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Optimizing energy output for Oscillating Water Column (OWC) wave energy converter system at Pantai Baron, Gunung Kidul, DI Yogyakarta

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ABSTRACT

The prototypes of the Oscillating Water Column (OWC) system constructed by BPPT at Pantai Baron, Gunung Kidul, in 2005 and 2006 were not sustainable. Based on its condition and location, the root cause of the problem was defined. Maximizing the total efficiency and capacity factor (Cf) of the OWC system was the main factor for optimizing energy output. Collecting factors that constructed the total efficiency and capacity factor of the OWC system was conducted. Selecting the appropriate turbine, generator, and chamber system led to an increase in the total efficiency of the OWC system. Reducing the effect of wave diffraction, finding optimum wave data for forecasting, finding optimum water depth area to avoid wave breaking area, reducing corrosion chance by selecting the optimum height of the OWC system, and using a control system to minimize stalling on turbine were factors that constructed capacity factor.

1. Introduction

Pantai Baron, Gunung Kidul, Yogyakarta, is an ideal location to develop renewable energy from ocean waves using an OWC converter on the south coast of Yogyakarta [1]. The potential electrical energy that can be generated by 1 OWC system reaches 2 MWh/year/m [2], although Pantai Baron is not an area that has the greatest energy potential on that area [3], [4]. BPPT, in 2005 and 2006, has developed OWC prototypes at Pantai Baron, where both prototypes did not give maximum results, although the design was quite good [5].

Developing an OWC system design that is quite economical and sustainable is necessary to improve the OWC system for the next step in this area. Several studies have been carried out, including the selection of turbine and generator technology [6], the use of the small pipe to distribute air pressure energy in the turbine tube [7] and also the selection of the ideal depth position for placement of OWC systems [2]. In this study, problem analysis and optimal solutions were to obtain a more economical and sustainable OWC system by collecting all aspects having been studied and adding some others undiscussed before. There had been no research combining all aspects which affect the optimization of the OWC system at Pantai Baron.

This research aimed to produce an economical and sustainable OWC system in Pantai Baron, although without addressing the structural aspect of the building. The researchers hoped that this research would be a reference for developing prototypes better than those developed.

2. Method

2.1. Prototype OWC Pantai Baron

BPPT developed two prototypes of the OWC system at Pantai Parang Racuk, Baron, in 2005 and 2006. Fig. 1 depicts the locations.

Fig. 1. The Location of the BPPT's OWC system prototype at Pantai Karang Racuk, Baron, Gunung Kidul

In 2005, BPPT set the OWC system up on a reef site too close to land. Such a condition made the system inefficient because it was not submerged at low tide, while the waves were already broken at high tide. The seawater up and down movement due to waves was far from optimal. Fig. 2 and Fig. 3 show the prototypes of 2005 and 2006, respectively [5].

Fig. 2. The BPPT's 2005 OWC system prototype

The 2006 prototype had a height of 8 m. The chamber height was only about 6 m. For this reason, the system could only be installed at a maximum depth of -3.0 m MSL, where the waves would still break. At such a depth at low tide, the chamber was not fully filled with water, thus preventing the air pressure due to the seawater up and down movement [5].

Fig. 3. The BPPT's 2006 OWC system prototype [5]

2.2. The Sustainable Factor for an OWC System

To build an OWC system that can be used sustainably and efficiently, we need to know two important things: the efficiency and the capacity factor of the OWC system. This can make the two prototypes of the OWC system in Pantai Baron more effective and can be used as long as it is needed.

2.2.1. The efficiency of an OWC system

The basic principle of an OWC system is to utilize the up and down movement of ocean waves in the chamber to push the air in it. The effect of the rising and falling pressure on the water surface due to the wave movement is the air pressure change in the chamber above the water surface. This air pressure can drive the turbine, the rotation of which can be channeled to a generator and converted into electrical energy [8], [9].

The chamber is a device in which the changes in wave height occur, putting pressure on the air therein. The hole in its mouth to make it always submerged by seawater is necessary to ensure that the energy generated by ocean waves be maximally absorbed. The rising and falling pressure of the seawater should not leak out of the chamber mouth at low tide to prevent the pressure from being the same as atmospheric pressure [10], [11].

The turbine should rotate with alternating airflow, either due to the air blowing or pulling from inside the chamber. When the water level rises due to waves, the water push will blow the air out through the turbine and make it rotate. When the water level drops, there is a suction effect from inside the chamber, so the air moves through the turbine and makes it rotate [8], [12]. The water level, to ensure that the air pressure in the chamber is efficient, must be at least above its mouth to ensure all air flows through the turbine. Maximum water level elevation must not touch the turbine surface to ensure the push and suction of the air in the chamber. The water level elevation applies both due to tides and the oscillatory motion of ocean waves [13].

