Development and Design of PIC controlled Buoy Wave Energy Converter System

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Abstract — This paper is conceptualized to generate electricity as an alternative due to increasing oil prices and as a possible solution to the energy crisis in the coming years. Even though, unpopular type of renewable energy, wave energy is seen as a potential source that could be used to generate the amount of power. Electricity can be generated by the mechanical force collected from the movement of waves in the oceans. Electricity will be stored to a 12 Volts Lead Acid Battery and monitored using a microcontroller. A prototype was built for testing the study in Pagudpud, Ilocos Norte. A 12-Volt battery is charged by a mechanical force acting to the alternator due to the movement of floating buoy on the surface because of the waves. The PIC microcontroller with the CPLD module will monitor the charging and automatically switch to charge another standby battery if the latter is full. The prototype was tested and proven to be functional. Another paper goal is to analyze the relationship between the wind speed and water depth to the power produced by the prototype. A regression equation was also developed for the prototype. It has proved that the water depth and wind speed has a direct relationship with the time of charging the batteries and the power produced.

Keywords — Float Buoy, Wave Energy Converter, PIC, Lead Acid Battery, CPLD

I. INTRODUCTION

Energy plays an indispensable role in modern society. We all depend on a constant and reliable supply of energy – for our homes, business, and for [13]. The current situation of power shortage in the country is alarming with continuous negative effects in many Small-Medium Enterprises (SME) and Multi-National Companies. The world suffers from the effects of climate change mostly coming from burning fossil fuels for electricity generation [14]. Those events continue to recur until a definite solution has been defined. The joint effort conducted by different sectors and government agencies to formulate plans and programs to annihilate these tribulations.

Frequent power cuts continue to cripple SMEs all over the country, hampering the workflow and making it difficult for to sustain smooth operations. The power cut is likely to put the manufacturing sector of the state in turmoil [15]. Power cuts during peak hours will bring down the production capacity of the industry sector, thereby impacting the revenue contribution to the state's economy. On the other hand, the Philippines experiences temperature spikes brought about by climate change. The climate disruption poses a fundamental threat to the vulnerable places, species and the people [13]. Therefore, an immediate response not only to administration but also to the people is in need to ensure maximum efficiency of power generation and reduction of greenhouse gasses.

Due to continuous effects that are given by power shortage and climate change, certain actions were needed for implementation to halt the possible catastrophic events. To satisfy the above challenge, developing the device that would generate electricity and environment-friendly using an alternative energy was a great option. Sustainable alternative energy has become attractive as oil costs rise and the negative effects of traditional energy systems begin to become apparent. One often overlooked, but the rapidly growing alternative was the wave power. Wave energy hasn’t grabbed as much popular attention as it should be compared to solar and wind energy.

The primary objective of the project is to promote renewable energy to generate electricity with the use of wave power. Therefore, Development and Design of PIC Controlled Float Buoy Wave Energy Converter System is an applicable project to conduct. The second objective of the project is to produce a device using wave water energy from the seas and oceans as a renewable source to generate electricity in Pagudpud, Ilocos Norte. Furthermore, the project aims to determine the optimal values of the parameters to generate electricity. The parameters to be measured on the charging speed of the batteries are the depth of water and the wind speed. The third objective is to configure and program the PIC microcontroller with CPLD as a controlling and monitoring module. The PIC microcontroller is an additional technology to monitor, detect and switch a dry cell to another in case it was already fully charged. The addition of PIC microcontroller will serve as a charge controller that will ensure that the batteries will not be an overcharge. The fourth objective is to prove if the water depth and wind speed have a relationship on the charging speed of the batteries. The last objective is to generate a regression equation that will predict the charging time of the batteries.

Harnessing wave energy was significant that it reduced human emissions and harmful environmental impact. The device could generate electricity that could be used to light our homes and reduce our electric consumption. Wave energy was a clean renewable that can reliably and economically replaced all current fuels sources used by the people. People generally would prosper from wave energy because it was globally available in sufficient quantity to power all human energy consumption for the foreseeable future. Important potential benefits of wave energy that was unseen by many includes replacements of hydropower dams
and fossil fuels, as well as employment opportunities for coastal communities’ residents. The study is also significant because it establishes and proves the concept that wind speed and water depth are factors to consider in wave energy. Another importance is to show that Pagudpod, Ilocos Norte is a potential site for wave energy electricity generation.

