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Solar tracker design on solar panel for stm32 microcontroller based on battery charging system

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Abstract. This paper describes about solar energy is one of the energy sources that won't terminated. Solar energy can be easily converted into electrical energy by using solar panels. Solar panels that are placed horizontally on the ground, the solar panel cannot absorb the light perfectly. Therefore, solar panels require an automatic *solar tracking system* to increase the efficiency of the solar panels. In this study, a solar tracker has been designed using a light dependent resistor (ldr) sensor based on the stm32 microcontroller. From the results of the study, the increase in power obtained from the use of a *solar tracker* was 27.97%. In *static solar panels*, the time required to fully charge the 12v, 7ah *lead acid* battery is 5 hours 10 minutes, while using a *solar tracker* the *lead acid* battery *charging time* is 3 hours 30 minutes. The use of a *solar tracker* saves battery charging time for 1 hour 40 minutes compared *to static solar panels.*

1. Introduction

Solar energy is one of the energy sources that won't terminated. And with this energy, we can obtain electrical energy without burning fossil fuels such as oil, gasoline and gas. Solar energy can be easily converted into electrical energy by using solar panels. Solar panels that are placed horizontally on the ground, the solar panel cannot absorb the light perfectly, and also the efficiency of using solar panels is only 14-16% depending on the amount of light absorbed by the solar panels. To get the maximum electric current, the solar panel must always be perpendicular to the incoming light [1]. Therefore, solar panels require an automatic *solar tracking system* that is accurate enough to increase the efficiency of the *solar panels*. This solution requires the right control system, sensors, and motors to make the *solar tracker* movement more accurate. The microcontroller must have the required *software* so that when the weather changes, the controller can quickly change the position of the solar panels [2]

In previous studies, *a two-axis solar tracker* system has been designed using *a light dependent resisto*r (ldr) *sensor* using an arduino uno controller where the *solar tracker* moves according to the direction of the sun, with an increase in efficiency of 10-40% [3]. However, the arduino controller still has drawbacks, namely that it can only perform simple processing, not yet at the stage of high-power efficiency and performance [4].

This research is devoted to making a *solar tracker* by using the stm32 arm cortex-m microcontroller. From the *datasheet* information obtained, this microcontroller has a *clock* frequency ranging from 32mhz to 400 mhz and only requires a voltage of 2-3,6v so that it can be applied to more complex microcontroller systems, high performance and better power efficiency than the ATMega microcontroller or Arduino board.

2. Solar Energy

The sun is a material composed of very hot gas with a diameter of 1.39 x 109 m, and a distance of 1.5 x 1011 m from the earth. The sun has an effective surface temperature of 5762 K. The temperature in the sun's core area ranges from 8x106 - 40x106 K and its density is estimated to be 100 times greater than water. The sun is essentially a continuous fusion reactor with its constituent gases held in place by the force of gravity. The energy emitted by the sun comes from fusion reactions. Energy is produced in the sun's interior and sent to the surface and then radiated out into space.

The sun is the main source for life on earth, the energy produced by the sun in the form of heat energy and light energy is used by living things to meet their needs. Earth receives 175x105 Watts of solar radiation in the outer atmosphere. Approximately 30% of the total radiation is reflected back into space, where the remaining 70% is absorbed by clouds, oceans, and land [5].

2.1. Solar cell principle

Solar panels have a p-n junction working principle, which is a junction between p-type and n- type semiconductors. This semiconductor consists of atomic bonds in which there are electrons as the basic constituent. The n-type semiconductor has an excess of electrons (negative charge) while the p- type semiconductor has an excess of holes (positive charge) in its atomic structure. The following is the working principle of solar cells on Figure 1.

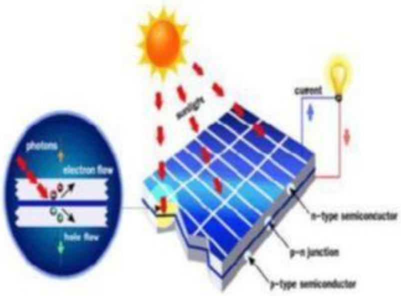

Figure 1. Solar Cell Principle

The condition of excess electrons and holes can occur by doping the material with dopant atoms. When the p-type and n-type semiconductors are in contact, the excess electrons will move from the n-type semiconductor to the p-type so as to form a positive pole on the n-type semiconductor, and vice versa the negative pole on the p-type semiconductor. As a result of the flow of electrons and holes, an electric field is formed which when sunlight hits the p-n junction arrangement it will push electrons to move from the semiconductor to the negative contact, which is then used as electricity, and vice versa the hole moves towards positive contact waiting for the electrons to come.

