Analysis of the Power Extraction for the Wave Energy Converter

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Abstract: *The goal of the system is to investigate the power extraction for the Wave Energy Converter (WEC) concept. The ideal case studied incoming waves are presented by input data. The WEC concept is based on a point absorber designed with a mechanical direct drive Power Take-Off (PTO). The present study shows that using a buoy for conventional point absorber principle is much efficient than any other device proposed till today in small scale wave tank. Two alternate configurations for harvesting power from waves are proposed. In the first configuration, the simulation results for power extraction in this system are described when the simulation time is 30s. In the second configuration, the experimental set up and results at the Water Park, Kan Taw Gyi in Mandalay for power extraction are investigated in wave height (15cm) and wave period (4s). According to the simulation results, the DC voltage is 15V and the DC output power is 22.5W when the ideal cased studied is wave height 15cm and wave period 4sec. In experimental test, the DC voltage is 9.8V and the DC output power is 20W. Comparing the experimental and simulation results, experimental results show lower absolute absorption power than the simulation results.*

Key Words: *Mechanical Direct Drive System, Power Take Off, Rotating Machine, Wave Energy Converter, Wave Energy*

1. INTRODUCTION:

Oil crisis in recent years forced people to explore alternate resources of renewable energy, raising the interest in large-scale power generation from ocean waves. Power available from wave energy is considerably high which is represented as higher potential energy in heave degree-of-freedom [8]. Wave energy shows salient advantages namely: i) time required for research and development is shortened by the proven re-engineering technologies of offshore oil and gas, wind power and shipbuilding industries; ii) wave power is predictable and dependable with the ability to accurately forecast the wave power spectrum, days in advance; iii) environmentally benign and non-polluting; and iv) minimum visual impact [4,6]. Different technologies attempted in harnessing wave energy in the recent past did not succeed to commercial models [2,3,8]; however, amongst those proposed, point absorbers are popular due to their reduce complexities as they are designed to utilize heave motion of floating bodies for harnessing wave energy. Critical factors namely: i) reliability under extreme sea states; ii) capability to connect in arrays; and iii) easy maintenance cost makes them a viable concept [7]. Although wave surging gives maximum energy, complexities in wave characteristics in actual sea state impose severe constraints to these devices under operation. Alternatively other parallel technologies involving application of turbine requires uniform flow of high pressure fluid to maintain the conversion at maximum efficiency. In addition, hydraulic and pneumatic power takeoff systems require precision machining and high maintenance cost. Such devices shall also suffer from variable tide and other wave conditions. Derived from the advantages of existing technologies, present study proposes a wave energy converter (WEC) that employs point absorber as wave energy capturing device [9].

In this system, WEC is direct mechanical drive system, semi-submerged point absorber and is tested by artificial waves at the Water Park, Kan Taw Gyi in Mandalay. The wave energy is carried out from the movement of a floating buoy. The buoy is connected to the shaft and pinion which is to convert transitional motion. This is connected to directional free wheels which rectifies rotational motion. And then, energy is stored the flywheel which is connected to the moving part of the generator. When the buoy moves with the waves, the permanent magnetized rotor gets rotary motion in the generator and a voltage is induced in the stator winding. Since the motion of the rotor is correlated with the wave motion, the voltage produced by the wave energy converter has a regular amplitude and frequency and has to be converted before it connected to the load. For an analysis of the electrical sub system system, the modeling of the rotating machine and rectified system was proceeded. The purpose of this research is to investigate the power extraction by simulation and experimental testing for ideal case studied. The model has been constructed in MATLAB-Simulink, which is a common used simulation program for electrical systems.

