Design, construction and characterization of a steady state solar simulator

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Photovoltaic (PV) cells and modules are rated at standard test conditions (STC: 1000W/m^2 irradiance, 25^{o}C temperature and AM1.5 global spectrum). This standard allows the measurement of PV performance only, without the effect of varying the temperature, irradiance and spectrum. Measuring the outdoor performance of photovoltaic cells and modules is important, but it's unlikely that the outdoor conditions at any instant ever repeat itself. The aim of this study is therefore to design, construct and characterize a solar simulator. A solar simulator is used because it provides illumination that approximates the intensity and spectral distribution of natural sunlight and it also provides a controllable indoor test facility. This simulator is using halogen lamps as the source of light and is used to accurately measure the I-V characteristics of various PV cells and modules under STC. The simulator can also be used to measure the I-V characteristics when the temperature, irradiance and spectrum are varied. The final paper will present the design and a detailed characterization of the simulator. Initial STC measurements of various PV technologies will be presented.

1. Introduction

The measurement of solar cells is a very important task and should be completed at least every three months, because the lamps and power outputs of simulators change overtime, which can lead to less than optimal results

A steady state solar simulator was designed, constructed and characterised. The simulator will be used to characterise various modules under the standard test condition (S.T.C: irradiance = 1000 W/m^2, temperature = 25°C and M1.5 global spectrum). The simulator adheres to STC conditions when the lamps are 60 cm away from the module.

2. Method

Figure 1 below shows the schematic diagram of the simulator. The simulator consists of the following: 6 halogen lamps (500 W each), a 1.5 m x 1 m frame, photovoltaic performance monitoring system (PVPM), spectrometer, a pyranometer and a computer system.

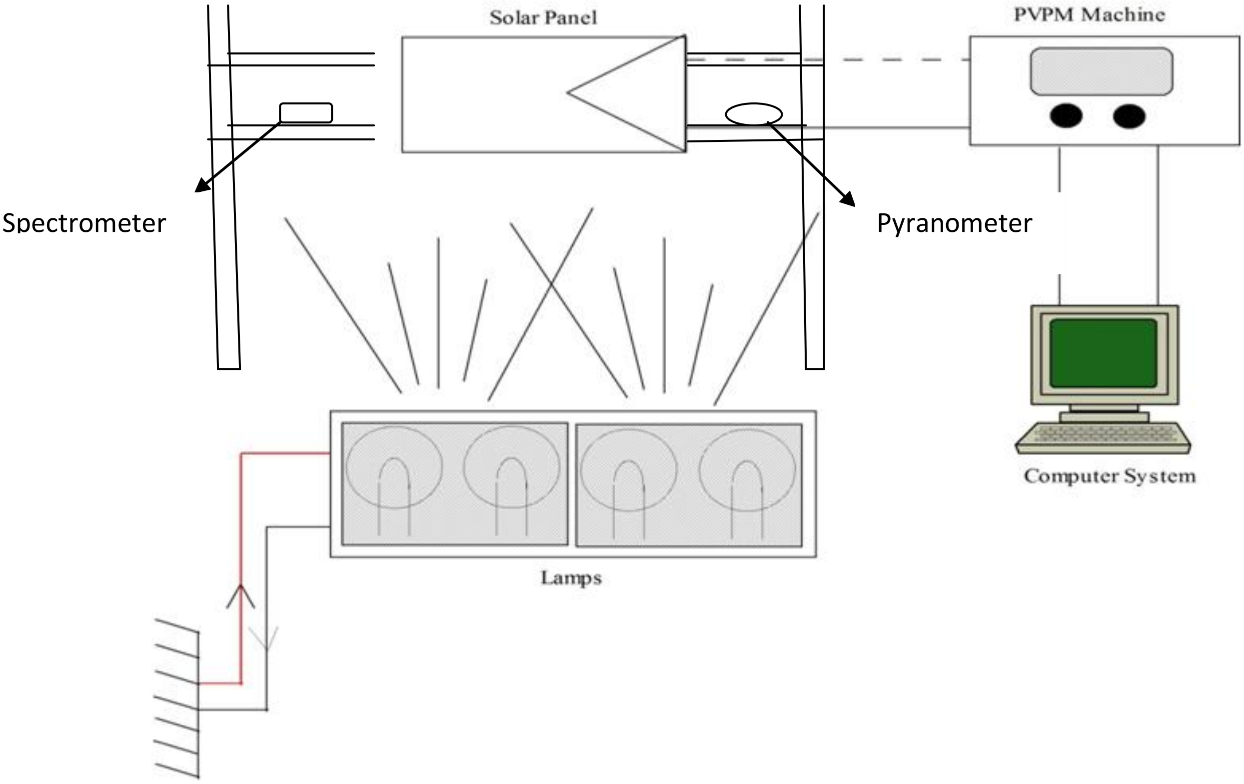

Figure 1: The schematic diagram of the simulator.

