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ANALYSIS OF SOLAR POWERED PUBLIC STREET LIGHTING DESIGN (PJUTS)

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Abstract

This research aimed to propose and demonstrate a Solar-Powered Public Street Lighting lamps concept as part of a Community Service (PKM) initiative conducted at the Halim Cluster Housing Complex in West Bandung Regency. The study employed an experimental method combined with product design. The findings revealed that the solar-powered Public Street Lighting (PJU) design offers an innovative and environmentally friendly solution to meet public lighting needs. The calculation and testing involved 5V/12W LED lights, 12V/50Wp solar panels, a 10A charge controller, and 12V/30Ah lithium batteries. The solar-powered street lighting system can operate for 12 hours, even under sunny and cloudy conditions.

Keywords: Battery, Charge control, Complex, Housing, LED.

1. Introduction

This research was based on Community Service (PKM) activities conducted by the PKM Team for the Undergraduate Computer Systems Study Program. The activity involved the installation of solar-powered public street lighting in the Daarul Haliim Cluster, located in the Housing Complex of West Bandung Regency. The project utilized solar panels to promote the use of New and Renewable Energy (EBT) for electricity generation.

According to Government Regulation (PP) Number 22 on National Energy in 2015 [1], Indonesia is required to shift toward using Renewable Energy Sources (EBT) as an energy source. However, energy generation in the country is still largely dependent on fossil fuels, with EBT accounting for only about 5% of total energy production (see Fig. 1). Furthermore, the share of EBT in the national energy mix for the electricity sector remains low, comprising just 10.5% of total production [2], as shown in Fig. 2.

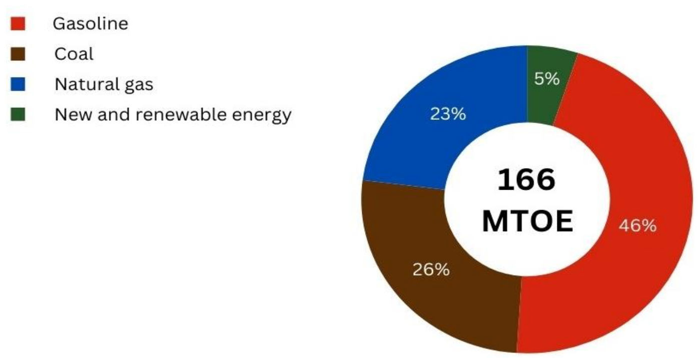

Fig. 1. Percentage of the energy mix in 2015.

The primary objective of the 2050 National Energy Policy (KEN) is to achieve national energy independence and security. To support this goal, one of the key principles is to maximize the utilization of EBT [3]. Among many renewable energies, solar power is a crucial resource that should be prioritized, particularly for electricity generation. The implementation of solar power in Public Street Lighting systems contributes significantly to increasing the use of EBT.

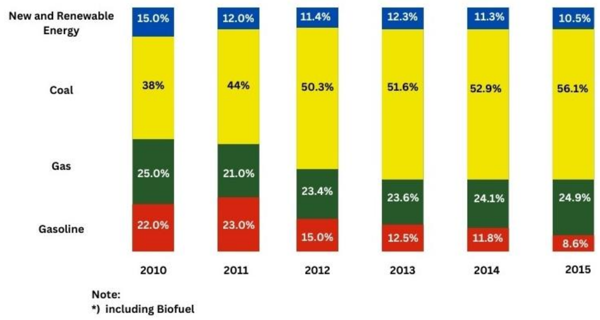

Fig. 2. Energy electricity production mix 2010-2015 [4].

Public street lighting (PJU) plays a crucial role in urban infrastructure, enhancing the safety and comfort of road users—both drivers and pedestrians—particularly during nighttime. Effective and efficient PJU systems are instrumental in reducing traffic accidents, improving community mobility, and fostering a secure, productive environment. However, conventional PJU systems that rely on electricity from the PLN network face several challenges, including high energy consumption, elevated operational costs, and negative environmental impacts due to reliance on fossil fuels [5, 6].

In the pursuit of sustainability and energy efficiency, renewable energy technologies, such as solar power, present promising solutions for street lighting systems. Solar panels, which convert solar energy into electricity, have gained popularity due to the abundance of solar resources, their environmental benefits, and their potential to reduce reliance on fossil fuels. The adoption of solar-powered PJU not only enhances energy efficiency but also supports global efforts to reduce greenhouse gas emissions and meet the Sustainable Development Goals (SDGs), particularly Goal 7 (affordable and clean energy) and Goal 13 (climate action) [7].

