A testbed of intelligent sun tracking system and thermoelectric generator with Fresnel lens at solar cell system for maximizing generated energy

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Abstract. Solar or photovoltaic cells are one of the most potent renewable technologies to be applied in Indonesia that have a relatively high average daily solar radiation rate of 4.5 kWh/m²/day. In conventional applications, solar cells still have some weaknesses, especially on the efficiency of output that only reaches in the range of 5—16%. In this paper, optimizing the production of electrical energy in conventional solar cell system is carried out by modifying the system construction and controller. Intelligent Mobile Thermophotovoltaic (IMT) is a modified solar cell system that combines utilization of two sources of solar energy that are photon and thermal energy to convert into electrical energy. The solar panel is intelligently controlled to maximize the received sunlight in solar cell. Fresnel lens is utilized for supporting the thermal energy collection of sunlight on the solar cell. The total energy produced by IMT is energy from Fresnel solar tracking concentrator plus the energy from thermoelectric heat collector and subtracted by energy which used for tracking system of about 2 Wh. The IMT can yield the electrical power of 91.815 Wh while the conventional solar cell system brought 55.15 Wh for 8 operation hours. This result showed that IMT can raise 66.46% the electrical energy production of conventional solar cell system.

1. Introduction

Solar cells are one of the renewable technologies that can convert solar light energy into electrical energy. This technology is highly potential to be applied in Indonesia which has a relatively high average daily solar radiation rate of 4.5 kWh/m²/day [1,2]. The development of research and application of solar cells as a major source of electrical energy in the future will be very rapidly along with the reduction of fossil fuel power sources and environmental pollution problems [3,4]. In conventional applications, solar cells still have some drawbacks, especially on the side of the output efficiency which reaches only
8.8–29.1% of the total solar energy that can be converted into electrical energy [5–8]. In this case, it takes a research and development that can optimize the output power of these solar cells [9,10].

Technically, the efficiency of solar cells will be proportional to the output power of the system, which is influenced by the magnitude of the solar radiation intensity received by the panel and will only be optimal if the module is perpendicular to the direction of sunlight [11]. In conventional solar cell systems, solar panels are mounted static so it cannot be optimal in receiving solar radiation throughout the day. Another disadvantage of conventional solar cell systems is that it only use solar radiation (photon) energy to generate electricity but thermal energy has not been utilized [12].

This paper discusses the research and development of a modified solar cell system that combines solar time tracker methods to keep the position of the solar panel perpendicular to the direction of sunlight and the use of a Fresnel lens to focus the sunlight received by the panel so as to optimize the intensity of sunlight absorbed by solar cells [13–16]. In addition, the use of thermoelectric modules will convert solar thermal energy into electricity so as to optimize thermal energy wasted. Thus, this modified solar cell system is capable of producing a larger and more stable output power throughout the day than conventional solar cell systems so that efficiency increases.

2. Methods

2.1. Types of Research
This research uses a development research [17,18]. The researchers examine the system that uses intelligent facing control system combined with the Fresnel lens for focusing the thermal energy and can be moved to the desired place. Therefore, this solar cell system is named Intelligent Mobile Thermophotovoltaic System (IMT). The proposed system is compared to the conventional solar cells system in term of the generated electrical energy.

2.2. Literature Study
Preparation is done by reviewing and looking for related materials to be the basis of theory in this study. The search was conducted with various literatures related to this research. Assessing and digging deeper about the problem of solar panel systems that are still low level of efficiency and still little application in the community as an alternative source of renewable energy [5–8]. The literature study on solar energy conversion and converter technology is done to add insight from the research idea. The selection of component is carried out to obtained the most appropriate and the best efficiency.

2.3. Analysis of System Requirements
Data collected during the literature study are analyzed based on the requirements of the desired system specifications. The data also include the tools and material that needed in the design and manufacture of the system. It also includes the preparation of hypotheses which will be useful in the evaluation of system performance.

2.4. Design and Manufacture of System
The position facing the solar cell determines the quantity of electrical energy that can be produced [11]. Solar tracking is utilized to the solar panel to maximize the electrical energy generated by keeping the surface of the solar panel always facing the position of the sun throughout the day. The tracking unit uses electrical energy to operates thus it sets to active and sleep modes since the tracking is designed to work constant intervally.

Drivers are designed to provide movement or rotation of the motor 9 degrees per step for every 30 minutes. The optimum angle of this system is calculated by counting the angle of irradiation with the corner of the cross-section of the solar panel or the lens to obtain a $90^\circ$ angle as indicated in Figure 1. Table 1 shows the angle of motor movement at 08.00 morning until 16.00 in the afternoon. Angle radiation is the angle between the sun and earth surface while angle of panel is the angle of solar panel
movement. By staying on the optimum angle, the solar panel can keep working on peak or maximum capability to achieve higher system efficiency.

