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Evaluation and Designing Street Lighting with Solar Cell: A Case Study

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***Abstract*— High operating costs, lux incompatible, and inefficient become a great problem in the street lighting of campus area that generated by fossil energy. In a case study at Sebelas Maret University, it is possible to shift the street lighting that generated from fossel to Solar Cell. This article aims to evaluate and design Street Lighting with Solar Cell. An evaluation framework was developed to evaluate the performance of current condition related to lux, distance, pole, and the amount of lamp power. We design the alternatives of Street Lighting by using DIALux application to fullfill the technical standard of Street Lighting. The specification of street lighting, the type of installation, and the material used were studied for designing new Street Lighting. A simulation-based analysis was used to determine the specifications of new design of street lighting. The results shows that the alternative of design street lighting that generated by Solar Cell can be used to substitute the existing one with better performance and reliability aspects.**

Keywords—Evaluation Street Lighting; Designing Street Lighting with Solar Cell;

I. INTRODUCTION

Electricity is an important energy for activities, to generated large scale production, office, street lighting, etc. High demand for electricity is inversely proportional to the growth of the supply of electric energy in Indonesia. Previous research showed that electricity reserve of approximately 25-30% in Java, 10% in Sumatra, and Eastern Indonesia less than 10% [1]. As the times increasing of electrical energy, it can be seen the use of electronic tools and the industry continues to grow. If the electricity continues to grow without balanced providence so it will lead to an energy crisis. The energy crisis is a fundamental in Indonesia, especially the problem of the electrical energy crisis. Electrical energy is necessary for modern living. In the event of a power outage, many activities will be halted at once [2]. Power outages, especially in the street lighting due to ineffective and inefficient power used obstruct activities that may affect the safety and comfort of society.

Based on the problems, development of the use of energy storage has good prospects to resolve the energy crisis that occurred at this time. One of development is applied on a solar street lighting. Street lighting using solar power to be used as a power source of lighting, it's low cost because the solar energy is unlimited free [3]. Sebelas Maret University is one of the green campus universities and has the development of energy storage by utilizing the lithium battery. As one of the colleges that have a work culture ACTIVE (Achievement Orientation, Customer Satisfaction, Teamwork, Integrity, Visionary, Entrepreneurship) see it as an opportunity resource that should be developed. As it is known that Sebelas Maret University still use the street lighting that use conventional power, so the application Solar Street Lighting it is applicable in the campus to support the energy efficiency.

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Solar energy had lots applied in around the world, if properly managed, solar energy has potential to be an alternative energy in the future. Sunlight received at the earth's surface that is 3 x 1024 joules per year, equal to 2x 1017 watt. That amount of energy equivalent to 10,000 times the energy consumption in the world [4], [20]. As a country located around the equator, Indonesia has great potential to generate solar energy for approximately 4.8 kwh / m^2 or equal to 112,000 solar energy GWP [5]. Certainly these benefits should be carefully studied. In addition to utilizing solar energy with PV technology can replace the conventional energy so as to provide a positive economic impact [6].

Implementation of solar power in street lighting be expected as a solution, street lighting with solar power has been important to support daily activities. Solar street lighting use lithium battery to be developed by the University as the depositary of energy derived from the sun. The importance of this research not only to do analysis the investment in implementation of solar energy for street lighting, but as well in support of lithium battery research currently developed at Sebelas Maret University. Besides, as a support strategy, develops lithium battery also meant to improve global competitiveness in Indonesia [7], [20]. The plan was to establish a mini plant to manufacture lithium battery to be implemented by an electric vehicle [8], [17] - [18].

An important stage to apply new technology is to study feasibility business plans using a several criteria that developed by management [7]. Feasibility Investments consist of both the technical and economic aspects. To implement street lighting by using solar power requires a technical analysis phase. Technical analysis of this study is an evaluation and design phase of street lighting

II. Components of Street Lighting

Street lighting as part of building installed on the left or right or in the middle (median) used to light the road and the surrounding roads, including the intersection of roads, bridges and the underpass. The detail unit consists of light source optical elements, electric elements, base, pole and lamps [8]. Street lighting is not only related to the driver's needs, but also required by the general public [10]. Street lighting has the function for [11]:

1. Generate the contrast between the object and the road surface
2. As a navigation tool
3. Improve the safety and convenience for the driver, especially as the night
4. To secure the region
5. To provide aesthetics

The source energy of solar power coming from sunlight to operate street lighting [3]. Solar street lighting is an energy-saving. Street lighting with solar power is cost-efficient because it uses energy derived from sunlight infinite. Solar street lighting using solar cell panels that function to receive sunlight and then convert it into electrical energy through the photovoltaic process. The lights can work automatically at night and off in the morning with an easy and inexpensive treatment [3]. A solar street lighting system consists of electricity generation, storage and management device (solar panel, battery and controller) and lamps [12]. Street lighting with solar power consist of several components which solar cells, LEDs, pole, and battery power regulator.

