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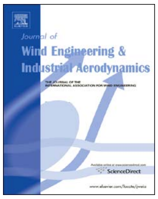

Mean flow through utility scale solar facilities and preliminary insights on dust impacts

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ABSTRACT

Deposition of dust on solar collectors has the potential to be a costly part of utility-scale solar energy production operation and maintenance. Large facilities are frequently located in arid regions with dusty soils. The orientation of solar fields with respect to the wind may affect how vulnerable or protected the soil surface is from the erosive power of the wind. Field measurements of wind flow through a utility-scale solar photovoltaic facility are presented. Multiple measurements of wind speed by spinning cup anemometer and wind direction by rotating vane were collected between consecutive rows of panels at two heights above the ground. This dataset provides preliminary insight into the mean flow field for a nominally two-dimensional solar array. A better understanding of non-steady flow components, turbulence, and conditions for the initiation of sand transport is needed for accurate prediction of dust impacts of such facilities.

1. Introduction

Many of the world's regions with high grade solar resources are also regions that are arid and prone to dustiness (Mani and Pillai, 2010). Dust deposition on solar photovoltaic (PV) and solar concentrating (CS) devices has been increasingly recognized as potentially deleterious to power production (El-Shobokshy and Hussein, 1993; Sarver et al., 2013; Sayyah et al., 2014). This is of considerable concern in the Middle East and especially the Arabian Peninsula (Adinoyi and Said, 2013; Al-Hasan and Ghoneim, 2005; Charabi and Gastli, 2012; Ghazi et al., 2014; Hegazy, 2001; Khonkar et al., 2014; Qasem et al., 2014; Said and Walwil, 2014; Touati et al., 2013) as well as countries along the Mediterranean (Kalogirou et al., 2013; Piliougine et al., 2013; Schill et al., 2015; Vivar et al., 2008; Zorrilla-Casanova et al., 2012). However, there have been studies of the effects of dust on PV power production in a variety of other geographical locations including North and South America (Boyle et al., 2015; Cabanillas and Munguía, 2011; Fuentealba et al., 2015; Michels et al., 2015), Central Europe (Appels et al., 2013; Klugmann-Radziemska, 2015), Asia (Xiao et al., 2013), and even Mars (Tanabe, 2008).

Within desert landforms there are order of magnitude differences in the susceptibility to wind erosion between surfaces of different geomorphic classification (Sweeney et al., 2011). Many desert surfaces, especially those with high silt and clay contents become much more prone to wind erosion when they are mechanically disturbed (Houser and Nickling, 2001; Macpherson et al., 2008) as is routinely the case when utility-scale solar (USS) facilities are built. These surfaces then become potential sources of dust within the USS. For these reasons, many USS facilities apply chemical soil stabilizers as a matter of good practice, which can reduce emission potential of dust by orders of magnitude – at least temporarily (Kavouras et al., 2009). However, this may be costly and have negative effects on the ecosystem when applied on such large scales (Hernandez et al., 2014) as well as hydrological processes such as runoff and erosion.

Related to this, the deposition of suspended particles such as dust (especially those larger than half a micron or so in diameter) onto an object is dependent on the amount of acceleration and turbulence the dust experiences when being directed towards the object (Zhang and Shao, 2014). Prior work that has considered wind effects on dust deposition on individual solar energy devices underscores the importance of the magnitude of the incident speed of dust-laden air as well as the direction with respect to elements of a solar collector (Goossens et al., 1993; Goossens and Van Kerschaever, 1999).

In this paper, we examine the mean wind flow through the rows of solar PV collectors within a large, USS facility. Ultimately, the interaction between wind and the solar field is the driving force for dust emission locally, dust deposition onto collectors, and the possible need for application of soil stabilizers. A medium-term goal for this type of research is to support the development of a model that can assist developers of USS facilities in estimating the operation and main-

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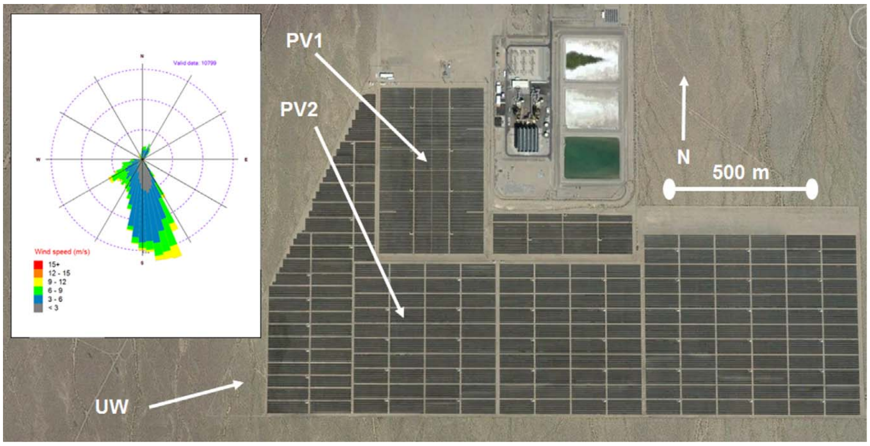

Fig. 1. Overview of experimental site showing locations of upwind site (UW) and two within-array sites (PV1 and PV2).

tenance (O & M) costs as they relate to issues of dust impacts on facility operation. The measurements presented here are unique and provide preliminary insight into relationships between ambient wind and USS mean flow fields as well as test data for comparison with numerical flow models and wind tunnel results.

