Development of static solar panel equipped by an active reflector based on LDR sensors

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Abstract. Solar panels are a very effective source of renewable energy in Indonesia. To increase the output power of solar panels, especially on the static solar panels, a reflector is required as an additional device. This paper describes development of a static solar panel equipped with an active reflector. Five LDR sensors are mounted on the top of the reflector, to detect the highest solar intensity. Meanwhile, a DC motor as a reflector drive system is mounted on the bottom of the reflector. The tilt angle of the solar panel is 45° to the negative x-axis and the reflector is 75° to the positive x-axis. The reflector will move in a semi-circular path, following the direction of the highest solar intensity detected by the LDR sensor. Three different reflectors used to optimize the output power, there are stainless steel, aluminium foil, and mirror. Solar panel with mirror reflector produces the largest output power compared to other reflectors. The output power of this device increases 1.6 times to the solar panels without reflector.

1. Introduction
Energy demanding is increasing along with the growth in world population. But the availability of fossil energy is limited, thus the renewable and environmentally friendly energy sources must be developed continually. Solar energy is a solution to the problem of the energy crisis in Indonesia. Indonesia as an equatorial country receives solar energy of 4.8 - 6.0 kWh/m² in an unprotected horizontal plane every day [1]. Through solar cells or photovoltaic, solar energy is converted into electrical energy that can be used extensively.

The performance of the solar system in converting of solar radiation depends on the solar panel's slope to the horizontal plane. The sun radiation should fall at a right tilt angle to generate maximum power of the solar panel. The optimum tilt angle of the solar panel will vary every month and season, along with the sun position changing [2].

Solar panels can be mounted either dynamic or static. In a dynamic system, the solar panel will move following the position of the sun and works as an active solar tracker. But it's hard to be applied on a large-sized solar panel. In the other hands, a fixed or static system, which solar panel does not follow the position of the sun, has less efficiency [3]. To increase the output power of static solar panels, a reflector is required as an additional device. The reflector is used to reflect the sun radiation to the solar panel's surface, so that the solar panel will receive both direct and reflected sun radiation. Optical performance is characterized in terms of specular reflectance that is the degree to which a reflector is capable of transferring directed radiation to a target receiver surface [4]. To maximize the highest intensity of the sun radiation received by solar panels, the proper tilt angle of the solar panel and the...
reflector is required in system design [5]. Intensity of reflected radiation by a surface depends on material properties, related to the microscopic flatness or surface roughness of the material [6].

2. Methods
Determining the optimal tilt angle of the solar panel and the reflector is basis of the working efficiency of solar panel system, each optimization was performed separately. First, optimization of solar panel's tilt angle towards the negative x-axis is executed in different angle variations. After the optimal solar panel's tilt angle is obtained, then the reflector's tilt angle towards the positive x-axis is optimized. Direction of the light source is adjusted to the tilt and azimuth angle of the sun in June 2018 around the area of East Jakarta. Three different reflectors used to optimize the output power, there are stainless steel, aluminum foil, and mirror. The selected reflector materials must exhibit very good specular reflectance; microroughness of the mirror surface, crazing of protective topcoats, or both, can result in scattering (loss) of light outside a specified acceptance angle [4].

This research used a solar panel size of 35 x 29 x 17 cm, and the reflector size of 30 x 35 cm. The reflector functions as a solar tracker will move in a semicircular path, whose inner radius is 22 cm and the outer radius is 52 cm. Five LDR sensors are mounted on the top of the reflector, to detect the highest solar intensity. Meanwhile, a DC motor as a reflector drive system is mounted on the bottom of the reflector. Measurement of electric current and output voltage of solar panels use the current sensor of INA219 and DC Voltage Sensor. The block diagram and device scheme are shown in Figures 1a and 1b.

\[
P_{out} = V_{oc} \times I_{sc} \times FF
\]

(1)

Meanwhile the Fill Factor (FF) is calculated by [7].

\[
FF = \frac{V_{oc} - \ln(V_{oc} + 0.72)}{V_{oc} + 1}
\]

(2)
3. Results and Discussion
The current and voltage sensors used in this research were previously characterized, so that the output power measurements of solar panel are more precisely. The following are presented the results of current and voltage sensors characterization, the tilt angle optimization of the solar panel and reflector, optimization of the reflector type, and the measurement of device output power.

