JPPIPA 10(3) (2024)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Development of Photovoltaic Power Plant Prototype as a Learning Media on The Subject of Renewable Energy

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Received: December 14, 2023
Revised: January 26, 2024
Accepted: March 25, 2024
Published: March 31, 2024

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DOI: 10.29303/jppipa.v10i3.6580

Abstract: Renewable Energy needs to be implemented in schools to build students' knowledge. This research aims to design a prototype of a Photovoltaic Power Plant (PLTS), which can be used as a medium for experimental high school physics activities. Besides that, the effect of light intensity on the power produced by the PLTS prototype was experimentally tested by observing temperature, humidity, and air pressure. The PLTS prototype is designed to be simple, with component selection (10 wp solar panels, SCC, batteries, lights and panel boxes) that are adapted to the learning media criteria, namely practical, durable, easy to use and able to demonstrate the concepts being taught. The PLTS prototype was tested when charging and discharging the battery. When charging the battery, the solar panel is tilted with a variety of tilt angles of 0°, 15°, 30°, 45° and 60°. When discharging the battery, lamps with varying powers are used, namely 3W, 5W, 7W and 9W. The research results show that the panel tilt angle is used to produce maximum voltage, current, and power when charging the battery, which is 30°. When the battery is discharged, a smaller lamp power can light the lamp for longer compared to a larger lamp power. In conclusion, the PLTS prototype can provide students with experience in conducting experiments and learning the application of physics concepts directly so that it can build students' knowledge and provide meaningful learning.

Keywords: Charging and discharging battery; PLTS Prototype; Renewable Energy

Introduction

Non-renewable energy sources, such as fossil energy, are available in limited quantities and are in decreasing supply. In addition, non-renewable energy contributes 76% of carbon dioxide which can influence climate change due to greenhouse gas effects (Denchak, 2023). Reducing reliance on fossil fuels and cutting costs while maintaining high electrical energy stability in the system are the key objectives of starting the use of renewable energy (Jaisin et al., 2019; Smirnov et al., 2021). Transitioning to renewable energy solves the energy crisis and has several advantages, including preventing drastic climate change (REN21, 2019). According to the Intergovernmental Panel on Climate Change (IPCC), we must halve greenhouse gas pollution by 2030 and achieve zero emissions by 2050 (IPCC, 2014).

The importance of insight into renewable energy must be carried out in education to broaden students' horizons, who will become the nation's next generation (Abdilah, 2022). The Merdeka curriculum emphasizes that educators can apply relevant learning, one of which is to the environment around them so that students are expected to be able to apply the theory they have acquired and be able to find potential energy sources in the environment around where they live (Kemdikbudristek, 2022). The Merdeka curriculum has three advantages, it is more straightforward, comprehensive, autonomous, pertinent, and interactive (Azhari et al., 2023). The concept of renewable energy is also discussed in the independent curriculum, namely in Fase E or Class 10, which contains energy material, forms of energy, the law of conservation of energy, energy conversion, the urgency of the issue of energy needs, renewable and non-renewable energy sources,

How to Cite:
Azizah, F., & Khotimah, S. N. (2024). Development of Photovoltaic Power Plant Prototype as a Learning Media on The Subject of Renewable Energy. *Jurnal Penelitian Pendidikan IPA*, *10*(3), 1469-1478. https://doi.org/10.29303/jppipa.v10i3.6580

the impact of energy exploration and use, and efforts to meet energy needs. In fact, students' knowledge about energy in daily life is included in the low category (Ilmi et al., 2020).

Interactive learning media is needed so that students can understand the concept of renewable energy and apply it. Interactive learning media can create a fun and meaningful learning environment (Daryanes et al., 2023). The importance of interactive learning media, such as prototypes used in the teaching and learning process, can help students understand and apply concepts more easily (Teran et al., 2021). Apart from that, the advantages of interactive learning media can increase students' active participation in the learning process (Atmajaya, 2017).

