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Design of IoT-Based One Axis Passive Solar Tracker

Dwi Nur Fitriyanah[a*], Bramasta Ghozi Abyrahman[a], Imam Abadi[b]

[a]*Department of Instrumentation Engineering,ITS Campus Sukolilo,Surabaya 60111,Indonesia*
[b]*Department of Engineering Physics, ITS Campus Sukolilo, Surabaya 60111, Indonesia*

Corresponding author : dwinur.fitriyanah@gmail.com

Abstract

Photovoltaic (PV) is a device that has the ability to convert solar energy into electrical energy. The most popular way to improve performance in PV is to add solar tracker technology. There are 2 solar tracker methods, namely passive and active, in this study focuses on the passive method where the slope angle of the PV is calculated using astronomical calculations. The difference in previous research is that the PV tilt angle can be adjusted via cellphone, it has a function if the Tracker system is damaged it can be replaced first using this system. In this study, the INA219 sensor is used to measure the current, voltage, and power at the PV output, and the GY52MPU 6050 sensor is used to measure the PV slope. The results obtained from this study are the accuracy value of the INA219 sensor is 98.67% for power and 97.67% for current and there is an error of 1.33% for power and an error of 2.33% for current values. There is also an accuracy value of the GY52MPU6050 sensor which is 99.6% and an error of 0.4%. IoT is also carried out where if the current value is greater, the delay that occurs is also higher. There is also an increase in performance between fixed-based and tracker by 21% in sunny conditions, and 15% in cloudy conditions.

Keywords: GY52MPU6050; INA219; IoT; Solar tracker

1. Introduction

Indonesia is in a geographical condition that is located on the equator, which allows a large potential for solar energy. Indonesia, which is always crossed by the sun, can produce solar energy reaching 4.8 kWh/m^2 every day. This fact shows the prospect of utilizing solar energy that does not produce waste and is environmentally friendly, which can be used as an effort to maximize new renewable energy through Solar Power Plants (PLTS) [1], [2].

PLTS uses photovoltaics as the main device to convert solar energy into electrical energy. The efficiency of this photovoltaic device still reaches 14-20% [3]. The main thing in the operational work of the system lies in the photovoltaic itself, namely the efficiency is quite low, so it needs photovoltaic components that can meet the desired power. As a result, photovoltaic is endeavored to always produce optimum power so that its efficiency does not decrease. An effort to overcome this is that photovoltaics can follow the direction of the sun's rays to obtain maximum energy. If the correct accuracy is not achieved, then a decrease in energy absorption may occur. One way to increase the efficiency of photovoltaics is to add a solar tracker system to its operation. The solar tracker can ensure that the photovoltaic moves to follow the movement of the sun so that the photovoltaic can be directed perpendicular to the angle of the sun's fall to maximize efficiency [4].

With increasingly rapid technological advances, technology helps a lot in human routine life, especially in the PLTS field. Previous research has found the optimal angle for the installation of solar panels by Tamer Khatib in 2012 with an increase of 5% compared to without calculating the optimal angle, but there is no solar tracker technology in the system [5]. Then in the development of further research in 2014 conducted by Abadi et. al., the tool already uses a solar tracker system, but there is no IoT implementation [6].

Considering the problems above and based on related research, the manufacture and development of tools were made. IoT-Based Remote One Axis Solar Tracker which can remotely find out the power, voltage, current, and angle generated every hour has a database and can control the solar tracker remotely. The purpose of the remote system is that when the solar tracker system malfunctions when the PV location is difficult to reach, such as on the roof of a 50th-floor building, toll gate roof, etc., we can find out if the tracking system has problems and can immediately adjust the PV angle remotely. So, this system is only used as a backup plan while making improvements to the solar tracker program.

2. Method

2.1. Solar Tracker

Solar tracker is an electromechanical system that works to control photovoltaic (PV) against the movement of the sun, keeping the PV perpendicular to the sun's rays [7]. This condition has the aim of obtaining maximum solar radiation for PV. Solar tracker is divided into 3 systems, namely tracking axis, tracking mechanism, and tracking control method.

2.2. Sun Position

Determine the position of the sun by using the horizontal coordinates of the earth with respect to the azimuth angle, elevation angle, and zenith angle [8]. The declination angle is the angle between the projection line on the equator plane that connects the center of the sun with the center of the earth with a range of -23.45° – 23.45°. The hour angle is the angle formed by the rotation of the earth to the sun, where the earth rotates 360° in 24 hours, the hour angle value is 15°/hour. Here is the equation for the angle of declination:

$$\delta = -23.45^{o} \cos [\ (n + 10,5)\ (360/365)] \quad (1)$$

where n is the day of the year with January 1 as n = 1

Table 1. Date order for sun position.

