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TRIPLE-AXIS TRACKING CONTROL ALGORITHM FOR MAXIMIZING SOLAR ENERGY HARVESTING ON A MOVING PLATFORM

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ABSTRACT

Triple-axis tracking control algorithm is an algorithm on tracking that used to increase the performance of solar cell. The tracker will increase on three basic needs on electricity such as current, voltage, and power. It also works in moving platform such as mobile car. The implantation keys are to make maximize harvesting energy on solar cell. In the paper delivered the fundamental difference between static solar cell and dynamic triple-axis solar tracker. The end goal of the research is to find the right algorithm on triple-axis to maximize the output power of solar panel in moving platform as the new future smart grid.

Index terms: triple axis algorithm, moving platform, and static solar cell.

1. INTRODUCTION

Solar power is a renewable energy that people has every day in our world. The solar cell is used in many countries in the world. It is also sustainable energy resource in our world. Sustainable means is using a power that the resource is not depleted or permanently damaged 1] People realize that renewable resource is the key part of green energy movement. The movement has been bringing betterment towards the environment. Moreover this potential energy is always seen as a good alter. This solar energy has a huge potential to contribute towards the power demands [2]. Even further, harvesting the solar power efficiently is always challenging. It is challenging due to efficiency and increases the power output on solar panel. Meanwhile, combine solar cell with tracking control system is a possible may to consider.

Tracking control system is possible to increase the energy output of the solar cell. Tracking control system is working by following direction of sunlight with an algorithm. An output result of solar cell by tracking system is presented in this paper [3]. On research of below paper is used maximum power point tracking (MPPT) for increasing demand of electricity. It works by capturing the maximum sunlight to convert it to useful energy. Those technique and research are presented in that paper [3] [4].

On making sun-tracking go smoothly, it can be used a dc motor to move the tracker on solar panel. It made of panel and hybrid driver. Hybrid driver for dc motor has function to increase efficiency. It is working with low consumption of power so by that it increases efficiency. The efficiency of solar tracker can see on two factors such as the first on solar panel output and a second on the efficiency of dc motor. The hybrid driver for dc motor is presented in the paper [4]. Each technique is used to point out differences between static and dynamic solar pane and how much significance of efficiency that created by the hybrid driver.

A solar tracker can be implemented on static platform and moving platform. Furthermore, the implementation of solar tracker on moving platform is a not to familiar. On the example of the electric car and electric bus, those are not common to use a solar tracker. Moreover, implementing solar tracker it supposes to do to increase their efficiency when absorbing light as energy maker. A solar tracker can work because it tracks a right direction of solar come. Furthermore, a solution for solar tracking has been proposed in order to exploit the maximum sun radiation [5].

Tracking technique and maximize works of servo are important to do. Algorithm takes a huge factor as supporter. As The key thing of a device, the algorithm has function control a work of device automatically base on artificial intelligence (AI). Algorithm fuzzy is a method that has been use in solar tracker by seeing in the perspective intensity of light. Fuzzy algorithm can help the smart system to combine a work upon servo and sensor [6].

Algorithm fuzzy is working due to the flexible nature of the control. Flexible of nature means that system follows a fluctuation of environment base on the integration of sensor. It is a standpoint in the fuzzy algorithm as solar tracking system [5] [6]. Choosing fuzzy to implement the algorithm technique is important to control right direction over the solar panel.

There are two basic axis uses on solar tracker. Those are single-axis and dual-axis tracker. Single-axis tracker can either has a horizontal or a vertical axis, while dual-axis tracker has both horizontal and vertical axis, thus making them able to track the sun's motion. The performance of dual axis solar tracking system was successfully analyzed based on data collected dual-axis solar is better than the static solar panel. The implementation of two basic axis uses with a full analysis on performance is presented in [7] [8] [9].

In this paper, a reference model for the triple-axis algorithm on moving platform is presented. The model of triple axis tracker has three motions such as horizontal, vertical axis and combination axis between horizontal and vertical. Those are making them able to track the sun's motion even better than single and dual motion. It also uses fuzzy algorithm in triple-axis model for maximizing

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output of current, voltage and solar power and compares with the static solar cell on moving platform. This project will introduce a fuzzy algorithm on triple axis for energy harvesting. Furthermore, the triple-axis fuzzy algorithm and data sheet of electricity output of triple axis solar panel are the main contribution of in this paper.

