A Renewable Energy Project for Senior Mechanical Engineering Students: A Wave-Powered Generator

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Abstract

The fundamental objective of the Petroleum Institute (PI) is to offer board yet comprehensive subjects for the next generation of engineers. The Mechanical Engineering program, in particular, provides its students the opportunity to work on design projects related to sustainable energy and environmental issues. With this in mind, an alternative energy project was offered in the form of a senior design project over the course of two semesters as a means to educate engineers on these topics. The objective of the design project was to develop a wave-powered generator for converting water wave energy to a stable direct current and further stored to power small size electronic sensors and actuators. The challenge, however, was to find the most efficient way to produce electricity by means of induction, and to create a low-weight and rugged setup [1]. Fundamental basis of design process were applied during two semesters to overcome a challenging problem related to environmental engineering.

1. Introduction

Importance of Senior Design Projects related to Environmental Issues

The rapid increase of global energy consumption, combined with current environmental issues, has created challenging problems with direct impact on future generations. To provide sustainable energy resource and eliminate environmental issues, innovative renewable energy industries (such as wind energy, solar energy, wave-powered energy, fuel cells, etc.) have grown rapidly over the past decade and require qualified engineers to tackle these issues. Therefore, a solid multidisciplinary engineering background becomes essential for an engineering student to overcome these challenges. An effective method of teaching a capstone course based on multidisciplinary subjects is to offer a senior design project to a group of students. In the Mechanical Engineering Department, the senior design course is offered during two semesters (MEEG414 and MEEG415). Students are required to develop their engineering teamwork skills in order to design and develop a challenging engineering product.

The wave-powered generator described in this paper has been offered as a senior design project to three students with a clear deliverable. Students were required to first design and fabricate a water channel for generating water waves and second to develop and construct a device for converting the energy from the water waves to 5 volts of direct current electricity. The entire process of engineering design (Figure 1) was taught and students were encouraged to propose innovative ideas for overcoming technical challenges during the design and the fabrication of the experimental setup.

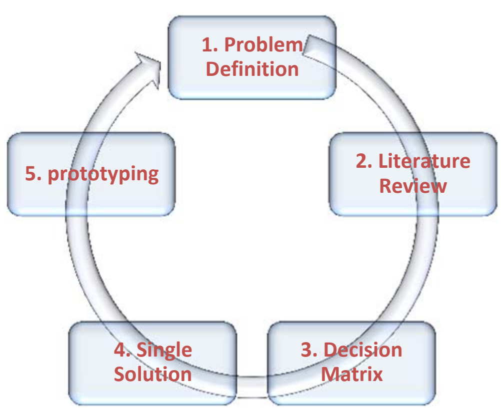


Figure 1. Engineering design process.

Description of the Project

Oceans cover over 70% of the world's surface. The movement of wind across these large bodies of water creates waves which contain considerable amount of kinetic energy (Figure 2). The energy production from water motion in oceans can be obtained using two ways: Tidal energy (large scale projects using barrages and turbines to control the natural tidal flow) and wave energy (medium to small scale projects using moving devices, either stationary or floating on the surface of the water waves). The obtained energy can be harnessed and used as an alternative source to power electrical circuits and devices such as sensors, actuators, and data loggers used on offshore experimental platforms. Despite many patents (Figure 3) and technical papers available in the literature [3-7], the wave power technology is still a new and promising research area and requires more engineering investigation before it can be effectively commercialized.

The objective of this design project is to develop a wave-powered generator using the Faraday induction technique. The experimental setup should convert the energy of water wave to a stable direct current and further store the resulting electrical power to power small size electronic sensors and actuators. The challenge, however, is to find the most efficient way to produce electricity by means of induction, and to create a low-weight and rugged setup.

2. Experimental Setup

Using the design engineering process and a decision matrix, a design was selected for the final experimental setup. As shown in Figure 4, the final experimental setup consists of four main parts: (a) a water channel, (b) a wave generator, (c) a power generator, and (d) an electronic circuit.

(a) Water Channel

A horizontal rectangular water channel was constructed and used as one of the tools to simulate stationary water waves in the laboratory scale. The 2000 mm long channel has a cross section of 200 mm by 300 mm. The water channel was fabricated form fiberglass using a single piece mould in order to minimize leaks. To minimize turbulence, the interior of the channel was constructed with a smooth surface. As shown in Figure 4-a, a tempered glass window was added to on one side of the channel to enhance flow visualization and allow further investigation of the flow using laser diagnostic techniques such as particle image velocimetry or laser doppler anemometry.

