UNIVERSITY OF CENTRAL FLORIDA

Buoy Array for Ocean Wave Power Generation

PI: Zhihua Qu **Co-PI**: Kuo-Chi Lin
Students: Shiyuan Jin (Ph.D), Steven Helkin (M.S.), Carlos Velez (M.S.), Karan Kutty (M.S.)

Description: The objective of this project is to develop a novel design that can extract ocean wave energy for commercial consumption. The design detailed herein is unique in that it is a wave point energy harvester that is small in size and contains all of the mechanical components directly within the buoy. As such, the buoy would simply need to be moored to the ocean floor and have cables to transport power to the shore, making it ideal for use in a multiple-unit wave farm. The project focuses mainly on the mechanical system within the buoy as well as methods to control the electrical load on the system. Different mechanical systems have been developed and tested on a motion platform to simulate use within a buoy in vertical heave—these systems have been analyzed and compared in order to provide an ever-increasingly effective design. Mathematical simulations have been developed to help optimize design parameters for use in subsequent prototype designs that will be able to be implemented in a wave pool or saltwater environment.

The research team has made arrangements with Harris Corporation representatives to work in collaboration with the Harris Maritime Communications Services department in order to develop a method to provide sustainable electrical energy for Harris's OceanNet buoy. The Harris Corporation has reached an agreement with the University of Central Florida to support research on three subprojects with a total budget of $10,000. Two of the projects are involved in the construction of a unique ocean energy buoy, which can convert wave energy to electrical energy. The third project seeks to design, construct, and test a sensor system that can monitor the activity of abandoned oil well heads, in an attempt to prevent large oil leaks from occurring.

Budget: $150,000
Universities: UCF

Progress Summary

Nature offers a tremendous source of renewable energy in the kinematic motion of ocean waves. This project involves the development and optimization of a wave energy converter model that is innovative in design. For this project, a prototype has been built using machine components. The prototype was mounted onto a special motion platform that can oscillate vertically to simulate wave motion, which drives a shaft to produce electricity using a permanent magnetic generator.

The project began with a literature review and a Matlab/Simulink simulation. Next, two prototype were developed and tested. The first prototype (Fig. 1) shows that a simulated wave moving up and down with an amplitude of 15-cm, can generate between 35 to 40 watts electricity. The experiences gained in testing of this prototype helped design and build the second prototype (Figure 2). The second prototype uses two sprockets and a longer chain giving more mechanical advantages. In addition, a more efficient generator that requires less torque reduces frictional losses imposed on the shaft. Test results have shown that the power output increases from 37.34 to 206 watts.

In order to make the generator run more continuously and, thus, generate more power for a given wave input, a load control mechanism was designed to dynamically control the electric load. This requirement is needed when there is no pulling force of the wave at the down-stroke and the load is not applied so that the flywheel runs continuously. Tests of the second prototype were done for a number of different configurations.

In addition to the prototype tests, the buoyancy force of the waves on a small buoy has been studied. For these experiments, the output of the force is recorded by a computer based data acquisition system and the results will help verify the computation fluid dynamics model to be used in the future.

A microcontroller will be used to replace the LabView computer in future real environment to automatically control electric load and a power control strategy is being designed for stabilizing the variable frequency, variable voltage output and for satisfying the grid requirements of constant voltage, frequency, and power. In addition, a power conditioning circuit simulation was conducted for the preparation of using a microcontroller in the new prototype.

In order to build a system that can utilize wave power more efficiently and operate reliably in the harsh ocean environment, the current prototype was modified. The next prototype, shown in Figure 3, was designed—the chain was replaced by a reliable belt; additionally a new gear train was used to convert excess rotational velocity into a greater driving torque. Alternatively, a rack-and-pinion may be used to replace the cable and pulley system. To verify the improved designs, the following two alternative prototypes were built and tested:

Alternative prototype 1

This first alternative prototype (Fig. 6) was built with the following main characteristics: (1) A cable is used instead of a chain to improve reliability (2) A large size aluminum flywheel to increase flywheel inertia (3) A 4:1 gear set for increasing RPM. The only drawback of this design is that although adding a gear set increases RPM, it also increases the torque.

