PERFORMANCE ANALYSIS OF SOLAR PANELS IN TROPICAL REGION: A STUDY CASE IN SURAKARTA INDONESIA

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ABSTRACT

The performance of solar panels affects the utilization of solar energy for daily life. This study aims to carry out the measurement of the performance of solar panels in Surakarta City is located between 110 ° 45 '15" and 110 ° 45" 35" East Longitude and between 7 ° 36" and 7 ° 56" South Latitude. Research used solar panels, current sensors, voltage sensors, temperature sensors, solar irradiance sensors, humidity sensors, Arduino and Labview. The solar panels 20 WP is used in the experiment. The measurement results obtained that the maximum energy value per day produced is 165 Wh and a minimum of 76.8 Wh with an average of 109.1 Wh. Temperature measurements were carried out in the range 37.2 ^{0} C to 41.0 ^{0}C which is the normal temperature for PV operations. The average irradiation measurement is 1834.3 W/m2 while the average humidity is 32.5%. The relationship between energy and temperature, energy with solar irradiance and energy with humidity find using Pearson Product Moment Correlation (PPMC). The result show that the effect of temperature and solar irradiance were more significant than humidity.

KEYWORDS solar panel, tropical region, energy.

INTRODUCTION

The sun is a star that has different advantages for all living beings on earth to live. The use of the sun as an energy source in Indonesia alone has not been used to the fullest. The position of Indonesia on the equator, however, has the ability to explore sunlight as an energy source. The solar radiation energy intensity in Indonesia is 4.5 kWh/m2 per day on average (Hasan et al, 2012; Tasri and Susilawati, 2014).

Indonesia is one of the developing countries in Asia, especially in Southeast Asia. In developing countries, electricity is a very important factor. Increased development, particularly in the industrial sector, economic growth, and population growth, have led to a significant increase in energy demand (Hasan et al, 2012). Energy demand is projected to continue to rise by 3 percent per year in Asia (Tasri and Susilawati, 2014), including Indonesia, of course. The government has expected, based on energy demand, that 25% of the energy supply will come from renewable energy by 2025. (Lestari, 2019). Solar energy is one possible renewable energy source that provides a replacement for fossil energy. Indonesia is situated on the equator, allowing it to benefit from solar energy availability during the day. The solar energy capacity in Indonesia is about 4.8 kWh/m2/day with a 9 percent monthly variance (Ratna et al, 2015).

In the energy sector, one of which can be utilized from the high intensity of sunlight in Indonesia is to maximize the device to convert sunlight into electrical energy called solar panels. The amount of output power produced by solar panels is influenced by several environmental conditions where a solar panel is placed such as temperature, the intensity of sunlight, the direction of sunlight and the spectrum of sunlight. Environmental conditions that always change every time cause the power output of solar panels also fluctuate (Huld et al, 2010; Ratna et al, 2015; Yousif et al, 2017).

The energy that a solar panel module generates depends on many factors. The most significant aspect is the amount of solar radiation obtained by the module of the solar panel, as well as local environment conditions, including air temperature, solar radiation, and wind speed (Huld et al, 2010). The key variables for solar panel production are solar radiation and temperature (Yousif et al, 2017). In order to determine the efficiency of solar panel systems during service in terms of success and loss analysis, analysis of the performance of solar panel systems is becoming increasingly necessary (Dolara et al, 2012). Many literature studies related to the performance of solar panel systems on the basis of measured data (Kymakis et al, 2009; Uberti et al 2010). Research on energy production and external energy from installed solar panels results in energy efficiency ranging from 6% to 9% during the day. On the other hand, the volume of external energy from the PV module is decreased from 8% to 10%. (Sudhakar and Srivastava, 2014). Several studies have been carried out to verify improvements in I-V and P-V characteristics in research related to the efficiency of solar panels that are affected by environmental effects, including dust, colour, light and shadow (Rajeshwari et al, 2015). For parameters such as voltage and current, solar panel output can be controlled directly. Data on performance of solar panels is suitable and generates the expected production power can be obtained from this study results.

