Determination of Fill Factor and Efficiency in Solar Cell Type (99 × 69) mm^2 with Arduino Uno R3 Based Drive assisted by Logger Pro 3.14.1

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Abstract
The purpose of this research is to determine the fill factor and efficiency of solar cell type (99×69) mm^2 with arduino uno R3 based automatic drive assisted logger pro 3.14.1. This study aims to determine the value of the fill factor and the efficiency of solar cell type (99×69) mm^2 on manual and automatic drives with a microcontroller collaboration using Arduino Uno R3 as a data acquisition tool. The use of samples in research on fill factors and the efficiency of solar cells with automatic drive rotating the surface of the solar cell follows the motion of the light source from 0° to 90° compared to without the automatic drive from 10° to 70°. The test results are then implemented to determine the fill factor and efficiency in variations in light intensity. In this experiment the type of solar cell used polycrystalline type (99×69) mm^2 was presented in front of a Philips 100 W/220 V light bulb at a distance of 18 cm and the solar cell automatic drive was controlled via an arduino uno R3 microcontroller. Current and voltage data acquisition is carried out with the help of DCP-BTA currents and VP-BTA voltage probes that are connected to the mini labquest transducer and displayed to a computer through software logger pro 3.14.1. Furthermore, the solar cell voltage-current data is diffitting using the exponential equation in logger pro software. Based on the results of solar cell research type (99×69) mm^2 percentage of the fill factor value of 60,2 ± 0,5 and efficiency of 26 ± 0,4 in manual motion. Whereas in the automatic drive percentage fill factor 66,3 ± 0,4 and efficiency 26 ± 0,1. Percentages in automatic drive can increase the accuracy and precision of current and voltage readings so that the fill factor increases by 10% while efficiency does not change. Furthermore, the greatest variation in light intensity is 993.34 W/m^2 with a fill factor of 71% and an efficiency of 31%. This fill factor and efficiency have an exponential relationship with light intensity.

Keywords: fill factor, efficiency, Arduino uno R3, logger pro software

I. Introduction

Sunlight can be used as a renewable energy source, namely solar cells. Solar cells during sunny afternoon or midday can produce an intensity of 1000 W/m^2, 25°C [1]–[3]In commercial solar cell modules the efficiency ranges from 10% to 30% depending on the composition of material making up [4]–[8]. The quality of the solar cell is determined by the fill factor (f_f), the energy conversion efficiency (η) and the concentration of sunlight received by the solar panel [9]–[12]

Fill factor is an energy storage parameter that is the ability of solar cells to store the received solar energy. Mathematically f_f is the ratio of maximum power (P_{max}) produced by solar cells to theoretical power (P_{th}). Whereas efficiency states the percentage of output of electric energy from solar cells to energy that comes in from the solar radiation. This efficiency is a parameter that describes the energy that can be converted by solar cells.

From preliminary studies that have been conducted by researchers about the effect of the panel angle on the solar cell energy of (99 x 69) mm^2, 5V it is obtained the fill factor for all variations of the solar cell plate tilt angle from 10º up to 90º. The maximum fill factor corresponds to a angle of 30° of 67% with a maximum power of 0.023 watts while the maximum efficiency produced is 0.07%. At this angle the direction of the light comes parallel to the direction of the solar cell area. This value is too small for manufacturer's solar cells, because the f_f for normal solar cells ranges from 10% to 30%. From the catalog of solar cell size (99 x 69) mm^2 it is obtained information that the solar cell was in 2017 so that within 2 years the f_f has not yet decreased from its original value.

From the re-examination of the data collection techniques, there is something that needs to be corrected, including the luxmeter used as an instrument for measuring the light intensity originated from a smartphone application. This instrument inaccurate after being matched with the luxmeter from Vernier Logger Pro and the LDR sensor on Arduino. In addition, the process of measuring voltage (*V*) and current (*I*) data is still too long time so that the sun's position has shifted from its original place. With this condition, the angle of incident ray is not perpendicular to the direction of the surface of the solar cell.

Therefore in this study the data collection technique was improved in an instrument for measuring the light intensity using Arduino R3 LDR. This Arduino can be programmed to allow rotating solar cell panels so that the surface of the solar cell always perpendicular to the direction of the incident sunlight. Voltage-current data was acquisited automatically using a voltage sensor and current sensor logger pro 3.14.1.