(b) Wave Generator

The purpose of the wave generator is to produce ripples in the water surface resulting in waves. A schematic over view of the wave generator is shown in Figure 4-b. The wave generator consists of a 200 mm by 350 mm rectangular plate made from acrylic. The plate is connected to a slotted rotating disc through a sliding link mechanism. The rotating disc is attached to a geared DC motor mounted on a heavy bottom vertical stand that ensures stability in the system. The sliding link mechanism allows the user to alter the wavelength and amplitudes of the wave by modifying the length and position of the stroke, and by adjusting the speed of the DC motor. The DC motor can operate at a maximum speed of 80 rpm is controlled using a variable DC power supply.

(c) Power Generator

Accounting for the following criteria: (a) innovation, (b) cost of production, (c) stability due to wave impact, (d) materials availability, (e) footprint, (g) sealing and simplicity, and (h) appearance, students chose a design similar to that of Hare and McCallie [1]. The power generator, which operates based on Faraday induction, consists of four sub-parts. These parts, as illustrated in Figure 4-c, include a floating base, four electric coils, four magnets, and supporting rods. Each coil consists of 637 turns of 0.4 mm copper wire and each magnet produces a magnetic field of 3 Tesla.

(d) Electronic Circuit

The function of the electronic circuit is to convert the AC current produced by the power generator through induction, into DC current. The circuit is shown in Figure 4-d. This is achieved by using a rectifier bridge circuit for each coil. A capacitor is placed in parallel of the output of the rectifier to smoothen the voltage output.

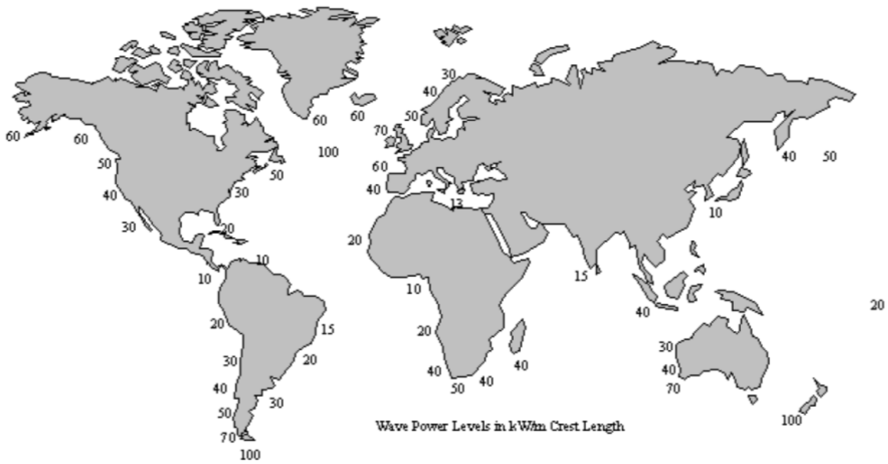
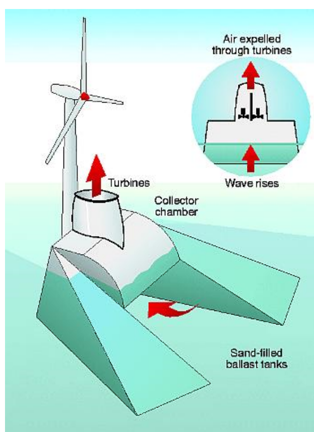
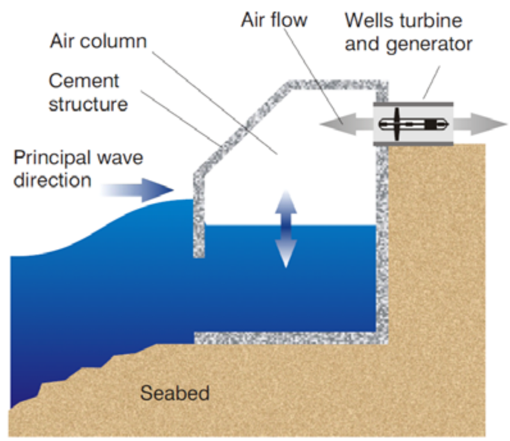


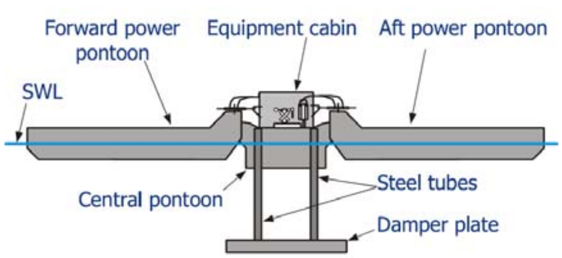
Figure 2. Approximate global distribution of time-average deep water wave power in kW/m of wave front [2].



