Development of a Novel Soiling Chamber for Testing Antisoiling Coatings

Preprint

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Development of a Novel Soiling Chamber for Testing Antisoiling Coatings

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***Abstract*—This study presents the development and validation of a novel soiling chamber. The chamber is novel in that it includes wind induced soiling, feedback from a low-cost particulate monitor, and in-situ Isc measurements. Validation with side-by-side identical modules within the chamber produced soiling losses of 7% over 19 hours while the soiling ratio was always within 0.5% between the two modules. Initial side-by-side testing of an anti-soiling coated module versus and uncoated module demonstrated significant wind induced cleaning of the coated module. Specifically, the coated module showed only 0.8% soiling loss while the uncoated module reached as much as 10.5% soiling loss.**

***Keywords*—photovoltaic soiling chamber, wind anti-soiling**

I. Introduction

Photovoltaic (PV) soiling loss is the well-known phenomenon where dust or other airborne particulates accumulate on the surface of PV modules causing light blockage and therefore power loss to the PV system. Soiling losses depend on local climate, geography, nearby pollution sources, module orientation and various other factors [1]. Annualized soiling losses can be as low as 0.5%/year in temperate climates with frequent rainfall and as high 30%/year in deserts such as the middle east [2, 3]. Revenue losses due to soiling losses depend on the specific PV system but can easily reach millions of dollars per year for large utility scale systems [4]. Cleaning or washing PV systems is the most common method to avoid lost revenue from soiling losses. While cleaning is effective, it is typically expensive and therefore there have been efforts in recent years to develop anti-soiling (AS) coatings that can be applied to the surfaces of PV panels. Such AS coatings are said to work by various mechanisms and are often divided into hydrophobic or hydrophilic categories. When dew drops form or rain hits the hydrophobic surface the water droplets quickly roll off a tilted surface and collect dust particles or clean the surface in the process. Hydrophilic surfaces can form a sheeting of water on a tilted surface and also rapidly carry soil away [5, 6]. In another example, the microscopic surface properties of the AS coating are such that dust or particulates cannot strongly adhere to the surface. Goosens, [7], tested an AS coating in an aeolian dust wind tunnel and reported that dust adhesive forces were lower for an AS coating compared to a standard anti-reflection coating. There are both laboratory and fielded studies to test the effectiveness and durability of AS coatings as both are important to determine the economic viability of coatings as a solution to PV soiling [5,6, 8-11]. As field tests are both time consuming and expensive there have also been efforts to develop soiling chambers or laboratory experiments for rapid testing of prototype coatings [5, 7, 9, 12]. Soiling chambers generally apply soil via a released cloud of dust, have humidity controls and temperature controls for the chamber and the module. Dust is allowed settle on the solar cell or sample and then the sample is removed from the chamber to measure soiling losses in between soiling events. In the case of the wind tunnel soiling study, [7], samples were placed in one section of the tunnel to soil and another section for wind cleaning. The samples then had to be removed from the tunnel for soiling measurements. Repeated handling of samples can be time intensive and therefore expensive. In this work we describe the validation of a novel chamber that was developed to include features of existing chambers but also to simulate wind-based soiling and cleaning as well as in situ measurements of soiling loss over multiple soiling cycles. We also present initial chamber measurement results of side-by-side testing of modules with and without an AS coating.

II. Soiling Chamber Build

A dust chamber was constructed by NREL as shown from a top view in Fig. 1.

