Energy cost unit of street and park lighting system with solar technology for a more friendly city

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Abstract. Street and park lighting system is part of a basic infrastructure need to be available in such a friendly city. Enough light will provide more comfort to citizens, especially at night since its function to illuminate roads and park environments around the covered area. The necessity to add more and more lighting around the city caused the rapid growth of the street and park lighting system while the power from PLN (national electricity company) is insufficient and the cost is getting higher. Therefore, it is necessary to consider other energy sources that are economical, environmentally friendly with good continuity. Indonesia, which located on the equator, have benefited from getting solar radiation throughout the year. This free solar radiation can be utilized as an energy source converted by solar cells to empower street and park lighting system. In this study, we planned the street and park lighting with solar technology as alternatives. It was found that for Kota Medan itself, an average solar radiation intensity of 3,454.17 Wh / m² / day is available. By using prediction and projection method, it was calculated that the energy cost unit for this system was at Rp 3,455.19 per kWh. This cost was higher than normal energy cost unit but can answer the scarcity of energy availability for street and park lighting system.

1. Introduction
Street and park lighting system is part of a basic infrastructure need to be available in such a friendly city. Enough light will provide more comfort to citizens, especially at night since its function to illuminate roads and park environments around the covered area. The necessity to add more and more lighting around the city caused the rapid growth of the street and park lighting system while the electricity from PLN (national electricity company) is very limited and the cost is getting higher. Therefore, it is necessary to consider other energy sources that are economical, environmentally friendly with fair continuity.

Since the fossil fuel supply is depleted the solution for this issue is by using renewable energy sources [2]. The most suitable renewable energy source for street lighting systems is by utilizing the energy from solar radiation converted by a solar panel [7], where the generation of energy can be done directly near the load on the lamppost of the street and the park.

Indonesia, which located on the equator, have benefited from getting solar radiation throughout the year. This free solar radiation can be utilized as an energy source converted by solar cells to empower street and park lighting system. In this study, we explored the possibility of the street and park lighting with solar technology as alternatives and analyzed several aspects related to it.
2. Materials and Methods
The selection of lamp types affects the quality of street lighting. The requirements for choosing the type and quality of street lighting are based on the efficiency, plan age and contrast of the road surface and the object [4]. As for some functions of street lighting are as follows:

1. Produce contrast between road and object.
2. Improving the safety and comfort of road users especially at night.
3. As a means of navigating road users.
4. Supports neighborhood security.
5. Increase the value of the beauty.

Solar cells or solar panel is a power house works based on converting solar radiation into an electric current. Solar cells work based on the electric photo effect on semiconductor materials to convert light energy into electrical energy. Solar cells can be analogous to devices with two terminals or connections, where when dark conditions or insufficient light work like diodes, and when exposed to sunlight can produce voltage. When irradiated, generally a commercial solar cell produces a dc voltage of 0.5 to 1 volt, and short-circuit currents in milliampere scale per cm². The magnitude of the voltage and current is not sufficient for many applications, so generally, a number of solar cells are arranged in series forming solar panels.

![Solar cell panel](image)

2.1 Street Lighting System
Planning the street lighting system was done by some calculation steps and component selection. The steps are as follows:

2.3.1 Number of lamps required
After the size of the location was measured, then we determined the type and power of lights and the height of the pole to be used. Furthermore, the required number of armatures can be calculated by Equation 1:

\[ n = \frac{E \times A}{\phi_{\text{armatur}} \times \eta \times d} \]  

(1)

With \( n \) = number of lights, \( E \) = the desired intensity of light (lux or lm / m²), \( A \) = area (m²), \( \phi_{\text{armatur}} \) = flux of light emitted by lamp (lm), \( \eta \) = efficiency of lighting and \( d \) = depreciation factor.

