www.bircu-journal.com/index.php/birci
Budapest International Research and Critics Institute-Journal (BIRCI-Journal)
Humanities and Social Sciences
ISSN 2615-3076 Online)
ISSN 2615-1715 (Print)

Design and Build a Sun Tracking System Using a Fuzzy Logic Controller to Optimize the Output Power of the Solar Cell Module

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Abstract

The solar cell module is an electric device that can convert sunlight energy to electric energy directly. Some matters cause solar cell module produceselectric energy unoptimally. One of the problem is position of solar cell module is not vertically coming through the sunlight. This problem is caused by daily earth rotation and yearly earth surrounding the sun. Major Topics of this research are producing a fuzzy logic controlling system so that orientation of solar cell module always follows position of sun periodically. And then comparing power of solar cell module which using controlling system to power of solar cell module which in static orientation. Result of this research, controlling system using fuzzy logic controller is produced, for controlling orientation of solar cell module follows sun position, with error about 4.270, so that power of this solar cell module is higher 10.8% than power of static solar cell module. Average power of static solar cell module is about 2,957 watts, and the energy is about 23,656 watt hour. Else power of dynamic solar cell module is about 3,276 watts, and the energy is about 26,208 watt hour.

Keywords
solar cell module; sun position; fuzzy logic controller; power

I. Introduction

The solar power plant is one of the renewable energy power plants, so it is very good to be developed to meet the increasing demand for electrical energy, especially in Indonesia. This power plant with the initial energy source of sunlight is very well developed in Indonesia because Indonesia is geographically located in the equator.

The main device for generating solar energy is a solar cell module, a solar cell module is a combination of a number of solar cells whose function is to directly convert light energy into electrical energy. The amount of electrical energy produced by the solar cell module is influenced by the intensity of sunlight captured by the solar cell module. The greater the intensity of light received by the solar cell module, the greater the electrical energy produced. One way to get optimal light intensity is to adjust the position of the solar cell module so that it remains perpendicular to the direction of the sun.

The daily cycle of the earth's rotation causes the sun's orientation from east to west which is called sunrise and sunset. The existence of the annual cycle of the earth's evolution towards the sun causes a shift in the position of the trajectory from sunrise to sunset, namely the tilt of the sun's trajectory position towards north or south a maximum of 23.50. The existence of these two phenomena causes the position of the sun to always change, therefore the orientation of the solar cell module must be able to follow the position of the sun to produce more optimal electrical energy.

Setting the direction of the solar cell module according to the sun's position can be done manually by shifting it periodically by an operator. If viewed from the efficiency of energy and time, this method is less effective, so it is necessary to build a system to adjust the direction of the solar cell module to the orientation of the sun automatically.

There are many methods of setting the direction or orientation of the solar cell module automatically that can be developed, one of which is the application of fuzzy logic controller to the orientator. By applying the fuzzy logic method, it will be easier to control the steering device to adjust the orientation of the solar cell module to the sun's position so that a more optimal conversion of electrical energy is obtained.

Goals and Contribution

1. To find out how the effectiveness and performance of the application of fuzzy logic control system as a guide for solar cell modules.
2. To get a comparison of the energy output of the solar cell module with a dynamic position using a control system for the energy output of the solar cell module with a static position.
3. To prove that the energy produced by the solar cell module is more optimal if the direction is perpendicular to the position of the sun.
4. After the research objectives are achieved, it is hoped that they can contribute in the form of a technical consideration for the community in planning and developing solar power plants.

II. Review of Literature

2.1 Solar Cells (Photovoltaic)

A solar cell (photovoltaic) is a semiconductor device where the absorption of sunlight will cause electric charges. Here the energy of sunlight is converted directly into electrical energy by dropping sunlight on the boundary of two kinds of semiconductor materials that exist in a solar cell element. [4]. To get the best possible solar energy, solar cells must be directed perpendicular to the sun's rays. To achieve this condition, the following relationship is used:

$$Am = \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)\ \frac{1}{\cos(\theta + \varphi)}$$

Where:

Am = the ratio of the irradiated area to the effective area with respect to the sun.
Θ = latitude angle (degrees)
φ = angle determined by the changen relative position of the sun [4]

2.2 Light Dependent Resistor (LDR)

LDR is a light sensitive resistor, where the LDR resistance value can vary, following changes in the intensity of light received by the LDR surface. If the light intensity decreases, the LDR resistance value increases, and vice versa if the light intensity increases, the LDR resistance value decreases.

