Computer-based solar tracking system for PV energy yield improvement

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ABSTRACT

Electric energy is the main driver of various daily activities, both to increase productivity as well as to improve life quality. Energy demand is continuously increasing in parallel to the progress in technology and population growth. Depletion of fossil energy sources and awareness of environmental protection make people resort to renewable energy sources like solar energy. Low efficiency and intermittent characteristic of solar energy may originate from the sun movement along the day as well as the year. Efforts have always been tried to deal with the drawbacks. This paper proposes a computer-based tracking system to fully monitor and control a solar panel movement. The designed system has proven a good performance of working at certain time intervals, either hourly, or even continuously, as desired. Energy yield improvement has been achieved by processing the tracking results with the help of a microcontroller to optimize the power generation of the solar panel.

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1. INTRODUCTION

Electric energy is vital to power various equipments. It makes people enjoy the life comfort and industry increase the productivity. Inspite being considered as an emerging world economic power, the energy consumption of Indonesia is still relatively lower than the neighbouring economic power [1]. Access to electricity is greatly differed, being as high as 99.99% in the western part of the country, while as low as 59.84% in the eastern part of the country [1, 2].

As a part of its contribution to global climate change reduction, Indonesia makes a great effort to meet its commitment under the Paris agreement. Benefitted from its strategic location around the equator, Indonesia also tries to have recourse to solar energy to fulfill its continuously increasing energy demand and to improve the electrification ratio. Harnessing solar energy can be accomplished using either a simple and low-cost system for the low-scale capacity or even more complex systems. However, the conversion efficiency is in general still quite low. The efficiency currently used in implementation is in the range of 6%-30%, while the highest record achieved in 2015 was 46%, based on the PV Efficiency Chart regularly updated and published by National Renewable Energy Laboratory (NREL) in Colorado, USA.

One important way to improve the energy yield of solar power generation, which means its efficiency, is the addition of solar tracker to find the maximum power point condition as given on the PV profile characteristics [3-11]. Even though it has been considered less effective because of the power consumption for the actuating motor, an efficiency improvement up to 32% had been achieved using the single-axis trackings [3, 9-11], or even up to 40% when using the dual-axis trackings [4, 12-14], being compared to the use of static system. The single-axis tracking could improve the yearly energy yield around 20-25% [15], even up to 25.2% [16] more than using a fixed-utility [17,18].

The addition of tracking system to enhance the energy yield has also been related to some direct application fields, like in wireless sensor network [14], green-house system [5], and sometimes being combined with the maximum power-point algorithms [19-20], and the use of artificial intelligence theories [8]. Microcontroller has normally been used to implement the control algorithms [5, 19, 21-24]. Some control algorithms have been based on calculation of the sun geometry to determine the position, while others benefitted sensors as output tuning to trim the azimuth and altitude angles [13, 20, 25-26].

This paper describes a contribution to the PV energy yield improvement using a computer-based single-axis tracking system to monitor and control a solar panel movement. The Riemann sum method [27-30] has been implemented to compute the energy yield based on the tracking results. The Riemann sum method is working by approaching the integration operation using the discretization and summation of total area underneath a curve on a graph [29]. The time interval between the beginning and the end of the data acquisition is divided into *n* subintervals, which are used as the Riemann rectangles [28]. The Riemann sum method has also been used to validate the experiment data in a shipboard microgrids under various quasi-balanced and unbalanced voltage conditions [30]. A comparison of the tracking results has been made to the results of a static solar panel. The testing and measurement were done both on the static and tracking modes based on the choice made using the computer program.

2. RESEARCH METHOD

The method used to achieve the research goal includes the design and construction of the system, the testing and measurement, and the data analysis. The system design comprises the software design and the hardware design.

2.1. Diagram of the system

The diagram of the designed system is given in Figure 1. As seen, the computer/PC was designed to be the master of all systems, whereas the microcontroller ran only what the computer commanded. The obtained sensor data went into the microcontroller, then were sent to the computer via TTL USB and displayed on the Delphi Solar Panel Time Changer application. The battery control regulator (BCR) considered in this study, was a 12V or 24V system, which had a maximum rating current of 20A, 11.1V over discharge protection and 17V over charge protection.

The solar panel base used was designed of ±160cmx140cmx40cm dimension, being capable of supporting two solar panels with a capacity of 100Wp each, weighing ±10kg. The solar panel was driven by an actuator with a current rating between 0.2-0.8 without load, and 0.2-3.2 with load. The actuator was capable of lifting loads up to 50 kg, and moving objects with a static weight of up to 250 kg.

