

Article

Optimization of Solar Energy for Control Systems and Electrical Grid Projections at Substations

Ayunda Wulan Permatasari^{1,a}, Nur Aini Fauziyah^{1,b*}, Moch.Syaifuddin^{2,c}, Riadhi Fairuz Tanjung^{2,d}

¹Department of Physics, Faculty of Engineering and Science, Universitas Pembangunan Nasional “Veteran” Jawa Timur,

² National Power Plant (PLN), Surabaya, Indonesia

E-mail: ^a22037010001@student.upnjatim.ac.id, ^bnur.aini.fisika@upnjatim.ac.id, ^cSyaiffudin@gmail.com, ^dRiadhi@gmail.com

*Corresponding author: nur.aini.fisika@upnjatim.ac.id Phone number: +6288228433466

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Abstract

This research examines the utilization of solar panels as an effort to optimize solar energy in the control systems and projections of the electrical grid at substations to support the transition to renewable energy in Indonesia. Dependence on fossil fuels, which causes high carbon emissions, and Indonesia's commitment to the Paris Agreement are the main backgrounds for this innovation. The system is designed using two 12 V solar cells connected in series to produce a 24 Vdc output, and is equipped with an automatic switching mechanism between the supply from the solar panels and National Power Plant (PLN). Observations over the course of one month showed an increase in current from 0.78 A to 1.55 A and power from 18.3 W to 38.2 W, indicating an improvement in energy conversion efficiency. However, the storage capacity significantly decreased from 35.56 Ah to 7.78 Ah, due to shorter charging durations and fluctuations in ambient temperature. This system has the potential to reduce dependence on fossil fuels, support sustainable electrification, and provide environmentally friendly electricity distribution solutions in areas not yet reached by conventional networks. Further development is needed in the energy storage aspect to enhance the overall performance of the system.

Keywords: Solar energy, Solar panels, Renewable Energy (EBT), Substation, Efficiency energy.

1. Introduction

The utilization of primary energy in Indonesia is still dominated by fossil energy sources compared to developed countries and neighboring countries. The contribution of renewable energy, which is energy derived from sustainable and environmentally friendly natural processes. Renewable energy is energy generated through the use of existing resources that can be reused after the resources are utilized. Renewable energy is considered more environmentally friendly than non-renewable energy because it can reduce pollution and environmental damage. The

recovery of renewable energy is more natural and faster [1], [2]. Compared to conventional energy sources, this energy source does not pollute the environment. Geothermal energy is a renewable energy source that may be available in the nation of Indonesia due to the abundance of volcanoes, as well as thermal and photovoltaic solar energy, which are two technologies that can be used to generate solar energy [3]. Energy from renewable sources derived from sustainable natural processes, such as sunlight, does not pollute the environment and does not contribute to global warming and climate change. Geothermal water, wind, and biofuel demonstrate that energy sources

are available and not harmful to the environment [4]. Renewable Energy is a term for energy management sourced from natural processes such as solar radiation, wind movement, heat flow, geothermal, and biomass. Due to the government's dependence on fossil energy, the government wants to increase the utilization and development of renewable energy in the electricity sector to maintain national resilience and reduce global warming. The use of solar energy has a master control system that can enhance operational efficiency and the stability of electricity supply, accommodating fluctuating electrical loads. According to Wardhani 2022, there is a difference between monocrystalline and polycrystalline solar panels, where monocrystalline solar panels generate voltage, current, and energy compared to polycrystalline solar panels. The average daily voltage value for monocrystalline solar panels is 21.09 V, while the value for polycrystalline solar panels is 19.32 V [5]. Evaluating solar panels in tropical areas affected by tilt angle and temperature. It has been shown that higher temperatures can reduce the efficiency of the panels. Therefore, ideal angle adjustment and thermal control are very important to maintain the efficiency and voltage of solar panels [6]. The application of technology can reduce carbon emissions generated from the burning of fossil fuels, thereby helping to mitigate negative environmental impacts. The potential of perovskite materials as phase change materials through the use of hydrothermal synthesis methods. High latent heat capacity, thermal stability, and low-temperature phase change capability make it a good perovskite for storing thermal energy in solar energy systems [7]. Substations can operate more independently and sustainably by using solar energy. Areas that are not yet fully covered by conventional electricity networks. That aligns with a more environmentally friendly and sustainable system. The national electrification target through the provision of more environmentally friendly energy sources. The main characteristic of renewable energy sources is that they are environmentally friendly, meaning their use results in lower greenhouse gas emissions compared to fossil fuels. The use of fossil fuels for power generation can have a negative impact on the environment because it increases greenhouse gas emissions, particularly CO emissions. Relying on fossil fuels faces three major threats: the depletion of oil reserves (if no new oil wells are discovered), price increases due to the rise in greenhouse gas pollution caused by the burning of fossil fuels. The

increase in greenhouse gas emissions is caused by the rise in electricity services and new power plants to meet the continuously increasing electricity demand [8]. The use of renewable energy sources significantly contributes to reducing carbon dioxide (CO₂) emissions, a gas produced from the combustion of fossil fuels and one of the main factors causing global warming. Moreover, reducing CO₂ emissions can help mitigate global warming. However, renewable energy still faces many challenges, such as limited energy transition regulations, high development costs, and system acceptance limitations. The issue with PLN as the electricity provider is the condition of over-supply and take or pay [9]. The Paris Agreement in 2016, which was signed by 171 countries, including Indonesia. The agreement document contains a monumental global pact to address climate change. The above agreement made Indonesia aware that forestry and land use are the most significant sectors in controlling climate change, especially because forest areas cover 65% of the country's land area. Based on Government Regulation Number 79 of 2014 concerning the National Energy Policy, Indonesia will target a minimum of 23% new and renewable energy usage by 2025 and 31% by 2050. And from that agreement, by 2060 Indonesia must achieve net-zero carbon emissions [18].

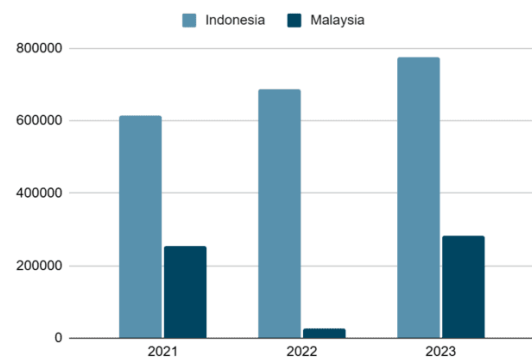


Fig. 1. Coal usage in Indonesia compared to Malaysia (Source: Badan Pusat Statistik)

Based on Figure 1, Indonesia is the country that dominates coal usage compared to other countries. Indonesia is the country that uses the most coal for electricity generation, with an annual increase in coal consumption. It is predicted that in 2024, Indonesia will use as much as 710,000,000 tons of coal. The electricity sector heavily relies on coal for power generation or as a supply of electricity. That regarding electricity regulations, they continue to change, using various approaches, which significantly impact the

industry as a whole. Specific regulations for renewable energy sources have also been established in the past ten years, and there have been growing concerns about the use of renewable energy sources. That regarding electricity regulations continue to undergo changes, using various approaches, which significantly impact the industry as a whole. Specific regulations for renewable energy sources have also been established in the last ten years, and greater concerns have emerged regarding the use of renewable energy resources. According to Yuwono 2021 [10], solar panels as an alternative energy source improve the efficiency and effectiveness in managing solar energy. External factors such as orientation, lighting, and panel position affect the output of solar energy. The use of solar panels results in higher energy emissions, with a total emission of 0.934 kg/KWh, which can be reduced by adjusting the solar energy output. According to Hasrul 2021 [11], the short installation duration of solar panels is due to the fact that 5 hours per day can be used as optimal energy. Because of the variation in usage time in tropical countries like Indonesia. According to Haryanto 2021 [12], the level of brightness greatly affects the charging process. If the weather is clear and the solar panels do not receive enough sunlight, the voltage and current received by the battery will increase and be accepted quickly. However, if the weather is cloudy or the solar panels do not receive enough sunlight, the voltage and current received by the battery will decrease and be processed more slowly. However, the weather changes every day and affects the amount of power generated. The intensity of light entering and being absorbed by the solar panels always fluctuates, but it is usually lower in the morning and evening. According to Widodo 2022 [13], solar panels have the ability to convert sunlight into electrical energy. The cooling system with heatsink and aluminum foil reflector is a solution for the less optimal output power of static solar panels. The full fin cooling system produces an output power of 58.78%, while the spaced fin cooling system produces an output power of 55.10%. According to Ahsan 2021 [9], Indonesia

plans to increase the list of renewable energy power plants by 14% or 10.6 GW by 2030, using fossil fuels. The country plans to build 9,300 MW of renewable energy in 2021 to achieve a target of 28% by 2030. The consumption of renewable energy in the country will become the main source of energy by 2050. In 2024, Indonesia aims to increase electricity production by 445 TWh or 78%, targeting a 4.7% growth in power generation by 2030. However, in previous research, there has never been an analysis and study on the optimization of solar energy use for control systems and network projections using a statistical approach. Therefore, this article examines the utilization of solar panels as an implementation of renewable energy. The research focuses on optimizing solar energy in the control system and projection of the electrical grid at the substations.

2. Material and Method

2.1 Material

In the design of renewable energy solar panels for emergency loads with this switch system, research was conducted for 3 months and 1 month for data collection on the system. The research was conducted in Palemwatu, Palemwatu Village, Menganti District, Gresik Regency, East Java.

In this research, the materials used for "Optimization of Solar Energy in Control Systems and Projection of Electrical Networks at Substations" include solar panels with a voltage of 12 volts, a step-up 12 V DC (Direct Current), Miniature Circuit Breaker (MCB) DC CAFF, DC energy meter, SCC (Solar Charge Control), LVD (Low Voltage Disconnect), Omron relay, battery, electrical insulation, and cables. The tools used include a voltmeter, pliers, scissors, load breaker switch, motor race, and Pulse Width Modulation (PMW) solar charge controller.

2.2 Method

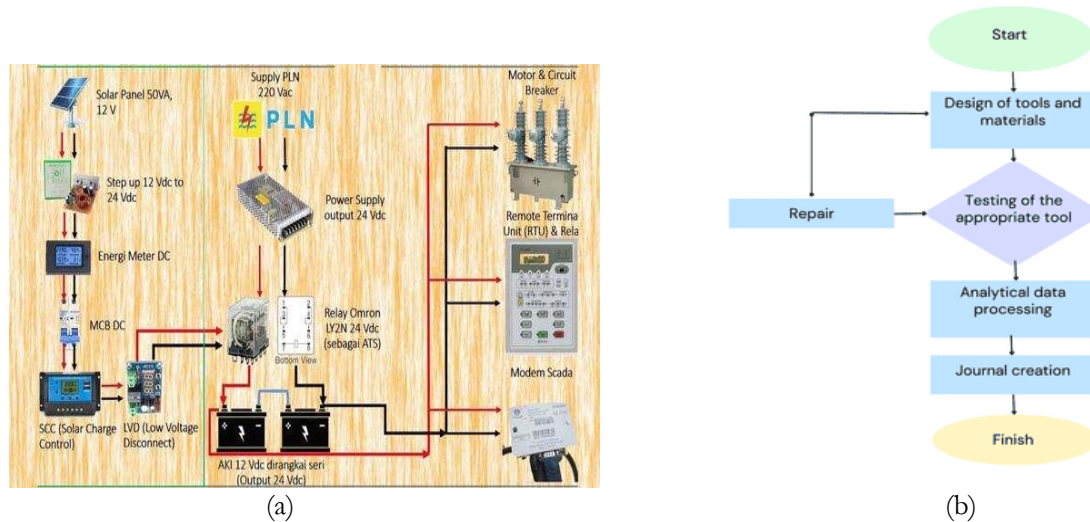


Fig. 2. (a) Flowchart, (b) Design Scheme

In this research, there is a flowchart shown in Figure 2(a) that outlines the steps to be taken before the creation of the journal and data analysis. The first step is the initiation of the design of the tool for solar energy optimization for control and projection systems. This is followed by the design of tools and materials before testing is conducted. The next stage is testing the tool to determine if it meets the requirements; if not, improvements will be made, and the tool will be tested again after the repairs. Once the tool testing is satisfactory, the next step is data processing and analysis regarding solar panels, also known as photovoltaics, as a replacement for the Potential Transformer (PT). After processing and analysis, the collected data can be used to create a journal titled "Optimization of Solar Energy for Control and Projection Systems in Substations." After the journal is completed, the research flow is finished. Meanwhile, in the schematic design shown in Figure 2(b), it explains the design of the device where the solar cell converts sunlight into electrical energy. The voltage generated by the solar cell, which is 12V DC, is then increased to 24V DC before being measured using a DC energy meter. When the weather conditions are unpredictable, the system can be controlled using an SSC (Solar System Controller) and LVD (Low Voltage Disconnect). If the output from the solar

cell is not optimal, the energy supply will automatically switch from the solar cell to the PLN supply. If a disturbance occurs or the generated voltage does not meet the specified standards, the Omron relay will function as an automatic switch to change the power supply source from the solar cell to PLN to ensure the continuity of a stable power supply.

3. Results and Discussion

Based on Table 1 and Table 2, results regarding solar energy before and after a 1-month testing period were obtained. The above results are an evaluation and optimization of the solar panel's performance in supplying electrical energy as a control and projection of the network at the Palemwatu substation, Gresik, East Java. The observation above was conducted by installing instruments on March 18, 2025, at 11:00 AM, followed by initial data collection before the one-month data collection, which was conducted on March 19, 2025, at 01:00 PM. Meanwhile, the one-month data collection was conducted the following month on April 20, 2025. This data collection was carried out to observe changes in system performance after operating for a full month.

Table 1. Results of Solar Panel Charging Time

No	Charging Time		Panel Voltage
	Overcast 28°C	Hot Weather 32°C	
1	4 h	3 h	24 V DC

Table 2. Results of Solar Energy Performance Observations Before and After 1 Month of Testing

Research Data	Current (A)	Power (Watt)	Input Voltage (V)	Ampere Hour (Ah)	Watt Hour (Wh)	Ampere Pick (Ap)	Maximum Voltage (Vm)	Watt Pick (Wp)
Before	0,78	18,3	23,49	35,56	5032	2,92	7,43	72,0
	0,79	18,5	23,5	35,56	5032	2,92	7,43	72,0
After A Month	1,55	38,2	24,7	7,77	5923	2,92	7,43	72,0
	1,54	38	24,69	7,78	5923	2,92	7,43	72,0

The main indicator in system optimization lies in the duration of solar panel energy charging, where weather conditions significantly affect the charging time. Based on Table 1, the charging time during cloudy weather (28°C) requires up to 4 hours of charging, whereas in hot weather (32°C), it only requires 3 hours of charging with a voltage on the solar panel of 24 V, which consists of 2 solar panels each with a voltage of 12 V. The difference mentioned above indicates that temperature and light intensity significantly affect the effectiveness of the battery charging process from the solar panel.

Based on Table 2, the observation results show that the current (I) value was 0.78 A before 1 month and increased to 1.55 A after 1 month. This increase in current can be said to indicate that the solar panel system is experiencing improved efficiency and receiving more consistent sunlight exposure during its operational period. The increase in the number of electrons moving due to higher sunlight exposure results in an increased current value. According to Prakash 2023 [14], the increase in temperature and light intensity can enhance electron excitation in solar panels, resulting in higher electrical current. The increase in current causes the electrical power (P) to rise in the system. The increase is valued at 18.3 Watts to

38.2 Watts. Although the input voltage experienced an insignificant increase or can be said to remain constant, which is from 23.49 V to 24.7 V. The increase in current is a factor in the increase in power. The increase in current can be said to indicate that the system is working more efficiently in converting solar energy into electrical energy. This is consistent with the working principle of photovoltaic modules, according to Kumar 2015, that the voltage of the panel tends to be stable, while the power is greatly influenced by the generated fluctuations [15]. However, the ampere hour value experienced a drastic decrease, indicating the current storage capacity over a certain period. Before 1 month, the ampere hour was valued at 35.56 Ah, whereas after 1 month, the ampere hour experienced a drastic decrease to 7.78 Ah. This decrease seems to contradict increase in current and power. Most likely related to different measurement times or shorter durations for energy storage. The current increases; if the storage time is shorter, then equation (1) is:

$$\text{Ampere Hour} = I \times t \dots\dots\dots (1)$$

If t (time) is short, then I is larger, but the result in ampere hours remains smaller. In addition,

changes in temperature and battery capacity degradation due to overheating can also reduce energy storage efficiency.

Based on Table 2, the observation results show an increase in the watt hour value from the initial data of 5032 to 5923 Wh after 1 month. This indicates that the total energy

expended during the operational period has increased overall, while the storage capacity per unit time may have decreased. The increase in total energy indicates performance in the system is becoming increasingly optimal.

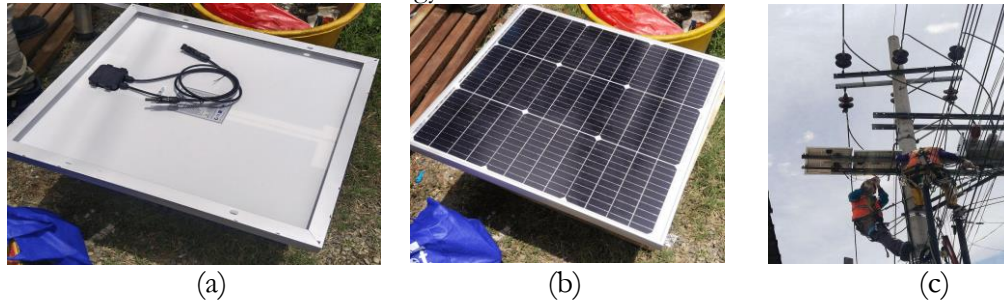


Fig. 3. (a) Bottom part of the solar panel, (b) Solar panel, (c) Installation of solar panels

