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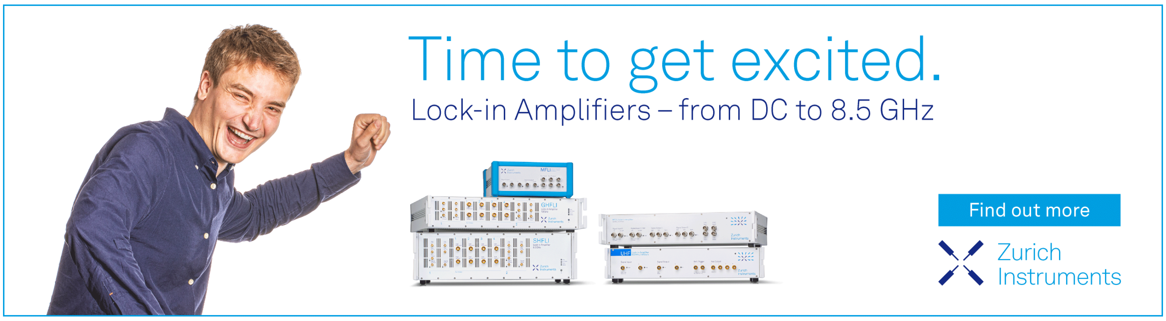

Techno Economic Analysis of Public Solar Street Light with Integrated Monitoring System for Parking Area

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Abstract. Indonesia has a great potential on solar energy since it is located across the equator.Therefore, it is beneficial to implement photovoltaic system in the area. One of the photovoltaic applications is solar street light system. The techno – economic analyses of public solar street light has been conducted including the potential for CO2 reduction and cost reduction analysis. The solar street was designed for parking area with moderate traffic. It has been designed to give 5.54 lux illumination and 12 hour service time. The additional system has been integrated to monitor daily power consumption and to ease the maintenance procedure. The energy input has been calculated by referring to solar energy data in North Jakarta. A 370 watt peak solar panel with 24V and 50Ah battery configuration are implemented for the public solar street light system. The system is designed to serve for 3 days of autonomy. **Keywords:** *Techno Economic, Solar Street Light, Monitoring System.*

INTRODUCTION

Electrical energy is an essential resource in modern life. The electricity is generated from coal-fired power plant. However, the generation lead to increased CO_2 gas emission which contribute to climate change. Indonesia have signed the Paris Agreement to limit global warming below 2ºC. the implementation of renewable energy may help to reduce CO_2 emission and reach the Paris Agreement goals. Indonesia have a solar energy potential up to 207 GW [1]. Therefore, the implementation of solar photovoltaic device is a promising way. The solar panel is a device that can convert solar energy to electricity and can be coupled with various application such as solar street light [2]

According to the PLN Statistic data in 2016, there are 205,940 solar street light in Indonesia which powered by electricity generated from coal. The conventional street light is still dependent to the electricity grid [3]. From the technical point of view, implementing solar panel will enable the streel light to be installed in rural area without any grid transmission infrastructure. Besides that, about 2,98-million-ton total CO_2 emitted by electricity usage of street light can be reduced by implementing renewable energy [4], [5]. Besides that, the solar panel implementation would save the electricity cost [6].

METHODOLOGY

The solar street light design is conducted by estimating site solar energy potential gathered from solcast.com. The data is acquired from location of -6.148 latitude and 106.939 longitude. The data is used to determine peak sun hour for the calculation. The flowchart of calculation is conducted as follows:

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Formula

The design was conducted by using the following set of formulas:

Lamp Distance

$$r = \sqrt{h^2 + c^2} \qquad \text{Eq. 1}$$

r = $illumination\ distance\ (m)$
h = $pole$ height (m)
c = $horizontal\ distance\ to\ road\ way\ (m)$

Light Flux

Light flux is total light emitted per second.

$$\Phi = \omega\ l \qquad \text{Eq. 2}$$

$$\Phi = K\ P \qquad \text{Eq. 3}$$

ϕ = light flux (lm)
I = $light\ intensity\ (Cd)$
P = $Lamp\ Power\ (W)$
K = $light\ efficacy\ (lm/W)$

Illumination

Luminance is a light or brightness measurement of lamp. Excessive luminance will give glare effect.

$$L = \frac{l}{As} \qquad \text{Eq. 4}$$

$$L = \frac{1}{r^2}\ cos \qquad \text{Eq. 5}$$

L = $Illumination\ (cd/cm2)$
I = $light\ intensity\ (Cd)$
r = $illumination\ distance\ (m)$
As = Luminaire surface area (cm)

