COMBINED OCEAN RENEWABLE ENERGY SYSTEM (CORES) FOR ISLANDIC AREA ON MALAYSIAN SEAS

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Abstract— **The island communities in Malaysia heavily depend on diesel or combined solar-diesel power plants. High cost of diesel, difficulties of transporting diesel during the monsoon seasons, low and variable solar flux, and the high maintenance cost of solar cells and batteries are perennial issues associated with these conventional energy systems on the islands. Hence, the next resort is to rely on renewable energy from the sea. However, Malaysian coastlines have low wave heights and low current speeds, giving rise to more challenges in optimizing devices for extracting wave and tidal energy sources. This paper presents study on the development of a combined offshore energy harvesting system in Malaysia seas condition. The main objectives are to develop, construct, and test a prototype demonstrator and test platform of the Combined Ocean Renewable Energy System (CORES) for the Malaysian sea. In order to harvest large power from the ocean, CORES combines wave and current devices on the same shared floating platform. Wave and tidal energy data from the chosen site location, Pulau Tinggi, in the state of Johor, Malaysia was assessed to estimate the output power to be produced. Meanwhile, a comprehensive study was conducted to optimize the CORES concept to verify its reliability, safety, and cost-effectiveness. Numerical simulations on the behaviors of the platform and oscillating water column, point absorber, savonius current turbine and solar devices were carried out at Marine Technology Centre at Universiti Teknologi Malaysia. Finally, a full scale prototype was built and deployed near an island in the South China Sea. The findings in this research are expected to bring significant reference towards more reliable large-scale ocean energy systems for the welfare of island communities in the tropical regions.**

Keywords— **Ocean Renewable Energy (ORE); Wave Energy; Tidal Energy; Oscillating Water Column (OWC); Point Absorber; Savonius turbine.**

I. INTRODUCTION

The electrical power generation in Malaysia is dominated by non-renewable energy resources such as oil, natural gas and coal [1]. Conventional electricity generation produces carbon dioxide that is released to the atmosphere, which contributes to greenhouse effects and global warming.

On another front, the island communities in Malaysia are lagging in development. For power, they depend mostly on diesel or combined solar-diesel power plants. Providing electrical power to the small island communities incur higher cost due to difficulties of transporting diesel during the monsoon seasons. Thus, ocean renewable energy (ORE) should be a better solution. The development of an ORE system can help small island community to source their energy from ocean, specifically from waves and currents from around them.

Since the wave and tidal current in Malaysian seas are rather small individually, a combined system plant that shares the same semi-submersible platform is the most practical solution. According to [2], the systems developed in Europe, Australia and North Asia are all single device, extracting only wave or current energy because the wave and current energy resources are high.

In Malaysia, the resources are small, thus a combined system will be the optimum solution to the low wave and tidal current of ocean energy. The combined system is new to ORE and will be the first attempt to combine more than one energy source-generation in one platform. This paper presents work undertaken at Universiti Teknologi Malaysia to develop a combined energy system that consists of ocean waves and tidal current energy devices. This prototype Combined Ocean Renewable Energy system (CORES) integrates all proven concepts of wave and tidal current devices, as well as solar photo-voltaic cells. The CORES platform was designed at Universiti Teknologi Malaysia and installed on Pulau Tinggi, off the east coast of Peninsular Malaysia.

II. Ocean Energy Devices

Previous work at Universiti Teknologi Malaysia (UTM) consists of development of standalone laboratory scale ocean wave and tidal current devices. Improvements had been made on the devices to suit low resource conditions in Malaysian seas. The devices were designed according to local conditions. The developments have been reported by [3]–[8]. Oscillating Water Collumn (OWC) and point absorber devices were developed for wave energy extraction, while for tidal current, vertical axis Savonius turbine was developed, taking into consideration the low current speed and shallow water.

Based on previous research on these two wave energy convertor (WEC) devices and vertical axis marine current turbine (VAMCT), the working models of the devices had been constructed, and their performances had been tested at the Marine Technology Centre, UTM. The point absorber consists of three components of buoy, power take off unit (linear permanent magnet generator) and foundation (mooring). The most important characteristic of the buoy is to have a high heave response amplitude operator (RAO) so that maximum amount of energy can be harnessed. For extracting the tidal current energy, Savonius turbine was chosen, as it has a good starting capability by a low current speed experienced in Malaysian seas. To improve their efficiency, some improvements had been made, such as integration of a deflector, which later was incorporated in the turbine frame structure. These models were tested in the Marine Technology (MTC) laboratory, UTM. Tests had shown a positive results regarding on the power produced.