2.3 Analog to Digital Converter (ADC)

ADC is an electronic component that functions to convert analog quantities into digital quantities. This component is absolutely necessary when the microcontroller is connected to a temperature sensor, pH, light and so on, each sensor produces an analog output, while the data that can be read by the microcontroller is only digital. Therefore, an ADC is needed to convert the analog output into digital quantities which will then be processed by the microcontroller

2.4 Microcontroller AT 89S51

Microcontroller is a chip that functions as an electronic circuit controller and generally can store programs in it. [5] The microcontroller has integrated central processing unit (CPU), ROM, RAM and I/O (input/output) devices. The following Figure 2-10 shows a block diagram of the AT89S51 IC architecture. Development of a wireless leak detection system using various sensors and microcontrollers that make the system Portable and nondestructive techniques. In this system parameters such as Humadity, temperature, pressure, sound detection around gas leaks are detected using sensors and microcontrollers (Adsul in Evalina et al, 2020).

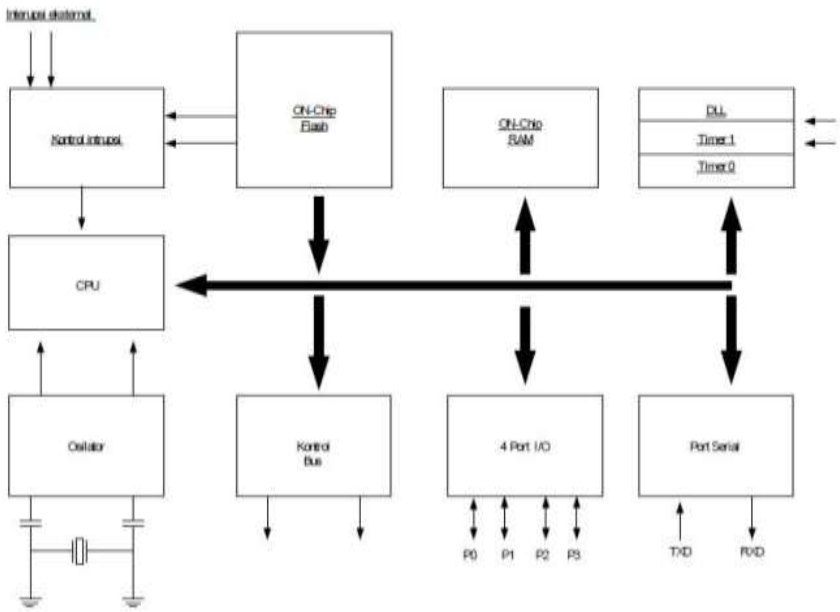

Figure 1. *AT 89S51 IC architecture block diagram. [5]*

2.5 DC Motor

A direct current electric motor is an electrical device that functions to convert direct current electrical energy into kinetic energy (mechanical rotary motion, rotation). [4] To reverse the direction of rotation of the motor, it can be done by reversing the polarity of the power supply. It is simply shown in Figure 2.