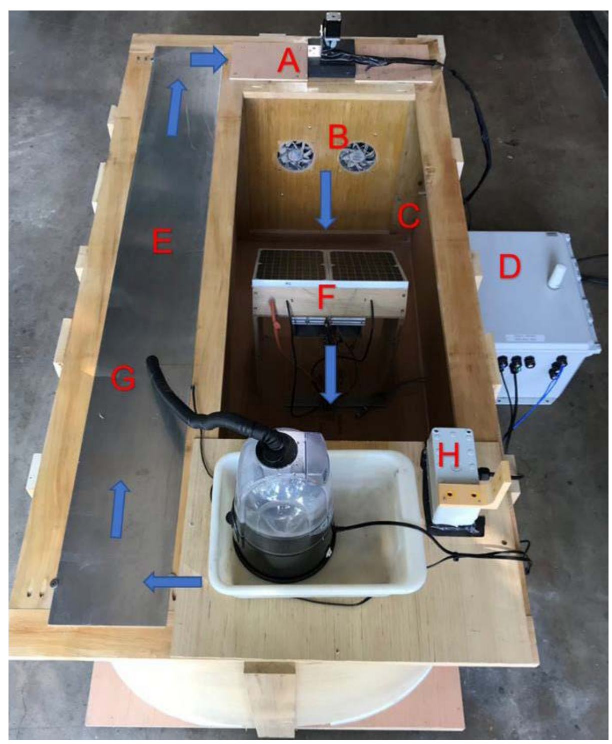

Fig. 1. NREL dust chamber (extended explanations for points A-H follow in the main text)

The chamber was designed to control blown dust dispersal, airborne particulate levels, wind speed, relative humidity, and module temperature. The chamber shown in Fig. 1 does not include a plexiglass sheet that covers the module area, completing the enclosure that enables maintaining humidity and dust levels within the chamber. The plexiglass cover provides access for cleaning the modules between differing tests, and it also provides the ability to illuminate the modules to record in situ short-circuit current, Isc, measurements. The following list provides details of the labeled points A-H in Fig. 1.

A: This black box contains Arizona road dust (Powder Technology Incorporated PTI 13448C, ISO 12103-1, A4 coarse test dust) and is connected into the chamber behind the vertical partition “B”. Mounted on top of the box is a stepper motor that turns a paddle within the box, which forces the release of dust through small holes in the bottom of the box. Immediately below the dust release point is an unseen fan that blows upward when dust is being released, effectively creating a dust cloud.

B: This vertical partition holds the two main chamber fans that are visible to the left and right of the “B” label. The partition serves to control circular chamber air flow, as well as providing a separate space for dust release.

C: Protruding through the chamber wall (just above the “C” label) is the chamber temperature and relative humidity probe, HMP60 by Vaisala.

D: The enclosure for the chamber control electronics and a Campbell Scientific CR1000X data logger. The data logger records temperature, relative humidity, and airborne particulate levels, and uses these measurements, as well as the data logger clock, to control dust deposition cycles for the two modules. The data logger also turns on illumination above the modules for an in situ Isc measurement at the end of each dust deposition cycle.

E: The left portion of the chamber is covered by an aluminum plate. There is an unseen vertical partition that divides the left and right portions of the chamber. Air flows from the fans at “B” and follows the pathway of the blue arrows to eventually complete a circular loop and reenter as input air to the main fans. The aluminum plate was designed to provide a sufficient heat transfer pathway between inside and outside the chamber air, i.e., the chamber internal temperature is designed to closely follow the ambient temperature of the larger surroundings of the chamber.

F: Two modules are mounted for side-by-side testing within the chamber. The modules are mounted on top of a common insulated enclosure. The enclosure provides common heating or cooling to the modules. T-type thermocouples are mounted to the back side of the modules within the enclosure to provide feedback to heating and cooling controls.

G: Chamber relative humidity can be increased above the outside ambient humidity through controlled injection of fog per a common reptile aquarium fogger run with deionized water.

H: The small grey enclosure houses two PMS5003 sensors (Plantower airborne particle sensors) and an Arduino Nano for controlling the sensors and communicating data back to the main data logger.

As noted in “D” the chamber includes automated illumination to measure in situ module Isc. Fig. 2. provides an image of one of the two lights (Sunco 150 watt LED, 21,000 lumens, 5000K daylight) and their spectrum.