The Combine Ocean Renewable Energy System (CORES) is an integrated system which combines several potential renewable energy devices to generate clean energy from the ocean. The development of this project started with the assessment of the previous proven design performance. In order to scale up the device into prototype scale, some numerical works and additional moel testing had been carried out in the laboratory. A floating structure was built to integrate all the devices into one system. Three ocean energy devices were built to harness this potential ocean energy, consisting of OWC, point absorber and Savonius tidal turbine, which were expected to produce 300W of power combined through 100W generator, respectively. In order to be able to produce the expected CORES power, Hybrid Ocean-Photovoltaic system had been introduced for the power configuration of the platform.

A. *CORES Floating Platform*

A floating structure to hold all these devices was constructed using PVC floating pontoon building blocks. The pontoons were held in place by a steel stainless steel grade 304 frame structure, as shown in Fig. 1. The wave energy devices were placed at the corners of the platform, while the Savonius tidal turbine was installed at the center of the platform, and the solar panels were installed on one side of the platform.

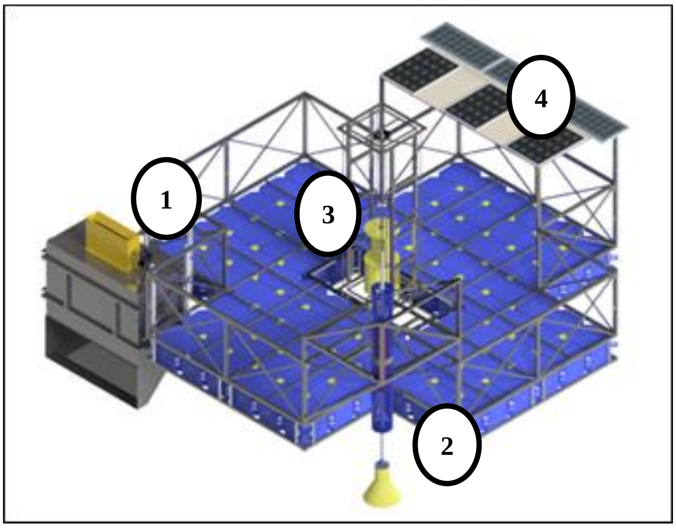


Fig. 1 CORES Platform - (1) OWC Device; (2) Point Absorber; (3) Savonius tidal turbine; (4) Solar panel

1) Structural Analysis of CORES Platform: The structural analysis of the platform was done by using the Solidworks software. The aim was to assess the strength of the floating platform. All devices weights were assumed to be point forces acting on the platform. Eight mooring lines were used to hold the floating platform at it places. The platform was supposed to maintain its draft around 0.1m. Summary of the main dimensions of the platform and associated masses are shown in Table I.

TABLE I
MAIN PARAMETERS OF CORES PLATFORM AND ASSOCIATED MASSES

Items	Values
Length	7.0 meter
Breadth	6.1 meter
Depth of the platform	4.89 meter
Draft	0.1 meter
Floating Platform (Body Mass)	1780.60 kg /17467.69 N
OWC	200.00 kg /1962.00 N
Point Absorber	60.00 kg /588.60 N
Savonius Turbine	60.00 kg/588.60 N
Mooring Line	30.00 kg /294.30 N (each)

The analysis on the structural part revealed that the critical parts for the floating platform were at the beams that held the outer frame of the cage to the center. The maximum displacement for the beam was estimated around 13mm. The result for the structural analysis is shown in Fig. 2.