One type of renewable energy that can be easily applied in Indonesia is Solar Power Plant (PLTS) because Indonesia is a tropical country where solar energy is easy to obtain and the best readily available natural energy (Sun Energy, 2021; Sari et al., 2023). Indonesia has energy potential from the sun of 4.8 kWh/m2 per day (National Energy Council, 2020). Apart from that, this PLTS discussion can be easily taught to students. PLTS uses solar panels as one of its main components to convert energy from the sun into electrical energy. Solar panels consist of three generations: the first generation based on inorganics, the second generation based on a thin layer, and the third generation based on sensitized dyes. The first generation of solar panels was made from inorganic materials, such as polycrystalline silicon, which had an efficiency of around 13% - 16% (Energy Informative, 2013).

Other simple components for designing a PLTS system are the Solar Charge Controller (SCC) and battery. SCC regulates battery charging by regulating the charging voltage and current based on the power available from the photovoltaic module. The function of the battery is to temporarily store energy produced by the photovoltaic module, to supply power used by the load (Ramadhani, 2018).

Charging of the batteries connected to the system occurs when excess energy is generated by the photovoltaic module, ensuring that energy is not wasted. Battery discharge occurs when the solar PV system takes power from the battery to electrical devices with insufficient sunlight. Efficient battery charging and discharging are critical to maintaining the performance and reliability of solar PV systems (Anethic, 2023; Tao et al., 2012).

The basic principle of PLTS technology is the photovoltaic effect. The photovoltaic effect generates voltage and electric current by solar cells after absorbing photon energy, which can excite electrons. Electric current can arise because photon energy absorbed by solar cells produces free electrons (Khalil, 2004). Solar cells consist of two types of semiconductors, p-type and n-type, which are joined by creating a P-N junction. When a P-N junction semiconductor is illuminated with light, electrons and holes can be released in the semiconductor. Excess charge will cause this charge to move due to the electric field in the depletion area (Electronics-tutorial, 2014).

One parameter that can influence the performance of solar panels is the panel tilt angle (Samsurizal et al., 2018; Angin et al., 2023). Solar panels can receive the maximum intensity of solar radiation if the tilt angle of the solar panels is set optimally (Shen et al., 2018; Rahmawati et al., 2020). You need to know the tilt angle of the solar panel to produce maximum power when using it (Sugiono et al., 2022).

Making a PLTS prototype is needed for physics experimental activities for students regarding renewable energy concepts (Young et al., 2014; Zhao & Niu, 2023; Frank et al., 2022). Physics learning is less varied, and experiments are rarely carried out, resulting in low student literacy regarding renewable energy (Yuliarti et al., 2023). Experimental activities can improve students' comprehension and learning of ideas related to renewable energy concepts (Pantchenko et al., 2011; DeWaters & Powers, 2011; Rachmanita & Ulma, 2022). This resulted in students becoming more independent and capable of constructivist learning activities (Nikolic et al., 2015; Alqahtani et al., 2018).

PLTS experiments can be outdoor or indoor. Indoor PLTS experiments can use halogen light bulbs as a substitute for solar radiation (Mansur et al., 2020; Dafalla et al., 2016; Milenov et al., 2020). Meanwhile, outdoor PLTS experiments can use direct natural sunlight. This research uses outdoor experiments because the students can find out directly about the PLTS system, which is widely used in society.

Based on the background described, this research aims to design learning media for physics experimental activities about renewable energy for high school students in the form of a PLTS prototype. The PLTS prototype was tested when charging and discharging the battery. When charging the battery, the solar panel is tilted with a variety of tilt angles of 0º, 15º, 30º, 45º and 60º. When discharging the battery, lamps with varying powers are used, namely 3W, 5W, 7W and 9W.

Method

The method used in this study is research and development (R&D), as proposed by Borg and Gall (2003), and it has been adapted to suit the research objectives. This method is a process used to produce a product according to the context and limitations of the research. At this point, this research is designing the PLTS prototype, conducting experiments and collecting data. The flow of this research can be seen in the following Figure 1.

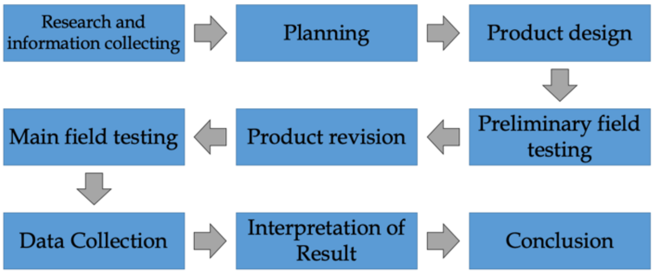


Figure 1. Research flow.