$$P_{out} = V_{oc} \times I_{sc} \text{ x FF} \quad (1)$$

$$F = \frac{Voc - \ln(Voc + 0,72)}{Voc + 1} \quad (2)$$

$$P_{in} = G \times A \quad (3)$$

$$\eta = \frac{\quad}{Pin} \; x\,100\% \quad (4)$$

$$\eta = \frac{Voc\; xIsc}{G\,x\,A} \; x\,100\% \quad (5)$$

Explanation : P_{out} – solar panel output power (Watt)
P_{in} – solar panel input power (Watt)
η – solar panel efficiency (%)
V_{oc} – open network voltage (V)
I_{sc} – short circuit current (A)
G – solar radiation intensity (W/m^2)
A – solar panel cross-sectional area (m^2)
FF – fill factor based on solar panel material

2.2. Factors that Affecting the Performance of Solar Panels

The main factors that affect the performance of the solar cell panels are [6]:

1. Materials for making solar cell
   Solar panels consist of solar cells which are arranged in series and parallel. The materials for making solar cells also vary, such as [8]:
   a. Crystalline as Cells
   b. Thin film
   c. Multijunction cells
2. Load Resistance
   The battery voltage is the operating voltage of the solar cell panel module, if the battery is directly connected to the solar cell module.
3. Sun light Intensity
   The greater the proportion of sunlight will produce a large current, but moving downwards which indicates a decrease in current and power.

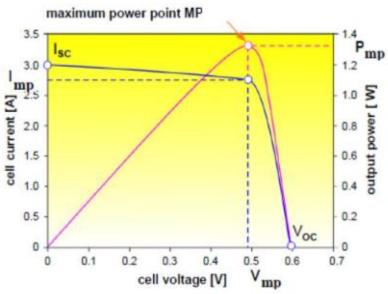

Figure 2. The relationship between solar radiation intensity and output power

4. Orientation and Tilt of panels or PV Arrays The orientation of the PV series (array) towards the sun is optimally important so that the PV panels / series can produce maximum energy.

2.3. Solar tracker

Solar Tracker is a combination of a system that is capable to detect and follow the direction of the sun in order to maximize the reception of solar energy. This solar tracker will be applied to photovoltaic or solar panels. The purpose of providing tracking on photovoltaic is in order to optimize the output of PV. The more perpendicular the PV is to the sun, the greater the output power generated every day. The electrical energy produced will increase when compared to static solar panels. The solar tracker consists of several important components such as sensors, controllers, motors, batteries, and photovoltaics.

2.4. LDR (Light Dependent Resistant)

LDR is an electronic component that has a resistance that can change according to changes in light

Figure 3. Construction form and schematic drawing of LDR sensor

2.5. Microcontroller STM32 ARM Cortex-M

STM32 ARN Cortex-M is a microcontroller produced by STMicroelectronics with a 32-bit RISC (Reduced Instruction Set Computer) processor. The STM32 microcontroller was developed by the Advanced RISC Machine (ARM) which was formerly known as the Acorn RISC Machine. There are several series of ARM Cortex processors from those that have simple functions to currently widely used in smartphones ranging from the smallest series of ARM Cortex-M, ARM Cortex-R to ARM Cortex-A. There are also ARM secure core and ARM Machine Learning series. The RISC architecture consists of the same large register file, loading and saving architecture, simple addressing modes and the same length instruction fields. Because of these characteristics ARM has high performance, simple code, low power consumption and small size. ARM can execute an instruction set called Thumb which consists of 32-bit to 16-bit instructions. Therefore, 16-bit and 32-bit instructions can be combined without affecting processor performance.

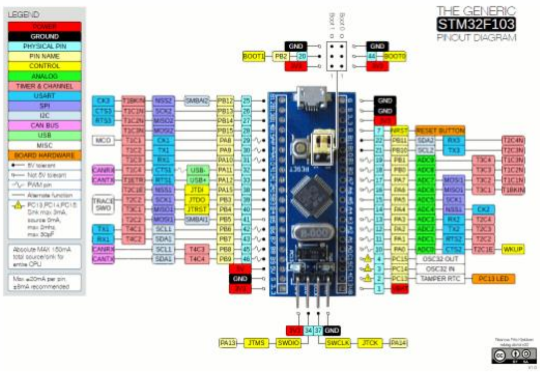

Figure 4. STM32 construction

2.6. Linear actuator

By controlling the voltage level, it is also possible to control the position and speed of the linear actuator in Figure 5 [15].

