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Design Study of Solar Panel-Based Energy Trees as Clean Energy for Lighting Green Open Spaces

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ABSTRACT

Research aims to design and build an energy tree system as an eco-friendly lighting solution in the parking area of Campus 1 Swadaya Gunung Jati University, Cirebon City. This energy tree utilizes Solar Power Generation technology with a solar panel configuration resembling a tree, consisting of five polycrystalline solar panels with a total power of 110 WP (Watt Peak). The electrical energy generated from the solar panels is stored in a 12V/8Ah battery and then converted through an inverter into alternating current (AC). The method used in this research is an experimental method, which includes the stages of design, assembly, installation, and performance testing of the system. Testing was conducted over three consecutive days, from 09:00 to 16:00 WIB, aiming to evaluate the electrical output parameters, specifically the voltage and current, of solar panels. The system's maximum power output reached approximately 99.57W, with an average panel efficiency of 90.13% compared to the theoretical maximum capacity of 110WP

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INTRODUCTION

Solar energy is at the heart of global energy diversification efforts due to its abundant potential around the world (Ukoba et al., 2024), (Lahope et al., 2024), (Dwisari et al., 2023), (Ibegbulam, 2023). In the present era, there has been a shift from the use of non-renewable energy sources to renewable ones (Bogdanov et al., 2021),(Breyer et al., 2022). Advancements in renewable energy offer a practical approach to addressing current energy needs (Strielkowski et al., 2021),(Darlington Eze Ekechukwu & Peter Simpa, 2024). Various sources—such as solar, wind, hydroelectric, geothermal, and others—are available to support this transition (Diantari et al., 2019), (Saleh et al., 2023). Among these, solar energy stands out as the leading candidate for electricity production due to its environmental friendliness, sustainability, and zero-emission nature (Jaleel Mahdi et al., 2024).

A wide array of solar technologies has been implemented, including PV/Trombe wall systems (Abdullah et al., 2022), (Luo et al., 2019), floating photovoltaic installations (Pouran et al., 2022), solar thermal collectors (Prasetyo et al., 2023), and rooftop solar panel configurations (Cui et al., 2023),(Priyono et al., 2020), Solar panel system installed on stadium rooftops,(Pradika et al., 2020). The aesthetically pleasing and attractive design of this energy tree concept offers an effective solution through its elegant appearance (Hyder et al., 2018), The presented design demonstrates the potential for implementing renewable energy solutions (Energy & Science, 2021), It also serves as a demonstration of environmentally friendly energy utilization (Ali & Windarta, 2020).

LITERATURE REVIEW

In principle (Rojas et al., 2021),(Anoi et al., 2020), solar cells work when exposed to sunlight (Kazim, n.d.), Produces direct current (DC) electricity (Yuliati et al., 2018), through the photovoltaic effect (Haegel et al., 2025). This current can be used directly or stored in a battery (Maka & Chaudhary, 2024),(Al-Salloomee et al., 2022), and it can be converted into alternating current (AC) using an inverter to power a lamp for lighting purposes (Siswanto & Rahayu, 2024). In their research, Ratna et al. developed a solar photovoltaic tree (SPVT) by constructing a vertical pole anchored in the ground as the trunk, connected to branching arms resembling leaves. PV modules are placed on these branches. A charging station is located in the panel box section, allowing visitors at the Kelengkeng Park in Simoketawang Village, Sidoarjo, to charge their phones while enjoying the area (Hartayu et al., 2022). Previous studies on energy trees have primarily focused on design aspects or their use as charging stations. In contrast, our research serves as a reference for large-scale development and deployment in strategic locations such as public parks and city squares.

Its tree-inspired design offers both aesthetic and functional value, operating effectively during both daytime and nighttime. During testing, the system was limited to lighting loads due to the relatively small battery capacity. To achieve more optimal results, increasing the battery capacity is necessary to enhance nighttime utilization and improve the overall efficiency of the energy tree system. Meanwhile, during daylight hours, the system performs optimally as the solar panels continuously charge the battery. Therefore, the system can be considered effective for operation during both day and night.

METHODOLOGY

This study employed an experimental method(Sobari et al., 2024), (Feng et al., 2024) aimed at developing and testing the concept of an energy tree as a lighting solution based on a Solar Power Plant (PLTS) system. The testing was carried out to evaluate the effectiveness of the solar panels in generating power, based on the incoming current and voltage data. In addition, the resulting data was analyzed using the power triangle formula to obtain more accurate calculations. The flow of the research stages is illustrated in Figure 1.