II. Theory

Solar Cell

The electric power generated by solar cells when getting light is obtained from the ability of the solar cell device to produce voltage when given a load and current through the load at the same time. Theoretical power is the power generated when the area of the I-V curve is $V_{oc} I_{sc}$ [13]:

$$P_{th} = V_{oc} I_{sc} \qquad (1)$$

where P_{th} theoretical power (watts), V_{oc} open circuit voltage (volts) and I_{sc} short circuit (amperes). The point on the *I-V* curve that produces the maximum current and voltage is called the maximum power point,

$$P_{\max} = V_{\max} I_{\max} \qquad (2)$$

where V_{max} is maximum voltage (volts), and I_{max} is maximum current (ampere). Intensity of the light received by the solar cell is defined as the power received from solar or light source (P_{in}) divided by the cross-sectional area of the solar cell (*A*).

$$I_r = \frac{P_{in}}{A} \qquad (3)$$

or

$$P_{in} = I_r A \qquad (4)$$

where Ir the intensity of the incident light (W/m^2) when the solar cell is in an open circuit condition or maximum current, whereas in the short circuit condition (open circuit) there is no current that can flow so that the maximum voltage is called the V_{oc} voltage. An important characteristic of solar cells is the fill factor stated in the equation:

$$f_f = \frac{P_{\max}}{P_{\mathrm{th}}} \qquad (5)$$

While the conversion efficiency is the ratio between the output power of the solar cell (P_{out}) to the input power of the light source used (P_{in}).

$$\eta = \frac{P_{\max}}{P_{in}} = \frac{f_f \; P_{th}}{P_{in}}$$

(6)

In experiments there are often errors in determining f_f and η. As in Figure 1 of the data points (V_i, I_i), then V_{oc} is usually taken from the last V_i data while I_{sc} is taken from the first data I_i. V_{oc} should be taken from the point of intersection of the curve with respect to the V-axis, and I_{sc} is the point of intersection of the curve with respect to I-axis. As a result, P_{th} becomes smaller than it should be [12]. Similarly V_{max} and I_{max} are obtained from the multiplication between V_i and I_i data. V_{oc} and I_{sc} should be obtained carefully if the data (V_i, I_i) is made a curve with the help of data fitting then the curve is extrapolated until it intersects with the V and I axes.

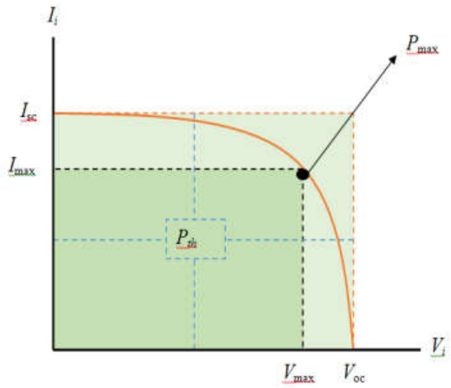

Figure 1. Solar cell characteristic curve

Arduino

Arduino is an electronic prototype device based on a microcontroller that is open source. Arduino functions as a controller of electronic circuits. Arduino has a microcontroller board based on ATmega328 with 14 input/output pins, 6 pins can be used as output, 6 analog inputs, USB connections, adapter sockets, ICSP header pins and research buttons using coding language in the form of C language [14]–[16].

Software Logger Pro

Logger pro is a software for data acquisition and analysis [17]. In this experiment Logger pro 3.14.1 is used to display data readings by voltage sensors and current sensors. In addition logger pro 3.14.1 is also used to fitting data (V_i, I_i) to obtain the V-I curve equation.

III. Methodology

Experimental procedure

This research was conducted at the Central Laboratory (Sensor and Transducer Laboratory) of UAD Physics Education. Some of the equipment used are: polycrystalline solar cell type (99 × 69) mm^2, Arduino Uno R3, servo motors, computers and USB labQuest (current and voltage sensors). A sollar cell drive device is arranged according to Figure 2.