2. TRACKING ALGORITHM

In proposed design, the model using Arduino Uno as a microcontroller combine with solar tracker is based three-axis. Three-axis will accumulate maximum solar energy from the sun. There are three categories of sun tracker such as single-axis, double-axis and triples-axis. The triple-axis solar is used in this research. Triple-axis is used to increase the performance of solar panel. Thus performance is increasing output power and maximizes the panel of solar panel.

Triple-Axis solar cell will be mounted in the top of mobile electric car. The main component part is Arduino Uno: single-board microcontroller. It can be used as computing platform to code. It decodes and creates the motion of triple-axis solar tracker. It also open source-computing platform that have develop environment for writing software for the board. Light Dependent Resistor (LDR) creates the solar tracking system to have a movement. Six LDR are connected to Arduino analog pin AO to A4 that acts as the input for the system. The analog value of LDR is converted into digital using the built-in Analog-to- Digital Converter. Pulse Width Modulation (PWM) is a technique for getting analog results with digital means. Digital control is used to create a square wave, a signal switched between on and off. The values of PWM pulse are to move the servos [11]. Thus servo is moved by the behavior of sun intensity. The maximum light intensity is captured by the two sensors of the LDRs. LDRs input will be selected and the servo motor will move the solar panel to the position of the LDR get high intensity of sunlight. The maximum light intensity captured by the one or two of the LDRs input will be selected basis on the range of value input from LDRs and the servo motors will move the solar panel to the position of the LDRs. It works by combine work of data that captured by different LDRs at the same time. LDRs are working on a set-up in the programming. There are three points of motor rotation; 0; 45, 90, 135, and 180 degrees. The positions of LDR are divided into six positions; which are centered; right; left; up, down and in font of mobile car. The 6 positions allow the highest intensity of sunlight to be can be detected. The microcontroller gets an analog input from the light dependent resistor (LDR), which is then converted, into digital signal by Analog-to-Digital converter. The movement of the solar panel is determined by Arduino Uno and monitored by the output given to the servomotor.

A. Software implementation

The software consist program that is implemented C language. The code logic is constructed by fuzzy algorithm. The code is uploaded in Arduino Uno to program the movement of triple-axis solar cell in moving platform Figure flow 1 chart describing the fuzzy algorithm.

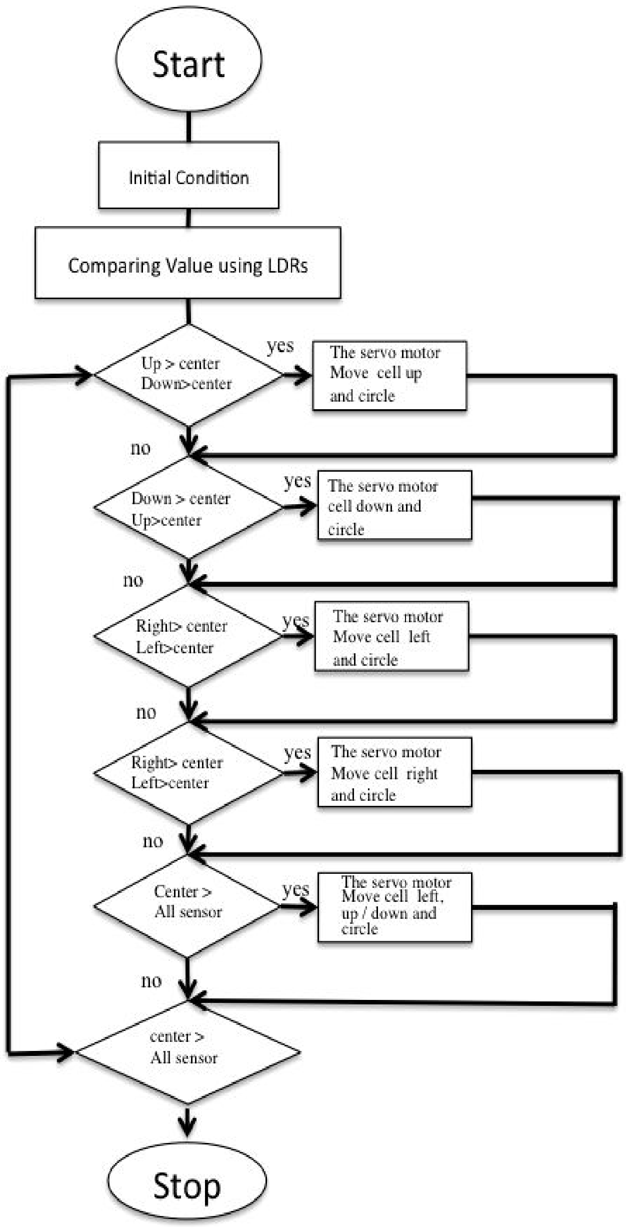

Figure-1. Algorithm triple-axis.