The simulator was characterized at different distances to determine the position where the irradiance is 1000 W/m^2 and above. The simulator was also used to characterise different technologies under STC.

3. Solar Energy

The sun radiates energy in all directions. The energy needs to travel about 155 million kilometers to reach the outside of atmosphere of the earth and by that time it will be reduced to a density of 1367 W/m^2 , which is referred to as the solar constant at air mass zero (AM0) [Messenger and Venture, 2000]. The maximum radiation that strikes the earth's surface, takes place when the sunlight is directly overhead and the sunlight has the shortest path length through the atmosphere. The path length could be approximated by 1/cosϕ, where ϕ is the angle between the sun and the point directly overhead and this path length is usually referred to as the air mass (AM) through which solar radiation must pass to reach the earth's surface which implies that AM = 1/cosϕ. When ϕ=48.2 then the air mass is equals to 1.5 or 'AM1.5'.Figure 2 shows the normalized spectral distributions of AM0, AM1.5 , Xenon lamps and the Halogen lamps.

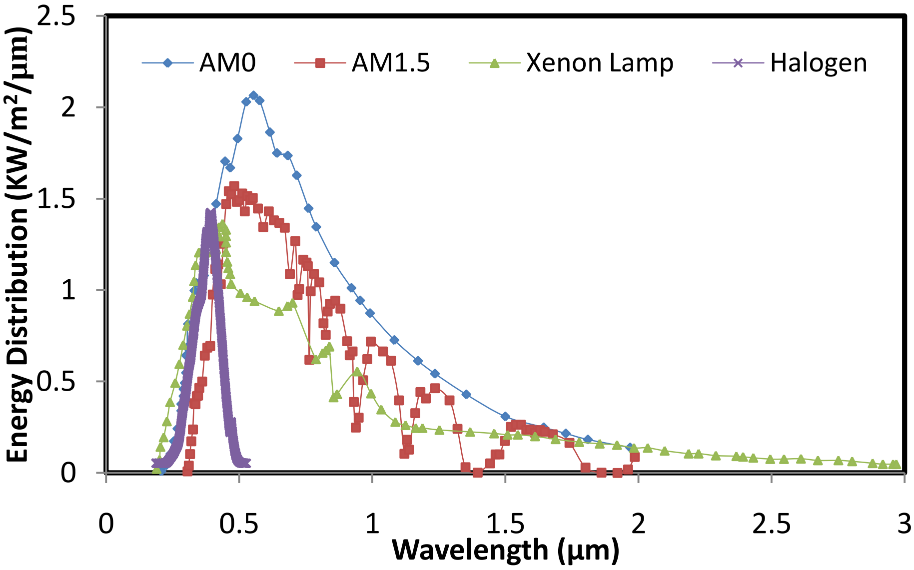

Figure 2: The spectral distribution of sunlight outside the earth's atmosphere (AM0), at the surface of the earth (AM1.5) when the solar altitude is 41.8^o, Xenon lamp and the halogen lamp.

4. Characterization of the Simulator

4.1 Irradiance level

The purpose of the solar simulator is to provide a controllable indoor test facility under laboratory conditions and is used for testing or characterizing the solar cells or modules. Six lamps (3000 W) were used as the source of light in this simulator. Table 1 shows the irradiance and the percentage difference of irradiance at various distances. It can be observed from the table that as the lamps are moved away from the frame, then the irradiance decreases and the decrease in irradiance will affects the IV curves. The table shows that when the lamps are 100 cm, then 47% of the irradiance is lost and that makes the 100 cm distance not to be desirable for characterising modules. Hence the best distance to characterise the modules is 60 cm. The spectral distribution of the lamps also shows that the distance 60 cm is the best to characterise modules.

Table 1: Irradiance at various distances.

Distance cm	*Irradiance W/m^2*	*% diff of irradiance*
60	*1081*	----
70	*844*	*21.9*
80	*628*	*42.2*
90	*525*	*51.4*
100	*507*	*53*

4.2. Modules used

Four photovoltaic (PV) technologies (Polycrystalline (poly-Si), amorphous silicon (a-Si) copper indium gallium selenite (CGIS) and photochemical (DSC)) were characterized under STC. Table 2 shows the rated characteristics of the modules and the two (a-Si and DSC) have not been rated.

Table 2: STC rated characteristics of photovoltaic modules

Module	I_{sc} (A)	V_{oc} (V)	P_{max} (W)
Poly-Si	0.61	21.6	10.0
a-Si:H	-	-	-
CIGS	0.36	22	5.5
DSC	-	-	-

4.3. Performance evaluation

The solar simulator is used to characterize the various technological modules under STC and figure 3 shows the IV curves that were attained. The modules were 60 cm away from the light source. The 60 cm distance is used because it is the position where we get irradiance that is above 1000 W/m^2.