2. PROPOSED WAVE ENERGY CONVERTER:

Fig. 2.1 shows the overall assembly of proposed Wave Energy Converter (WEC). It consists of a floating buoy with chain drive arrangement employed for converting reciprocating (vertical) motion into oscillatory (rotary) motion. While the floating buoy is connected to the shaft (2), vertical shaft is assembled with the gear to protect the floating buoy from encountered waves. Driving sprockets mounted on this shaft is supported by ball bearings; secured pinion gears are subsequently connected to free-wheel sprocket. Overall assembly of WEC is fixed on a platform. As the approaching wave moves the floating buoy upwards, toothed on the shaft, attached to buoy rotates the pinion gear (3) clockwise while the other pinion gear (4) rotates anti-clockwise. This is due to the free wheel sprocket that prevents interference with rotation of pinion gear (3). On the other hand, for the waves moving floating buoy downwards, toothed gear rack attached to buoy rotates the pinion gear (3) anti-clockwise while the pinion gear (4) rotates clockwise due to free wheel sprocket (7). Power transmission is through pinion gear (3) in the upward motion while it is through pinion gear (4) in the downward motion; that is connected to shaft of electric generator. The dimensions of the buoy can be found in Table 2.1.

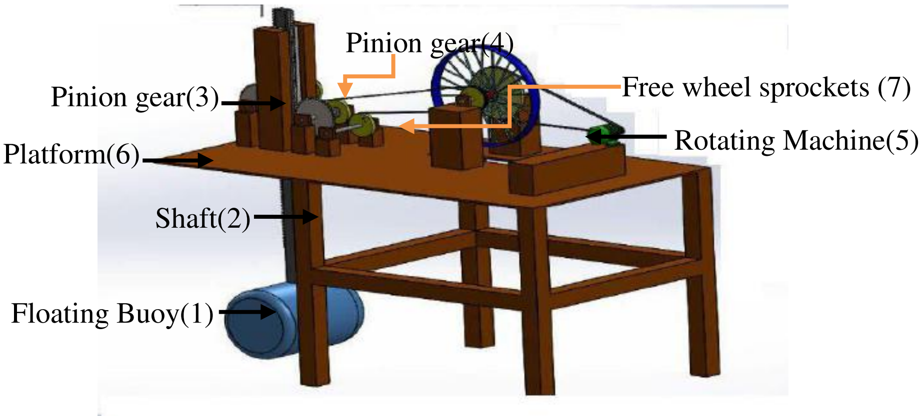


Figure 2.1. Proposed Wave Energy Converter

Table 2.1. DESIGN PARAMETERS OF THE BUOY

Description	Design parameters
Diameter of buoy	26 cm
Height of buoy	36 cm
Mass of buoy plus chain	6kg
Density of water	1000 kg/m^3
Wave conditions at Water Park	15 cm, 4s

The device under investigation in this study is the Wave Energy Converter developed. This prototype has been tested and used in operation outside at the Water Park, Kan Taw Gyi in Mandalay. The idea was to make a simple, light and cost-effective device.

3. DESIGN OF A WAVE ENERGY CONVERTER :

The proposed wave energy converter consists of two sub systems, mechanical sub system and electrical sub system.

3.1 Design for Chain Drive for Mechanical Sub System

The simple roller chain is chosen for design of chain drive. This type of chain is very simple, low cost. It is suitable for low speed and power. An open chain drive system connecting the two sprockets is shown in Fig. 3.1. Design data for chain drive are computed on the basis of the following;

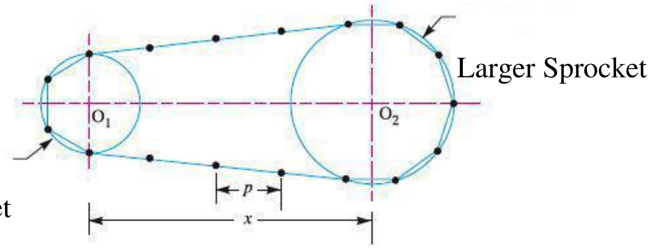


Figure 3.1. Length of chain [1]

The velocity ratio of a chain drive is

$$V.R = \frac{N_2}{N_3} = \frac{T_3}{T_2} \tag{1}$$

Where, N_2 = Speed of rotation of smaller sprocket in r.p.m., N_3 = Speed of rotation of larger sprocket in r.p.m., T_2 = Number of teeth on the smaller sprocket, and T_3 = Number of teeth on the larger sprocket.

