Design of an Instrumented Soiling Chamber for Solar Photovoltaic Coating Research

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Abstract

To support ongoing research efforts in solar photovoltaic (PV) coating development, a custom environmental soiling chamber has been developed. The soiling chamber was designed to have control over environmental variables, including temperature, tilt angle, relative humidity, and dust deposition. Furthermore, the soiling chamber was designed with automated routines for simulating heating profiles or dew cycling. The sample plate inside the soiling chamber was designed to accommodate up to 100 1-in^2 samples with integrated proportional temperature control and was designed to be adjustable from 0° to 45° tilt angle.

Keywords

Student Poster, Soiling, Dew cycling, Solar Photovoltaic, Dust

Introduction

Soiling is the accumulation of dust particles on solar panels and other photovoltaic (PV) surfaces which results in transmission losses by absorbing, scattering, and reflecting a fraction of the incoming sunlight. By introducing additional operating and maintenance costs, soiling has a negative impact on the economic revenue of PV installations. Power reductions of more than 50% have been reported in the literature because of soiling [1]. Since soiling experiments are performed in outdoor conditions, the results from those experiments are more likely to be unpredictable due to uncontrolled environmental variables including tilt angle, dust deposition, temperature, and humidity. Furthermore, the soiling chamber can simulate different simulation processes such as dust deposition and dew cycles for a few hours which results in reducing the experimentation time. According to the literature, various instrumented soiling chambers were developed with different approaches in simulating soiling and dew cycling. It turns out that the major concern in building the soiling chamber is the dust disposition techniques which affect the uniformity of the deposited soil. Dust uniformity is an important factor in dust characterization which is the main concern in building a soiling chamber [2-4].

Methodology

To mimic and maintain the environmental conditions that solar PV modules experience such as dew cycling and soiling, an instrumented soiling chamber was designed and built. For the dew cycling simulation, the soiling chamber sample plate was designed to be cooled down to 0°C and heat up to 100°C with integrated temperature control. Furthermore, a humidifier was added for simulating the humidification process that happens during the dew cycle. For soiling, the soil was introduced to the chamber using a dust capsule by applying compressed air. Figure 1 shows the sample built that was designed to accommodate up to 100 1-in^2 samples.

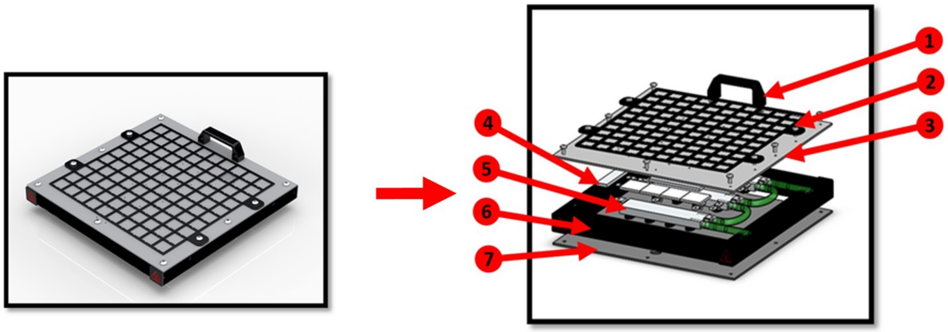
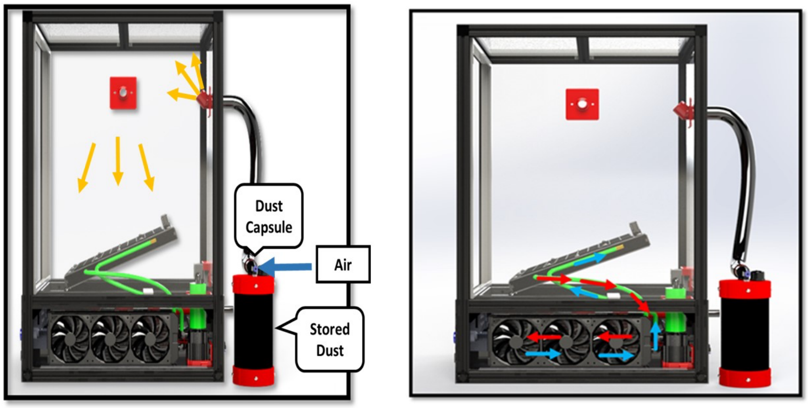


Figure 1: Soiling Chamber Sample Plate Top View

Figure 1 above shows the sample plate divided into seven layers. Layer one is the sample plate handle that was used for adjusting the sample plate. Layer two is the aluminum sample grid that accommodates up to 100 1-in^2 samples. Layers three and four comprise an aluminum base plate where positive temperature coefficient (PTC) thermistors (for heating), Peltier modules (for heating and cooling), temperature sensors, and cooling blocks were mounted to the back side of the aluminum base plate. Layer five is an integrated chiller loop, and layer six is the main extrusion aluminum frame of the sample plate. Layer seven is the sample plate back cover that was used to protect and insulate the sample from the dust during soiling. For cooling down the sample to 0°C, twelve Peltier modules were used as cooling elements with a rated power of 20W per module resulting in a 20 °C temperature difference and a total of 210W cooling power. For heating the sample plate to 80°C, Peltier modules were used in the reverse polarity for heating and PTC modules were used for additional heating capacity resulting in a total of 493W heating power.