Month	n (Date-i)	Month	n (Date-i)
January	i	July	181 + i
February	31 + i	August	212 + i
March	59 + i	September	243 + i
April	90 + i	October	273 + i
May	120 + i	November	304 + i
June	151 + i	December	334 + i

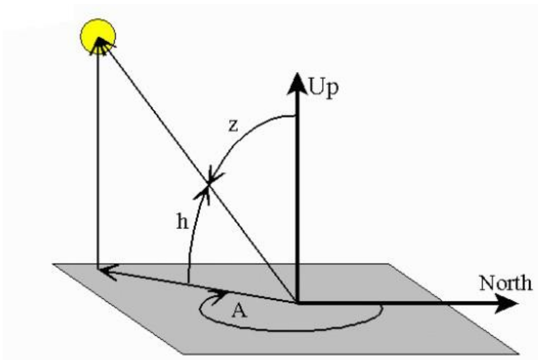

Figure 1. Angle of sun position.

2.3. Elevation Angle

The elevation angle is the angular height of the sun in the sky calculated from the horizontal [9]. The angle of elevation always changes throughout the day, the angle of elevation also depends on the degree of latitude of a location and day. Elevation can be obtained using the following equation:

$$\alpha = \sin^{-1} [\sin \delta \sin L + \cos \delta \cos L \cos (HRA)] \quad (2)$$

$$HRA = 15^{o}(LST\text{-}12) \quad (3)$$

where,

δ = declination angle

L = degrees of latitude

LST = lokal solar time

2.4. Photovoltaic System

Photovoltaic (PV) is an electric power generation module composed of solar cells arranged in series - parallel. The working principle of solar cells is to utilize the PV effect with materials from silicon semiconductors so that they are able to convert solar energy (photons) into direct current (DC) electricity.

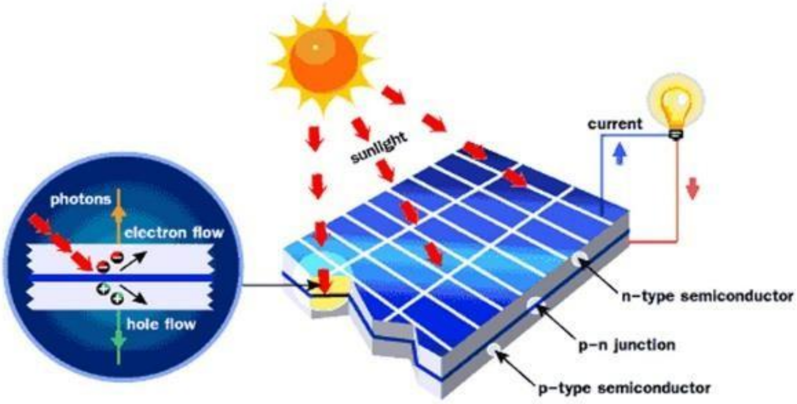

Figure 2. Work system of PV.

Figure 2 shows the process of solar cells absorbing sunlight. From the picture, sunlight (photons) hit the surface of the solar cell, then some of the sunlight is reflected and passed where electrons are released from their bonds by photons with a certain energy level. The movement of electrons produces an electric current.

To understand the characteristics of PV there is a graph. Based on the current (I) and voltage (V) curves, the electrical properties of the PV are known. The figure shows when the cell is connected to a load (R). the load gives resistance as a linear line with the I/V = I/R line, thus showing the power generated depends on the resistance value. If R is small then the cell operates in the MN curve region, where the cell operates as a constant current source or short circuit current. If R is large, the cell operates in the PS curve area, where the cell operates as a constant voltage source or an open circuit. If it is connected to the optimal resistance (Root), the solar cell will produce maximum power with maximum voltage and current [10].

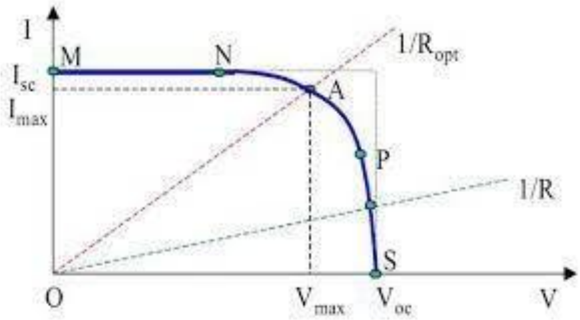

Figure 3. PV character graphics.