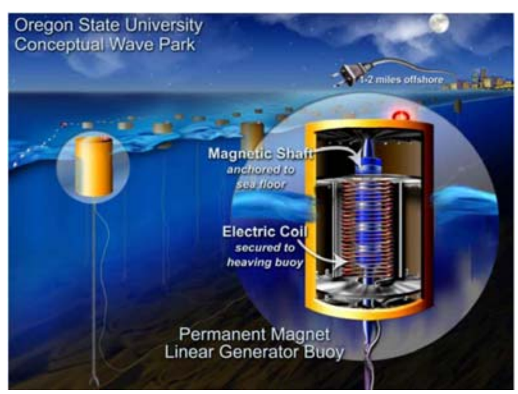
a) Wave-powered electricity generator [3]



b) An oscillating water column (OWC) [4, 5, 6]

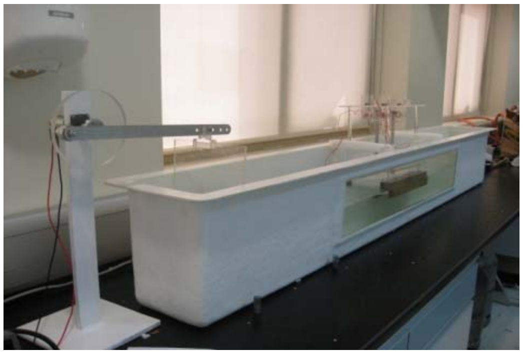


c) The McCabe wave pump [6, 7]

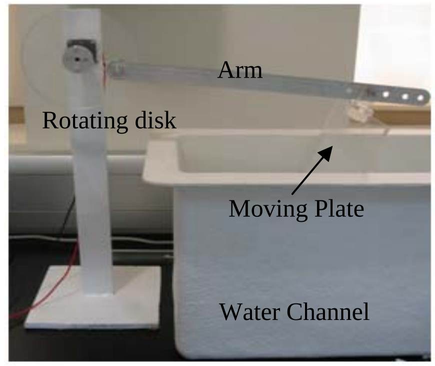


d) The linear Generator Buoy (Oregon State University Conceptual Wave Park)

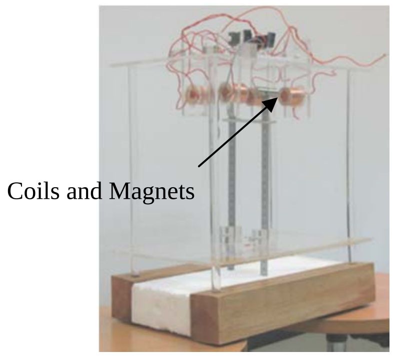
Figure 3. Wave Powered Generators.



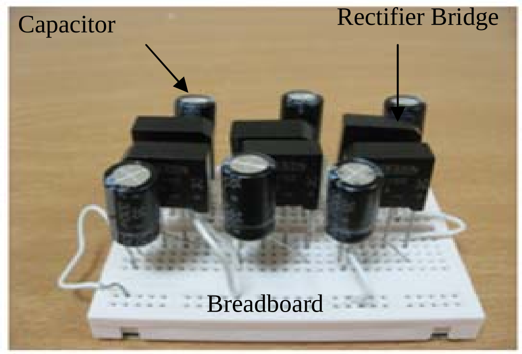
(a) The laboratory scale water channel with transparent windows for flow visualization



(b) The wave generator is to produce ripples in the water surface resulting in waves



(c) The power generator which operates based on Faraday induction consists of 4 sub-parts



(d) The Electronic circuit converts AC current to DC current

Figure 4. Experimental setup.

3. Obtained Results and Problems Encountered

Students were able to generate an output voltage of 1.25VDC from each coil, thus producing a total of 5VDC. The produced current was sufficient to power a single LED. One of the challenges encountered during the design phase was instability in the power generator due to its inability to return to its equilibrium position after being displaced. To increase stability the center of gravity and the center of buoyancy of the floating power generator were modified. This was achieved by using lighter coils. In initial designs the coils weighed 1140 gr and where eventually reduced to 240 gr.

Another problem was the drift of the wave-powered generator toward the end of the channel. This caused the generator to collide with the channel end wall and restricts it oscillatory motion. Moreover, when the generator reaches the locations of wave peaks, it starts to move up and down vertically which limits the vibration transferred to the magnets. Therefore, it was decided to limit the motion of the wave-powered generator into a location where maximum and consistent output can be extracted. To do so, two Plexiglas rods were used to limit the motion of the generator and act as path for the generator.