Alternative prototype 2

This second alternative prototype (Fig. 7) was built in order to generate consistent power in both directions (up and down). The rack has teeth on both sides which mesh with two gears on two separate shafts. When the motion platform moves up, one shaft runs clockwise; when moving down, the other shaft runs counter-clockwise. The movements of both shafts rotate the generator in the same direction, thus developing consistent power in both directions. Each shaft has one gear set installed to increase RPM. The drawback of this prototype is that it is difficult to fix the top of the rack in the ocean, and it is possible for the rack and gears to become unmeshed.

Wave Energy Conversion (WEC) system

A Wave Energy Conversion (WEC) simulation model (Fig. 4) was built for stabilizing the variable frequency, variable voltage output and for satisfying the grid requirements of constant voltage, frequency, and power. Using experimental three-phrase AC voltage data of the generator, a three-phase breaker is turned on and off by the control system to output DC voltage, shown in Fig. 5. The simulation is a stepping-stone to build a micro-controller that can run the buoy control system in the future. This work is for future preparation once the buoy power system is deployed in the ocean.

Generator performance analysis

Due to the lack of generator parameter information provided by the manufacturer, a performance analysis was carried out to determine a function that relates voltage produced by the generator to both the torque applied to the shaft and the resistance connected. The approach taken to derive the function utilized a system involving an electrical circuit, a data acquisition system (DAQ), and a torque-producing system utilizing various force-load pull boxes. It was found that the voltage produced by the generator, the torque (in pounds) applied to the shaft, and the resistance (in ohms) acting on the generator are related by:

$$V(T,R) = (0.4711 \cdot \ln(R) - 0.694) \cdot T + (0.0084 \cdot R^2 - 0.5211 \cdot R + 1.83).$$

As such, it was found the voltage increases linearly with increase of torque applied to the shaft. Additionally, the back-torque produced by the generator could be derived from the above relation based on the expected voltage output.