2.5. Sensor GY52MPU6050

This tool uses the sensor to measure the slope of the PV. The MPU-6050 sensor is a combination of 3 types of sensors, namely accelerometer, gyroscope and magnetometer. This sensor can detect acceleration in 3 axes (x, y, and z). The sensitivity of this sensor can be adjusted according to the needs for +-2g, +-4g, +-8g, and +-16g accelerometers, and for +-250, +-500, +-1000, +-2000°/sec and +1200Mt gyroscopes. for magnetometers.

2.6. Monitoring System at Solar Tracker

The monitoring system for the solar tracker is used to determine the current and power generated during the day using the INA219 sensor where data is taken every 1 hour. In addition to the INA219 sensor to determine current and power, there is a GY52 MPU6050 sensor to measure the PV tilt angle every hour during the day, for the angle sensor will be placed behind the photovoltaic. There are 4 types of elements in the measurement system. The four types of elements are shown in the measurement block diagram of Figure 4.

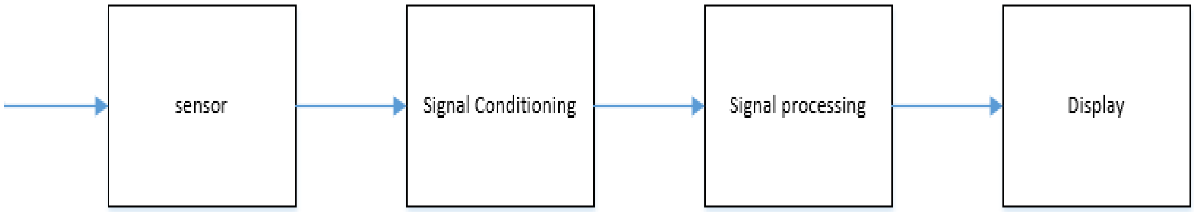

Figure 4. Monitoring system at solar tracker.

2.7. Design of Solar Tracker System Model

Before making hardware and software, it is necessary to design a solar tracker system model. The function is to visualize what is in your mind by designing a solar tracker system, designing a 3D solar tracker and designing a HMI solar tracker. At this stage it has a function when making the tool, there is no confusion because there is already a design for the solar tracker system, mechanical and wiring forms and HMI design.

The system model that will be used in this research has been shown in Figure 5 prototype of an IoT-based remotely one-axis solar tracker design that will be equipped with hourly scheduling and IoT- based monitoring using a smartphone.