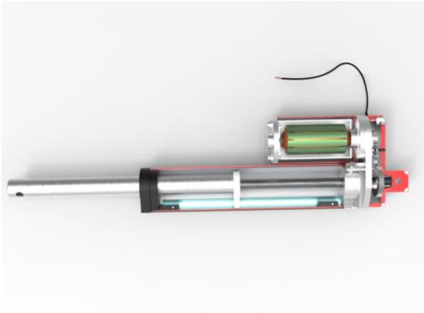

Figure 5. Linear actuator construction

2.7. Solar charge controller

Solar Charge Controller is an electronic circuit that regulates the process of charging the battery or battery circuit. The main component in a solar charge controller is the Buck Regulator.

In buck regulators, the average output voltage Va, is less than the input voltage-Vs., so the name "buck" has become a popular regulator. The circuit diagram of a buck regulator using a BJT is shown in Figure 6.

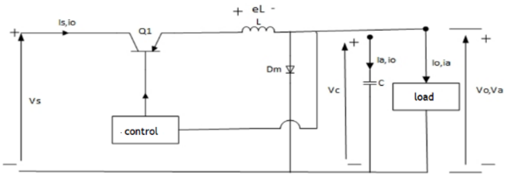

Figure 6. Buck Regulator

2.8. Batteries

Batteries are devices that contain electrical cells that can store electrical energy that can store energy that can be converted into power. Batteries generate electricity through chemical processes on Figure 7.

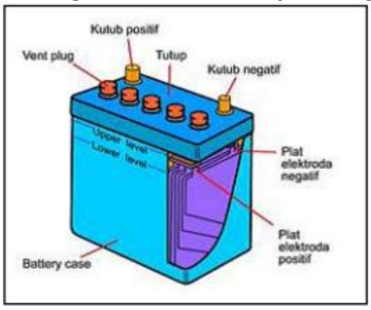

Figure 7. Batteries Construction

3. Research Methods

In this research that aims to produce a battery charging system using Solar Panel Tracking with the STM32 ARM Cortex-M microcontroller, several stages of the research method are used as follows with the research flow shown in Figure 8.

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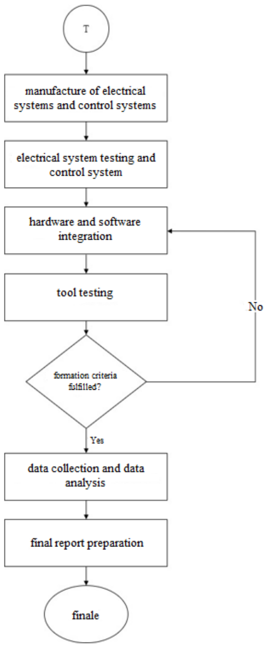

Figure 8. Research Path

3.1. Design of Solar Tracking and Battery Charging System

The equipment used in the design are:

a. The microcontroller circuit used is the STM32 ARM Cortex-M. Microcontroller
b. Using 2 Linear Actuators as the main driver of the solar tracker.
c. The main energy source is the Solar Panel type SP-80-P36 with a maximum power of 80-Watt peak (WP). Watt Peak is the highest unit of power that can be produced by solar panels under standard conditions, namely radiation (E) equal to 1000 W/m2, air mass (AM) equal to 1.5 and temperature 25°C.
d. The study was conducted using lead acid batteries with specifications 12V, 7AH.
e. The Solar Charge Controller used uses the principle of the Buck DC-DC Converter electronic circuit.
f. The research was conducted on the 4th floor of the Department of Electrical Engineering, University of North Sumatra.
g. Solar tracker design is made in accordance with the block diagram that can be seen on Figure 9.