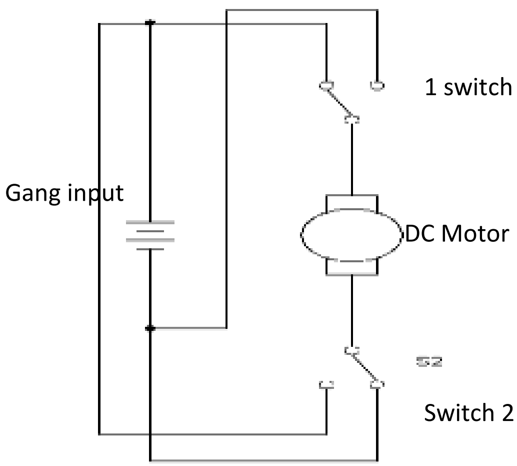

Figure 2. *Setting the direction of rotation using the SPDT switch*

2.6 Fuzzy Logic (Fuzzy Logic)

In general, fuzzy logic is a counting methodology with variable words (linguistic variables). Instead of counting with numbers. Words are not as precise as numbers, but they are closer to human intuition. Humans can immediately feel the value of the variable words that they use everyday. Thus fuzzy logic gives space and even exploits the tolerance for inaccuracy. Fuzzy logic requires lower costs in solving various fuzzy problems.[1]

a. Fuzzyfication

Fuzzyfication process is a process to change non-fuzzy variables (numeric variables) into fuzzy variables (linguistic variables). The input value which is still in the form of a numerical variable that has been quantized before being processed by the fuzzy logic controller must first be converted into a fuzzy variable. Through the membership function that has been compiled, the input values become fuzzy information which is useful later for fuzzy processing as well. This process is called fuzzyfication. [1]

b. Knowledge Base

Knowledge base has an important function in controlling with fuzzy logic because all processes: fuzzification, inferenceand defuzzificationwork based on existing knowledge in the knowledge base. Knowledge base is divided into two, namely data base and rule base. The data base contains important definitions of fuzzy parameters such as fuzzy sets with defined membership functions for each linguistic variable. The formation of the data base includes defining the universe space, determining the number of linguistic values used for each linguistic variable, and forming a membership function. The rule base contains fuzzy control rules that are executed to achieve control objectives. Each control rule is an implication and conditional statement **IF** –**THEN.** [2]

c. Inference

Inference is a transformation process from an input in the fuzzy domain to an output (control signal) in the fuzzy domain. The transformation process in the inference section requires fuzzy rules contained in the rule bases. The inference block uses reasoning techniques to select rule bases and rules from the knowledge base block. [2]

d. Defuzzification

To change the crisp value of the fuzzy quantity, a defuzzification process is needed. The process is the conversion of fuzzy values into crisp values required by the actuator or controller. This process is very important to produce the crisp price required by the system. Fuzzy values are only needed in the fuzzy solution process. The defuzzification process depends on the fuzzy set output generated by fuzzy rules. [3].

III. Research Methods

3.1 System Block Diagram

The concept of system design and the relationship between sub-systems is shown in Figda block block diagram, figure 3.

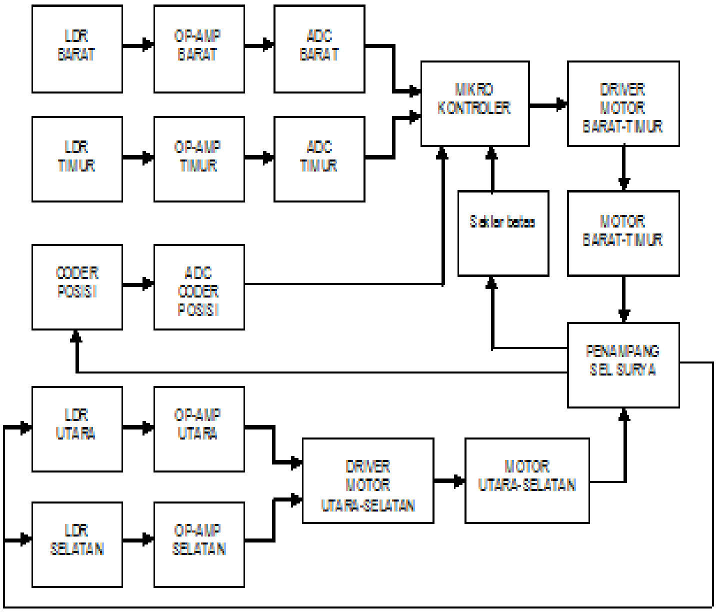

***Figure 3**. Block diagram of the system*

3.2 Flowchart

In order to facilitate the implementation process of both hardware and software, in addition to block diagrams, a flowchart is necessary to form, which describes how the expected working conditions of the system will be. Figure 4 below is a flowchart for east-west motor control.