2.3.2 Total Power per Day
Total power per day was calculated to determine the type and power of solar panels used later. Where power per day was calculated by Equation 2:

\[ E = P_{\text{lamp}} \times t \]  

(2)

With \( E \) = power per day (Wh), \( P_{\text{lamp}} \) = Light power (Watt) and \( t \) = duration of lights on (hours).
2.2. Solar Panels
To calculate the power of solar panels to be used depends on the energy that solar panels are supposed to serve for the load and also the duration of solar panels getting solar radiation. Equation 3 is used to calculate the energy that solar panels should produce.

\[ E_{\text{panel}} = \frac{P_{\text{load}} \times \eta_{\text{battery}}}{100\%} \]  

(3)

To calculate the length of solar panels to get sunlight we need to know the intensity of solar radiation where the location of solar panels will be installed. The duration of solar panels getting solar radiation is calculated by Equation 4:

\[ t_{\text{panel}} = \frac{\text{intensity of sunlight}}{\text{global maximum light}} \]  

(4)

And the nominal power of solar panels is calculated using the following Equation 5:

\[ P_{\text{nom}} = \frac{E_{\text{panel}}}{t_{\text{panel}}} \]  

(5)

With \( E_{\text{panel}} = \text{energy from panel (Wh/day)} \), \( P_{\text{load}} = \text{Power used (W)} \), \( t = \text{period of lamp is ON (hour)} \), \( \eta_{\text{battery}} = \text{battery efficiency (\%)} \), \( t_{\text{panel}} = \text{period when panel get sunlight (hour)} \), \( P_{\text{nom}} = \text{nominal power of solar cell (Watt)} \).

The efficiency of the solar panel is the ratio between the output power (Pout) and the input power (Pin). The output power (Pout) is the multiplication of the open circuit time voltage (Voc) with the short circuit current (Isc) and the fill factor (FF) of a solar panel. Equation 6 shows the amount of solar panel fill factor:

\[ FF = \frac{V_m x I_m}{V_{oc} x I_{sc}} \]  

(6)

And the efficiency of solar panels is expressed by Equation 7 below:

\[ \eta = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{V_{oc} x I_{sc} x FF}{S x F} \]  

(7)

With FF= fill factor, \( V_m = \text{nominal voltage of solar cell (volt)} \), \( I_m = \text{nominal current of solar cells (volt)} \), \( V_{oc} = \text{open circuit voltage (volt)} \), \( I_{sc} = \text{short circuit current (volt)} \), \( F = \text{radiation intensity (watt/m^2)} \), \( S = \text{Area of solar cell (m^2)} \)

2.3 Battery Capacity
In a solar electrical system, the selection of the battery is a significant thing considering the generation that can only be done during the day while the newly generated energy is used at night. Before determining the total capacity of the battery, first calculated the expense reserve in one day is expressed by Equation 8:

\[ \text{reserve load} = \frac{E_{\text{load}}}{V_b} \]

(8)

The total battery capacity based on the desired storage period is calculated by Equation 9:

\[ ib = \frac{E_{\text{maks}} + \text{reserve load (Ah)}}{DOD \times \eta_{\text{battery}}} \]

(9)

With \( E_{\text{load}} = \text{lamp energy (Wh)} \), \( ib = \text{battery capacity (Ah/Ampere.hour)} \), \( V_b = \text{battery voltage (volt)} \), \( DOD = \text{deep of discharge (\%)} \), \( E_{\text{maks}} = \text{number of solar cells x } E_{\text{panel}} \).
2.4 Economic Analysis

In a plan, the relationship between planning, analyzing, and a cost is so important, all decisions are evaluated financially so that a project to be executed does not incur losses [1]. The basic parameters that affect the economic estimate of solar cell systems are Investment Cost; this cost is the biggest cost in lighting systems using solar technology and second is operation and maintenance cost. Maintenance cost is the cost used for replacement of components after the life of the service. The total cost of care using the present value method is:

\[ P = F \left( \frac{P}{F}, i\%, N \right) \tag{10} \]

With \( P \) = Present Value, \( F \) = Future Worth, \( N \) = number of periods, \( i \) = interest rate per period

For the energy produced, the cost per kWh is the total discharged divided by the generated energy.

\[ \text{Biaya per kWh} = \frac{I + O + P}{E} \tag{11} \]

With \( I \) = Investment, \( O \) = Operational, \( P \) = Maintenance and \( E \) = energy output

2.5 Field Testing

Field Testing was conducted at Department of Electrical Engineering and Administration Building of FT USU, i.e., measuring the location to be fitted with lighting and reviewing existing lighting. These data are obtained from the Climatology Meteorology and Geophysics Station of Deli Serdang Climatology, which includes data of the intensity of monthly solar radiation and air temperature.