2. Methods

Wind parameters were measured at a large USS PV facility (the PV Facility, hereafter) near Las Vegas, Nevada, USA (Fig. 1). Measurements were conducted at three locations within the PV Facility. The first and second measurement locations (PV1 and PV2, respectively) corresponded to two different locations deep within the PV Facility. The third was intended to represent the upwind conditions in the absence of the PV Facility (UW). “Upwind” in this instance should not be interpreted as literally upwind, but rather as minimally influenced by the presence of the array. Depending on wind direction the UW location could in fact be downwind of the solar array. However, even in such instances, it is likely that the wind speeds measured at UW are approaching those of the flow if it was unimpeded by the array. This is because the heights of the array elements are on the order of 1.8 m while the distance between the UW location and the edge of the array is on the order of 140 m, so that the wind would have traveled the equivalent of about 80 times the physical roughness of the solar array before reaching the UW station. By similar argument, the measurements at PV1 and PV2 are only representative of the flow regime deep within the array and little or no information about the flows near the edges of the array can be gleaned from them. Thus, the results of this study are applicable to the large interior region of the array, where flows are relatively invariant with distance, but not to the perimeter of the array where there may be large differences between successive rows.

The arrays of instruments at PV1 and PV2 were located between successive rows of solar panels. The basic, contiguous unit within each row was a section that was approximately 120 m in length with the distance between rows (on the order of 3 m) varying slightly between PV1 and PV2. For maintenance purposes, every 20 rows in PV1 and every 14 rows in PV2, the inter-row spacing increases to about 6 m in order to allow for the passage of maintenance vehicles. At the end of each contiguous string of solar panels that constitute a row section, a space of 4–6 m has been left before the next row section continues the row, again for the purpose of maintaining the facility. Given that the length to width ratio between rows is about 40 (120 m/3 m) and the break in between row sections is small compared to the length of the row sections, the solar array was assumed to provide an essentially two-dimensional obstruction to the flow.

The configuration of specific measurement instruments are provided in Fig. 2. All height measurements are above ground level (AGL). At the UW location, cup anemometers (Met One, model 014A) were installed at heights of 0.96 m, 1.85 m, and 3.3 m. These were used to obtain the wind speed profile near the ground. A combination wind speed propeller and direction vane (RM Young, model 05103) was installed at a height of 6.0 m. This higher wind monitor was for determining wind direction and quantifying surface wind speeds well above the height of the surface roughness. Temperature and relative humidity (Campbell Scientific, CS215) were monitored at a height of 2 m.

The PV1 and PV2 locations were instrumented similarly to one another, with some differences in the wind sensor horizontal spacings due to slightly different geometries. At each of the two locations, twelve cup anemometers (NRG Systems, 40C) were installed as shown in Fig. 2, with seven at a height of 35 cm and five at a height of 54 cm. In panels b and c of Fig. 2, the spacing between sensors relative to one another are shown in plan and cross-sectional views, respectively. In panel b, horizontal distances to each sensor from the edge of the solar panels that is lowest are provided along the left side of the panel. This measurement is illustrated in panel c as the distance “X”. The same type of information is provided for PV2 in Fig. 2d and e.

The overall intent was to provide measurements across the gap between successive rows. The precise locations of the measurements were dictated to some extent by the lattice structure that was used to support the anemometers. The structure consisted of two parallel steel tracks (width=2 cm, height=1.7 cm) where anemometer arms could be mounted at set locations, with some ability to slide the anemometer closer or further away from the lowest edge of the solar panels.

Due to physical limitations of the lattice structure, it was not possible for all of the anemometers at the 35 cm height to be located within the same row. In the PV1 array, two of the anemometers were located in the row adjacent to where the other five anemometers were, while for PV2, one anemometer was located in the adjacent row to the other six anemometers. These anemometers are shaded in yellow in Fig. 2b and d, respectively. It was assumed that the average flow would be essentially identical for all rows in the vicinity of the measurement arrays, because the arrays were located deep within the solar facility, so that the flow would be at its long-fetch equilibrium. While the instantaneous wind vectors within successive rows are certainly different, there is no reason to believe that average flows should differ greatly among rows. Therefore, the anemometers that are shaded in Fig. 2b and d, are treated as though they are located in the same rows as the other 35 cm height anemometers (i.e., treated as if they were located in the open circle shown in the figures). With this assumption in mind, the 35 cm height anemometers at PV1 were installed at