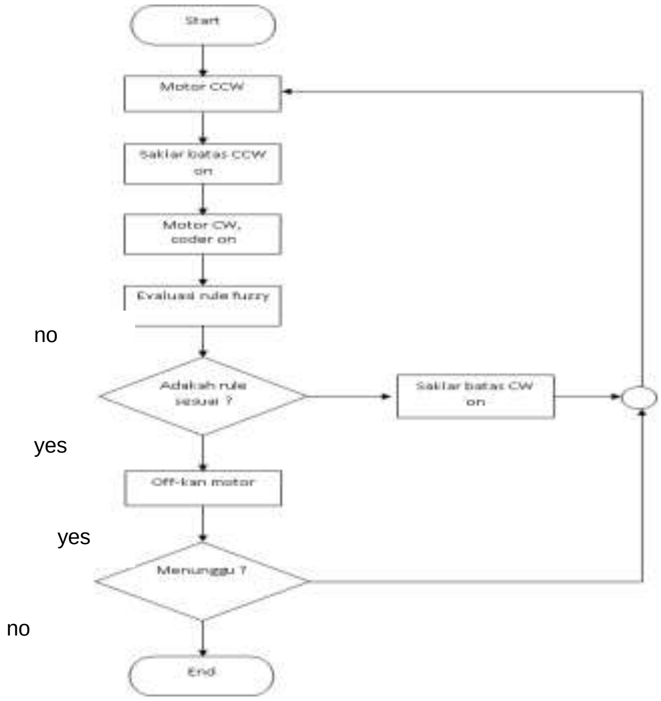

***Figure 4**. Flow diagram of the east-west motor control system.*

3.3 General Design Principles

The west and east LDRs act as sensors to detect the sun's position in the west or east based on the intensity of the light it receives. Variations in light intensity are converted into voltage variations to be forwarded to the op-amp circuit. The op-amp circuit performs amplification as needed. The output of the op-amp is analog, in the range of 0 volts DC to 5 volts DC. By the ADC analog quantities are converted into digital codes (binary), because the microcontroller can only read digital codes. Furthermore, digital codes (high-low) are sent to the microcontroller to be processed according to the rules programmed on the microcontroller. The microcontroller acts as the main control center that will send a digital signal to the east west motor driver. The signal received by the motor driver circuit is in the form of digital codes to regulate the performance of the motor turning right (CW), turning left (CCW) and turning off. The driver circuit is the last circuit to control the motor. The results of the operation of a DC motor that moves CW or CCW, in the form of an east-west cross section in the range of 50 to 1750 from the support. The cross-sectional position is read by a marker (coder). The results of the reading of the marker (coder) are still in the form of analog quantities, then need to be converted into digital codes by the ADC. The work of the ADC coder is forwarded to the microcontroller for further processing. in the form of an east-west cross section in the range of 50 to 1750 from the support. The cross-sectional position is read by a marker (coder). The results of the reading of the marker (coder) are still in the form of analog quantities, then need to be converted into digital codes by the ADC. The work of the ADC coder is forwarded to the microcontroller for further processing. in the form of an east-west cross section in the range of 50 to 1750 from the support. The cross-sectional position is read by a marker (coder). The results of the reading of the marker (coder) are still in the form of analog quantities, then need to be converted into digital codes by the ADC. The work of the ADC coder is forwarded to the microcontroller for further processing.

