Measuring the commercial solar panel performance

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Abstract. Solar panel operation depends on sunlight intensity where solar panels are placed. This study aims to design a real-time monitoring device for measuring the performance of solar panels. From the assessment sample, the designed device is successfully measure the parameters of solar panel characteristics and environmental parameters. The designed monitoring system is also able to identify the effect of wind speed and humidity.

1. Introduction

Solar panels are the main equipment of solar power generation system that serves to directly convert solar light energy into electrical energy. The output power generated from the conversion process is determined by some environmental conditions where solar panels are placed, such as the intensity of the sun, the temperature and the direction of sunlight [1-3]. Environmental conditions that are constantly changing over time causes the solar panel output power also fluctuate. In order to determine the power output, radiation level of 1000 W/m² at 25°C with light angle perpendicular to solar panel and air mass spectrum 1.5 are selected [4,5].

Apart from environmental factors that affect the output of solar panels, the type of solar panels used in generating electrical energy also greatly affects the amount of electrical power it generates [6,7]. This paper reports the design of solar panel measurement device. Besides voltage and current, the effect of wind speed and humidity on solar panel is also determined. Existing devices are available such as in [8, 9] which are correlating the solar cell capacities to solar cell position. The device proposed in this paper is aimed to compare two solar panel characteristics in the fairly way.

2. Circuit design

Figure 1 shows the designed circuit where some sensors are controlled by the controller. The chosen controller is Arduino module as it gives quick and easy set up. Sensors to measure solar panel and environment parameters include voltage, current, temperature, wind speed, humidity and solar radiation.

In order to read voltage and current generated by solar panel, DC voltage sensor and ACS712 current sensors are employed. DS18B20 is used to determine environment temperature. Humidity sensor makes use of DHT11 which has a negative temperature coefficient thermistor. A piranometer is used to measure solar radiation in watt per meter unit. An anemometer is employed for measuring wind speed.
The voltage sensor used is a voltage sensor module that uses the principle of voltage divider. This module can reduce the input voltage up to 5 times from the original voltage. The maximum analog input voltage of the microcontroller is 5 volts so that the voltage module input not exceeding 5 x 5 Volts or by 25 Volts. The Arduino analog pin can receive values up to 10 bits so as to convert analog data to 1024 states. This means that 0 represents a voltage of 0 volts and a value of 1023 represents a voltage of 5 volts.

Hall effect Allegro ACS712 is a precise sensor as AC or DC current sensor in current readings in industrial, automotive, commercial and communication systems. In general, this sensor application is usually used for motor control, electrical load detection; switched-mode power supplies and overload protection.

The DS18S20 temperature sensor has a digital output even though it is small (TO-92), the way to access it is by serial 1 wire method. This sensor greatly saves pin port microcontroller, because 1 pin microcontroller port can be used to communicate with some other devices. This sensor also has a fairly high accuracy of 0.5 °C in the temperature range -10 °C to +85 °C, so it is widely used for temperature monitoring system applications.

Wind is a vector that has magnitude and direction. The magnitude means the speed while the direction means where the wind comes from. Wind speed is calculated from the wind counter (cup counter anemometer) divided by time (length of measurement period). The direction of the wind is indicated by a wind-vane connected by a wind direction device or in a number. Wind flow or wind movement is generally measured by means of anemometer, in which there are two sensors, namely: cup counter sensor for wind speed and wind vane sensors for wind direction.
DHT11 sensor is one of the sensors that can measure two parameters at once, namely temperature and humidity (humidity). In this sensor there is a NTC (Negative Temperature Coefficient) type thermistor to measure temperature, a resistive humidity sensor and an 8-bit microcontroller that processes both sensors and sends the result to the output pin in a single-wire bidirectional format. Figure 10 shows the air humidity sensor.