A. Solar Cell Panel

The most important parameter in the performance of solar panels are solar radiation intensity, the number of sunlight surface per board area [4]. Solar radiation can be used to define power to produce solar cells. The solar cells consist of silicon, that function to convert the intensity of sunlight into electricity. Photons moving to electrons and generate current and voltage. Electric current is an electric direct current or DC [3]

B. Battery Charge Regulator

In one package battery charge regulator there are several components, *i.e.* a battery, controller, block terminal, and battery management system [13]. It uses lithium battery as a storage of energy. Lithium battery was chosen because it has advantages than others battery, lithium has no memory effect, rechargeable battery without vacating the completely before disposal. A life time is more durable than VRLA battery. Lithium battery for solar street lighting life time estimated for five years. The Battery can store in large capacity.

Another component is a solar charge controller (SCC), which functioning as control time and storage control of street lighting and maintains a direct current filled to the battery and extracted from the battery to the load. Besides battery and SCC there are BMS (Battery Management System) which functions to cut off If the battery is fully charged, and function to set the power outputs required. BMS manage and monitor the condition of the battery, and the maintain the balance of battery [14]. Terminal block in the box function as current divider, in a case which is needed of damage does not occur difficult to repair process and to minimize sparks.

C. LED

Application of street lighting with solar power using LED as a lighting output. Majority, street lighting using neon, mercury and sodium, compared with LED course more profits LED lights. The average life cycle of LED is 50,000 hours - 10.000. If it is assumed that life time is 50,000 hours with 12 hours per day, so can estimate life time of the lamp can last up to 1 years. Compare with fluorescent lamps with a life cycle is 2,000 hours if used for 12 hours per day, then less than 1 year of usage. Use LED power consumption is more efficient, because with capacity 40-120 watts, can replace fluorescent in 150-350 watts [20].

LED is environmentally friendly because not contain mercury. UV emits a fluorescent light, can contaminate the environment if disposed carelessly. It also provides reduced rate of higher performance, lower efficiency and a shorter life than LED, which is needed a higher initial investment [15].

Research and analysis shows that LED have great potential to replace fluorescent light, driven by the reduction in power related to the replacement of lamp one-to-one (or retrofit). But, consumers should be aware inherent characteristics of LEDs, such as the quantity and quality of light levels in areas of the working [16].

III. Study Area

The problem in this research is to evaluate and design related planning street lighting at Sebelas Maret University. Fig. 1 is described about process evaluation street lighting on campus. Fig.2 Show method for designing street lighting to choose the best alternative based on comparative advantages and disadvantage each alternative. And then in Fig.3 show method to redesign street lighting using solar power. Application of solar street lighting on campus certainly needed to design simulations to be performed. It can determine in advance the research object, which is the object of observing to be simulated. Observation by measuring illumination using a Lux meter and for distance and light centre height using LDM (Lases Distance Meter). Street lighting measurements carried out in the Faculty of Engineering UNS.

In this study will be made the object of the simulation is a street lighting in the Faculty of Engineering, Sebelas Maret University. Existing condition of street lighting that is known there are 17 light points spread across the main street area of the engineering faculty, mapping with Google Maps. The following will be presented a map of the location of the lamps on campus in Fig.4