![Figure 1. Scheme of Solar Tracking System](image)

### Table 1. Angle of Motor Movement

| Time        | Angle of Radiation | Angle of Panel | Optimal Angle |
|-------------|--------------------|----------------|---------------|
| 08:00—08:30 | 18—27              | 72             | 90            |
| 08:30—09:00 | 27—36              | 63             | 90            |
| 09:00—09:30 | 36—45              | 54             | 90            |
| 09:30—10:00 | 45—54              | 45             | 90            |
| 10:00—10:30 | 54—63              | 36             | 90            |
| 10:30—11:00 | 63—72              | 27             | 90            |
| 11:00—11:30 | 72—81              | 18             | 90            |
| 11:30—12:00 | 81—90              | 9              | 90            |
| 12:00—12:30 | 90—99              | 0              | 90            |
| 12:30—13:00 | 99—108             | -9             | 90            |
| 13:00—13:30 | 108—117            | -18            | 90            |
| 13:30—14:00 | 117—126            | -27            | 90            |
| 14:00—14:30 | 126—135            | -36            | 90            |
| 14:30—15:00 | 135—144            | -45            | 90            |
| 15:00—15:30 | 144—153            | -54            | 90            |
| 15:30—16:00 | 153—162            | -63            | 90            |

The Fresnel lens chosen for use on this system is a plastic-based circle lens and with a diameter of 40cm. Consideration of the selection of this type is because of its lightweight mass and size that has been adjusted to the size of solar panels that we use for testing the solar panel 10W with size of 32x26 cm and the Fresnel lens has a focus as far as 22 cm. This construction is depicted in Figure 2. The gap distance between lens and solar panel (x) is 4.4 cm obtained by calculating a tangential angle as follows.

\[
\tan \alpha = \frac{\frac{1}{2} \delta_f}{f} = \frac{\frac{1}{2} \delta_x}{f-x}
\]

\[
\frac{1}{2} \cdot \frac{40}{22} = \frac{1}{2} \cdot \frac{x}{22-x}
\]

\[x = 4.4 \text{ cm}\]
2.5. System Testing and Measurement

Testing of the proposed system is conducted directly under the sun at daylight from 08.00 to 16.00. In order to obtain valid results and balanced comparison, then 2 identically solar panels is operated which are static and dynamic position as it is depicted in Figure 3.

![Figure 3. Testing and Measuring of Solar Cell](image)

The experimental data is retrieved as follows: both solar panels are run simultaneously and separated from each other. The collected data consists of *instant output voltage* (V) and *output current* (A) that recorded every 30 minutes as shown in Table 1.

2.6. Data Analysis

The experimental data were analyzed to determine the comparative study on the electrical energy generated by static (conventional) solar cell systems and the IMT. The results obtained from the measurement of voltage and current on both systems will be arranged in the form of tables and graphs.
3. Results and Discussion

3.1. Design of Intelligent Mobile Thermophotovoltaic System

The IMT is a further development of modified solar cell systems that have been designed in the previous studies as shown in Figure 4. This system is a modified solar cell system that combines the utilization of two sources of solar energy that is photon energy and thermal energy to be converted into electrical energy. The photon energy is utilized by integrated solar panels with single axis solar time tracker and the addition of fresnel lenses placed at a certain distance above the solar panel to focus the sunlight received by the panel, so that the intensity of solar light absorbed by the solar panel will be maximized. The use of timer-based tracking system aims to reduce the power usage of the generators themselves, as this system will only work for a few seconds per hour[11]. While thermal energy is utilized by several thermoelectric modules that are strung together and placed under solar panels, a heatsink cooling system is used to create a temperature difference between the hot and cold sides of the larger thermoelectric module.

![Figure 4. Design of the IMT](image)

Although it is not a new thing anymore, solar cell development is still very rare in Indonesia. This research is a form of effort to popularize solar power plants. The addition of fresnel lens as solar concentrator and thermoelectric module as a companion solar cell system integrated with single axis solar time tracker gives nuance of novelty because it has not developed hybrid system of this type in Indonesia[19].

3.2. Electrical Energy Result of Sun Tracking Solar Cell

The effect of the sun tracking system for regulate the direction facing the surface of the solar panel is studied. The tracking solar panels system are operated in conjunction with conventional (motionless) solar panel. Output voltage and power are measured and recorded every 30 minutes as shown in Figure 5 and Figure 6. The tracking solar panel has 2.1V voltage output in average higher than the conventional one. Both of solar panel has maximum output voltage at the most equal value, 21.3V and 21.6V for the conventional and the sun tracking solar panel respectively. However, the sun tracking system solar panel has higher minimum output voltage indicated that the tracking system improves the output voltage stability of the solar panel. The stability performance of the sun tracking solar panel system is also confirmed with it’s power output value that changing from 7.1W to 9.94W. It is more stable than the
conventional solar panel that has power output range from 3.8W to 9.79W. In average, the sun tracking solar panel system has higher output voltage and higher output power respectively 11% and 30% than the motionless solar panel system. This is consistent with the results of previous studies [20–22] which stated that the upright position of the solar panels will produce the most power. The arrangement of the solar panel aims to make the panel surface always perpendicular to the sun. The sun tracking solar panel system also produces a more stable voltage and power so that it will provide a stable supply of energy to the load.

