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Design of Compact Raspberry Pi Based Tracker to Improve Conversion Efficiency of Solar Energy

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ABSTRACT

The installations of power plants scattered from solar energy resources have been increasing in various countries with the availability of renewable energy policy and carbon emission reduction. In addition to being environmentally friendly, the construction of solar power plants in load centers can reduce network losses, land investment costs, and not dependence from fossil energy, thereby increasing energy security and independence. This paper describes the development and optimization of the utilization of solar energy through the design, construction, and upscaling of solar panel position tracker mechanisms to increase the efficiency of solar power plants. The purpose of this study is the development of technology for optimizing solar energy conversion using a raspberry pi based solar tracker. The prototype of a sensorless solar tracker of previous studies has been scaled up and implemented on the large-scale PV system 3.12 kWp. The external memory and RTC module have been reduced by using Raspberry Pi based solar tracker. The research results that have been obtained are a solar tracker system that operated without sensors but move based on a database of sun position. The advantages of the proposed tracker system can increase the efficiency of solar energy conversion to electricity up to 29% with a compact controller circuit and can be reprogrammed.

Key words: Raspberry Pi based solar tracker, Optimizing the utilization of solar energy, increasing efficiency.

1. INTRODUCTION

Indonesia in the tropical area has a huge solar energy potential of around 4.8 kWh/m^2/day or equal to 112,000 GWp, but only 71.02 MWp has been utilized, in both interconnected and off-grid [1]. Reduction or elimination of electricity subsidies and implementation of incentives for the use of renewable energy have led to increased development and construction of solar power plants on rooftops and buildings [2]. In addition to being environmentally friendly, the construction of solar power plants in load centers can reduce network losses, land investment costs and dependence on fossil energy, thereby increasing energy security and independence [3]. In addition, maintenance and operation is also easy but the impact is significant to reduce pollution and the greenhouse effect [4]. However, in conventional applications solar panels have many shortcomings, especially on the side of the relatively low output efficiency [5]. There are several factors that affect the electrical power produced by solar panels, such as the type of solar cell material, the magnitude of the level of light intensity and the working temperature of the solar panel.

The performance of solar panels is very dependent on the sunlight it receives. Generally solar panels are set up in fixed on the holder. This installation technique will cause sunlight in the morning and evening are not in the right position towards the direction of the sun's shine, so that the electrical energy that can be generated is less than it should be [6]. To improve the results of solar energy conversion, a solar position tracker mechanism is needed that directs the solar panel to the upright position of solar lighting [7] and a dc-dc converter setting that forces the solar panel to operate at the MPP point [8], the operating point where it produces the maximum power optimal according to the intensity of solar radiation.

The sun-tracking systems using either two axes or one axis can be categorized into two classifications, i.e. passive (mechanical) and active (electrical) tracking methods [9]. Previous studies using passive tracking have revealed that efficiency increases between 2% -23% compared to fixed systems [9]-[11]. Whereas active trackers consisting of single axis trackers and dual axis trackers generally use electric motors as actuators, based on several studies revealing that active trackers are able to increase solar energy conversion compared to fixed systems with an average increase of 29.37% [12].

Several previous studies in the development of active solar tracker both one axis and two axes require a large power supply for the movers [13]. The amount of energy absorbed by the solar panel can be increased through the implementation of a solar tracking system. The sunlight tracking system can be installed by using one or two axis. Actually, the two-axis trackers are most efficient to use but it can increase more complexity. It can be the best choice for locations where the position of the sun continues to change throughout the year in different seasons. While, one axis tracker can be a good solution for places located around the equator that have no significant changes in the sun's position throughout the year [14]. The use of a tracking system will allow PV cells to lead to the sun accurately, which is able to compensate for changes in the height of the sun (throughout the day), to latitude of the sun (during seasonal changes) and to change in azimuth angle.

The use of an Arduino microcontroller as a sensorless solar tracker controller requires an additional module to read the time and date uses the RTC module and external SD memory to save sum position database [13]. This causes the Arduino control system to become more complex to be able to read time and determine the exact position of the sun. Therefore, there is a needed of a better, faster controller system that has a real-time clock on-chip module uses raspberry pi as a solar tracker controller. This paper presents the results of the development of previous research [13] especially in applications in larger and real PV systems with simpler control systems using Raspberry Pi.

