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# Performance Characterization of a PV Module for Multiple Operating Parameters

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## Abstract

In this work, we investigate the impact of environmental conditions on the performance of solar cells. Experiments were performed in industrial test chambers. First the surface temperature was monitored as a function of time. Experiments revealed that a 5 °C temperature increase in the surface caused about 2% reduction in the output voltage. Ambient humidity levels were varied from 35% to 70% at a constant temperature (35 °C). It was found that output voltage was affected by both temperature and humidity levels. To investigate the internal structure damage, a laser irradiation technique was employed. The panel was mounted on a traversing stage to perform the laser measurements in x and y directions. Both open circuit voltage ($V_{OC}$) and short circuit current ($I_{SC}$) measurements revealed non-uniformity in the solar cell output which could be related to the internal structure damage of the solar panel. The effect of dust accumulation was also monitored in a dust chamber with controllable test parameters where 10-micron size dust particles were used to cover the solar panel surface. A 1.0 mm thick dust layer was able to reduce the output voltage by 80%.

**Keywords: Solar Panel, Performance, Panel Temperature, humidity, dust**

## 1. Introduction

Enough sunlight (4E18 Joules) reaches earth annually to meet the current world's energy demand (3E14 Joules). However, there are few practical limitations that may cause the solar cell efficiencies to deteriorate sharply. First, the sunlight consists of a spectrum of wavelengths as can be seen in Figure 1. Solar cells on the other hand are made of semiconductor materials that cannot respond to the full spectrum. As much as 30% of light is reflected from the surface of the cell (only absorbed light can produce electricity)[1-5]. Solar cell characterization is a very well researched field. Research papers covering different related topics on solar cell characterization in a greater detail are included in the reference section of this paper.[5-8]

Solar cell output efficiencies strongly depend on internal and external factors. For instance, internal impurities can cause the charge to "recombine" and thus become incapable of generating electricity. Other factors that may affect the efficiency include the angle of incidence of the sun, cloud cover, shading (even a small amount of shading reduces output dramatically), dirt, snow, and other impurities on cell surface. Another problem is associated with heating. Solar cells are exposed to radiation from the sun for long periods of time and because of this experience an increased

temperature. This heating causes the efficiency to go decline at a rapid rate[9-10]. High levels of humidity can also affect the solar cell performance especially in coastal areas[11-14]. The use of solar cells in desert and windy areas also brings

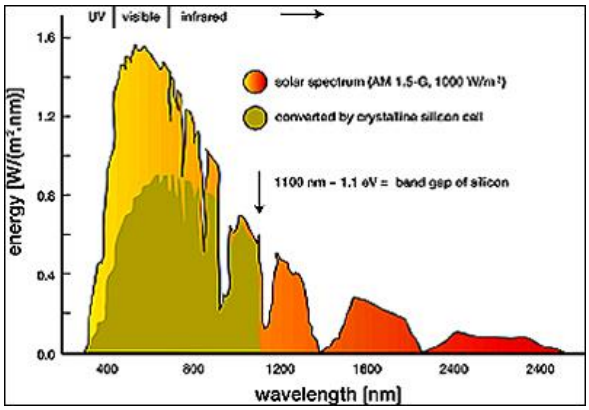



Figure 1. Solar Spectrum. Only the mustard photons can be "absorbed" and create electricity in a crystalline silicon cell. [http://solarcellcentral.com/limits_page.html]

a unique set of challenges. Accumulation of dust will deteriorate the solar cell efficiency by blocking the solar irradiation and heating up the solar panel surface to higher temperatures[15-17]. Another important factor to consider is the internal structure damage that may occur during the production and fabrication of the solar panels. Usually, one has no control over this, but methods are available to detect any severe internal damage for the cell before its application[18].

Looking at these above-mentioned limitations, it is important to characterize the performance of the solar cell by considering various factors that may cause its efficiency to deteriorate with time. This was the main objective of this research work as explained in the next section.

## 2. Objectives

The main objective of this research work was to investigate how various factors that affect solar cell performance. Different environmental factors were selected for this study. These included the ambient temperatures, humidity levels, and environment settling dust over the surface of solar cell. These environmental conditions were intentionally varied to monitor the output voltage of the solar cell over time and to estimate the possible performance deterioration of the cell under investigation. The last experiment was performed to investigate solar panel internal structure damages by using a non-intrusive laser technique. Various industrial testing chambers were used to conduct these experiments and are described in this work. The set of experiments conducted in this study helped students become aware of different performance evaluation techniques along with data acquisition methods to acquire and analyze experimental data obtained in this study. The following section describes the equipment and associated accessories in a greater detail.