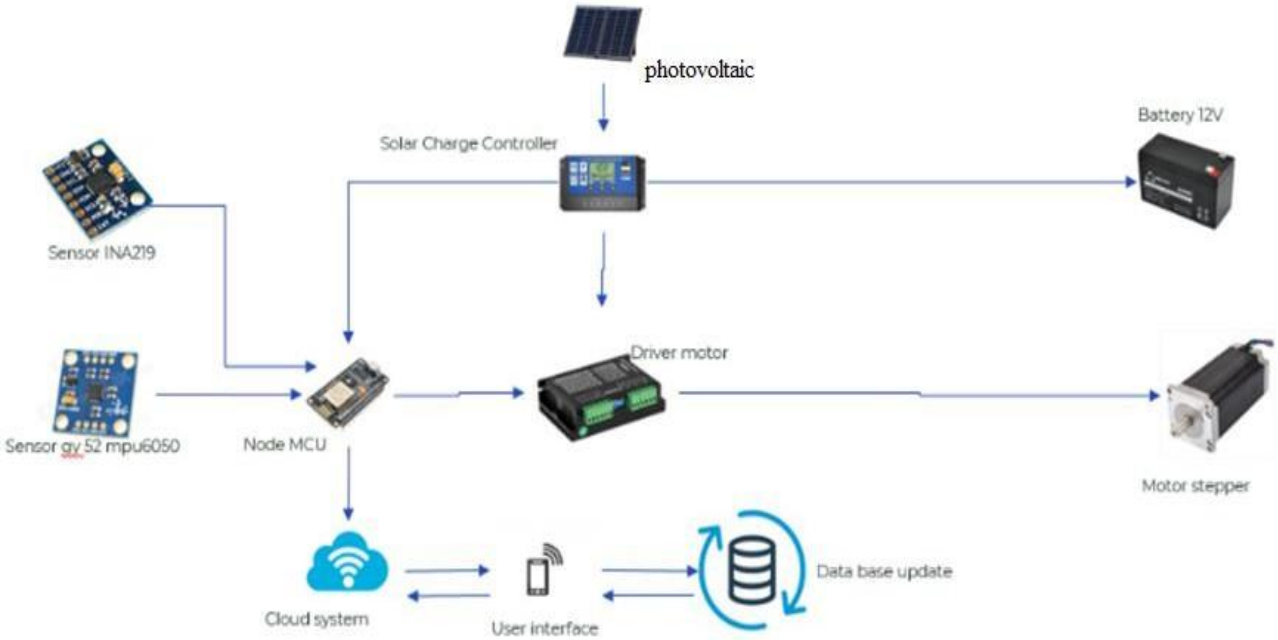

Figure 5. Solar tracker remotely work system.

In the design of an IoT-based remote control one-axis solar tracker system, we enter the desired angle according to the calculation of the sun's position. The angle entered is different depending on the clock at that time through the cellphone. The tool moves according to the angle entered by the actuator in the form of a stepper motor. The GY 52 MPU 6050 sensor is used to retrieve data in the form of the PV slope angle. The data will be updated every 1 hour in the form of power, current, and angle recorded in the database. This tool charge controller uses PWM (Pulse with Modulation) which will be the power supply of the microcontroller and motor driver. For the battery using 12V 7.5Ah. The block diagram of the measurement system of this tool is as follows.

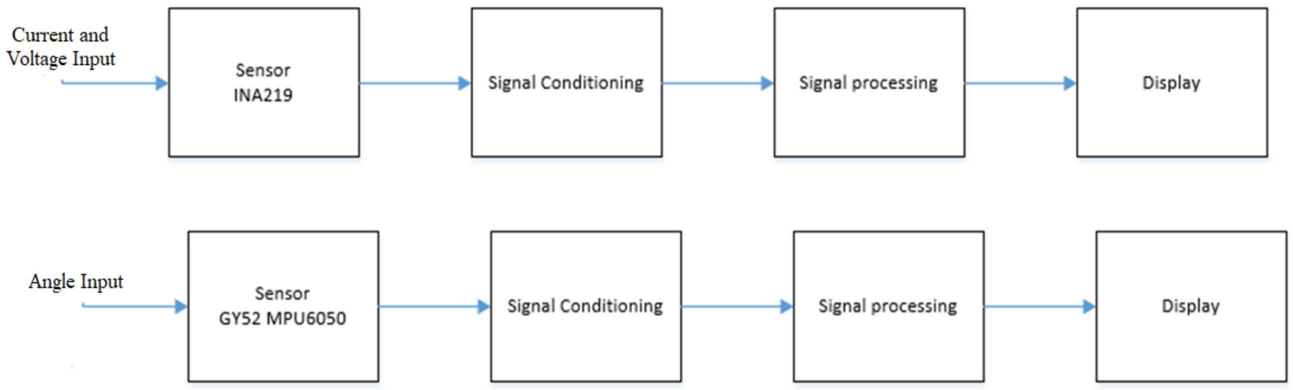

Figure 6. Measurement block diagram.

Based on the block diagram, the sensing element used is the INA219 sensor and the GY52 MPU6050 sensor which will send the measurement result signal, after the signal is conditioned and adjusted according to the standard signal, namely 1-5vdc or 4-20 mA. After that the signal will be transmitted to the controller to be processed according to the desired conversion and then transmitted to the display to display the measurement data in the form of current, voltage and angle.