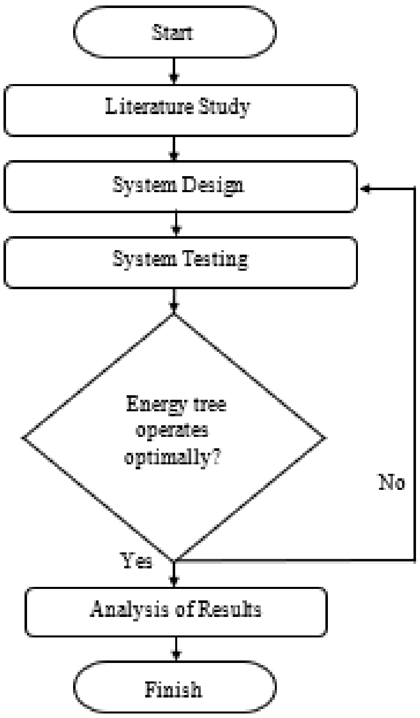

Figure 1. Research Flowchart

2.1 System Design

Figure 2 shows the design of the energy tree installation, using a 2.5-inch iron pipe with a height of 2.8 meters. Part of the pipe is embedded in the ground at a depth of 40 cm. At the top of the pipe, there are extensions resembling tree branches that serve as supports for the solar panels. A total of five solar panels are mounted, each supported by an arm measuring 70 cm in length.

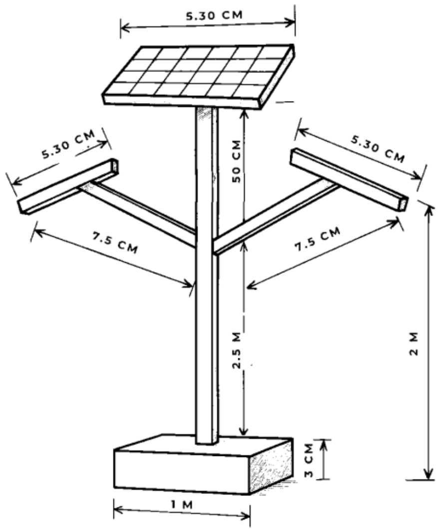

Figure 2. Design of Energy Trees

Based on Figure 2, the energy tree structure is designed with detailed measurements for each component. The structure consists of a base, a vertical pole, and four angled arms that serve as supports for the solar panels.

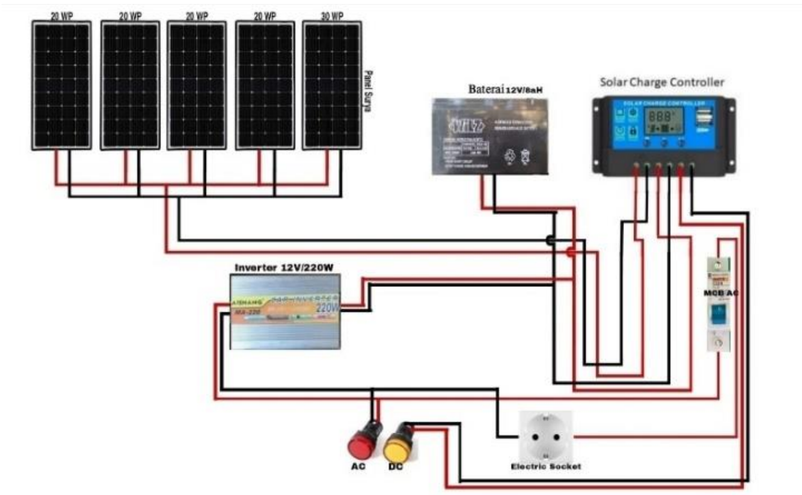

Figure 3. Research Flowchart

Table 1. Specifications of a 20 Watt Peak Solar Panel

Parameter	**Value**
Type	Polycrystalline
MaximumVoltage	18 Volt
Minimum Current	1,89 A
Maximum Output Power	20 Watt
Dimensions	530 x 350 x 16 mm

Table 2. Specifications of a 30 Watt Peak Solar Panel

Parameter	**Value**
Type	Polycrystalline
MaximumVoltage	18 Volt
Minimum Current	1,68 A
Maximum Output Power	30 Watt
Dimensions	650 x 350 x 25 mm

Based on Figure 3, the solar panel generates electricity by harnessing sunlight through a process known as the photovoltaic effect, where light striking the surface of the solar cell triggers the movement of electrons, producing an electric current. Electricity from the panel is directed to the Solar Charge Controller (SCC) to regulate battery charging. From the SCC, the electricity flows to a terminal that connects to the inverter and a circuit breaker. The inverter converts 12V DC voltage into 220V AC, enabling electrical devices to draw power from the solar system. The final output is delivered to a power outlet. Between the inverter and the outlet, an MCB (Miniature Circuit Breaker) is installed to protect against short circuits. DC and AC indicator lights are used to show whether DC power from the battery and AC output from the inverter are flowing, allowing electrical devices to be operated more safely and reliably.