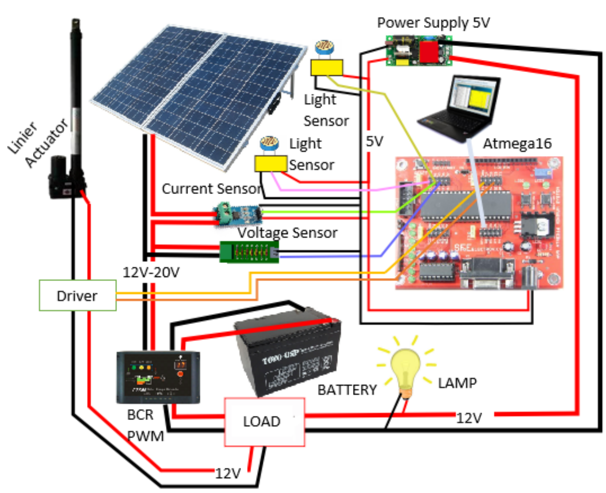


Figure 1. The diagram of the designed system

2.2. Software design

The functioning of the microcontroller and the Delphi application are given in Figure 2. As indicated, the functioning of the designed system has been based on the interface software on the Delphi Borland system, the Atmega-16 minimum system as the processor of sensor input-output data, and the controller of motor driver.

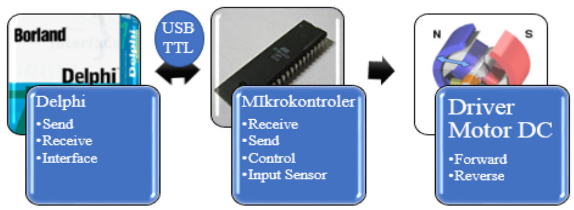


Figure 2. The functioning of microcontroller and Delphi application to actuate motor

Each of the Delphi applicaton and microcontroller had their own respective performance. They were interconnected via USB through their related Tx, Rx, and ground. Prolific USB Serial Adapter has been used as the driver of the USB TTL. The Delphi worked as an interface and master, while the microcontroller worked as the processor of sensors data and control the switch of motor driver.

The software design includes the design of interface program on the Delphi Borland application system and the design of the microcontroller program to process the sensor input-output data using CVAVR application. The Delphi program was Windows OS-based, as it was run on PC. The flowchart of the computer programming is given in Figure 3, whereas that of the microcontroller programming is shown in Figure 4.

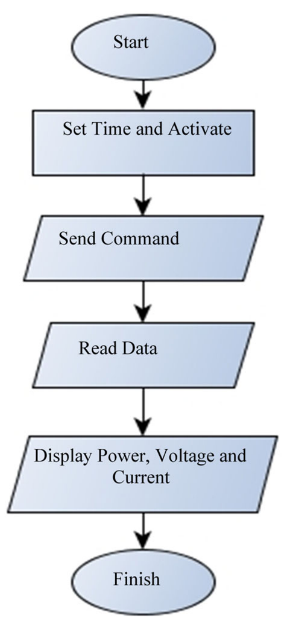


Figure 3. Flowchart of the computer programming

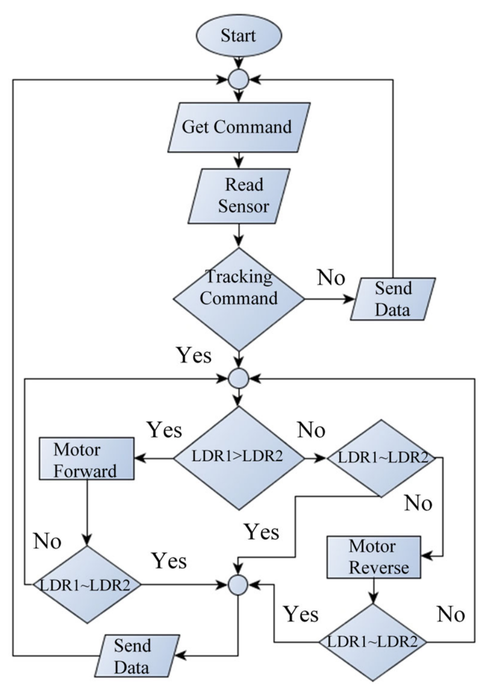
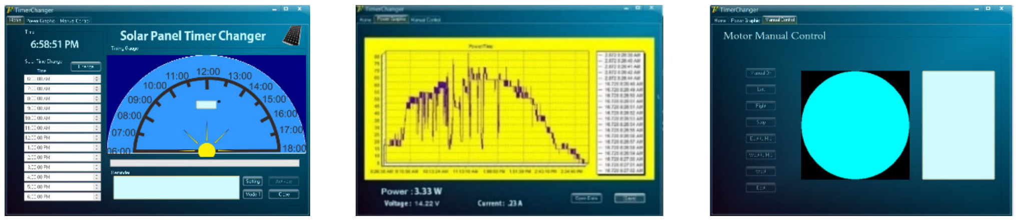


Figure 4. Flowchart of the microcontroller programming

The Delphi interface has been divided into three Tabsheets, as seen in Figure 5. The first Tabsheet (a) has been used as the homepage, where the user could control the time the solar panel to be moved.

The second Tabsheet (b) has been used as the power graphic feature, which would display power graphic after the activation of microcontroller, sensors and the Delphi application. The resulted data could be stored and opened using Microsoft Excel program for further process. The third Tabsheet (c) has been used as the manual control feature, which was made so that the solar panels could be moved as desired.



(a) (b) (c)

Figure 5. Delphi interface, (a) homepage control, (b) power graphic feature, (c) manual control feature

2.3. Simulation of the Whole System Design

The whole system comprises the unification of the hardware design and the supporting software design. It has been simulated using the Proteus software and by connecting the Delphi application. The simulation circuit design using Proteus software is given in Figure 6.

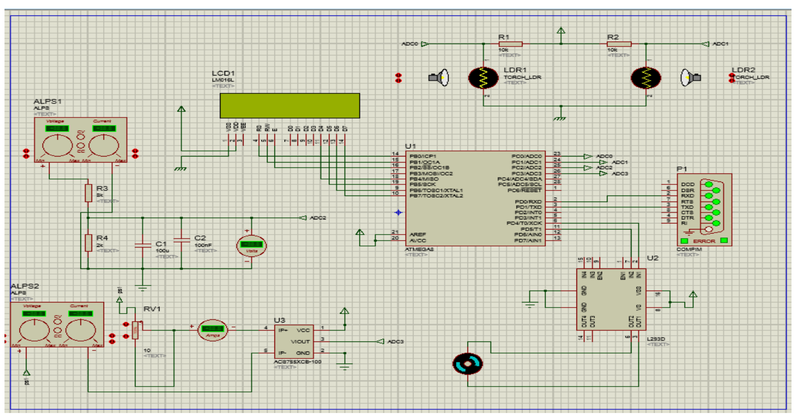


Figure 6. The whole system circuit design using Proteus software simulation

Delphi program took the role as the user interface to determine the timing of microcontroller activating to drive motor. Motor was to be activated based on the ADC data received by LDR. Two LDR sensors were installed to detect the highest solar intensity. Motor was stopped once the optimized solar intensity was found. Proteus simulated the function of hardware components such as microcontroller, sensors, motor driver, and DC motor.

3. RESULTS AND DISCUSSION

3.1. Program setting

Experiment has been done by connecting all components of Figure 1. Solar Panel Time Changer was used to set-up the Setting and adjust the port into Prolific USB TTL Serial Port, as seen in Figure 7, connecting the Delphi application to the microcontroller. After the connection of all components has been succeeded, activating the Setting made the program work to monitor the current, voltage and power generated by the solar panel. Based on the chosen time interval, the system modul changed the position according to the solar intensity captured by the LDR sensors.

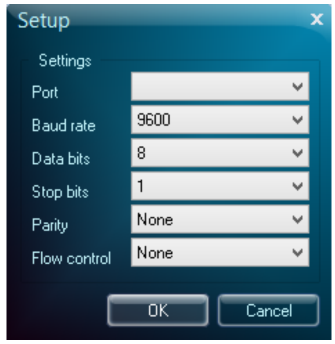


Figure 7. Set-up setting

3.2. Motor power consumption

Motor to actuate the tracking system has been tested by operating it in no-load and under load conditions. Solar panel has been used as motor load. The results of motor loading experiment are given in Table 1.

Table 1. The power usage by motor

Variable	No-load condition	Loading condition
Power (watt)	2.4-5.4	4-9
Current (ampere)	0.2-0.3	0.23-0.75
Voltage (volt)	12-18	12-19

As indicated by Table 1, the power consumed by motor was relatively small, as motor was not the main actuator. It has been used only in the hydraulic fluid pump of the actuator.

3.3. Tracking experiment

The static condition of solar panel was facing northwards at an angle of about 30°. The tracking condition has been started with initial position of facing eastwards. The tracking experiment has been done by considering three different positions of the solar panel; facing southwards, facing northwards, and during the tracking from east to west direction. The power generated by the solar panel is given in Table 2. The data have been taken in Bantur village, Malang regency of East Java province, with the earth coordinates of 8°18’29.7”N 112°34’41.0”E. The temperature during the experiment was around 24° - 33°C. The altitude of the location was 360m above sea level.

Table 2. The power generated by solar panel

Time	Power generated by static solar panel	Power generated by tracked solar panel	Time	Power generated by static solar panel	Power generated by tracked solar panel
09:52:59	53.77	47.43	13:30:09	57.9	50.78
10:10:38	40.21	50.48	13:40:46	53.72	56.62
10:20:01	56.94	50.18	13:50:35	57.56	57.58
10:30:03	60.66	50.48	14:00:44	53.72	40.44
10:41:23	20.68	29.96	14:10:36	49.59	45.24
10:50:02	43.43	76.84	14:20:44	41.2	37.02
10:57:47	23.02	78.15	14:31:54	33.3	36.81
11:11:23	53.77	82.72	14:40:56	29.23	36.4
11:14:48	53.17	64.34	14:51:32	25.09	36.6
11:51:06	79.8	81.34	15:01:14	13.97	32.17
12:12:17	66.8	78.15	15:11:41	14.06	31.43
12:15:37	62.87	73.62	15:21:07	14.06	19.65
12:30:51	24.93	71.14	15:31:40	13.88	31.62
12:40:36	62.87	66.8	15:41:48	10.34	27.5
12:52:11	62.87	63.24	15:51:29	6.8	15.44
13:01:47	62.87	67.58	15:59:20	3.33	3.75
13:10:26	62.5	70.73	15:59:21	3.33	3.75
13:21:36	62.13	66.02			

Table 2 shows that power generated by solar panels in static condition was good enough, and also indicated that the solar panel was in good position to receive the coming sunlight. However, the tracked solar panel resulted in higher generated power, as in this condition the solar panels receive longer sunlight.

3.4. Comparison of static panel and tracked panel

The graphical results of generated power under the static panel condition facing southwards, facing northwards, and using the tracked solar panel, are given in Figure 8.

Using the tracking system, the generated power could be increased or optimized. This optimization would result in more generated power per day. The optimization percentage could be found out using (1).

$$Optimization\ (\%) = \frac{P_{tracker} - (P_{static} + P_{motor})}{(P_{motor} + P_{static})} x100\% \quad (1)$$

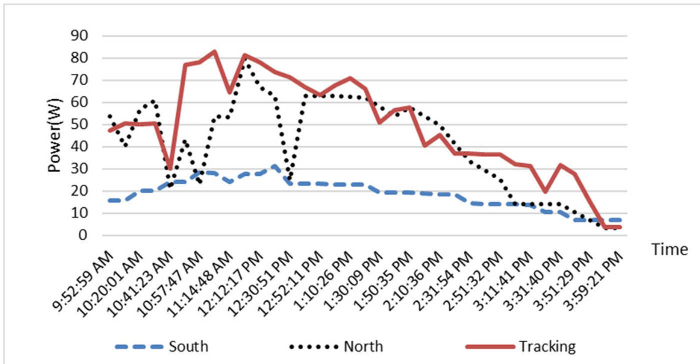


Figure 8. Comparison between static panel and tracked panel results

Using (1), the resulted optimization of the generated power is given in Figure 11.

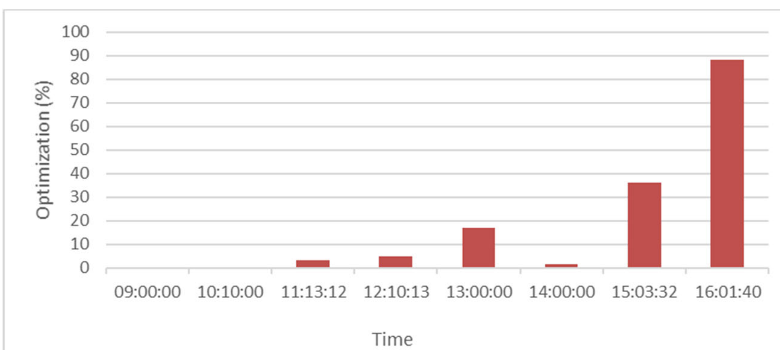


Figure 9. Graphical results of the generated power optimization

As shown in Figure 9, at 09:00:00 and 10:10:00 there were no power optimization because at those moments the solar panels tracking would face eastwards but not be completely illuminated because of the wall shadow on the testing site. In the afternoon the solar panels would face northwards and started not getting sunlight, making the power value dropped. However, under the tracking position the panel still got sunlight, so the optimized value was quite large.