The PLTS experimental prototype consists of various components, which are assembled into a prototype that is simple and easy to implement for students. The design of the PLTS prototype circuit is shown in Figure 2. The following are several components used to make the PLTS experimental prototype, including 10wp (watt peak, namely the peak power produced) solar panels made from Silicon Polycrystalline (first generation), Solar Charge Controller (SCC) 10A, battery (valve-regulated lead-acid 12V), 1 set of lights (DC 12V, 3W/5W/7W/9W), volt amperage display meter, solar panel support (50cm×2.4cm), additional electrical components (470μF capacitor and IC 7812), connecting cable, box (24.3cm×13cm×25cm), protractor (d = 20 cm).

The initial trial stage must be carried out to determine the PLTS experimental prototype that previous plans and designs have made. At this stage, we check whether the PLTS experimental prototype created is suitable for collecting experimental data. At this stage, measuring tools are added as applications from the Play Store, namely the Lux Light Meter to measure light intensity and the Humidity and Temperature meter application to measure temperature, humidity, and air pressure. Figure 3 displays the applications available on the Play Store, which can be downloaded for free.

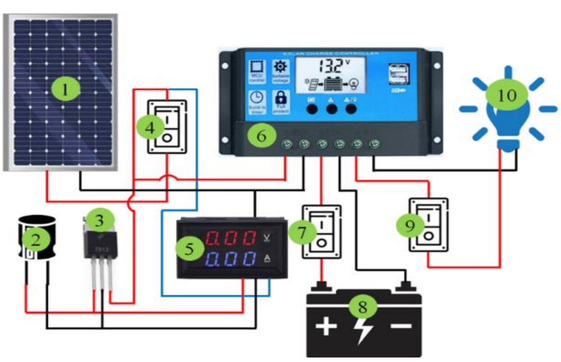


Figure 2. PLTS prototype circuit design.

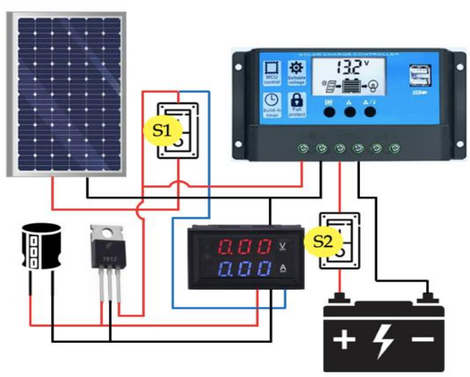
Information:
1. Solar panels
2. 470μF capacitor
3. IC 7812
4. Solar panel switch
5. Multimeter display
6. SCC
7. Battery Switch
8. Battery
9. Light Switch
10. DC Lamp

(a) (b)

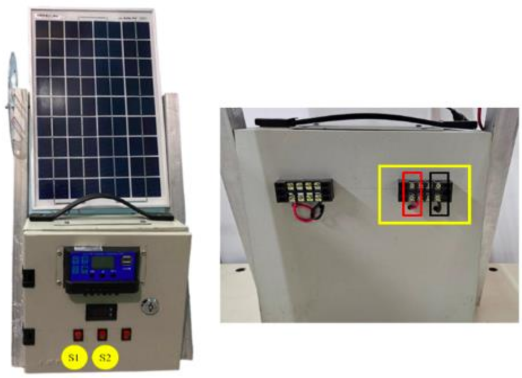
Figure 3. (a) lux light meter dan (b) humidity and temperature meter.

Observations of the light intensity and power produced by the PLTS experimental prototype need to be conducted to determine the relationship between the two. The observation procedure for charging the battery is as follows: 1) Connect the solar panel cable to the PLTS prototype box according to the circuit according to Figures 4 (a) and 3 (b). On the back of the PLTS prototype box on the right (marked with a yellow box), the solar panel connecting cable is red (+) connected to the line on the red PLTS prototype box (marked with a red box), as well as the black solar panel connecting cable (-) connected to the line on the black PLTS prototype box (marked with a black box). 2) Adjust the tilt degree of the solar panel according to Figure 6. 3) Turn the battery switch (S2) to on (1 is pressed). 4) Turn the panel switch (S1) to on (1 is pressed). 5) Observe and record the data on the voltage (volts) and current (amperes) display every 10 minutes. 6) At the same time as Step 5. data on sunlight intensity, humidity, temperature, and air pressure are recorded.