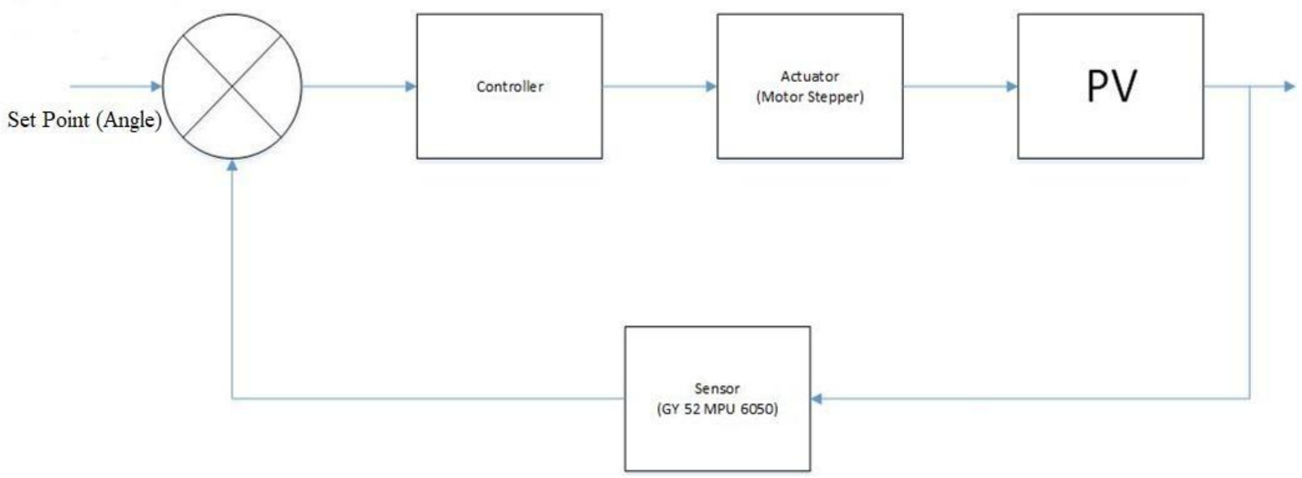

Figure 7. Control block diagram.

The design of the tool uses a closed loop diagram where the set point is a different angle in each hour. The actuator uses a stepper motor because it requires a smooth movement. The actuator will work every hour and stop immediately.

In designing the tool, 3D images are needed to visualize the shape you have in mind. The mechanical system has a function as the laying of solar panels, as the azimuth axis of rotation. Making a mechanical system begins with making a 3D design using a sketch up. The components that make up the solar tracker are as follows:

1. Actuator : Stepper Motor
2. Sensor : MPU 6050 and sensor INA219
3. Controller : Node MCU
4. Plant : photovoltaic

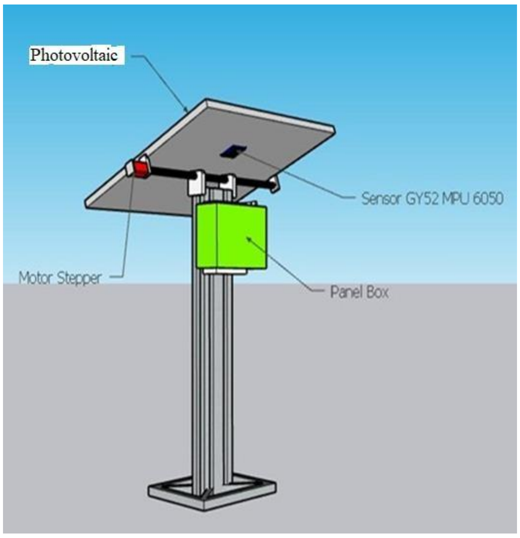

Figure 8. Design 3D of solar tracker remotly.

In designing a wiring system, a wiring schema diagram is needed in advance to plan what components are needed. In addition, the wiring scheme is needed as an initial plan for making tool wiring. In Figure 9 there is PV as the main component, SCC which is connected to PV, at the PV output there is an INA219 sensor which functions to measure the current and output voltage from PV, then there is a GY52MPU6050 sensor as a slope sensor used to measure the slope of the PV, then there is an MCU Node As a microcontroller, the stepper motor is equipped with a driver and then there is a battery.

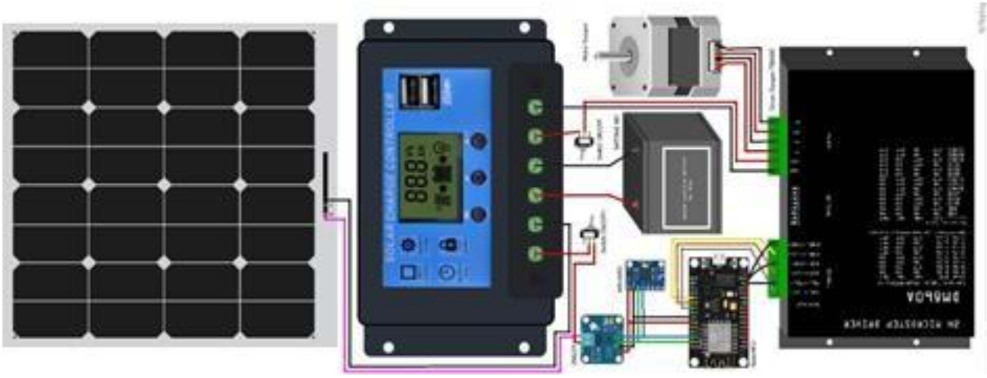

Figure 9. Solar tracker wiring schematic.

