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Integrated Linear and Rotary Generator Design using Scotch Yoke Mechanism with IoT Wireless Monitoring System

Sidro Michael dela Cruz [1], Christopher Gonzaga Jr.[1+] and Michael Pacis [1]

[1] School of Electrical, Electronics and Computer Engineering – Mapua University, Intramuros, Manila, Philippines

Abstract. A lot of previous studies were conducted to develop an approach to effectively harness energy from renewable energy sources such as solar, wind, and hydro. An emerging source, wave energy, is currently a topic many studies because of its potential brought by its availability and power energy density. This study aims to construct a wave energy conversion device applying scotch yoke mechanism with linear and rotary generators integrated with wireless monitoring and transmission of data. This mechanism generates electrical energy from the to-and-from movement of the wave for the linear generator and at the same time convert the linear motion into rotary motion to generate electrical energy from the rotary generator. A Node MCU ESP 8266 microcontroller was attached to the device to allow wireless transmission of data and monitoring through Internet of Things (IoT). The prototype constructed by the researchers was deployed in a controlled and uncontrolled environment for several trials to test its electrical energy generating capacity. With the use of MATLAB, the researchers were able to calculate the total energy generated per trial when the prototype was deployed. Based on the results, the mechanism was able to generate a peak value of 976.33 mW power while its total energy produced tallied a highest of 3981751.99 mW-s.

Keywords: Wave energy conversion device, Scotch yoke mechanism, Node MCU ESP 8266 microcontroller, wireless transmission and monitoring, Internet of Things (IoT)

1. Introduction

The effect of heavy reliance on non-renewable energy sources produces Greenhouse Gases (GHGs) from the burning of fuels which contribute to global warming. Renewable Energy Sources (RES) is still a low percentage contributor in global power generation mix, wherein the average share of renewables in global electricity production last 2020 was equal to 29% [1-2]. Many countries, like the Philippines, now utilize renewable energy sources for electricity generation. To strongly support the use of these sources, the Philippines has approved the Republic Act No. 9513, or the Renewable Energy Act of 2008 that affirms the country's commitment to utilizing renewable energy sources [3]. Another possible source of renewable energy source is wave energy but it is not widely implemented yet. Still, it has the potential due to its advantages in availability on all the world's seas and coasts with a power energy density of 2-3 kW/m2 as compared to wind and solar, which have 0.4-0.6 kW/m2 and 0.1-0.2 kW/m2, respectively. Using wave energy to produce electricity will significantly increase the percentage of utilizing RES It is fuel-free, predictable, and environmentally friendly, with a probable worldwide wave power resource of 2 TW [4].

Many Wave Energy Converter (WEC) device were fabricated with the aim of harnessing wave energy and convert it into electrical energy. One of the studies that focused on WEC expounded on the design and fabrication of a wave energy conversion system utilizing an axially magnetized linear generator while others explored in designing and building an integrated WEC device comprising of rotary and linear generators [5-6]. This study presents the application of a mechanism called scotch-yoke and tested its applicability in different wave conditions.

The main objective of this study is to design and fabricate a wave energy conversion device applying the scotch yoke mechanism using linear and rotary generators capable of converting surface wave energy into electrical energy with a wireless monitoring system. Specifically, the research aims: (1) to integrate a linear

[+] Corresponding author. Christopher L. Gonzaga, Jr. Tel.: 0287123221.
E-mail address: gonzagachristopher13@gmail.com.

and rotary generator design in a scotch yoke mechanism capable of converting linear to rotary motion for the generation of electricity from to-and-fro wave movement (2) to fabricate a floating-watertight hull that can handle the weight of the proposed mechanism and withstand the deployment in a controlled and uncontrolled environment (3) to develop an IoT (Internet-of-things) wireless transmission system for data monitoring (4) to test the prototype in both controlled and uncontrolled environment (5) to evaluate the data gathered by the wave energy conversion device using the statistical analysis of variance.

2. Methodology

A process flowchart illustrated in Fig. 1 guided the researchers in conducting this study. This flowchart helped ensure that their actions aligned with the study's objectives.

The study proposed implementing the scotch yoke mechanism to wave energy converter design. The computed parameters were the foundation for the design of the generators, and the mechanism was constructed based on design calculation. After ensuring the assembled mechanism was sturdy. The researchers tested it according to its intended function. Aside from that, testing of the mechanism also confirmed to the researchers that the expected values were generated. The design of the wireless data transmission was based on the microcontroller Node MCU ESP 8266, which was a wide range of connection. The researchers conducted several data-gathering trials in both controlled and uncontrolled environment. Statistical treatment of data gathered followed through, and several programs were used, like MATLAB and Microsoft Excel.