2.6 Analysis

Once the data are collected, the data is analyzed by theories from the literature. The analysis includes:

- Counting the number of poles.
- Calculates the power to be installed.
- Calculate the power of solar panels.
- Calculates the battery used
- Determine the current rating of solar charge controller.
- Calculates the cross-sectional area of the cable.
- Calculate the corners of the pole and handlebar ornaments

3. Result and Discussion

The lamps used are LED lights with 20 watts of power, where the lamp is installed with a height of 6 m, and the intensity of lighting expected for pedestrian safety purposes is 3 lux.

A). For the Administration Building Page of the Faculty of Engineering USU

With an area of 60 m x 40 m = 2400 m², the number of lamps required according to Equation 1 is:

\[ n = \frac{3 \times 2400}{2000 \times 0.65 \times 0.7} = 7.91 \text{ unit} \]

Therefore it can be made eight lamp pole with distance between pole 20 m

B). Garden Department of Electrical Engineering

With an area of 60 m x 30 m = 1800 m². The number of lamps required according to Equation 1 is:

\[ n = \frac{3 \times 1800}{2000 \times 0.63 \times 0.7} = 6.12 \text{ unit} \]
It can be made with six poles, with the distance between pole 20 m. Total pole for Park Department of Electrical Engineering and Administration Building of FT USU is 14 unit pole. The ignition uses an automatic switch (timer) which will start at 18:00 and extinguishes at 06.00, so the lamp lights up for 12 hours. So the power required per pole every day according to Equation 2 is:

\[ E_{armatur} = 20 \text{ watt} \times 12 \text{ jam} = 240 \text{ wh} \]

To determine the power of solar panels must first know the intensity of solar radiation where the location of the solar panel is installed. In this planning, the data is obtained from the Climatology Meteorology and Geophysics Station Climatology Deli Serdang. The data of solar radiation intensity for Medan City area can be seen in the following table:

**Table 1.** Intensity of solar radiation Medan City per month

| Month | Avg Intensity Radiation (W/m²) | Avg Temp max (°C) | Length of Exp (%) |
|-------|-------------------------------|-------------------|-------------------|
| JAN   | 3391                          | 32.4              | 55                |
| FEB   | 3317                          | 31.9              | 45                |
| MAR   | 3688                          | 33.6              | 60                |
| APR   | 4271                          | 34.2              | 52                |
| MAY   | 3725                          | 33.6              | 44                |
| JUN   | 3644                          | 33.3              | 61                |
| JUL   | 3990                          | 32.6              | 63                |
| AUG   | 3940                          | 32.9              | 58                |
| SEP   | 4061                          | 32.6              | 60                |
| OCT   | 2919                          | 31.7              | 35                |
| NOV   | 2196                          | 31.1              | 23                |
| DEC   | 2308                          | 31.6              | 39                |

Source: BMKG Deli Serdang

It can be seen from Table 1 the lowest intensity of solar radiation occurred in November at 2196 Wh/m²/day and the maximum global beam was 1000 W/m²/day. So that the duration of solar panels gets solar radiation according to Equation 4 is:

\[ t_{panel} = \frac{2196 \text{ Wh/m}^2}{1000 \text{ W/m}^2} = 2.196 \text{ jam} \]

The energy that solar panels should produce to serve the 20 Watt lamp load according to Equation 3 is:

\[ E_{panel} = \frac{20 \times 12 \times 90}{100} \times 100\% = 266.67 \text{ Wh} \]

And the nominal power of solar panels using Equation 5 is:

\[ P_{nom} = \frac{266.67 \text{ Wh}}{2196 \text{ h}} = 121.43 \text{ W} \]

So that can be made the solar panel with power 120 WP with the specification in table 2.