The average velocity of the chain is

$$v = \frac{\pi DN}{60} \quad (2)$$

Where D = Pitch circle diameter of the sprocket in metres, and p = Pitch of the chain in metres.

The length of the chain (L) must be equal to the product of the number of chain links (k) and the pitch of the chain (p). Mathematically,

$$L = k \times p \quad (3)$$

The number of chain links may be obtained from the following expression,

$$k = \frac{T_3 - T_2}{2} + \frac{2x}{p} + \left[\frac{T_3 - T_2}{2\pi}\right]^2 \frac{p}{x} \quad (4)$$

The value of K as obtained from the above expression must be approximated to the nearest even number.

Pitch circle diameter for small sprocket D_3,

$$d_3 = p \operatorname{cosec}\left(\frac{180}{T_3}\right) \quad (5)$$

$$D_3 = d_3 + 1.25p - d_1 \quad (6)$$

Pitch circle diameter for large sprocket D_2,

$$d_2 = p \operatorname{cosec}\left(\frac{180}{T_2}\right) \quad (7)$$

$$D_2 = d_2 + 1.25p - d_1 \quad (8)$$

Calculated data from the above equations are described in Table 3.1.

Table 3.1. GEOMETRIC CHARACTERISTICS OF THE CHAIN DRIVE

Description	Geometric parameters
Pitch, p	12.7 mm
Roller diameter, d_1	8.51 mm
Width between inner plates	7.75 mm
Diameter of small sprocket, D_3	73 mm
Diameter of larger sprocket, D_2	80 mm
No. of teeth on smaller, T_3 and larger sprockets, T_2	(16, 18)

3.2. Electrical sub system

As shown in Fig. 3, the electrical sub system mainly consists of the rectification and filtering circuit, the voltage regulator circuit, and the charge controller. The alternating current is transformed to direct current by the rectification and filtering circuit. The direct current power source is then regulated by the voltage regulator. The regulated direct current power source is then stored in a battery, and provides power for equipments at the same time. This will ensure the generator to produce power even at circumstances of relatively small wave.

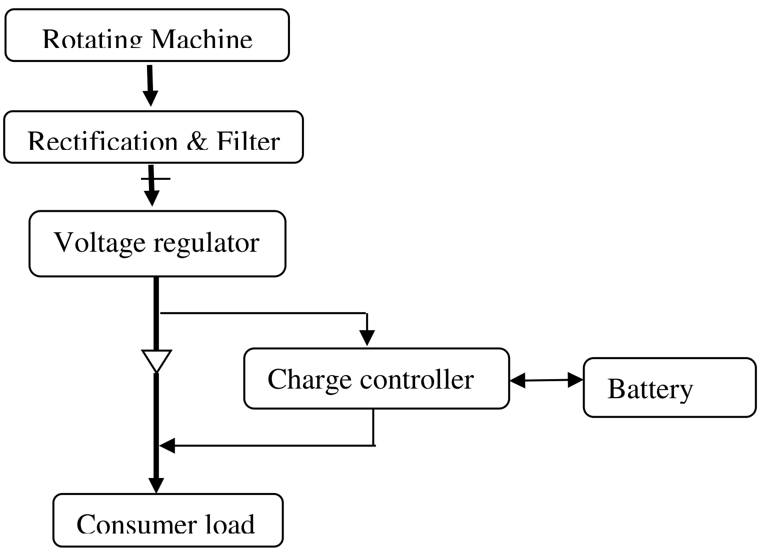


Figure 3. The flow diagram of the electrical sub system

4. SIMULATION RESULTS :

The proposed wave energy converter (WEC) is the mechanical direct drive wave energy converter. This conversion system consists of three main parts that are wave specification, mechanisms and electrical system with rotating machine and DC-DC converter.Therefore, this simulation model of this three parts are shown in Fig 4.1. The selected location of the wave height is 15cm and the wave period is 4sec according to the measurement data.This data is used as an input of the simulation block diagram. The ideal case studied is input for this system.