The focus of the design was limited to charging two dry cells. The things that are not included in the study are the effects of the buoy design, frictional losses, and duration of the wind blowing in the rate of charging the battery. It was also not included in the study in situ and remote wave measuring systems which record various parameters. The study focused and limited only to evaluating the wave power data to see if Pagudpod is a suitable wave site.

II. METHODOLOGY

A. Project Design

The experimental method was used in this study to check the accuracy of the device. The prototype was developed to be deployed in the seas of Pagudpod. The study focuses on wave energy to explore other probable concepts in generating electricity through the tremendous energy available in waves.

The experiment was set over different environmental variations, namely, the depth of the water to determine the optimum water level to achieve maximum mechanical input for the generator and its relationship to charging speed and average wind speed for each water depth of testing to analyze its relationship again with the charging speed.

In the first situation, the depth of the water was varied to examine the response of the generator to different levels of water. The site for testing was Pagudpod in the island of Luzon. The depths of the water tested were the following: 2, 2.5, 3, 3.5, and 4 feet, respectively.

In the second situation, the wind speed was also tabulated every five minutes until the batteries were fully charged for each water depth and then averaged. Attempts were also made to examine its relationship to creating the optimum mechanical input for the generator. The wind speed was measured by a digital anemometer.

The third situation was to monitor the time of charging of the batteries for each depth with their average wind speed.

This experiment also examined and proves if Pagudpod is a good site for wave energy extraction. Each test was tabulated and carefully observed to ensure the accuracy of the device. The variables were then carefully analyzed to determine the most suitable parameters that could be applied for device operation.

B. Technical Design

The first task was to visualize the concepts relating to the importance of using wave energy. Wave energy is a renewable form of energy that will be utilized to generate and be stored in the battery. To make it possible, the procedure involved research and professional consultations from several knowledgeable individuals who gave a clear view as well as suggestions for the design.

The next procedure was prototype construction. It involved the assembly of the buoy, the generator, the batteries, and the PIC-CPLD. The discussion of the prototype’s flowchart is on the next page.

After the construction of the prototype, the next thing to be done was to test the ability of the prototype to meet the specific requirements needed for electricity generation, in which the procedures were prescribed in the research design provided. The results were then tabulated and recorded.

The last task was the final documentation, including the manual for its operation, and the presentation of the device to be constructed. This also presented the highlights of the device developed and the research study conducted.

C. Prototype Design

The flowchart shown above is composed of two fields, in which the latter will be combined into one, with the prototype is the result. The two said fields are the inputs, which are the wave as the energy source which will be transformed into electricity and stored in the batteries, and the PIC microcontroller - CPLD as a controlling mechanism.

The first side of the flowchart is about wave power. The initial move and idea were to understand fully how the waves in the oceans generate electricity. The research included several methods and designs on how to harness waves in the ocean. It also included a map of potential sites of wave power in the world. The ways of converting wave power into electrical energy were also carefully analyzed to determine which one was most suitable for the study. Other factors that were considered in the study were the availability of the materials needed and if the ideas were feasible. Therefore, based on the ideas examined in several articles, the float or buoy system was identified as the most
appropriate one. The first thing to be considered was the design of buoy. The application of concepts in electrical machinery on how to generate electricity was applied in choosing the best alternator. The buoy is connected to a reel by a tether cable. As the wave passes over the device, the buoy rises and pulls up the cable thus rotating the cable reel. As the buoy passes over the wave crest and begins to descend the reel rewinds the cable thereby returning again to its original length. The mechanical movement of the generator as the cable reel rotates and returns is converted to electrical power which is transferred to the shores using an underwater transmission line and stored in dry cell batteries. The electricity produced in the generator is AC, so, it needs to be rectified to become DC.

The next side of the flowchart depicts the use of the PIC microcontroller with CPLD. A charged battery will be used as the source for the PIC microcontroller and CPLD module. Voltage regulation is required to provide good charging supply passed on to the Microcontroller - CPLD.