(a)



(b)



Front Back

Figure 4. Battery charging circuit (a) PLTS prototype circuit design and (b) front and back views of the PLTS prototype box.

The degree of tilt of the solar panel in the second observation procedure for charging the battery is set at a tilt degree of 0°, 15°, 30°, 45° and 60°. Observations of battery charging were carried out for five consecutive days on July 17 – 21, 2023, for each degree of tilt of the solar panel. The 0° angle will be carried out on July 17, 2023; the 15° tilt will be carried out on July 18, 2023; the 30° tip will be carried out on July 19, 2023; the 45° angle will be carried out on July 20, 2023, and the 60° tilt will be carried out on July 21, 2023, the following is an illustration of the tilt of the solar panel (0° on the horizontal line and 90° on the vertical line) and the inclination for each degree:

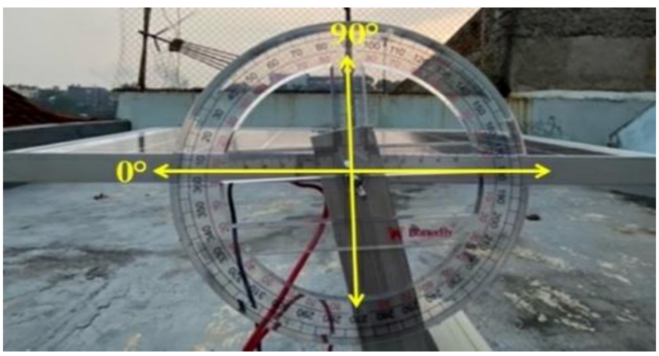


Figure 5. An illustration of the position of the solar panel tilt degrees 0° and 90°.

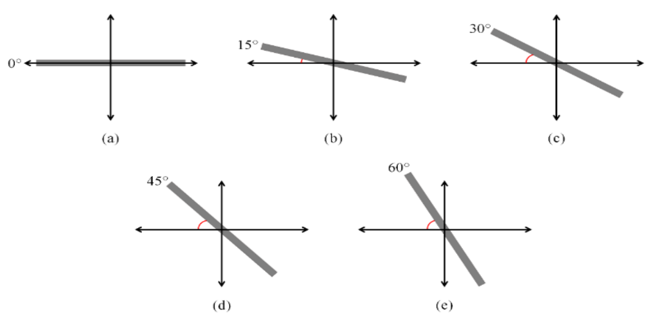
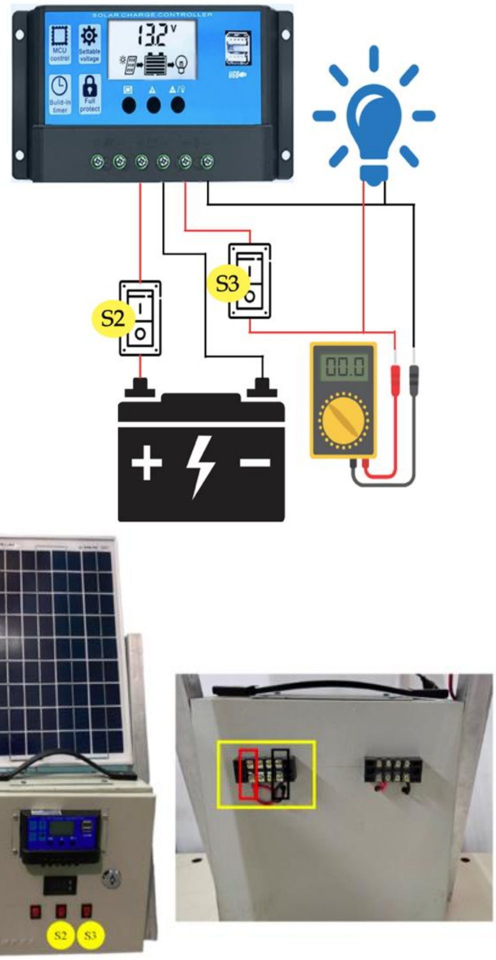


Figure 6. Illustration of the position of each degree of tilt of the solar panel (a) 0°, (b) 15°, (c) 30°, (d) 45°, and (e) 60°.

