Assessment of in-house build low cost solar panel simulator

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Abstract. It is well known that solar simulator is a very important equipment in solar panels research and development (R&D). Solar simulator is mainly used to assess the efficiency of solar panels. However, the cost to acquire such system is expensive and prone to malfunction when used repeatedly. The cost to repair solar simulator when malfunction is also expensive and time consuming. As an alternative, low cost solar simulator has been built independently by a group of researcher from Faculty of Electrical Engineering Technology (FTKE), University of Malaysia, Perlis (UniMAP) using 88 GU-10 halogen bulbs. This paper presents the assessment of the in-house build low cost solar panel simulator. The simulator was tested in three separate experiments to plot the current-voltage (IV) curve. The IV curves obtained from these experiments were analysed to determine the irradiance input (in Wm$^{-2}$) of the solar simulator. Results have shown that the in-house build solar simulator has an input of 350 ~ 400 Wm$^{-2}$ if solar panels are suspended 20 cm above the halogen bulbs.

1. Introduction
Solar simulator is a man made artificial sunlight. Although it cannot 100% emulate the characteristic of sunlight irradiance, it is the accepted testing method among the academics and industries around the world. Evaluating the solar panel’s efficiency outdoor with real sunlight is not doable due to temperature and sunlight irradiance that keep changing every time. That is why owning a solar simulator is essential to enable the R&D works to be carried out indoor in a controlled condition.

Owning a solar simulator will open up other branch of solar photovoltaic R&D. For example, the effects of partial shading in series or/and parallel connections [1]. However, the high cost of owning a sophisticated, easy to use solar simulator may become a hurdle for any researcher who wishes to embark in photovoltaic R&D. In addition, if the solar simulator becomes malfunction, huge expense is also needed to repair the equipment and the process is also time consuming. Due to these reasons, a group of researchers from FTKE, took an effort to build a low cost solar simulator as show in Figure 1.
The solar simulator are built with two modules (A and B). So by having two modules, two solar panels can be placed side by side. So it is possible to do the series or parallel connection when two panels are adjacent to each other. The beams shown in these figures are used to adjust the height of the solar panels. Altogether, there are 4 beams installed. Two beams each at the front and rear. The distance between the front and rear beams is 62 cm.

There are 44 GU-10 halogen bulbs installed at each module. The brightness of the bulbs are controlled by dimming knobs located inside the metal box attached to the frame (refer to Figure 1(a)). Halogen bulbs are chosen for this project due to low cost and ease of controlling the brightness. Each of the bulb are rated at 50 W. This solar simulator uses standard 240 Vrms, 50 Hz single phase supply. The cost to built the solar simulator is RM 2500 (or USD 600).

The measurement of the irradiance was proven to be difficult by using TES1333R solar power meter. This device is unsuitable to measure the irradiance from the solar simulator. So alternatively, IV measurement has to be carried out to determine the irradiance input. In this work, three separate experiments have been carried out to obtain the IV curves.

Based on the IV curves, the maximum power can be determined. In return, the input irradiance can also be estimated.

2. Methodology

Standard test condition (STC) for solar panels must have two important parameters to be kept constant. Firstly, the temperature of solar cell itself has to be 25°C. Secondly, the irradiance of light is kept constant at 1000 Wm⁻² [2,3]. In this section, three experiments were conducted. Meaning, three IV curves have been acquired. The first experiment was conducted using single solar panel. For the second and third experiments, series and parallel connections were utilized. The electrical connections of all experiments are shown in Figure 2.
Figure 2. (a) Single panel (b) series and (c) parallel connection for IV measurements

The temperature of the solar panels was kept constant at 25°C with the help from Fluke 62Max infrared thermometer. The distance between the solar panels and the light source is 20 cm. The 47 Ω ± 5% variable resistor used in this experiment has power rating at 20 W. The solar panels used were from monocrylalline type with the maximum output power of 50 W according to the data provided by the manufacturer [4]. Details of the important parameters are stated in Table 1.