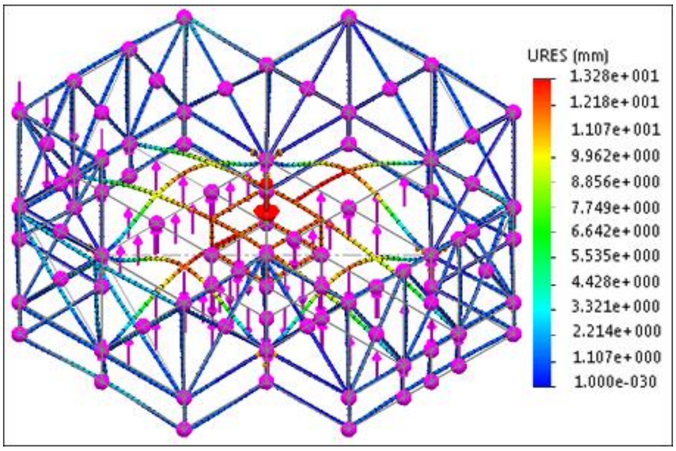


Fig. 2 Deformation of CORES Platform by using Solidworks

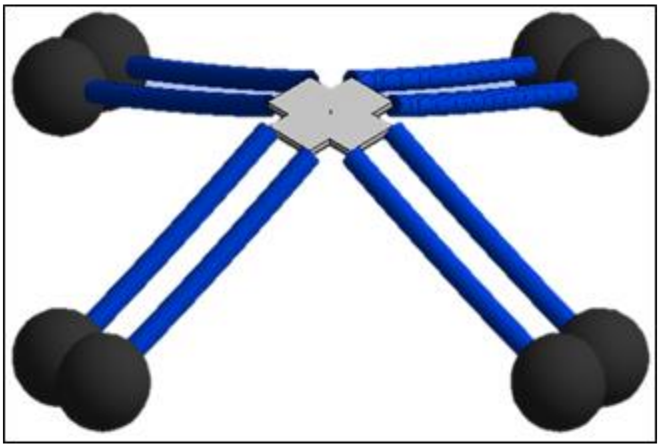


Fig. 3 Selected mooring chain configuration

2) Motion Analysis of CORES Platform: The motion analysis of the platform was carried out by using ANSYS Aqwa. This analysis can give predicted motion of the platform when it is deployed in real sea condition. The analysis on the data of wave around Pulau Tinggi, Mersing showed that the input wave amplitude and period for this analysis were 0.5m and 5s-6s, respectively. Several configurations for the mooring chain attachments had been suggested before choosing the best. Each mooring chain had a length of 15m with mass of 4.97kg/m. Data of the mooring chains are shown in Table II below.

TABLE II
PROPERTIES OF MOORING CHAIN BASED ON SUPPLIER

1	**Mass/Length**	4.97 kg/m (303kg/200ft)
2	**Equivalent Cross Sectional Area**	0.0004021 m^2
3	**Stiffness, EA**	8042000 N
4	**Maximum Tension**	98100 N
5	**Equivalent Diameter**	0.032 m (0.016 m x 2)
6	**Longitudinal Drag Coefficient**	0.025

The results from this simulation showed that the configuration with two mooring chains at each side of the platform gave smaller motion in all directions compared to other configurations. This can give extra safety to the platform in case one of the mooring chains corrodes and breaks. The maximum motion in x, y and z directions were around 0.22m, 0.1m and 0.2m, respectively. Fig. 3 and Fig. 4 show the configuration of the mooring chains to the floating platform, and motions of the platform in all directions.

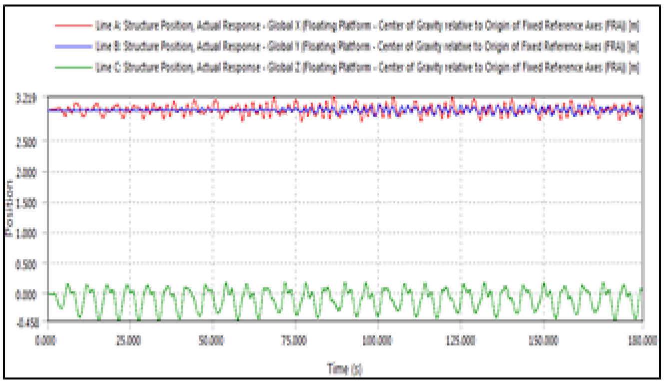


Fig. 4 Motion of CORES Platform by ANSYS Aqwa simulation

B. Oscillating Water Column(OWC)

Oscillating Water Column (OWC) was one of the energy devices installed on the starboard of the platform (Fig. 5).

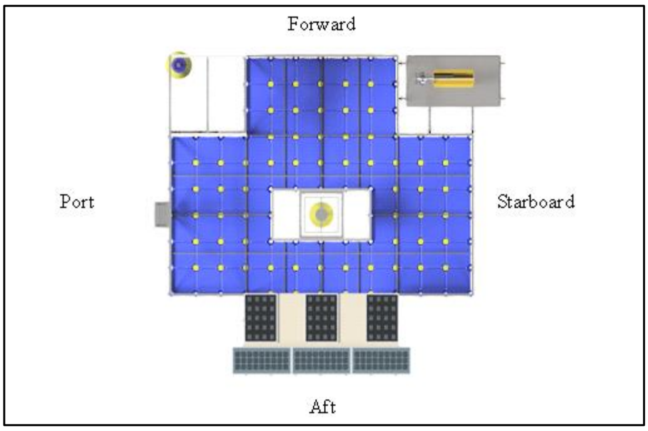


Fig. 5 Top View - OWC Installation Position on the CORES Platform

The OWC system installed on CORES platform consists of three parts, which are the OWC chamber, the turbine system and the generator unit (Figs. 6 and 7).