Based on these, three energy conversions are the conversion of ocean wave energy into air pressure, namely, in this case, in the chamber, the conversion of air pressure to drive the rotor in the turbine, and the conversion of the rotation of the rotor into electrical energy in the generator. Each conversion system has its own efficiency, so the total efficiency of the OWC system is the multiplication of all the efficiency of each part [13].

The chamber efficiency is the potential for ocean wave power the chamber can absorb in the OWC system. The turbine efficiency is the efficiency of the turbine used by the OWC system. Meanwhile, the generator efficiency is the efficiency of the generator used by the OWC system [13]. The total efficiency of an OWC system, according to several studies, ranges from 0 to 20% of the total potential energy generated by the waves, depending on the wave height and period [13], [14].

2.2.2. Capacity Factor

The height and period of the waves, which is very difficult to get accurate predictions of wave height data. This causes the level of absorption of electrical energy (capacity factor = CF) [15] due to waves very low. Another thing that affects CF is when the height and period of the wave are small, so the energy is not able to move the rotor in the turbine, this is often called calm wave.

At certain times where the waves are very high, the air pressure is also very big, so that a turbine that has certain specific range will experience a loss of energy, this is called stalling [16]. This effect can also affect the amount of CF, besides can also cause damage to the turbine. Based on several studies, the CF (capacity factor) of the OWC system is 0.1 – 0.4 [17], [18].

Many OWC systems are installed in onshore areas, where in shallow sea areas there will be a wave transformation and then it will break. As a result of breaking waves will result in a loss of energy from the ocean waves where the energy loss due to breaking waves is about 15% [19]. Changes in water level due to tides will also affect energy loss in the OWC system, but this is not very significant when compared to changes in wave characteristics [20]–[22].

3. Results and Discussion

3.1. Turbine and generator

Increasing the turbine and generator efficiencies should consider the turbine and generator types, which should be most suitable for the characteristics of the waves of Pantai Baron. The types of turbine and generator that match those characteristics are Savonius Turbine and Synchronous Generator.

3.2. Chamber

An OWC would be installed at Pantai Baron at a water depth of -5.0 m MSL, with a chamber mouth hole measuring 2.4 x 2.4 m, which should always be under the seawater surface at the lowest low tide [2]. The 2D sketch of the OWC system is presented in Fig. 4. The turbine would be at an elevation of +5.0 m MSL to not be submerged by seawater in the highest tide. A turbine submerged under the seawater level will cause the pressure due to the seawater rising and falling to be ineffective [23]. Another factor that affects the chamber absorption efficiency is the chamber material. The chamber shape can also affect its fluid movement hydrodynamics [8], [10]. Its wall thickness can also affect the energy transfer efficiency [10]. Further research is needed to determine the optimal chamber material, shape, and wall thickness for a better OWC system at Pantai Baron.

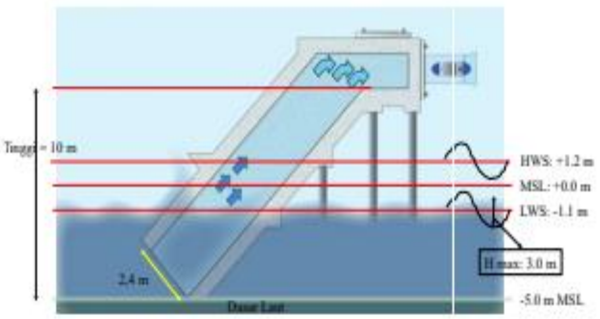

Fig. 4. 2D Sketch of the water level versus OWC system height

3.3. Refraction, shoaling and diffraction

Diffraction is a change in the ocean wave height due to the presence of a barrier or wall [10], [24]. Based on existing research, an OWC that can move freely produces energy higher than a fixed OWC does [1], [25]–[27]. So, to reduce the effect of diffraction in the chamber hole for a fixed OWC, it is necessary to pay attention to the angle of incidence of the wave so that the direction of the OWC system must be perpendicular to the incident wave front [28]. The Ref-Dif software is usable to determine the direction of the incoming wave. The example of changes in the direction of incoming waves, with a wave height of 1.08 m, of deep seas from the east can be seen in Fig. 5.

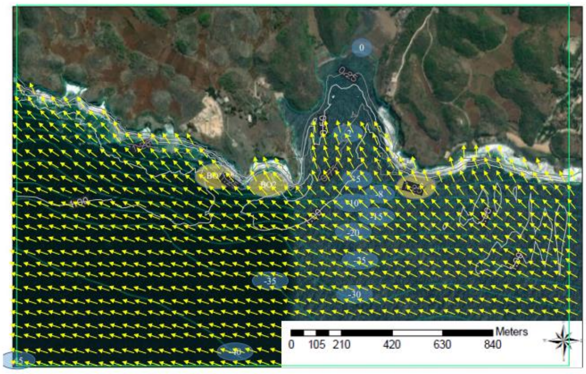

FIGURE 5. Incoming wave direction transformation from deep sea at Pantai Baron (H = 1.08 m, T = 9.73 s, East).