## 3. Equipment and Associated Accessories

All experiments included in this work were conducted at Hastest Solutions Inc. in their industrial chambers. Figure 2 shows chambers (Model HPCH-252XSUH) in which both ambient temperature and humidity levels were controlled to evaluate the solar cell performance. For temperature measurements, k-type thermocouples were used. Keysight Agilent data acquisition unit (Model 34970A) was used to record and extract experimental data that was then downloaded on Microsoft Excel for further analysis.

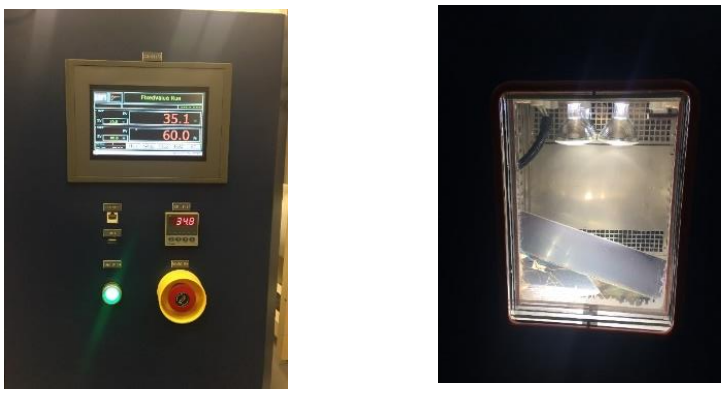


Figure 2. Hastest Solutions Inc.'s Humidity and Temperature control chamber.

Figure 3 shows the dust chamber where commercially available 10-micron size dust was dispersed over the surface of the solar cell. The first experiment was performed to measure the output voltage as the dust was dispersed and allowed to accumulate on the solar cell surface. This was achieved by setting a target dust cycle duration and frequency. In the second experiment, the option of controlled sudden vibrations was used that allowed a heavy dust accumulation on the surface of the solar panel under investigation. This mode of vibration was used to see the impact of sudden dust storm bursts on the cell performance.

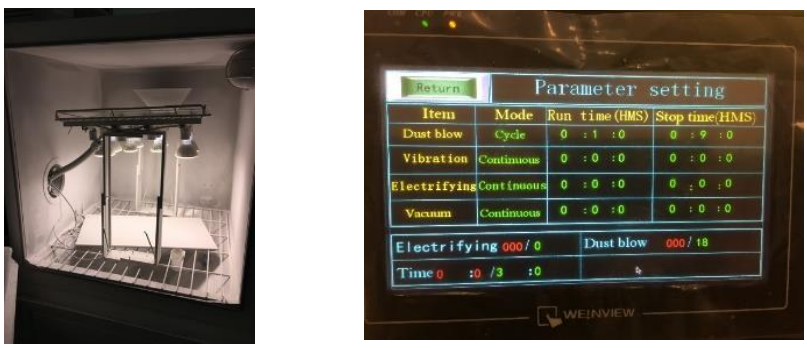



Figure 3. Hastest Solutions Inc's Dust chamber with automated control panel.

In these experiments two solar panels were employed. The first solar panel with a dimension 12"x12" whereas the second, smaller solar panel was about 4″x4" in size. The bigger panel was used to evaluate the solar performance as a function of ambient temperature and humidity levels. This large size panel was also employed to investigate the dust accumulation effects in a dust chamber. A 6-bulb (50W halogen bulbs) light fixture was developed to radiate the solar panel in the dust chamber, Figure 3. K-type thermocouples were installed to measure the temperature and output voltage of the solar panel as dust accumulated on the panel surface.

The small solar panel was used to perform the laser irradiation experiment for detecting any internal structure damage by focusing the laser on the panel surface. Figure 4 shows the He-Ne laser setup that was used to investigate the internal structure damage within the solar panel. The diameter of the incident laser beam was measured and was found to be around 0.75 mm ($1/e^2$ profile). A 20x microscopic objective lense was used to focus the laser beam to a smaller area. The focused laser spot size was estimated to about 20 microns using standard Gaussian beam optics equations[19]. The solar panel was mounted on a translation stage that could be moved both in x and y directions with a step size of 0.1 and 0.2 inch, respectively. The laser experiment was conducted for two conditions – open circuit voltage and short circuit current measurements. A RWS225 Beckman Industrial Multimeter was used to take measurements of both voltage and current as the laser spot was moved across the solar cell surface. A MATLAB program was developed to plot the data in 3D format to visualize fluctuations in the output current and voltage readings as the laser was scanned across the panel surface.

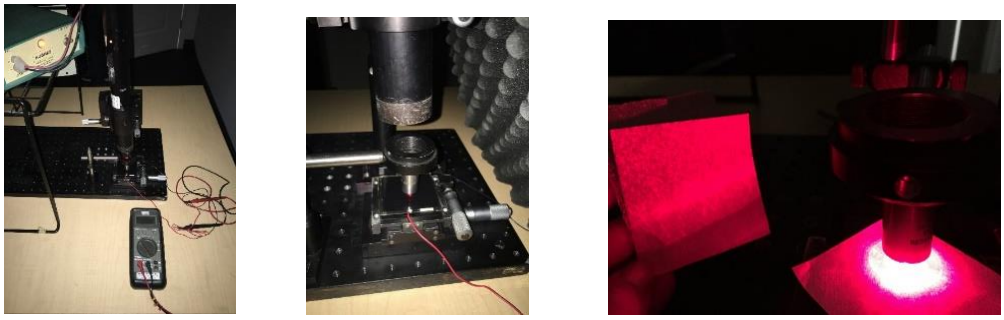


Figure 4. Laser experimental setup for detecting internal structural damage inside the solar panel.

## 4. Experimental Results and Discussion

Figure 5 shows the first test results where the 12″x12″ solar panel was irradiated with the light source (six 50 W Halogen bulbs) and monitored inside the Hastest test chamber for an hour. The average temperature of the panel increased by 8.33% and a reduction in the panel output voltage was recorded. On average, for the selected solar panel with the incident light flux of 1.95 mW/cm$^2$, a reduction of 12.5 mV/C was noticed, Figure 5. This trend in output voltage reduction rate was also observed by many other researchers. (Thermocouple 3 has been omitted from the Figures due to inaccurate readings.)

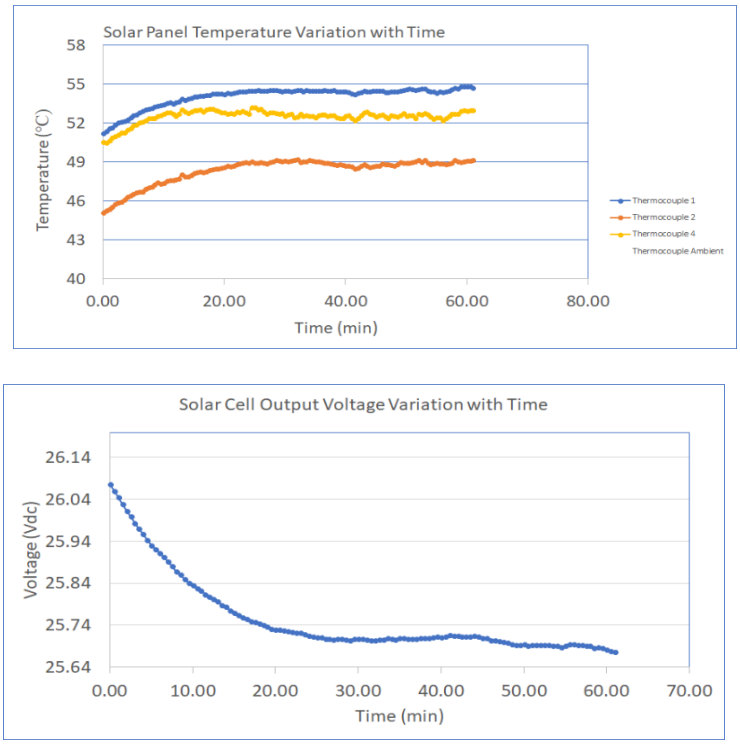



Figure 5. Variation in the output voltage of the solar panel due to panel heating.

Figures 6 and 7 show further experimental results for the cases were the relative humidity level was varied from 40% to 70%. In this case, the panel and its light source fixture were inside the humidity chamber and temperature readings were recorded as a function of time. Individual test results for humidity and voltage for each operating condition are shown in Figure 6. Figure 7 shows a 6% reduction in the solar panel average maximum temperature as the humidity

increased from ambient (~17%) to 40%. Slight increases in the average solar panel temperature was also observed as the humidity levels are increased up to 70%.

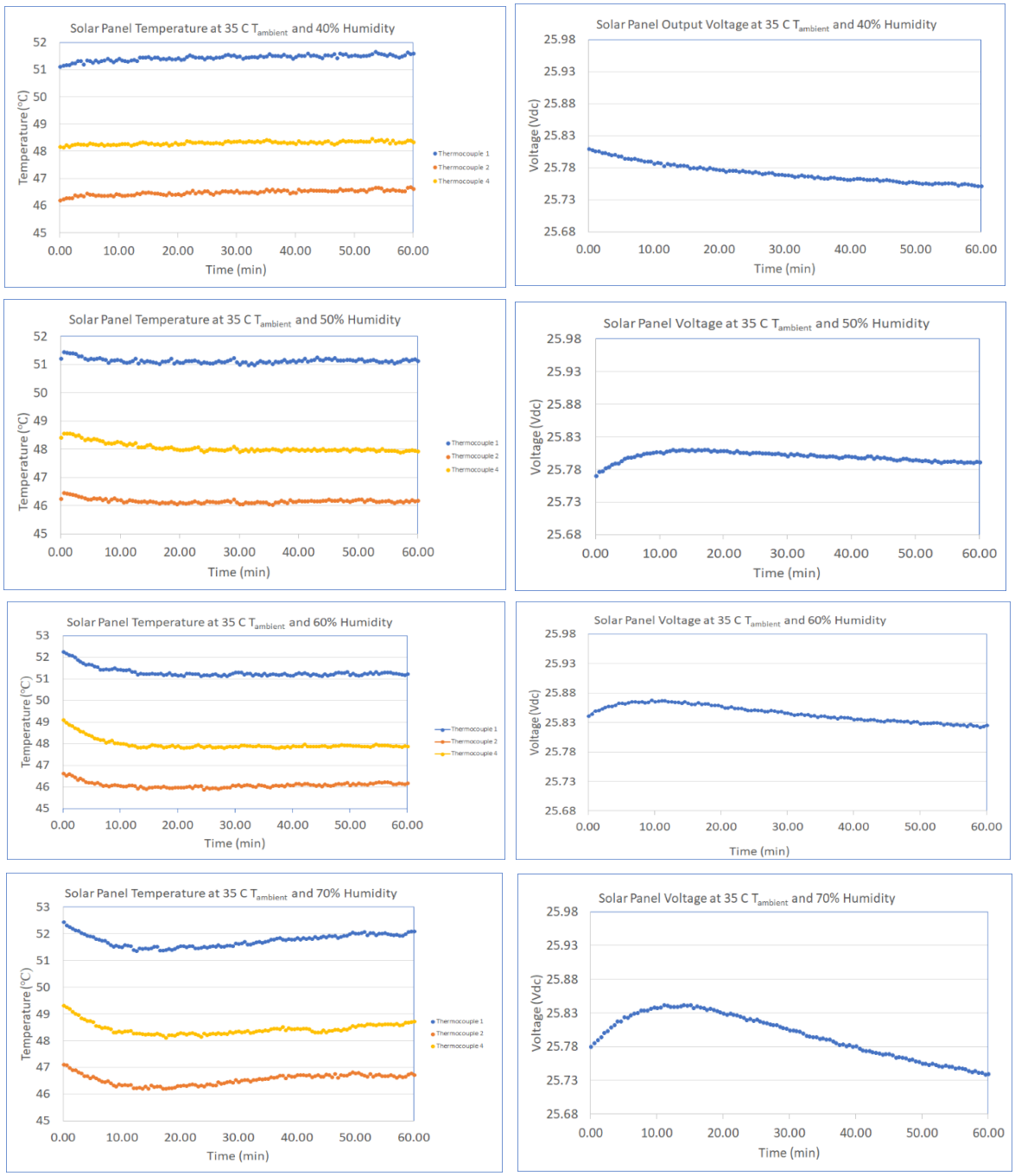



Figure 6. Solar panel output voltage at various humidity levels at a 35 C ambient temperature.

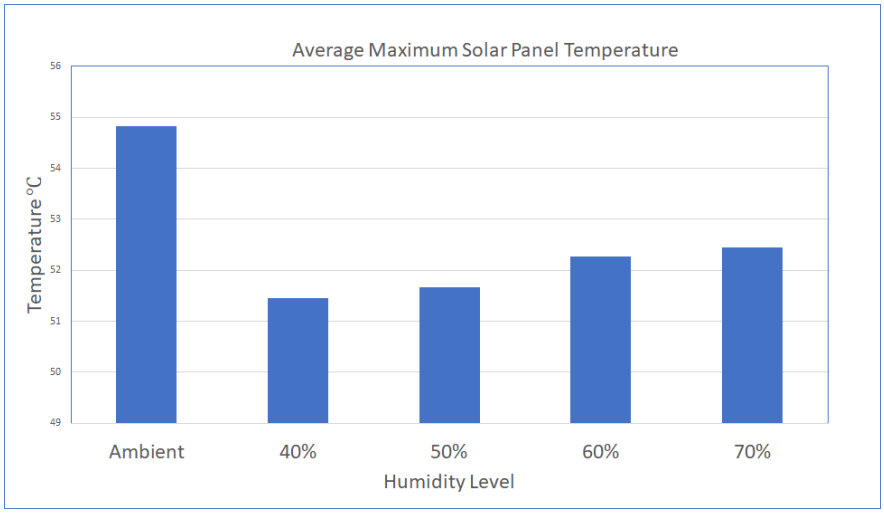
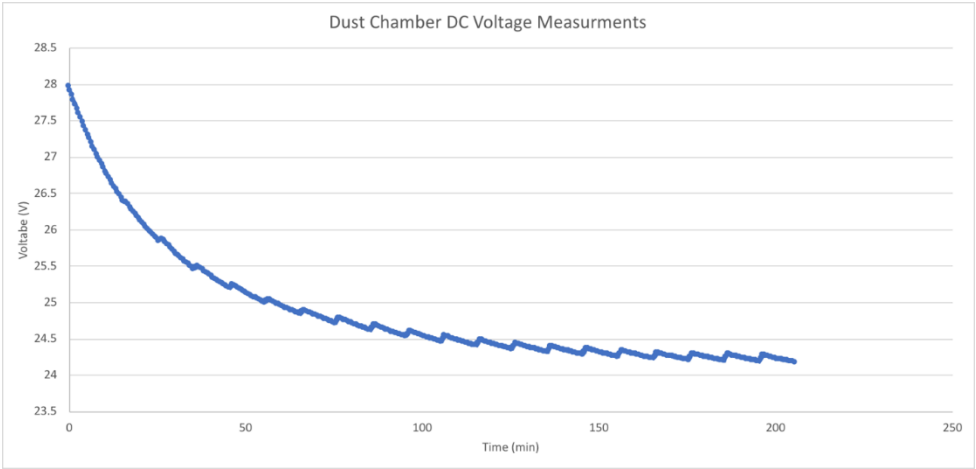


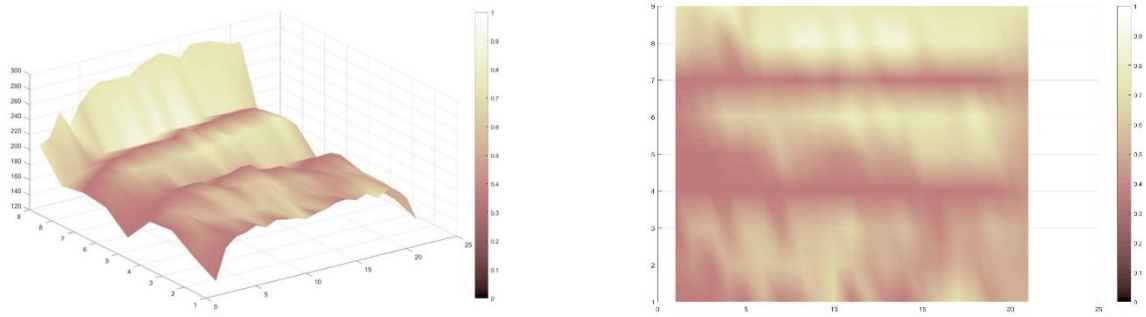

Figure 7. Average maximum solar panel temperature as a function of humidity levels.