MATERIALS AND METHODS

2.1 Profile Location

Surakarta City is located at a longitude between 1100 45 '15 "and 1100 45'35" east longitude and a latitude between 70 36"and 70 56" south latitude. This area is a tropical region. Surakarta City has 2 seasons, namely the rainy season and the dry season. The latitude and season in the city of Surakarta affect the received solar radiation. The duration of solar radiation is related to the length of the day (daily sunlight). The length of day in a region is related to the solar declination and latitude of an area (Nwokolo & Ogbulezie, 2018), (Budiyanto et al, 2020), (Asilevi et al, 2019):

$$\cos\left(\frac{t_\odot}{2}\right) = -\tan\left(\delta_\odot\right).\tan(\varphi) \qquad (1)$$

where :

$t_\odot$: daily sunlight

$\delta_\odot$: solar declination

φ : location latitude

The formula of solar declination in a day nd = sequence of days in 1 year, 1… 365) according to formula (2), below:

$$\delta_\odot = 23^0, 45.\sin\left[\frac{360(n_d+284)}{365}\right] \qquad (2)$$

For the calculation of solar radiation, it is formulated as formula (3) below (Asilevi et al, 2019):

$$H = \left(0.25 + 0.5 \frac{t_n}{\frac{t_\odot}{15}}\right) \left[\frac{24 \times 60}{\pi} I_{SC} . d_\odot (\frac{t_\odot}{2} \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\frac{t_\odot}{2})\right] \quad (3)$$

I_{SC} : solar constant = 1366 w/m2
$d_\odot$: distance between solar and earth (1,50 x 108 km)

The Surakarta City is located in the southern hemisphere, the sun is in the southern latitudes between September - December - March so that in theory, the length of the daily sunlight is large so that the intensity of solar radiation is also large. The months of September - March in Surakarta City are more rainy season so that solar radiation is blocked due to the weather so that the intensity of solar radiation is relatively lower. Surakarta City is in the tropics so the difference in solar radiation is also small. The distribution of solar radiation values in Surakarta is shown in Table 1.

Surakarta City Region is a low-lying area with an altitude of ± 92 m above sea level. The temperature in the city of Surakarta in 2017 ranged from 15.1 ° C to 33.5 ° C. While air humidity ranges from 69 percent to 87 percent. The most rainy days fell in January and February with a total of 24 rainy days. The sun as a source of radiation will pass through the zenith of Surakarta and its surroundings around March and September. When the sun is in the zenith of an area, the radiation intensity will be maximal regardless of weather factors.

Table 1. Average Air Pressure, Wind Speed and Solar Radiation Monthly in the Surakarta 2017

Month	Air Pressure (mb)	Wind Speed (knot)	Solar Radiation (%)	Solar Radiation in Surakarta (Kwh/m2)/month
January	10.6	4.0	42.0	220.42
February	1011.3	5.0	56.0	261.90
march	1011.5	5.0	70.0	356.91
April	1011.6	4.0	59.0	285.71
May	1012.0	5.0	67.0	330.37
June	1012.7	5.0	87.0	412.22
July	1013.4	6.0	90.0	442.43
August	1013.4	7.0	95.0	473.19
September	1013.6	6.0	75.0	367.78
October	947.0	6.0	82.0	422.81
November	976.1	4.0	41.0	207.68
December	782.3	3.0	42.0	221.39

Table 2. Average Temperature and Humidity Montly in Surakarta 2017

Month	Temperature (°C)			Humidity (%)
	Maximum	minimum	Average	
January	30.8	22.0	26.1	87.0
February	31.0	21.4	26.0	86.0
March	32.3	21.6	26.6	83.0
April	31.0	21.9	26.8	84.0
May	32.7	21.1	27.5	76.0

June	32.4	21.5	26.9	79.0
July	31.4	21.4	26.3	75.0
August	32.3	22.2	26.5	69.0
September	33.5	22.4	27.4	73.0
October	30.9	22.5	27.9	72.0
November	30.4	18.4	26.2	84.0
December	25.2	15.1	26.7	83.0

Table 3. Amount of Rainfall and Rainy Days Monthly in Surakarta City 2017

Month	Amount of rainfall (mm)	Amount of Rainy Days
January	13.60	24.00
February	19.90	24.00
March	7.80	19.00
April	9.80	22.00
May	1.00	9.00
June	4.40	9.00
July	2.60	3.00
August	0.00	0.00
September	4.70	6.00
October	3.20	12.00
November	12.80	23.00
December	5.30	16.00

2.2 System Description

In this paper the performance of photovoltaic systems in the city of Surakarta, Indonesia has been discussed. Figure 1 is a system design that is created and analyzed. The system was used to collect data in the form of voltage, current, temperature, humidity, and solar irradiation. Voltage and current data obtained from photovoltaics using sensors.