Figure-1 algorithm triple axis is showing the correlation light intensity analysis between each LDRs trough servos movement. The project use three servos that work and move with algorithm base on solar input on LDRs

Algorithm fuzzy is used for implementing of both hardwires and software. Figure-1 shows the developed triple-axis solar tracker in moving platform. The implementation is involved to compare the ratio of each LDRs sensor that put above on car. Fuzzy algorithm is worked on 0 until 1. It means there is no exact true and exact false. Seeing the figure 5 to know more about the LDRs.

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The first step is finding the value of up motion on LDRs sensor. When the value of up sensor is AB, is bigger then the intensity value of down which is CD. It will make the direction of solar panel goes to AB. It works by move the first servo and second servo trough up direction.

The second step is finding the value of down motion on LDRs sensor. When the intensity value of up sensor, which is CD, is bigger then the value of down which is AB. It will make the direction of solar panel goes to CD. It works by move the first servo and second servo trough down direction.

The third step is finding the value of Left motion on LDRs sensor. When the intensity value of up sensor, which is AC, is bigger then the value of down which is BD. It will make the direction of solar panel goes to AC. It works by move the first servo and second servo trough left direction.

The fourth step is finding the value of Right motion on LDRs sensor. When the intensity value of up sensor, which is BD, is bigger then the value of down which is AC. It will make the direction of solar panel goes to BD. It works by move the first servo and second servo trough right direction.

The fifth steps front all and back all are the step to decide to go more front trough the car. More up front or back is a motion that used the move of third servo to approach more front to the car and back to the car.

The sixth step when all dark will create no motion. The algorithm is working on looping mode. The LDRs average intensity value will use as the compass the first servo, second servo and third servo. The third servo will work only when all average value of LDRs in front or back of car is bigger than other the average of AB, CD, AC and CD. The movement of servo in four-direction is made all servos. There are as circle to the left or right move by first servo, up down moves by second servo and front all or back all move by third servo.

B. Hardware implementation

The main hardware in this project is used a three servos, solar panel, and six LDRs and LED voltmeter. Triple servo is used to make three degrees of freedom. The degree of freedom creates to maximize the input power of solar tracker. The three-degree freedom means a direction to X, Y, Z direction of solar panel. The triple axis solar cell is with a voltmeter LED. It uses the hardware to show the amount of electricity voltage each second. Thus data is shown on LED voltmeter. LDRs are works as the light sensor to get the real time sun input. The research also creates a car racetrack with a light that work automatic will explain more on bellow explanation.

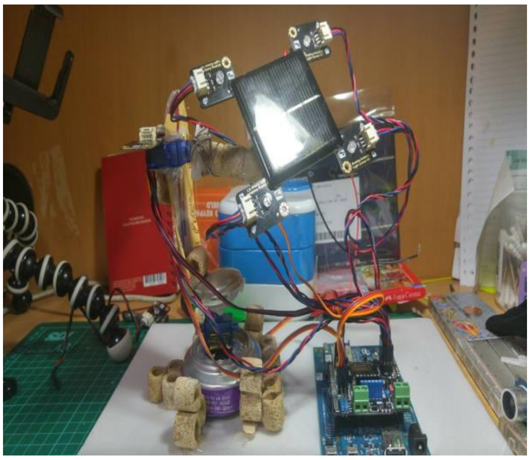

Figure-2. Triple-axis solar tracker.

Triple-Axis solar tracker is built in 3 servos, 6 LDRs. Thus, are the key component to decide the motion input and output.

C. Automated light on solar tracker

Automated Light is imitating time sun input. Time sun input means the light will move base on timetable that same with sun. The Solar Tracker developed has the capability for tracking the sun. It is created to make easy to compare a result of both Solar Tracker and the immobile Solar Panel. The accuracy is improved by putting a triple axis solar tracker that mounted on the car. The comparison is created on both scenarios, which are static versus dynamic triple axis. Seven light works as a new feature of a stable automated light source is created. It could act as a prototype to the sun's actual trajectory.

