Sensorless *Solar Tracker* Optimization on *Photovoltaic* (PV)

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***Abstract*— The development of renewable energy technology is getting more rapid, one of which is using solar energy through photovoltaic (PV) systems. A solar tracker is a device used to optimize the absorption of sunlight by solar panels by following the sun's movement. However, using sensors on solar trackers often requires quite complicated manufacturing. Therefore, this research aims to design a sensorless solar tracker on a photovoltaic (PV) system. The method in this study is to attach the actuator motor to the solar panel frame and move it automatically using Arduino Uno. Data was collected in real-time within three days using three different power supplies. Data collection started at 09.00 WIB with a solar panel tilt of 45° and went to 15.00 WIB with a solar panel tilt of 135°. The results of measurements using a solar tracker on photovoltaic (PV) obtained an average current of 0.74 amperes (A), an average voltage of 18.7 volts (V), and an average power of 14.4 watts (W).**

Keywords— Photovoltaic (PV), Sensorless, Solar Energy, Solar Tracker.

I. Introduction

Solar panels are electronic devices that collect sunlight and convert it into electrical energy. Solar panels are widely used in renewable energy applications, such as solar power plants for households, industries, and commercial facilities [1].

Solar panels generate maximum electricity when exposed to direct sunlight. However, the position of the sun changes throughout the day and year. Therefore, designing a system that can follow the sun's movement can improve the energy efficiency produced by solar panels. The energy output can be increased by ensuring that the solar panel is always facing the sun. This will optimize the utilization of existing resources and generate more electricity, especially in variable weather conditions throughout the day [2], [3], [4].

Some geographic regions may have different weather variations and sunlight intensities throughout the year [5]. In the Madiun area, there is enough light potential for the application of solar panels, and a system that can be adjusted to this change will help maximize the potential of renewable energy.

Based on these problems, it is necessary to design a solar tracker on photovoltaic panels, which is expected to maximize the absorption of sunlight on solar panels. Innovation in this area can open the door for the development of more efficient and environmentally friendly solutions in the future [6].

II. Materials and Methods

A. Material

a. Photovoltaic

Photovoltaic(PV) technology uses semiconductor materials to generate DC (Direct Current) electricity. Photovoltaics produce electrical energy when the surface is exposed to light; if the surface is not exposed to sunlight, the photovoltaic stops producing electrical energy [7]. There are three types of photovoltaics: Monocrystalline Silicon, Polycrystalline Silicon, and Thin-Film Solar Cells.

1. Monocrystalline Silicon is made of silicone. The shape of this solar panel is thin and black. Although the production of monocrystalline solar cells requires a high cost, monocrystalline solar cells have the highest efficiency of all solar cells. In laboratory studies, the efficiency of a single solar cell reached about 24% [8].

2. Polycrystalline Silicon is made of silicone material and then melted. This solar panel is characterized by its neat and tight physical appearance. Compared to monocrystalline solar cells, polycrystalline silicon is cheaper but less efficient. [9].

3. Thin-film solar Cells are the second generation of solar cells, and the thin-film type only uses 1% silicon raw material. These solar cells are manufactured to reduce the cost of solar cells [10]. This solar panel technology manufactures solar panels using thin solar cells that are then attached to the base layer so that they have two layers.

b. Arduino Uno R3

Arduino uno R3 is a microcontroller board based on Microchip ATmega328P microcontroller. The first type of Arduino Uno R3 was released in 2011. R3 itself refers to the third revision type [11]. It has 14 input and output pins, of which six can be used as PWM outputs, six analogue inputs, a 16 MHz crystal oscillator, a USB port, a power jack, an ICSP header, and a reset button. [12].

c. Motor Actuator

An actuator is a mechanical device that drives or controls a mechanism or system. Actuators use electrical energy converted into motion and then can move objects where the actuator is installed. This tool is used to move the solar panel to get the specified position [13].

