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Prototype of an Auto Cutoff Battery Charging System Using Solar Panels

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Abstract
Solar panels are devices that convert solar energy into electrical power. The use of solar panels is typically coupled with batteries for energy storage. While short charging times are desirable in battery power systems, improper charging can damage both the system and the battery. Batteries play a critical role as energy sources when sunlight intensity is low, making optimized charging essential for maximizing battery performance as energy storage devices. This study aims to design and evaluate a fast-charging battery controller with an automatic shutoff system using solar panels. The controller is based on constant current and voltage (CCV) control principles, utilizing a buck-boost converter to stabilize the solar panel output voltage at 5 volts. The research methodology involved designing a prototype system comprising a 5WP solar panel, XL6009 buck-boost converter, TP4056 charging module, and a 2400mAh Li-Po 18650 battery. Testing was conducted over three days in January 2025 in Angsana Village, South Kalimantan, with data collection at different time periods (08.00–11.00, 12.00–14.00, and 15.00–18.00 WITA) to evaluate system performance under varying solar irradiation conditions. The results demonstrate that the charging time for a 2400mAh battery is approximately 2–3 hours under optimal solar irradiation conditions. The controller exhibits high accuracy and effectively prevents overcharging. The system employs a dual-indicator mechanism: a red LED illuminates during the charging process, while a blue LED activates when the battery reaches full charge or when the auto-cutoff mode engages at 4.2 volts.

Keywords: solar panels, Overcharging Battery, Buck Converter, battery charging, Auto Cutoff

INTRODUCTION

Electrical energy is very important for human life. Almost all human activities require electricity, from using mobile phones and laptops to powering lights in homes. The Ministry of Energy and Mineral Resources (EMR) revealed that the projected domestic electricity demand in 2024 will increase by 3.6% to 4.2% compared to 2023, reaching 283.12 terawatt hours (TWh).

Based on the increasing energy needs, it is necessary to develop alternative energy sources that are affordable, pollution-free, and natural (Algarni, Tirth, Alqahtani, Alshehery, & Kshirsagar, 2023; Bhuvanesh, Christa, Kannan, & Pandiyan, 2018; Maiti, Karan, Kim, & Khatua, 2019; Nautiyal & Ramlal, 2021; Singh, 2024). Data from the Directorate General of New Renewable Energy and Energy Conservation (EBTKE) show that Indonesia has a new renewable energy potential of 441.7 GW. Meanwhile, the realized potential of renewable energy as of now is 8.89 GW. This indicates that Indonesia still has much work to do in the renewable energy sector. One of the key sources of renewable energy is photovoltaic, or more commonly known as solar power (Mammadov, Ganiyeva, & Aliyeva, 2022; Nwaigwe, Mutabilwa, & Dintwa, 2019; Sahu, 2015).

Solar panels or Photovoltaic (PV) technology function to directly convert solar radiation into electrical energy. In a solar module, a solar panel consists of several solar cells that can be arranged in series or parallel to increase voltage or current output as needed.

However, the use of solar energy encounters several issues, mainly seasonal changes and environmental factors that affect energy production. Therefore, using batteries as an energy storage medium is essential. The power generated from solar energy through the charging process can be stored in batteries and used directly for electrical energy needs.

The output voltage produced by solar panels is direct current (DC), which makes it a renewable energy source suitable for battery charging (García-Triviño, Torreglosa, Fernández-Ramírez, & Jurado, 2016; Gupta et al., 2021). However, in a solar panel system, several components are required to regulate, stabilize, and limit the energy produced. These components ensure that the electricity generated is safe and efficient for charging.

Previous research has explored various aspects of solar panel battery charging systems. Ainun Lina Huda Nur Syahadhah et al. (2021) conducted monitoring on the storage process and battery discharge from solar panels using a 50WP solar panel system integrated with a renewable energy smart trolley. However, their study did not implement a battery charging safety system, resulting in uncontrolled charging (overcharging) when the battery reached full capacity, as the system lacked an automatic cutoff mechanism. Similarly, Muhammad Iqsan Fauzi et al. (2022) designed a solar garden lighting and mobile phone charging system for open green parks, but their focus was primarily on dual functionality rather than optimizing charging safety and efficiency. Irwan Heryanto et al. (2020) analyzed the continuity of electricity supply in hybrid systems combining rooftop solar panels with PLN sources, emphasizing energy supply reliability but not addressing battery protection during the charging process.

These studies highlight a critical gap in solar battery charging system research: while various applications and energy management strategies have been explored, the integration of fast charging with automatic overcharge protection remains underexamined—particularly for small-scale portable battery systems. Overcharging poses significant risks, including reduced battery lifespan, thermal runaway, and potential safety hazards—issues that become increasingly important as the adoption of solar-powered portable devices grows (Daag, 2025; Hasan et al., 2023; Li et al., 2025; Nwaigwe et al., 2019; Wadekar & Mittal, 2025).

The urgency of this research stems from the growing reliance on portable electronic devices and the increasing adoption of solar energy as a sustainable charging solution. Without proper charging control mechanisms, battery degradation accelerates, leading to premature replacement costs and increased electronic waste. Furthermore, Indonesia's strategic position near the equator provides abundant solar irradiation, making it essential to develop optimized solar charging systems that can safely harness this renewable resource.

The novelty of this study lies in the integration of constant current and voltage (CCV) control with an automatic cutoff system specifically designed for small-capacity Li-Po batteries charged by solar panels. Unlike previous studies that focused primarily on monitoring or hybrid systems, this research addresses the complete charging safety cycle—from voltage stabilization through buck-boost conversion to intelligent charge termination at the safe threshold of 4.2 volts. The system employs a TP4056 charging module combined with an XL6009 converter to ensure a stable 5-volt input regardless of solar irradiation fluctuations—a configuration not comprehensively evaluated in existing literature for this battery capacity range.

Therefore, the author deems it necessary to carry out this study to develop an efficient and safe solar-powered battery charging system that prevents overcharging while optimizing charging time (Balal, 2023; Hasan et al., 2023; Heeraman, Kalyani, & Amala, 2024; Ullah et al., 2024; ur Rehman et al., 2025). The study aims to provide a practical solution for portable renewable energy applications and contribute to the body of knowledge on intelligent solar charging systems.

This forms the basis for the author to conduct research on the benefits of solar panels in battery charging through a scientific paper entitled *Prototype of an Auto Cutoff Battery Charging System Using Solar Panels*.

Based on the background above, the limitations of the study are as follows: the research focuses on measuring the performance of the battery charger circuit in the auto cutoff system using an electrical source from solar panels. The main parameter of this study is the use of solar panels as an alternative energy source for battery charging. The research was carried out during the daytime until sunset to analyze the output of the battery charging system and solar panels to determine the most effective duration and timing for battery charging.

Referring to the background, the problem formulation of this study includes several key questions: how can a circuit be designed to carry out the charging process of an auto cutoff battery using an electrical source from solar panels? Which solar panel configuration is most effective for charging Li-Po 18650 batteries? How long does it take for a solar panel to fully charge a battery with a capacity of 2400 mAh? These questions guide the investigation toward developing a reliable and efficient solar-based charging system that ensures safety, effectiveness, and practicality in operation.

The objectives of this research are to determine the design of a battery charging circuit capable of performing the auto cutoff process using an electrical source from solar panels, to identify the most effective solar panel configuration for charging batteries, and to analyze the charging duration and amount of electrical energy required to fully charge a 2400 mAh battery. The benefits of this study are expected to include a better understanding of the battery charger design with an auto cutoff system using solar energy, an assessment of the effectiveness of solar panels as an energy source for charging, and insights into the optimal time required to fully charge batteries using a solar panel setup.

METHOD

This research was carried out on the terrace of a house with an open roof in Angsana Village, Angsana District, Tanah Bumbu Regency, South Kalimantan for three months, namely January to March 2025, with data collection for three days. The location selection was carried out so that the research equipment could be easily monitored and obtain maximum exposure to sunlight. The research procedure begins with the identification of problems related to new and renewable energy systems using solar panels, followed by literature studies from books, journals, proceedings, and online resources regarding solar panels, batteries, and charger series. The next stage is the design of the tool model by determining components such as solar panels, converters, and batteries, then testing is carried out to determine the performance of the system. The test results are analyzed through the data obtained and compiled in reports. The system is designed using a 5 WP solar panel connected to a buck-boost converter circuit to stabilize the voltage to 5 volts before being fed to the TP4056 charger module which functions to regulate the charging of 3.7 volts to the safe limit of 4.2 volts with an auto cut off system. Calculations show that an energy requirement of 4,284 Wh is required for a full charge of a 2.4 Ah battery in about 2.4 hours, so only one solar panel with a capacity of 5 Wh is needed. The assembly is carried out by connecting the solar panel to the XL6009 converter, the TP4056 module, the battery, and the VA meter to monitor the voltage and current. The prototype was then implemented at the research site to be tested in real conditions, including weather factors and panel mounting positions. The test was carried out for three days by taking voltage and current data at different hours, namely 12.00–14.00 WITA, 15.00–18.00 WITA, and 08.00–11.00 WITA. From the results of simulation and testing, the system performance was analyzed by comparing the power output, current, and voltage from the solar panel to the battery charging needs so that conclusions were drawn about the effectiveness of the auto cut off battery charging system using solar panels.

RESULT AND DISCUSSION

Discussion

1. Solar panel voltage testing

The first test is the solar panel voltage test to determine the performance of the solar panel in absorbing sunlight. The test results can be seen in the table below:

Table 1. Solar panel output voltage table

Time (WITA) 22 Jan 2025	Weather Conditions	Solar Panel Voltage (Volts)
12.00	Bright	11.01
12.30	Bright	11.01
13.00	Bright	11.01
13.30	Bright	11.01
14.00	Overcast	5.00
14.30	Overcast	11.01
15.00	Overcast	10.80

Source: Experimental data collection (2025)

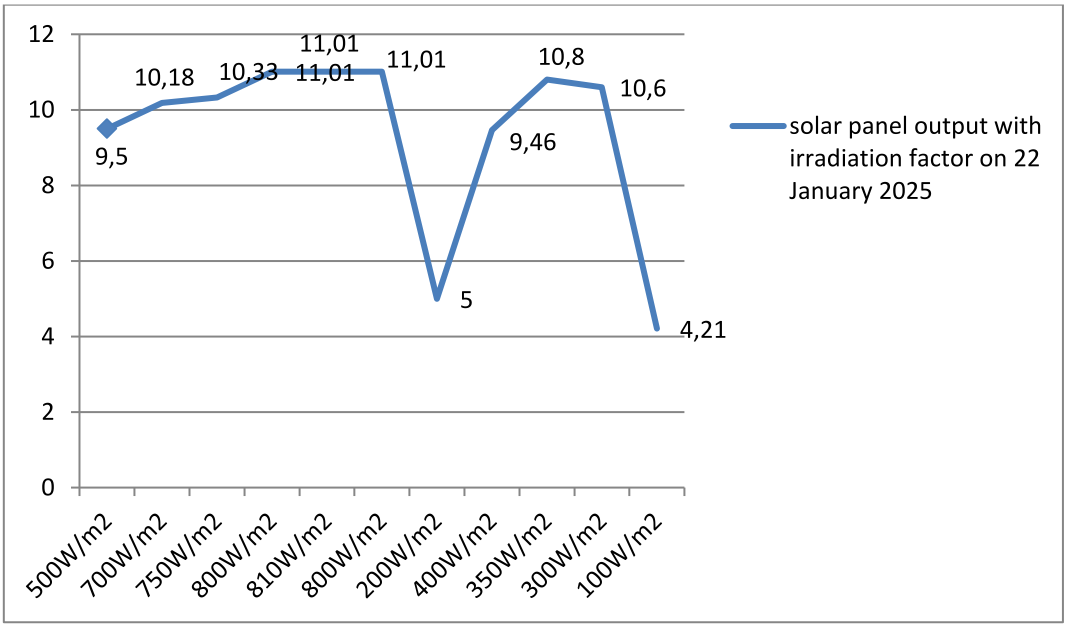

Figure 1. Solar panel output voltage irradiation factor

Source: Experimental data collection (2025)

2. Testing Converter XL6009

The test aims to determine the performance of the XL6009 Converter based on the output voltage of the Converter at the time the solar panel is applied. The test results can be seen in the table below:

Table 2. Conv output voltage table. XL6009

Time (WITA) 20 Jan 2025	Weather Conditions	Solar Panel Voltage (Volts)	Conv. XL6009 Output Voltage (Volts)
08.00	Bright	9.20	5.1
08.30	Bright	9.77	5.1
09.00	Bright	10.18	5.1
09.30	Bright	10.31	5.1
10.00	Bright	10.33	5.1
10.30	Overcast	8.10	5.1
11.00	Overcast	4.06	5.1

Time (WITA) 21 Jan 2025	Weather Conditions	Solar Panel Voltage (Volts)	Conv. XL6009 Output Voltage (Volts)
15.00	Bright	9.46	5.1
15.30	Bright	10.60	5.1
16.00	Bright	10.80	5.1
16.30	Bright	10.20	5.1
17.00	Bright	10.60	5.1
17.30	Bright	10.60	5.1
18.00	Overcast	4.21	5.1

Time (WITA) 22 Jan 2025	Weather Conditions	Solar Panel Voltage (Volts)	Conv. XL6009 Output Voltage (Volts)
12.00	Bright	11.01	5.1
12.30	Bright	11.01	5.1
13.00	Bright	11.01	5.1
13.30	Bright	11.01	5.1
14.00	Overcast	5.00	5.1
14.30	Overcast	11.01	5.1
15.00	Overcast	10.80	5.1

Source: Experimental data collection (2025)

Table 2 shows the Converter's output voltage stable at 5volts during the testing process. In the table, the results are obtained that the XL6009 Converter has a function as a buck and boost voltage.

3. Overall tool testing

The overall test was carried out to determine the performance of the system used as a 3.7volt battery charger. This test uses the main source of the solar panel, the output voltage will be stabilized by the XL6009 Converter to stably reach the value of 5volt for the input of the TP4056 module. The open voltage of the battery before the first battery charge is 2 volts, then the second and third batteries are 3.3 volts. This test was carried out at 08.00 – 18.00 WITA. On the output of solar panels and Converter XL6009, a digital avo meter is provided for data collection purposes.

Table 3. Overall tool testing table

Time (WITA) 20 Jan 2025	Weather Conditions	Solar Panel Voltage (Volts)	Conv. XL6009 Output Voltage (Volts)	Battery Charging Voltage (Volts)	Battery Charging Current (A)	Tool System Status
08.00	Bright	9.2	5.1	2.0	1.00	Charging
08.30	Bright	9.77	5.1	3.5	1.00	Charging
09.00	Bright	10.18	5.1	3.6	1.00	Charging
09.30	Bright	10.31	5.1	3.6	0.80	Charging
10.00	Bright	10.33	5.1	3.9	0.82	Charging
10.30	Overcast	8.1	5.1	4.1	0.18	Charging
11.00	Overcast	4.06	5.1	4.2	0.00	Cut Off

Time (WITA) 21 Jan 2025	Weather Conditions	Solar Panel Voltage (Volts)	Conv. XL6009 Output Voltage (Volts)	Battery Charging Voltage (Volts)	Battery Charging Current (A)	Tool System Status
15.00	Bright	9.46	5.1	3.3	0.80	Charging
15.30	Bright	10.60	5.1	3.7	0.80	Charging
16.00	Bright	10.80	5.1	4.0	0.62	Charging
16.30	Bright	10.20	5.1	4.1	0.62	Charging
17.00	Bright	10.60	5.1	4.1	0.33	Charging
17.30	Bright	10.60	5.1	4.1	0.21	Charging
18.00	Overcast	4.21	5.1	4.1	0.10	Charging

Time (WITA) 22 Jan 2025	Weather Conditions	Solar Panel Voltage (Volts)	Conv. XL6009 Output Voltage (Volts)	Battery Charging Voltage (Volts)	Battery Charging Current (A)	Tool System Status
12.00	Bright	11.01	5.1	3.4	0.85	Charging
12.30	Bright	11.01	5.1	3.7	0.79	Charging
13.00	Bright	11.01	5.1	3.9	0.82	Charging
13.30	Bright	11.01	5.1	4.0	0.62	Charging
14.00	Overcast	5.00	5.1	4.1	0.02	Cut Off
14.30	Overcast	11.01	5.1	4.2	0.00	Cut Off
15.00	Overcast	10.80	5.1	4.2	0.00	Cut Off

Source: Experimental data collection (2025)

Table 3 shows that the battery voltage will rise to 4.2 volts during the charging process. In the table, it can be concluded that the relationship between charging voltage and clock is directly proportional, the longer the charging time, the higher the voltage during the battery charging process. The voltage generated by the solar panel from 08.00 WITA to 18.00 WITA is on average 10 volts and the charging current produced is inversely proportional to the charging voltage in the battery. In this test, the process of charging a 3.7-volt battery with a capacity of 2400mAh takes 2-3 hours from the state of battery 2 and 3.3 volts to 4.2 volts. The speed or slower charging process depends on the amount of current value and capacity of the battery used. The maximum charging current of the output battery of the TP4056 module is 1A and becomes 0A when the process is cutt off of the charging system.

CONCLUSION

Based on the analysis, the designed battery charging circuit using a 5WP solar panel is effective for charging a 2400 mAh 18650 battery, requiring approximately 2–3 hours under optimal watt-peak conditions. Maximum energy production occurs between 09.00 and 15.00

WITA when solar irradiation and cell temperature are high. The study also highlights that upgrading the TP4056 module to one with a higher capacity (above 1A) could improve charging efficiency, while increasing solar panel capacity could support larger devices such as laptop chargers. Additionally, integrating a cooling component for the XL6009 converter is recommended to enhance system durability. For future research, it is suggested to explore the integration of Internet of Things (IoT)-based monitoring and adaptive control systems to optimize energy regulation and ensure real-time performance tracking of solar-powered battery charging systems.

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