Analysis of linkage type sea wave power plant design through motion study and 3D printed modelling

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Abstract. Sustainable energy generation is becoming increasingly important because of the expected limitations in current energy resources and for reducing pollution. Wave energy generation has seen significant developments in recent years. This research has produced a linkage-type PLTGL design that utilizes ocean waves to raise and lower the float lever and move the linkage mechanism which then causes a back and forth movement of the rack gear which will rotate the pinion and cause the dynamo drive shaft to rotate. Using ocean wave data in the waters of Tanjung Berik, Bangka Tengah, and with the help of the SolidWorks application, this design is then simulated to determine the resulting movement and rotation. The rotation generated through the simulation can reach 532 Rpm with the assumption that it does not involve friction forces and material loads that exist in the PLTGL design. This design was made in 3D using the CR-10 V3 type 3D printing machine which produced a model with a scale of 25% of the original design. The model is used as a discussion material for designers to improve the design.

1. Introduction
Hasan et al. [1] conducted research that describe the examination of pattern power plants and emissions in Indonesia during a 23-year period, from 1987 to 2009. According to the findings of this study, Indonesia's power sector is still heavily reliant on fossil fuel resources, particularly diesel oil and coal, as key energy sources, which contributes significantly to the country's greenhouse gas emissions. Indonesia currently still relies on fossil fuels to generate electricity [2], while many alternative electricity producers are driven by nature, such as ocean waves. Ocean waves are a natural phenomenon at sea in which simply the ocean waves move up and down with an endless amount of supplies and the wind is the main factor in generating ocean waves. Electricity-generating technology that utilizes ocean waves has great advantages in addition to being friendly to environment, it can also be obtained free of charge. Research on the use of ocean waves has been widely carried out, among others, by Al Habaibeh [3], Uihlein [4], Wahyudie [5], Hidayati [6], Inovasita [7], and Kim [8]. The spirit of looking for new alternatives for ocean wave power producers has received support from the Government of Indonesia through the National Energy Management Plan 2005-2025 which targets 0.2% of electricity supply to come from ocean wave power [9].
Previous research on the analysis of ocean wave power plants (PLTGL) has been carried out by Ubed, Ari, and Nova [10]. This PLTGL utilizes ocean wave motion received by the buoy and then forwarded by the float lever which is connected directly to the link and rack so that the rack rotates the gear connected to the shaft or converts vertical motion into rotation, then the shaft is connected to the v-belt to the motor which will convert it into energy, electricity. Figure 1 shows the three PLTGL designs made by the three previous researchers, each using a combination of rack gear and link, rack and pinion system, and circular rack and pinion.

The PLTGL analysis uses wave data on the coast of Berikat, Bangka Island by using sea wave data from the Geospatial Information Agency (BIG) with the highest sea waves (1.22 meters) and the lowest (0.28 meters) in January 2019 period and by motion analysis using the SolidWorks application, it was found that the maximum rotation of the shaft was 29.16 RPM on the circular rack and pinion type [10].

Looking at the results of these studies, it is concluded that the rotations produced from the three designs are still not satisfactory to be able to drive a dynamo which can then generate electricity. There is something interesting from a study by Ubed that uses the linkage mechanism. To illustrate, linkage is a term used to describe a mechanism that can convert an up and down motion into a back and forth motion. The author assumes that through this linkage design, the back and forth motion applied to the linkage rack gear will be able to rotate the motor shaft higher than previous studies. For this reason, the design of PLTGL with the linkage type needs to be made and studied with motion analysis and utilizing 3D modeling with a 3D printing machine to be discussed further by the experts needed for the development of the PLTGL design.

2. Research Methodology
Designing and drawing the PLTGL mechanism is done through the SolidWorks application. Motion studies of the PLTGL design were also carried out with this application. There are several variables that will be used as fixed variables in the motion study data processing, including wave height and wave period. From the known variables, the variables that will later be used as the purpose of the design analysis are obtained, namely the frequency of the period, angular velocity, and rotation in RPM. Meanwhile, for the manufacture of 3D printing modeling is carried out with the help of the CR-10 V3 3D printing machine. The 3D printing process requires design data obtained from the PLTGL design and with certain parameters such as feeding and temperature as well as filament material from Polylactic acid (PLA) material with a printing temperature of 205°-225° Celsius.

The design of the PLTGL linkage has a maximum capacity at a sea wave height of 0.24 m. This has an impact when entering data into the simulation in the motion study data used using scaled data which is assumed to be the same as data from the Geospatial Information Agency.
3. Results and Discussion

3.1. PLTGL Linkage System Design

The design of the PLTGL linkage system was agreed upon by the PLTGL design team and made using the SolidWorks application. The dimensions of the PLTGL design are still in the estimation stage or only assumptions and do not take into account the mechanics of the material strength and the working forces. Figure 3 shows the results of the linkage type PLTGL design. There are three mechanisms that work here, namely the float lever mechanism, the linkage arm mechanism, and the shaft mechanism.