After configuring the generator and the Microcontroller-CPLD, the device was ready to use. The next step was to combine the two important parts of the prototype. The dry cell batteries to be charged were interfaced with the generator. These dry cell batteries were then connected to the PIC-CPLD. The PIC-CPLD then monitored the batteries. The PIC-CPLD would switch to another battery in case the previous battery was fully charged.

D. Statistical Analysis

Multiple regression is a method used to examine the relationship between one dependent variable \( Y \) and one or more independent variables \( X_i \). The regression parameters or coefficients \( b_i \) in the regression equation

\[
Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + \ldots + b_K X_K
\]

are estimated using the method of least squares. In this method, the sum of squared residuals between the regression plane and the observed values of the dependent variable are minimized. The regression equation represents a (hyper) plane in a \( k+1 \) dimensional space in which \( k \) is the number of independent variables \( X_1, X_2, X_3, \ldots X_K \), plus one dimension for the dependent variable \( Y \).

ANOVA F-test was used to test the significance of the regressor variable. The statistical hypotheses:

\[ H_0: \beta_1 = \beta_2 - \text{all variables are not important} \]
\[ H_a: \beta_1 \neq \beta_2 - \text{at least one variable is important} \]

The test statistics \( F_c \) and critical value \( F_{tab} \) were formulated at the level of significance. The decision rule was “Reject \( H_0 \) and accept \( H_a \) if \( F_c \geq F_{tab} \); else accept \( H_0 \)”.

III. RESULTS AND DISCUSSION

Using a calibrate Wind Anemometer, the wind speed will be obtained for various depth every 5 minutes, and this will be tabulated and analyzed to prove if these variables have a direct relationship with time of the charging and power produced by the developed system.

TABLE I. WIND SPEEDS AT 2.0 FT WATER DEPTH COLLECTED EVERY 5 MINUTES UNTIL THE BATTERY IS FULLY CHARGED

Table I shows the wind speeds at 2.0 ft water depth collected every 5 minutes until the battery was fully charged. A similar table was constructed to tabulate the wind speeds for 2.5, 3.0, 3.5, and 4.0 ft respectively. It shows that at two ft depth and average wind speed of 4.03 km/hr, the total charging time was equivalent to 59 minutes.
Table II shows that at 2.5 ft depth and average wind speed of 4.08 km/hr, the total charging time is equivalent to 46 minutes.

Table III shows that at three ft depth and average wind speed of 4.37 km/hr, the total charging time is equivalent to 44 minutes.

Table IV shows that at 3.5 ft depth and average wind speed of 4.72 km/hr, the total charging time is equivalent to 27 minutes.

Table V shows that at four ft depth and average wind speed of 5.56 km/hr, the total charging time is equivalent to 23 minutes.

To analyze the data above all the units were converted. The time of charging had an original unit of minutes converted to seconds. The water depth in feet was converted to meters and the average wind speed which was in km/hr was converted to m/s. The units were converted because the formula in obtaining power was in meters and seconds.

To create an equation to predict the charging time of the batteries when the water depth and wind speed varies, multiple regression analysis was used. To determine whether a significant relationship exists between the dependent variable and the set of all the independent variables, the Analysis of Variance of Multiple Regression was used.

The procedure for determining the formula to solve for multiple regression coefficients is similar to that of solving for simple regression coefficients. The formulas are established to meet an objective of minimizing the sum of squares of error for the model. Hence, the regression analysis shown here is referred to as least square analysis. For multiple regression models with two independent variables, the result is three simultaneous equations with three unknowns (b0, b1, and b2).
TABLE VII. ANALYSIS OF VARIANCE (ANOVA) TABLE FOR MULTIPLE REGRESSION

A. Statistical Analysis for Time of Charging vs. Water Depth vs. Wind Speed

TABLE VIII. MICROSOFT EXCEL’S RESULT FOR THE THREE UNKNOWNS IN THE MULTIPLE REGRESSION EQUATION OF TIME OF CHARGING VS. OTHER VARIABLES

Based on the results given by Microsoft Excel, the regression equation in predicting the charging time with known water depth and wind speed was formulated.