The pyranometer is a type of the actinometers used to measure solar irradiation on a flat plane. The pyranometer has a sensor that can measure the density of solar radiation flux in units of watts per square meter. The pyranometer is also called a solar meter. It function by being mounted on a surface of the field and then by light hitting exactly at light sensor it will be forwarded to the computer display in the form of the diminution of the magnitude of the given flux of light.

3. Implementation results

Figure 2 shows the implementation of solar panel measuring device with two solar panels to be measured and compared. The measurement output is printed in a text file. The measurement results are compared to standard measurement devices, error of measurement is then determined.

Table 1 shows a sample of the current measurement comparison between the designed device and ampere meter. In this measurement sample, measurements are repeated ten times. The presented data is from one of the solar panel modules. The ampere meter, device measurement and the error of measurement are shown.

| Measurement | Time    | Amperemeter (A) | Device (A) | Error (%) |
|-------------|---------|-----------------|------------|-----------|
| 1           | 13:58:58| 4.25            | 4.18       | 1.64      |
| 2           | 13:52:00| 4.25            | 4.26       | 0.23      |
| 3           | 13:52:01| 4.24            | 4.18       | 1.41      |
| 4           | 13:52:03| 4.21            | 4.18       | 0.71      |
| 5           | 13:52:05| 4.16            | 4.11       | 1.20      |
| 6           | 13:52:07| 4.10            | 4.04       | 1.46      |
| 7           | 13:52:08| 4.05            | 3.96       | 2.71      |
| 8           | 13:52:10| 4.01            | 3.96       | 1.24      |
| 9           | 13:52:12| 3.95            | 3.96       | 0.25      |
| 10          | 13:52:14| 3.90            | 3.81       | 2.30      |
Table 2 shows the sample of voltage measurement comparison between the designed device and voltmeter. Likewise, by measuring ten times, the voltmeter measurement, device measurement and error are shown.

| Measurement | Time       | Voltmeter (V) | Device (V) | Error (%) |
|-------------|------------|---------------|------------|-----------|
| 1           | 12:12:23   | 19.22         | 19.16      | 0.31      |
| 2           | 12:12:25   | 19.29         | 19.16      | 0.67      |
| 3           | 12:12:27   | 19.26         | 19.18      | 0.41      |
| 4           | 12:12:29   | 19.27         | 19.18      | 0.46      |
| 5           | 12:12:31   | 19.25         | 19.18      | 0.36      |
| 6           | 12:12:32   | 19.25         | 19.18      | 0.36      |
| 7           | 12:12:38   | 19.23         | 19.16      | 0.36      |
| 8           | 12:12:39   | 19.22         | 19.13      | 0.46      |
| 9           | 12:12:41   | 19.18         | 19.11      | 0.36      |
| 10          | 12:12:43   | 19.17         | 19.11      | 0.31      |

Table 3 shows the sample of temperature measurement comparison between the designed device and PHB-318. By measuring ten times, the measurement results from device and PHB-318 can be compared.

| Measurement | Time       | PHB-318 (°C) | Device (°C) | Error (%) |
|-------------|------------|--------------|-------------|-----------|
| 1           | 12:12:23   | 44.26        | 44.81       | 1.24      |
| 2           | 12:12:25   | 44.26        | 44.81       | 1.24      |
| 3           | 12:12:27   | 44.26        | 44.81       | 1.24      |
| 4           | 12:12:29   | 44.01        | 44.56       | 1.25      |
| 5           | 12:12:31   | 43.51        | 44.06       | 1.26      |
| 6           | 12:12:32   | 43.14        | 43.69       | 1.27      |
| 7           | 12:12:34   | 44.01        | 43.56       | 1.25      |
| 8           | 12:12:36   | 43.55        | 43.50       | 1.26      |
| 9           | 12:12:38   | 42.45        | 43.56       | 1.29      |
| 10          | 12:12:39   | 43.01        | 43.69       | 1.27      |

Sample of impact of humidity, wind speed, to solar panel performance can be redrawn in table 4 and plotted as in figure 2. Although to produce precise characteristic requires long period measurement, the result proofs that the designed device works as expected and is able to determine environment parameter impact to solar cell outputs.

