for more than two years. The results of this study can be found in the report by Barstow and Haug (1994). This was the first successful assessment of wave characteristics in Fiji and was also useful in mapping the wave energy resource of the South Pacific. The Fiji Ministry of Energy carried out short term directional wave resource assessment at Naidrodro Pt in Kadavu in 1993 and at Matuku in 1994 (Deo, 1995). Barstow reported wave power densities of 25 kW/m to 30 kW/m for the months of March to July. Energy potential dropped after July and ranged from 15 kW/m to 20 kW/m for the months of August to February. There were significant effects of the El Niño climate phenomena on the results of the study, especially in the year 1992. Numerous cyclones passed over the region and hence influenced the wave characteristics. The study was carried out with the aid of the Norwegian Agency for International Development (NORAD). Following the end of this study in 1995, there was a lull in wave energy research in Fiji until 2002. SOPAC jointly with the US Wave Energy and the Fiji Department of Energy carried out near-shore wave measurements at Muani in Kadavu at a depth of 18 m (Mario, 2003). A bathymetric multi-beam mapping exercise was carried out in this area in the hope of installing a 500 kW wave energy module later. The raw data from the underwater pressure transducer was recovered from the Fiji Department of Energy to ascertain the wave energy potential in this area. A MATLAB code was written to analyze this non-directional data of sampling frequency and surface elevations. Spectral analysis was carried out on the data of six months.

The offshore wave energy potential reported by Barstow has been used to represent the wave energy potential in the Fiji Islands. While the offshore wave energy shows moderate potential which is more than required to meet the islands' electricity demands, construction of a wave energy device in offshore locations will be a major challenge for this developing nation. With numerous cyclones crossing the Fiji Islands EEZ, it makes the prospects of an offshore wave energy device to be almost impossible (South Pacific Cyclone Season, Wiki, 2012). While the benefits of wave energy utilization in terms of offsetting fuel imports are substantial, the initial capital investment and the high risk involved in offshore installations have deterred any further activity in offshore wave energy in Fiji. Offshore power plants would have high operation and maintenance costs along with added submarine transmission costs simply due to its distance from land. The devices will have a higher chance of damage or being lost during storms and cyclones. The remote islands are small and pilot-scale projects could be sufficient to meet the requirements of many communities. Offshore installations have higher associated capital input and risks at the gain of only some extra wave energy. For this reason recent studies have been focused mainly on near-shore wave energy resource assessment. Offshore waves can be classed as deep water waves where wave particle orbits are circular while nearshore waves are shallow and intermediate whereby particle orbits tend to be elliptical. Nearshore or shallow water waves are affected by the sea bed profile unlike deep water offshore waves. The shallow water waves are also defined to have a depth which is less than 1/20 of the wavelength of the wave.

Near-shore wave energy

Recent studies have shown that near-shore wave resources are not only easier to exploit but also not significantly lower compared to the offshore values (Folley and Whittaker, 2009; Cornett and Zhang, 2008; Near-shore vs offshore, Waveroller online report, 2013). Waves propagating from offshore to near-shore region undergo various transformations such as shoaling, refraction, diffraction and reflection (Kim et al., 2011). The propagation directions of shoaling surface gravity waves change owing to refraction by spatial variations in water depth (Herbers et al., 1999). The near-shore resource has often been considered as simply a less energetic version of the offshore resource. However, the interaction of the seabed with the incident waves and the surrounding landmasses changes the characteristics of the wave climate from the offshore to the near-shore (Mirfenderesk and Young, 2003) so that a simple scaling of the wave climate inadequately describes the near-shore wave climate. The loss in wave energy amounts to around 7–22% of the energy available offshore (Folley and Whittaker, 2009) and can be attributed to the sensitivity of the wave to bottom conditions after a certain depth. This is a very small loss compared to the difference in depths for offshore and near-shore waves. It is inherently important that the mechanism of wave energy loss be understood properly so that a sound decision can be made on the location and design of a possible WEC. Waves propagating over a bed lose energy due to interaction with the bed. One of the most important dissipative mechanisms is associated with bed friction, which causes a thin boundary layer to develop above the ocean bed (Mirfenderesk and Young, 2003). As waves enter shallow water from deeper water, the waves transform and as a result, the height, length and celerity of the wave change. Refraction involves wave direction and height changes due to depth variations (Dean and Dalrymple, 1991). It causes the wave to align to the shoreline and loose its multi-directional propagations. At some locations where bottom configuration suddenly changes (or a barrier is present), a part of the wave is reflected and another part is transmitted (Horikawa, 1978). Wave shoaling causes a reduction in the wavelength and the speed of propagation of the wave. The period of the wave remains unaltered. Shoaling causes an increase in the wave height which in turn increases the wave steepness and leads to wave breaking. The largest energy loss suffered by offshore waves approaching the near-shore region is by energy dissipation through bottom friction. The study by Folley and Whittaker (2009) also reveals a 44% reduction in omni-directional wave resource which is good for directionally sensitive WECs such as the popular oscillating water column (OWC). Iglesias and Carballo (2010) used the SWAN coastal model to transform offshore buoy data to a near-shore region for selection of a wave energy farm using hindcast data. This is a common way to estimate near-shore wave energy resources. The extent to which wave energy reduces from offshore to onshore locations depends on the nature of the seabed and other factors at that location. While it was clear that near-shore wave energy devices are less expensive, easier to maintain and had a much longer lifetime — it can be seen from recent research that near-shore wave power potential differs very little from offshore energy potential. On an overall assessment, which includes the feasibility of installing the first wave farm in a region, a near-shore wave energy