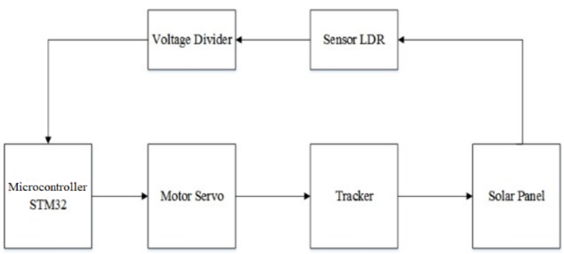

Figure 9. Tool Design Diagram Block

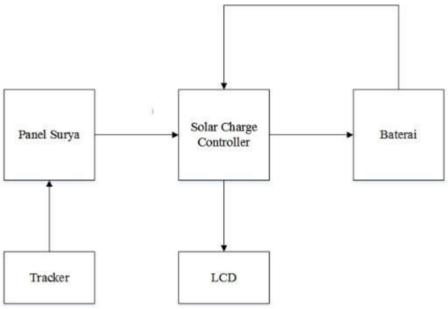

Figure 10. Battery charging system block diagram

Data retrieval in the form of current, voltage, solar panel output power and battery-charged capacity can be done when the tool has been completed.

3.2. Arduino IDE program development

At this stage, a program is made that will be entered on the STM32 microcontroller which will control the entire system of the tool automatically.

The procedure in programming in the IDE is to determine the program algorithm which includes how the tool will work, sketch the program, compile it, choose the communication path, and upload the program. The procedure carried out is as follows on Figure 11 and 12.

1. Writing program instructions
2. Program Saving
3. Installing type board STM32
4. Installing driver ST-Link
5. the type of board to the system used by clicking Tools – Board – “Generic STM32F1 series”
6. Set port on ST-Link option
7. Perform compilation (verify) to check the results of the program
8. Upload the program

Figure 11. Arduino IDE program development

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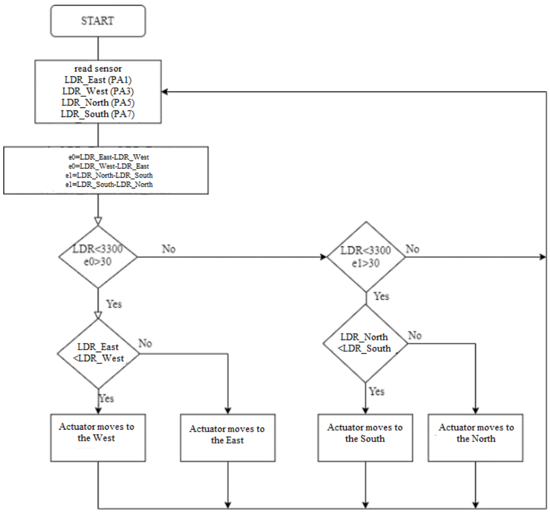

Figure 12. Flowchart solar tracker

3.3. Mechanical system manufacturing

At this stage, the authors utilize the existing solar tracker framework in the Power System Analysis Laboratory and then modify it to fit the expected tracker working principle. The mechanical framework of this system can be seen in Figure 13.

Figure 13. Solar tracker framework

The mechanical frame is then connected to two hydraulic dc motors, each of which moves on the azimuth and zenith axes as shown in Figure 14.

Figure 14. Solar tracker framework after modification

3.4. Electrical system manufacturing

The electrical system is needed to connect the controller and actuator so that the system can work properly. There are several electrical systems used in the manufacture of this solar tracker, including:

1. Power supply
2. LDR Sensor Circuit
3. Signal Conditioning Circuit
4. DC motor drivers

The workflow of the electrical system can be seen in Figure 15.