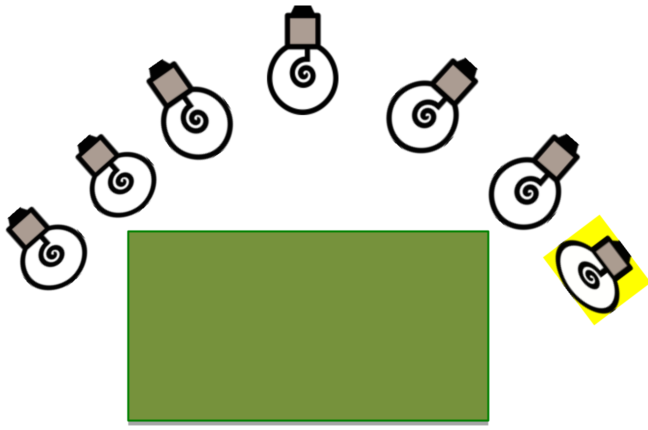

Figure-3. Automatic light.

Figure-3 illustrates the project of automatic light. Yellow color means the light on. In the illustration model the light will be move each four minutes. The implementation on artificial sun could act as sun actual trajectory. It is located in above the simple car track. It starts moving from right to left. In twenty-eight minutes after all of artificial sun works is a time to end the car race. The condition of car is divided by two ways. The first trial

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car will move with static solar panel and second trial the car will move with triple-axis solar tracker.

D. Car track on looping condition

The car track is created as the track for mobile robot. On the top of mobile car is mounted with triple axis solar tracker. Mobile car will loop on the track. The track is created to monitor a responsiveness of triple axis solar tracker. It also created to support the research on moving platform. The track prototype is used 1-meter x 1-meter track. It is shown under Figure-8. This project only use simple track for easy move of mobile car.

E. Active tracking

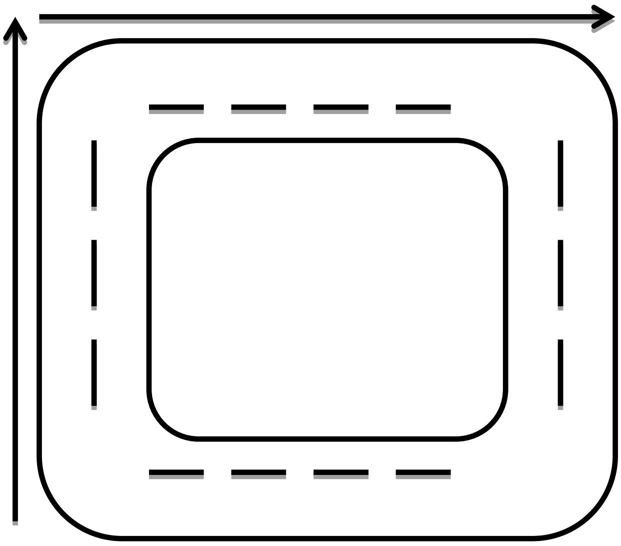

Figure-4. Car track.

Triple Axis tracker is an active tracker, which is controlled by computer program (via an Arduino). This means, it uses sensors to find the brightest source of light at all times. It easy to check the respond by takes a flashlight and shine it at the sensors the tracker. It would follow it around. The sun is highly predictable. This system uses a computer program that changes the angle of the panel based on the intensity of solar that compare by 6 sensors LDRs. Active tracker in fact far more efficient provided everything is set up properly. The LDRs component that used to input direction is shown under Figure-3.

The program works by comparing the resistance of the six sensors and moving the servos. How sensitive each sensor is completely depends on code. The same goes for the servos. Program is has been set up our code so that servos can only move within certain predefined area and at a set speed. These two aspects can also be changed very easily in the code. Helping things along and remove a bunch of wiring this project use an Arduino sensor shield. This is mainly to plug the there Servos into.

F. Checking light intensity sensor and validation using processing

Checking light intensity is a condition when hardware LDRs Arduinois work as the interface between solar panel and the processing for real-time monitoring. Analog voltage output and current of solar panel is acquired using analog pins of Arduino. Arduino pin is transferred to the processing. Acting the software interface for Arduino and processing [10]. Processing is software show a real time monitor the performance of each LDR. The processing apps help to decide the place to put LDRs.

Real time performance of the solar tracker and static solar panel has been performed. Figures 2-4 depicts real time plots of Voltage; Current and Power for the given input light source.