The efficiency of the measured solar cell is calculated from the measured power and the measured radiation comparisons. As from the measurement sample, the efficiency of solar panel decreases as humidity of environment increase. Once again, this characteristic is drawn as a proof that device works properly. Precise results require intensive and long period measurement.

Likewise, as from the sample, the efficiency decreases when air speed increases. However, the more heat from the sun which increases temperature causes efficiency increases. Again, intensive measurement is required to produce precise results.
Table 4. Sample of the environment impact determination

| Humidity (%) | Wind speed (mps) | Temp (°C) | Voltage (V) | Current (A) | FF | Calculated Power (W) | Measured Radiation (W) | Efficiency (%) |
|--------------|------------------|-----------|-------------|-------------|----|----------------------|------------------------|---------------|
| 33.00        | 1.00             | 45.00     | 21.25       | 5.12        | 0.82| 88.79                | 390.73                 | 22.72         |
| 32.00        | 1.00             | 43.00     | 21.66       | 4.81        | 0.82| 85.30                | 396.61                 | 21.51         |
| 31.00        | 1.00             | 42.00     | 21.49       | 5.18        | 0.82| 91.01                | 392.69                 | 23.18         |
| 30.00        | 1.00             | 43.00     | 21.56       | 5.35        | 0.82| 94.35                | 392.69                 | 24.03         |
| 29.00        | 1.00             | 44.00     | 21.42       | 5.14        | 0.82| 89.97                | 392.61                 | 22.92         |
| 28.00        | 1.00             | 45.00     | 21.39       | 5.25        | 0.82| 91.75                | 394.65                 | 23.25         |
| 26.00        | 2.00             | 47.00     | 21.49       | 6.87        | 0.82| 120.71               | 383.55                 | 31.47         |
| 27.00        | 2.00             | 46.00     | 21.17       | 5.95        | 0.82| 102.73               | 378.32                 | 27.16         |
| 28.00        | 2.00             | 45.00     | 21.12       | 5.28        | 0.82| 90.93                | 380.28                 | 23.91         |
| 29.00        | 2.00             | 44.00     | 21.08       | 4.92        | 0.82| 84.54                | 378.97                 | 22.31         |
| 30.00        | 2.00             | 43.00     | 21.08       | 4.22        | 0.82| 72.51                | 380.28                 | 19.07         |
| 31.00        | 2.00             | 44.00     | 21.05       | 4.59        | 0.81| 78.74                | 380.93                 | 20.67         |
| 26.00        | 3.00             | 52.00     | 20.61       | 4.91        | 0.81| 82.18                | 386.16                 | 21.28         |
| 27.00        | 3.00             | 50.00     | 21.32       | 5.88        | 0.82| 102.37               | 397.27                 | 25.77         |
| 30.00        | 3.00             | 42.00     | 20.78       | 3.54        | 0.81| 59.82                | 384.85                 | 15.54         |
| 31.00        | 3.00             | 42.00     | 20.51       | 3.57        | 0.81| 59.41                | 379.63                 | 15.65         |
| 32.00        | 3.00             | 42.00     | 20.83       | 3.61        | 0.81| 61.17                | 386.16                 | 15.84         |

Figure 3. Sample of the environment parameters impact determination to solar panel efficiency

4. Conclusions

This paper has reported solar panel measurement device design where the environment and solar panel parameters are measured. Samples of measurements show that the designed device is able to determine environment impact to solar panel outputs. As from the sample data, the increments of humidity and wind speed cause decrement of efficiency. On the other hand, increase of environment temperature means increase on sun light that results increment of efficiency. Those statements are taken from sample short data as proofs that the designed
device works as its purpose. Precise results can be obtained only by intensive long period measurement.

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