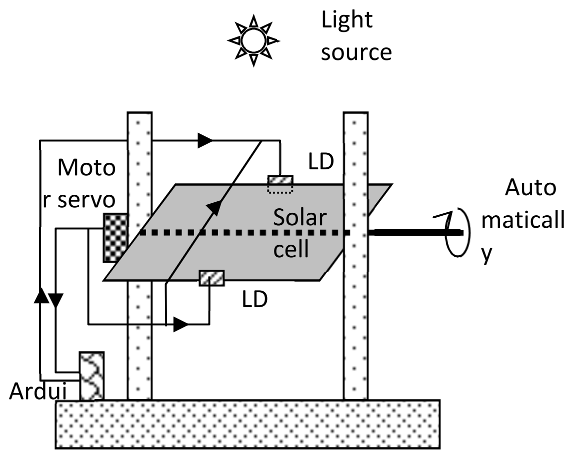

Figure 2. Schematic of solar cell experiment kit assisted by Arduino uno R3

In Figure 2, a solar servo motor is used to drive the solar cell which is connected to the arduino pin. Servo motors have 3 red power cables (VCC) connected to an arduino 5 volt source. Then the black ground wire (GND) is connected to the Arduino GND pin. While the orange signal (data) cable is connected to the Arduino digital 9 pin as a regulator of the rotating direction of the servo motor. Then the LDR (light dependent resistor) is installed as a controller to give the drive command to the servo motor. LDR 1 is connected to the VCC servo motor cable then connected to Ardunio A_0 pin. Whereas the LDR 2 is connected to the GND pin of the servo motor and pin Arduino A2. Arduino uno R3 voltage source is taken from laptop power using a serial cable. The tilt angle of the solar cell can be read directly through the protractor that has been mounted on the solar cell. Then the Arduino program is run to activate all components that are already installed.

Voltage VP-BTA and current DCP-BTA sensors were used collecting solar cell voltage-current data. These sensors were connected to labquest mini transducer and the reading values were displayed using the logger pro software.. The current and voltage sensors are connected to the labquest mini transducer where the positive current sensor is connected to the positive solar cell cable and the voltage sensor cable is connected to the pin 2 potentiometer. The negative cable of current sensor and the positive cable of voltage sensor are connected to pin 1 potentiometer. The time for data collection was set on 30 seconds and the sampling rate was 0.05 seconds / sample. Furthermore, Philips 100W/220V bulb as a light source is installed by connecting to the PLN voltage source. The potentiometer was rotated from minimum to maximum to obtain the value of a set of data (V_i, I_i).

Data analysis method

The research was carried out following the scheme in the figure

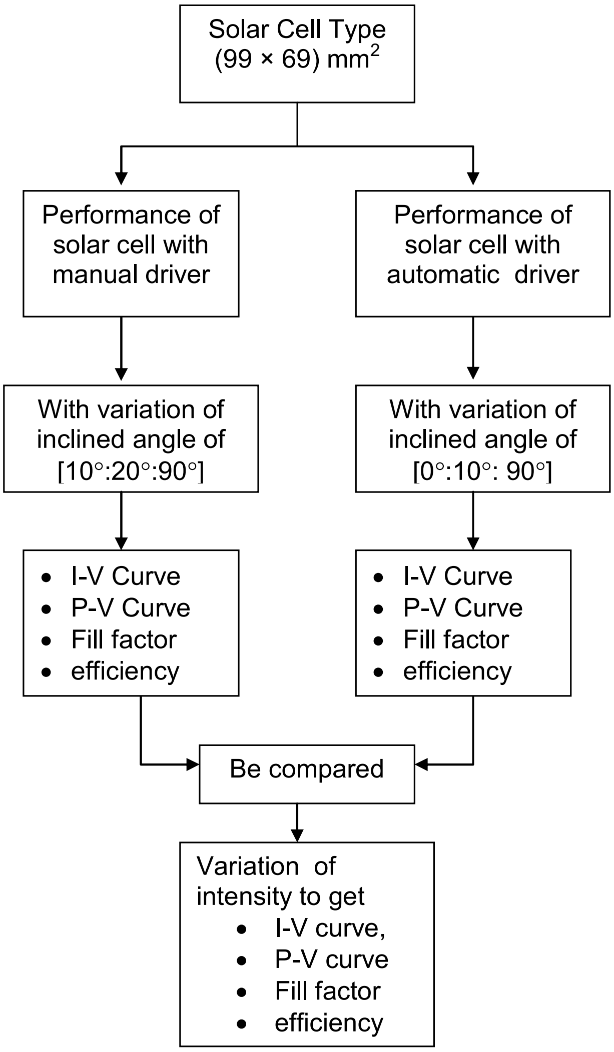

Figure 3. Scheme of experiment and data analysis

V_{oc}, I_{sc}, V_{max} and I_{max} values are obtained from the V-I curve resulted from data fitting of (V_i, I_i) according to the natural exponential function,