The cross-sectional positioning system in the north-south direction is designed to be simpler than the east-west controller. This is because the position of the sun to the north or south is only a maximum of 23.5^0, And it happens every six months. A light sensor in the form of an LDR is still needed to map the position of the sun in the north or south. After being amplified by the op-amp, the output signal with a maximum voltage of 5 Volt DC is forwarded to the north-south motor controller circuit, to set the DC motor to move CW or CCW, and goes out. The rotation of this DC motor causes a change in the direction of the cross section to the north or south

3.4 East and West Censors

LDR (Light Dependent Resistor) is a variable resistor, where the resistance value varies depending on the intensity of the light it receives. The greater the intensity of the light received, the smaller the resistance, and vice versa. Based on these characteristics, the LDR can be applied as a light sensor that can map the position of the sun based on the strength of the light it receives.

The east and west sensor system designs are depicted in Figure 5.

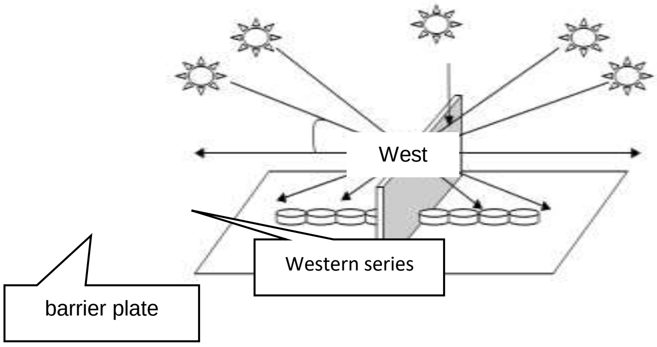

Figure 5. *Design of east and west sensor systems*

Four LDRs are connected in series, one each for the east and west LDRs. (see figure 6)

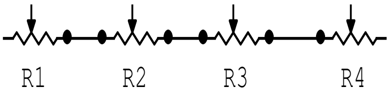

Figure 6. *LDR series relationship*

The four LDRs will form a total resistance of:

Total resistance = R1 + R2 + R3 + R4

By placing the limiting plate, it is hoped that this sensor system can map the position of the sun based on the fall and the length of the shadow of the barrier plate that covers the sensor surface. Suppose the shadow of the boundary plate covers the east sensor, meaning that the sun's position is in the west. The more to the west of the sun's position, the shadow of the plate will be longer or the surface area of the eastern sensor that is closed, if the surface area of the sensor is closed, the higher the total resistance value. The variation of the sensor resistance value as a result of variations in the sun's position is used as a reference to regulate the overall system performance.

3.5 Fuzzy System Design

The main component of this control system is the microcontroller at 59s51. Fuzzy rules are written in C/C++ language. Then converted into *.hex files and entered into the memory of the microcontroller

The fuzzy rule base as an If-Then function is as follows:

IF sensor is bright east AND sensor is bright west THEN motor rotates moderately
IF the east sensor is bright AND the west sensor is a bit bright THEN the motor spins a lot
IF the east sensor is bright AND the west sensor is dim THEN the motor rotates very far
IF the east sensor is light AND the west sensor is a bit dark THEN the motor is very far away
IF sensor light east AND sensor dark west THEN motor rotates maximum
IF the east sensor is a bit bright AND the west sensor is bright THEN the motor rotates close
IF the east sensor is a bit bright AND the west sensor is a bit bright THEN the motor rotates moderately
IF the east sensor is a bit bright AND the west sensor is dim THEN the motor spins a lot
IF the east sensor is a bit light AND the west sensor is a bit dark THEN the motor rotates very far

IF the east sensor is a bit light AND the west sensor is dark THEN the motor rotates very far
IF east sensor is dim AND west sensor is bright THEN motor rotates very close
IF the east sensor is dim AND the west sensor is a bit bright THEN the motor rotates close
IF east sensor is dim AND west sensor is dim THEN motor is rotating moderately
IF the east sensor is dim AND the west sensor is a bit dark THEN the motor spins far
IF the east sensor is dim AND the west sensor is dark THEN the motor rotates very far
IF the east sensor is a bit dark AND the west sensor is bright THEN the motor rotates very far
IF the east sensor is a bit dark AND the west sensor is a bit light THEN the motor rotates very far
IF the east sensor is a bit dark AND the west sensor is dim THEN the motor spins far
IF the east sensor is a bit dark AND the west sensor is a bit dark THEN the motor rotates moderately
IF east sensor is a bit dark AND west sensor is dark THEN motor rotates close
IF sensor dark east AND sensor light west THEN motor rotates maximum
IF the east sensor is dark AND the west sensor is a bit bright THEN the motor is very far away
IF sensor dark east AND west sensor dim THEN motor rotates very far
IF the east sensor is dark AND the west sensor is a bit dark THEN the motor spins far
IF sensor dark east AND sensor dark west THEN motor rotates moderately

