Feasibility Study of Using Wave-PV-Wind Hybrid System for AL Hallaniyat Island

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Abstract. Al Hallaniyat Island is located in the southern part of Oman. The island has a low number of population and is currently fed by a number of diesel generators with a capacity of 1568 kW. Decreasing the emission of greenhouse gases is one of the main goals for the country's vision of 2040 as well as Oman's commitment to net-zero emissions by 2050, in line with the Paris Agreement of limiting global warming to 1.5°C. The purpose of this paper is to study the feasibility of replacing diesel generators with 100% renewable energy sources. The proposed energy source for the Island will be a hybrid system consisting of the wave energy converter, PV, wind and battery storage system. Real load data was used in the model with measured wind speed and solar radiation. The Hybrid Optimization Model for Electric Renewables software is used in this study. Several systems were proposed but the most economical one is PV-Wind-Wave-Battery system that resulted in levelized cost of energy of US$/kWh 0.1586 and Net Present Cost (NPC) of US$ 5,010,594 . Having PV-Wave-Battery will result in levelized cost of energy of US$/kWh 0.174 whereas having Wind-Wave-Battery will increase the energy cost to US$/kWh 0.42.

1 Introduction

Wave energy is obtained from winds as they blow across the seas. The power in a wave depends on square of the wave amplitude and period. Thus, large amplitude (around 2 m) and long wave (7-10 second) having energy that ranges between 40-70 kW per m width of coming wave [1]. The energy intensity of the wave decreases near the coast due to interaction with the seabed. Marine energies are of untapped resources when compared with solar and wind energies in countries that have seas and oceans. Wave energy has the highest energy density among other marine renewable energy sources [2]. Several studies explored the possibility of utilizing wave energy in various locations around the world, such as Gulf of Oman [3,4], the Persian Gulf [4,5], the Atlantic coast of Europe [6-7], Atlantic Ocean [8] and many other locations. There are several advantages of utilizing

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wave energy such as, having limited environmental impact, the energy is available throughout the day, and having high-energy fluxes.

Most modern countries worldwide are working hard to shift their power generation away from fossil fuels and toward renewable sources. The environmental consequences associated with producing power with fossil fuels, as well as their storage limitations, are particularly troubling for our human beings [9]. Coal is the world's primary fossil fuel used to generate energy [10]. A technical and economic analysis of a hybrid renewable energy system for powering small plant auxiliary units was presented by many researchers [11]. Electrical system developers and legislators identified integrated units to be highly beneficial in distribution systems, which are dependent on the total characteristics of each unit, such as solar power systems, wind systems, load characteristics, and local renewables [12].

The increase in energy demand in Oman, which mainly depends on fossil fuels, causes more emission of gases as well as a depletion of fossil-fuel reserves [13]. Oman is blessed with a high level of renewable energy resources (Solar, Wind and wave). The solar density in Oman is among the highest in the world in all governorates [14-16]. Wind is another good potential for renewable energy, particularly in Oman's coastal and southern regions [17-20].

Wave energy is another undeveloped renewable energy source. Oman, with over 2000 kilometres of maritime border with the Indian Ocean, Arabian Sea and the Gulf of Oman, possesses a potential and relentless source of wave energy that calls for special attention. Sea waves are among the largest potent energy carriers in renewable energy sources since they have abundant energy resources in all geographical zones. Scientists believe that around the world, energy generated from the ocean waves can reach up to 2 Tearawatts (TW) per year. The total theoretical energy from waves equals to 8*10^6 Terawatt hours (TWh) per year, meaning it's approximately 100 times the total hydroelectric power of the entire plant [21]. Producing this electricity with fossil fuels would result in 2 million tons of CO_2 emissions. The International Energy Agency (IEA) predicts that fossil fuels contribute to around 80% of gross primary energy by 2030, assuming a 1.6% annual increase in world energy consumption [22]. Wave energy, when used in accordance with the Kyoto Protocol, can help to reduce air pollution [21]. The development of wave energy conversion has been ongoing for many years. Models and sizes of the produced technology vary which results in expensive and time-consuming operations for big and complex machinery. As we all know, wave motion is highly arbitrary. As a result, a mechanism is required to use and convert the erratic input to a consistent and steady output in the form of electricity. Wave forces are absorbed by an absorber. This absorbed energy can be transformed immediately into electricity using a Linear Permanent Magnet Generator or in stages utilizing Hydraulic and Mechanical transducers. Some factors to consider when selecting a converter include durability, longevity, efficiency and reliability [23].

