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The potential of using textured and anti-reflective coated glasses in minimizing dust fouling

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Abstract

The effect of texturing and anti-reflective coating of PV module glass cover on the overall performance of modules was investigated. The results indicate that texturing a module's surface and adding an anti-reflective coating boosts the power output of a clean PV module by an average of 4–8%. Clean modules covered with an anti-reflective coating exhibited the largest increase in power output. Texturing the module surface generally raises the temperature relative to that of flat glass modules. The study also confirms that dust accumulation can lead to a drastic reduction in PV module power output (a 10–17% reduction after six weeks of exposure without cleaning). Texturing and anti-reflective coating of PV modules glass cover can relatively reduce power reduction due to dust coverage.

Keywords: Glass texturing; Anti-reflective coating; Dust fouling

1. Introduction

The Gulf countries have one of the highest direct normal irradiation (DNI) resources in the world and are prime locations for harnessing solar energy technology. The Kingdom of Saudi Arabia (KSA) recently has announced Saudi Arabia's ambitious plans to install 16 gigawatts (GW) worth of solar PV systems by 2032. Qatar state plans to install 1.8 GW of PV power-plant capacity by the end of 2015, while Dubai aims to satisfy 5% of its power supply with solar energy by 2030 (Alnaser and Alnaser, 2011). However, harsh environmental conditions – for example, high temperature, humidity and dust storms which are exacerbated by a lack of rainfall pose a real challenge for effectively harnessing solar energy in the Gulf region. The average degradation of PV module performance due to dust accumulation is highly dependent on the site and local weather. In the KSA, for example, a 50% drop in PV power output was seen after six months of outdoor exposure in Dhahran (Said, 1990; Adinoyi and Said, 2013; Said and Walwil, 2014), and a 2.8% loss per day in short-circuit current was reported in Arar (Ibrahim, 2011). In the United Arab Emirates, which has climate very similar to that of the KSA, power output fell by 10% within five weeks of outdoor exposure (Mohandes et al., 2009). In Qatar, the same 10% reduction in PV module efficiency was observed after 100 days of outdoor exposure (Touati, Massoud, et al., 2013), while in Egypt a 60–70% power reduction over a period of six months and a drop in glass transmissivity of approximately 20% after one month of exposure has been reported (Hegazy, 2001; Elminir et al., 2006).

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Dust is one of the most common causes of reduced PV module performance. In general, dust deposition decreases PV module performance (El-Shobokshy and Hussein, 1993; Kaldellis et al., 2011; Qasem et al., 2011) by lowering the spectral and overall transmissivity of the module glass cover (Hegazy, 2001; Elminir et al., 2006; Qasem et al., 2011). However, the severity of the problem may differ from one surface to another, wherein plastic, PVC and acrylic generally exhibit a greater transmittance loss than glass (Garg, 1974; Nahar and Gupta, 1990) which one of the reason of using glass cover for PV module.

Glass with a flat surface is the material most commonly used to cover PV modules. Surface engineering can help increase the amount of light transmitted into the cell and thus the device's overall sunlight-to-electricity conversion efficiency. A previous study (Duell et al., 2010) examined the impact of textured glass on the surface temperature, light transmission and power output of PV modules in the USA. It found that textured surfaces yield a noticeable increase in light transmission and thus an increase in the power output. Increasing the module temperature due to the high ambient temperature resulting in an overall reduction in the cell's fill factor and hence, efficiency (Meyer and van Dyk, 2004). During high temperature time, an obvious drop in PV performance was observed (Omubo-Pepple et al., 2009; Adinoyi and Said, 2013; Touati, Al-Hitmi, et al., 2013). Textured glass was found to be 3.5 °C cooler than flat glass, especially at high wind speeds and relatively low solar radiation (Duell et al., 2010). In addition, in term of annual energy yield, an increase by about 3.5% compared to flat glass has been observed due to using pyramid-like textured glass and improved angle dependence of the short circuit current (I_{sc}) (Grunow et al., 2005).

The above finding motivated the investigating of the capability of employing textured and anti-reflective coated glasses on PV modules performance in dusty areas such as KSA. Therefore, the present study besides investigating the overall effect of glass texturing as well as anti-reflective coating on PV module performance, it looks into the potential of using textured and anti-reflective coated glasses in reducing the dust fouling effect on PV module power output through outdoor exposure testing for PV modules as well as a series of glass experiments to test their self-cleaning properties. To unambiguously determine the effect of using textured and coated surface as a glass cover on the performance of PV module, different types of commercial flat, textured and anti-reflective coated glasses were installed on 12 identical PV modules. The scale of surface texture includes nano, micro and milli scales. Also, the glass samples were passed through multiples characterization tests; in order to study glass self-cleaning properties.

2. Module setup and testing

The test facility in this study (see Fig. 1) is located in Dhahran, Saudi Arabia (Lat. 26.17′N, Long. 50.09′E, Alt. 24 m), which is situated about 10 km from the Arabian Gulf. The testing period was between September and December of 2013. The ambient temperature was ranged between 8 and 45 °C. The relative humidity reached up to 90%. Rainfall is scarce and the maximum rainfall was about 6.1 mm. The wind speed was ranged between 0 and 10.5 m/s. The modules have similar specifications (cell data) as can be seen in Table 1. The difference between the modules is the type of glass cover used: a flat glass surface with no anti-reflection coating, a flat surface with anti-reflection coating, a micro-textured surface with no anti-reflection coating, a micro-textured surface coated with anti-reflection coating and a mm-scale textured surface were used as PV covers (see Figs. 2 and 3 and Table 2). Each glass surface has a transmittance of over 90%, as shown in Table 2. During the test period the top row of modules was cleaned daily using fine brush and clothes while the bottom row was not (the dust deposits can be seen in Fig. 1). The different electrical performance characteristics of PV modules as well as ambient conditions were measured and recorded using a data acquisition unit. All measurements of a PV module's power output were carried out under actual operating conditions. The surface topography and roughness have been determined using Atomic Force Microscopy (AFM) and Scanning Electron Microscope (SEM) as shown in Figs. 2 and 3 and Table 3. Surface wetting measurements and self-cleaning properties tests have been conducted using a goniometer.

Fig. 1. PV modules test facility at Center of Research Excellence in Renewable Energy (CoRE-RE) – KFUPM.

Table 1
PV module specifications (cell data).

Manufacturer	Fraunhofer ISE
Cell type	Monocrystalline
Number of cells	6
Cell efficiency	18.2–18.4
Maximum power rating (P_{max})	4.39–4.44 Wp
Open circuit voltage (V_{oc})	625 mV
Short circuit current (I_{sc})	8.9 A
Voltage at maximum power (V_{mp})	525 mV
Current at maximum power (I_{mp})	8.4 A
Temperature coefficient of current (α)	+0.04%/K
Temperature coefficient of voltage (β)	−0.33%/K