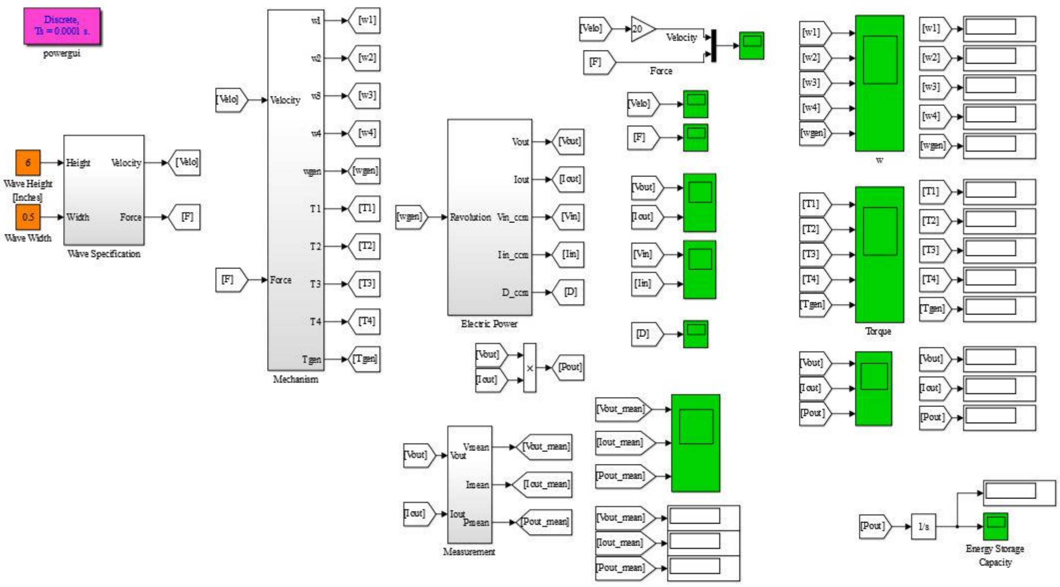
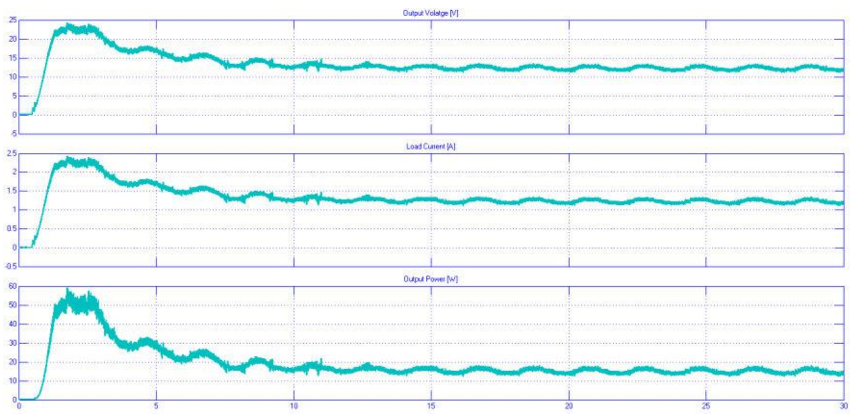


Figure 4.1. Simulation Block Diagram for Wave Energy Conversion System

Table 4.1 shows the parameters for the rotating machine. The simulation was performed by regular wave.

