Permanent Magnet Synchronous Generator Based Standalone Wave Power Conversion System for Sustainable Power Supply at Perhentian Island.

Norhafizan Ahmad1*, Nahidul Hoque Samrat1, Imtiaz Ahmed Choudhury1; Zahari Taha2

1Centre for Product Design and Manufacturing (CPDM), Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
2Innovative Manufacturing, Mechatronics and Sports Laboratory (iMAMS), Faculty of Manufacturing Engineering, University Malaysia Pahang, 26600 Pekan, Pahang Malaysia.

norhafizan@um.edu.my1, sam_3e60@yahoo.com1*, imtiaz@um.edu.my1, zaharitaha@ump.edu.my2.

Keywords: Oscillating Water Column (OWC), Standalone wave energy system, Permanent magnet synchronous generator (PMSG), dc-link voltage, Island electrification.

Abstract:
In developing country like Malaysia, the development of islands is mostly related to the electric power availability. Because there are many islands in Malaysia where the power grid is not available. As an island surrounded by sea, wave energy can be considered one of the environmental friendly power generating sources for island communities. But, high dependency on weather conditions is the main drawback of wave energy source. To overcome this drawback; wave energy device, energy storage devices and the electronic converters need to be integrated with each other. This study presents a battery storage standalone oscillating water column wave energy conversion system for island electrification in Malaysia.

1. Introduction:
Energy was, is and will remain the one of the fundamental economic development foundations of any nation. In developing country like Malaysia, the development of islands are mostly related to the electric power grid is not available. Among these island communities electricity supplied by traditional energy sources but the fuel cost increase significantly with remoteness. Furthermore, the energy produced by the conventional sources raise the greenhouse gas emissions, which may be the key source of global warming. For this reason, the Malaysian government is very much concern about environmental issue and the government wants overall improvement of the greenhouse gas emission. So as an island surrounded by the sea, electric power generated by wave energy sources can be considered as an efficient and environmentally friendly power generating sources for Malaysian island electrification.

Wave energy is an environmentally friendly and fastest growing green energy source for a sustainable electrical power generation of the future. Extensive research on the idea of wave energy extraction from ocean waves has been conducted since the oil crisis in the year 1970s [1-2]. However, the first patent of wave energy extraction was recorded in the late 18th century [3]. Many wave energy conversion system’s (WECSs) have been patented and new patents are granted each month [4-5], which are based on nine basic techniques. These nine basic techniques are cavity resonators or oscillating water column, heaving and pitching bodies, pressure devices, particle motion converters, surging wave energy converters, Russell’s rectifier, Cockerell’s rafts, Salter’s duck and wave focusing techniques [5-6]. In this study, an OWC wave energy converter device is preferred because, OWC is generally considered one of the most promising wave energy conversion devices among the various wave energy converters [1-2]. Unlike others green energy resources; wave energy can produce electric power all over the year. But high dependency on weather conditions are the main drawbacks of the commercialize power generation from the wave energy conversion devices. Therefore, the wave energy conversion device (WEC) intermittently produces power which means that it may not totally satisfy the load demand at each instant. In order to eliminate the intermittent power generation nature of WECD, a locally placed small-scale energy storage standalone wave energy conversion system is proposed. This proposed standalone system, is used the DC-DC bidirectional buck-boost converter
(BBDC) controller for maintaining the constant dc-link voltage. It also accumulates the surplus power of the ocean wave in the battery bank and supplies this power to the load during the wave power shortage period. A three-phase complex vector control scheme voltage source inverter is used to control the load side voltage in terms of the frequency and voltage amplitude. Based on the simulation results obtained from MATLAB/Simulink, it has been found that the overall hybrid framework is capable for working under the variable wave and load conditions. It could be found from the analysis in reference [1-2] that Perhentian Island has an average 15.9 kW/m of wave power level. So the Perhentian Island site identified as economically viable for commercial scale wave power generation in Malaysia. Because any site in the world is able to produce wave power at competitive prices if it has an average wave power level equal or above 15 kW/m. The main aim of the propose standalone system is to establish a commercial scale standalone wave power plant in the Perhentain Island by eliminating the intermittent power generation nature of wave energy source.