Soiling Process **Cooling Cycle**

Figure 2: Soiling Process and Cooling cycle

Figure 2 above shows the soiling process and cooling cycles of the soiling chamber. The cooling cycle on the right was implemented inside the soiling chamber to remove the heat from Peltier's hot side for increasing the efficiency of the cooling process. The red and blue arrows on the right image show the direction of the coolant that passes from the cooling blocks to the radiator to the pump. A total of 400W of heat was needed to be removed from the system using a liquid cooling cycle. The cooling cycle consists of three channel aluminum radiators with a cooling capacity of 500W, three aluminum cooling blocks, three fans rated at 3000 rpm, and a 24V DC pump that has a maximum flow rate of 20L/min and a maximum head pressure of 11m. For the soiling process, the image on the left shows the direction of the dust deposited on the sample plate. A dust capsule was designed to store the dust that will be introduced inside the chamber by applying compressed air of 40 psi which results in the formation of a dust cloud that is introduced to the chamber. Figure 3 below shows the experimental setup for characterizing the heat distribution and soiling uniformity.

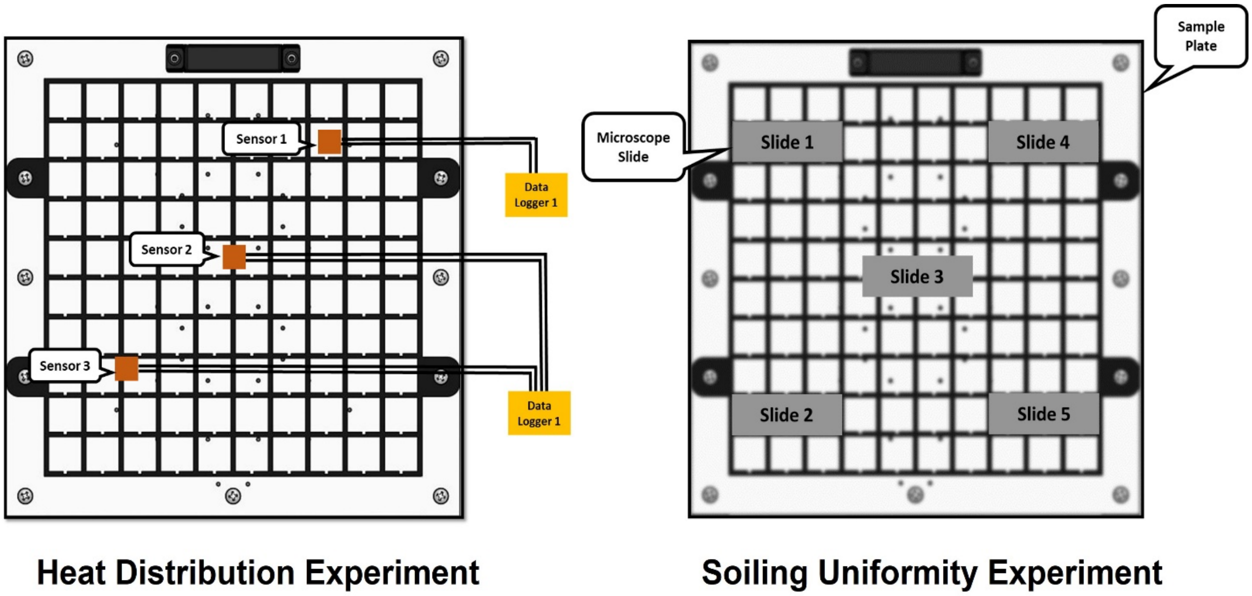


Figure 2: Heat Distribution and Soiling Uniformity Experiments

The temperature distribution of the sample was characterized using three type-K thermocouples mounted diagonally along the sample plate and two different data loggers for recording the temperature of the plate. The heat distribution experiment was made for testing the heat uniformity along the sample plate and for estimating the required time for reaching the maximum heating temperature and cooling temperature. Furthermore, both the heating and cooling rates of the sample plate were independently measured by heating the sample plate from the minimum cooling temperature to the maximum heating temperature and by cooling the sample plate from the maximum heating temperature to the minimum cooling temperature. For the soiling uniformity experiment, the image on the right side of Figure 3 shows a total of five microscope slides cleaned and weighted before being placed on the sample plate in five different locations. 25g of Arizona test dust (ATD; Powder Technology, Inc., Arden Hills, MN) was placed inside the dust capsule and 40 psi of compressed air was applied to the dust capsule resulting in the formation of dust cloud inside the chamber with a 20-minute dust settlement time. After that, the microscope slides were taken out of the chamber and weighed to determine the total amount of dust deposited.