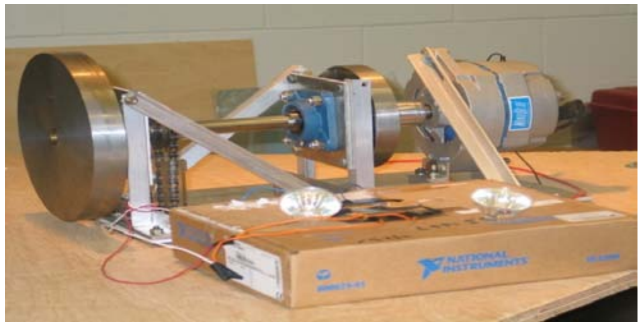

Fig. 1 First generation of prototype

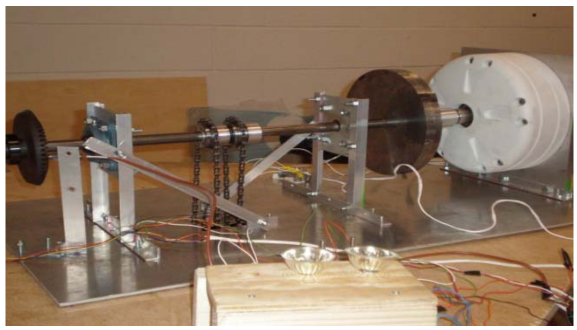

Fig. 2 Second generation of prototype

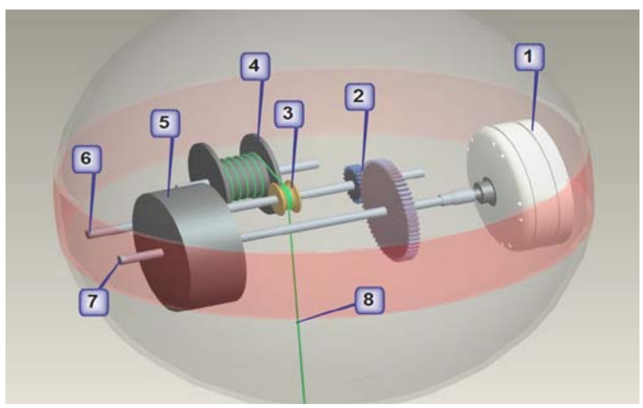

Fig. 3 Conceptual design of next generation

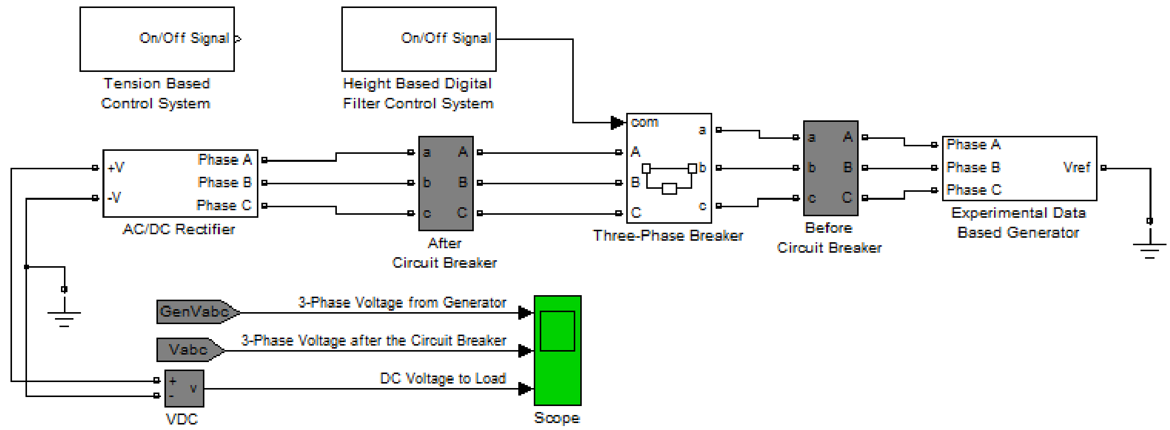

Fig. 4 Schematic for Wave Energy Conversion (WEC) system

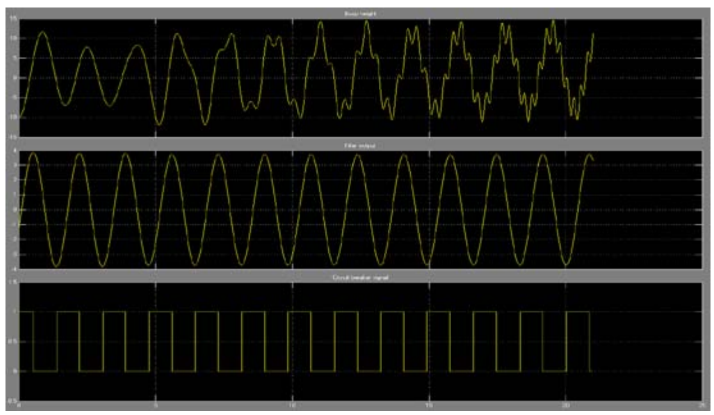

Fig. 5 Height-based control system output

Fig. 6 Alternative Prototype 1

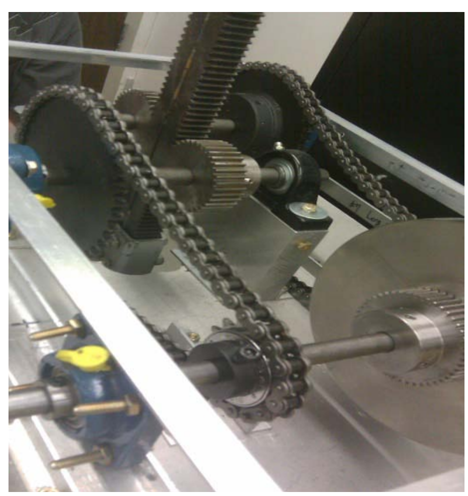

Fig. 7 Alternative Prototype 2

Industrial collaboration and technology commercialization

The Harris Corporation has reached an agreement with the University of Central Florida to support research on the following three subprojects with a total budget of $10,000.

Subproject 1: Bi-directional Water Turbine Prototype (Fig. 8 & 9)

The design will implement a floating buoy that closely follows the vertical motion of passing waves that is attached, via a rigid shaft, to the turbine rotor submerged some distance below the ocean surface. The proposed bi-directional turbine has the ability to apply torque on the rotor in a single direction, independent of the direction of the water flow [1][2]. This is accomplished by using a symmetric rotor blade and by initially turning the fluid such that the fluid path is tangent to the direction of blade rotation, illustrated in Fig. 8. This in effect imparts a reaction force on the rotor blades as the fluid is again redirected within the turbine channel. Additionally, in order to increase the fluid velocity through the turbine blades, a converging channel can be used, as shown in Fig. 9. For prototype testing, the motion table will be used to plunge the turbine up and down in a water tank at various amplitudes and frequencies, so as to mimic the heaving motion of ocean waves.