Al Hallaniyat Island utilizes diesel generators for energy generation. Due to massive investments requirement, extending the grid to the Island will be uneconomical and technically very difficult [24]. The aim of this paper is to study the possibility of utilizing wave, solar and wind energy with battery storage system to replace diesel power generation. Due to their balancing nature and low carbon emissions, the combination of wave, wind and solar energy provides reliable and cost-effective options for forming a hybrid renewable energy system for power generation in the Island.

2 Existing System

2.1 Generations

Diesel generators are currently utilized to provide the energy requirement for the Island; the total capacity is around 1568 kW.

2.2 Load Profile

The monthly peak load profile for Al Hallaniyat Island for the year 2021 is presented in Figure 1 [25]. The demand during summer time is low owing to the monsoon season, the demand increases during the month of May to 485 kW and 445 kW in September.

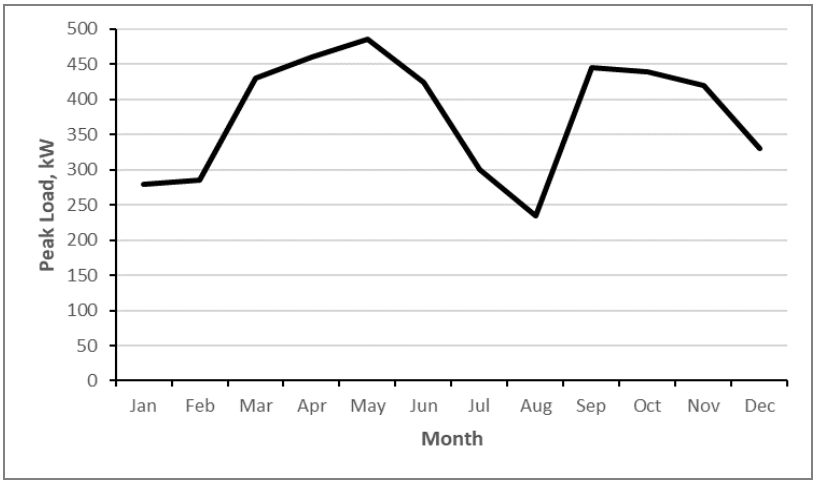

Fig. 1. Measured Monthly Peak Load at Al Hallaniyat Island, 2021

2.3 Solar Irradiance

The measured result for the solar irradiancefor the year 2022 is shown in Figure 2. The Directorate General of Meteorology, Civil Aviation Authority [26], provides these data for a site close to Al Hallaniyat Island.

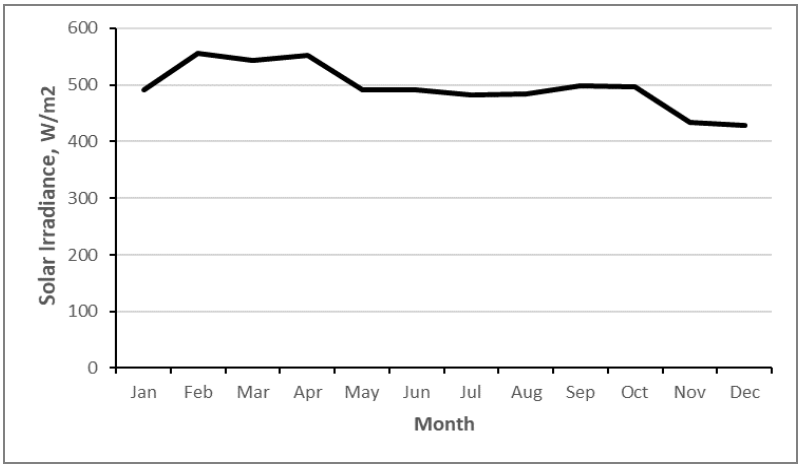

Fig. 2. Measured Monthly Average Daily Global Radiation at a Site (Shalim) Near Al Hallaniyat Island, 2022

2.4 Wind Speed

The wind speed during the monsoon season is high reaching more than 10 m/s, however the wind speed drops to around 3 m/s during wintertime as depicted in Figure 3. The wind speed was measured at 10 m anemometer height and provided by the Directorate General of Meteorology, Civil Aviation Authority [26].