Total Monthly Energy

Monthly energy is calculated by considering lamp power, number of lamp, and time of service. The energy required is calculated using the following formula:

$$E_m = P_t\ x\ t\ x\ N \qquad \text{Eq. 6}$$

E = $Monthly\ Energy\ consumption\ (Wh)$
Pm = $Lamp\ Power\ (W)$
t = $time\ of\ service$ (hour)
N = $number\ of\ lamp(s)$

Battery Energy

The energy of battery is calculated by considering Depth of Discharge (DoD), Autonomous Day (AD), Daily Energy Consumption (Eday). The following formula is used:

$$E_{batt} = \frac{E_{day}\ x\ AD}{DOD} \quad \text{Eq. 7}$$

$$C_{batt} = \frac{E_{batt}}{V_{nom}} \quad \text{Eq. 8}$$

E = $Battery\ Energy\ (W\text{h})$
AD = $Autonomous\ Day\ (day)$
DOD = $Depth\ of\ Discharge\ (\%)$
$Cbatt$ = $Battery\ Capacity\ (A\text{h})$
$Vbatt$ = $Battery\ Nominal\ Voltage\ (V)$

Solar Panel

Required Solar Panel power is calculated using following equation :

$$P_{pv} = \frac{E_{day}}{PSH\ x\ \eta} \quad \text{Eq. 9}$$

PPV = $daily\ energy\ consumption\ (W\text{h})$
PSH = $Peak\ Sun\ Hour\ (\text{hour})$
E_{day} = daily energy consumption (Wh)
η = $Solar\ Panel\ Efficiency$

Solar Charge Controller

The solar charge controller rating is determined by following formula:

$$i_{scc} = \frac{P_{pv}}{FF\ x\ V_{oc}} \quad \text{Eq. 10}$$

$$FF = \frac{V_{mpp}\ x\ I_{mpp}}{V_{oc}\ x\ I_{sc}} \quad \text{Eq. 11}$$

FF = $filling\ factor$
I_{scc} = $solar\ charge\ controller\ current\ rating\ (A)$
Voc = $solar\ panel\ open\ voltage\ (V)$
Vmpp = $solar\ panel$ rated $voltage\ (V)$
$Impp$ = $solar\ panel\ short$ - $circuit\ current\ (A)$
Isc = $solar\ panel\ rated\ current\ (A)$

Electricity Tariffs

Implementing solar panels to the street light pole installation can reduce the grid electricity consumption. The reduced electricity tariff is calculated using following formula:

$$M = U\ x\ E_m \quad \text{Eq. 12}$$

M = $Monthly\ tariff\ (Rp)$

U = $electricity\ cost$ (Rp/kWh)
Em = $Monthly\ Energy\ consumption$ (Wh)

RESULTS AND DISCUSSION

Design and Analysis

The light luminance is calculated by choosing 40-watt LED lamps as a load for solar street light. Light efficacy of LED light is > 110 lm/watt [7]. Hence, the design is calculated using previous Formula

Light Luminance

According to eq 2 and eq 3, the calculated light luminance is:

$$l = \frac{K\ P}{\omega}$$

$$l = \frac{40\ 110}{4\pi} = 350.14\ Cd$$

Illumination

The illumination is calculated using eq 1 and eq 5 for column height of 7 meter and parking area distance to 3 m. Therefore, the r = 7,615 meter and L = 5,54 lux. The value of illumination intensity with the lamp of 40 watt is 5,54 lux. The solar street light is design to illuminate an open space parking area. Based on Indonesian National Standard (SNI) number 7391:2008 [8], for low mobility level the minimum illuminance is 2 lux for pedestrian safety and 5 lux for vehicle traffic. Based on the calculation, the 40 watt LED implementation is suitable for both pedestrian and vehicle traffic safety.

Energy Consumption

Load Energy consumption

According to the previous calculation, a 40 Watt LED lamp comply to the street light standard. Therefore, it is used as a load for the solar street light. The system will have time of service for 12 hour from 6 p.m. to 6 a.m. The Daily energy consumption for each solar street light is 480 Wh and 14400 Wh based on the eq. 6. Monthly load energy consumption is 14,400 Wh. Recent system, include the online monitoring system which include lamp dimmer. The lamp will be dimmed on 30% power from 12 am to 6 am. The following operation scheme will increase the energy saving even further. Therefore, by dimming the lamp to 30%, the required energy is
$E_m = ((40\ x\ 6) + (40x30\%x6)\ x\ 1\ x\ 30\ days$
$E_m = (240 + 72)\ x\ 1\ x\ 30\ days$
$E_m = 9360\ Wh$

Battery Energy Consumption

The battery energy demand is calculated by considering daily load consumption. The DOD of the battery is determined by the technology. Current solar street light is designed to use lithium iron phospate technology for the energy storage for it is have 80% DoD and approximately 3000 cycle. The 3 day of autonomous day is choosen based on the data reported by the Agency of Metrology, Climatology, and Geophysics (BMKG). The data showed that in December 2020, the city of Jakarta has 11 days without rain (35% chance of not raining). The average rainy day in the rainy season is 17 days. The data is shown in Table 1. It can be inferred the in general, jakarta will experience one day of rain for every 3 days . Therefore 3 days of autonomy is implemented in calculation. By using eq 8, the battery capacity is 45 Ah. By considering the commercially available battery, the 50Ah battery is chosen for system.