Designing a solar-powered PJU system involves a comprehensive technical approach, which includes selecting solar panels, determining battery capacity, choosing energy-efficient lighting (such as LEDs), and implementing control systems to ensure optimal durability and performance. Key factors such as solar radiation intensity, energy consumption patterns, lighting duration, and installation location influence the system's effectiveness and efficiency. In Indonesia, with its tropical climate and high solar intensity, the potential for this technology is significant. However, challenges remain, including relatively high initial costs, system maintenance requirements, and the availability of suitable local components [8].

The objective of this study is to evaluate and develop a reliable, efficient, and contextually appropriate solar-powered Public Street Lighting (PJU) system. The findings are expected to provide technical guidance and practical recommendations for advancing solar-powered street lighting systems in Indonesia using an integrated analysis and design approach. In this regard, this research supports Indonesia's transition to clean energy while advancing sustainable road lighting technologies [9].

2. Research Method

To assemble the Solar Powered Public Street Lighting system, several key components were required: (i) 12V/20W LED lights, (ii) 12V/60Wp solar panels, (iii) a 10A charge controller, and (iv) 12V/80Ah lithium batteries.

Solar panels, or photovoltaic panels, convert sunlight into electrical energy (see Fig. 3). The capability of the solar panels is measured in Wattpeak (Wp). The calculation for determining the required capacity of the solar panels to match the output load is provided by Eq. (1) [2, 10]:

$$\mathrm{P_{solar\ panels}} = \frac{\mathrm{ET}}{\mathrm{solar\ insolation}} \tag{1}$$

where $P_{solar\ panel}$ is Panel Power (Wp), ET is Power Usage (Wh), and solar insolation is the effective sunlight time per day.

Fig. 3. 12V/60Wp solar panel.

The electrical energy generated by the solar panels is stored in lithium-ion batteries. The battery capacity is calculated using ampere-hour (Ah) as the unit. To ensure compatibility between the solar panel capacity and the output load (LED lights), the calculation provided in Eq. (2) was used [2, 11].

$$\mathrm{Ah} = \frac{\mathrm{ET}}{\mathrm{V_s}} \quad (2)$$

where Ah is Battery Power (Ah), V_s is the Battery Voltage used (volts).

Additionally, the calculation of the battery capacity must take into account a Depth of Discharge (DOD) of 80% [2]. The battery capacity, considering DOD, is calculated using Eq. (3) [12].

$$\mathrm{Cb} = \frac{\mathrm{Ah}}{\mathrm{DOD}} \quad (3)$$

where Cb represents the battery power after considering the DOD, Ah is the battery power before considering the DOD, and DOD is set to 80%. The battery used in this research is shown in Fig. 4.

Fig. 4. 12/30Ah lithium-ion battery [13].

This research employed Light-Emitting Diode (LED) lights in the form of a Direct Current (DC) lamp to produce illumination (see Fig. 5), as the public street lighting system does not utilize an inverter [14].

Fig. 5. 12V/20W LED lamp.

The charger control system regulates the flow of electricity between the solar panel, battery, and LED lights. It acts as a conduit, directing electrical energy from the solar panel to the battery for charging and preventing overcharging. Additionally, the charger control transfers electrical energy from the battery to the LED lights to ensure they turn on as needed (see Fig. 6). This system also manages the energy flow, turning the LED lights on and off at the designated times [15]. The charge control capacity can be determined using Eq. (4) [16].

$$I_{max} = \frac{P_{max}}{V_s} \tag{4}$$

where I_{max} is the Charge Control Current Capacity (A), P_{max} is the Capacity of the Solar Panel (Wp) and V_s is the Solar Panel Voltage (V).

Fig. 6. Charge control 10A.

3. Results and Discussion

As shown in Fig. 5, the solar-powered public street lighting (PJU) system utilizes LED lights. Each LED light consumes 20W of power and operates for 12 hours daily, requiring 240Wh of energy daily. To support the daily energy consumption of the LED lights, a solar panel with a 60Wp capacity is needed. This calculation is based on the LED lights' daily energy requirement of 240Wh and the average solar insolation time of approximately 4 hours in West Bandung Regency, as shown in Eq. (1) [17].