G. Placement of LDR

Placement of LDRs is used to enhance the performance of Servo movement. The four LDRs are placed in the solar panel.

And two of LDRs is located in the front and back of car body.

The four LDRs will mount in the around plate of solar panel tracker

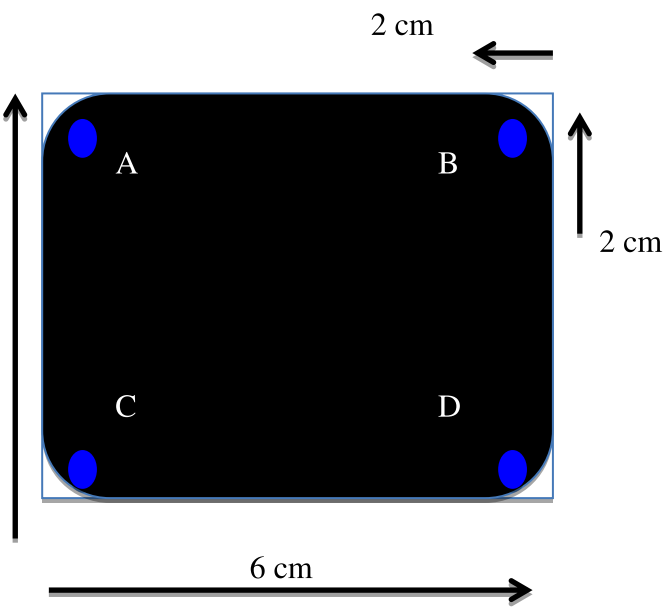

Figure-5. LDRs in solar plate.

Figure-5 illustrates the project of LDRs. The blue circle color is LDRs. Black square is place of solar cell and white edges color will be the plate to mounted solar cell. The location on implementation is a same as the true prototype. The placement of the LDRs is very important to make each LDRs can get maximum light intensity for every direction on board. The works of code in LDRs is taking the biggest average intensity over AB, AC, CD, and BD. The biggest average of solar intensity will be a compass to decide the there servos movement.

Figure-6. Center LDRs.

Figure-6 illustrates the project of center LDRs. The blue circle color is LDRs. The location on implementation is in the center back of solar panel. The faction front LDR and back LDR is to decide the movement of third servo and decide the stability of movement of each servo. If the center LDRs both in average bigger than the other LDRs than the solar tracker will not move. It because the high intensity of light on the center face of solar panel. The placement of the LDRs is very important to make each LDRs can get maximum light intensity for every direction on board. The

H. Triple axis code algorithm

The C program is working on the triple axis algorithm. The triple axis is the work of the servo on three degrees of freedom. The first is a vertical direction, a second horizontal and the last combination of both to forward or backward. Forward and backward third servo like an arm that can move 90 degrees to the front -90 degrees to the back of the car. Thus a degree of freedom is created approach the sun intensity. The end goal of this algorithm to increase the electricity power output and create a new triple axis algorithm that is suitable for moving.

3. IMPLEMENTATION

A. Results of experiment

Experiment was conducted on a lab in three hours with four times experiment. The setup is using automatic light in the data communication lab. Proper care had to be taken to ensure that no shadow was affecting the performance of the panel. The test results are as follows. This research also use mobile car to check the work performance on moving platform.

Table-1. Electricity output on voltage unit.

Time (minutes)	**Voltage** (MV)	
	Without tracker	**Solar tracker**
4	0.61	0.64
8	0.41	0.92
12	0.43	0.66
16	0.32	0.72
20	0.33	0.67
24	0.34	0.72
28	0.42	0.89
Average	0.408	0.745

Table-1 Explain the result of research in 4 minutes average each angle of light. The angle light was used such as 30 degrees, 45 degree, 60 degree, 75 degree, 105 degree, 120 degree 135 degree, 145 degree in 4 minutes each. The value on the table is the average value each minute on the real test to account voltage in millivolt.

The first solar tracker value was obtained by the condition when 30 degree light that comes to the solar panel. Solar panel was moving on up position. At that time, the value of up sensor is AB, got bigger light intensity than the intensity value of down which is CD. It will make the direction of solar panel goes to AB. It creates by implementing 30 degree up movement. The movement of solar panel makes the value of output was 0.64 MV in 4 minutes average. But, the result of static panel (without tracker) didn't follow the light. The result of first panel without tracker was 0.61MV.