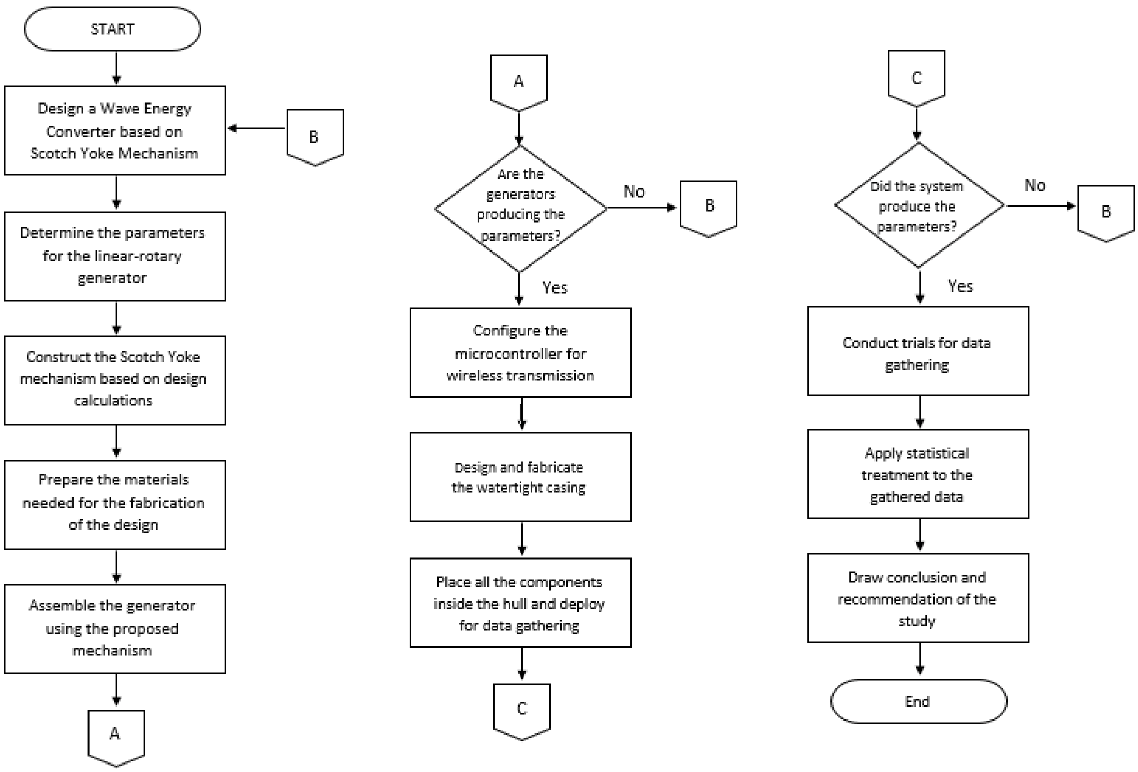

Fig. 1: Process flow chart

2.1. Design of the scotch yoke mechanism

The prototype of this study utilized a novel design, the scotch yoke mechanism. This reciprocating device can convert linear motion into rotary motion or vice versa. The proposed mechanism requires low torque application, easy to assemble, less fix and joints and self-weight independent [7]. Table 1 shows the utilized dimensions and parameters for building the prototype with a supporting visual presentation of the designed and actual mechanism indicated in Fig. 2.

Table 1: Scotch yoke mechanism parameters and dimensions

Parameters	Dimensions
Crank Wheel Outer Diameter	14 cm
Sliding Yoke Length	17 cm

Sliding Yoke Thickness	2.5 cm
Length per Connecting Rod	17 cm
Crank Wheel Holder Height	12.5 cm
Connecting Rod Stand	12.5 cm