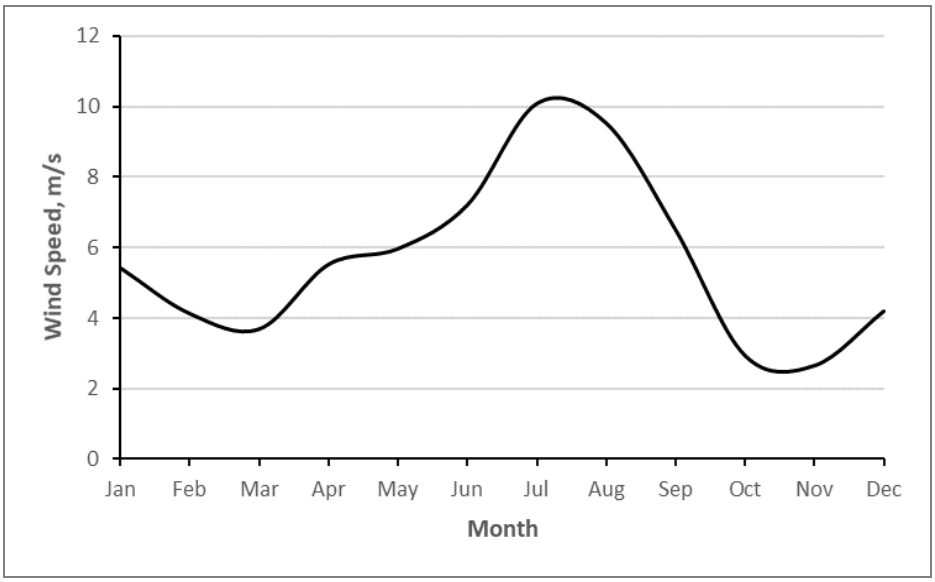

Fig. 3. Measured Monthly Average Daily Wind Speed at Al Hallaniyat Island, 2022

2.5 Wave Energy

Figure 4 represents the average monthly wave heights near Al Hallaniyat Island obtained from the Directorate General of Meteorology, Civil Aviation Authority [26]. During the monsoon season, high wind speed creates the highest wave height with high-speed wave, as indicated in Figure 5. The wave speed is calculated using equation 1 [27]:

$$\text{Wave Speed} = 1.56 * T \quad (1)$$

Where:

T is the wave period in seconds

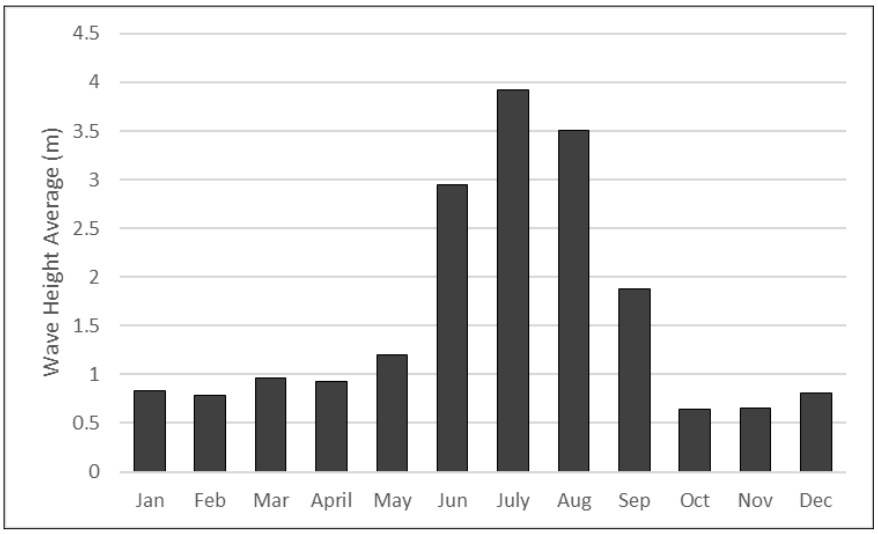

Fig. 4. The Monthly Average Wave Height Data

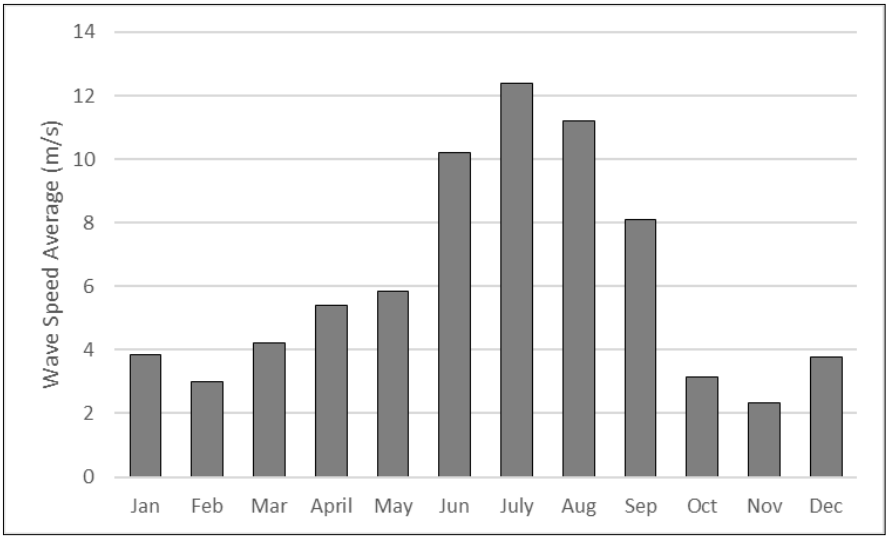

Fig. 5. The Monthly Average Wave Speed Data

The power of the wave can be calculated using the following equation 2 [28]:

$$P=H^2T \quad (2)$$

Where, H is the wave height in meter, T is the wave period in second and P is the wave power in kW/m. Figure 6 presents the monthly average power (kW/m). The peak power occurs during the period from June to September owing to the high wind speed.

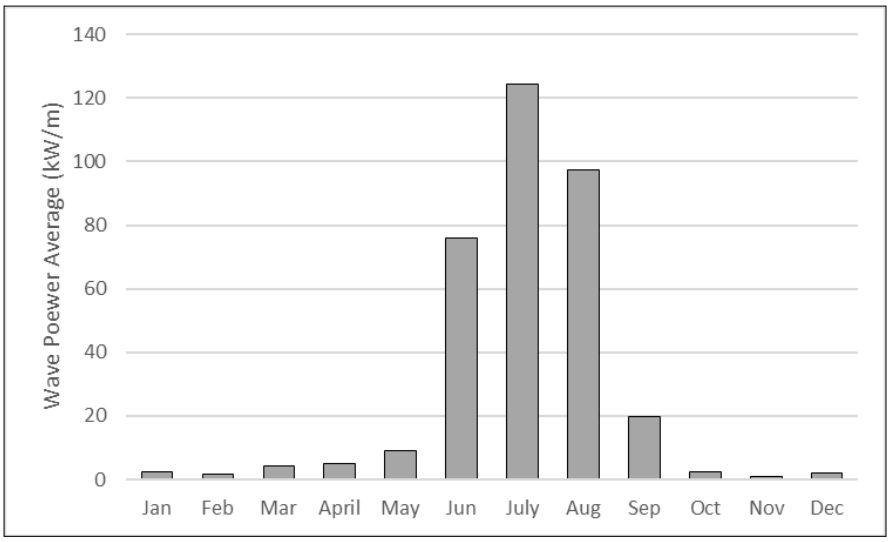

Fig. 6. The Monthly Average Power Output (kW/m) Trend Line

3 Modeling of the Proposed System Using Homer

Replacing diesel engines with renewable energy sources will reduce greenhouse gas emission. To meet the load demand from only renewable it is recommended to install a hybrid system consisting of PV, wind and wave energy converter since all of them are promising resources, and with energy storage. The schematic of the proposed hybrid system is shown in Figure 7. Solar PV generates electricity only during the day whereas wind turbines can produce energy when there is sufficient wind speed during day and night. Wave energy converter generates energy during the wave movement, which happens during the whole day. The cost and technical data for various components of the hybrid system are presented in Table 1. The whole system was modeled using HOMER Pro software [29].