The analysis is carried out by comparing the power generated in order to identify the optimal usable power. In the final results, it will determine the number of lamps that can be used and how long they can stay lit during the night. For the power output calculation, the following formula is applied (Ferdiansah et al., 2023), (Malik Al Jabbar & Fahmi Hakim, 2023), (Iqbal et al., 2021).

$$P = I \times V$$

Where: P = Power (Watt)

I = Current (Ampere)

V = Voltage (Volt)

2.2 Experiment Setup

The experiment was conducted in the vicinity of Swadaya Gunung Jati University (7GCW+C68), Sunyaragi, Cirebon City, West Java, Indonesia. The testing took place over three consecutive days, from May 15 to May 17, 2025, between 9:00 AM and 4:00 PM, under partly cloudy weather conditions with an average temperature of 32°C. The solar panel was positioned statically facing east. The voltage and current generated by the solar panel were measured using a multimeter.

Figure 4. Energy Trees

Based on Figure 4, the result of the energy tree structure design includes detailed measurements for each component. The structure consists of a base, a vertical pole, and four angled brackets that serve as supports for the solar panels. Additionally, a panel box has been added, housing the system wiring to ensure the energy tree operates optimally.

RESULT AND DISCUSSION

The energy tree was tested over a period of three days. From the testing results, hourly average values of voltage and current generated by the solar panels were recorded during the three-day period, from 9:00 AM to 4:00 PM. These average values are presented in graphical form as shown in Figures 5 and 6.

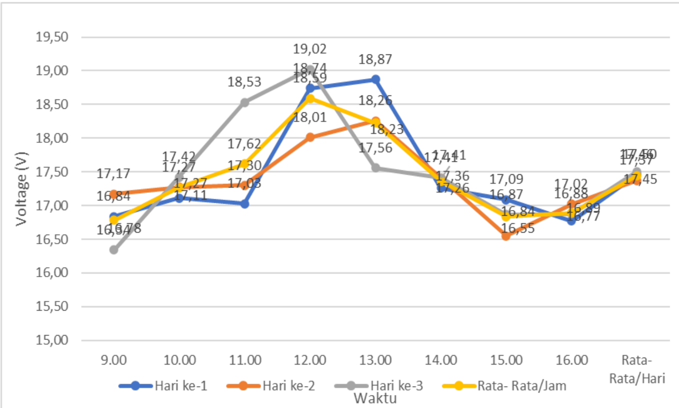

Figure 5. Solar Panel Output Voltage Graph

Based on Figure 5, the average voltage of the solar panel can be calculated by summing the hourly average output voltages and dividing by the total number of data points. This yields the daily average voltage of the solar panel as a reference. On the first day, the average voltage was 17.46 V, followed by 17.37 V on the second day, and 17.50 V on the final day of testing. Over the three-day testing period, the overall average voltage was 17.45 V.

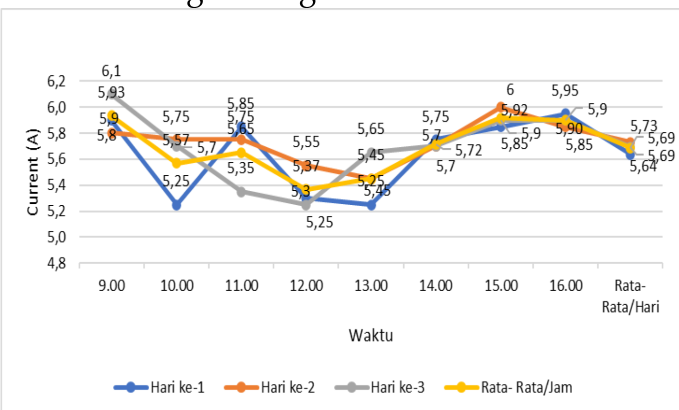

Figure 6. Solar Panel Output Current Graph

Based on Figure 6, the average daily output current of the solar panel was calculated by summing the hourly average output current and dividing it by the number of data points. This provided a daily reference value for the panel's output current. On the first day, the average output current was 5.64 ; on the second day, 5.73 A; and on the final day of testing, 5.69 A. Over the three-day testing period, the overall average output current was 5.69 A.