Results and Discussion

Figure 4 below shows the sample plate heat distribution data for the heating and cooling profiles. For the heating profile, the left image shows the recorded temperature after heating the sample plate from minimum cooling temperate 0°C to 80°C. The heat distribution was not evenly distributed due to the location of the PTC modules, but the non-uniformity of the heat was acceptable in performing the dew cycles. The estimated time for heating was 8 minutes for the sample plate to reach 80℃. For the cooling profile, the image on the center shows the recorded data from the maximum heat temperature of 100℃ to the minimum cooling temperature of 0℃. The heat distribution was uniform across the sample plate due to the evenly distributed locations of the Peltier modules. The estimated time for cooling was 22 minutes for the sample plate to reach 0℃. As a result, the total time for simulating the dew cycle is 30 minutes. For the soiling uniformity experiment, the image on the bottom shows the uniformity of the dust on the right and left sections of the sample plate except for the middle. The uniformity in the middle section resulted from the accumulation of the soil particles on the top section of the chamber due to the strong impact of the soil particles from the applied air pressure.

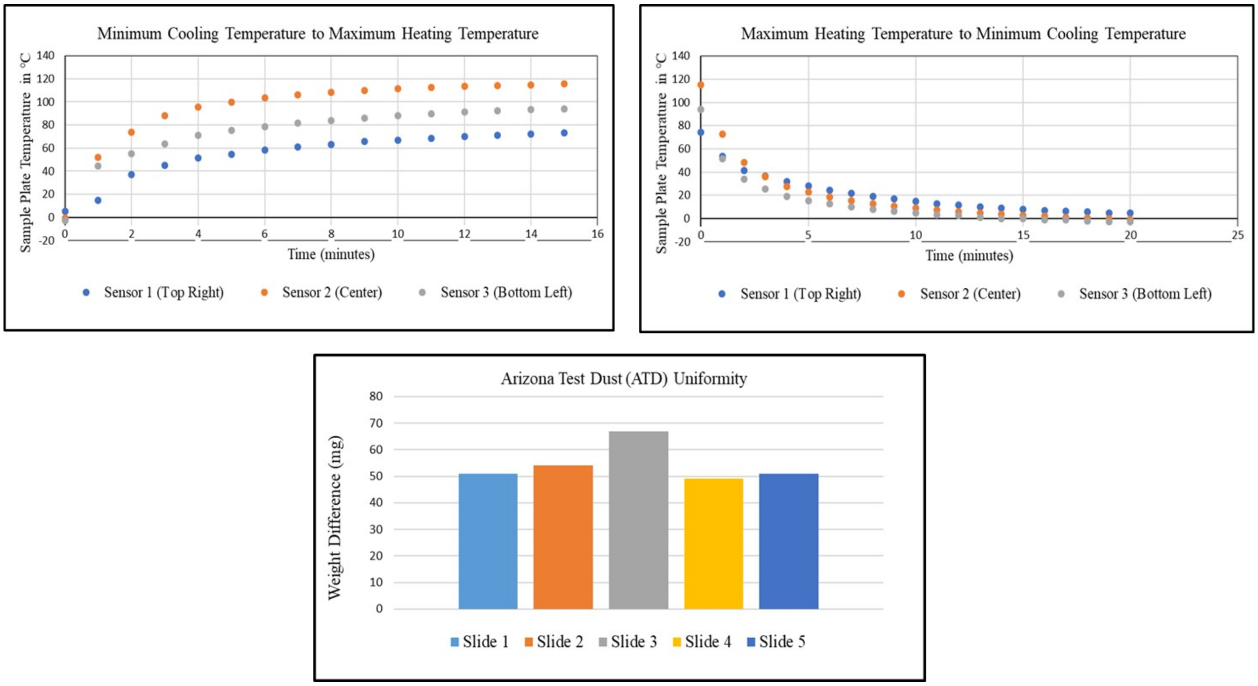


Figure 3: Heat Distribution and Soiling Uniformity Experiments Data

Conclusion

An instrumented soiling chamber was designed and built to study soiling and dew cycling effects on PV modules during operation and under controlled conditions. After building the soiling chamber, the temperature uniformity of the sample plate was measured to estimate the cooling rate for the sample plate to reach 0 ℃ and heating rate to reach 80℃. The data shows non-uniformity in heat distribution during the heat process due to the location of the PTC modules which was acceptable for the dew cycle simulation. Furthermore, the heat distribution during the cooling process was uniform across the sample plate. The estimated time for simulation of the dew cycle was found to be 30 minutes for one cycle. A dust uniformity experiment was made to test the uniformity of the deposited dust using Arizona test dust (ATD). The data show the uniform dust distribution across the sample plate in the right and left sections except for the center section. As a result, the center section will be avoided during future experiments.

References

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