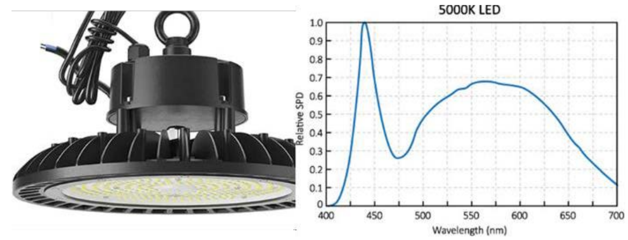

Fig. 2. (left) LED lights used to illuminate modules within the NREL dust chamber for Isc measurements, (right) 5000K spectrum of the LEDs used within the light on the right.

The dust chamber measures 183 cm long, by 91 cm wide, by 65 cm tall. The width in the partitioned area that holds the side-by-side modules is 61 cm wide. The modules are centered from side-to-side in the partitioned width and are mounted at 30-degree tilt. The centerline module height along the 30-degree tilted side is 36 cm. The main chamber fans have a centerline height of 36 cm (in line with the module centerline). The leading edge of the modules is 36 cm from the main fans. The two main chamber fans are Wathai 4-wire pulse modulation units. They measure 9.2 cm by 9.2 cm and operate at 12 volts, and 1.2 amps. At full duty cycle, these fans produce an 8 m/s second wind speed at the leading edge of the modules.

III. CHAMBER CONTROLS AND VALIDATION

The data logger provides the ability to design various accelerated soiling cycles to simulate different outdoor climates and soiling conditions. The initial focus of this work is to simulate conditions similar to windy, low humidity desert PV soiling environments in southern California. While conditions vary from site-to-site, across geographies, and across seasons; NREL has examined a number of sites in southern California and found that during long soiling periods it is common for the relative humidity (RH) to be 55% or less, dew cycles are not typical, winds in excess of 5 m/s increase airborne particulates, and periods of three or more months without rain can easily result in accumulated soiling losses of 10-20% [1]. With this under consideration, what is called Cycle 1 was developed.

Cycle 1: RH < 50%, module temperature (TM) set to 45 ± 1 °C (daytime nominal on-sun temperature), cycle length = 10 minutes, airborne particulate matter (PM) minimum thresholds set to achieve 7-10% soiling loss over 24 hours (144 cycles) on a control module. The cycle is conducted as follows:

1) 0-10 seconds LED lights are turned on and Isc measurements are recorded.

2) 16-300 seconds: the main chamber fans are on at full duty cycle and PM is maintained at the minimum threshold. If PM drops below the threshold, dust release is triggered and the main fans reduce to a 30% duty cycle. Dust release continues until PM is sufficiently above the threshold. The dust release period is typically achieved in 5-10 seconds.

3) Between 300-500 seconds the main fan duty cycle is reduced to 50% and the PM minimum threshold is reduced 20%.

4) Between 500-600 seconds the main chamber fans are turned off and PM levels are no longer maintained (dust is allowed to settle).

5) Test room RH is < 50% and RH is allowed to fluctuate with the ambient RH.

6) Module temperature is automatically maintained throughout the cycle.

In this study all modules tested are 10 Watt Topsolar modules that were commercially purchased. As purchased, the module package is built from uncoated tempered low-iron glass, ethylene vinyl acetate, 2 monocrystalline silicon solar cells, Tedlar/Polyester/Tedlar, and an aluminum frame. Two uncoated modules (UC1 and UC2) were mounted in the NREL dust chamber and allowed to soil per Cycle 1. The process was repeated three times and representative results are shown in Fig. 3. Within the three validation tests, the soiling ratio between the two modules deviates no more than 0.5%, module temperature is maintained within 2 °C of the target, and the soiling rate varies from 0.33%/hr to 0.45%/hr. The variation in soiling rate shows that caution should be taken when one run is compared to another run. This variation is expected for two reasons: 1) the Plantower PM sensor is generally considered a low-cost, low-accuracy sensor, 2) the chamber is not cleaned between runs, which allows dust to build up on the floor and other surfaces of the chamber; this deposited dust can then reenter the air stream as the fans are turned to full velocity. While caution should be taken in comparing runs, more importantly the side-by-side modules demonstrate near-identical soiling in a single run, allowing side-by-side coated and uncoated soiling to be compared.