IV. Results and Discussion

4.1 Mechanical System Testing

Mechanical system testing is done by assembling all sub-systems, which consist of power supply, sensors, coder, op-amp, ADC, microcontroller, motor and mechanical devices. Tests were conducted throughout the day from 8.30 to 16.30. in sunny conditions. The purpose of this test is to compare the orientation (direction) of the solar cell module to the position of the sun. The test results are shown in table 1 and Figure 7 below.

Table 1. Mechanical system test results.

No	Hour	Sun position Eastward (0)	shadow (cm)		Position of the cross section on the support (0)	Difference (0)
			brt	tmr		
1	8.30	38.6	2.5	0	30	8.6
2	9.00	41.6	2.25	0	30	11.6
3	9.30	53.1	1.5	0	50	3.1
4	10.00	57.9	1.25	0	55	2.9
5	10.30	63.4	1	0	70	6.6
6	11.00	75.9	0.5	0	82	6.1
7	11.30	82.8	0.25	0	90	7.2
8	12.00	87.1	0.1	0	90	2.9
9	12.30	90	0	0	90	0
10	13.00	87.1	0	0.1	90	2.9
11	13.30	97.2	0	0.25	100	2.8
12	14.00	104.1	0	0.5	100	4.1
13	14.30	116.6	0	1	120	3.4
14	15.00	122.1	0	1.25	120	2.1
15	15.30	126.9	0	1.5	130	3.1
16	16.00	138.4	0	2.25	140	1.6
17	16.30	141.4	0	2.5	145	3.6

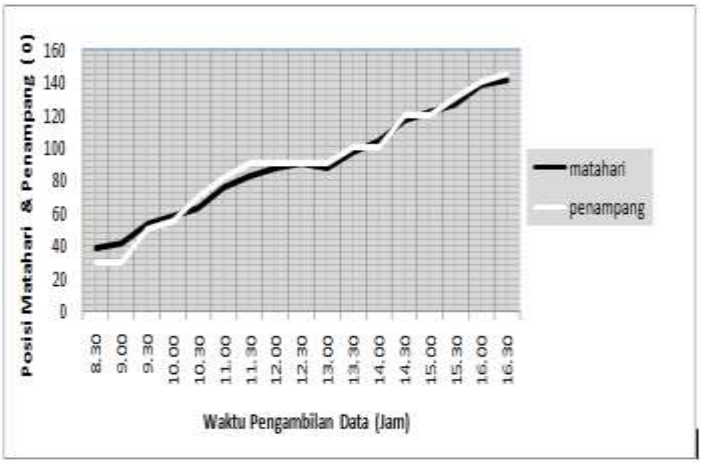

Figure 7. *the comparison of the position of the sun to the position of the cross section*

Table 1 and Figure 7 above show that the control system can adjust the direction of the cross section to the position of the sun. The test results also show a slight difference, a maximum of 11.60, the average difference of 4.270. The existence of differences is a natural thing to happen. These differences can be caused by several factors, including the accuracy of the measuring instrument, the tolerance of the potentiometer coder and other electronic components, the rotating moment of the motor, the delay time of the relay on the motor driver, human error, and the characteristics of the fuzzy logic control system itself.