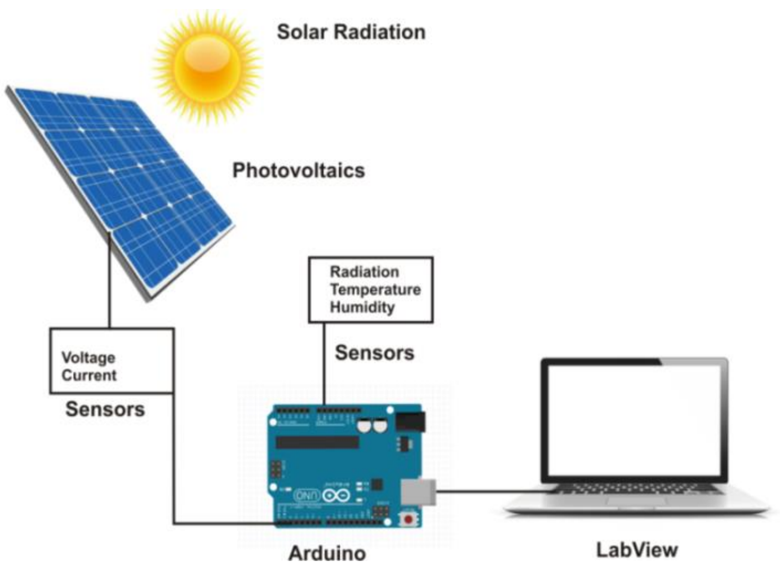


Figure 1. System Design Analyzed

2.2.1 Voltage Measurement

Voltage measurements using the voltage divider circuit shown in Figure 2. Input voltage Vin derived from a photovoltaic system and Vout signal to Arduino Board. The input of Arduino Board maximum is 5 Volt, so that the voltage output from PV must be reduced to a maximum of 5 V. Based on Table 4, the Open Circuit Voltage (Voc) condition has a voltage of 22.14 V, based on equation 1 (Vieira, 2016) Vin reduced to maximum 5 Volt with the values of R1 and R2 are respectively each is 35 KΩ and 10 KΩ.

$$V_{out} = \frac{V_{in} \times R_2}{R_1 + R_2} \quad (4)$$

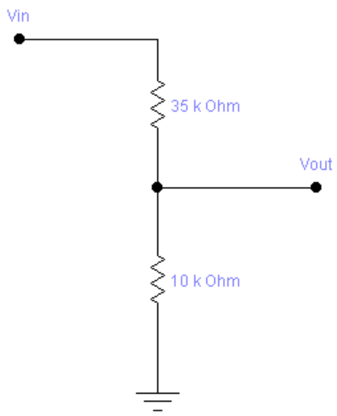


Figure 2. Voltage divider circuit

2.2.2 Measurement of Electrical Current

Measurement of electric current in this study used the ACS712ELC 30A Sensor. This sensor requires a limit of 5 V power and the outside was connected to arduino with a range of values of 2.5 V to 5 V. This sensor can calculate AC and DC voltages of up to 30 A and provides an output voltage proportional to the current being measured. The sensor output voltage is an analog output with a linearity of 66 mV / A.

2.2.3 Temperature Measurement

Temperature is a factor that influences the performance of PV (Dubey, 2013), for that it needs to be measured. In this study temperature measurements used the LM 35 temperature sensor. LM35 signal output has a linear value to the temperature value in degrees Celsius with a scale of 10 mV / ° C.

2.2.4 Measurement of Humidity

Based on (Kazem, 2015) humidity has the most influence on the performance of PV for this research, this is one of the factors used in analyzing PV performance. In this study the measurement of humidity used the DHT 22 sensor. The DHT 22 sensor is a combined sensor of a temperature and humidity sensor whose output is a calibrated digital signal. The humidity range is 0-100% RH with a humidity measurement precision of ± 2% RH. The DHT 22 sensor in the system used a different Arduino board.