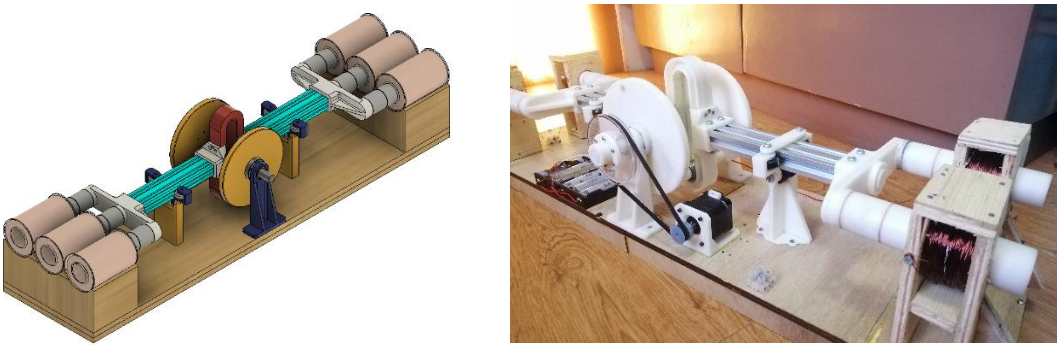

Fig. 2: Designed and actual scotch yoke mechanism

2.2. Design of the linear generator

The design of the linear generator comprises of four (4) N52 Neodymium magnets in a single tubular magnet passing through a single AWG #24 coil slot with 700 turns having a diameter of 2 and ½ inches. Indicated below are the parameters and the calculated output of the linear generator with sample computations [6].

Table 2: Linear generator design parameters

Description	Symbol	Result
Number of Phases	Phases	1
Number of turns	Nturns	700
Number of poles	P	1
Magnetic field strength	B	0.3265
Wire radius (m)	Rwire	0.00025528
Wire resistance (per 1m)	Reswire	0.0842
Velocity (m/s)	Vel	0.7
Winding radius (m)	Windrad	0.0175
Ideal min efficiency	Eff	0.5
Acceleration (m/s)	G	9.8
Length of object traveling (m)	l	0.12

Table 3: Linear generator design parameters

Description	Symbol	Formula	Result
Time to cross one pole (s)	tpole	l/vel	0.17
Loop area (m^2)	A	π (windrad^2)	0.000962113
Output voltage	Emf	P*Nturns*A*(B/tpole)	1.293476
	Emftotal	(P*Nturns*A*(B/tpole))*4	5.1739
Winding resistance	Windres	wirelength*reswire	6.48079
	windrestotal	(wirelength*reswire)*4)	25.923166
Max current (A)	Maxcurrent	Emf/windres	0.199586
	Maxcurrenttotal	(Emftotal/windrestotal)	0.7983446
Max force (N)	Maxforce	maxcurrent*wirelength*B	5.015673
	Maxforcetotal	maxforce*4	20.06269211
Max power (P)	Maxpower	0.25(Emf^2/windres)	0.129079955
	maxpowertotal	maxpower*4	0.5163198
Current at Max power (A)	Imaxpower	Emf/(2*windres)	0.0997930
	imaxpowertotal	(Emf/(2*windres))*4	0.399172
Force at max power (N)	Fmaxpower	imaxpower*wirelength*B	25.07836513
	Fmaxpowertotal	(imaxpower*wirelength*B)*4	100.313461
Wire Length (m)	Wirelength	P*Nturns*2pi*windrad	76.96902
Motor mass (lbs)	mass	Wirelength*0.0101706	0.782821

2.3. Results and discussion

To test the functionality of the prototype, Fig. 3 displays the deployment of it in a controlled and uncontrolled environment. The goal of deploying in a controlled environment is to test the consistency of the prototype in generating power for three trials. In an uncontrolled environment, the test was conducted at three varying distances from the shoreline to determine if it affects the prototype output capacity. Data gathered were undergone data analysis of variance (ANOVA) and Post -hoc analyses.

For linear generator assessment, indicated in the Fig. 4 below shows it shows that in the controlled environment the maximum generated power is 19.59mW (Trial 3) while in the uncontrolled environment the linear able to generate 30.29mW (Trial 3).

For the rotary generator deployment, as shown in the Fig. 5 below the maximum generated power in a controlled environment is 817.86mW (Trial 3) and for the uncontrolled environment the recorded peak power was 976.33mW (Trial 3).

With the of use *trapz function* in MATLAB, the energy produced for each generator per trial was able to be calculated. The most energy produced for linear generator is 117550.37mW-s while for the rotary generator is 3981751.99 mW-s.