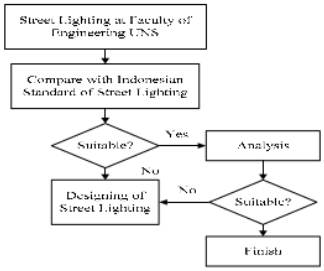

Fig. 1. Approach to Evaluation Street Lighting

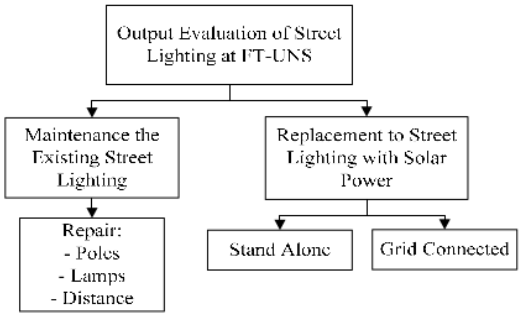

Fig. 2. Method to Designing Street Lighting

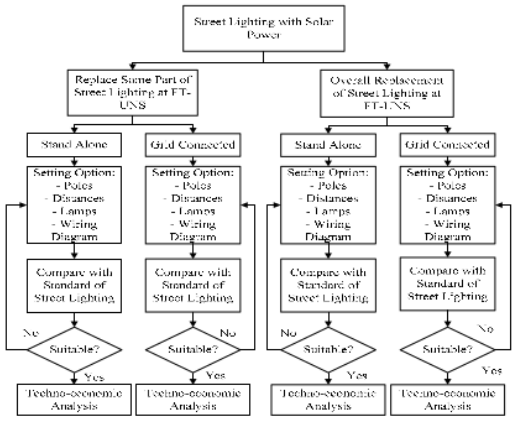

Fig. 3. Method to Redesign Street Lighting at FT UNS

Fig. 4. Location Street Lighting at Faculty of Engineering UNS

IV. Evaluation and Design Street Lighting

Evaluation of the condition street lighting is applied at this time is not only the number and location of the reference point of lamps in decision-making, also the specifications of an existing street lighting. It is needed as a basis for determining the amount of power used for the first lamp unit and serves as a basis of comparison component in designing street lighting based solar power. Based on the results of field studies that have been done can be seen from the street lighting specifications in the Faculty of Engineering, Sebelas Maret University. There are two types of street lighting used in the campus, the main street lighting and street lighting support. In this research study focused only street lighting on the main road. For street lighting on the main campus of street uses manifold mercury lamp. Power is used for each lamp of diverse, yet for street lighting on the main road using 125 watts. The lamp used Philips lamp HPL-N 125 watt / 542.

For sources of energy used street lighting in the Faculty of Engineering still use conventional electricity as the main source of energy. Street lighting in campus work using key Switch ON / OFF. Operating hours for street lighting lamps

for 12 hours at 6 p.m. until 6:00 pm. To evaluate the existing street lighting in the Faculty of Engineering, Sebelas Maret University is taking the measurements the existing condition. The measurement as an evaluation whether the existing lighting is in conformity with standards [11]. The following measurements have been done in Table I.

After finding out the results of measurements next steps is calculate the requirement of lighting, and the last stage is to evaluate. Here are the results of the calculation of the requirement of street lighting. And the result of evaluation can be seen in fig. 5

The first calculation is to calculate light intensity (Candela)

$$\boldsymbol{i = \frac{\emptyset}{\omega}, \omega = 4\pi} \quad (1)$$

$$\boldsymbol{K = \frac{\emptyset}{P} \quad \emptyset = KxP} \quad (2)$$

$$\mathbf{i = \frac{K\,x\,P}{\omega}} \quad (3)$$

$i = light\ intensity\ (cd)$

$K = luminous\ efficacy$

$\emptyset = Flux\ (lm)$

The K average luminous efficacy of 125 watt lamp types HPLN is 49.6 Lumens / watt with power (P) 125 watts and the angle ω = 4π space

$$\mathbf{i = \frac{K\,x\,P}{\omega} = \frac{49{,}6\,x\,125}{4.3{,}14} = \frac{6200}{12{,}56}} \quad (4)$$

$$\mathbf{i = 493,63\ cd} \quad (5)$$

The next step is to calculate the luminance at the road. The distance to the end of the street lamp (r):

$$\boldsymbol{r = \sqrt{5^2 + 4,9^2} = 7\ m} \quad (6)$$

$$\mathbf{E_B = \frac{i}{r^2}\cos\beta = \frac{493{,}63}{7^2}.\frac{5}{7} = \frac{2468.15}{343} = 4{,}71\ lux} \quad (7)$$

After calculating the luminance of the existing lighting conditions and Indonesian standard street lighting, which should be a difference in the result. For existing condition can be known luminance at point 1 is 4 lux while the conditions that should be owned by a street lighting is supposed to have is 6 lux.