Voltage, Current and Power Calculation

This test is carried out by measuring the no-load voltage, load voltage, and load current, and then power will be obtained. Measurements were made on two solar cell modules with the same specifications. One module is placed on a flat plane with the direction of the surface of the solar cell module facing upwards, while the other solar cell module is placed on a mechanical device, to follow the position of the sun.

The test results for solar cell modules with static orientation are shown in table 2 and figure 8

Table 2. The results of measuring voltage, current and power calculations from static solar cell modules

no	Hour	VOC (V)	VLoad (V)	iLoad (mA)	PLload (count) (W)
1	8.30	17.2	16	150	2.56
2	9.00	17.5	16.5	161	2.7225
3	9.30	18.35	17.16	164	2.944656
4	10.00	18.35	17.3	166	2.9929
5	10.30	18.4	17.35	168	3.010225
6	11.00	18.46	17.5	170	3.0625
7	11.30	18.5	17.7	171	3.1329
8	12.00	18.7	17.85	172	3.186225
9	12.30	19.1	18.17	173	3.301489
10	13.00	18.8	17.6	168	3.0976
11	13.30	18.6	17.55	167	3.080025
12	14.00	18.5	17.5	165	3.0625
13	14.30	18.4	17.3	163	2.9929
14	15.00	18.3	17.2	160	2.9584

15	15.30	18.2	17	158	2.89
16	16.00	17.5	16.5	155	2.7225
17	16.30	17	16	152	2.56

Graphically the power value is shown in Figure 8.

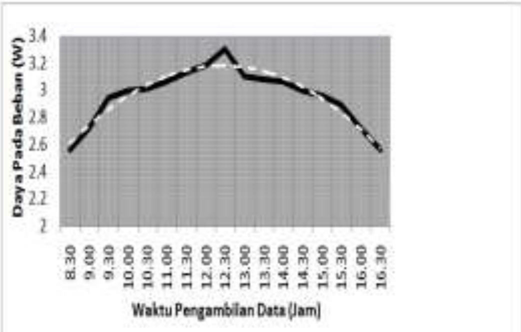

Figure 8. *Graph of power on load (PLoad) of static position solar cells*

Based on table 2 and figure 8, that the trendline curve, the white curve shows the values of the voltage, current and power values are low in the morning, and slowly increase in the afternoon, and slowly fall again in the afternoon. In other words, it can be stated that the value of voltage, current and power is low when the position of the sun and the direction of the solar cell module form a large angle, namely in the morning and evening. The value of voltage, current and power increases when the sun's position and the direction of the solar cell module form a small angle, namely at noon.

The average load power is 2,957 watts. The average energy received by the load all day for 8 hours of testing is 23,656 watt hours.

The test results for solar cell modules with dynamic orientation are shown in table 3.

Table 3. The results of measuring voltage, current and power calculations from dynamic solar cell modules

no	Hour	VOC (V)	VLoad (V)	iLoad (mA)	PLload (count) (W)
1	8.30	18.9	17.9	181	3.2041
2	9.00	18.8	18	181	3.24
3	9.30	19	18.2	182	3.3124
4	10.00	19	18.26	183	3.334276
5	10.30	19	18.2	182	3.3124
6	11.00	19.2	18.4	184	3.3856
7	11.30	18.9	17.9	180	3.2041
8	12.00	19	17.94	181	3.218436
9	12.30	19.4	18.3	184	3.3489
10	13.00	19.2	18.3	184	3.3489
11	13.30	19	18.2	183	3.3124
12	14.00	19	18.2	183	3.3124
13	14.30	19	18	180	3.24
14	15.00	19	18	181	3.24
15	15.30	18.9	17.9	180	3.2041
16	16.00	18.9	18	180	3.24
17	16.30	18.75	18	179	3.24

Graphically the power value is shown in Figure 9.