The Second solar tracker value was obtained by the condition when 45 degree light that comes to the solar panel. Solar panel was moving on up position. At that time, the value of up sensor is AB, got bigger light intensity than the intensity value of down which is CD. It will make the direction of solar panel goes to AB. It creates by implementing 45 degree up movement but the up movement is almost fully up greater than the first solar tracker angel. The movement of solar panel makes the value of output was 0.92 MV in 4 minutes average. But, the result of static panel (without tracker) didn't follow the light. The result of second panel without tracker was 0.41MV. 0.92MV output produces by the up position in and tracker algorithm focus the light and the value intensity of sun and by moving the third servo to right.

The third solar tracker value output was obtained by the condition when 60 degree light that comes to the solar panel. Solar panel was moving on up position. At that time, the value of up sensor is AB, got bigger light intensity than the intensity value of down which is CD. It will make the direction of solar panel goes to AB. It creates by implementing 60 degree up movement. The movement of solar panel makes the value of output was 0.66 MV in 4 minutes average. It almost same with the first result because the light intensity who touch panel almost same. But, the result of static panel (without tracker) didn't follow the light and get more shadow rather than light in the panel. The result of first panel without tracker was 0.43MV.

From the three-sample explanation, writer notice that movement over algorithm help increase the output.

Table-2. Electricity output on current unit.

Time in minutes	Current (MA)	
	Without tracker	**Solar tracker**
4	50.2	58.2
8	45.3	78.4
12	46.3	60.4
16	39.2	67.8
20	40.4	65.5
24	41.4	67.7
28	43.3	72.2
Average	43,728	67.171

Table-2 Illustrates the result of research in 4 minutes averages each angle. The angle was used such 30 degree, 45 degree, 60 degree, 75 degree, 105 degree, 120 degree 135 degree, 145 degree, 160 degree in 4 minutes each. The value on the table is the average value each minute on the real test to account voltage in milliampere.

The first solar tracker value was obtained by the condition when 30 degree light that comes to the solar panel. Solar panel was moving on up position. At that time, the value of up sensor is AB, got bigger light intensity than the intensity value of down which is CD. It will make the direction of solar panel goes to AB. It creates by implementing 30 degree up movement. The movement of solar panel makes the value of output was 58.2 MA in 4 minutes average. But, the result of static panel (without tracker) didn't follow the light. The result of first panel without tracker was 50.2.

The Second solar tracker value was obtained by the condition when 45 degree light that comes to the solar panel. Solar panel was moving on up position. At that time, the value of up sensor is AB, got bigger light intensity than the intensity value of down which is CD. It will make the direction of solar panel goes to AB. It creates by implementing 45 degree up movement but the up movement is almost fully up greater than the first solar tracker angel. The movement of solar panel makes the value of output was 0.78MA in 4 minutes average. But, the result of static panel (without tracker) didn't follow the light. The result of second panel without tracker was 45.3 78.4 MA output produces by the up position in and tracker algorithm focus the light and the value intensity of sun and by moving the third servo to right.

The five solar tracker value output was obtained by the condition when 135 degree light that comes to the solar panel. Solar panel was moving on down position. At that time, the value of up sensor is CD, got bigger light intensity than the intensity value of down which is AB. It will make the direction of solar panel goes to CD. It creates by implementing 95 degree of servo the bottom servo goes left movement. The second servo goes to the bottom around 35 degrees. And third servo movement of solar panel rounds 25 degree to right. It makes the value of output was 65.5 MA in 4 minutes average. It almost same with the first result because the light intensity who touch panel almost same. But, the result of static panel (without tracker) didn't follow the light and get more shadow rather than light in the panel. The result for fixed panel around is 40.4 MA. From the three-sample explanation, writer notice that movement over algorithm help increase the output. And in average performance was obtained solar tracker output was bigger than fixed solar panel.