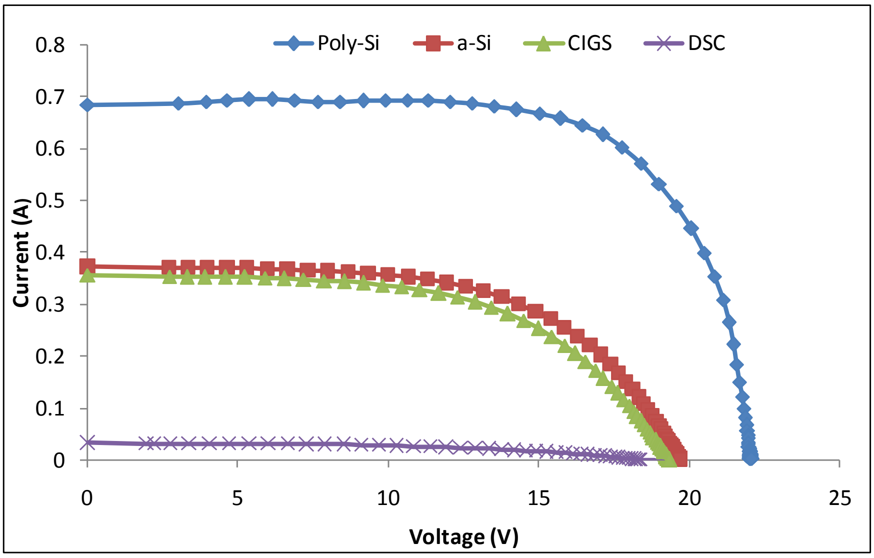

Figure 3: IV characteristics of various modules.

The figure 3 shows that the poly-Si module has the highest short circuit current of 0.68A and the percentage difference is 94 % between poly-Si and DSC. The table below shows that the maximum power of the poly-Si under STC and the rated are equal and it has 11% of efficiency, which implies that this module performs better when compared to other modules.

Table 3: The measured IV characteristics of various modules under STC.

Module	I_{sc} (A)	V_{oc} (V)	P_{max} (W)	η (%)	ΔP_{max} (W)
Poly-Si	0.66	22.04	10.0	11.0	0
a-Si:H	0.38	19.76	4.5	3.41	-
CIGS	0.29	19.12	4.7	9.09	0.8
DSC	0.04	18.67	0.3	3.64	-

Figure 4 shows the current (I) that is normalized using the short circuit current (I_{sc}) and the voltage that is normalised using the open circuit voltage (V_{oc}). The curve of CIGS shows that it has a high series resistance, because if the resistance increases then IV curve begins to sag towards the origin producing a decrease in the terminal voltage and a slight reduction in the short circuit current.

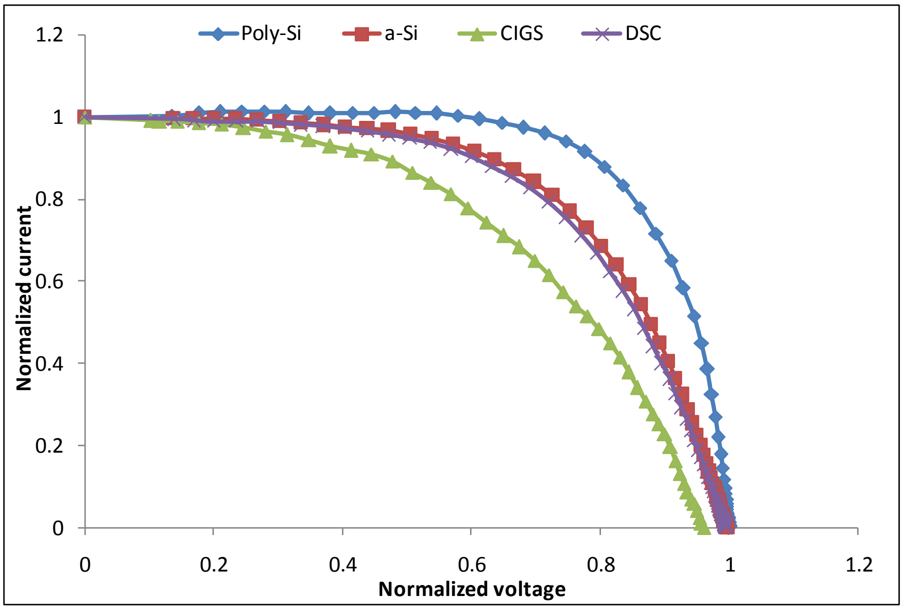

Figure 4: The normalized IV characteristics of various modules.

Conclusion

In conclusion modules are rated at standard test conditions and characterization of the module become an integral part in improving and maintenance of the technology.

The measured modules showed that the polycrystalline is by far the best module compared to other modules. The efficiency of this module is at 11 %, which makes it higher than of other modules.

References

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