(a)

(b)



Front Back

Figure 7. Battery discharge circuit (a) PLTS prototype circuit design and (b) front and back views of the PLTS prototype box.

The observation procedure for discharging the battery is as follows: 1) Connect the cable connecting the lamp or load and multimeter to the PLTS prototype box according to the circuit according to Figure 7 (a) and Figure 7 (b) on the back of the PLTS prototype box on the left (marked with a yellow box), the cable connecting the lamp and multimeter red (+) is connected to the cable on the red PLTS prototype box (marked with a red box), as well as the cable connecting the lamp and multimeter black (-) is connected to the cable on the black PLTS prototype box (marked with a black box). 2) Turn the battery switch (S2) to on (1 is pressed). 3) Turn the light or load switch (S3) to on (1 is pressed). 4) Observe and record the data shown by the multimeter, namely voltage (volts) and current (amperes) every 10 minutes. 5) At the same time as Step 4. the light intensity data is recorded.

The data obtained in this experiment are voltage (V), current (I), sunlight intensity, humidity, temperature, air pressure, and lamp light intensity. The voltage (V) and current (I) are obtained from the solar panel circuit for charging and discharging the battery. Voltage (V) and current (I) produce power data using Equation 1.

$$P = V \times I \quad (1)$$

where,
P = power (W)
V = voltage ($volt$)
I = current (A).

The efficiency of solar panels can be determined by calculating the ratio of power output to power input. Several parameters used to assess the efficiency of solar panels are open circuit voltage (V_{OC}), short circuit current (I_{SC}), and fill factor (FF) (Chen, 2011) (Bisquert, 2020). To determine the efficiency of solar panels, first select the input power using the following equation:

$$P_{in} = I \times A \quad (2)$$

where,
P_{in} = power input (W)
I = solar radiation intensity (W/m^2)
A = panel area (m^2)

Then, determine the FF first to decide on the output power using the following equation:

$$FF = \frac{V_{mp} I_{mp}}{V_{OC} I_{SC}} \quad (3)$$

where,
FF = fill factor
V_{mp} = max voltage ($volt$)
I_{mp} = max current (A)
V_{OC} = open circuit voltage ($volt$)
I_{SC} = short circuit current (A)
FF can be shown in Figure 8 (Al-Jumaili, 2019).

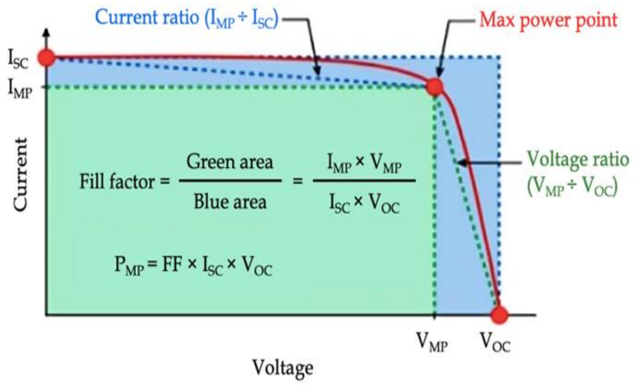


Figure 8. Fill factor on solar panels

After obtaining the FF, the output power can be determined using the following equation:

$$P_{out} = V_{OC} \times I_{SC} \times FF \quad (4)$$

where,
P_{out} = power output (W)

So, to calculate solar panel efficiency η (%), the following equation can be used:

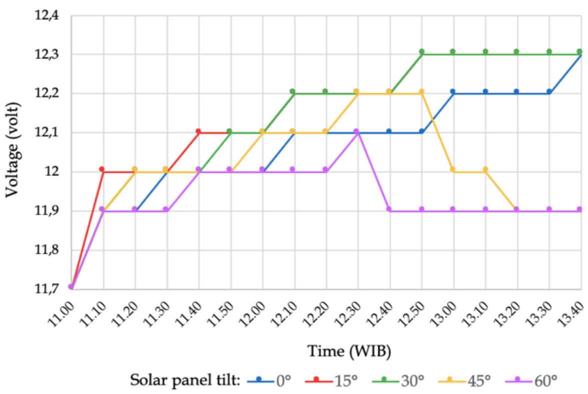
$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \quad (5)$$

Result and Discussion

This observation measured voltage, current, sunlight intensity, temperature, humidity, and air pressure in the battery charging circuit using a PLTS prototype. This observation was conducted to determine the power generated from the PLTS prototype. The power produced by solar panels results from calculations using Equation 1.

This observation was carried out on Jl. Kebon Bibit Utara No. 99, Tamansari, Bandung Wetan, with a geographical location of 6°53'47.0544" South Latitude and 107°36'24.5376" East Longitude, this location comes from Google Maps, which was converted from a coordinate system of decimal degrees (DD) to degrees minute seconds (DMS). These observations were conducted outdoors at 11.00 - 13.40 WIB on five consecutive days.

Based on the observation location, to obtain optimal sunlight intensity, the solar panels on the PLTS prototype are directed towards the equator, namely towards the north because the observation location is south of the equator. Based on this observation location, the solar panels on the PLTS prototype were tilted by 0°, 15°, 30°, 45°, and 60° to determine the power produced at each tilt of the solar panels.



(a)

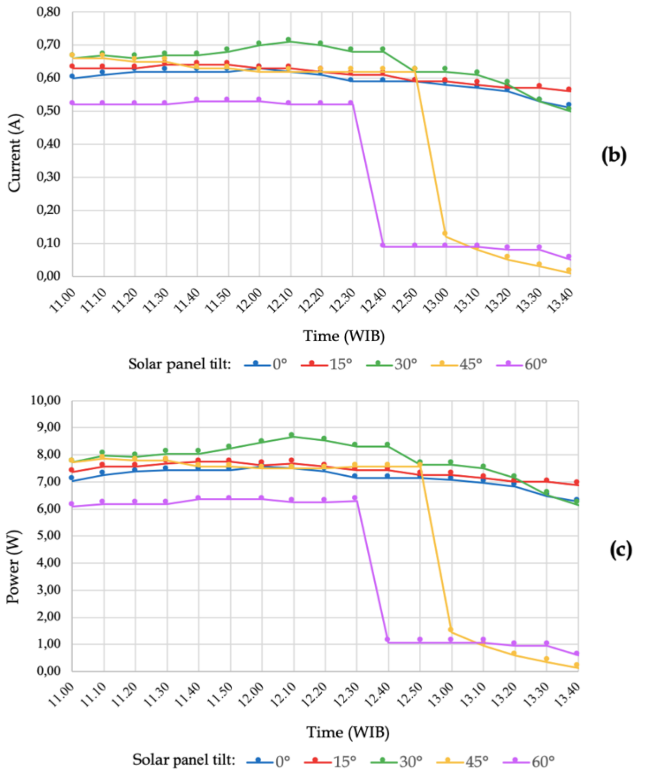


Figure 9. Graph against time when charging (a) voltage, (b) current, and (c) power.

Based on the graph in Figure 9 (a), the initial voltage was obtained at 11.7 volts at 11.00 WIB at all degrees of tilt of the solar panel (0º on Monday, 15º on Tuesday, 30º on Wednesday, 45º on Thursday, and 60º on Friday) and the final voltage at 16.30 WIB was 12.3 volts for 0º, 15º and 30º, and 11.9 volts for 45º and 60º. The graph in Figure 9 (a) shows that the voltage on the solar panel increases as the charging time increases. However, the voltage decreases when the battery is charged at solar panel tilt degrees of 45º and 60º. At 45º, the solar panel's tilt degree decreases at 12.50 WIB on Thursday, and 60º reduces at 12.30 WIB on Friday. This could be because the intensity of sunlight received by the solar panels on that day is decreasing (clouds cover the sun and are overcast). Figure 9 (a) shows the results that the degree of tilt of the solar panel to produce the best voltage during charging is 15º and 30º.