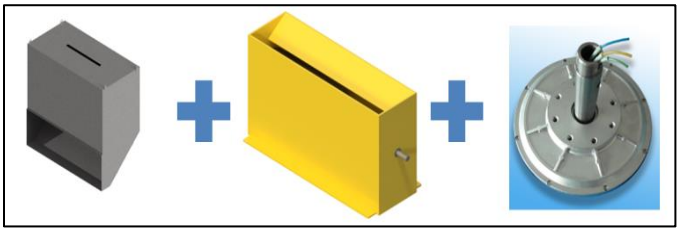


Fig. 6 Fragment of OWC component (From left: OWC Chamber, in the middle turbine system and low speed generator unit at the right)

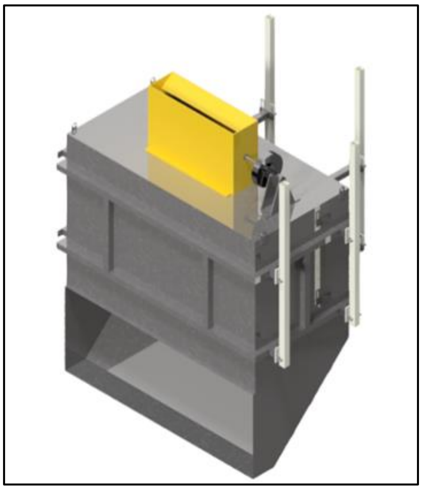


Fig. 7 Full OWC System Assembly

The OWC chamber was built from Stainless Steel 304 of 1mm thickness, and strengthened by 50mm x 50mm with 1mm thickness supporter beam (Fig. 8). The support beam was tack welded with OWC chamber to give a strong support for the whole system weight and as connection bridge between the OWC and the platform.

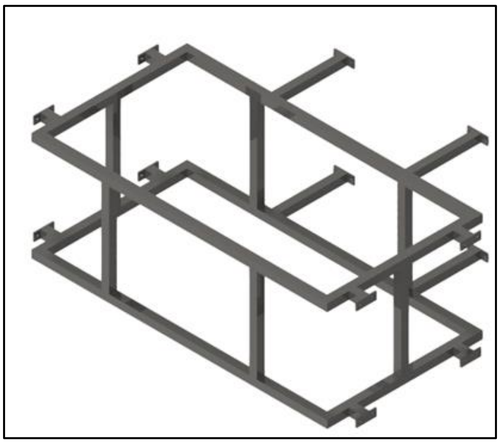


Fig. 8 OWC Supporter Beam

The turbine used for extracting air (wind) energy from chamber was a drag type. The two-stage Savonius turbine was used to capture the wind energy (Fig. 9). The turbine was coupled with a turbine holder to allow air pass through from the orifice and come out from turbine unit.

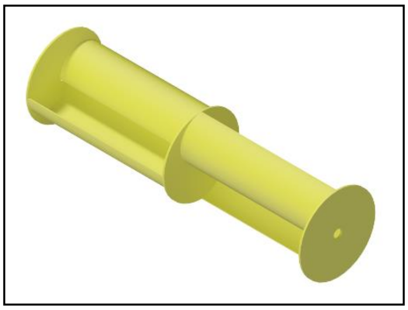


Fig. 9 Savonius two stage unit

The turbine holder (Fig. 10) was designed to allow the Savonius turbine to rotate efficiently in one direction, even if air fluctuated in and out from the orifice.

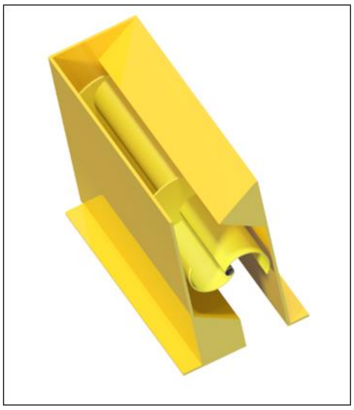


Fig. 10 Cross section view of turbine holder with savonius turbine

The Savonius turbine was coupled with low rpm generator (Fig. 11) with rated power of 100W at 130RPM.

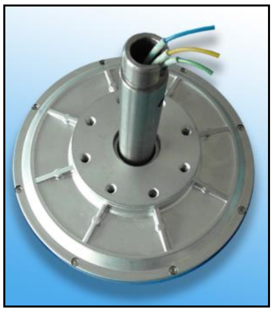


Fig. 11 Low RPM Generator

1) OWC Chamber Development: The OWC chamber characteristics were developed by using computational fluid dynamic method. ANSYS CFX with 292,878 elements was used to obtain the optimum geometric sizing and shape. The optimum geometric sizing and shape were determined according to OWC efficiency formula as given in Eq. 1 [9].

$$\eta_{owc} = \frac{P_{air}}{P_{inc}} \times 100\% \qquad (1)$$

The power produce by air (Eq. 2 [9]) is equal to energy produced by air (E_{air}) per second (T).

$$\boldsymbol{Power\ produced\ by\ air,\ P_{air} = \frac{E_{air}}{T}} \qquad \textbf{(2)}$$