The battery capacity required to support 240Wh of daily consumption is 20Ah, as calculated using Eqs. (2) and (3). However, during field observations, cloudy conditions persisted for four consecutive days, prompting an increase in battery capacity by 30%, bringing the required capacity to 26Ah (approximately 30Ah). The battery used in this research is shown in Fig. 4. A charge controller was selected based on the specifications of the 60Wp/12V solar panel, which has a current rating of 5A (approximately 10A), as calculated in Eq. (4). After finalizing the component specifications, assembly and testing were conducted. The operational principle of the solar-powered public street lighting system is shown in Fig. 7.

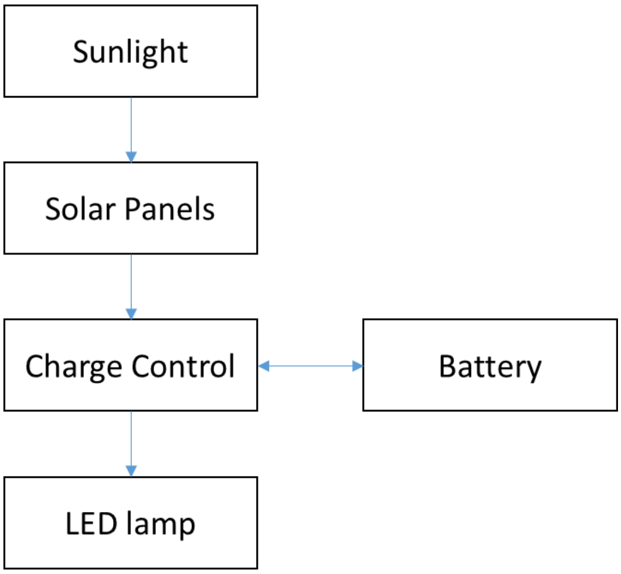

Fig. 7. Working principle of the proposed solar-powered public street light [18].

The operation of a series of Solar-Powered Public Street Lighting (PJUTS) lamps follows these steps [4]:

i) Solar panels capture sunlight, which the charge controller converts into electrical energy to meet the battery's requirements.

ii) Based on signals from the charge controller, the LED lights are powered on using electrical energy stored in the battery.

iii) The charge controller determines when the LED lights are activated, typically when there is no sunlight reaching the solar panel (during dusk and night).

iv) The charge controller also regulates the time it takes for the LED lights to turn on, automatically activating them depending on the light intensity.

Testing was conducted to verify the functionality of the components. Figure 8(a) shows the testing process for the solar street lighting components at night. During the night, when the solar panel is not receiving sunlight, the charge controller directs the flow of electrical energy from the battery to power the LED lights.

Figure 8(b) shows the testing conditions during the day. When the solar panel receives sunlight, the charge controller allows electrical energy from the panel to charge the battery while cutting off power from the battery to the LED lights.

(a) (b)

Fig. 8. Testing of solar-powered public street lighting lamps: (a) during daytime and (b) during nighttime

The final stage involves testing and analysing the solar panel's performance to determine the battery power stored from morning to evening. This analysis aims to identify the optimal charging time for the battery (see Table 1). After conducting 48 tests under two weather conditions (sunny and cloudy), the results are as follows:

i) As shown in Table 1, during the hours of 10:00–13:00 under both sunny and cloudy conditions, the solar panel provided a total battery charge of approximately 27.5 Ah per day on average (Tests 5–8).

ii) On average, the solar-powered public street lighting system can operate for 11 hours per day (from 18:00 to 05:00). This indicates that the battery, charged during the 10:00–13:00 period (sunny or cloudy), can support the system's operation during the night.

iii) The battery charging process halts completely between 18:00 and 05:00 or during rainy conditions due to insufficient light intensity, which results in a Solar Panel voltage of less than 10V, preventing the battery from charging.

iv) Tests 1–4 and 9–12 showed no significant increase in battery power, as the Solar Panel voltage was consistently below 10V, rendering the charging process ineffective.

Table. 1. Solar panel voltage measurement results.

No.	Time	Bright Condition (volts) *	Cloudy conditions (volts) **	Average (volts)	Light condition
1	06.00	2.40	1.43	1.91	Off
2	07.00	3.00	1.67	2.33	Off
3	08.00	4.00	2.00	3.00	Off
3	08.00	4.00	2.00	3.00	Off
4	09.00	7.00	3.00	5.00	Off
5	10.00	12.00	10.00	11.00	Off
6	11.00	12.00	10.00	11.00	Off
7	12.00	12.00	10.00	11.00	Off
8	13.00	12.00	10.00	11.00	Off
9	14.00	8.00	6.00	7.00	Off

Table. 1 (continue). Solar panel voltage measurement results.