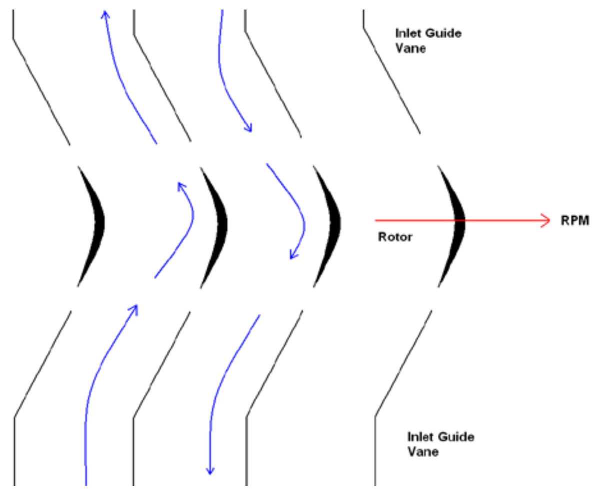

Fig. 8 Bi-Directional Blade Schematic

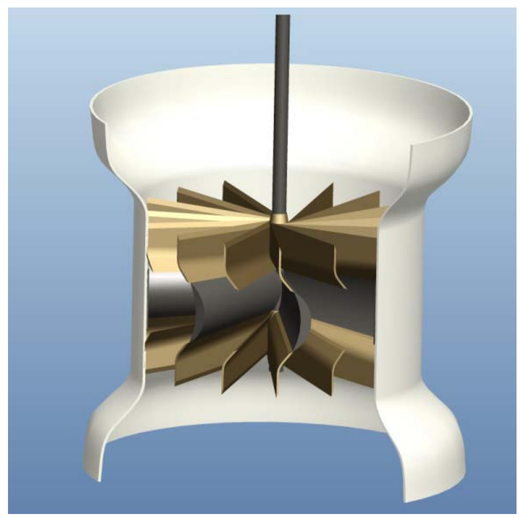

Fig. 9. Converging channel design

Subproject 2: Buoy construction for Bi-directional Turbine (Fig. 10)

The project goal is to construct a housing for the bi-directional turbine and build a mechanical system which would ensure that no water would enter the buoy or damage the mechanical system. The buoy geometry must be carefully designed to promote a stable buoy motion. A schematic of the initial buoy geometry and structure is shown in Fig. 10.

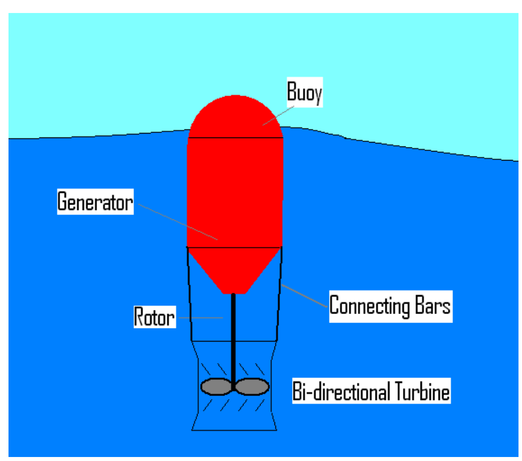

Fig. 10 Buoy Design for Bi-directional Turbine

Subproject 3: Abandoned Oil Well Monitoring System

The objective of this subproject is to design, construct and test a sensor package which can be installed on underwater abandoned oil well heads to detect oil leakage. The sensor package would automatically measure the surrounding water for oil concentration in an attempt to determine if the well is leaking. Additionally, the use of pressure sensors can be used to detect pressure or velocity fluctuations surrounding the oil well which could be produced from an oil leak. By testing the sensor system in a salt water environment the correct material can be chosen which can resist the effects of corrosion. The use of various sensors can be used to monitor the status of the oil well, while reporting electronically the status of the well. Additionally, the wave energy device created above can be used to provide power for the sensor package.