Table 4.1. SPECIFICATION OF ROTATING MACHINE PARAMETERS IN WEC

Name of Parameters	Rated Value	Unit
Inductance, L	3.594	mH
Resistance, R	3.97	ohm
Inertia, J	1.9	Nm
Motor torque constant, K_m	0.9	Nm/A
Number of rotor teeth, N_r	50	_
Rotational damping, B	1	Nms/rad



Time (sec)

Figure 4.2. Voltage, Current and Power waveforms at the output of the WEC

According to the simulation results, the voltage produced by a wave energy conversion system is given in the first plot of Fig. 4.2. It can be clearly seen that the voltage is 24V between 1sec and 4sec and then the stable of output voltage (15V) is occurred in the range of 5sec and 30sec according to the simulation results.

Finally, the output power is 59W between 1sec and 3sec at the transient state and then the power is approximately stable 20W.

5. EXPERIMENTAL SET-UP AND RESULTS :

The wave tank facility that was used for the experimental study on the physical model is located at the Water Park, Kan Taw Gyi in Mandalay. The wave tank is 10000 square feet and 6 inches deep. The selected location has wave height 15cm and wave period 4sec.

5.1 Components of Wave Energy Converter

The components of proposed wave energy converter consists of floating buoy(1), shaft(2), pinion gear(3,4), Rotating machine(5), platform(6), free wheel sprockets(7), voltage doupler rectifier(8) and DC load(9) are shown in Fig. 5.1(a). When the buoy moves with the waves, the permanent magnetized rotor gets rotary motion in the generator and a voltage is induced in the stator winding. This machine included wave energy converter is shown in Fig. 5.1(b). And then, the rotating machine produces AC voltage. This voltage is rectified DC voltage that circuit is described in Fig. 5.1(c).

(a) (b) (c)

Figure 5.1. (a) Proposed Wave Energy Converter, (b) Permanent Magnet Rotating Machine and (c) Voltage Doupler Rectifier

5.2. Experimental Results

Experimental testing of the wave energy converter at wave tank is shown in Fig. 10. This testing includes floating buoy, shaft, pinion gear, rotating machine, platform, free wheel sprockets, voltage doupler rectifier and 10W two LED DC load. According to the measurement of the oscilloscope, the DC output Voltages at DC load 20W is described in Fig. 11. It can be clearly seen that the voltage is 9.8V in the plot at DC load 20W.

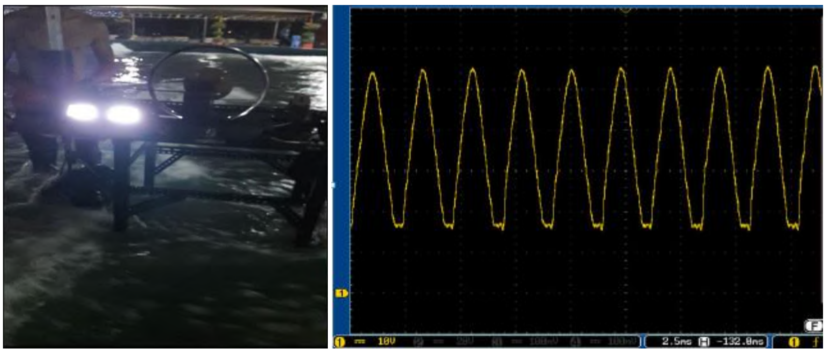


Figure 5.2(a) Experimental Testing of Wave Energy Converter and (b) DC output Voltage at load 20W in 2.5ms

6. CONCLUSION:

In this research, the power generation from wave energy is described by direct mechanical drive wave energy converter. For the analysis, the wave generation modeling and the simulation were performed. The simulation was performed single operation. According to the simulation results, the DC voltage is 15V and the DC output power is 22.5W when the ideal cased studied is considered wave height 15cm and wave period 4sec. In experimental test, the DC voltage is 9.8V and the DC output power is 20W.Therefore, the difference between the simulation and experimental results is 2.5% and 5.2% in the DC voltage and DC power. Simulation and experimental results prove that energy absorption from waves. Comparing the experimental and simulation results, experimental results show lower absolute absorption power than the simulation results because of the real case study is varied in wave height.

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