Based on Figure 3, this study uses 2 solar panels where 1 solar panel has a voltage of 12 V. This study explains that the working voltage of the device must use 24 V so that the voltage of the LBS (Load Break Switch) system can operate optimally. In the solar panel above, a series installation is carried out using 2 solar panels to achieve the desired working voltage output. The main components of the LBS are the motor

breaker, remote motor thermal unit, circuit breaker, and SCADA modem. The 24 Vds solar panel is a direct current from the LBS internal. The solar panel above shown in image 3 indicates that the solar panel is needed to supply power to the LBS keep point to replace the existing power supply. That it can be used as a potential transformer (PT).

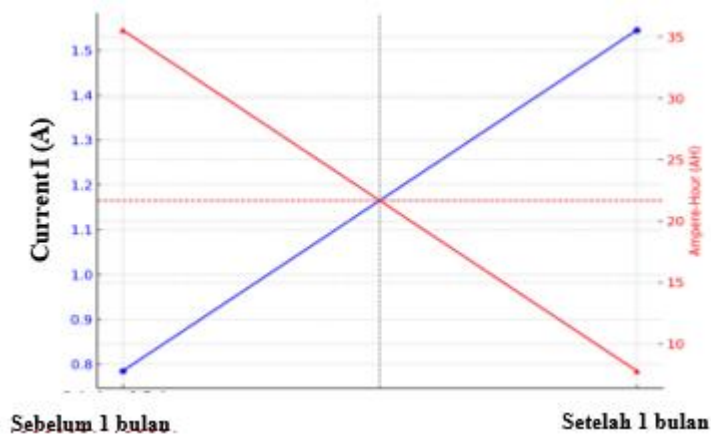


Fig. 4. The relationship between current I (Ampere) and charge capacity (Ampere Hour)

Figure 4 presents the relationship between current (amperes) and charge capacity (ampere hour) of the solar panel system before and after one month of operation. The graph shows that the current increased from 0.78 A to 1.55 A, as indicated by the blue line, while the orange line represents a drastic decrease in charge capacity from 35.56 Ah to 7.78 Ah. The intersection of both lines illustrates a deviation that mathematically represents the average values of each parameter.

Further discussion has been added to clarify this observation. The reduction in ampere hour can be influenced by several factors, including battery degradation, charging cycle inefficiency, and thermal effects during operation. Battery degradation may occur due to repeated charge-discharge cycles over the observation period, leading to a decline in storage capacity. Additionally, variations in temperature could affect the electrochemical performance of the battery, thereby reducing its effective charge retention. The increased current, meanwhile, may

indicate higher instantaneous power generation but not necessarily improved storage efficiency. Overall, these factors collectively explain the observed decline in ampere hour despite the rise in current.

Basic theory of electrostatics and energy storage, the ampere hour value should be directly proportional to the current if the measurement duration and storage efficiency remain constant. However, research results show that the ampere hour value exhibits an inverse relationship, where the ampere hour value decreases while the current increases. The influencing factors are external factors where the energy storage capacity, such as shorter charging times, and the storage efficiency decrease due to high temperatures or cell degradation. According to Liao 2012 [16], high temperatures can cause an increase in internal resistance within lithium batteries, ultimately reducing the battery's ability to store charge efficiently. This significant decrease in AH is likely due to the environmental temperature during the measurement after 1 month being higher compared to the initial data collection. The cross point in Figure 4 indicates an imbalance between the increase in energy supply and the unequal storage capacity. The situation indicates that there is a gap between energy production and utilization that needs to be addressed. The deviation above regarding the optimization of the solar energy system must be noted, even though the system is capable of generating higher power, there is a decrease in storage performance. The effectiveness of the system will decrease overall even when the weather is cloudy.

4. Conclusions

This study demonstrates that after one month of operation, the solar panel system showed an increase in current from 0.78 A to 1.55 A and a rise in power output from 18.3 W to 38.2 W, while maintaining a relatively constant voltage. These results indicate an improvement in the system's energy conversion efficiency. However, the charge capacity (Ampere-Hour) decreased significantly from 35.56 Ah to 7.78 Ah, suggesting a reduction in the battery's energy storage capability. This decline is likely caused by shorter charging durations or decreased battery efficiency due to elevated operating temperatures. The cross-plot between current and Ampere-Hour further reveals an imbalance between energy generation and storage performance, emphasizing the need for system optimization—particularly in improving

thermal management and battery charging regulation to ensure stable and efficient operation.

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