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Analysis of ocean waves in 3 sites potential areas for renewable energy development in Indonesia

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ABSTRACT

During the recent years, Indonesian government rapidly increase the electrification program which is mainly using coal energy. However, some areas are still need any supports of electricity. As an archipelagic state, Indonesia is surrounded by seas which is potential for developing the wave energy. Three areas were selected for examining the wave energy potential i.e., Meulaboh (in Sumatera), South Kuta (in Bali) and Manokwari (in Papua), which is the representative of the region in west, middle and east of Indonesia, respectively. Ocean wave characteristics were analyzed for each monsoon from 2012 to 2017, based on ocean wave forecasting using Sverdrup, Munk and Bretschneider method. The electrical power calculations were done by using Floating Oscillating Water Column formulas. Based on our analysis, the average of highest significant wave heights and periods in 3 sites happen in the West Monsoon and the lowest average of significant wave heights and periods mostly happen in the East Monsoon. Thus, among the three locations that were examined, South Kuta Bali is the best location to develop wave energy.

1. Introduction

In the last decades, the world has faced energy crisis issues. The problem of energy in Indonesia is the availability of fossil energy that continues to decline (Alifdini et al., 2016, 2017). However, Indonesia, as one of developing countries in Asia struggle to make an energy sustainability for the citizens (Sukarno et al., 2015). As a result, the electrification process in Indonesia has been accelerating in the past two decades (Ramdani and Setiani, 2017). The electrical capacity of Indonesia in the form of renewable energy are solar, wind and biomass energy. Plan to increase the use of renewable energy (including hydropower) is 19% and 23% in 2019 and 2025, respectively (IEA, 2015).

Hydropower consists of 10% of the total electrical generation capacity in 2013. There is only a little growth from this energy source in the last decade. Therefore, Indonesia plans to develop several mini-hydropower plants adding 2 GW capacity in 2019. The government strongly supports investment in these plants, particularly in remote areas, to increase the electrification rate (IEA, 2015). One of hydropower plant that can be developed is ocean based hydropower plant since 70% of Indonesian region consist of ocean area. There are some kind of ocean based hydropower, one of them is harnessing energy from ocean waves. The developments of ocean wave energy in Indonesia are quite promising because some areas in Indonesia are directly facing Indian Ocean and Pacific Ocean that have great wave energy.

Among of some devices that have been developed for wave energy conversion is Oscillating Water Column (OWC). This device is a wave energy conversion that the most extensively studied in the recent years (Şentürk and Özdamar, 2011). Oscillating Water Column (OWC) is a device that transforms the mechanical energy of the waves into electrical power. The waves enter to the chamber to compress and decompress the air around Still Water Level (SWL) so that an oscillate airflow will be created. This airflow is passed through a power take-off (PTO) system which consists of a turbine and an induction generator that transforms this motion into electrical power (Garrido et al., 2015).

There are some kinds of Oscillating Water Column (OWC) that have been developed, one of them is Floating OWC that can absorb power from the waves (Bull and Johnson, 2013). Floating OWC's are increasingly attractive due to their ability to benefit from more energetic wave energy (Bailey et al., 2016). Floating OWC was demonstrated in 1:4 scale device off the Irish coast based on the Japanese bent backward duct buoy concept. It has been in the water since December 2006. Other than that, Oceanlinx have tested three devices and have tested two

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different turbines: the Dennis Auld and the Hydro Air. There are several other floating OWCs, e.g., Embley Energy's machine and The Mighty Whale. Despite not tested yet, Embley Energy's machine is a simple robust machine, while The Mighty Whale was deployed in Japan, but was not considered a success (Minns, 2012). In addition, floating OWC devices have been studied and developed with the self-rectifying Wells turbine (Gomes et al., 2011) that is floating independently (Konispoliatis and Mavrakos, 2016). The concept of floating OWC can be described as follows; it consists of a relatively long vertical tube, open at both ends and attached to a floater. This concept has been considered since the early pioneers of wave energy conversion (Falcão and Henriques, 2016).

Firdaus et al. (2011), identified some of potential locations in Indonesia to develop wave energy. In addition, Zikra et al. (2016) also studied some areas in Indonesia that are potential to be developed for wave energy based on the characteristics of wave climates. They considered the potential areas based on temporal variation in significant wave height using ERA-Interim reanalysis data from ECMWF (European Center for Medium-Range Weather Forecasts) for 35 years in the period from 1980 to 2014. Some locations that are potential are in the Western of Sumatra Island, Southern of Java Bali Nusa Tenggara Island and Northern of Papua Island. In this study, 3 locations were examined to represent the western part, middle part and eastern part of Indonesia. They were Meulaboh, South Kuta and Manokwari representing western, middle and eastern part of Indonesia, respectively. Meulaboh is a coastal region located in the western part of Sumatra Island that facing the Indian Ocean (Marlian et al., 2015). The usage of electricity in Meulaboh is still need to be developed since Meulaboh is located in the outer region of Indonesia. On the other hand, South Kuta is one of the most popular beach in Bali Island which is located in the Southern part of Bali Island (Purwanto, 2011). This location is very easy to access and becomes the popular area for tourism. Because of the high tourism activity, the demand of electricity is also high. Manokwari is the capital city of West Papua Province, which has seven districts. Those districts are North Manokwari, East Manokwari, West Manokwari, South Manokwari, Sidey, Tanah Rubuh and Masni (Runtuboi et al., 2015). The district that has a wave energy potential is North Manokwari because this location directly face the Pacific Ocean. The electricity uses in Papua Island is still need to be developed with renewable energy, because there is a limitation in access to develop conventional energy in Papua Island due to the extreme morphology and topography.