2.2.5 Radiation Measurement

Radiation measurements used LDR (Light dependent resistor), the LDR output signal will be received by Arduino and converted to Solar Radiation W/m2 with reference to equation 5 (Vieira et al, 2016). The same Arduino microcontroller board was used for the solar radiation measurement system. LDR is a semiconductor device whose resistance varies in a linear manner with the incident light intensity. When it is turned on, this system decreases resistance and rises with less illumination.

$$Rad = 4464.9 \times e^{-17.73 \times Vout} \quad (5)$$

Where:
Rad is Solar Radiation,
Vout is the LDR output range read by Arduino.

2.2.6 PV Module

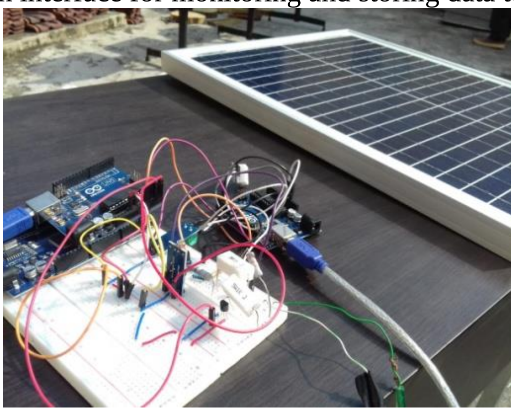
The PV Module used in this study was the Sunlite Polycrystalline 20 WP Model with the specifications in Table 4.

Table 4. PV specifications

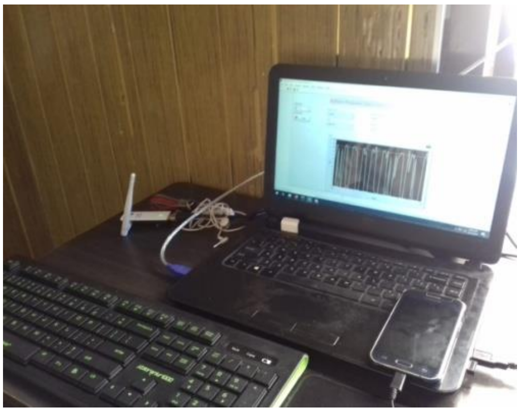
Specifications	Value
Maximum Power (Pmax)	20 W
Maximum Power Voltage (Vmp)	18.5 V
Maximum Power Current (Imp)	1.08 A
Open Circuit Voltage (Voc)	22.14 V
Short Circuit Current (Isc)	1.16 A
Maximum System Voltage	1000 VDC
Dimention	485x360x25 mm
Efficiency	15 %

2.2.7 Panel Installation

Measurement of parameters that affect the performance of PV was carried out as shown in Figure 3. PV and various sensors and Arduino were placed on a table exposed to the sun. Arduino was connected to the Laptop with the Labview program which is used as an interface for monitoring and storing data to Excel.



(a)



(b)

Figure 3. Installation of PV

RESULT AND DISCUSSION

Surakarta City is located with latitude around -70.76, located in the southern hemisphere close to the Earth's equator or it is called the tropics. The amount of solar radiation is related to the declination of the sun, the latitude of a place, weather factors and geographic location of a place (Nwokolo & Ogbulezie, 2018), (Budiyanto et al, 2020), (Asilevi et al, 2019), (Lestari et al., 2019). Surakarta City where is located in the south, should have the highest intensity of solar radiation around November, December, January, February, but in those months are the rainy season so that the highest intensity is in June - September with the peak in August. This research chose August because this month the intensity of solar radiation is high and the dry season.

Data measurements were carried out on 5 to 9 August 2019 and on 12 to 16 August 2019 the total data collection took 10 days. Measurements were made between 8:00 a.m. to 4:00 p.m. The measurement results are presented in Table 5. Based on Table 5, it can be seen that the average power produced is 109.1 Wh with the smallest value is 76.8 Wh and the highest is 165.8 Wh. This large range of differences is generally due to sunny and cloudy weather conditions.

The relationship between solar radiation energy and temperature is quite significant. Temperature is the main factor determining the amount of electrical energy produced by solar panels (Yousif, 2017). In Table 5, it can be seen that measurements were made in a temperature range of 37.20C to 41.00C, this measurement temperature is below the maximum operational temperature of PV at 500C (Vieira, 2016). Normally the higher the temperature, the greater the amount of electrical energy emitted by solar panels. The results of the study show the relationship between energy and temperature, as in Figure 4.