Figure 1. Motor Actuator

d. Inverter

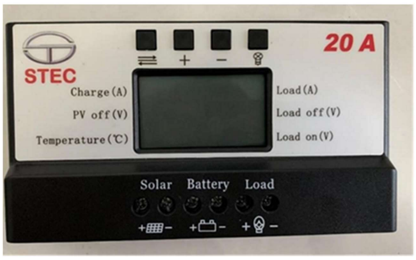
An inverter is one of the main components of a solar panel system. It converts DC electricity into AC, which can be consumed by existing loads [14]. Solar panels absorb sunlight and generate DC electrical energy. For electronic needs at home, the majority of which use AC electricity, not DC.

e. Battery

Solar panel batteries are part of a solar power plant (PLTS) that stores the energy generated by solar panels during sunlight. The function of the battery is not only to store energy, but it will also generate electricity when the solar panel is not producing energy. [15].

f. Solar Charge Controller

Solar Charge Controller (SCC) is an electronic component in solar PV that regulates battery charging using photovoltaic modules to make it more optimal. Solar Charge Controller (SCC) works by controlling the charging voltage and current based on the photovoltaic module's available power and the battery's charging status [16].



Gambar 2. SCC (*Solar Charge Controller*)

g. Real Time Clock

A Real-Time Clock, Also known as RTC, is a chip that can accurately calculate time, from seconds to years, and also maintain or store time data promptly in real-time [17].

Once the timer is complete, the output is saved or sent to another device via the interface system.

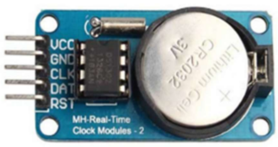


Figure 3. RTC (*Real Time Clock*)

h. Driver Motor

A motor driver is an electronic component that controls a DC motor. The motor driver is responsible for converting the signal received by the microcontroller into an output signal that can drive the DC motor. This DC motor driver has a PWM function and can output a current of up to 43A. The DC source voltage can be between 5.5V27VDC, and the input voltage level can be between 3.3V-%VDC [18].

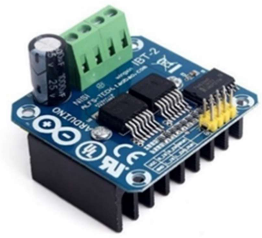


Figure 4. Driver Motor BTS7960

B. Method

a. Place and Time of Research

The research was carried out in the UNIPMA Integrated Lab, precisely on the 5th (five) floor of room T08, and was carried out from March to July 2024.

b. Research and Design Stages

1. Research Stages

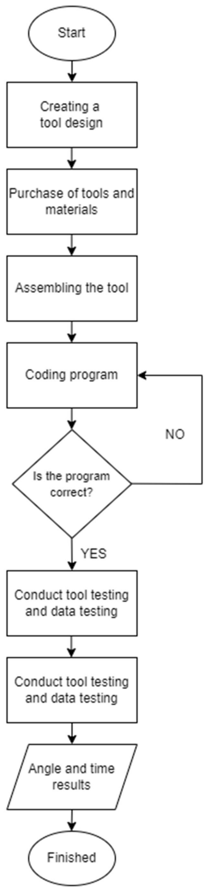


Figure 5. Research Stage Flowchart

2. Software Flowchart

Based on this study, there is a flowchart that describes how the solar tracker works. In Figure 6, the algorithm flowchart explains the operation of the tool starting from the RTC to read the time, when the time indicates the time of 12:00 and 12:30 the actuator motor will work, and when the time shows the time 12:09 and 12:39 the actuator motor will stop moving.

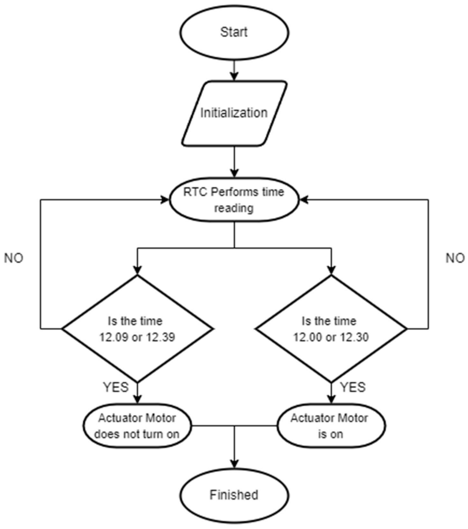


Figure 6. SoftwareFlowchart

3. Electronics Networks

The arrangement of the Real Time Clock (RTC) cable and the Motor Driver consists of;

- A4 pin connected to SDA Real Time Clock (RTC) pin
- A5 pin connected to SCL Real Time Clock (RTC) pin
- 2 digital pins connected to the R-is pin of the Motor Driver
- 3 digital pins connected to the L-is pin of the Motor Driver
- 5 digital pins connected to RPWM Motor Driver pins
- 6 digital pins connected to LPWM Motor Driver pins

Then, the LCD pin itself follows the pin out on the RTC for the electronics circuit, as seen in the picture below.

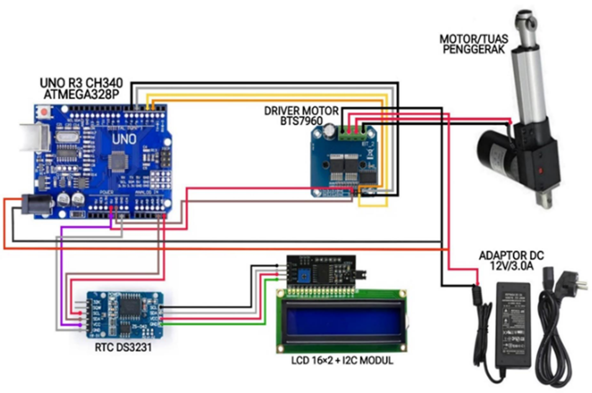


Figure 7. Electronics Network

III. Results and Discussion

A. *Real Time Clock (RTC) Testing*

The Arduino will command the actuator motor to move every 30 minutes for 9 seconds and stop when 9 seconds have passed. For example, if the RTC shows the time at 10:00:00, the motor will move for 9 seconds and stop at 10:00:09. The bike will move again at 10:30:00 and stop at 10:30:09.

Table 1. Real-Time Clock Testing

Early Hours	Actuator Motor Condition	End Hours	Actuator Motor Condition
09:30:00	Move	09:30:09	Stop
10:00:00	Move	10:00:09	Stop
10:30:00	Move	10:30:09	Stop
11:00:00	Move	11:00:09	Stop
11:30:00	Move	11:30:09	Stop
12:00:00	Move	12:00:09	Stop

B. *Testing determines actuator movement time*

To achieve an angle of 7.5°, an actuator must move for a certain amount of time. So, a test was carried out to determine the length of time that the researcher would use to reach the second angle, which was 52.5°.

Table 2. Determining the Timer

Stopwatch (Seconds)	Initial Angle	Angle of Results	Difference
00.06.16	45°	50°	5°
00.08.32	45°	51,5°	6,5°
00.09.17	45°	52,5°	7,5°
00.10.33	45°	55°	10°

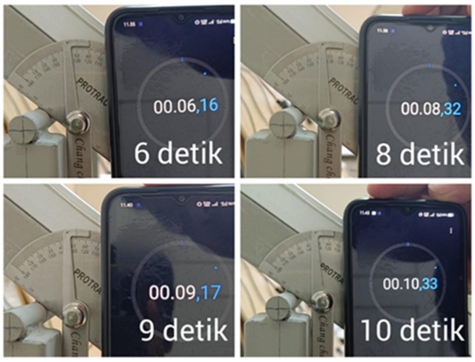


Figure 8. Proof Table

After some time tests, the time data showing 7.5° is 9 seconds to reach the second angle of 52.5°, which can be seen in Table 2 and Figure 8.

C. *Solar Tracker Testing*

The test begins by manually moving the actuator motor assembled with solar panels without a program to determine the time it takes for the drive to reach the desired angle. The time it takes for the drive to reach the desired angle.

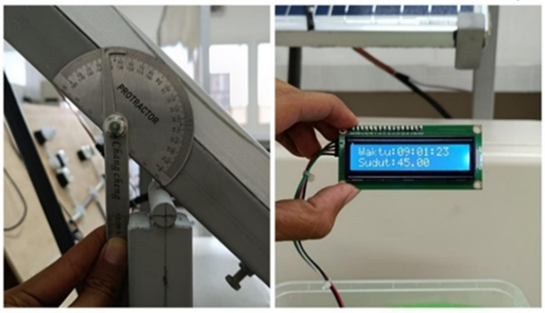


Figure 9. Starting Position (9 a.m.)

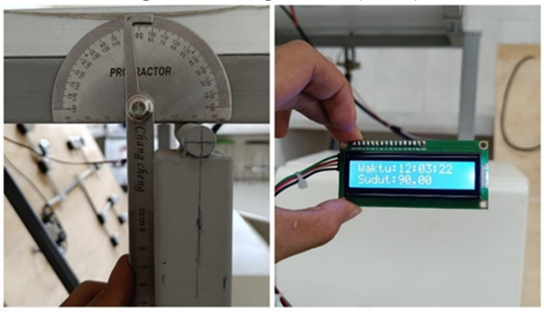


Figure 10. Middle Position (12 noon)

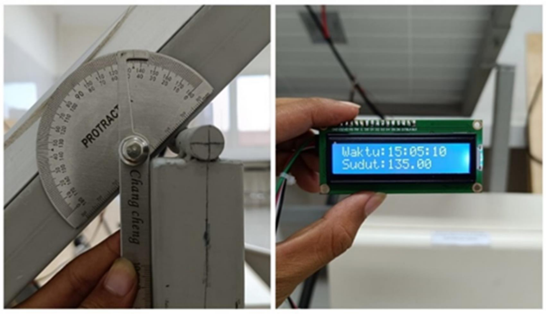


Figure 11. Final Position (3 p.m.)

D. *Angular Data Collection*

Table 3. Day One Testing

Time	Measured solar panel angle	Display angle on LCD	Difference
09.00	45°	45°	0°
09.30	52,5°	52,5°	0°
10.00	60°	60°	0°
10.30	67,5°	67,5°	0°
11.00	75,5°	75°	0,5°
11.30	82,5°	82,5°	0°
12.00	90°	90°	0°
12.30	97,5°	97,5°	0°
13.00	104,5°	105°	-0,5°
13.30	113,5°	112,5°	1°
14.00	120°	120°	0°
14.30	127,5°	127,5°	0°
15.00	136°	135°	1°
Average			0,15%

Table 3 shows a test using a USB connected to a laptop. This test has a slight drawback: the computer must always be on because it will be the tool's power supply. The drawback is that it still has to use PLN electricity to supply the motorcycle driver.

Table 4. Day Two Testing

Time	Measured solar panel position	Display angle on LCD	Difference
09.00	45°	45°	0°
09.30	52,5°	52,5°	0°
10.00	61°	60°	1°
10.30	67,5°	67,5°	0°
11.00	75°	75°	0°
11.30	83°	82,5°	0,5°
12.00	90°	90°	0°
12.30	98°	97,5°	0,5°
13.00	104°	105°	-1°
13.30	112,5°	112,5°	0°
14.00	120°	120°	0°
14.30	128°	127,5°	0,5°
15.00	135°	135°	0°
Average			0,11%

Table 4 shows a test that uses an adapter connected to an outlet (PLN electricity) as a power supply for the solar tracker. In this test, the set of tools must be close to the PLN power source. If the PLN power source is cut off, the drive will also turn off because the supply used is electricity from PLN.

Table 5. Third day of testing

Time	Measured solar panel position	Display angle on LCD	Difference
09.00	45°	45°	0°
09.30	52,5°	52,5°	0°
10.00	61°	60°	1°
10.30	67,5°	67,5°	0°
11.00	75°	75°	0°
11.30	82,5°	82,5°	0°
12.00	90°	90°	0°
12.30	97,5°	97,5°	0°
13.00	105°	105°	0°
13.30	112,5°	112,5°	0°
14.00	120,5°	120°	0,5°
14.30	128°	127,5°	0,5°
15.00	135,5°	135°	0,5°
Average			0,19%

Table 5 shows data capture using a 12v adapter connected directly to an inverter connected to the solar panel. By using an inverter connected to the solar panel battery, this test will reduce the power stored in the solar panel battery.

E. *Results of Current, Voltage, Power Data Collection*

Data is collected by measuring current, voltage and power at each angle of inclination the solar panel has achieved. The test is carried out for 7 hours and tested every 30 minutes, starting from 09.00 WIB to 15.00 WIB. The test was carried out at that hour because sunlight was efficient for only 7 hours. Here is the data on the current, voltage, and power obtained [19].

Figure 12. Data Collection Process

Table 6. Data collection of current, voltage, power

Time	Angle (°)	Current (A)	Voltage (V)	Power (W)
09.00	45°	0,34	16,68	5,7
09.30	52,5°	0,33	17,18	5,6
10.00	60°	0,34	18,14	6,1
10.30	67,5°	0,34	17,66	6,1
11.00	75°	0,81	17,96	14,5
11.30	82,5°	1,87	20,60	38,6
12.00	90°	1,65	19,84	32,8
12.30	97,5°	1,04	20,11	21,0
13.00	105°	0,82	19,88	16,4
13.30	112,5°	0,28	20,05	5,7
14.00	120°	0,92	18,55	17,1
14.30	127,5°	0,67	18,81	12,6
15.00	135°	0,31	17,64	5,4
Average		0,74	18,7	14,4
Minimum		0,28	16,68	5,4
Maximum		1,87	20,60	38,6

F. *Angular Test Results*

Table 7. Day 1 to Day 3 Testing

Time	Day - 1	Day - 2	Day - 3
	Using a USB Laptop	PLN 12v electric adapter	Adaptor 12v Inverter
	Angle		
09.00	45°	45°	45°
09.30	52,5°	52,5°	52,5°
10.00	60°	60°	60°
10.30	67,5°	67,5°	67,5°
11.00	75°	75°	75°
11.30	82,5°	82,5°	82,5°
12.00	90°	90°	90°
12.30	97,5°	97,5°	97,5°
13.00	105°	105°	105°
13.30	112,5°	112,5°	112,5°
14.00	120°	120°	120°
14.30	127,5°	127,5°	127,5°
15.00	135°	135°	135°

G. *Error Graph*

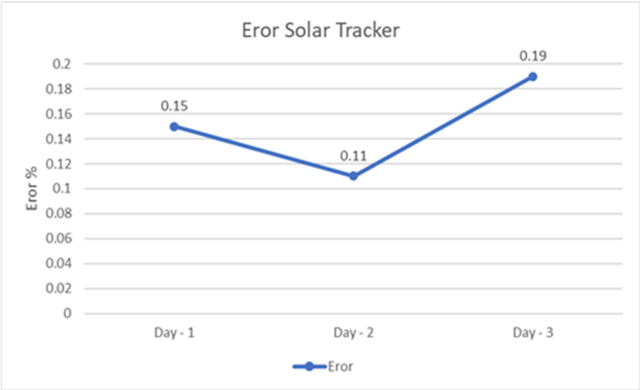


Figure 13. Error Graph

Based on the test results of the actuator motor, the actuator motor can drive the minor solar panel at an angle of 45° and the maximum angle position at 135° with the frame used by the researcher. The error on the first day of testing was 0.15%, the second day of error testing was 0.11%, and the third day of error testing was 0.19%.

To prevent possible damage to the actuator motor or control system that may occur if used continuously, it is recommended to monitor the condition of the actuator motor, carry out regular maintenance, and set a safe angle range.

H. *Current Test Results*

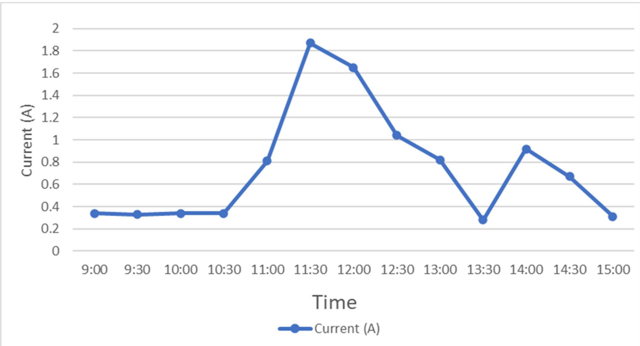


Figure 14. Current Test Results

Figure 13 shows the results of the current measurement (A). From the graph above, the highest current (A) was obtained at 11.30 AM with 1.87 amperes (A) of 82.5° of the solar panel's inclination angle and the lowest current at 13.30 with 0.28 amperes (A) of 112.5° inclination.