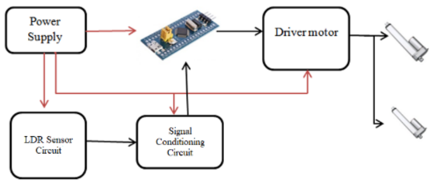

Figure 15. Solar tracker electrical system

The working principle of this system is to compare the readings of the four LDR voltage values. The LDR sensor is a type of resistor whose resistance value depends on the intensity of the light it receives. The resistance value will decrease when the light is bright and the resistance value will be high when it is dark. In other words, the LDR sensor functions to deliver electric current if it receives a certain amount of light intensity and inhibits electric current in dark conditions. The LDR sensor will read the resistance value based on the intensity of the sunlight it receives. Then the microcontroller will read the voltage value on the resistance (RV1.RV2, RV3, RV4) which functions as a voltage divider that is connected in series with the LDR sensor (resistance source). This voltage is used as a microcontroller input. Microcontroller is a semiconductor component in which there is a microprocessor system such as the Arithmetic and Logic Unit (ALU), memory, and input/output devices. To be able to run commands, the microprocessor requires code or machine language code that is used as a medium of communication between the programmer and the machine. After being understood by the machine through the program compile process, the microcontroller will process the input voltage and compare the input voltage value according to the program that has been made. However, the microcontroller cannot directly drive the motor, therefore a DC motor driver is used to take over the task of the microcontroller as a motor drive. The output of the microcontroller which is the input for the driver is in the form of signals 0 and 1. The motor driver is an electronic circuit that functions to supply the current used by an electronic device. The driver circuit used is type L298 with an H-bridge circuit. It is called an H bridge because the principle of disconnecting and connecting an electric motor with four transistors that resembles the letter H. The motor driver works based on the input signal given by the microcontroller, namely 0 and 1. If the motor driver input 1 is 1 and input 2 is 0, then actuator 1 will move vertically up, but if input 1 is 0 and input 2 is 1, the actuator will move vertically down. Likewise for the actuator 2 input settings. Thus, the LDR sensor will continuously track the greatest intensity of sunlight until it reaches a condition where the 4 microcontroller input voltages have the same value. If the values of the four sensors are the same, it can be concluded that the solar panel is in a position perpendicular to the sun and the motor will stop moving. Linear actuators are positioned to regulate 2 different directions. Actuator 1 is to regulate the vertical movement of the solar panels and Actuator 2 is to regulate the horizontal movement of the solar panels.

The illustration of the movement of this system is depicted when the sun is in position, then actuator 1 will move up vertically until it reaches its setpoint. After that, actuator 2 will move to adjust horizontally until it reaches the four LDR voltages of the same value.

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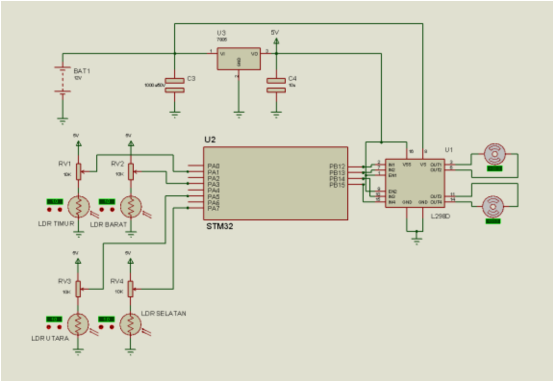

Figure 16. Solar tracker system

4. Results and Discussion

4.1. Static Solar Panel Test

This test is carried out to observe the output of the Solar Panel in the form of DC voltage and DC current, while the power is obtained by multiplying the current and voltage. At the time of testing, measurements were also made of the intensity of solar radiation, ambient temperature, and the intensity of sunlight. The test is carried out in a state of the solar panel parallel to the ground surface. Table 4.1 shows data collection in the form of solar panel output currents and voltages.

Table 1. Result

JAM (WIB)	TEGANGAN (V)	ARUS (A)	DAYA (W)	SUHU (°C)	INTENSITAS RADIASI MATAHARI (W/m2)	INTENSITAS CAHAYA MATAHARI (Lux)
10.30	14.08	2	37	30.42	155.6	42000
10.45	14.10	2.08	29.23	31.74	479.4	44000
11.00	14.01	1.22	17.09	31.64	529.4	35600
11.15	13.76	1.02	45.19	31.92	501.9	43000
11.30	13.92	1.55	32.95	31.66	168.1	37200
11.45	15.83	2.3	19.67	32.38	204.4	15900
12.00	15.08	2.08	39.28	32.92	628.1	43100
12.15	14.49	1.02	22.41	31.89	155.6	14000
12.30	14.47	1.02	22.72	32.61	511.9	22100
12.45	16.27	0.89	22.28	32.10	288.1	26500
13.00	17.37	0.78	26.17	32.43	393.1	34800
13.15	19.64	0.66	22.09	33.44	203.1	14100
13.30	19.20	0.67	14.11	32.67	196.9	15900
13.45	19.36	0.73	21.98	31.64	133.1	8000
14.00	17.75	1.1	14.43	32.20	196.9	11200
14.15	17.29	1.01	12.70	31.79	143.1	9000
14.30	17.66	1.02	13.39	31.79	168.1	12200
14.45	18.05	1.1	10.16	31.26	69.4	5000
15.00	14.27	0.50	7.14	31.23	58.1	7000

Based on Table 1, it is found a graph of changes in the intensity of solar radiation against time at the time of data collection.