$$y = A\exp^{-Cx} + B \tag{7}$$

With, $x = I$, $y = V$ and A, B, C are the fitting coefficients of equation (7). The value of Isc is obtained from the intersection of the curve with respect to the x-axis and V_{oc} is obtained from the intersection of the curve with respect to the y-axis. By entering $x = 0$ in (7) for I_{sc} and $y = 0$ for V_{oc} we get:

$$I_{sc} = A + B \tag{8}$$

Whereas the V_{oc} equation

$$V_{oc} = -\frac{1}{C}\ln\left(\frac{B}{A}\right) \tag{9}$$

By multiplying eq. (8) and eq. (9) the theoretical power value is obtained as stated in equation (1). Maximum power is obtained from the multiplication of voltage (x_i) and current (y_i) and then taken from the largest value. The light intensity of the lamp is obtained from eq. (3) with A solar cell module area (99 × 69) mm^2. The f_f solar cells is obtained from equation (5), which is the ratio of maximum power and theoretical power. The value of f_f is expressed in percent. Sollar cell efficiency η is obtained from equation (6).

IV. Results and Discussion

In Figure 4.a the results of the design of a solar cell automatic drive type (99 × 69) mm^2 are used using Arduino Uno R3. Whereas in Figure 4.b is the use of pro logger software to display V_i and I_i results.

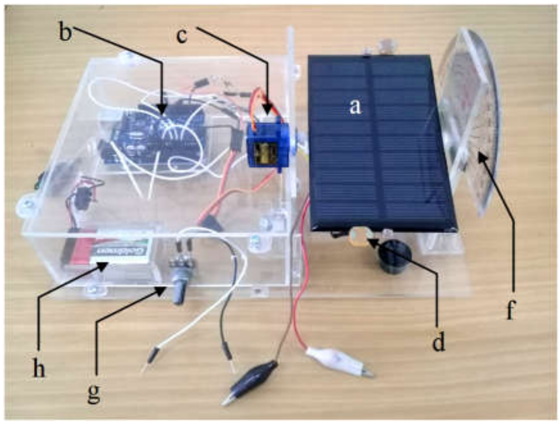

Figure 4. The set of experimental tools, a. Solar cell b. Arduino uno, c. Servo motor, d. Light sensor e. LDR f. Protractor, g. Potentiometer, h. Battery.

Manually solar cell performance

Figure 5 shows the performance of a solar cell type (99 × 69) mm^2 without an automatic rotation motor in the form of a voltage-current curve at the various angle of the incident beam from 10° to 70°. The angle is varied manually and at the beginning, the surface position of the solar cell in the direction of the incident beam. During data acquisition the position of the solar cell remains at its initial angle, while the position of the light source has shifted from its original position according to the sun's rotation.

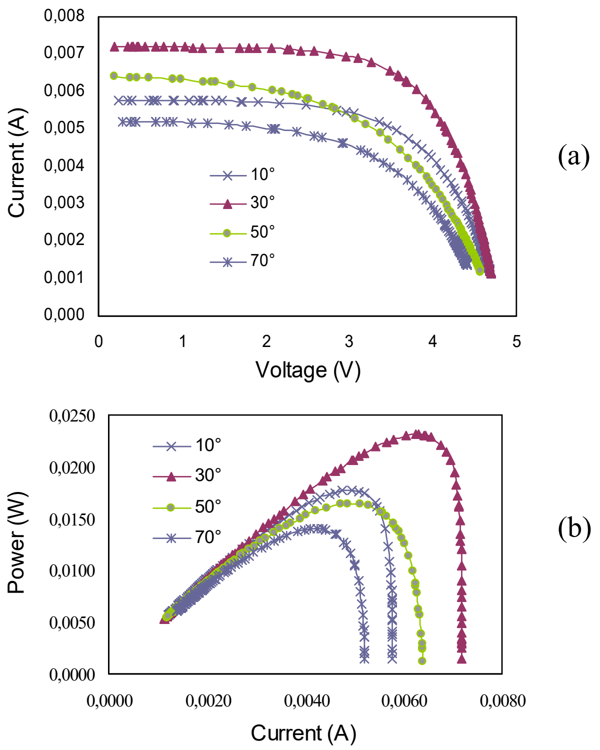

Figure 5. Characteristic of solar cells without a driving motor, (a) current-voltage curve, (b) the maximum power.