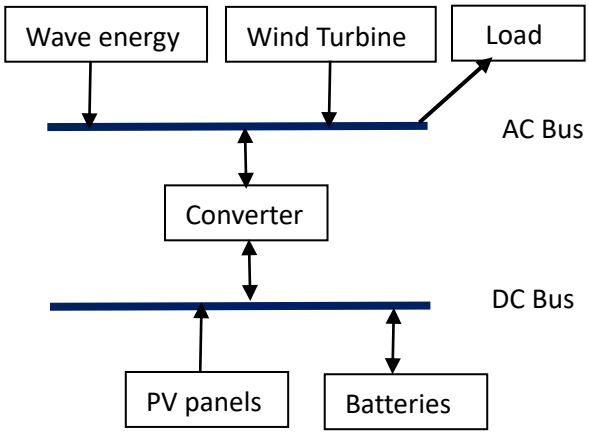

Fig. 7. Schematic Diagram of the Proposed System (PV-Wind-Wave Converter-Batteries)

Description	Data	Description	Data
PV		*Wave converter [36]*	
Capital cost	1000 US $/kW	Power rating	70 kW
Lifetime	25 years	Life time	25 years
O&M cost	10 US $/kW/year	Capital cost	6000-2200$/kW
Wind		Replacement cost	5750-2000 $/unit
Capital cost	900 US $/kW	Maintenance cost	3% of initial cost/year
Lifetime	25 years		
O&M cost	36 US $/kW/year		
Inverter			
cost	250 US $/kW		
Lifetime	15 years		
O&M	0 US $/year		
Diesel unit			
Each unit	250 US $/kW		
Diesel	0.67 US $/Liter		
Discount rate	7.55%		
Inflation rate	2%		
capacity shortage	2%		

Table 1. Cost and Technical Data for PV, Diesel Engine, Wind turbine and Inverter [30-35].

4 Discussion of Results

4.1 Existing System

Al Hallaniyat Island is fed by group of diesel generators, the schematic diagram for the existing system is presented in Figure 8. The energy production in MWh for the whole year is shown in Figure 9. The peak demand occurs in May and October, which are the hot months in the Island. The summertime represents the lowest energy demand due to moist monsoon wind blowing from the Indian Ocean towards the land.

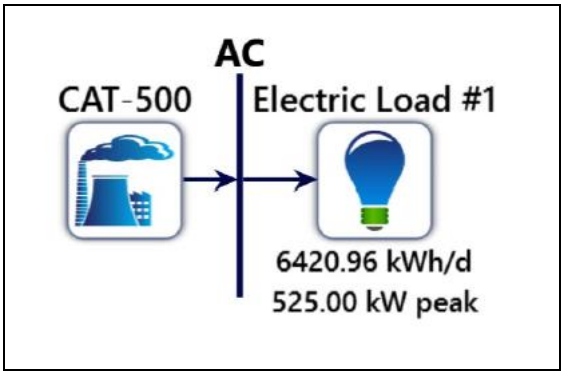

Fig. 8. Schematic Diagram for the Existing System [29]

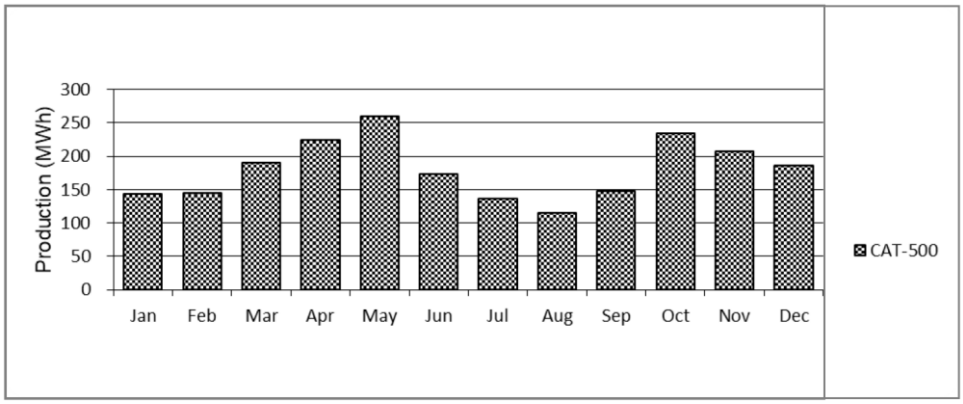

Fig. 9. The Monthly Energy Production of Al Hallaniyat Power Station

4.2 The Hybrid System

The schematic diagram for the proposed system is shown in Figure 10, which consists of a Wave energy converter, PV, Wind and storage batteries. In this system, the generation sources which are 100% renewable serve the electrical load. The Monthly Energy Production for the system is presented in Figure 11. In the proposed system, the wave energy converter, PV and Wind sources serve the electrical load with large contribution of PV. Both PV and Wind will provide energy during the whole year whereas the wave energy converter provides energy for eight months and can provide the energy for the whole day. The wave energy converter [70kW] has a total annual production of 323,792 kWh/yr. It contributes with 13.8% of energy production, has a capacity factor of 52.8% and has a levelized cost of energy of 0.209 $/kWh as shown in Table 2. Noteworthy, removing wind or PV sources from the system will increase the levelized cost of energy.

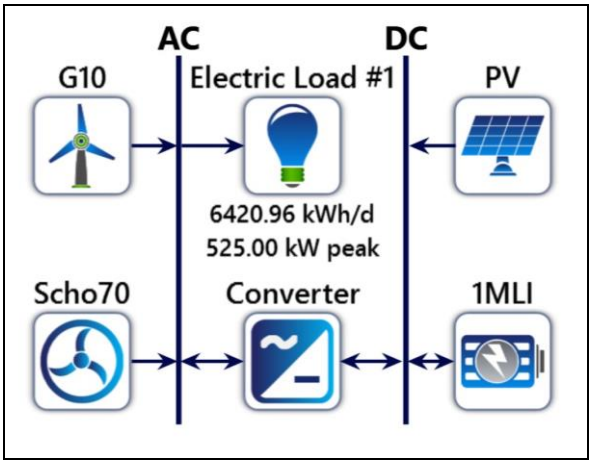

Fig.10. Schematic Diagram for Wave energy converter with PV, Wind and Batteries [29]

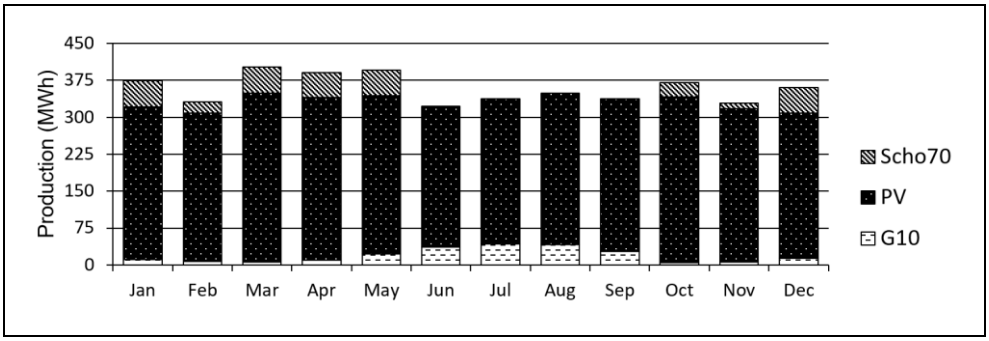

Fig. 11. The Monthly Energy Production for PV-Wind and Batteries Station

Table 2. The Wave Energy Converter Parameters

Wave Energy Converter	Value
Rated Capacity	70.0 kW
Capital Cost	$420,000
Hours of Operation	5,832 hr/yr
Levelized Cost	0.209 $/kWh
Capacity Factor	52.8 %
Total Production	323,792 kWh/yr
Maintenance Cost	12,600 $/yr
Maximum Output	70.0 kW
Hydrokinetic Penetration	13.8%

5 Conclusions

Al Hallaniyat Island is currently fed by diesel generators only, which have high operating costs as well as emission of greenhouse gases. Oman placed a target to increase renewable energy in its energy mix. The target based on Oman's vision should reach 20% by 2023. Several renewable energy large and small projects are already operating. In this paper, we propose to utilize a hybrid energy system (100% renewable) for this Island to meet the load requirement. A combination of PV, Wind, Wave energy converter and batteries are proposed. The Net Present Cost (NPC) is found to be US$ 5,010,594 and the levelized cost of energy is US$/kWh 0.1586. The proposed system cost is high owing to the capital cost of the Wave energy converter. It is expected that the cost of wave system to decline since several countries are planning to utilize this kind of energy source.

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