Based on Figure 9 (b), the initial current varies for each degree of tilt of the solar panel at 11.00 WIB, namely 0.6 A at a tilt degree of 0º, 0.63 A at a tilt degree of 15º, 0.66 A at a tilt degree of 30º and 45º, and 0.52 A at a tilt degree of 60º. In Figure 9 (b), the results show that as the charging time increases, the current produced by the solar panel decreases. Figure 9 (b) shows the results that the degree of tilt of the solar panel to have the best current during charging is 30º.

Based on Figure 9 (c), the initial power that varies for each degree of tilt of the solar panel at 11.00 WIB is 7.02 W at a tilt of 0º, 7.37 W at a tilt of 15º, 7.72 A at a tilt degree of 30º and 45º, and 6.08 W at an inclination of 60º. Figure 9 (c) shows that the longer the charging time increases, the less power the solar panel produces. This could be due to the influence of the current, which is also decreasing. Figure 9 (c) shows the results that the degree of tilt of the solar panels to produce the best power is 30º.

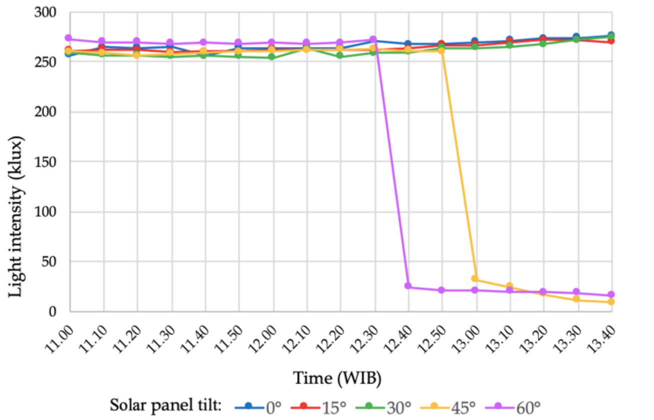


Figure 10. Graph the relationship between light intensity and time for each solar panel tilt when charging the battery.

The graph in Figure 10 was taken sequentially on July 17 – 21, 2023, for each solar panel tilt. The chart with the solar panel tilt degrees 0°, 15°, and 30° shows that the light intensity increases and decreases between 250 – 300 klux. The graph with a solar panel tilt of 45° shows that the light intensity decreased drastically at 13.00 WIB and continued to decrease until it approached 0 klux at 13.40 WIB. The graph with a solar panel tilt of 60° shows that the light intensity decreased drastically at 12.40 WIB and continued to decrease until it approached 0 klux at 13.40 WIB. The drastic reduction in the two degrees of inclination of the solar panels, 45° and 60°, is caused by the sun being blocked by clouds.

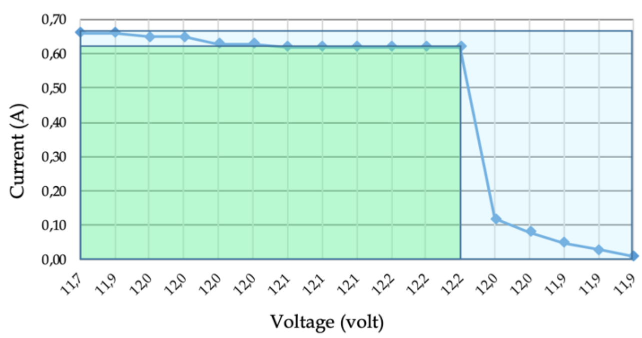


Figure 11. Fill factor (FF) in the graph of the relationship between current and voltage at a solar panel tilt of 45° when charging the battery.

Figure 11 depicts the fill factor (FF) in the green area when observing battery charging using a PLTS prototype with a solar panel tilt 45º. The FF value obtained using this PLTS prototype is 0.63. Meanwhile, the FF value in the specifications of solar panel is 0.74. Compared with the FF value on the solar panel and at the time of observation, the FF value at the time of word is still close to the FF value of the solar panel in ideal conditions. Then, the efficiency value of the solar panels used is based on solar panel specification data, namely 9.81%.