2. RASPBERRY PI BASED SOLAR TRACKER

Raspberry Pi is a Single Board Computer (SBC) provides 40 GPIO pins that can be used to access a variety of I/O device. The Raspberry Pi use Linux-based operating system and Python as a primary programming language providing connections wired or wireless such as Bluetooth, Wi-Fi and ethernet port. On the other hand, the Raspberry Pi also use a System on Chip (SoC) 64-bit architecture that can perform more complex tasks much faster than usual microcontroller. Arduino does not have a real-time module, while Raspberry Pi has its own real-time module which will be updated automatically from the network time protocol of global server when connected to the internet and large memory. This makes the Raspberry Pi-based solar tracker control application simpler than using Arduino.

The main components of the propose solar tracker controller system consist of: Raspberry Pi, 12 Volt DC Linear Actuator, 500mm, 1000N, 2 pc mounting brackets and a 0.75 mm2 DC cable. While the additional components that need to be prepared are: 12 V batteries, panel construction, and solar panels (1 unit to 12 units or 260 Wp to 3120 Wp). The DC actuator specifications features are: 1100N load capacity:, 12mm/s of speed, 12V DC input voltage, 500mm/20 inch stroke length, 10%, duty cycle and work in -20°C to + 75°C ambient temperature. Standard protection class is IP54, has low noise level less than 42dB.

The solar controller power supply uses a 12 V power supply for an actuator motor and a 3 V power supply for Raspberry Pi. Panel construction is in accordance with the number and size of the panels, the maximum number of panels is 12 units or 3120 Wp for 260 Wp/unit. The Raspberry Pi-based solar tracker design is as shows in Figure 1.

Figure 1: Solar tracker controller circuit

The solar tracker control circuit consists of two toggle switches to adjust manual or auto operation functions. In manual conditions, the second toggle switch is connected as shown in Figure 2 to be able to move the actuator motor forward or backward. In the first toggle switch condition in the auto position, the Raspberry Pi based relay circuit will function. where relay 1 and relay 2 function to regulate the motor actuator forward or backward while relay 3 functions to disconnect the auto system during manual operating mode in order to protect system from short circuit.

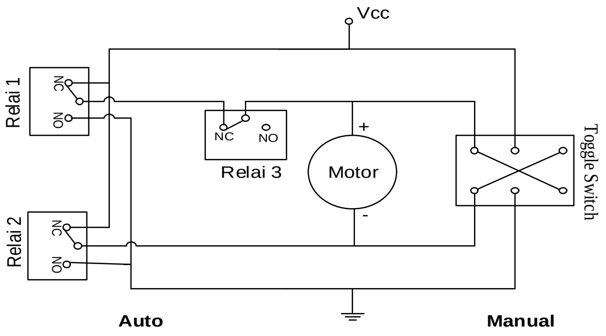


Figure 2: Control circuit of solar tracker controller.

3. METHODOLOGY

The performance of the solar panel with the tracker system is tested using the following testing circuit:

Figure 3: System Test

Two identical 260 Wp solar panels were used simultaneously in this test. Likewise, measurements are carried out simultaneously using two units of the measurement system using a digital volt-ampere, solar charger controller and the same load as shown in Figure 4.

Figure 4: Two identical measurement devices.

The increased energy conversion efficiency produced by using solar tracker calculated using equation below:

$$\%\ Efficiency_{improve} = E_{improve}/E_{fixed} \times 100\% \quad (1)$$

Where:

$\%\ Efficiency_{improve}$ = Improved Efficiency
$E_{improve}$ = Improved energy
= $E_{Tracker}$ - E_{Fixed}
$E_{Tracker}$ = Energy using solar tracker
E_{Fixed} = Energy using fixed panel

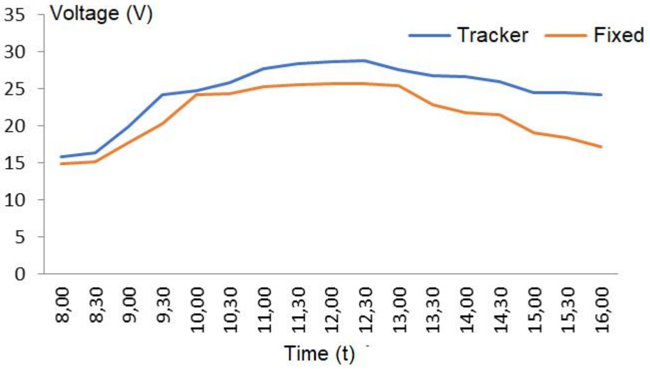
4. RESULT AND DISCUSSION

The performance of the solar panel with the tracker system was tested using similar test system and environment as shown in Figure 3 and 4. The identical 260 Wp solar panel was installed and measured simultaneously with a measurement system consisting of 2 digital amperes/volts, 2 resistive loads and 2 charger controllers. The test results of the current and voltage readings are shown in Table 1.