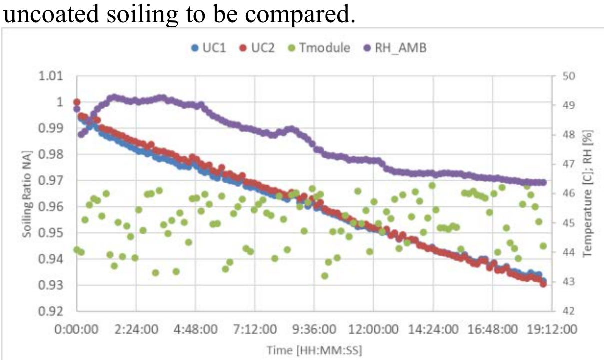

Fig. 3 The soiling ratio of two control modules measured in-situ in the NREL soiling chamber over 19 hours with Cycle 1.

IV. Initial Anti-Soiling Coating Results

After validation that two side-by-side modules (UC1 and UC2) soiled at the same rate, module UC2 was replaced with a module of identical build but an AS coating was applied to the new module, called P1. With UC1 and P1 mounted side-by-side in the NREL chamber, three tests were run using Cycle 1 (R1, R2, and R3), where R1 and R2 were allowed to soil for 23 hours and R3 was extended for 41 hours. The average RH for all three tests was 44.3%. In between each run, P1 and UC1 were cleaned as follows: 1) Dust was blown off the modules with compressed air. 2) The modules were misted with deionized water and wiped free of moisture with a clean white microfiber cloth. This cleaning was repeated at least 3 times and until no discoloration could be seen on the microfiber cloth. 3) The modules were then allowed to dry for 30 minutes before the next test run.

The results show that while P1 achieves an average loss of 0.8% in all three runs, there is no statistically-significant soiling rate over time. Alternatively, the uncoated module achieves a near linear soiling rate in all three tests with ~7% loss after 23 hours and 10.5% loss after 41 hours. The in situ soiling ratio results for both UC1 and P1 are provided in Fig. 4.

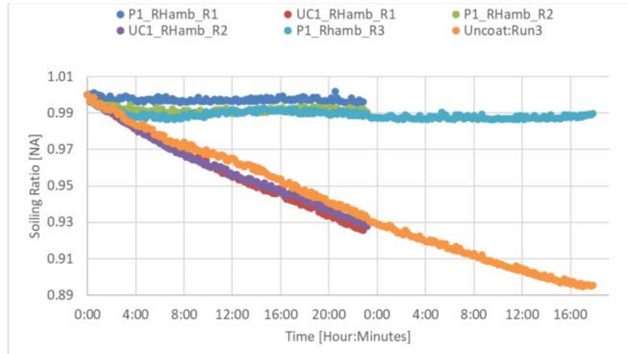

Fig. 4 In situ measured soiling ratios for the uncoated module, UC1, and a module with an applied AS coating, P1, for 3 test runs, R1-R3.

V. Conclusions

This work has demonstrated build of a novel soiling chamber which allows soiling of side-by-side PV modules through wind carried soiling while uniquely controlling the airborne particulate levels per feedback from a low-cost PM sensor. The validation in fig. 3 demonstrates that, over ~20 hours of 10 minute soiling cycles, the soiling ratio for the side-by-side modules varies by no more than 0.5%. The validated chamber was then implemented to test a module with and AS coating against a similar module with no surface coating. The results in fig. 4 show that under the chamber test conditions, the module with an AS coating soiled to an average loss of 0.8% while the uncoated module had losses from 7-10.5% depending on the duration of the test run.

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