3.1. Sensor characterization
Characterization of DC voltage sensor is carried out by comparing the measured voltage by the sensor with the measured voltage by the voltmeter. The input voltage given starts from 0.1 Volt to 20.0 Volt, and the addition of 0.1 Volts. Measurements were repeated three times. The result of DC voltage sensor characterization is depicted in Figure 2a. It appears that the actual voltage (V) of the DC voltage sensor (Vs) for the range of 1.5 Volts to 20.0 Volts is following the equation:

\[ V = 1.0023 \times V_s - 0.068 \]  

The maximum of measurement relative error is 0.77%. This shows that the DC voltage sensor is good enough to measure the solar panel output voltage in the range of 1.5 Volts to 20.0 Volts.

\[ I = 0.9759 \times I_s + 0.0805 \]  

with \( I \) is the actual current value measured by multimeter (Ampere) and \( I_s \) is the current measured by the sensor (Ampere).

3.2. Optimization of solar panel's tilt angle
In this research, optimization of the solar panel's tilt angle was done two times, according to the scheme in Figure 1c. The first optimization is at tilt angle of 15°, 30°, 45°, 60°, dan 70° to the negative x axis. Then the second one is at angle of 25°, 30 °, 35 °, 40 °, 45 °, and 50 ° to the negative x axis. The second acquisition data is shown in Figure 3a. Optimization shows that the average maximum output power is 12.0987 mW, at a tilt angle of 45°, by a difference of 0.06 mW.

3.3. Optimization of reflector's tilt angle
Optimization of reflector's tilt angle using a stainless steel reflector was performed to determine the reflector's position that produce the maximum power output of solar panel. Optimization is executed at tilt angle variation of 80°, 75°, 70°, 65°, 60° dan 0°(without reflector) to the positive x axis. Meanwhile
the optimized position of solar panel (tilt angle of 45°), is in front of the reflector as shown in Figure 1d. The result of Optimization of reflector's tilt angle shown in Figure 3b. The average maximum solar panel output power is 6.2455 mW, at a tilt angle of 75°.

3.4. Optimization of reflector type
Reflector type optimization to determine the reflector that has highest reflectivity to produce maximum output power. The type of reflector used in this optimization are Aluminum Foil reflector, Stainless Steel reflector, and Mirror. The reflector is set in north direction, and the solar panel is set in south direction. The result of reflector type optimization are shown in Figure 3(c).

The mirror reflector has the highest output power compared to other types of reflector, its difference is 31.33% to the stainless steel type reflector and 17.78% to the aluminum foil reflector. This result is higher than other research conducted by Eko Adhi and Khariah Dewi [8].

![Figure 3](image)

Figure 3. (a) The output power to the tilt angle of solar panel (b) The Output power of different tilt angle’s reflector, (c) The Output Power of 3 Types of Reflector.

3.5. The output power of device
The voltage and current of solar panels measured by sensors are automatically recorded in the memory card, thus the average output power that shows the device's performance can be calculated. The reflector moves towards the highest sun intensity detected by the LDR sensor, in a semicircular path. Measurements were performed at 9:00 a.m. to 3:00 p.m. in four days, in the two conditions: (i) the solar panel leads to the sun, (ii) the solar panel in the opposite to the sun. Temperature, humidity and weather conditions are measured during data collection, as additional data. As a comparison, the same measurements of current and voltage are applied in other passive solar panels built without reflectors device. The measurement results are shown in Figure 4.
Figure 4a and 4b show that device equipped reflector has higher output power than device without reflector. The highest output power's difference reached 1.6 times at 09.00 - 09.30 in the second day, meanwhile the smallest output power's difference of 0.8 times occurred at 14.00 in the second day. Figure 4c and 4d show that the output power of a device equipped a reflector (first device) is lower than a device without a reflector. The reflector does not have a good function to reflect of sun radiations, because the reflector's position is back to the direction of sun radiations. The power output is not optimal, because some of the solar panels are covered by the reflector, nevertheless they cannot receive sun radiation to the fullest. The output power declines at 11:30 a.m., Figure 4d, because of the weather conditions suddenly cloudy, thus the sun was blocked by clouds.

![Comparison The Output Power on Solar Panel With and Without Reflector on the First Day](a)

![Comparison The Output Power on Solar Panel With and Without Reflector on the Second Day](b)

![Comparison The Output Power on Solar Panel With and Without Reflector on the First Day](c)

![Comparison The Output Power on Solar Panel With and Without Reflector on the Second Day](d)

**Figure 4.** The output power of device (a) Solar panel leads to the sun in the first day (b) Solar panel leads to the sun in the second day (c) Solar panel in the opposite to the sun in the first day (b) Solar panel in the opposite to the sun in the second day

### 4. Conclusion
Development of static solar panel equipped a mirror reflector based on LDR sensors has been carried out successfully. The device increases power output up to 1.6 times when the solar panel in opposite direction to the sun.

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