The energy of air was obtained by using Eq. 3 [9]. The instantaneous air pressure *p(t)* in Pascal (Pa) at the orifice of the chamber was measured using a manometer, while the air velocity in meter per second was measured by using anemometer.

$$\boldsymbol{Energy\ produced\ by\ air,\ E_{air} = \int_0^T p(t)q(t)dt} \qquad \textbf{(3)}$$

The power of the incident wave was calculated by multiplying the wave energy (E) and wave group celerity (C_g) as in Eq. 4 [9].

$$\boldsymbol{P_{inc} = EC_g(Wm^{-1})} \qquad \textbf{(4)}$$

The wave energy expression is given by Eq. 5 [9] where ρ is water density, g is gravitational force and a_0 is the amplitude of the incident wave.

$$\boldsymbol{Wave\ Energy, E = \frac{1}{2}\rho g a_0{}^2} \qquad \textbf{(5)}$$

The wave group velocity (Eq. 6 [9]) considers the average water depth (h) and the wave number (k).

$$\boldsymbol{C_g = \frac{d\omega}{dk} = \frac{c}{2}\left[1 + \frac{2kh}{\sin 2\,kh}\right]} \qquad \textbf{(6)}$$

The main dimension of OWC was obtained by simulation. Its draft was 0.3m based on JAMSTEC guideline for designing OWC's curtain wall [10] and the optimum opening mouth was 0.7m, while the best angle for the reflector is 45° [3]. The final dimensions are shown in Fig.12

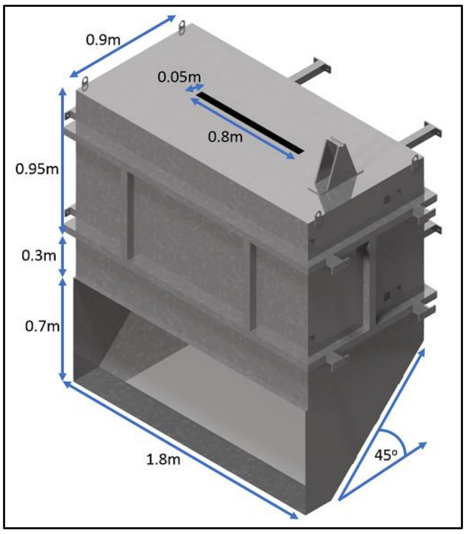


Fig. 12 Dimension for OWC

C. Point Absorber

A point absorber is capable of absorbing energy and possesses a large potential capture width [11]. The overall efficiency and power of the point absorber can be optimized when the natural frequency of the device correspond to the incident wave period [12]–[13] due to its enhanced amplitude [14]–[15].

Direct drive linear generator point absorber is an energy conversion device that extracts energy in heave direction only. It has two main parts, buoy and generator. The buoy acts as a hydrodynamic interaction body, where it will capture wave energy based on the incident waves, while the linear generator restricts the remaining movements. Linear generator is a power take-off that converts mechanical energy into electrical energy (Fig. 13). The main component of a linear generator is the moving part of stator, which contains winding of conductors or armature windings and translator, where permanent magnet is mounted.

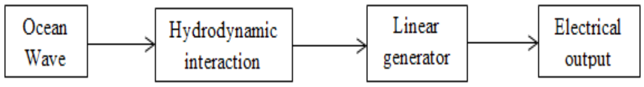


Fig. 13 Wave motion to electrical generation

For this study, the translator was assembled with supporting structure on the floating platform. The supporting structure functioned to ensure that the linear generator would be held tightly and to restrict the buoy to move in heave direction only (Fig.14).

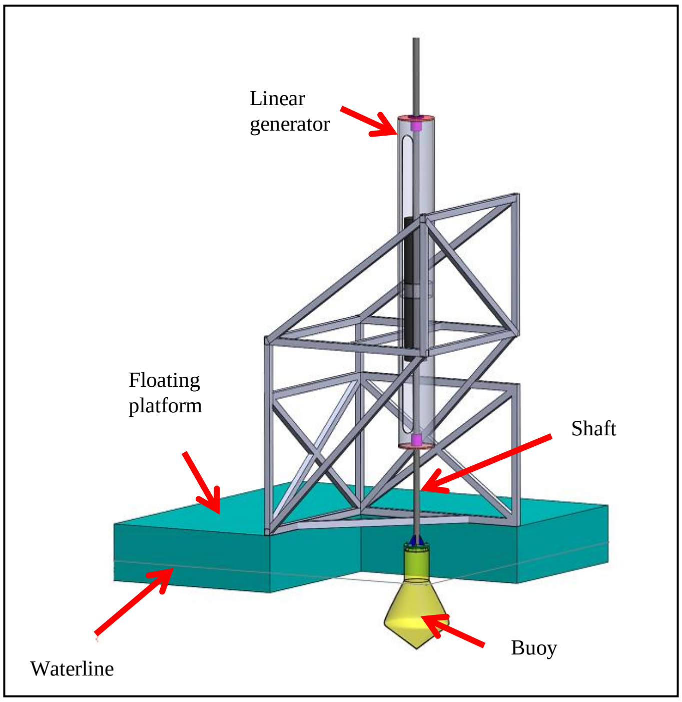


Fig. 14 Point absorber system assembled with supporting structure

D. *Savonius turbine*

The tidal current turbine was based on the Savonius vertical axis turbine designed to operate at the Malaysian average tidal current speed of 0.5m/s.