Table 5. PV Performance Data

Day	Energi (Wh)	Iradiation (W/m2)	Temperature (^{0}C)	Humidity(%)	Weather condition
5-8-2019	159.1	2009.3	39.8		Sunny
6-8-2019	129.2	2071.3	38.8		Sunny
7-8-2019	85.8	1946.4	37.2		Cloudy
8-8-2019	82.1	1656.3	37.9	32.2	Cloudy
9-8-2019	89.1	1691.9	41.0	29.2	Cloudy
12-8-2019	76.8	1796.8	40.2	33.0	Cloudy
13-8-2019	77.7	1708.2	39.0	34.1	Cloudy
14-8-2019	117.8	1856.7	39.2	33.4	Sunny
15-8-2019	107.4	1699.0	39.7	34.1	Sunny
16-8-2019	165.8	1906.7	39.6	31.2	Sunny
Average	109.1	1834.3	39.2	32.5	-

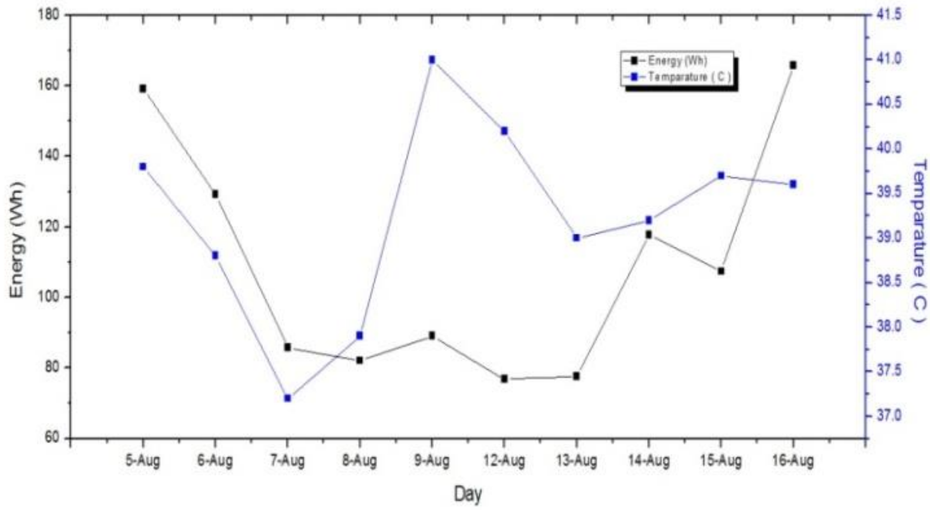


Figure 4. The Curve Solar Energy and Temperature

Sunny or cloudy conditions affect the energy output of the solar panels. The results of research that show the relationship between energy and power when cloudy are shown as shown in figure 5. The results of research that show the relationship between energy and power when sunny are shown in Figure 6.