Fig. 3: Controlled and uncontrolled deployment

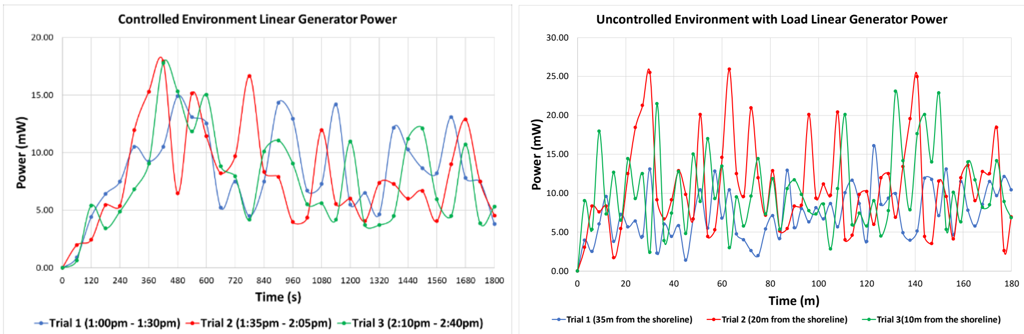

Fig. 4: Linear generated power in controlled and uncontrolled environment

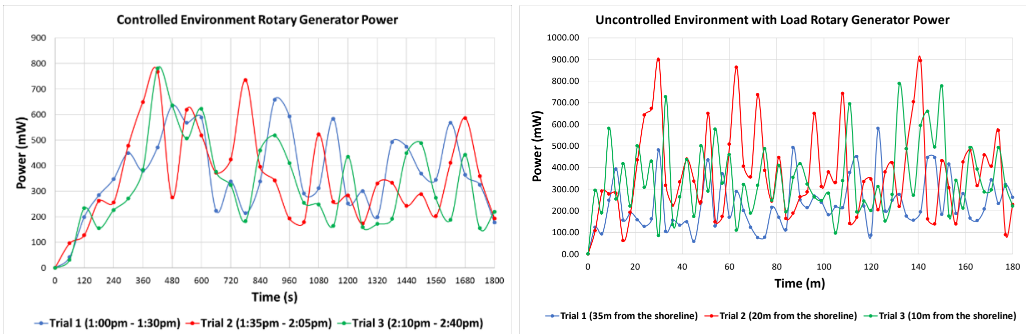

Fig. 5: Rotary generated power in controlled and uncontrolled environment

2.4. Conclusions

The researchers were able to achieve the main objective of the study which is to design and fabricate a wave energy conversion device applying the scotch yoke mechanism using linear and rotary generators capable of harnessing surface wave energy and converting it into electrical energy with a wireless monitoring system and its specific objectives.

As observed on the controlled environment, there is no statistical differences between the mean of linear and rotary generator in three trials. It is because the prototype received the same amount of wave height and crest. On the uncontrolled environment, it is a different scenario where it results to a significant statistical difference between the means of both linear and rotary in three trials. Trial 3 obtained the most generated power as it is deployed near shoreline while trial 1 obtained the least as it was deployed farthest among the trials.

It can be also observed that wave height and generated power are directly proportional to each other. The researchers conducted set of trials in both controlled and uncontrolled environment to evaluate the prototype effectiveness. Using the *trapz function*, the researchers were able to conclude that the prototype effectively generates power using both generators.

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4. References

[1] J. P. Sierra, C. Martín, C. Mösso, M. Mestres, and R. Jebbad, "Wave energy potential along the Atlantic coast of Morocco," Renew Energy, vol. 96, pp. 20–32, Oct. 2016, doi: 10.1016/j.renene.2016.04.071

[2] IEA (2021), Global Energy Review 2021, IEA, Paris https://www.iea.org/reports/global-energy-review-2021K. Elissa, "Title of paper if known," unpublished.

[3] "Republic act no. 9513: Govph," Official Gazette of the Republic of the Philippines,16-Dec-2008. [Online]. Available: https://www.officialgazette.gov.ph/2008/12/16/republic-act-no-9513/. [Accessed: 14-Jan-2023].

[4] López, J. Andreu, S. Ceballos, I. Martínez De Alegría, and I. Kortabarria, "Review of wave energy technologies and the necessary power-equipment," Renewable and Sustainable Energy Reviews, vol. 27. pp. 413–434, 2013. doi: 10.1016/j.rser.2013.07.009.

[5] K. Cruz, F. Dator, J. Ong, N. Bumanlag, and M. C. Pacis, "Harnessing of wave energy using axially magnetized linear generator with data logger using Gizduino microcontroller," Journal of Physics: Conference Series, vol. 1304, no. 1, p. 012013, 2019.

[6] J. R. M. Aves, P. N. M. Bacud, H. M. O. Canilang, D. V. P. Valera, G. Magwili and M. C. Pacis, "Integrated Wave Energy Conversion System by Linear and Rotary Generator with Energy Management and Monitoring using Raspberry Pi", 2019

[7] M. Pramoth Kumar, K. Akash, and M. Venkatesan, "Scotch-yoke mechanism for a syringe pump - A case study," IOP Conference Series: Materials Science and Engineering, vol. 149, p. 012221, 2016.