Table 1. Rainy days data of jakarta in 2020 based on Agency of Metrology, Climatology, and Geophysics (BMKG) and Daily Global Horizontal Irradiance (GHI) from solcast.com

Month	Rainy Days	GHI ($kWh/m^2/day$)
January	20	4.51
February	24	4.58
March	17	5.23
April	13	4.98
May	7	4.88
June	4	4.54
July	1	4.91
August	1	5.65
September	3	5.87
October	5	5.55
November	13	4.97
December	16	4.47
Average Rainy Days (dry season)	**4**	
Min GHI		**4.47**

One PSH is equal to 1 kWh/m.day, hence, following calculation is used to convert GHI to PSH : hence the PSH equal to 4.47 $Hour$. The η is calculated by considering battery efficiency and system efficiency which are 90% and 80% , respectively. Hence the efficiency is 72%.
According, the eq 9, solar panel power is :

$$P_{pv} = \frac{1170}{4.47 \ x \ 72\%}$$

$$P_{pv} = 363 \ Wp \approx 370 \ Wp$$

The 370 Watt Solar panel is chosen which specification is shown by table 2.

Table 2 Solar Panel Specification

Parameters	Nominal
Peak Power (Wp)	370
Open Voltage (Voc)	40.9
Short – Circuit Current (Isc)	11.52
Rated Voltage (Vmpp)	34.4
Rated Current (Impp)	10.76

Solar Charge Controller

The current rating of solar charge controller is calculatd using eq 11 and eq 10. The calculation result show that minimum solar charge current rating is 11.5 A. Therefore, the the solar charge controller with 15A rating is choosen since it can provide higher safety feature and prolong the devices life cycle. The summary of all component in system is shown by table 3.

Table 3 Summary of Component in solar street light systems

Components	Specification
Solar Panel	370 Wp
Battery	24 Volt 50 Ah $LiFePO_4$
LED Lamp	40 Watt
Solar Charge Controller rating	15 A

Economical Analysis

Electricity Tariff

Implementing the solar panel and battery into the solar street light system eliminate the conventional electricity usage. The reduced electricity usage can be calculated by considering monthly energy consumption for each lamp. According to the regulation of ministry of energy and mineral resources No 31/2014 [9], the street light is classified to P-3/TR category with electricity cost of 1.444,7 Rp/kWh. Hence, the monthly electricity tariffs is:

$$E_m = 9360\ Wh$$
$$M = 1{,}444.7\ x\ 9360\ /\ 1000$$
$$M = Rp.13{,}522\ /\ month$$

Carbon Tax

According to Climate transparency [10], the emission factor in Indonesia is 761 gCO_2/Kwh. Besides that, the it is proposed that Indonesia will apply carbon tax of Rp 75.000/tons CO_2. The emitted CO_2 gas from each lamp is:
$CO_2\ emission = E_m\ x\ emission\ factor$
$CO_2\ emission = 9.360\ \text{kWh}\ x\ 743\ gCO2/kWH$
$CO_2\ emission = 7.122\ gram\ CO2\ /month$

Indonesia proposed a carbon tax for Rp. 75.000/tons CO_2, therefore the system reduces IDR 534.55 for carbon tax per pole installed.

CONCLUSION

The solar street light system is designed to illuminate open space parking area with low-activity. The street light installed with 7 meter octagonal pole. The system use 40 watt LED lamp as the load equipped with dimmer device. To fulfill the 3 days of autonomy, a 25.6 V 50 Ah LiFePO4 battery is implemented. The charge current is governed by solar charge controller with 15A current rating. To charge the battery to full capacity in one day, a 370 Wp solar panel is used. The system deliver 5.54 lux which comply to SNI 7391:2008 about illumination standard for parking space area.

The economical analysis shows that the system will reduced the cost of electricity by Rp. 13.522 per month. Beside that, the implementation of solar panel make the street light to be installed in rural area without any grid connection which reducing the capital cost on grid transmission construction as well. By implementing renewable energy on the system reduced 6,954 gram CO2 emission monthly hence reducing Rp. 521.55 carbon tax monthly for each lamp installed.

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