Table 1. The manufacturer’s data of the 50 W solar panel [4]

| Parameter                        | Value       |
|----------------------------------|-------------|
| Maximum power (W)                | 50 W        |
| Voltage at maximum power (V_{mp})| 18.68 V     |
| Current at maximum power (I_{mp})| 2.68 A      |
| Open circuit voltage (V_{oc})    | 22.32 V     |
| Short circuit current (I_{sc})   | 2.86 A      |

Before the variable resistor was included in the circuit, the short circuit current (I_{sc}) and open circuit voltage (V_{oc}) were measured. Every time the resistance value was changed, the current and voltage across the variable resistor were measured using digital multimeters. For every case, 15 measurements were carried out.

The brightness of the bulbs was adjusted to the maximum for every measurement. The reading at the multimeters has to be recorded as quick as possible because high temperature originated from the bulbs would fluctuate the voltage and current reading. After the readings were recorded, the bulbs were completely turned off and allow the temperature of solar panels to drop to 25°C. The time taken was normally between 5 to 10 minutes. When the temperature dropped to 25°C or slightly below, the resistance was increased to about 3~4 Ω higher than previous value. Then, the new voltage and current readings were recorded again.

3. Results and Discussion
Result of the IV measurements for single panel, series and parallel connections are tabulated in Table 2. During the measurements, only the current and voltage across the variable resistor were measured. The power absorbed by the resistor was calculated using P = VI formula. For every set of measurement, the power at I_{sc} and V_{oc} are equal to zero. The italic numberings shown in Table 2 indicate the
measurements of $I_{sc}$ and $V_{oc}$. As shown in Table 2, the maximum power for single panel, series and parallel IV measurements are 17.75 W, 34.55 W and 33.67 W respectively.

The $I_{sc}$ of the single panel is equal to 1.29 A which is far below the data provided by the manufacturer (refer to Table 1). However, the $V_{oc}$ (21.13 V) measurement shows that the value is close to the manufacturer’s data. The panel delivered highest power to the load when the resistance is equal to 17.2Ω.

For the series connected solar panels, both panels delivered short circuit current of 1.43 A. This is higher compared to the single panel. The reason for the slightly higher current in the series connection is due to the measurement that was conducted at the different time and day. Solar panels can have fluctuation in the current reading due to the presence of defects. However, the $V_{oc}$ (21.13 V) measurement shows that the value is close to the manufacturer's data. The panel delivered highest power to the load when the resistance is equal to 17.2Ω.

In the parallel connection experiment, both solar panels have produced the $I_{sc}$ of 2.68 A. Parallel connection always produce high current because it sum up all of the individually produced current from each panel. However, in this kind of connection, the $V_{oc}$ is 21.14 V, which is very close to the single panel value. The highest power (33.67 W) is seen when the current, voltage and resistance equal to 2.02 A, 16.67 V and 8.8 Ω respectively.

Table 2. The readings of current and voltage from three different experiments. The power calculated based on $P = VI$ formula.

| Single panel | Series connection | Parallel connection |
|--------------|-------------------|--------------------|
| Current (A) | Voltage (V) | Power (W) | Current (A) | Voltage (V) | Power (W) | Current (A) | Voltage (V) | Power (W) |
| 1.29 | 0.00 | 0.00 | 1.43 | 0.00 | 0.00 | 2.68 | 0.00 | 0.00 |
| 1.21 | 5.00 | 6.05 | 1.34 | 5.64 | 7.56 | 2.35 | 12.00 | 28.20 |
| 1.17 | 8.60 | 10.06 | 1.31 | 9.51 | 12.46 | 2.02 | 16.67 | 33.67 |
| 1.14 | 12.10 | 13.79 | 1.29 | 14.90 | 19.22 | 1.46 | 18.30 | 26.72 |
| 1.11 | 15.29 | 16.97 | 1.27 | 18.80 | 23.88 | 1.20 | 18.76 | 22.51 |
| **1.02** | **17.40** | **17.75** | **1.26** | **22.80** | **28.73** | **0.97** | **19.30** | **18.72** |
| 0.90 | 18.34 | 16.51 | 1.19 | 26.60 | 31.65 | 0.85 | 19.56 | 16.63 |
| 0.80 | 18.89 | 15.11 | 1.13 | 28.91 | 32.67 | 0.75 | 19.76 | 14.82 |
| 0.69 | 19.40 | 13.39 | 1.10 | 30.20 | 33.22 | 0.65 | 19.90 | 12.94 |
| 0.61 | 19.60 | 11.96 | 1.05 | 32.60 | 34.23 | 0.59 | 20.05 | 11.83 |
| 0.55 | 19.70 | 10.84 | **0.99** | **34.90** | **34.55** | 0.54 | 20.25 | 10.94 |
| 0.51 | 19.92 | 10.16 | 0.93 | 36.00 | 33.48 | 0.49 | 20.34 | 9.97 |
| 0.56 | 20.00 | 9.20 | 0.86 | 37.10 | 31.91 | 0.47 | 20.50 | 9.64 |
| 0.43 | 20.50 | 8.82 | 0.81 | 37.65 | 30.50 | 0.44 | 20.90 | 9.20 |
| **0.00** | **21.13** | **0.00** | **0.00** | **42.40** | **0.00** | **0.00** | **21.14** | **0.00** |