Table 1: Test results for current and voltage readings

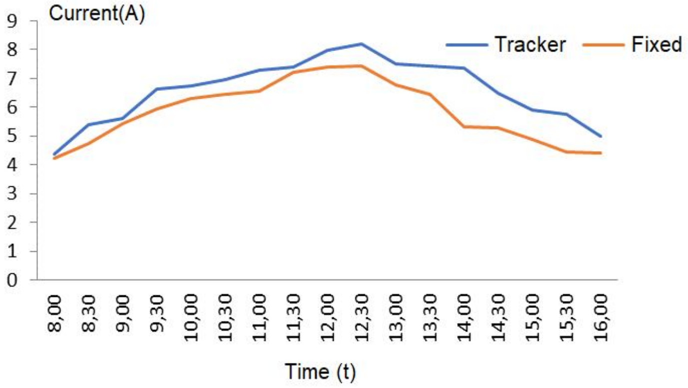
No	Time	Fixed		Tracker	
		Current	**Voltage**	**Current**	**Voltage**
1	08.00	4.24	14.87	4.38	15.8
2	08.30	4.73	15.17	5.4	16.3
3	09.00	5.43	17.64	5.61	19.8
4	09.30	5.94	20.23	6.62	24.2
5	10.00	6.32	24.11	6.75	24.65
6	10.30	6.44	24.34	6.94	25.78
7	11.00	6.56	25.2	7.29	27.62
8	11.30	7.22	25.48	7.4	28.35
9	12.00	7.38	25.62	7.99	28.64
10	12.30	7.42	25.67	8.18	28.71
11	13.00	6.78	25.33	7.5	27.48
12	13.30	6.46	22.79	7.43	26.72
13	14.00	5.31	21.72	7.36	26.66
14	14.30	5.29	21.44	6.48	25.93
15	15.00	4.89	19	5.92	24.47
16	15.30	4.45	18.4	5.74	24.4
17	16.00	4.42	17.2	4.98	24.19

From the data in table 1 it can be seen that the increase in current and voltage is generated by using the solar tracker. Furthermore, it can be calculated the increase in power by multiplying current and voltage. Comparison of the results of voltage current measurements and power calculations between dynamic systems with a tracker and static fixed fixed is like Figure 5 below:

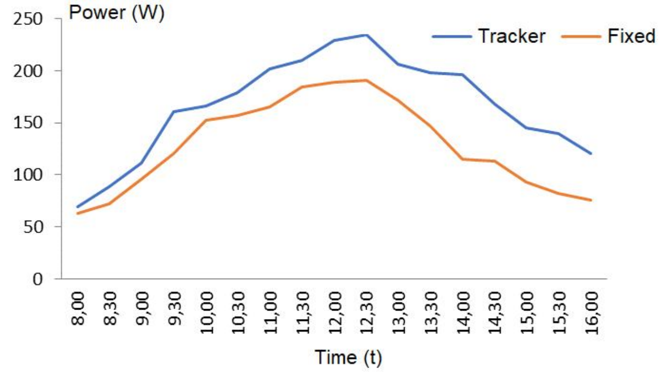


a. An output voltage vs time curve

b.



b. An output current vs time curve



c. An output power vs time curve

Figure 5: Current and voltage measurement and power calculation curves

The increase in energy between the panel with tracker and without tracker can be calculated through the equation 1 as follow:

$$E_{Improve} = E_{Tracker} - E_{Fixed}$$

$$= 1411.443 – 1093.615$$

$$= 317.828 \text{ Wh}$$

$$= 0.317828 \text{ kWh}$$

$$\% \text{ Efficiency}_{improve} = E_{improve}/E_{fixed} \times 100\%$$

$$= (317.282/1093.615) \times 100\%$$

$$= 29.06\%$$

The increased energy conversion efficiency produced by using solar tracker is 29.06%.