Performance of solar cells with automatic solar cell rotation

Furthermore, the performance of solar cells as discussed in the sub-sections above is compared with the performance of solar cells if the solar cells are rotated automatically with a motor driven by Arduino. With this motor, the surface of solar cell can always follow the light source so that the surface direction of the solar cell is always parallel to the direction of the light source. In this way, to vary the tilt angle of solar cells becomes more flexible. In this study the slope angle is varied from 0° to 90°. Profile of current-voltage and power- current curve as shown in Fig. 6.

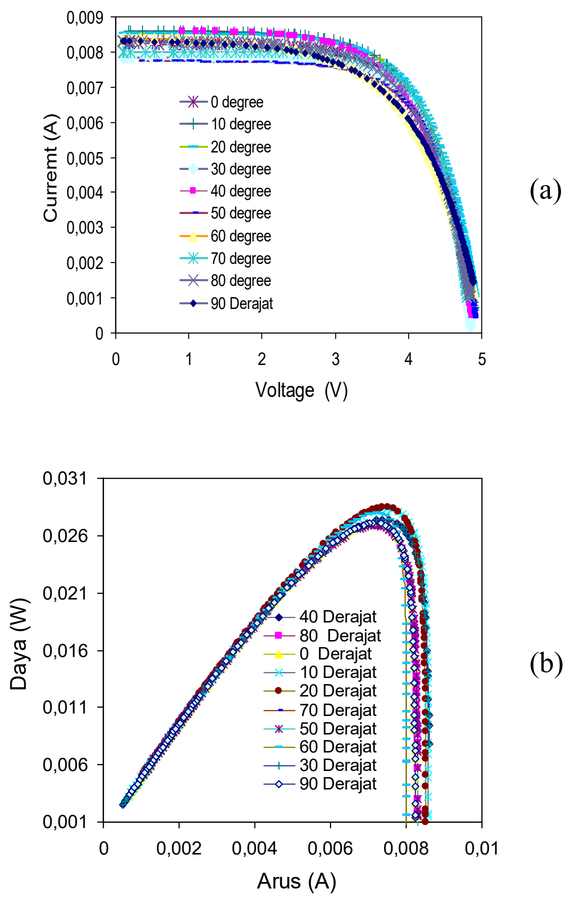

Figure 6. Characteristic curve of a solar cell with a milling motor, (a) current-voltage, (b) maximum power

Figure 6 shows the solar cell output power at various currents obtained by calculation. The power is obtained from the light of a data lamp with an intensity of 981.73 W/m2 that is imposed on the surface of the solar cell. by varying the load resistance so as to produce a current from 0 A to 0.01 A then record the voltage V between the two poles of the solar cell. Next Pmax is determined which corresponds to the peak position of each curve in Figure 6 (b). By varying the tilt angle of the solar cell panel the charging factor is obtained which varies slightly between 66% to 72% and the efficiency varies from 25% to 27%.

Furthermore, the performance as obtained in subsections 1 and 2 included fill factor and efficiency is then compared, and the results are tabulated in the table 1.

Table 1. a comparison of solar cell performance without and with automatic drive

Performance Parameter	With manual driven	With automatic driven	Increasing (%)
Fill factor	60,2 ± 0,5	66,3 ± 0,4	10
Efficiency	26 ± 0,4	26 ± 0,1	0

From table 3 it is clear that the fill factor using automatic drive is larger and more precise than that from manual drive. This can be seen from the value of standard deviation which is smaller than the value of standard deviation in manual drive. For efficiency, both methods display the same value, but the efficiency of solar cell from the automatic drive is more precise than manual drive. Thus the use of solar cell drives automatically can increase the accuracy and precision of the fill factor and efficiency. Furthermore, after knowing the method to determine the fill factor and the efficiency of solar cells using automatic is better then the solar cells with a manual drive methods, variations in the intensity of the incident light on solar cells are carried out.