TABLE I. MEASUREMENT RESULT OF STREET LIGHT AT CAMPUS

Existing Condition							Standard of Street Lighting		
Point	Lamp Condition	Lamp Type	Lux (lx)	Distance (m)	Width of the Road (m)	Light Centre Height (m)	Width of the Road (m)	Light Centre Height (m)	Lux (lx)
1	ON	HPLN 125 watt	4	26	4.9	6.3	5	6	6
2	OFF	HPLN 125 watt	0	97.5	5.0	7.0	5	6	6
3	OFF	HPLN 125 watt	0	26.6	5.0	6.2	5	6	6
4	ON	HPLN 125 watt	4	21.37	5.0	6.1	5	6	6
5	OFF	HPLN 125 watt	0	40.23	5.0	6.0	5	6	6
6	ON	HPLN 125 watt	6	40.2	4.1	5.9	4	6	3.5
7	OFF	HPLN 125 watt	0	43.1	4.1	5.1	4	5	3.5
8	ON	HPLN 125 watt	13	47.1	4.1	4.4	4	4	3.5
9	ON	HPLN 125 watt	48	46.2	4.1	2.8	4	4	3.5
10	OFF	HPLN 125 watt	0	75.5	4.1	3.5	4	4	3.5
11	OFF	HPLN 125 watt	0	24.2	4.1	3.4	4	4	3.5
12	ON	HPLN 125 watt	21	72.4	4.1	4.1	4	4	3.5
13	ON	HPLN 125 watt	6	21.4	4.7	6.7	5	6	6
14	ON	HPLN 125 watt	18	29.5	4.7	4.3	5	4	3.5
15	OFF	HPLN 125 watt	0	40.4	4.9	6.0	5	6	3.5
16	ON	HPLN 125 watt	17	84.1	4.9	3.6	5	4	3.5
17	ON	HPLN 125 watt	9	32.9	4.9	5.6	5	5	3.5

Fig. 5. Evaluation Result of Street Lighting

Based on the results in figure 5 can be know there are 9 lamps that not suitable with standard of street lighting, it be known from the red line on the figure. Green line stating that the lighting is good. While in the blue line stating that the lighting is not efficient because a considerable difference in height between the existing conditions and standards required.

Based on evaluation street lighting on the campus is inefficient, so that require to design the existing street lighting. There are several design alternatives, all designed with consideration structure road and Indonesian Standard of Street Lighting. The first alternative perform maintenance on the street lighting at campus, can be done by changing the entire street lighting or even by improving over of street lighting that does not comply with standards. Repair includes replacement or installation of the power needed, adjusting the height of the light center height, and adjust the distance between the lamps. For the first alternative is to use conventional power. A second alternative for street lighting with solar power, to do some of this alternative option, first make improvements in whole or several point lights only. After the election of the system will have is to use stand alone or grid connected.

Table II describes the advantages and disadvantages of both alternatives. Based on the results of the street lighting by using solar power is more profitable than conventional electricity, so select the street lighting with solar power. Based on the table it is known that street lighting with solar power

not using conventional energy (fossil fuel), but using solar power to generate the lighting. Solar energy is free to consume, so the street lighting with solar power is more efficient than conventional street lighting that using fossil fuel. Table III and IV describe the design of street lighting at Faculty of Engineering UNS based on Indonesian Standard of Street Lighting [11]. In this study using LED lights, then adjusting the lamp power to the lamp power suggested by the standard.

TABLE II. COMPARISON OF CONVENTIONAL AND SOLAR POWER STREET LIGHTING

Conventional Street Lighting		Street Lighting with Solar Power	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Lower initial investment cost	Maintenance cost and limitations Expensive manual failure check	Street lighting with solar power are independent, so the operation cost are	Initial Investment is higher
	Street Lighting operational cost is higher	Non-Polluting source of electricity	Risk of theft is higher
	Light pollution, energy wasted illuminating the sky ecological damage to birds and insects	Street lighting with solar power require much less maintenance compared to	
	Street Lighting energy cost is higher	Easy to use	
	Dark area and broken lights lower safety and security	Environmentally Friendly	

TABLE III. DESIGN STREET LIGHTING

Lamp Type	Lights Centre Height (m)	Width of the Road (m)		Lux
		4	5	
LED 30 W	4	31	30	3.5
	5	33	32	3.5
LED 50 W	6	48	47	3,5
LED 50 W	6	34	33	6
LED 80 W	6	48	47	6

The distance between the light pole in meters.

TABLE IV. QUANTITY OF LAMPS

Roadway (m)	Distance (m)									
	31	30	33	32	48	47	34	33	48	47
276	9	9	8	9	6	6	8	8	6	6
218	7	7	7	7	5	5	6	7	5	5
281	9	9	9	9	6	6	8	9	6	6

The quantity of lamps in units.