Fig. 5. Wave height of 1.08 m, of deep seas

The deep-sea waves that occur on Pantai Baron come from 3 directions, namely east, southeast, and south [2], so that the facing direction of the OWC system is the resultant energy of the energy quantity from each direction to the frequency of the wave occurrence. The calculation of the resultant energy in the research by Kurniawan, et al. [2], showed that in the OWC system at Pantai Baron that used three research points, the chambers; facing directions were -36.20, -9.740 and -29.140, respectively, with the reference to the south being 00. So, the chambers' facing directions should tend to face southeast. The placement of the facing direction of the OWC system at Pantai Baron can be seen in Fig. 6.

Refraction and Shoaling can result in changes in the sea wave height due to changes in the seabed contours, where, at a certain time, the sea waves would break because they can no longer contain their energy. The breaking of ocean waves can result in an energy loss. Therefore, the OWC system should not be in the breaking wave area. No breaking waves occur in a depth of -5.0 m MSL, thus avoiding energy loss [2]. The position of the breaking wave concerning the placement point of the OWC system is shown in Fig. 6.

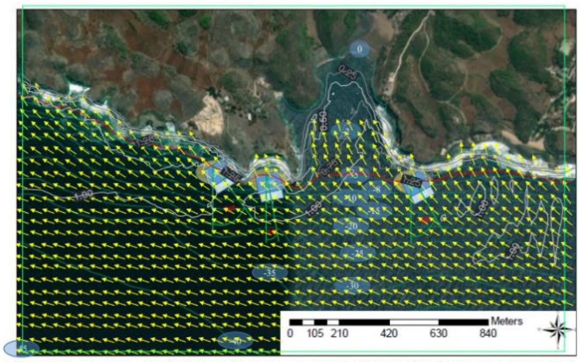

FIGURE 6. The placement of the OWC system for 3 locations compared with the location of the breaking wave (red line), the distribution of wave height (white line) and the direction of the incoming wave (yellow arrow).

Fig. 6. Breaking wave concerning the placement point of the OWC system

3.4. Calm Wave

The turbine is driven by air pressure due to the ocean wave up and down movement. Ocean waves significantly depend on the wind speed. The slower the wind, the lower the wave. A wave with a small height is also called a calm wave. Wind speed and effective fetch length are necessary for forecasting wave height, where the effective fetch originating from the land direction is considered zero. If the wind comes from the land, the wave height is zero too.

Calm wave is one of the causes of the low-capacity factor of wave energy, especially the OWC system. When calm waves should be used as an ideal time for maintenance [29]. Sufficient data of a minimum of 10 years is also useful for forecasting more accurate wave height. The average wave height at Pantai Baron at a depth of -5.0 m MSL ranges from 1.0 - 2.2 m based on 3-year data [2]. The more data, the more accurate wave height data for determining strategies to increase the capacity factor figure.

3.5. Corrosion

One of the factors that can reduce the turbine efficiency is corrosion-based damage. To avoid corrosion, apart from selecting materials resistant to seawater corrosion, placing the turbine in a position so that it is not submerged by seawater is the easiest choice. Based on Fig. 3, if placed above an elevation of +5.0 m MSL, it is less likely being submerged by seawater, thus reducing the risk of corrosion

3.6. Control System

The problem that often occurs regarding the sustainability of the OWC system is the frequent occurrence of stalling on the turbine due to the wave height that produces pressure exceeds the limit of the turbine capacity. Such a stalling can cause the absorbed energy to be reduced significantly because the turbine does not rotate properly because of the wave height occurring. Besides, stalling, if running continuously, also can cause damage to the turbine [13]. A modification of the pressure absorption by the turbine using a control system to prevent stalling and control the pressure entering the turbine is necessary [13], [30]. For the OWC system at Pantai Baron, the researchers modified the turbine from a single-pipe turbine to a multiple-smaller pipe turbine to regulate the high pressure to prevent excessive pressure on the turbine that can cause stalling [7].

4. Conclusion

The OWC system at Pantai Baron can generate electrical energy of 2 MWh/year/m. The system efficiency can be optimized by selecting the most suitable turbine and generator and determining the most appropriate depth. The capacity factor can be maximized by adjusting the facing direction of the chamber to that of the incoming waves. The placement of the OWC system must also be free from breaking waves. Forecasting the maximum wave height can also help provide accurate data in determining the amount of energy possible to be generated to make both calm and extreme waves more predictable. Corrosion is another problem. Using the proper material and placement above the maximum water level can reducedamage caused by corrosion. Calm waves will cause the turbine not to rotate, while very high wave heights can cause stalling. Therefore, regulating air pressure using a control system is beneficial to maximize the energy generated. The height of the OWC building reaching 12 m becomes a challenge in the design process. Further research is necessary to develop an OWC structure suitable for the characteristics of Pantai Baron. Diffraction occurring in the chamber hole needs to be studied to get a more accurate data on decrease in wave height. The selection of the materials, the shape, and the thickness of the chamber walls also needs further research.

Declarations

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