Furthermore, observations for discharging the battery using the PLTS prototype measured voltage, current, and lamp intensity with different lamp power variations, namely 3W, 5W, 7W, and 9W. This observation was carried out for 3 hours with an interval of every 10 minutes. This observation was conducted to determine the power generated from the PLTS prototype. The power produced when discharging the battery using the PLTS prototype results from calculations using Equation 1.

Table 1. Battery discharge results for each type of light power on the PLTS prototype.

Type of lamp	Light intensity (lux)		Power (mW)	
	Initial	Final	Initial	Final
3W	446	391	13.76	13.27
5W	680	629	18.84	17.52
7W	715	582	19.22	16.40
9W	762	679	19.85	18.50

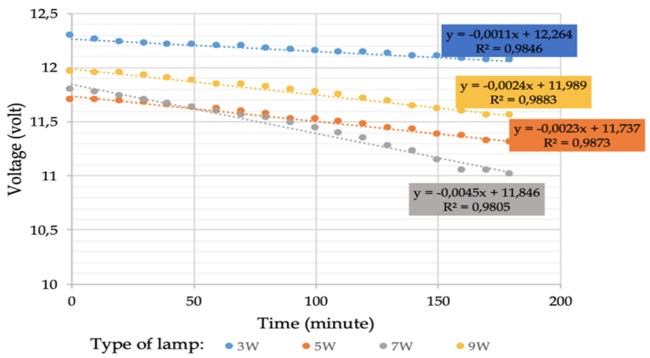


Figure 12. Graph the relationship between voltage and time for each type of lamp power when the battery is discharged.

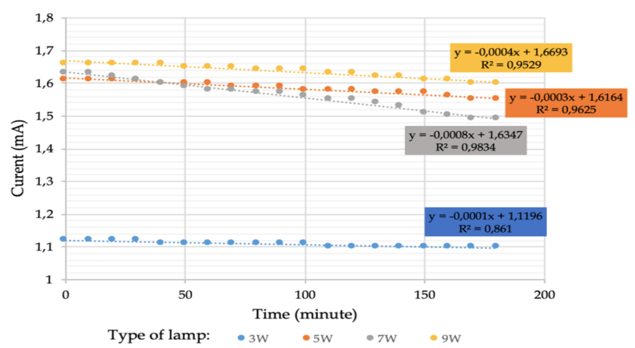


Figure 13. Graph of the relationship between current and time for each type of lamp power when the battery is discharged.

Figure 12 and Figure 13 show the voltage, current, and initial power that are different for each type of lamp used. The initial voltage that appears is the initial battery voltage when the battery is discharged. The voltage decreases for each kind of lamp when the battery is discharged. The largest voltage drop occurs at the type of 7W lamp. Furthermore, the current that flows to turn on the lamp shows a different initial current for each type of lamp. This also indicates that the higher the current flowing through the lamp, the brighter the light produced (seen from the intensity of the initial lamp light). The dimmest light is 3W, and the brightest is 9W.

Then, based on Table 1, the differences in initial power for each type of lamp are also shown. This initial power shows the power required for each type of lamp to turn on the light. The initial power of a 3W lamp is smaller than a 5W lamp, the initial power of a 5W lamp is smaller than a 7W lamp, and the initial power of a 7W lamp is smaller than a 9W lamp. A smaller lamp power can keep the lamp on longer than a larger one.

Conclusion

The PLTS prototype carried out several variable variations, such as the tilt of the solar panel when charging the battery and various types of light power used when discharging the battery. Based on the results of experiments and analysis, it was found that the degree of tilt of the panel to produce maximum voltage and current when charging the battery is 30°. When discharging the battery, lamps with power variations of 3W, 5W, 7W, and 9W are used, indicating that the smaller the lamp power used, the smaller the power required to light the lamp so that a smaller lamp power can burn longer when compared to greater light power. The PLTS prototype can be used as a learning media for renewable energy concepts to provide students with the experience of conducting experiments and studying the application of physics concepts directly to build students' knowledge and provide meaningful learning.

Acknowledgments
Thanks to the physics lecturers at FMIPA, Bandung Institute of Technology.

Author Contributions
The authors in this research are divided into executor and advisor.

Funding
This research received no external funding.

Conflicts of Interest
The author declares no conflict of interest in this research.

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