I. *Tension Test Results*

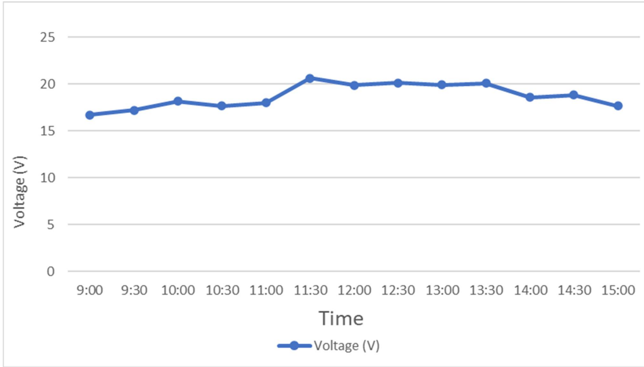


Figure 15. Tension Test Results

From the graph above, the highest voltage (V) is obtained at 11.30 AM with a 20.60 voltage (V) tilt angle of 82.5° solar panel and the lowest voltage at 09.00 AM with a 16.68 voltage (V) tilt angle of 45°.

J. *Power Test Results*

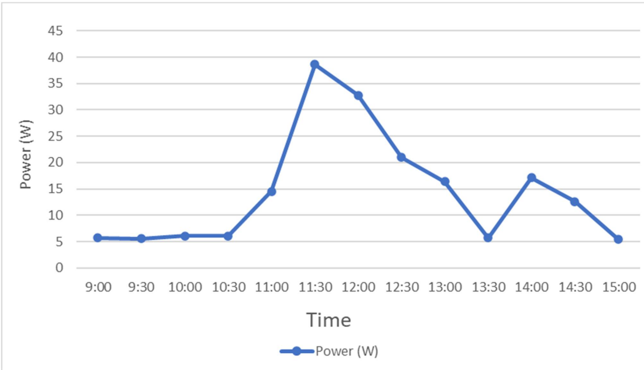


Figure 16. Power Test Results

The highest power (W) was obtained at 11.30 WIB with 38.6 watts (W) of solar panels' 82.5° tilt angle, and the lowest power was received at 15.00 WIB with 5.4 watts (W) of solar panels' 45° tilt angle.

K. *Analysis of Results*

Sensorless solar trackers on photovoltaic (PV) systems typically use algorithms or mathematical models to estimate the sun's position. This increases reliability because there is no reliance on light sensors, which can be subject to damage or environmental interference (such as dust, dirt, or shadows). Using a sensorless solar tracker is usually more energy efficient because it does not require sensors or sensor data processing systems that run continuously. This reduces the power consumption used by the tracker itself, which means more power can be used for primary purposes.

- Advantages

- If appropriately optimized, sensorless solar trackers can increase energy absorption by 20-30% compared to static solar panels. Sensorless solar trackers are more

resistant to external disturbances (bad weather conditions), thus minimizing the maintenance required.
- The reduction in power consumption by the control system increases the amount of clean energy produced by the solar panels.

- Disadvantages

- Without a sensor that directly monitors the sun's position, the accuracy of the tracker's movement angle may not always be optimal, especially on cloudy days or when there is a rapid change in the sun's position, causing a slight decrease in efficiency.
- The system may be less flexible in adjusting to local weather conditions in real time, so it may not always achieve the optimal angle in dynamic conditions.
- The inaccuracy of the algorithm in adjusting the panel angle may reduce some of the benefits of reduced power consumption.

IV. CONCLUSIONS

A. Conclusion

Based on the discussion and research that has been carried out for 6 days where testing per day starts from 09.00 WIB to 15.00 WIB, it can be concluded that the design of solar panel drives following the direction of the sun gets the following results:

1. The tool designed by the researcher, namely the solar panel drive following the sun's direction, can run with an error value of 0%, starting at 09.00 WIB at an angle of 45° to 15.00 WIB at an angle of 90°. The actuator has a movement, which is once every 30 minutes from 09.00 WIB to 15.00 WIB, or 12 movements during the test; in one movement, the actuator takes 9 seconds to reach the required angle, which is 7.5°.
2. The tilt angle of the solar panel that has been tested resulted in an error of 15% on the first day, 0.11% on the second day, and 0.19% on the third day.
3. The total current produced is 9.72 amperes (A) with an average of 0.74 amperes (A). The total voltage generated is 243.1 volts (V) with an average of 18.7 volts (V). The total power produced is 187.6 watts (W) with an average of 14.4 watts (W).

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