Theoretically, calculation of energy using fixed solar panel and solar tracker is shown under the formula. If that the average solar radiation intensity over majority of areas in Indonesia is I=3500w/m^2. The theoretical calculation of received energy is carried out for a period of 12 hours i.e. day length, t=12hr=43,200s. The angular velocity of sun is = 7.37 x 10^{-5} rad/sec [1]. On static solar panel without triple axis algorithm the solar radiation will be S=Soxcos, where (=t) is the angel of inclination ranges which is 90 degree to -90. By that data the research getter dw=IxSd there (= t) is the degree of inclination ranges between 90 to +90 and So is the collector area. The differential falling energy is dw=I×Sdt. So the total energy obtains by formula on a static solar panel [7]

$$W = \int_{21600}^{-21600} I \times dt$$

$$= \int_{+21600}^{-21600} I \times \cos wt \, dt$$

$$= So\ [\sin \frac{wt}{w}]_{+21600}^{-21600}$$

$$= 2 \times I \times \frac{so}{w}$$

$$= 2 \times 3500 \times \frac{0.3671}{7{,}37 \times 10^{-5}}$$

= 3.5 MWh/m^2/day

4. PERFORMANCE EVALUATION

Figure-7 Is showing the result of the project. The data is obtained from the real count data on the voltmeter. The researches use 30 degrees until 145 degrees of light source. The light is the automated light. In the illustration model the light will be move each four minutes. The result shows tracker panel creates a bigger voltage than fixed panel. The triple axis servo and the LDRs are able to detect and move the solar panel on right position. It movements possible create a bigger electricity output in voltage.

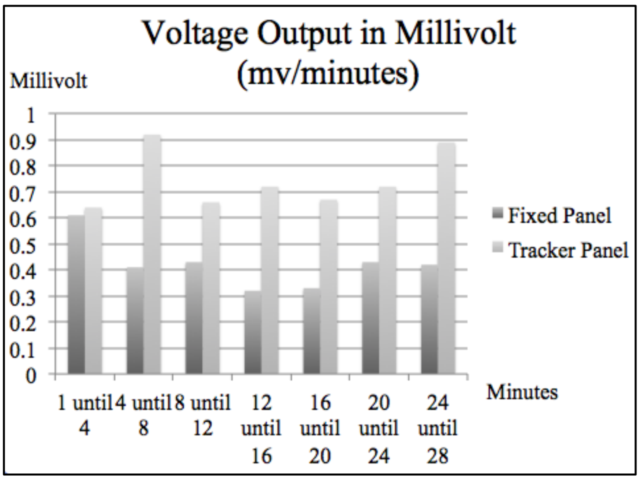

Figure-7. Voltage output.

Figure-8 is showing the result of the project. The data is obtained from the real count data on the voltmeter. The research uses 30 degrees until 145 degrees of light source. The light is the automated light. In the illustration model the light will be move each four minutes. The result shows tracker panel creates a bigger current than fixed panel. The triple axis servo and the LDRs are able to detect and move the solar panel on right position. It movements possible create a bigger electricity output in voltage. The right algorithm of triple axis create possible move that can harmonize the servo combination and LDRs.

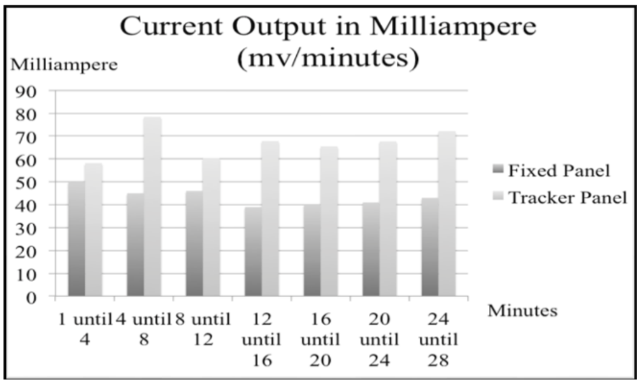

Figure-8. Current output.

5. CONCLUSIONS

As a means to provide an efficient solar distributed generation system, this paper presented Triple Axis Algorithm. The system was constructed and working successfully. In a real counts table shows the triple axis working to increase the voltage and current. The value was count in millivolt and milliampere. The measurement was taken in real time. They real time measurement done on the certain parameter. It was obtained from the real power output of solar panel. The built prototype shows a design and algorithm help to increase the electricity output. The results were shown an average voltage margin around 0.337 MV. The result of voltage of triple axis solar panel is bigger than fixed solar panel. The system also create bigger current margin around 23.442 MA. As same as voltage the result of triple axis tracker is bigger than fixed panel.

The solar tracker algorithm could be implemented in the future as the algorithm to increase the output power of solar cell. The uses of 6 LDRs and logic code create the three servos movement. The embedded code in the servo movement from making this research can obtains the way to implement in certain platform such as moving and static platform. This model could also use in household sector, which will use the energy generated by the triple axis solar tracker to overcome the problem of frequent power cuts in majority areas of the country.

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