4. Cost Estimate

One of the advantages of the experimental setup described in the paper is that it is low-cost and utilizes equipment commonly found in mechanical engineering and physics laboratories such as a personal computer and variable power supply. Besides the fiber glass tank, the entire setup was fabricated in our mechanical workshop which contributed to cost saving. Table 1 shows the approximate price list for the required components of the proposed setup. Excluded from the list is the cost of personal computer and variable power supply.

Table 1. Price list for the components of the experimental setup.

Component	Approximate Price (USD)
Water Channel	250
Waver Generator	100
Power Generator	50
Electronic circuit	20
Data acquisition unit	150
Total	**570**

5. Teaching Strategy

The presented design project could provide considerable insight about the concept of renewable energy for undergraduate students in a Mechanical Engineering Program. The wave-powered generator project highlights the importance of using multidisciplinary knowledge for solving modern engineering problems. As shown in Figure 5, for completing the project, students were required to apply several fundamental concepts studied in previous courses: energy conversion (MEEG480), data acquisition and signal analysis using LabVIEW™ software (MEEG438), wave characterization (PHYS191), stability of floating objects (MEEG354). In addition to theoretical concepts, students had the opportunity to improve their engineering skills in terms of managing a project (MEEG479), engineering drawing using SolidWorks® software (STPS201 and STPS251), fabricating parts in the machine shop (MEEG345), communicating with vendors, supervisor and, laboratory staff (COMM101 and COMM151).

6. Conclusions

An experiment consisting of a water channel, a wave generator, and a power generator was designed by three senior ME students. The fundamental objective was to develop a series of design for a wave-powered generator based on the following criteria: (a) innovation, (b) cost of production, (c) stability due to wave impact, (d) materials availability, (e) foot print, (g) sealing and simplicity, and (h) appearance. The final selected design was based on an original design by Hare and Mc Callie [1]. Students were able to generate an output voltage of 1.25VDC from each coil producing a total of 5VDC. The produced current was sufficient to turn on a single LED. The design project represented a rich experience for students in terms of dealing with problems related to energy research, prediction and overcoming difficulties during the design process, and satisfying the final deliverable required by the mentors. All three students completed their studies and obtained the highest grade in the senior design courses (MEEG414 and MEEG415) and are currently employed as engineers in various operating companies under the umbrella of the Abu Dhabi National Oil Company (ADNOC).

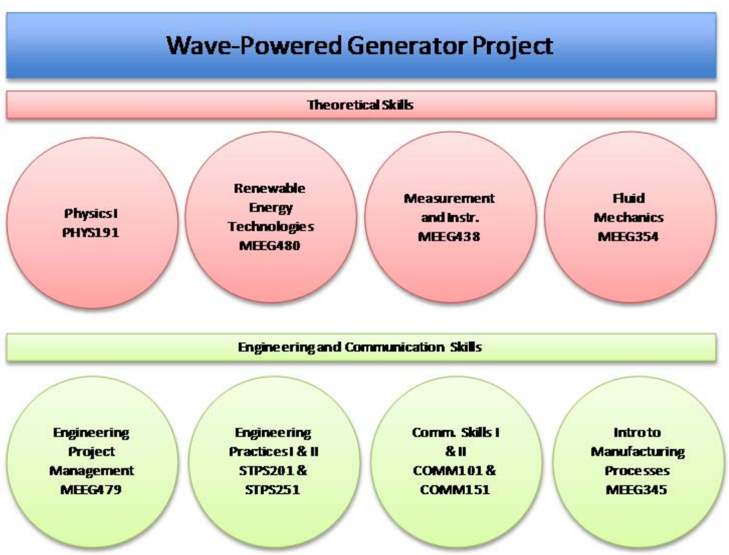


Figure 5. Relation between the wave-powered generator project and various courses offered at The PI.

7. References

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Author Biographies

An expert in experimental fluid mechanics, **Dr. Afshin Goharzadeh** obtained his Ph.D. at the University of Le Havre in France (2001). After his Ph.D., he worked during three years at the Max Planck Institute in Germany as scientific researcher. In 2005 he joined the Petroleum Institute as an Assistant Professor in Mechanical Engineering Department. He is currently teaching Fluid Mechanics, Basic Measurements and he is coordinator for the Senior Design Project II Course.

As a Senior Laboratory Engineer, **Mr. Arman Molki** joined the Petroleum Institute in 2004 after several years of working in both the industry and academia in the United States. He has broad knowledge of sensors, instrumentation, computer-based data acquisition, and computer aided design. He received his degree in computer science with upper level concentration in mathematics from the University of Maryland, College Park, U.S.A. He also holds an M.B.A. in Management of Engineering and Technology from Northcentral University.