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Accelerated testbed for studying the wear, optical and electrical characteristics of dry cleaned PV solar panels

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ABSTRACT

A testbed was designed and built for studying the impact of brush-based dry cleaning on glass samples and photovoltaic (PV) solar panels. A sand deposition shaking system was integrated into the testbed to continuously deposit dust on the brushed surfaces simulating the real environmental dust conditions for a 20-year equivalent time of cleaning. The cleaning efficiency was evaluated for different types of brush materials of nylon, cloth and silicon rubber foam. In this piece of work, the focus was mainly on brushing real solar panels, which already have anti-reflective coating applied to measure the output short circuit current, which is the IV characteristics dominant factor. While some materials had a notable impact on the solar panels, no permanent or significant negative impact was found to affect the solar panels as a result of the brush-based dry cleaning with the other materials. In fact, an enhancement in the maximum power output of solar panels cleaned with silicone rubber was around 1% from the unbrushed initial power output, which could be attributed to the created surface geometry. The silicon rubber foam — a novel brush material, with no previous research literature describing its use as a brush material — provides a low cost material and allows for a simple brush design, which could reduce the cost of the brush used in robotic cleaning systems, while providing highly effective, nonabrasive cleaning.

1. Introduction

A majority of newly installed photovoltaic (PV) modules use anti-reflective (AR) coatings since this is an easy and cost effective way to improve the efficiency. Some — if not most — of these AR coatings are not very wear resistant, and since soiling accounts for 0.1% to 0.5% per day loss, destroying the AR, which increases efficiency by about 4%, it is not at all negligible. For robotic cleaning systems, it is definitely a concern that requires proper selection of the brush type.

2. Previous studies

The regions where yearly solar insolation is highest (those around the equator) are primarily desert regions. In these regions much of the reduction in solar panel efficiency can be attributed to the significant challenge of pervasive dust and insufficient rain to naturally remove accumulated dust resting on the panels. For example, in Saudi Arabia the peak irradiation occurs between May and August with 7–8 kW h/m^2/day on average (Rehman, 1998), which is also when the harshest conditions exist, such as high levels of dust, lack of rain, and high temperatures.

A recently published review (Alshehri et al., 2014) includes a comparative survey of cleaning mechanisms for solar power plants, with a focus on their application in arid regions. In these regions, dust accumulation can have a severe and detrimental effect on the productivity of solar arrays. The primary concern of that analysis was to address the need for a commercially viable cleaning solution, and present candidate dust mitigation technologies that show promise in enabling solar technologies in the sun-rich, arid regions of the world. In addition to comparing the cleaning mechanisms categorically, specific examples from each category were referenced to demonstrate the specific attributes of such tools. The survey focused primarily on currently available product categories for the analysis, while fewer well-characterized technologies were reviewed for their potential strengths and weaknesses. The categories of cleaning solutions considered in the study included the following: manual cleaning, mechanized cleaning, hydraulic cleaning, installed robotic cleaning, and deployable robotic cleaning. The review also revealed various research-stage technologies, such as electrostatic curtain technologies (Mazumder et al., 2013, 2007; Biris et al., 2004) and hydrophobic nanocoatings (He et al., 2011; Parkin and Palgrave, 2005; Zhu et al., 2010; Park et al., 2011; Niu et al., 2009). The

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comparative survey indicated that the overall cost of installed robotic systems could be, at least in some cases, the lowest of all the systems. This is especially true when frequent cleaning is considered and the true cost of water and labor are included.

Recently, we have published an article about the impact of dust deposition and brush-based dry cleaning on glass transmittance for PV module applications (Al Shehri et al., 2016). In this study, brushed samples were restored to their original state of optical clarity after cleaning with water, suggesting that there was no functional damage caused by dry-brushing the surface. This study provided preliminary assessment strategies and results, which prove useful in more expansive studies that assess alternate brush types, such as soft clothes brushes and brushes with longer bristles, to further investigate the cleaning efficiency and related impact on the panel. Selection of the optimal brush is essential for meeting the required level of cleaning, while preventing damage to the surface of the solar panels.

The effect of dust on the performance of PV cells has been experimentally investigated (Adinoyi and Said, 2013; El-Shobokshy and Hussein, 1993; Mani and Pillai, 2010a; Mokri et al., 2013). In a study done by El-Shobokshy and Hussein (1993) different kinds of dust particles, which are often present in the atmosphere, were studied including limestone, cement, and carbon particulates, with different size distributions.

Multiple literature studies have shown the effects of soiling on the PV module performance and have explored the high correlation between solar power losses, weather conditions, and geographical locations (Almasoud and Gandayh, 2014; Salim et al., 1988; Wakim, 1981).