Data regarding ambient temperature, voltage and current output of solar panels. The graph of the relationship and influence of temperature on the current and output voltage of the solar panel can be seen in Figure 17 and 18.

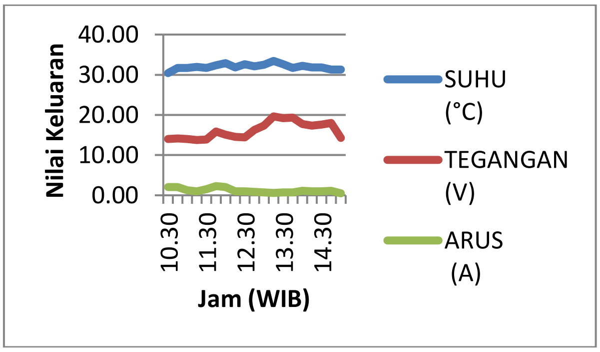

Figure 17. Temperature, voltage and current graph

From the observations, the current and voltage obtained from the solar panel output, which means we can calculate the solar panel output power. The solar panel output power data table is shown in Table 1.

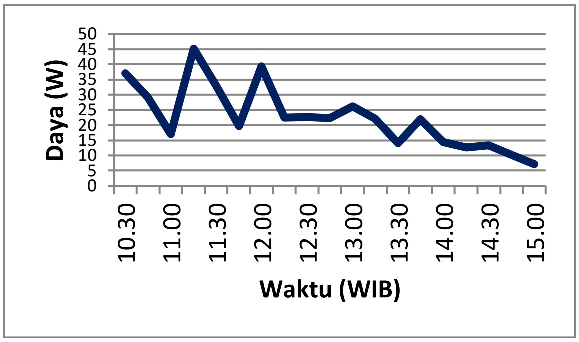

Figure 18, Power-to-time graph

4.2. Testing with solar tracker

The results of the tests and observations can be seen in Table 2.

Table 2. Results of the tests with solar tracker

WAKTU (WIB)	TEGANGAN (V)	ARUS (A)	DAYA (W)	Intensitas Radiasi Matahari (W/m2)	SUHU (°C)	INTENSITAS MATAHARI (Lux)
10.30	17.63	2.61	46.01	546.9	31.74	44600
10.45	18.35	1.88	14.21	238.1	31.84	43400
11.00	14.10	2.07	29.19	621.9	32.02	41800
11.15	14.85	3.13	46.48	369.4	31.33	43900
11.30	15.56	4.15	64.57	616.9	32.59	41200
11.45	13.84	1.02	51.82	145.6	31.20	13200
12.00	16.95	3.11	52.71	143.1	32.00	48600
12.15	14.23	1.07	15.23	564.4	32.67	12200
12.30	14.80	1.88	27.82	159.4	32.90	19500
12.45	15.49	1.74	26.95	235.6	31.89	21300
13.00	16.28	1.56	25.40	168.1	31.59	34200
13.15	15.2	1.47	22.34	203.1	32.85	14100
13.30	17.09	1.42	24.27	249.4	32.05	14400
13.45	15.57	1.01	15.73	199.4	32.07	7200
14.00	17.36	1.04	18.05	153.1	31.82	14000
14.15	17.03	1.02	17.37	148.1	31.89	11000
14.30	16.46	1.02	16.79	173.1	32.33	12300
14.45	18.42	1.55	28.55	188.1	31.82	5000
15.00	14.07	0.49	6.89	121.9	31.26	4000

Table 2 above shows the data taken with the solar panel tracking system. Testing is carried out from 10.30WIB-15.00WIB on the 4th floor of the Electrical Engineering Masters building.

In Table 2, the ambient temperature, voltage and output current of the solar panel have been obtained using a tracking system. Thus, the output power generated by the solar panels can also be calculated. The graph of changes in temperature, current and voltage can be seen in Figure 19.