Beside demand factors as mentioned above, another important factor was also required for choosing sites for wave energy developments, i.e., water depth (DasGomes et al., 2018; Sugianto et al., 2017). Wave energy converters are mostly planned/installed for depths less than 100 m and closer to the shore they will experience a decrease in the available wave energy that can be captured depending on the slope and roughness of the sea floor (Sundar et al., 2010). Where the water is deep (> 40 m depth), near shore and offshore devices will necessarily be of the moored type (Thorpe, 1992) (Thorpe, 1999). Based on LPI bathimetry map in the scale of 1:50,000, Meulaboh has water depth ranging from 0 to 60 m. South Kuta Bali waters has the depth from 0 to 200 m (BIG, 2018) and Manokwari has waters depth from 0 to 400 m (Hatta, 2014). In general, Meulaboh, South Kuta and Manokwari waters are suitable for developing wave energy.

Other than that, floating OWC has been tested successfully in Gokasho Bay, Japan with the most predominant significant wave height and period are 0.5 m and 6 s, respectively. Moreover, there are also some waves with significant wave height over 4.0 m. In other words, it is proven that the test site is generally relatively calm but in severe weather, the wave height rises very much (Washio et al., 2001). On the other hand, the percentage of time for which the significant wave height is lower than 0.5 m (calm sea condition) is an ideal floating device would be easily accessible (Martinelli et al., 2013). Based on research of Utami (2010) and Saragih (2017), the western ocean of Aceh to North Sumatra (including the Meulaboh area), Southern ocean of Bali to NTB and northern ocean of Papua have a mean significant wave heights from 0.3 to 1.3 m, 0.4 to 1.5 m and 0.4 to 1.25 m, respectively. The percentage of significant wave height lower than 3 m is 95% in all locations. Because of that, these locations are quite possible to implement floating OWC to harness electricity from waves.

2. Materials and methods

2.1. Research locations

Wave energy resources were examined in three locations. They were Meulaboh, South Kuta and Manokwari with the following coordinates: from 4°11′24.39” N to 4°10′51.06″N and 95°56′41.59” E to 96° 0′24.74″E; from 8°51′53.79″S to 8°52′46.07″S and 115° 7′30.99″E to 115° 9′12.02″E; and from 0° 4′47.76″S to 0°14′48.88″S and 132°47′7.14″E to 132°32′4.04″E, for Meulaboh, South Kuta and Manokwari, respectively.

2.2. Wave forecasting

In this study, ocean waves were forecasted from wind data. Wind data were obtained from Geophysical, Climatological and Meteorological Agency of Indonesia from 2012 to 2017. The wave forecasting was done using Sverdrup-Munk-Bret Schneider's (SMB) method (CERC, 1984). The wave height and period were determined based on the wave fetch conditions. There are several criteria for determining wave characteristics based on fetch condition:

2.2.1. Fetch limited

In the fetch limited conditions, the wave heights and periods are determined by equations (1)–(3).

$$\frac{gH}{U_A^2} = 0{,}283 \tanh\left[0{,}530\left(\frac{gd}{U_A^2}\right)^{3/4}\right]\tanh\left(\frac{0{,}00565\left(\frac{gF}{U_A^2}\right)^{1/2}}{tanh\left[0{,}530\left(\frac{gd}{U_A^2}\right)^{3/4}\right]}\right) \quad (1)$$

$$\frac{gT}{U_A} = 7{,}54 \tanh\left[0{,}833\left(\frac{gd}{U_A^2}\right)^{3/8}\right]\tanh\left(\frac{0{,}0379\left(\frac{gF}{U_A^2}\right)^{1/3}}{tanh\left[0{,}833\left(\frac{gd}{U_A^2}\right)^{3/8}\right]}\right) \quad (2)$$

$$\frac{gt_d}{U_A} = 5{,}37\ x\ 10^2\left[\frac{gT}{U_A}\right]^{7/3} \quad (3)$$

Equation (1) is used to determine the wave height (H) based on its fetch length, whereas Equation (2) is used to determine the wave period (T). equation (3) is used to determine the wind duration (t_d) based on the wave period (T).

2.2.2. Fully developed sea

If $T_{1/3}$ is considered as 0.95 Tm then, the value of wave height and period can be determined by equations (4)-6).

$$\frac{gH_{mo}}{U_A^2} = 2{,}433 \times 10^{-1} \quad (4)$$

$$\frac{gT_p}{U_A} = 8{,}134 \quad (5)$$

$$\frac{gT_d}{U_A} = 7{,}15\ x\ 104 \quad (6)$$

Where: H_{mo} is wave height (m), U_A is wind speed (m/s), T_p is wave period (s), t is wind duration (s) and F is fetch length (m).

The interaction between U and F will produce a value of H_{mo} and T_p. In limited circumstances, the wind fetch moves above the water surface