The regression equation for the charging time of the batteries (y) is

\[ y = 5087.863636 - 4175.91267x_1 + 886.3636364x_2 \]

TABLE IX. EXCEL’S ANOVA TABLE FOR TIME OF CHARGING VS. WATER DEPTH VS. WIND SPEED

Testing for Significance: F-Test

Hypothesis: 
- \( H_0 : \beta_1 = \beta_2 \) - all variables are not important
- \( H_a : \beta_1 \neq \beta_2 \) - at least one variable is important

Test Statistics: 
\[ F = \frac{MSM}{MSE} \]

Rejection Rule: 
Reject \( H_0 \) if \( F \geq F_{\alpha} \), where \( F_{\alpha} \) is based on an F distribution with \( p \) d.f. in the numerator and \( n - p - 1 \) d.f. in the denominator.

Results: 
\[ F = 1496802/70637.73 = 21.18984 \]
For \( \alpha = 0.05 \) significance level, \( F_{0.05} = 19.00 \).

We can reject \( H_0 \) since 21.18984 \( \geq 19.00 \). Therefore, we can say that at least one of the variables is important.

B. Statistical Analysis for Power vs. Water Depth vs. Wind Speed

TABLE X. DATA OF THE POWER PRODUCED AT DIFFERENT DEPTHS WITH THE WAVE HEIGHT AND WAVE CYCLE AS REGRASSOR VARIABLES

Al-Hababeih et al (2009) stated in their study entitled “An innovative approach for energy generation from waves” that determining the power produced by waves has a direct relationship to the wave height and wave time cycle [1]. The equation in finding the power:

\[ P = 0.5 H^2T \]

Where:
- \( P \) = Power produced in terms of kW / m
- \( H \) = wave height in terms of meters
- \( T \) = wave time cycle in terms of seconds

TABLE XI. Data of the Power produced versus water depth and wind speed

TABLE XII. MICROSOFT EXCEL’S RESULT FOR THE THREE UNKNOWNS IN THE MULTIPLE REGRESSION EQUATION OF POWER VS. OTHER VARIABLES

Based on the results given by Microsoft Excel, the regression equation in predicting the power with known water depth and wind speed could be formulated.

The regression equation for the power (y) is

\[ y = 0.101075758 + 0.34926032x_1 + 0.007575758x_2 \]
Testing for Significance: F- Test

Hypothesis:  
- $H_0: \beta_1 = \beta_2$ - all variables are not important
- $H_a: \beta_1 \neq \beta_2$ - at least one variable is important

Test Statistics:  
- $F = \frac{MSM}{MSE}$

Rejection Rule:  
- Reject $H_0$ if $F > F_a$, where $F_a$ is based on an $F$ distribution with $p$ d.f. in the numerator and $n - p - 1$ d.f. in the denominator.

Results:  
- $F = 0.01458/2E-05 = 745.977$
- For $\alpha = 0.05$ significance level, $F_{0.05} = 19.00$

We can reject $H_0$ since $745.977 > 19.00$. Therefore, we can say that at least one of the variable is important.

Both of the F- Test has $F > F_a$. Therefore, using Analysis of Variance (ANOVA), it can be stated that either wind speed or the water depth where the system was placed has an impact in the time of charging of the batteries and power produced by the energy converter.

IV. CONCLUSION

There many types of renewable energy that can be utilized to generate electricity. One of the less widely known of renewable energy that has yet to be tried is wave energy. It was proven by the testing of the conducted study that wave energy is a potential type of renewable energy that can be developed in the country soon. It can be concluded from the study that the deeper the water depth and the faster the wind speed, the better it is. The testing of the prototype was able to prove that water depth and wind speed have a direct relationship on charging time. The testing of the prototype was able also to prove that water depth and the wind speed have a direct relationship to power. The data obtained from testing the prototype was thoroughly analyzed to generate a regression equation that will predict the charging time of the batteries and the power produced. The regression equation for the charging time of the batteries ($y$) is $y = 5087.863636 - 4175.91267x_1 + 886.3636364x_2$ while the regression equation for power ($y$) is $y = 0.101075758 + 0.34926032x_1 + 0.007575758x_2$. The PIC - CPLD module was able to monitor and switch a dry cell to another in case it was fully charged by the alternator, which also depends on the time of charging and the state of health of the batteries.

TABLE XIII. EXCEL’S ANOVA TABLE FOR POWER VS. WATER DEPTH VS. WIND SPEED

<table>
<thead>
<tr>
<th>Model</th>
<th>Error</th>
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<td>MSE</td>
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</table>

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