Performance of solar cells at various intensity

The intensity of the light was varied from 967 W/m2 to 983 W/m2 and the position of the solar cell is parallel to the direction of the incident light. Furthermore, by varying the load resistance the current and voltage are recorded between the poles of the solar cell. Current-voltage and power-current curves was displayed in Figure 7.

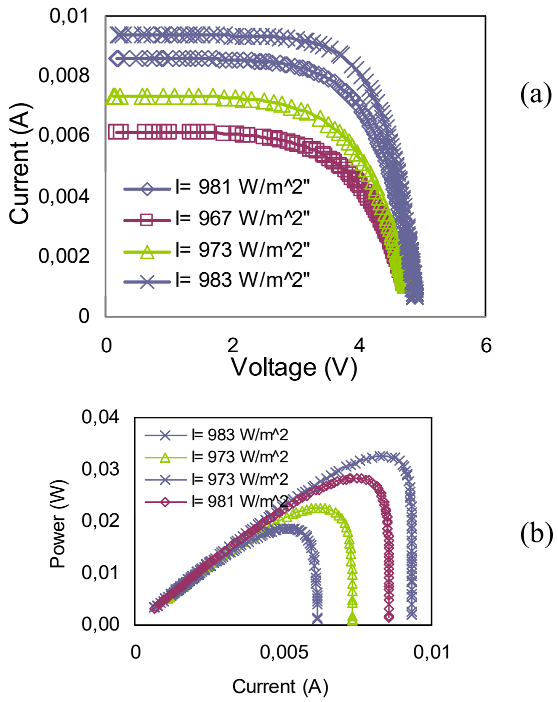

Figure 7. Performance of solar cell on the various intensity. (a) voltage – current curve, (b) Power – current curve

From figure 8 it appears that the greater the intensity the greater the fill factor and efficiency. This is consistent with the phrase that has conducted research on the fill factor and efficiency of solar cells for variations in intensity from 250 W/m^2 to 1000 W/m^2 and the greater the intensity of the higher current while the voltage is almost unchanged and the conclusion is the greater the intensity the greater the power the maximum achieved [18], [19].

Based on the Fig. 9 the greatest of maximum power obtained at an intensity of 983,344 W/m^2 is equal to 0.0326 watts. The fill factor (*ff*) and their efficiency (η) are listed in Table 2. From the table it appears that the lowest fill factor and efficiency valuee is lie at an intensity of 967.51 W/m^2 which is 63% and 18% respectively. While the highest fill factor and efficiensy is at an intensity of 983.34 W/m^2 that is 71% and 31% respectively. The increasing intensity will increase the maximum power and theoretical power of solar cell so that the fill factor and efficiency also increase. The type of increasing fill factor and efficiency is directly proportional to the exponent of its intensity.

Table 2. Value of fill factor and efficiency at various intensity of incident light

Intensity (W/m^2)	V_{oc} (V)	I_{sc} (A)	P_{th} (W)	P_{max} (W)	ff (%)	η (%)
967.51	4.82	0.0061	0.03	0.019	63	18
976.71	4.86	0.0073	0.036	0.023	64	22
981.73	4.94	0.0085	0.042	0.028	67	27
983.34	4.92	0.0093	0.046	0.033	71	31

V. Conclusion

Based on the results of analysis and studies that have been carried out regarding the determination of fill factor and efficiency in solar cell type (99 × 69) mm^2 with microcontroller based drive Arduino Uno R3 assisted with logger pro 3.14.1, we conclude as follow:

1. It has been successfully designed an automatic driver of a solar panel (99 × 69) mm^2 with an arduino uno R3 microcontroller using an arduino software coding program and using a logger pro software as data acquisition software.
2. Determination of the performance of solar cells using an automatic drive machine can improve the accuracy and precision of current and voltage readings so the fill factor might be increased up to 10% while the efficiency of solar cells does not change.
3. In testing solar cells using variations in light intensity, the increasing intensity can increase the fill factor and efficiency of solar cells. Fill factor and efficiency have an exponentially relationship to light intensity.

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