Computational Fluid Dynamic (CFD) analysis was used to find the best configuration of the turbine. The process of optimising the turbine dimensions have been described in [4]–[7].

Turbine performance was assessed using Eq. 7 [4] where *As* is the swept area obtained from the product of Savonius rotor with height *H* and diameter *D*.

$$\boldsymbol{C_p = \frac{P}{\frac{1}{2}\rho A_s U^3}} \tag{7}$$

The main dimensions of the two-stage Savonius turbine are shown in Table III.

TABLE III
MAIN DIMENSIONS OF THE PROTOTYPE

No	Specification	Value
1	Height of rotor, H_p	0.7 m
2	Diameter of rotor, D_p	0.35 m
3	Aspect ratio, α	3.5
4	Overlap ratio, β	0.21
5	Nominal speed, V_p	0.56 m/s

Past research has shown that simple rectangular plate placed upon the incoming flow of the water to Savonius rotor can increase its performance. Thus, the use of deflector in this current project was improvised by having the holding structure of the turbine surrounding it to act as a small deflectors, as in Fig. 15.

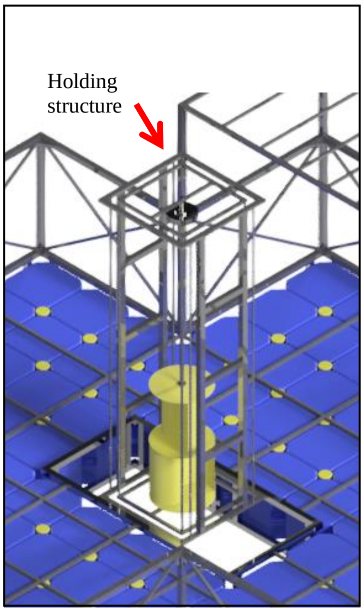
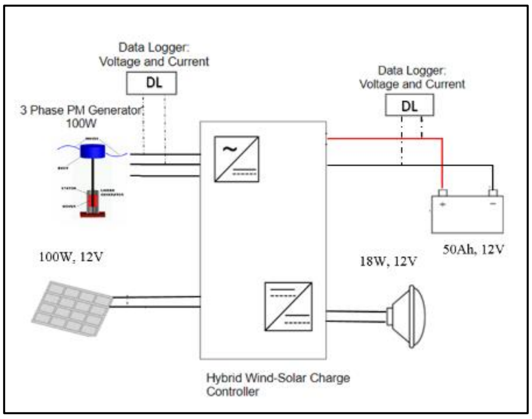


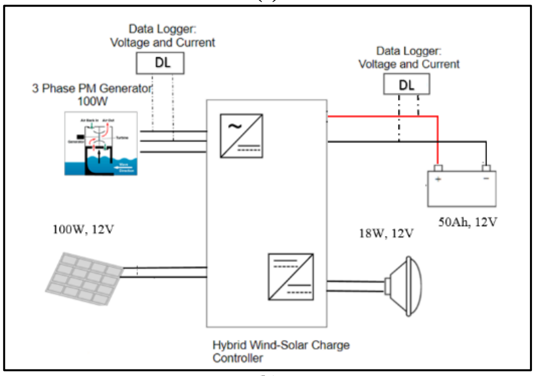
Fig. 15 Two-stage Savonius turbine with holding structure acting as the added deflector to the turbine system

III. CORES POWER GENERATION SYSTEM

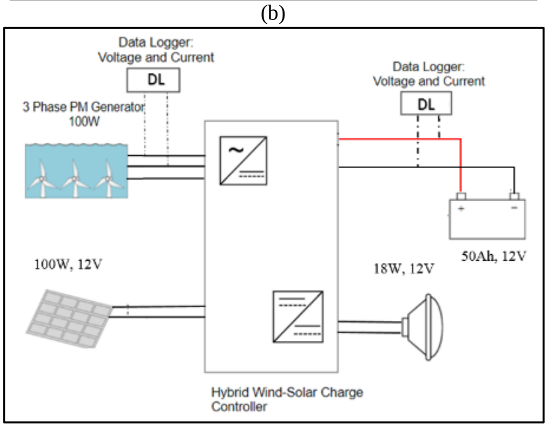
The power generation system required in developing the CORES platform is called the Hybrid Ocean-Photovoltaic System. Three units of photovoltaic (PV) were used to hybrid with Oscillating Water Column (OWC), Point Absorber, and Savonius turbine independently. The purpose of the independence was to investigate which ocean energy device would be able to provide the best hybrid system based on Malaysian ocean conditions. In addition, each hybrid system was supported by an acid lead battery, which acted as a storage element. This CORES system was designed as 12V system voltage with 3 autonomy days of supply. Fig. 16 (a), (b) and (c) show the configuration of the installed system for OWC, Point Absorber, and Savonius turbine, respectively.