The software design on this tool uses a smartphone to display the output data from the solar tracker. The variables displayed on the smartphone are current, voltage, and slope angle and there is a menu to adjust the PV slope every hour. The workings of the system as, the first step is to connect the microcontroller with wifi and then set the set point in the form of a tilt angle using a smartphone. The next step is to wait for the device to move according to the set point that has been determined via the smartphone. The next step is to initialize the MPU6050 and INA219 sensors. Then the reading data is displayed on the smartphone.

3. Results and Discussion

3.1. Angle Test Data

One thing that affects the absorption of power in the Tracker system is the accuracy of the elevation angle between the solar panel and the sun. Elevation angle validation data retrieval compares the set points obtained from the sun locator application and the Tracker system. Data collection was carried out from 08.00 - 16.00. The validation value of the set point angle was obtained from the sun locator application and the Tracker system. Data collection was carried out from 08.00 to 16.00 due to mechanical limitations. The mechanical restriction in question is the maximum angle that the tool can reach is 20° and 160° at 07.00 the angle of elevation according to the sun locator is 17° as well as at 17.00 the angle of elevation is 3.5°. Based on the table, the average error is 0.15%, where the maximum error for the control system is 5%. After testing the system, this tracker system is feasible to use.

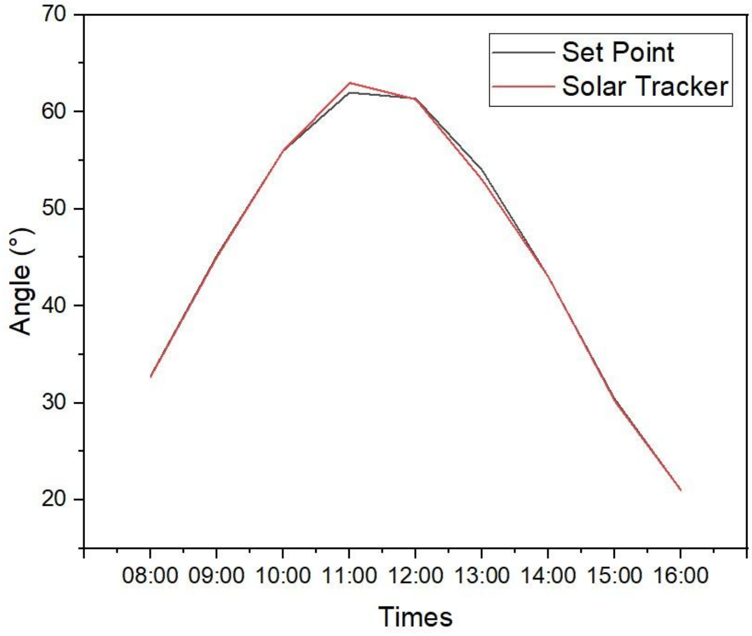

Figure 10. Angle validation graph.

Figure 10 is a comparison of the movement of the elevation angle obtained in the sun locator application and the Tracker system. Data is taken from 08.00 – 16.00. from the graph obtained an average error of 0.15%, where the maximum error for the control system is 5%. After testing the system, this tracker system is feasible to use.

3.2. IoT Testing

In this tracker system there is an IoT system that has a remote monitoring function that can make work easier. What is monitored on the smartphone is current (A), voltage (V), elevation angle (°), and sensor angle (°). After installing the IoT system, an IoT test is needed where what is tested is how fast the data is sent to the cellphone. This tracker system uses the blynk application.

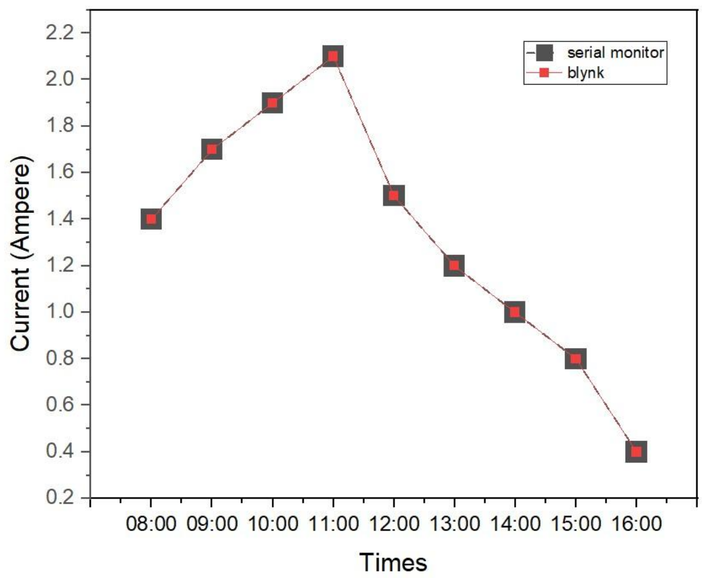

Figure 11. Comparison of serial monitor and blynk.