In this study conducted a simulation of the alternative design street lighting. In Fig. 6 and Table V can be seen the results of the simulation using the software DIALux. If the result known that the specifications of the lamp 50 watt lamp 6 meters high and results for this alternative is suitable for street lighting condition at campus.

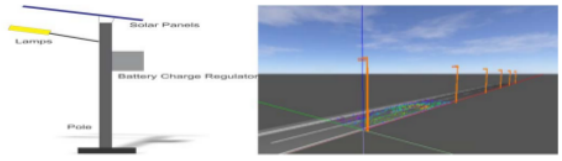

Fig. 6. Design of Street Lighting

TABLE V. SIMULATING RESULT USING DIALUX

	Lm (cd/m2)	U0	UI	TI(%)	EIR
Actual Value according to calculation	0.86	0.54	0.62	8.26	0.44
Required values according to class	≥ 0.50	≥ 0.40	≥ 0.60	≥ 15.00	≥ 0.30
Fulfilled/ Not Fulfilled	√	√	√	√	√
Assigned observer (2):					
Observer	Position (m)	Lm (cd/m2)	U0	UI	TI(%)
Observer 1	(-60.000, 1.250, 1500)	0.86	0.58	0.86	4.52
Observer 2	(-60.000, 3.750, 1.500)	0.91	0.54	0.62	8.26

As previously known that the street lighting with solar power using sunlight as an energy source. Therefore, the operating system street lighting solar power is divided into two systems, namely a stand alone system, it is street lighting solar power is not connected to the electricity network and street lighting system with solar power connected to the grid or grid connected system.

The use of solar cells as an alternative source of energy has been widely applied, one application in street lighting. For the application itself can independently or not connected to the electricity grid and can be operated by plugging in the power grid. For street lighting with independent network equipped with a backup battery, the battery is used to store electrical energy that will be used to turn on the lights at night.

As for street lighting solar power system connected to the grid output of the inverter that converts DC power to AC directly linked (fused) with the electrical installation systems for interior synchronized with the output power of the PLN. In such a system is necessary KWH meter two-way function to read the electricity from two directions, namely electricity flowing from utility to utility and flows [20]. Street lighting systems with electric power systems connected to the electricity grid without battery backup in case of outage on the main source of conventional electricity, then the system must be extinguished although at the same time the panels were generating electricity and it is referred to as the anti-islanding.

Street lighting solar power can also be combined among the above model, the street lighting grid connected solar power with battery backup. In this system allows electricity generated from solar power can be used as a backup energy, to turn on the AC load without the need to have multiple installations, as well as being able to send power to the utility. Purposes that can be obtained with the use of street lighting system network-connected solar electricity with battery backup is to [20]:

1. The electricity will be generated by the panels can be directly used by the electrical load without double installation in solar street lighting
2. When the electric power consumed bean is smaller than the power produced by the panel, the more power can be supplied to utilities

3. Using this system, the user has the option to choose whether to use the power of the PV to supply power to the load or save it to a battery for later use when night
4. If the power of the PV module is used to load and store the battery at the same time it will not be efficient.

V. CONCLUSION

Based on evalution performance of existing street lighting in campus consist of lux, distance, pole, and the amount of lamp power compare with Indonesian Standard of Street Lighting. There are several lamps not suitable with standard such as the pole is too short, low brightness of the lamps makes lux incompatible, distance between the lamps does not fit with requirement, so it can makes street lighting in campus inefficient and ineffective. Based on comparison result, the lux, distance, pole, and the amount of lamps not suitable with standard. Evaluation street lighting in campus is obtained that street lighting it need to improvement.

Improvement of this problem is to designing street lighting in campus based on technical standart of street lighting. In designing street lighting that considering several factors there are specification of street lighting, the type of installation, and the material. To determine the specification of street lighting using DIALux application for simulating the several alternative design. A simulation based on specification of street lighting such us distance, lights center height, pole distance, width of road, and lamps. Selected material for battery using lithium battery because it has advantages than others battery. Application of street lighting with solar power using LED as a lighting output because LED more efficient than other lamps. The type of installation of street lighting is using a grid connected system. In grid connected system the user has the option to choose whether to use the power of the PV to supply power to the load or save it to a battery. Based on results shows that the alternative of design street lighting that generated by Solar Cell can be used to substitute the existing one with better performance and reliability aspects.

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