3.3. Electrical Energy from Fresnel Thermoelectric Heat Collector
The purpose of utilizing the Fresnel lens is for focusing and collecting the sunlight beam to a point at the solar panel. The thermoelectric generator is placed at the focus point of the Fresnel lens, thus the sensor will receive a large amount of sunlight. Six thermoelectric generators are used in this experiment and the resulted electric voltage and power output is shown in Figure 7. The generator has output voltage above 6V for 4 hours when the temperature of the solar panel is above 50ºC. In average, generator produces output voltage of 8.33V and output power of 2.8W, thus the average energy per hour is 23.32Wh.

Figure 5. Output voltage of the sun tracking system
Figure 6. Output power of the sun tracking system

Figure 7. Output voltage and power of thermoelectric generator
3.4. Electrical Energy of Intelligent Mobile Thermophotovoltaic System

The resulted energy of IMT system is the sum of energy from the sun tracking solar cell system and Fresnel thermoelectric heat collector and minus the power required for tracking drive. Motor drive consumes 2Wh for moving the solar panel in order to keep it perpendicular to the sun. The electrical energy of the IMT proposed system is shown in Table 2 compared to the conventional solar panel system.

At 08.00-10.00, IMT could generate electric power generated about 10W while in conventional panel has 6W. This is because conventional panel has decreased energy caused by solar panel is not perpendicular to sunlight. Furthermore, at 10.00-14.00, IMT and conventional panels to produce their maximum power where IMT system yield about 50% higher than conventional solar panel system which results from the combining of the tracking system energy \(E_{\text{tracking}}\) and the thermoelectric generator \(E_{\text{thermoelectric}}\) reduced by motor energy \(E_{\text{motor}}\). Therefore, usable electrical energy from IMT expressed as follows.

\[
E_{\text{IMT}} = E_{\text{tracking}} + E_{\text{thermoelectric}} - E_{\text{motor}}
\]

\[
E_{\text{IMT}} = 71.38 \text{ Wh} + 22.43 \text{ Wh} - 2 \text{ Wh}
\]

\[
E_{\text{IMT}} = 91.81 \text{ Wh}
\]

While,

\[
E_{\text{conventional}} = E_{\text{solar panel}}
\]

\[
E_{\text{conventional}} = 55.15 \text{ Wh}
\]

In other studies, Authors [20] proposed solar tracking systems with 52.4% efficiency and Authors [22] with 35% efficiency. Compared to both, our IMT systems are better with 66.46% efficiency. The use of IMT system, solar cell system can work optimum in a hole daylight.

With the discovery of modified solar cell systems capable of generating greater electrical energy than conventional solar panels it will make the public interest to use solar panels increasing. Because one factor is still reluctant people to use solar panels to meet the needs of electrical energy is the level of efficiency is still low[8].

| Time | IMT  | Conventional |
|------|------|--------------|
|      | Watt | Watt         |
| 08.00| 7.47 | 3.8          |
| 08.30| 8.03 | 4.72         |
| 09.00| 9.17 | 5.07         |
| 09.30| 10.14| 6.33         |
| 10.00| 11.63| 7.03         |
| 10.30| 12.62| 7.33         |
| 11.00| 13.56| 7.96         |
| 11.30| 14.52| 9.15         |
| 12.00| 15.22| 9.79         |
| 12.30| 15.21| 9.45         |
| 13.00| 14.97| 8.69         |
| 13.30| 14.47| 7.91         |
| 14.00| 13.65| 7.20         |
| 14.30| 11.77| 6.76         |
| 15.00| 10.37| 6.13         |
| 15.30| 8.77 | 5.54         |
| 16.00| 7.76 | 4.29         |
| Average| 11.73 | 6.89 |
4. Conclusion

Optimizing the production process of electrical energy in conventional solar cell systems can be done by modifying the system by adding some specific components and methods. The designed solar cell system which used in this research is combines two methods of utilizing solar energy with several modifications. The use of timer-based tracking system aims to reduce the power usage of the generators themselves, as this system will only work once every hour for 10 seconds per hour. Meanwhile, to utilize the concentrated heat used thermoelectric that does not produce noise pollution. So the system is suitable for household electricity, especially in remote areas. The result of test and measurement of solar cell system by using Intelligent Mobile Thermophotovoltaic System shows solar cells can work at optimum conditions at any time and can increase the production of electrical energy by 66.46%. Subsequent research is expected to reduce power consumption for control systems and increase temperature differences in thermoelectric modules as well as the addition of other components capable of increasing the total energy of modified solar cell systems.

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