Figure 11 is a comparison picture of the current that appears on the serial monitor and blynk. In this Figure, there is no difference between serial monitor and blynk at 11.00, there is a delay of 3 seconds, and there is also a delay at 09.00, 10.00, and 12.00 for 2 seconds, due to sending large currents and there is internet speed that affects how fast or slow the data displayed on blynk.

3.3. Angle Change Reference Time

O This tracker system uses a stepper motor as an actuator. In the tracker system, it takes time to move the slope from the initial angle to the end angle, so it takes a reference time to change the angle to find out how long the PV moves from the initial angle to the final angle.

Table 2. Angle change reference time.

No	Angles (º)	Time (s)
1	20 to 30	48
2	30 to 40	44
3	40 to 50	49
4	50 to 60	47
5	60 to 70	41
6	70 to 80	56
7	80 to 90	41
8	90 to 80	42
9	80 to 70	41
10	70 to 60	42
11	60 to 50	42
12	50 to 40	42
13	40 to 30	44
Average		44,53846

In Table 2, it can be seen that the reference time for angle changes in multiples of 10 starting from 20° facing east to 30° facing west, the average time is 44.5 seconds. It takes a long time to get an accurate angle between the set point and the tracker system that has been made. as for the cause of the long time is the load from the PV itself which is quite heavy for a stepper motor.

3.4. Testing of 2 PV

In this research, there are 2 photovoltaics, the first using a solar tracker system and a fixed based one. The 2 PVs will be compared to determine the difference in power output when the tool is tested. The test was carried out for 14 days and was taken from 08.00 to 16.00; data was taken every 1 hour.

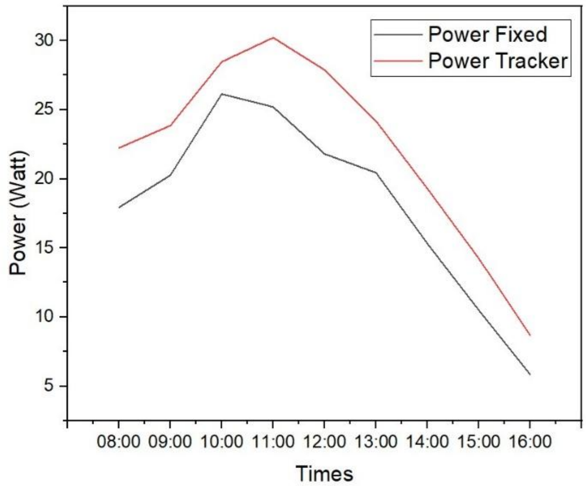

Figure 12. Power comparison of fixed based & tracker in sunny weather.

Figure 12 shows the comparison of the power generated by PV between fixed based and tracker, data is taken in sunny weather from 08.00 to 16.00 data is taken every hour. The increase in PV power performance is obtained by calculating the total energy difference divided by the total energy of the fixed and multiplied by 100%. Based on the calculation, the performance increase of 21.7%.

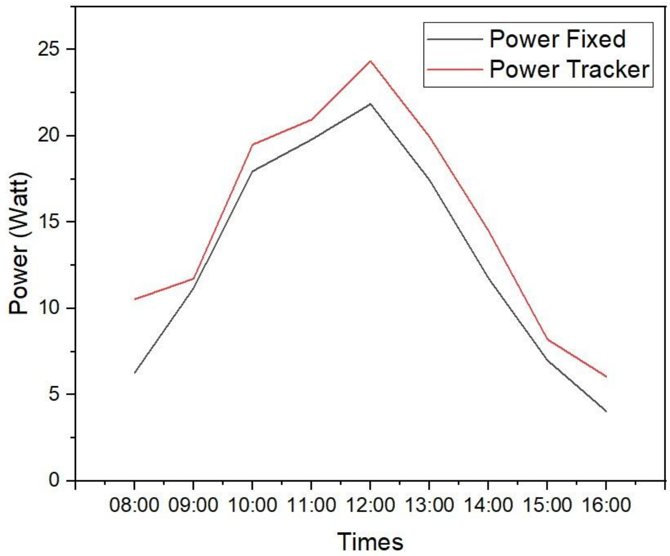

Figure 13. Power comparison of fixed based & tracker in cloudy weather.