***Figure 9**. Graph of power at load (PLoad) of dynamic position solar cells*

Based on table 3 and figure 9, that the trendline curve, the white curve forms a straight line, it shows that the value of voltage, current and power is relatively stable at high values, starting in the morning, afternoon to evening. This stability occurs because the direction of the solar cell module with the average sun position forms a small angle (4,270), approaching perpendicular. The average power at load is 3,276 watts. The energy received by the load all day for eight hours of testing is 26.208 watt hours.Furthermore, a comparison of the power at the load of the two modules is carried out. The results of the power comparison are shown in Figure 10

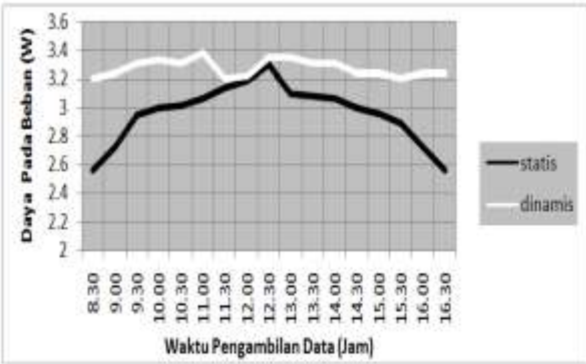

***Figure 10.** Comparison of Power at Load (PLoad) between static modules and dynamic modules*

The comparison results show that the magnitude of the voltage, current and power in the dynamic module is greater than the static module. The difference (difference) in the values in the morning is bigger, namely 0.64 watts or 25%, and tends to get smaller by 11:30 in the afternoon. The difference grew again starting at 15.00. The biggest difference occurred at 16.30. ie 0.68 watts or 26.6%. This proves that the difference in the position of the sun with respect to the direction of the solar cell module will affect the energy output of the solar cell module.

The average power load on the static solar cell module is 2,957 watts. The energy received by the load from the static module is 23,656 watt hours. While the average power load on the dynamic solar cell module is 3,276 watts. The energy received by the load from the dynamic module is 26.208 watt hours. The difference in the average power of the static module compared to the dynamic module is 0.319 watts. While the difference in energy is 2,552 watt hours. Based on the quantitative data obtained, it can be stated that energy optimization can be done by adjusting the orientation of the solar cell module to the sun's position.

V. Conclusion

a. The system for regulating the direction of the solar cell module following the sun's position using fuzzy logic control can function properly.
b. For east-west orientation, the difference between the direction of the solar cell module to the sun's position is an average of 4.270, this difference can be caused by several things, namely accuracymeasuring instruments, tolerances of the potentiometer coder and other electronic components, the torque of the motor, the delay time of the relay on the motor driver, human error, and the characteristics of the fuzzy logic controller system.
c. Optimizing the energy produced by the solar cell module can be done by adjusting the direction of the solar cell module perpendicular to the direction of the sun's position. Energy optimization of 2,552 watt hours
d. The energy received by the load from the dynamic solar cell module is greater than the energy received by the load from the static solar cell module. The energy received by the load from the static module is equal to 23,656 watt hours, while the the energy received by the load from the dynamic module is 26,208 watt hours. Energy difference of 2,552 watt hours
e. The power received from the static solar cell module is 2,957 watts. While the power received from the dynamic solar cell module is 3,276 watts. The average power difference is 0.319 watts.
f. In static solar cell modules, the power generated tends to be high when the angle between the solar cell module and the sun's position is small (midday), and conversely the power generated tends to be low when the angle between the solar cell module and the sun's position is large (morning and evening).
g. In dynamic solar cell modules, the power generated tends to be constant.

To produce a better scientific work, as a follow-upFollowing on from this scientific work, the author suggests several things, as follows:

a. We recommend using membership functions, more linguistic variables to increase the accuracy of this fuzzy logic control system.
b. We recommend using the PWM system motor control, so that the motor is easier to control.
c. The area of the research object should be expanded, for example using panels, or solar cell arrays to clarify the difference in energy between static solar cells and dynamic solar cells.
d. It is necessary to research the performance of solar cell modules by adding variables other than light, such as temperature, humidity, location (area), and others.
e. It is necessary to conduct energy efficiency research, by comparing the increase in energy of solar cell modules using a control system to the energy losses used by the control system itself.

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