At night, a test was conducted using a 10W floodlight as the load. A 12V battery with a capacity of 8Ah was used. From this data, the battery's energy output was calculated as follows:

$P = V \times I$

Where:

P= Power (Watts)

V = Voltage (Volts)

I = Current (Amperes)

$P = 12V \times 8Ah = 96W$

From the above calculation, it was determined that the battery has 96 watts of energy.

To determine the current drawn by the 10W lamp:

$I = P \div V$

$I = 10W \div 12V = 0.83A$

This shows that the lamp draws 0.83 amperes. To calculate how long the lamp can operate:

$T = Abattery \div Aload$

$T = 8A \div 0.83A \approx 9.63$ hours

10 W

T = Ah x V : W

T = 8Ah x 12V : 10W

T = 96 Wh : 10 W

T = 9,6 Hour

30 W

T = Ah x V : W

T = 9,6 Wh x 12 : 30 W

T = 3.2 Hour

50 W

T = Ah x V : W

T = 96 Wh x 12 : 50 W

T = 1,92 Hour

In the experiment involving lighting loads, a 10W lamp and two 20W lamps were tested. Based on previous calculations, the 10W lamp could remain illuminated for approximately 9.63 hours. However, as the total power load increased, the system's operational duration decreased. When the 10W lamp was combined with one 20W lamp—resulting in a total load of 30 watts—the battery sustained the system for only 3.2 hours. When an additional 20W lamp was added, increasing the total load to 50 watts, the battery could operate the system for just 1.92 hours. These results show that, without solar input, a 10W lamp can operate for about 9 hours, a 30W load for 3.2 hours, and a 50W load for only 1.92 hours. The relevant calculations are provided below, and the overall performance is visualized in the accompanying graph.

Table 3. Lightning Operation

Daya Lampu (Watt)	Durasi Menyala (Jam)
10	9.6
30	3.20
50	1.92

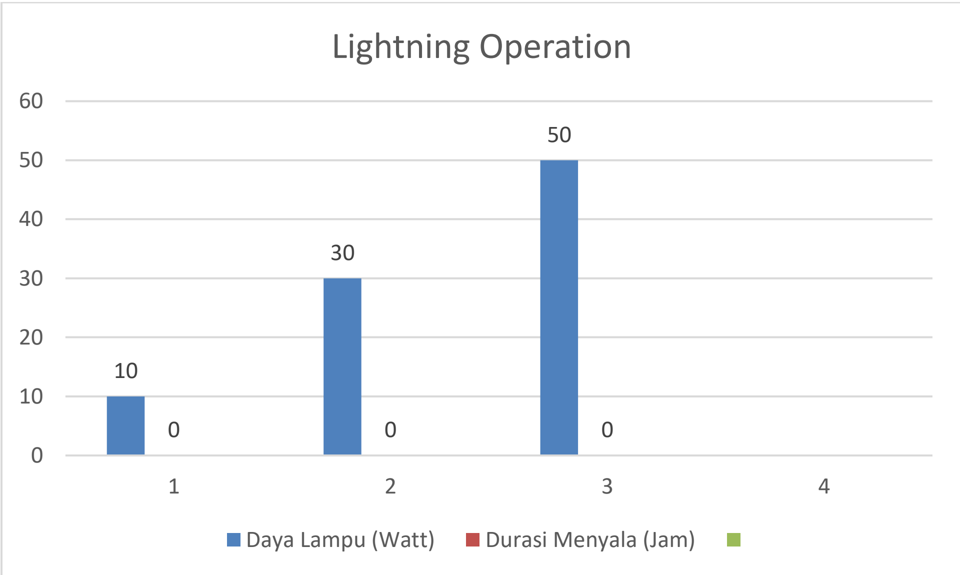

Figure 7. Lightning Operation Graph

In the measurement of voltage and current from the solar panel output, the test results showed that the average voltage produced was 17.45V and the current was 5.69A. The system's maximum power output reached approximately 99.57W, with an average efficiency of 90.13% based on the theoretical maximum capacity of 110WP.

CONCLUSIONS

At night, the solar panel is unable to generate electricity due to the absence of sunlight. As a result, the system relies entirely on the energy stored in the battery during daylight hours. Given the limited battery capacity, electricity usage at night must be carefully managed. Experimental results indicate that with the current battery capacity, only a 10W lamp can be used as the primary light source, operating optimally for up to 9 hours. In a subsequent test, a 20W lamp was added, resulting in a total installed load of 30W, which reduced the operational duration to 3.2 hours. In the final test, another 20W lamp was added, increasing the total load to 50W, and the system was only able to sustain the lighting for 1.92 hours. Therefore, the most ideal configuration is to use only the 10W lamp as the main light source, allowing for continuous operation for up to 9 hours before the battery is fully discharged.

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