2010 Annual Report

The objective is to analyze, design, and demonstrate a wave power generation system with novel multi-functional energy converting devices. The tasks include component design and modeling, system integration, system testing and evaluation. The proposed system consists of an array of buoys floating on the ocean and tethered to the floor. Each of them has one or multiple devices inside that can convert the kinetic energy of the motion of the waves into electrical energy. The electricity generated is then transmitted through the cable that goes along or inside the tether to the ocean floor, expending to an energy processing/storage station on the ocean shore.

The result for this phase of the effort is presented in the following table which gives the timeline, task and description of actions and results.

Progress Report

Timeline	Main Task	Description
10/15/2008 - 11/30/2008	Literature review Matlab/Simulink modeling and simulation	A literature review was performed to demonstrate the novelty of the project. Matlab/Simulink was used to solve hydrodynamic and mechanical differential equations and simulate the wave input and electric power output.
12/01/2009 - 3/31/2009	First prototype design	Mechanical AutoCAD design and implementation of the prototype were done. Initial tests show that a simulated wave moving up and down with amplitude of 15-cm, can generate between 35 to 40 watts of electricity (see Fig. 1).
	Motion platform setup and LabView data acquisition	A 6-DoF motion table was set up to simulate the wave motion. A LabView machine was used to collect measurement data for analysis
	Hydrodynamic test	The buoyancy force of the waves on a small buoy was studied. The wave motion pushes the buoy up and down and motion force readings from the force transducer were shown to vary accordingly. The output of the force is recorded in a computer based data acquisition system. The results will help verify the computation fluid dynamics model in the future.
4/1/2009 - 7/31/2009	Second prototype design	A second prototype was designed with two sprockets and a longer chain in order to utilize more mechanical advantage (see Fig. 2). A more efficient generator that requires less torque and reduced frictional losses imposed on the shaft. Power measurements increased from 37.34 to 206 watts.
	Electric load control; RPM, potentiometer, strain gauge sensor data measurement	A number of sensor data were measured: voltage output, shaft rpm, chain tension force, platform motion instantaneous height. These data are useful for electric load control and buoy design.

8/1/2009 - 9/14/2009	Different configuration tests and system optimization	Second prototype was tested in different configurations: two sprockets running in opposite/same direction, different number of flywheels, and load control window size. Results were used to remodel the system and maximize the power output based on the model for a given wave size. The power output was shown to be directly proportional to the angular velocity of the shaft in the system
9/15/2009 - Present	Microcontroller and circuit conditioning design	The existing LabView control machine is planned to be replaced by a PIC microcontroller in order to achieve a real environment and to dynamically control the electric load. Furthermore, a power control strategy is required for stabilizing the variable frequency, variable voltage output and for satisfying the grid requirements of constant voltage, frequency, and power.
	Next generation prototype and buoy design	To build a system that can operate reliably in the harsh ocean environment, the current prototype will be changed, and reinforced, and redesigned (see Figure 3). Planned procedures are: • The chain should be replaced by a reliable belt. • The input and output shafts are coupled together through the use of a gear train which can convert excess rotational velocity into a greater driving torque for new generator GL-PMG-3500. Different buoy designs are under discussion.
8/1/2009 - 9/14/2009	Different configuration tests and system optimization	The second prototype was tested in different configurations: two sprockets running in opposite/same direction, different number of flywheels, and load control window size. Results were used to remodel the system and maximize the power output based on the model for a given wave size. The power output was shown to be directly proportional to the angular velocity of the shaft in the system.
9/15/2009 - Present	Wave Energy Conversion (WEC) system	A Wave Energy Conversion (WEC) simulation model (see Fig. 4) was developed. • Used to stabilize the variable frequency and voltage output and to satisfy the grid requirements of constant voltage, frequency, and power • Will be used for future preparation once the buoy power system is deployed in an ocean environment
9/15/2010 - 12/1/2010	Alternative Prototype 1	The first alternative prototype (see Fig. 6) was built with the following characteristics: • A cable is used instead of a chain to improve reliability • A two-shaft system is used that allows motion on both upstroke and down-stroke without need of additional pulleys to be mounted to the floor • A large size aluminum flywheel is used to increase the inertia of the rotating system • A 4:1 gear set increases the RPM and power output
9/15/2010 - 12/1/2010	Alternative Prototype 2	The second alternative prototype (see Fig. 7) was built with the following characteristics: • Replaces the pulley and cable system with a rack-and-pinion to drive the shaft • Also uses a two-shaft power drive system with ratchets on each to generate consistent power in both upward and downward motions