(a)



(b)



(c)

Fig. 16 System configuration for CORES Hybrid Ocean-Photovoltaic System

In addition, this system was integrated with data monitoring using Internet of Things (IoT). The voltage generated from OWC, Point Absorber, and Savonius turbine, as well as the current from to/from battery, were collected via IoT platform as shown in Fig. 17. The platform was divided into three main parts: 1) In Situ Data Logger, 2) Cloud Database and 3) Web Application. In the first part, voltage and current data were collected every one second and kept on board. Every one minute, the maximum recorded data would be transmitted to the cloud database server, which could be accessed via the Web Application developed; meaning that the data can be accessed from any device connected to the internet via its browser.

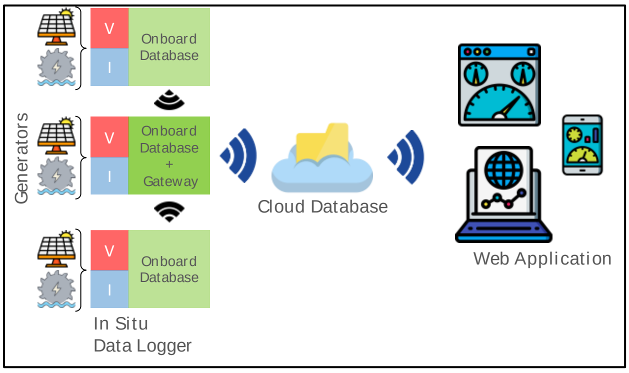


Fig. 17 The IoT platform for data collection and dissemination

IV. CORES Device and Platform Construction

As mentioned in previous section, the CORES platform including the devices holder and OWC devices were fabricated using stainless steel grade 304. The point absorber buoy and Savonius current turbine were constructed from fibre reinforced plastics. The selection was mainly because of the ease of construction and cost effectiveness. Fig. 18 to 23 show the construction process of the CORES devices and platform.