2. System Description:
In this section, the detail simulation model of standalone wave power generation system briefly described. Figure 4 shows the complete configuration of the stand-alone wave energy supply system. The developed stand-alone system consists of four main parts: OWC system, battery bank, a BBDC with proportional integral (PI) control duty cycle and a plus-width-modulation (PWM) insulated-gate bipolar transistor (IGBT) inverter located at the load side. The OWC system configured by the bi-directional darrieus turbine driven permanent magnet synchronous generator (PMSG) and an AC-DC three phase rectifier.

In the stand-alone system, the renewable wave energy system is considered as a main power generation sources to meet the system load demand and battery bank is used as a backup energy storage system. The stand-alone system is proposed to implement in island areas in Malaysia; hence, if generated power from wave energy system is not enough to meet the system load demands, then battery bank will be delivered power to balance the system power demand. To interface wave and battery bank in stand-alone framework, the dc-link voltage must be constant. Hence, a BBDC with PI controller is used in the stand-alone system to maintain the constant dc-link voltage. A single-phase IGBT inverter is use at load to meet the AC load demands. The details description of each component of the overall stand-alone system and controller are given in reference [2].

Figure 4: Circuit topology of the proposed stand-alone wave energy system configuration.
3. Simulation Results and Discussion:

The simulation model of the proposed battery storage standalone wave energy supply system is built in Matlab/Simulink environment under the different operating conditions. PMSG is modeled in Matlab/simulink from the literature [7-8] and the parameters are taken from [2]. In addition, the parameters used for OWC design and darrieus turbine are also mentioned in reference [2]. In this section, the average wave height and wave period of February, March, and June months from the reference [2] is used to observe the performance of the standalone system under the variable load condition.

![Figure 8: Powers Distribution.](image1)

![Figure 9: DC link Voltage](image2)

The performance result of BBDC converter controller is presented in Figure 8 and 9. Figure 8 shows the power distribution curve of generated wave power, load power and battery bank power. From Figure 8 it shown that power from the battery bank changes (discharge/charge) to maintain the power stability of the system during the wave power and required load variation. So it could be clear from Figure 8 that when the generated wave power is more than the required load power then the controller are able to charge the battery bank, and when the required load power is more than generated wave power then controller are able to discharges the battery bank . Further, it can also be established the constant dc-link voltage at 650 V when there is a change in wave power and load demand, as shown in Figure 9. So it noted that the performance of the BBDC controller is quite satisfactory in both transient as well as steady-state of the wave power and load demand condition.
Figure 10: Output line current response with change in required load power. (a) Output load line currents throughout the full simulation time; (b) Output line current when the load increase at simulation time 3.94 s to 4.1 s.; (c) Output line current when the load decreases at simulation time 11.94 s to 12.1 s.

Figure 11: Output voltage response with change in required load power. (a) Output load voltages throughout the full simulation time; (b) Output voltage when the load increase at simulation time 3.96 s to 4.06 s.; (c) Output voltage when the load decreases at simulation time 11.97 s to 12.07 s.

From the above simulation results, it can ascertained that the proposed standalone wave energy supply system can able to meet the load demand at each instant with constant voltage and current.
4. Conclusion:

A novel stand-alone wave energy supply system with appropriate power flow controllers is designed and modelled in this paper for island users where the electric power grid is not available. The power generated by wave sources is highly dependent on environmental conditions. To overcome this, wave energy converter system integrated with the battery bank is developed. It has been seen from the simulation results that the controller can maintain the dc-link voltage at a constant value in spite of variation in generating wave power and required load power. Furthermore, the controller is developed in such way that the battery bank has been able to accumulate the excess power generated by waves. And supply it to the system load during the wave power shortage by controlling BBDC. This controller not only maintain the constant dc-link voltage but also it perform as a dc-link side active filter and reduces the generator torque oscillation of PMSG during the variation in load. The simulation results show that the performance of the proposed standalone system is satisfactory under the steady-state as well as transient waves and load power conditions. This study can be considered as the initial part for building physical prototype standalone wave energy supply system. The future work will aim to setup of a standalone wave energy supply system in the University of Malaya laboratory to verify the simulation results with experiment.

Acknowledgement:

The authors would like thanks to the KeTTHA, Ministry of Energy, Green Technology and Water (53-02-03-1102) and the Postgraduate Research Fund, University of Malaya (PG085-2013B) for providing financial support.

Reference: