Design Of Automatic Switching System And Data Acquisition On Mobile Hybrid Solar Tracking System For Stand Alone Small PV With Reflector

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Abstract. A hybrid solar tracker is required to maximize the energy efficiency of solar power. This system is inaccurately monitored and is not user-friendly managed. A simple and low-cost data acquisition system is needed to successfully designed for data acquisition and automatic switching on the hybrid solar tracker. The result reveals that the sunlight intensity with 3.5 volts threshold voltage becomes the switching parameter on hybrid solar tracker which affects the LDR voltage. The maximum distance of data transmission systems using telemetry 3DR module for blocked location is 120 meters, while the unblocked location is 350 meters. The existence of the automatic switching on the solar tracker may increase the output efficiency of the hybrid solar tracker PV with reflector can reach 51.56% compared to the fixed PV, with an energy deviation of 183.88 Wh. The energy generated by the tracker PV is 540.47 Wh, while the energy consumption of the main component is 71.68 Wh. Therefore, the energy that can be saved is 468.79 Wh.

1. Introduction
Along with technological developments, many renewable energies have been developed, i.e. solar energy utilization using solar cells (photovoltaic). Solar power as a source of clean energy becomes much in demand for further research [1]. Electrical energy can be used for many uses, for example, the use in everyday life as a lamp charger, air heater, and also as a power plant that will connect directly to the nets of PLN. Solar cells are devices that can convert solar light energy into electrical energy. However, in the process of energy conversion in solar cells is influenced by many factors that can reduce the maximum work of energy conversion. These factors include the orientation of the position of the sun is always changing that can reduce the maximum work of solar panels in the conversion of solar energy into electrical energy. One effort to improve the efficiency of solar panels is by adding a solar tracking system [2]. Research on solar tracking system has been done, one of them by Ferdaus, R. A et al. in 2014 in Bangladesh, by applying a hybrid dual-axis method to compare the energy generated hybrid tracking vs. continuous (active) tracking. With hybrid tracking resulted in 25.62% greater output power than static panels, continuous tracking resulted in a 28.1% increase of static panels. While the power consumption in the motor on hybrid tracking more efficient by 44.44% of continuous tracking [3]. In 2017, subsequent research was conducted by Tharamuttam, J.K. et al. in Singapore. With the title of "Design and Development of an Automatic Solar Tracker" research which also applies a hybrid dual-
axis method, get the value of hybrid tracking system output voltage better than active tracking that is equal to 14% of fixed PV [4]. Hendro et al. conducted a study on photovoltaic panels reflecting. The study results showed that adding reflectors to photovoltaic panels mounted on a 70 ° slope would increase efficiency by 17.02% [5]. Along with the development of technology, the system of acquisition of renewable energy data using similar technology emerged, especially the system of monitoring conditions in Solar Power System (PLTS), starting from prototype data logger developed based on microcontroller developed for monitoring LED Road Lighting LED [6], PLTS monitoring system which consists of Power Line Carrier (PLC) and data logger [7] modules, and up to a PLTS monitoring system with the addition of a GSM network as real-time data reception on a user's phone [8], therefore radio telemetry radio communications systems need to be added. So that encourages authors to research by making a switching system, and real-time data acquisition on mobile hybrid solar tracker dual axis with reflector is expected to produce solar panel system that can be monitored properly and can increase the maximum energy efficiency.

2. Theory and Methodology

2.1. Solar Tracker
Solar tracker is an electromechanical device that works to control the orientation of the photovoltaic (PV) field to changes in the direction of solar motion to keep the PV always perpendicular to the direction of sunlight [9]. These conditions aim to maintain maximum solar radiation gain for photovoltaic. The application of how the solar tracker works is divided into three namely based on the tracking axis, tracking mechanism, and tracking control method [10]. Single-axis tracking system (one axis) is indicated on the elevation or azimuth angle movement, in which one of the desired movements depends on the technology used in the solar tracker system. The double axis tracker (two axes) shown in Figure 2 has two degrees of freedom acting as a rotation axis. A dual-axis sunlight can be played simultaneously in horizontal and vertical directions.

![Figure 1. Dual Axis Solar Tracker](9)

Based on the tracking method, the solar tracker system is divided into two kinds, namely, passive and active methods. The passive tracking method is a method whose tracking process does not take direct measurements of physical quantities of objects or tracing techniques based on astronomical calculations, whereas active tracking methods are methods whose tracking processes perform direct measurements of objects [11][13][14].

2.2. Solar Position
Solar position is determined by the elevation angle (α) and the azimuth angle (γ). Both angular positions change overtime throughout the year. To know the position of the sun broadly required two parameters, namely the location and measuring time. Location-related parameters are the longitude and latitude coordinates. The time-related parameters are the hours and the date. To determine the position of the sun (the angle of elevation and the angle of azimuth) over time, sun-related knowledge is required. Here are some terms and calculations related to sun time. [11][15]
• **Local Time.** Local time of a location on the surface of the earth due to time zone adjustment of a region.

• **Local Standard Time Meridian (LSTM).** The local standard time meridian is the time of a location-based on the longitude position against the Greenwich time standard (GMT). The LSTM equation is,

\[
LSTM = 15^\circ \cdot \Delta T_{GMT}
\]  

(2.1)

• **Equation of Time (EoT).** The equation of time (minutes) is an empirical equation that corrects the eccentricity of the earth’s orbit and the slope of the earth’s axis. Equation of time formula is,

\[
EoT = 9.87 \sin 2D - 7.53 \cos(D) - 1.5 \sin(D)
\]  

(2.2)

Where,

\[
D = \frac{360}{365} (n - 81)
\]  

(2.3)

\(n\) is the number of days calculated from the beginning of the year.

• **Time Correction.** Time correction (min) is calculated based on LSTM time variation in a given time zone due to longitude variation in time zone and EoT. The time correction equation is,

\[
TC = 4 \text{ Longitude} - LSTM + EoT
\]  

(2.4)

Factor 4 comes from the fact that the earth rotates 10 every 4 minutes.

• **Local Solar Time.** LST is defined as the time when the sun is at the highest position in the sky. The local solar time equation is,

\[
LST = LT + \frac{TC}{60}
\]  

(2.5)

• **Hour Angle (HRA).** HRA converts local sun (LST) time into the number of degrees in which the sun moves across the sky. The hour angle equation is as follows,

\[
HRA = 15^\circ (LST - 12)
\]  

(2.6)

• **Declination Angle.** The declination angle (\(\delta\)) occurs due to the axis of the earth's rotation in the circumference of the sun. The declination angle equation is as follows:

\[
\delta = 23.45 \sin \left[ 3 \frac{60(284+n)}{365} \right]
\]  

(2.7)

\(n\) is the number of days calculated from the beginning of the year.

![Figure 2. Solar Position](image)

• **Elevation Angle.** The elevation angle (angle of altitude) is the height of the sun's angle in the sky measured from the horizontal. The elevation angle (\(\alpha\)) can be found using the following formula:

\[
\alpha = \arcsin \sin \delta \sin \varphi - \cos \delta \cos \varphi \cos HRA
\]  

(2.8)

• **Zenith Angle.** The zenith angle (\(\zeta\)) is the angle of the sun measured from the vertical direction. The relationship of zenith angle and elevation angle can be formulated as follows,

\[
\zeta = 900 - \alpha
\]  

(2.9)

• **Azimuth Angle.** The azimuth angle is the direction of the sun compass measured from the north (0\(^\circ\)) rotates clockwise. The azimuth angle varies throughout the day, as shown in Figure 2.

\[
\text{Azimuth} (\gamma) = \arccos \left[ \frac{\sin \delta \cos \varphi - \cos \delta \sin \varphi \cos HRA}{\cos \alpha} \right]
\]  

(2.10)
Sunrise, noontime, and sunset time. Sunrise and sunset every day of the year are not the same. Sunrise and sunset are affected by the location of latitude, declination angle, elevation angle and time correction (TC).

\[ \text{sunrise} = 12 - \frac{1}{15} \arccos \left( -\tan \phi \tan \delta \right) - \frac{TC}{60} \]  
(2.11)

\[ \text{sunset} = 12 + \frac{1}{15} \arccos \left( -\tan \phi \tan \delta \right) - \frac{TC}{60} \]  
(2.12)

\[ \text{noon} = \frac{\text{sunrise} - \text{sunset}}{2} \]  
(2.13)

2.3. Data Acquisition System

Data acquisition is a system used to retrieve, collect, and prepare data that is running; then, the data is processed further in the computer for certain purposes [12]. The elements are: Multiple physical parameter, Sensing element (transducer), Signal conditioning element, Multiplexer, Analog to digital converter, Multiple output data

2.4. Research Methodology

This final project work is done according to research methodology, which has been arranged to run systematically. Figure 3 shows the flow diagram of the research methodology as follows,

2.4.1. Secondary Data Collection. Data specification of each component required in this final task research aim is to facilitate workmanship in designing a data acquisition system on hybrid solar trackers.

2.4.2. Designing Hybrid Solar Tracker. At the design stage of this solar tracker basically consists of mechanical and electrical systems (electromechanical). The design of solar tracker is done by designing the tool measurably using Autodesk Inventor Professional 2017 software [16][17][18]. Then realize the solar tracker framework hardware shown in Figure 4.

2.4.3. Automatic Switching Design. At this stage, the merging of two types of solar tracker is an active and passive solar tracker that has been designed and implemented in 2 separate programs.

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**Figure 3.** Flowchart of Research Work
2.4.4. **Radio Telemetry Test**. This telemetry radio test is done by testing the 3DR telemetry module. This test aims to find out how far the maximum distance the module can send data.

2.4.5. **Designing of Data Acquisition System**. In this system of hybrid solar tracker data acquisition, it takes some electronic elements.

3. **Results and Discussion**

3.1. **Results of Data Acquisition System Test**

Data acquisition system in this research in the form of monitoring and recording the value of voltage and current on PV tracker, azimuth motor, elevation motor, controller, battery, and PV Fix. In addition, the measured variables are angular azimuth angles, temperature and solar irradiation. Data acquisition of data acquisition system is done when data collection of mobile solar trackers on June 3, 2018, with a time range of data storage to micro SD and excel in visual basic every 5 seconds.

![Figure 5](image)

**Figure 5.** Display of Data Logger on Microsoft Excel

Figure 5 above shows data logger on excel that has been processed. The logger data includes the date, time, large-volume PV tracking, PV tracking current, motor voltage 1 (azimuth), motor current 1 (azimuth), motor voltage 2 (elevation), motor current 2 (elevation) controller voltage, battery voltage, battery current, fixed PV voltage, fixed PV current, temperature, solar radiation, azimuth angle, and elevation angle.

3.2. **Results of Automatic Switching Tests**

The testing of the automatic switching system is done by test tracking the voltage for a full day from 05.30 to 17.30, is to determine the magnitude of the threshold voltage to be used as switching parameters on the hybrid solar tracker. The relatively low LDR voltage profile is a range 2 to 4 volts. The result is used as switching parameters as a threshold voltage of 3.5 volts.

3.3. **Results of PV Performance Test on Hybrid Solar Tracker**

This test is done by integrating solar tracker system to work in hybrid mode. There are two 250Wp solar panels used, one of them using solar tracker and in a fixed position (fixed). Solar tracker will operate
automatically into the current mode when the LDR voltage is more than 3.5 volts, and passive mode will operate when LDR voltage is less than 3.5 volts. This test is done in two ways, namely hybrid solar tracker with reflector and hybrid solar tracker with reflector.

3.4. Results of PV Performance Test on Hybrid Solar Tracker Without Reflector

Performance test of PV panel of hybrid solar tracker was done on Saturday 14 July 2018 in real-time at 05.30 - 17.30 WIB at the parking department of physics engineering ITS fixed based (silent) with conditions. The data retrieval technique is done using an integrated data logger system, with data taking every 5 seconds. After that, the data is processed on average with a period every 5 minutes. If in the solar tracker passive mode test, the controller setpoint uses azimuth angle and elevation while in active solar tracker utilizing LDR voltage, then for hybrid solar tracker is determined the combined mechanism of both methods with the provision during the average of 4 LDR voltage above the threshold value (V threshold = 3.5 V) then the active mode of the solar tracker operating.

3.5. Current Output, Voltage Output and Power Output of PV Panel Hybrid Solar Tracker With Reflector

The maximum current occurs at 11.30 WIB is 2,364 A for a PV panel of hybrid solar tracker. While at the maximum fixed current PV occurred at 11:35 pm, approached the PV tracker, which is equal to 1.954 A. This is in accordance with the position of the sun at the time of the solar noon that occurred at 11:34 pm and at that time conditions bright clouds and has the intensity of solar radiation maximum of 1003.21 W/m². The difference between the resulting current PV tracker with an average fixed PV of 0.401 A, with a maximum current difference of 0.86 A which occurred at 08:25 pm. The maximum difference of output voltage generated by both PV is 1.39 V which occurred at 09.45 WIB. The maximum output voltage produced by PV tracker without reflector and fixed PV respectively for 33.39 V and 32.66 V. The difference in average power output generated by PV tracker with PV fix of 13.64 watt with the maximum difference that occurred at 09.00 WIB at 29.18 watt. The increase in total power generated by PV panel hybrid solar tracker compared with fixed PV of 42.89%.

3.6. Results of PV Performance Test on Hybrid Solar Tracker With Reflector

The solar tracker was added a reflector with a slope angle of 70°. Data collection on hybrid solar tracker testing was conducted on Sunday 10 June 2018 in real-time at 05.30 to 17.30 WIB the area around the Department of Physics Engineering ITS mobile-based (moving) with cloudy sunny conditions. The data retrieval technique is done using an integrated data logger system, with sampling period every 5 seconds.

3.7. Current Output, Voltage Output, and Power Output of PV Panel Hybrid Solar Tracker With Reflector

The difference of average power output generated by PV tracker with PV fix 15.22 watt with the maximum difference that occurred at 2:55 pm which is equal to 34.07 watts. Increased total power generated by PV panel hybrid solar tracker compared with fixed PV of 51.56%. The maximum output voltage generated by the PV tracker and the fixed PV occurs at the same is 11.50 to 12.00 WIB, the maximum output voltage produced by PV tracker and fixed PV is 33.19 V and 32.69 V respectively. The maximum output difference of the voltage generated by both PV is 1.91V which occurred at 17:25 WIB. The maximum current occurs at 11:00 pm which is 2.367 A for PV on diesel hybrid tracker. While the maximum fixed current PV occurs at the same time with the PV tracker at 11:00 pm for 1.885 A, both PV produces the maximum current at the same time because at the time of data collection at that time when the weather is sunny and there is no obstacle and has radiation intensity maximum. The difference between the resulting current PV tracker with the average fixed PV of 0.451 A, with the maximum current difference occurred at 2:55 pm with a current difference of 1.039 A.
3.8. Energy Consumption and Increasing PV Panel Performance Analysis on Hybrid Solar Tracker

Table 3 shows the energy consumption of each of the major components (microcontroller, azimuth motor and elevation motor). Total energy consumption for PV panel with reflector 71.68 Wh while for PV panel without reflector 62.92 Wh with difference of 8.76 Wh.

| Controller            | Azimuth Motor | Elevation Motor |
|-----------------------|---------------|-----------------|
| a. Energy (Ws)        | b.            | a.              | b.           |
| 13136.26              | 13068.76      | 63566.63        | 63643.37     |
| Energy (Wh)           | 3.65          | 3.63            | 17.66        |

Table 4 shows the amount of energy produced by each photovoltaic for the PV panel with the reflector and with out the reflector. Higher energy yields on PV panels with reflectors due to full-day weather on data retrieval with brighter and warmer reflectors and data retrieval techniques from reflected PV panels and PV panels without different reflectors that are mobile-based, and fixed base (silent), so not necessarily increase its energy to PV fix bigger too. From table 4, can be seen difference for PV panel tracker with reflector compared with fixed PV of 183.88 Wh while the difference for PV panel tracker without reflector compared with fixed PV of 165.44 Wh.

| With Reflector | With Reflector |
|----------------|----------------|
| PV Panel Tracker | PV Fixed     |
| Energy (Ws)     | 1945698.37    | 1283744.69    |
| Energy (Wh)     | 540.47        | 356.60        |

| With Reflector | With Reflector |
|----------------|----------------|
| PV Panel Tracker | PV Fixed     |
| Energy (Ws)     | 1984326.25    | 1388728.82    |
| Energy (Wh)     | 551.20        | 385.75        |

It can be known that the energy efficiency produced by PV panel hybrid solar tracker with reflector compared with fixed PV is 51.56% while PV panel hybrid solar tracker with reflector compared without fixed PV of 42.88%. So that the improvement of energy efficiency PV panel with reflector compared with PV panel without reflector equal to 8.68%. It can be seen that a large net of energy that can be stored in batteries showing hybrid solar tracker is very effective in improving energy efficiency which has a large output of 468.79 Wh for PV panel without reflector and 488.28 Wh for PV panel with reflector, with a net efficiency of 31.46% for PV panels with reflectors and 26.58% for PV panels without reflector when compared to PV fix respectively. Compared with previous research conducted by Much. Faisal at the beginning of 2018, the net efficiency generated in the research was 27.18% so that in this study has greater efficiency with the difference of 4.18% for PV panel with reflector.

4. Conclusion

Parameters that affect the switching on this hybrid solar tracker are the intensity of sunlight, where the intensity of the sun will affect the LDR voltage with 3.5 volt voltage threshold which is used as switching parameters. Wireless data acquisition system using radio frequency module 915 MHz with interfacing using visual basic 2015 successful designed with a maximum performance distance of 120 meters if the location with a barrier, and as far as 350 meters if the location is free with a barrier. Energy consumption of the main components of motor 1 (azimuth), motor 2 (elevation), and controller is 71.68 Wh, while the energy generated by PV panel hybrid solar tracker with reflector is 540.47 Wh, so that energy can be saved equal to 468.79 Wh with an efficiency improvement of 31.46%. The design of hybrid solar tracker using PV panel with reflector higher than fixed photovoltaic to reach 51.56%, while for hybrid solar tracker with PV panel without reflector equal to 42.88% so that energy efficiency improvement in PV panel with reflector increased by 8.68% compared to PV panel without reflector.
References

[1] Batayneh W, Owais A and Nairoukh M 2013 An intelligent fuzzy based tracking controller for a dual-axis solar PV system Automation in Construction 29 pp100-106

[2] Abadi I, Musyafa’ A and Soeprijanto A 2015 Design and Implementation of Active Two Axes Solar Tracking System Using Particle Swarm Optimization Based Fuzzy Logic Controller International Review on Modelling and Simulations (IREMOS) 8(6)

[3] Ferdaus R, Mohammed M, Rahman S, Salehin S and Mannan M 2014 Energy Efficient Hybrid Dual Axis Solar Tracking System Journal of Renewable Energy pp 1-12

[4] Tharamuttam J and Ng A 2017 Design and Development of an Automatic Solar Tracker Energy Procedia 143 pp 629-634

[5] Nugroho R A, Facta M and Yuningtyastuti 2014 Memaksimalkan Daya Keluaran Sel Surya Dengan Menggunakan Cermin Pemantul Sinar Matahari (Reflector)

[6] Purwadi A, Haroen Y, Ali F, Nurafliat D and Assegaf A 2011 Prototype Development of a Low Cost Data Logger for PV Based LED Street Lighting System Int Conf on Electrical Engineering and Informatics

[7] Han J, Lee I and Kim S 2015 User-friendly monitoring system for residential PV system based on low-cost power line communication IEEE Transactions on Consumer Electronics 61(2) pp 175-180

[8] Belghith O and Sbita L 2014 Remote GSM module monitoring and Photovoltaic System Control First International Conference on Green Energy

[9] Jain D and Cheema S 2012 Simulation Studies on Dual Axis Solar Photovoltaic Panel Tracking System Patiala: Electrical & Instrumentation Engineering Department Thapar University

[10] Degratu S, Rizescu A, Alboteanu L, Caramida C, Rotaru P, Boncea I et al 2014 Using a Shape Alloy Memory Spring Actuator to Increase the Performance of Solar Tracking System

[11] Zobaa A and Bansal R 2011 Handbook of renewable energy technology Singapore

[12] Husein 2010 Weather Monitoring Telemetry System Prototype Based On XBEE IEEE.804.15.4 Jurnal Aplikasi Fisika 6(2) pp 97-103

[13] Abadi I, Imran, C and Faza N 2019 Smart Solar Tracking System Based on Fuzzy PI Controller for Maximizing the Power of PV AIP Conference Proceeding

[14] Abadi I, Musyafa’ A and Soeprijanto A 2015 Design and Implementation of Active Two Axes Solar Tracking System Using Particle Swarm Optimization Based Fuzzy Logic Controller. International Review on Modelling and Simulations (IREMOS) 8(6)

[15] Setyawan E, Abadi I and Kusumawarni S 2019 Estimation of Hourly Solar Radiation on Horizontal Surface Using GAMF (Genetic Algorithm Modified Fuzzy) (Case Study in Surabaya) IOP Conference Series: Materials Science and Engineering

[16] Abadi I, Musyafa A, Baskoro K and Fitriyanah D 2019 Design and Implementation of Mobile Active Two-Axis Solar Tracker with Reflector Based on Particle Swarm Fuzzy Controller. International Review on Modelling and Simulations (IREMOS) 12(2)

[17] Fitriyanah D and Abadi I 2019 Fuzzy Logic Control Design of Mobile PV Using Bacterial Foraging Optimazion Proc. 2018 International Seminar Intelligent and Its Application ISITIA 2018