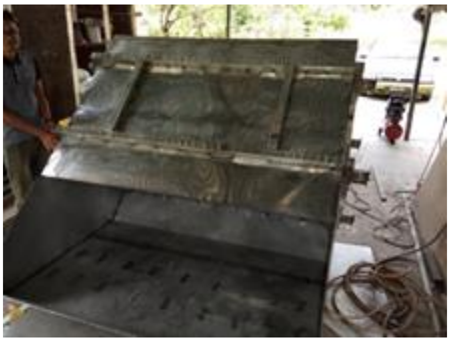


Fig. 18 OWC construction with supporting structure

Fig. 19 OWC turbine construction with shaft

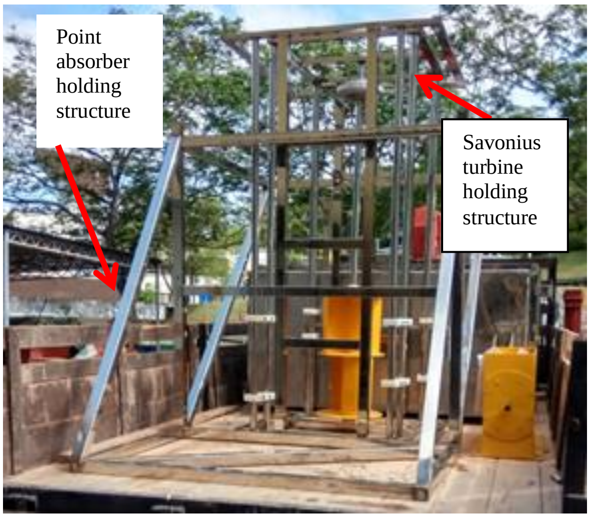


Fig. 20 Point absorber and tidal current turbine holding structure

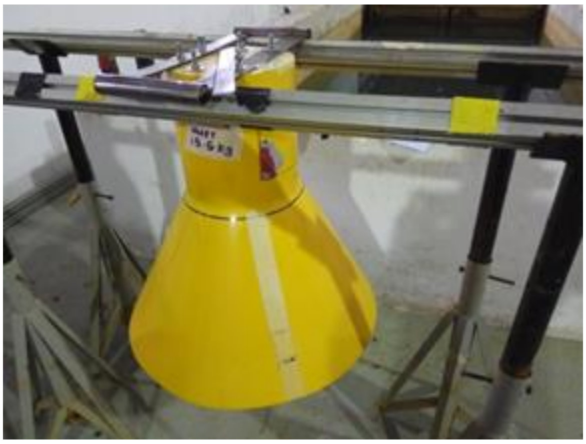


Fig. 21 Point absorber buoy construction and balancing

Fig. 22 Savonius tidal current turbine after construction

Fig. 23 Platform construction with HDPE buoy installation

V. CORES Device Prototype Demonstrator

All three devices were first tested in the Marine Technology Laboratory before final integration and deployment. The demonstration proved that the device functioned successfully. Fig. 24 shows the setup for OWC demonstrator. Some issues regarding the OWC installation had been identified, including the requirement of tight seal between the turbine unit and chamber, and installation of mechanical turbine bearing to reduced stress on the shaft (turbine shaft generator alignment).

Fig. 24 OWC demonstrator with turbine–generator system

The point absorber buoy, as shown in Fig. 25, used in this system was first ballasted and balanced as shown in Fig. 21. Wave height from 0.04m to 0.1m corresponding to 1.4s to 2.3s wave period were applied during the demonstration. Some important points were taken during this demonstration, such as alignment and bearing issue. Since the point absorber was connected directly to the linear generator, the alignment issue had been critically solved.

Fig. 25 Point absorber demonstrator

Tidal current device was successfully demonstrated by the attachment at the front of the towing carriage (Fig. 26). Once the device was attached, the carriage towed the turbine under certain speed. Since the size of the towing tank was large enough to fit the turbine with the design holding structure, it was the only device that demonstrated with the prototype holding structure. Savonius turbine was operated at several speeds ranging from 0.35m/s to 0.75m/s, corresponding to the real condition of the tidal current of the area of interest. Savonius turbine able to rotate at all designated current speed. The same issue as faced by previous two ocean WEC that needed to be solved first during the demonstration was the shaft alignment issue with the turbine and generator. All demonstrations were completed within 3 months.

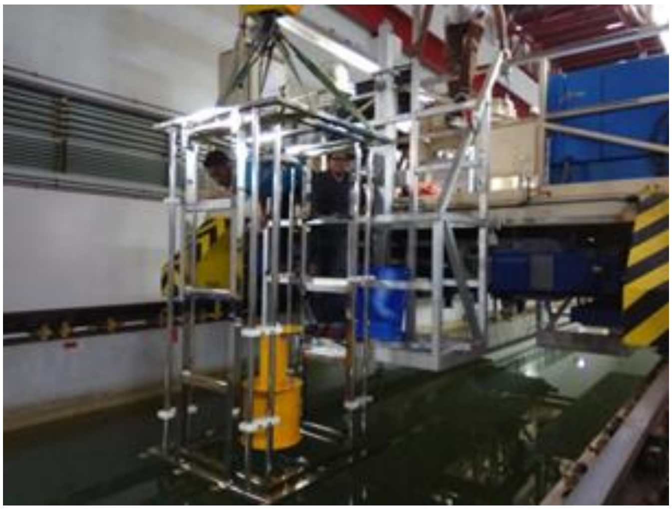


Fig. 26 Savonius tidal current turbine demonstrator

Fig. 28 Anchor for CORES platform mooring

VI. CORES Device Prototype Sea Deployment

Fig. 27 shows the exact location of deployment of the CORES platform and its devices on Pulau Tinggi, an island off the east coast of Peninsular Malaysia.

Fig. 27 Pin point location of CORES Platform

All three devices with their respective holding structure had been transported to the island, then installed with the platform into one unit. Installation work took around two weeks before sea deployment was made. Installation involved welding works between the devices holder with platform, loading and unloading devices, mooring chain location determination (Fig. 28) and other related work. Underwater job was required as well for OWC mounting process.

Fig. 29 CORES Power Generation of Hybrid Ocean–Photovoltaic System installation

Fig. 30 shows the CORES integrated ocean energy system (Savonius turbine was fully submerged underwater as in Fig. 30). Testing and commissioning processes were still on-going.

Fig. 30 CORES Platform sea deployment

Fig. 31 Savonius turbine underwater

VII. CONCLUSIONS

The CORES project has been successfully operated by sea deployment. The devices and platform have been intensively studied before the prototype construction processes were carried out. At each design stage, issues or problems were identified and solved. Prototype laboratory testing eases the sea deployment process by detection of several issues as mentioned in section VI. Though the deployment process has its own challenges, they have been successfully handled. To date, the device has not yet finished the commissioning stage. Maintenance work from time to time is essential in order to make sure the devices are working and actively producing power.

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