In contrast to the humidity tests, a sharp decrease in the solar panel output voltage was observed when the dust test was performed inside the dust chamber. Figure 8 shows a sharp reduction of about 14 percent in the output voltage as dust could settle over the surface for a period of 200 minutes. In this case, the dust chamber was run in a cyclic mode where run time was controlled. In the heavy vibration mode, about 1 mm dust accumulated over the surface and in a 82% reduction in the output voltage was observed, Figure 8. It seems that the solar panel still generated about 5 volts of output even though its surface was fully covered with the dust.

In the laser experiment, for both open circuit voltage and short circuit current measurements, values from the voltmeter were recorded by hand. This data was transported into MATLAB where 3D graphs for the voltage and current were generated. Figure 9 shows the results. Fluctuations in the output signal for both current and voltage indicate a variation in the internal structure of the solar panel. These may appear due to stresses developed during fabrication. More advanced experiments are required to further investigate the internal structure imaging of the solar panel.

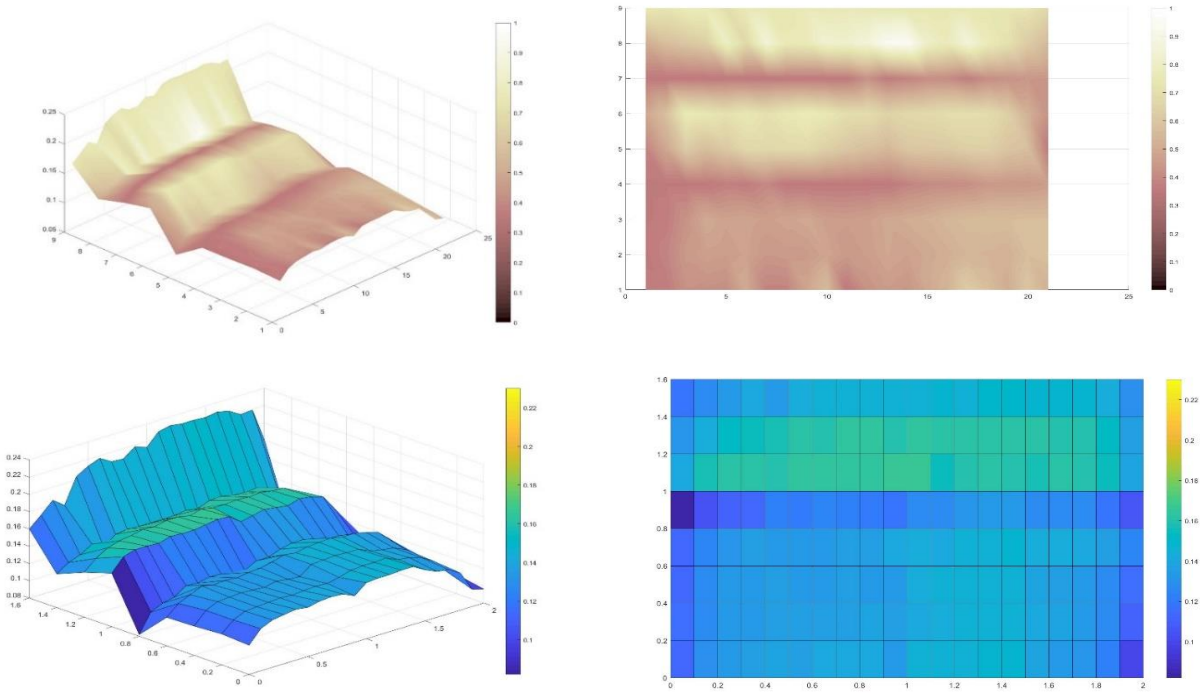



Figures 8. Reduction in solar panel output voltage as a function of dust accumulation on the surface



(b) Open circuit voltage test data. Fluctuations in the pattern showing variations in the output voltage as a function of position on the solar panel

Figure 9. Open circuit voltage and short circuit current test data revealing the internal structure possible damage areas.



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## 5. Conclusions

This work was performed to understand various techniques that may be used to characterize the performance of solar panels. Various test chambers were operated under different conditions. This enhanced our ability to perform characterization tests for different size solar panels. To avoid any sudden variation in the test conditions, measurements were made inside the controlled environment of Hastest industrial chambers. In general, experimental results show that the performance of solar panels strongly depends on the environmental parameters along with cell structure integrity and pose an obstacle once the solar panel is mounted for its operation. The preliminary work presented here opens a new platform for students to conduct research in this field in greater depth. We anticipate that new research results and their in-depth analyses will be presented in coming conferences.

## 6. Acknowledgements

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