Hottel and Woertz (1942) earlier investigated the impact of dust on solar thermal systems, and reported a maximum degradation in thermal collector performance of 4.7% due to the dust accumulation over seven weeks in an industrial area.

Grag (1974) compared the transmittance between different samples of glass plates and plastic films at vertical and horizontal orientations. He concluded that the accumulation on glass plates is less than that found on plastic polyvinylchloride (PVC) films, and that transmittance was severely reduced by sand storms. A daily cleaning was highly recommended by the study for harsh environments and arid regions.

Studies on wind velocity and the relationship between the PV performance and orientations were reported by Goossens et al. (1993). The results indicated an increase in dust accumulation with increased wind speed. An increase in ground elevation of the PV modules was shown to decrease the accumulation of dust at increased wind speeds.

In addition to these field studies, a mathematical model was developed to evaluate the incident radiation on a solar module with dust particles settled on its surface (Al-Hasan and Ghoneim, 1998). The results revealed a linear relationship showing that transmittance decreases with more sand dust particles settled on the glass with a reduction up to 50%, when spherical particles form a layer that fills the entire surface of the glass.

Another experiment conducted in Egypt by Elminir et al. (2006) observed that fluctuating levels of humidity led to the formation of coagulated dust on the PV surface, and recommended a weekly cleaning cycle to minimize this effect in moderately dusty regions.

In another paper (Mani and Pillai, 2010b), a comprehensive and general recommendation of mitigation measures against the impact of dust accumulation on PV performance is listed according to different categories related to climatic zones and characteristics.

A recent study on the assessment of solar radiation resources in Saudi Arabia could provide deep insights and open new venues about the effect of dust on the irradiance in relation to the proposed geographical patterns (Zell et al., 2015).

The effect of dust on the long-term performance degradation of PV modules, which were left without any cleaning procedure, was investigated in a recent (Tanesab et al., 2015) study in Perth, Australia. Although the degradation was mostly due to non-dust related factors such as corrosion, a significant contribution of 16–29% was recorded due to dust with a fairly uniform impact on the performance degradation of PV technologies.

Dry cleaning is one such technology, which aims to mitigate the impact of dust mitigation by removing deposited dust. This solutions offers promise in mitigating the impact, but it is important to recognize that synergistic technologies that could actually reduce dust accumulation are also an important topic of research and development. With the sum of this research in mind, the following sections assess the impact of using brush-based robotic solutions on the panel's surface. This research was conducted specifically to determine the cleaning efficacy of such solutions, and to determine whether this method causes significant damage or output of current losses, when used on real solar panels.

3. Testbed design and experiments

To conduct this research, a custom accelerated wear testbed was designed and built. The testbed was designed with the objective of facilitating a method for the repeated systematic and consistent brushing of small glass and PV module samples (see Figs. 1–3).

The testbed measures 1140 × 700 × 600 mm and it can be used as either a benchtop or floor-mounted equipment. It features a central aluminum fixture plate equipped with accessories to carry either microscope slide-sized (i.e., 3 × 1 in.) glass samples, or PV modules no larger than 10 × 7 in.. The fixture plate is in turn designed to move along a belt-driven and rail-guided horizontal axis of motion, with an effective travel length of 465 mm at a maximum linear speed of 694 mm/s. A lead screw-driven vertical axis

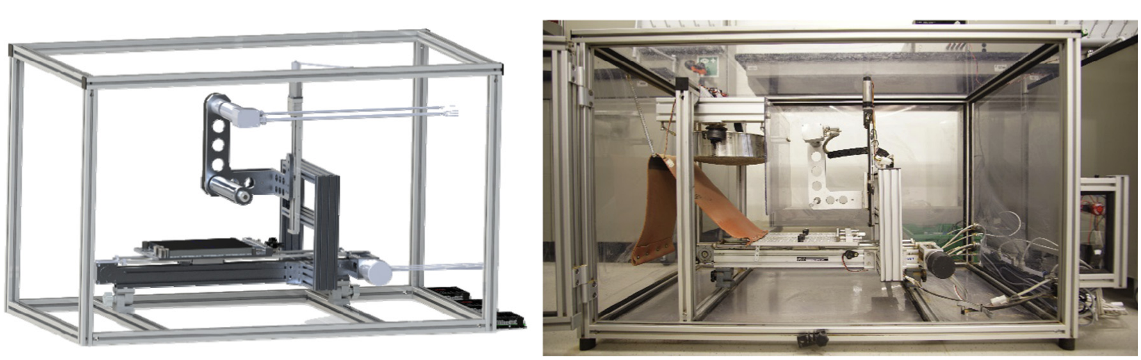

Fig. 1. Rendered 3D CAD model (left) and final assembly (right) of our accelerated wear testbed.