Figure 13 shows the comparison of the power generated by PV between fixed based and tracker, data is taken in cloudy weather from 08.00 to 16.00 data is taken every hour for 4 days in cloudy conditions. The increase in PV power performance is obtained by calculating the total energy difference divided by the total fixed power and multiplied by 100%. Based on the calculation, the performance increase is 15%.

3.5. The Effect of Irradiation and Temperature on PV Output

In this sub-chapter, we will discuss the effect of irradiation and temperature on PV power output. The highest radiation value in cloudy weather is 807 W/cm^2 at 12.00 and produces a current value of 1.8 A, in sunny weather, the highest radiation value is at 11 o'clock with a value of 822 and produces a current of 2.11 A. on cloudy conditions, the highest power is generated at 24.34W at 12.00, on sunny conditions, the highest power is generated at 11.00, which is 30.2W. There is a difference in the average power in the two conditions, for cloudy conditions it produces an average power of 15.03 W while in sunny conditions it produces an average of 22.11W.

4. Conclusions

Based on the design and data analysis that has been carried out, temporary conclusions are obtained as there is an increase in performance of 21.7% in sunny weather and 15% in cloudy weather with the largest power difference of 6.04W in sunny weather and 3.9W in cloudy weather. The INA219 sensor has 98.29% accuracy and 1.08% error on voltage validation, 97.29% accuracy and 2.71% error on current validation, on gy52MPU6050 sensor obtained 99.6% accuracy and error 0.4% of both sensors are feasible to use.

References

[1] N. A. Shoffiana *et al.*, “PV Maximum Power-Point Tracking by Using Artificial Neural Network,” *2023 Int. Conf. Adv. Mechatronics, Intell. Manuf. Ind. Autom. ICAMIMIA 2023 - Proc.*, pp. 859–863, 2023.

[2] I. Abadi, C. Imron, M. Musa Bachrowi, and D. Nur Fitriyanah, “Design and implementation of battery charging system on solar tracker based stand alone PV using fuzzy modified particle swarm optimization,” *AIMS Energy*, vol. 8, no. 1, pp. 142–155, 2020.

[3] R. Delfianti, A. Soeprijanto, A. Priyadi, A. L. S. Budi, and I. Abadi, “Energy Management Efficiency and Stability Using Passive Filter in Standalone Photovoltaic Sudden Cloud Condition,” *2020 3rd Int. Semin. Res. Inf. Technol. Intell. Syst. ISRITI 2020*, pp. 716–720, 2020.

[4] I. Abadi, T. Oktavia Hardiana, C. Imron, D. Nur Fitriyanah, Y. Jani, and K. Abdullah, “Design of Adaptive Neuro-Fuzzy Inference Control Based One-Axis Solar Tracker on Battery Charging System,” *E3S Web Conf.*, vol. 190, 2020.

[5] T. Khatib, A. Mohamed, and K. Sopian, “2012 IEEE International Power Engineering and Optimization Conference [front matter],” no. June, pp. c1–c1, 2012.

[6] I. Abadi, A. Soeprijanto, and A. Musyafa, “Design of single axis solar tracking system at photovoltaic panel using fuzzy logic controller,” in *The 5th Brunei International Conference on Engineering and Technology*, 2014.

[7] A. Singh and N. Aphiratsakun, “solar tracking system,” *ECTI-CON 2015 - 2015 12th Int. Conf. Electr. Eng. Comput. Telecommun. Inf. Technol.*, vol. 6, no. 9, pp. 994–999, 2015.

[8] F. M. Al-Naima, R. S. Ali, and A. J. Abid, “Design of an embedded solar tracking system based on GPS and astronomical equations,” *Int. J. Inf. Technol. Web Eng.*, vol. 9, no. 1, pp. 12–30, 2014.

[9] N. Sharma, P. K. Tiwari, G. Ahmad, and H. Sharma, “Optimum Tilt and Orientation Angle Determination with Application of Solar data,” *Proc. - Int. Conf. Artif. Intell. Smart Syst. ICAIS 2021*, pp. 477–481, 2021.

[10] I. Abadi, D. Nur Fitriyanah, and A. Ul Umam, “Design of Maximum Power Point Tracking (MPPT) on Two Axes Solar Tracker Based on Particle Swarm Fuzzy,” in *AIP Conference Proceedings*, Mar. 2019.