**Table 2.** Specification of solar panel 120 WP

| Parameters and values | Values |
|-----------------------|--------|
| Maximum Power (Pmax)  | 120 W  |
| Type cell             | Monocrystalline |
| Parameter                                | Value       |
|------------------------------------------|-------------|
| Voltage at Pmax (Vmp)                    | 17.8 V      |
| Current at Pmax (Imp)                    | 7.51 A      |
| Short circuit current (Isc)              | 6.74 A      |
| Open circuit voltage (Voc)               | 21.6 V      |
| Dimension (mm)                           | 1209 x 808 x 50 |

Source: Sollatek

To measure the efficiency of solar cell first calculate the fill factor by using Equation 6:

$$FF = \frac{17.8 \times 7.51}{21.6 \times 6.74} = 0.92$$

Surface area of solar panel: 1209 mm x 808 mm = 976,872 mm² = 0.977 m².

The efficiency of the solar panel according to Equation 7 is:

$$\eta = \frac{21.6 \times 6.74 \times 0.92}{0.977 \times 1000} \times 100\% = 13.71\%$$

The maximum efficiency of solar panels used is 13.71 %

In the battery, selection should also be considered the battery efficiency factor and at the time of use is not recommended to use the battery until the battery is discharged. Because Indonesia is on the equator where sun exposure occurs throughout the year, the load reserves are set in one day only. That is determined by using Equation 8:

$$\text{cadangan beban} = \frac{240}{12} = 20\text{ Ah}$$

The total capacity of the battery based on the desired storage period according to Equation 9 is:

$$ib = \frac{1 \times 414.5 + 20}{80\% \times 0.9} = 75.75\text{ Ah}$$

Minimum battery capacity as calculated is 75.75 Ah. From Sollatek catalog the capacity of the battery that allows is 84 Ah.

Furthermore, for economic analysis, the calculated costs are investment cost, maintenance cost and operational cost for 25 years with an estimated price increase of 10% per year. All components are replaced according to the manufacturer's standard life. Where LED lamps should be replaced 11 years, and the battery is changed 15 years. The cost of maintenance for replacement LED lights and batteries using Equation 10 is:

For LED Lights
$$P = Rp 450.000(P/F, 10\%, 11) + Rp 450.000(P/F, 10\%, 25)$$
$$P = Rp 450.000(0.35050) + Rp 450.000(0.09230)$$
$$P = Rp 199.260$$

For battery ; $$P = Rp 1.850.000(P/F, 10\%, 15) + Rp 1.850.000 (P/F10\%25)$$
$$P = Rp 1.850.000(0.23940) + Rp 1.850.000(0.09230)$$
$$P = Rp 613.645$$

The operational cost here is for solar panel cleaning. The cost of cleaning per solar panel per year is Rp 50,000, and the cost of cleaning 14 solar panels is Rp 700,000 so the total cost of cleaning solar panels for 25 years is Rp 17,500,000.

The investment cost includes the overall purchase cost of the material and its installation.
For the calculation of cost per kWh, we calculate the total energy generated by solar cells for 25 years by taking the average radiation value discussed in the previous section of 3454 Wh / m² / day. The average energy that solar panels produce per day is:

\[ E_{\text{1 panel}} = 120 \times 3,454 = 414,48 \text{ Wh} \]

Energy for 14 solar panels:

\[ E_{14\text{panel}} = 14 \times 414,48 = 5802,72 \text{ Wh} = 5,80272 \text{ kWh} \]

And the total energy generated for 25 years = 9,125 days is:

\[ E_{\text{total}} = 5,80272 \times 9125 = 52,949,82 \text{ kWh} \]

The price of electricity per kWh according to Equation 11 is:

\[ \text{Cost per kWh} = \frac{Rp 164,639,000 + Rp 17,500,000 + Rp 812,905}{52,949,82} = Rp 3,455,19 \]

Therefore the price of electric power tariff if using solar cell energy source is Rp 3,455.19 per kWh.

4. Conclusion

Based on the results of the discussion conducted, we obtained some conclusions that for the Park Department Electrical Engineering and Building Faculty of Engineering USU required six poles each and eight lamps lighting poles. The distance between the pole of 20 meters and the pole height of 6 meters and 20 Watt LED lights so obtained the quality of lighting according to street lighting standards.

The energy that can be generated by a solar cell of 120 WP with an average solar radiation intensity for the Medan City area is 3,454.17 Wh / m² / day at 414.48 Wh.

The price of electricity per kWh using the solar cell energy source is available Rp 3,455.19 per kWh. This price is still quite high compared to conventional electricity prices that cost about Rp 2,000 per kWh.

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