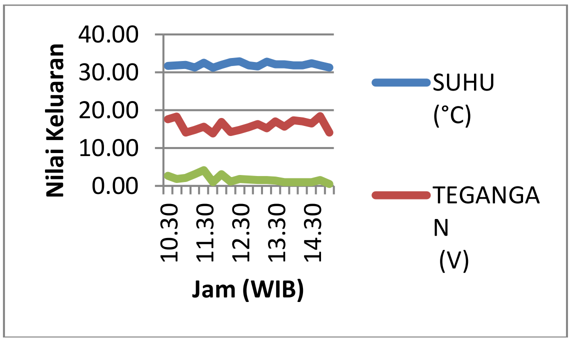

Figure 19. Temperature, voltage and current graph

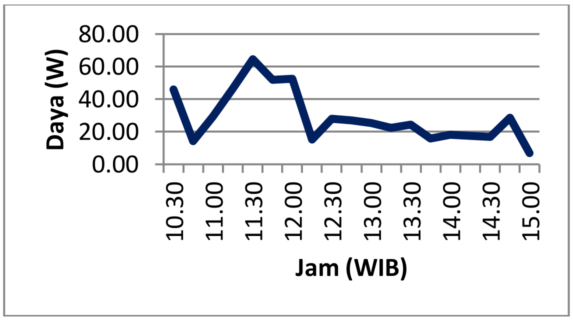

Figure 20. Power-to-time graph

Figure 19 shows that at 10.30 WIB - 10.45 WIB there is a decrease in the output power of the solar panels.

4.3. Power comparison of static tracker and tracking system

After the intensity of sunlight received by the solar panel, the output power of the solar panel must also be compared to determine the efficiency of using a solar tracker based on the output power of the solar panel. Tracker power data can be seen in Table 3.

Table 3. Comparison of static solar panel power and using a solar tracker

WAKTU (WIB)	DAYA STATIC (W)	DAYA TRACKER (W)
10:30	37	46.01
10:45	29.33	14.21
11:00	17.09	29.19
11:15	45.19	46.48
11:30	32.95	64.57
11:45	19.67	51.82
12:00	39.28	52.71
12:15	22.41	15.23
12:30	22.72	27.82
12:45	22.28	26.95
13:00	26.17	25.40
13:15	22.09	22.34
13:30	14.11	24.27
13:45	21.98	15.73
14:00	14.43	18.05
14:15	12.70	17.37
14:30	13.39	16.79
14:45	10.16	28.55
15:00	7.14	6.89
Daya rata-rata	22.63	28.96

4.4. Comparison of battery charging time

From Table 4, it can be seen that using a tracking system can save 1 hour 40 minutes of time to charge a 12 V, 7Ah lead acid battery. The time efficiency can be calculated in the following way.

Table 4. Comparison of Time

WAKTU (WIB)	KAPASITAS TERISI BATERAI (Ah) TANPA TRACKER	KAPASITAS TERISI BATERAI (Ah) MENGGUNAKAN TRACKER
10.30	0.00	0.00
10.45	0.35	0.90
11.00	0.83	1.63
11.15	1.10	1.98
11.30	1.47	2.83
11.45	2.01	3.12
12.00	2.50	3.77
12.15	2.92	4.22
12.30	3.15	4.77
12.45	3.42	5.22
13.00	3.61	5.65
13.15	3.80	6.12
13.30	3.95	6.42
13.45	4.08	6.73
14.00	4.39	7.00
14.15	4.66	7.00
14.30	4.93	7.00
14.45	5.18	7.00
15.00	5.56	7.00
15.40	7.00	7.00

$$time\ efficiency = \left|\frac{charging\ time\ tracker - charging\ time\ static}{charging\ time\ static}\right| x100\% \tag{6}$$

$$time\ efficiency = \left|\frac{210\ minute - 310\ minute}{310\ minute}\right| x100\% \tag{7}$$

$$time\ efficiency = 32{,}25$$

5. Conclusion

Based on the results of the study, it could be concluded that the design of the solar tracker system using the STM32 microcontroller with LDR sensor has been successfully carried out with the average power produced by a static solar panel is 22.63 W, while the average power generated by a solar panel using a solar tracker is 28.96 W and the increase in power generated by solar panels with a solar tracking system is 27.97%. While charging the 12V,7Ah lead acid battery takes 5 hours 10 minutes to fully charge 7Ah using a static solar panel, and using a solar panel with a tracking system the battery can be fully charged for 3 hours 30 minutes. So, the use of solar panels with a tracking system saves 1 hour 40 minutes or

32.25% of the time required for a static solar panel to fully charge a 12V,7Ah lead acid battery. Based on the conclusions, it can be suggested to pay attention to the placement of the solar tracker, because the placement of the solar tracker greatly affects the movement of the tracker and for development, it is very important to use the Internet of things to monitor the movement of the solar tracker.

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