No.	Time	Bright Condition (volts) *	Cloudy conditions (volts) **	Average (volts)	Light condition
10	15.00	6.00	4.00	5.00	Off
11	16.00	3.00	1.67	2.33	Off
12	17.00	2.40	1.43	1.91	Off
13	18.00	0.00	0.00	0.00	On
14	19.00	0.00	0.00	0.00	On
15	20.00	0.00	0.00	0.00	On
16	21.00	0.00	0.00	0.00	On
17	22.00	0.00	0.00	0.00	On
18	23.00	0.00	0.00	0.00	On
19	00.00	0.00	0.00	0.00	On
20	01.00	0.00	0.00	0.00	On
21	02.00	0.00	0.00	0.00	On
22	03.00	0.00	0.00	0.00	On
23	04.00	0.00	0.00	0.00	On
24	05.00	0.00	0.00	0.00	On

Note: *)March 10, 2024; **) May 15, 2024

3.1. Results of analysis [19]:

i) System Efficiency: The solar-powered street lighting system boasts high efficiency, with solar panels absorbing an average of 18–20% of the total sunlight received. The battery efficiency reaches 90%, while LED lights consume only 10–15% of the energy used by incandescent bulbs.

ii) Investment costs: The initial cost per unit of lighting ranges from IDR 5 million to IDR 10 million, depending on the solar panel capacity and battery quality. However, the system results in 100% electricity cost savings, as it operates independently of the National Electricity Company (PLN) grid.

iii) System Durability: The main components, such as solar panels, have a lifespan of up to 25 years, while batteries need to be replaced every 5–7 years, depending on usage intensity.

iv) The implementation in remote areas: This system is highly effective for remote areas without access to the electrical grid. In regions such as East Nusa Tenggara and Papua, its implementation has significantly improved road safety and facilitated nighttime activities.

3.2. Technical discussion [20]:

i) Optimal System Design: The design process requires careful calculations to determine the ideal installation locations (areas with high sunlight intensity) and the power needs of the lights, which are based on factors such as road length and the desired brightness level (lumens).

ii) Maintenance Challenges: A significant challenge is maintaining the batteries and solar panels, particularly in regions with extreme weather conditions, such as heavy rainfall or dust, which can impair the efficiency of the solar panels.

iii) Connectivity and Automation: The system can be integrated with automatic light sensors and Internet of Things (IoT) connectivity to enable real-time performance monitoring.

3.3. Benefits and impacts [21, 22]:

i) Environment: Reducing reliance on fossil fuels.
ii) Economy: Lowering electricity costs and enhancing lighting efficiency.
iii) Social: Improving road safety and supporting community activities during nighttime.

4. Conclusion

The design of solar-powered Public Street Lighting (PJU) offers an innovative, eco-friendly solution to meet public lighting needs. This study illustrates how the application of solar energy technology can reduce dependence on fossil fuels, decrease carbon emissions, and provide long-term cost savings compared to traditional methods. The design analysis presented in this paper covers the selection of key components, including solar panels, storage batteries, LED lights, and controllers. With an optimized design, the system can deliver stable, reliable lighting that adheres to relevant street lighting standards. Based on the findings of this research, the following recommendations for future studies are proposed: (i) Design Optimization: Further research is needed to enhance battery storage capacity, ensuring the system operates efficiently under extreme weather conditions or limited sunlight; (ii) Large-Scale Implementation: Government and relevant stakeholders should consider deploying this lighting system in remote areas or regions beyond the reach of the electrical grid, contributing to more equitable street lighting infrastructure; (iii) Monitoring and Maintenance: Integration of an IoT-based monitoring system is recommended to track performance and detect issues in real time, extending the system's lifespan and improving operational efficiency; (iv) Community Outreach and Education: Efforts should be made to raise awareness and educate both the community and authorities about the benefits and operation of solar-powered street lighting, fostering greater acceptance of this technology; and (v) Cost Analysis: Further evaluation is necessary to assess the initial investment, maintenance costs, and component replacement requirements to ensure the system's long-term economic viability.

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