The movement mechanism of this float lever moves up and down according to the sinusoid of the wave (but in this study it is driven using a cam system). This lever is connected to the linkage arm mechanism which is the main component in this design. The movement of the scissor arm will move the connection arm, then this connection arm will pull and push the iron plate connection that has been connected to the rack gear, which later this mechanism will make the rack move back and forth and move the pinion gear. The last mechanism is the shaft mechanism. The back and forth movement of the rack gear is converted into one direction rotation with the help of a ratchet system mounted on the shaft after the pinion gear. This causes the shaft to only rotate in one direction and will eventually rotate a dynamo that has not yet been designed but is expected to use a belt and pulley transmission.
3.2. Motion study
Simulations in SolidWorks use a scale of 20% of the ocean wave size obtained from BIG. This is because the designs made have not taken into account the results of the realization of sea wave heights, while the designs that have been made have a limit of being able to rise to 0.24 meters. This situation causes the ocean wave data to be adjusted to the scale obtained by dividing the lowest wave divided by the highest, which is 20%. Furthermore, the highest value is 1.22 m x 20% = 0.245 m and the lowest value is 0.285 m x 20% = 0.057 m. The procedure for getting rotations per minute in the SolidWorks application, first the sea wave height data is converted to Frequency which is entered into the SolidWorks application and then the Angular Speed will appear which is then converted into rotations per minute after converting the units of deg/sec to rad/sec.

Figure 3. Linkage type PLTGL design

Figure 4. Simulation analysis procedure
Table 1 shows the results of the calculation values looking for frequency, angular speed, rotations per minute.

### Table 1. Motion study results

| No | Wave Heights (m) | Frequency (Hz) | Angular Speed (Deg/s) (Max) | Angular Speed (Deg/s) (Min) | Rotation Per Second (Rps) | Rotation Per Minute (Rpm) |
|----|------------------|----------------|-----------------------------|-----------------------------|------------------------|------------------------|
| 1  | 0.245            | 4.06           | 3192                        | 2822                        | 8.86                   | 532                    |
|    |                  |                | 7.83                        | 470                         |                        |                        |
| 2  | 0.057            | 1.12           | 520                         | 105                         | 1.44                   | 86.4                   |

The results of the rotation on the PLTGL design with the linkage type which is assumed to get a larger rotation than the previous research has proven to be true, the rotation produced is greater than the previous research with the assumption that there are no obstacles or frictional forces that occur from this design.

The height of the wave also affects the magnitude of the resulting rotation, the higher the wave, the greater the rotation of the shaft that can be generated, otherwise if the wave height is low, the rotational results on the shaft are also small. If the wave period is large, the resulting rotation is small, on the other hand, if the wave period is smaller, the greater the rotation will be. It is these two variables that have the most influence on rotation, namely waves with large heights and small periods that are best for applying this linkage type PLTGL design.

### 3.3 3D Printing Modelling

The linkage system PLTGL prototype model is made based on a design that has been simulated through the SolidWorks application. The model was made with the help of a CR-10 V3 type 3D printing machine. The parameters applied to this machine are a print temperature of 210 degrees Celsius with a print speed of 60 mm/second, and a layer height of 0.3 mm. The variation in the completion time of the eleven parts of the PLTGL model is from 11 minutes to 2 hours 55 minutes.

![](image.png)

**Figure 5. PLTGL Model**

The material used as the model material is a filament of polyactic acid (PLA). The advantage of this PLA is that it is easy to print and is not too sensitive to room temperature and not to water. All parts of
this model are not produced from the printing process with a 3D printing machine but are combined with other materials, namely aluminum plates and rivet fastening elements. As a result, this model is formed from a combination of PLA and aluminum plates and can be physically simulated for later discussion by designers to see possible improvements to the designs that have been made. The discussions that emerged in this PLTGL analysis were, among others:

- The movement of the mechanism in the PLTGL indicates a comparison of the scale of the movement between the up and down motion of the float with the horizontal linear motion of the gear rack. It is necessary to analyze the presence of acceleration in the horizontal linear movement of the gear rack.
- In the resulting model, the Arm 2 part needs to be redesigned to avoid a collision with the Scissors Arm 2 in the float position in the up position. The redesign results in maximum buoy lift and a linear motion step of the rack gear bar.

4. Conclusion

The linkage type PLTGL design has been produced with various assumptions that this design only looks from the point of view of the movement that converts the up and down motion of the buoy due to ocean waves to the back and forth motion of the gear rod that rotates the shaft to generate electrical power in a dynamo. Simulations in the SolidWorks application have helped designers to visually better see the movements in question and even know the final rotation of the driven shaft with certain limitations such as not involving the mechanical forces that occur in the PLTGL system. Furthermore, a 3D model is created to be able to see from the point of view of the PLTGL movement in three dimensions. This helps designers to decide important things to do in the future for this linkage type PLTGL product. The next research is expected to answer things that have not been accommodated in this study, for example the effect of friction on the final rotation of the shaft, the effect of variations in the characteristics of sea waves on the final result of the shaft rotation, as well as continuing the results that were made in the form of electric power and it was carried out by prototyping PLTGL.

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