1/1/2010-4/1/2010	Generator performance analysis	Due to the lack of information regarding several important generator parameters provided by the manufacturer, a performance analysis was carried out. • Developed a function to relate voltage produced by the generator with the moment applied to the shaft • Determined a relation between the RPM of the shaft, the load acting on the generator, and the back-torque developed
	Mathematical simulation for optimization	An updated mathematical model was designed to simulate buoy motion on an ocean wave. • Can be used to estimated power output for given conditions • Allows for different design parameters to be varied to optimize design • Will be used to prepare for next-generation, optimized design
5/1/2010-8/31/2010	Development of new system designs	Alternative power take-off methods for wave energy collectors were researched and analyzed. Several potential designs were developed and compared.
	Meetings with Harris Corporation representatives	Harris's OceanNet buoy was researched and visited for appropriate methods to provide power. Basic design analyses were performed on multiple potential systems for ocean power production. Designs were presented to Harris representatives for approval, and agreements were reached to begin a continuation project.
	Selection of team members for future project design	Three teams of senior UCF Engineering students were recruited for each of the three subprojects associated with the continuation project design.
9/1/2010—	Bi-directional water turbine prototype	The design will implement a floating buoy that closely follows the vertical motion of passing waves that is attached, via a shaft, to the turbine rotor submerged some distance below the ocean surface. The proposed bi-directional turbine has the ability to apply torque on the rotor in a single direction independent of the direction of the water flow.
	Buoy construction for bi-directional turbine	Construct housing for the bi-directional turbine and build a mechanical system which would ensure that no water would enter the buoy or damage the mechanical system.
	Abandoned oil well monitoring system	Design, construct and test a sensor package which can be installed on underwater abandoned oil well heads to detect oil leakage. The sensor package automatically measures the surrounding water for oil concentration in an attempt to determine if the well is leaking.

List of Presentations and Conferences for Wave Energy Project

PAPERS

Carlos Velez, Dr. Kuo-chi Lin, Dr. Zhihua Qu, Steven Helkin, and Shiyuan Jan, *Novel Design of an Ocean Wave Power Device Utilizing a Bi-directional Turbine*, OCEANS 2010 MTS/IEEE Seattle, September 20-23, 2010.

Carlos Velez, Steven Helkin, Dr. Zhihua Qu and Shiyuan Jan, Renewable Ocean Energy and the Marine Environment Conference, November 3-5, 2010 (In Preparation)

Carlos Velez, Steven Helkin, Dr. Kuo-chi Lin, Dr. Zhihua Qu and Shiyuan Jan, Renewable Energy ELSEVIER Journal. (In Preparation)

SHOWCASES

Carlos Velez and Steven Helkin, Showcase of Undergraduate Research Excellence, April 1st 2009

Carlos Velez, Showcase of Undergraduate Research Excellence, April 1st 2010

Carlos Velez and Steven Helkin, Progress Energy UCF Symposium,April 14th, 2010

Carlos Velez and Steven Helkin, Progress Energy UCF Symposium, April 14th, 2009

FESC Summit

Steven Helkin, Carlos Velez, Dr. Zhihua Qu, 2009 FESC SUMMIT, University of South Florida, Tampa Florida, September 29-30 2009

Steven Helkin, Carlos Velez, and Shiyuan Jin, Buoy Array for Ocean Wave Power Generation, 2010 FESC SUMMIT, University of Central Florida Student Union, Orlando, Florida, September 28-29, 2010

References

[1] Setoguchi, T, Takao, M, Kinoue, Y, et al. Study of an Impulse Turbine for Wave Energy Conversion. International Journal of Offshore and Polar Engineering, 2000, 10(2):355-362

[2] Setoguchi, T, Santhakumar, S, Maeda, H, et al. A Review of Impulse Turbines for Wave Energy Conversion. Renewable Energy, 2001, 23: 261-292