To find out the produced energy per day, the obtained power value should be multiplied by the time during which the solar panel was working. Under the tracking position, the value must be reduced by the energy consumed by the motor and microcontroller. The total generated energy per day has been approximated using the Riemann sum method, giving the optimized generated energy per day [27-30].

The implementation of the Riemann sum method on the graphical results of generated power using the static panel and that using the tracked panel are given in Figure 10 and 11 consecutively.

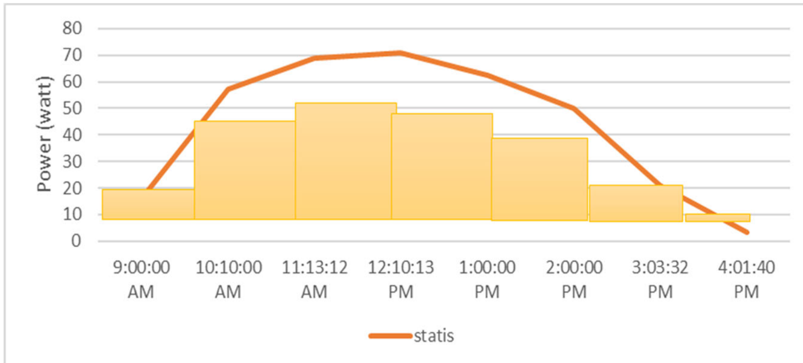


Figure 10. Riemann sum method on the generated power using the static panel

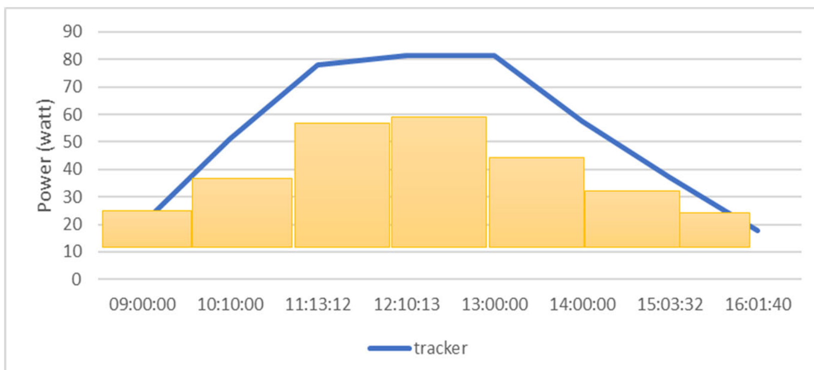


Figure 11. Riemann sum method on the generated power using the tracked panel

As seen in Figure 10 and 11, the linear regression made the power values look more stable with no drastic, but gradual drop or increase of power. The step-by-step calculation results of the daily produced energy is shown in Table 3. Based on Table 3, comparing the total generated energy using the static panel and the tracked panel resulted in the optimization as much as 16.51%.

Table 3. Total energy generated by the panel

Time	Using static panel	Using tracked panel
09.00–10.00	15.99	51.08
10.00–11.00	57.26	78.15
11.00–12.00	68.77	81.34
12.00–13.00	70.73	81.34
13.00–14.00	62.5	57.58
14.00–15.00	53.4	36.99
15.00–16.00	20.88	17.58
Total	352.86 W-day	424.05 W-day

4. CONCLUSION

The use of a computer-based tracking system made the observation of the power produced by solar panels and the data storing easier. The use of a linear actuator as a driver was the right choice because of the small power usage by the motor. The motor could be controlled with an Atmega16-controlled H-Bridge circuit, and a time changer solar panel program as the master mind. The performance of the tracking system was quite good, because the tracking system enabled the solar panel receive sunlight longer than when it was in a static condition. When using a single-axis tracking, there was an increase in generated energy compared to static solar panel, meaning an optimization of solar power production.

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