Figure 3 shows the IV curve for single panel. This figure is produced from Table 2 where the current and voltage are represented at the vertical and horizontal axis respectively. The point where the current and voltage produces the highest power is shown as $P_{max}$.

The kink shown near the 20 V, is due to the fluctuation of reading that occurred during the experiment. When the bulbs are turned on, sometimes, the voltage reading can ‘shoot’ away from the original curve. The deviation of voltage reading at the multimeter possibly due to the low sensitivity of the multimeter to read small current at high voltage.
The fill factor (FF) calculated from this Figure is equal to 0.65. This is less than 0.78 provided by manufacturer. Lower FF is an indication that the presence of external resistive load will alter the shape of IV curve.

![Figure 3](image-url)  
**Figure 3.** The IV curve of a single solar panel

**Figure 4** shows the IV curve of two solar panels in series connection. Similar to **Figure 3**, the maximum power point on the IV curve is also shown. This IV curve however, does not show any kink. The FF calculated from this figure is 0.57.

![Figure 4](image-url)  
**Figure 4.** The IV curve of two solar panels in series connection

The IV curve of the two solar panels in parallel connection is shown **Figure 5**. Similar to **Figure 3**, these panels also produces kink at 20 V. As stated before, the presence of kink is related to the fluctuation in recording the voltage value at that point. The FF calculated for **Figure 5** is 0.6.
Figure 5. The IV curve of two solar panels in parallel connection

From the results shown, it is obvious that the in-house build solar simulator does not produce irradiance close to 1000 Wm$^{-2}$ if the panels are suspended 20 cm above the bulbs. If the irradiance was close to 1000 Wm$^{-2}$, the power delivered to the load should be in the range of 45–50 W for single panel or 90–100 W for double panels.

Three experimental results have shown that the open circuit voltages measured are close to the manufacturer’s data. However, low current observed in these experiments contributed to the lower conversion efficiency of the tested solar panels.

This observation agrees well with other scientific publications [6,7,8]. If irradiance is reduced, the $I_{sc}$ will also reduced. Lower irradiance will slightly reduce the $V_{oc}$. However, $V_{oc}$ is largely affected by temperature.

Smaller FF observed in series and parallel connection shows that connecting two or more solar panels will increase the overall series resistance.

4. Conclusion
This paper has presented the experimental results from three set of experiments to determine the input irradiance coming from the 88 halogen bulbs. As all of the results from the IV curves have shown, the output power of the solar panels come close to about ~18 W for single and ~35 W for dual panels respectively. These output power are about 64–65% lower compared to the data provided by the manufacturer. If we assume that by having irradiance of 1000 Wm$^{-2}$ the 50 W of output can be delivered to the load (or 100 W for dual panels), then the input irradiance of the 44 halogen bulbs is equals to 350–360 Wm$^{-2}$. The irradiance of ~400 Wm$^{-2}$ might be seen if the experiments were conducted without connecting the panels with resistive load.

The results have shown that the irradiance of 44 GU-10 halogen bulbs does not produce the irradiance close to 1000 W/m$^2$. The low irradiance of solar simulator could be attributed to inefficiency of halogen bulbs in converting electrical energy to visible light. It is well know that incandescent and halogen lamp produce light through heating of tungsten filament. So more than 90% of electrical energy is converted to heat [9]. The way forward is to redesign the module and use more efficient light source such as LED.

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