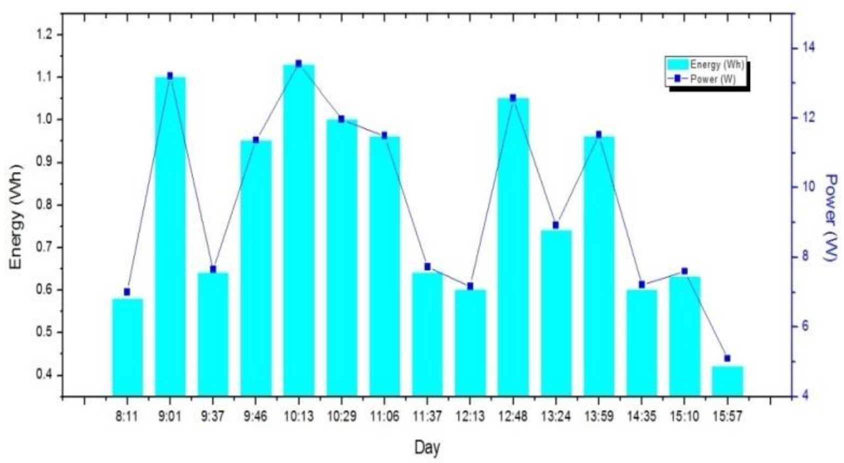


Figure 5. The Relationships Between Energy and Power in Cloudy Conditions

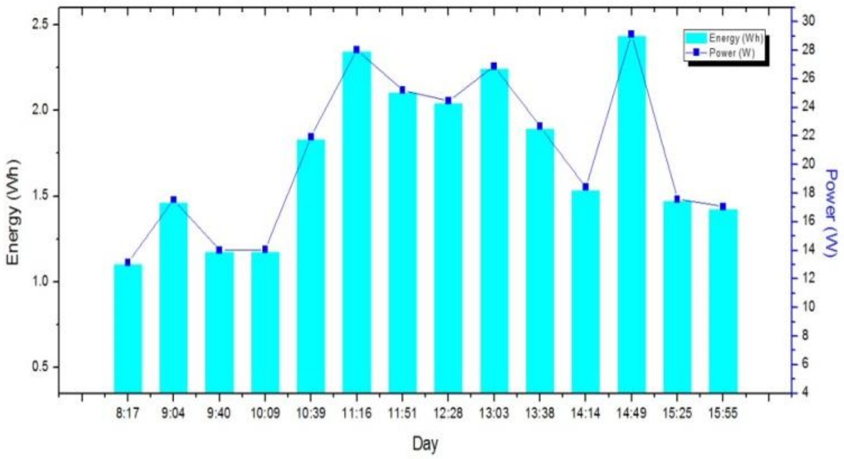


Figure 6. The relationship Between Energy and Power in Sunny Conditions

Solar irradiance greatly affects the electrical energy produced from solar panels (Yousif et al, 2017). Solar irradiance depends on the amount of radiation reaching the Earth's surface. The luminosity of the Sun and the distance from the earth to the sun affect the Solar Irradiance. The results of the study show the relationship between energy and irradiation, as shown in figure 7.

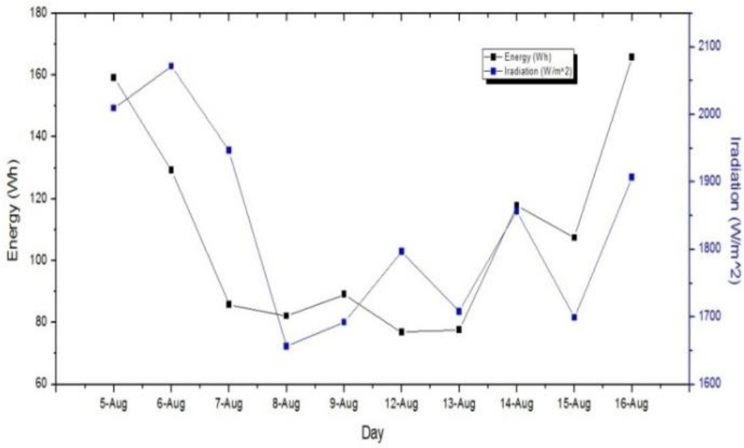


Figure 7. The Relationships between Energy and Solar Irradiance

Humidity is a weather factor that affects the energy output of solar panels. Effect of humidity is not as strong as temperature and solar irradiance. The results of the study show the relationship between energy and humidity as shown in figure 8 below:

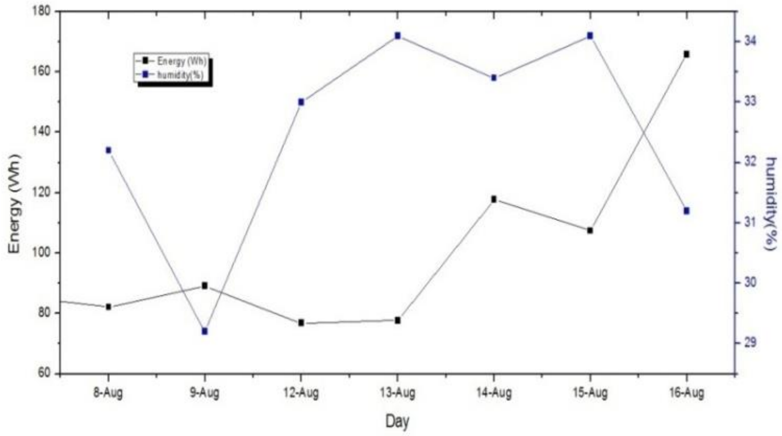


Figure 8. The Relationships between Energy and Humidity

The solar cell does not rely on the magnitude of the silicon field region in generating electrical energy (the sunlight energy becoming /photon) and can continuously generate energy in the range of ± 0.5 volts up to 600 mV at 2A, with a solar radiation power of 1000 W / m2 = '1 Sun' producing an electrical current (I) of about 30 mA / cm2 per solar cell. When the cell temperature remains normal, solar cells will work optimally (at 250C). An increase in the temperature of 10 Celsius solar cells (from 250C) will decrease the voltage value (Voc) Any increase in the temperature of 10 Celsius solar cells (from 250C) will decrease the total power created by about 0.4 percent or will double (2x) the fold for the increase in the temperature of the cell per 100C (Yadav, 2012). Solar radiation from different places on Earth varies and depends very much on the state of the Earth's solar spectrum. The solar insulation would have a little effect on the voltage of the current (I). Solar cell arrays can help cool the surface temperature of glasses in the solar cell array (Tamizharasi, 2014). The state of the atmosphere of the earth is gloomy, the form of particles of air dust, smoke, water vapor (Rh), fog and pollution significantly influence the maximum effects of electrical current from a solar cell line. It is necessary to optimize the orientation of the solar cell series (arrays) towards the sun so that the panel/solar cell series can generate maximum energy (El-Ghonemy, 2012).

The intensity of solar radiation influences the amount of output of the solar panel, where the low intensity of the power produced is low, while the high intensity of the power generated will also increase. The amount of solar radiation intensity in a location depends on the sun's altitude and declination. If the Sun is at the zenith of the observer, the strength of the Sun is maximum. As a result of the revolution of the Earth to the sun, the declination of the sun also alters (Celik, 2013). The sun does not always move through the zenith of the observer. This research was carried out near the equator at latitudes 7 ° 36' and 7 ° 56' in the South Latitude region. Every day, the sun reverses the meridian of the observer. From morning to noon, the solar radiation intensity will increase and fall down at dusk. In this study observations were made in August, the location of the sun north of the equator. August is the dry season so that solar radiation can be obtained every day. Cloudy disturbance can occur. The sun moves south and around on September 23rd declination of sun 00.

Pearson Product Moment Analysis Correlation uses the correlation coefficients of energy and irradiation, temperature, humidity, and (PPMC). In order to determine the degree or intensity of a relationship between samples, Pearson Product Moment Correlation (PPMC) is widely used. Generally speaking, the r values (generated from PPMC) range from -1 to 1, with a correlation of 1 indicating a perfect positive linear relationship and a correlation of -1 indicating a perfect negative linear relationship. It is possible to determine the coefficient using the following equation (Asri et al, 2016):

$$r = \frac{\mathbf{n}(\sum \mathbf{xy}) - (\sum \mathbf{x})(\sum \mathbf{xy})}{\sqrt{\left[[\mathbf{n}\sum \mathbf{x^2} - (\sum \mathbf{x})^2][\mathbf{n}\sum \mathbf{y^2} - (\sum \mathbf{y})^2]\right]}} \quad (6)$$

where

n = number of pairs of scores;

$\sum \mathbf{xy}$ = sum of the products of the paired scores;

$\sum \mathbf{x}$ = sum of x scores;

$\sum \mathbf{y}$ = sum of y scores;

$\sum \mathbf{x^2}$ = sum of squared x scores;

$\sum \mathbf{y^2}$ = sum of squared y scores

The correlation coefficient is ranging between-1.0 and +1.0.The positive coefficient means a positive relationship between the two variables and verse versa for the negative coefficient (Kazem and Chaichan, 2015). The correlation coefficients from the table 5 between Energy and irradiation, temperature, humidity are 0.965,0.951 and 0.949 respectively. This mean that the correlation is positive and the correlation irradiation and temperature is dominant than that humidity.

CONCLUSION

Measurement of energy output generated from solar panels or PV depends on solar panel performance factors and external factors. The measurement of PV performance in Surakarta City. It is located between 110 ° 45 '15 "and 110 ° 45" 35 "East Longitude and between 7 ° 36" and 7 ° 56 "South Latitude. The results showed that the solar panel energy output was influenced by weather factors and solar irradiance. The measurement results showed the relationship of energy output with temperature, solar irradiance and humidity. Temperature and solar irradiance factors show a significant effect. The irradiation and temperature is dominant effect than that humidity for energy output of PV.

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