2. Test on large solar panel 12 unit @260 Wp

The 12-unit solar panel frame structure design is as in Figure 6
follows:

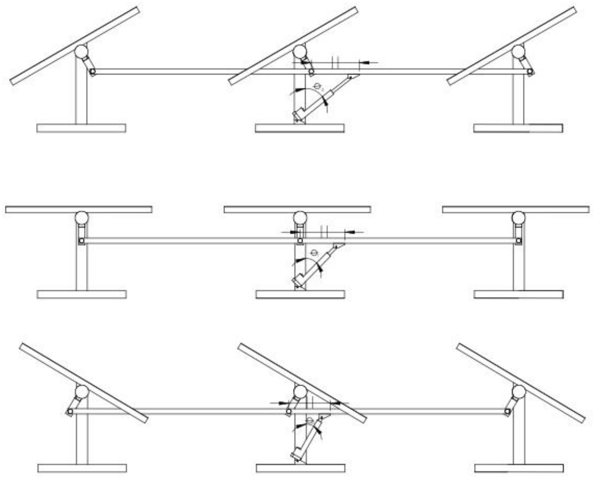


Figure 6: Side view of the 12-unit solar panel frame structure

The angle formed between the center pole with the DC actuator lever is used as the basis for determining the position of the sun. The movement of the panel will move from morning to evening with an angle $\theta_0 < \theta_1 < \theta_2$. The top view of communal solar panel arrangement is shown in Figure 7.

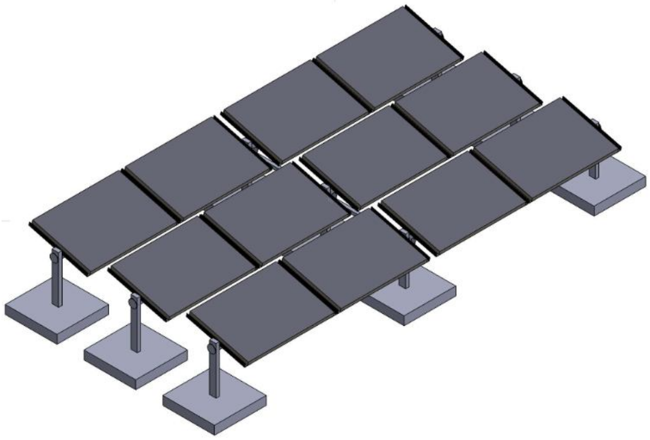


Figure 7: The top view of the solar panel arrangement

Testing of large-scale solar panel tracking systems is carried out on the on-grid PV plat and off-grid PV systems as shown in Figure 8 below:

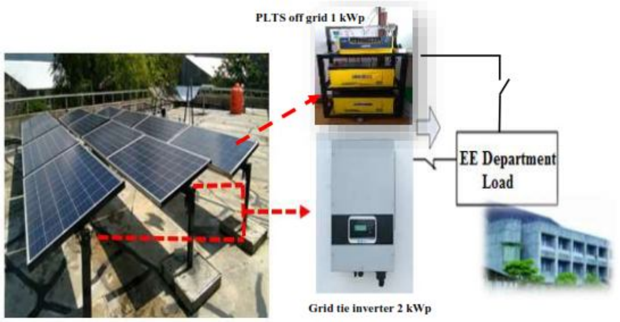


Figure 8: Large-scale solar panel solar tracking system

There are 12 unit 260 Wp solar panels installed on the roof of the Electrical Engineering Department building as a source of solar energy in the on-grid and off-grid systems. The ongrid PV has been equipped with a monitoring system to see the conversion of solar energy into electrical energy. The sun's tracking position is mounted on the central axis of the solar panel arrangement. Installation of large-scale solar panel solar tracking can work, but the movement is still not stable. The results of reading the monitoring system for 3 days of online data collection are shown in Figure 9 below:

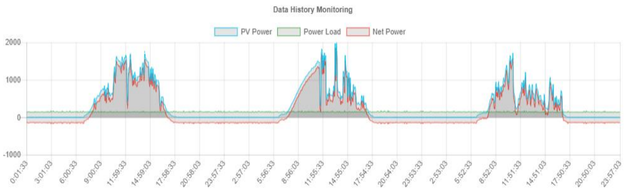


Figure 9: The results of the reading of PLTS on grid 2 kWp for 3 days

5. CONCLUSION

The design and installation of Raspberry Pi-based solar tracker has been carried out. The external memory and RTC have been reduce by using Raspberry Pi based solar tracker. The results of testing the use of solar panel tracker products show an increase in the efficiency of solar energy conversion by an average of 29%, but for communal solar cell systems the movements are less stable because the panel loads are too heavy. Therefore, further research is needed to improve the frame structure with the addition of a panel movement damping spring using a passive tracker system.

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