August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering
ICWE 16

The impact of utility-scale solar photovoltaic power stations on the near-surface wind flow in a desert area

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SUMMARY:
Deserts are ideal places to develop ground-mounted large-scale solar Photovoltaic (PV) power station. In order to avoid damage to a solar PV power station in sandy area, it is necessary to investigate the characteristics of wind-sand movement under the interference of solar PV array. The study was undertaken by measuring near surface wind speed variation of different wind directions above shifting dunes and the solar PV array in the Hobq Desert, China. The results showed that after the construction of the solar PV power station, the interference effect of that on airflow commonly was the shelter efficacy and it has a significant correlation with the intersection angle between PV array and wind direction. The interference effect was maximum with the intersection angle close to +90° between solar PV array and wind direction, wind speed within the height range of 200cm for solar PV array was less than 60% of that above the shifting dunes, and it was minimum with the intersection angle close to 22.5°. The wind direction in the solar PV array is more concentrated than in the shifting dunes with the small intersection angle, and it more dispersed when the intersection angle exceeds 45°.

Key words: *Solar photovoltaic power station; Shelter efficacy; Hobq Desert*

1. Introduction

Solar photovoltaic (PV) technology is one of the most important tools used by many countries to wean themselves off the dependence on conventional fossil fuel-based energy sources and reduce greenhouse gas emissions (Garcia et al., 2014). Field studies have shown that the surface air flow characteristics can be altered with the installations of PV facilities in sandy area, resulting in further loss of soil under the surface of PV panels and formation of sand ridge landforms between the panels (Kopp et al. 2002, Kopp et al. 2012). The geomorphological changes of PV power stations caused by the surface erosion processes can aggravate the release rate of surface dust and increase the dust deposition on PV panels firstly. Seconddly, erosion can expose the panel column base and lead to instability of the PV panel infrastructure. As such, wind controls the formation and development of surface geomorphology in sandy area. Numerous studies using wind tunnel and numerical simulation tests have confirmed the effect of PV arrays on the near-surface wind flow field in desert areas is related to the wind direction (Warsido et al. 2014, Jubayer et al. 2014). For crosswinds, the wind load is maximized for the first windward row of panels in an array, the sheltering effect from the upwind panels reduces the wind load on the downstream panels (Schellenberg et al. 2013, Bitsuamlak et al. 2010). However, for skew winds

(45° and 135° wind directions in relation to the panel array), all of the rows have similar overturning moment coefficients (Mohapatra 2011, Schellenberg et al. 2013). Currently, the impact of solar PV array on transit airflow and its relationship with wind directions is still under debate. The aim of this study was was to systematically analyse and clarify this relationship, which can be used to determine the technical scheme of wind-sand hazard prevention and control in solar PV power stations to ensure safe and stable operation of the plants.

2. METHODS

The study area was located at the middle part of the Hobq Desert in China (37°20′~39°50′N, 107°10′~111°45′N). Field observations were conducted from March 20th to April 25th, 2019. The wind velocity and wind direction were recorded using a HOBO sensor (Onset Computer Corp., MA, U.S.A.) at the observation sites at the between panels in the hinterland of the solar PV array and the shifting dunes, the observation sites of shifting dunes was set up 300 m west of the solar PV power station and it free of the influence of the solar PV array. Cup anemometers were arranged at heights of 20, 50, 100, and 200 cm. A wind vane was installed at a height of 200 cm. The acquisition interval was 3 seconds.

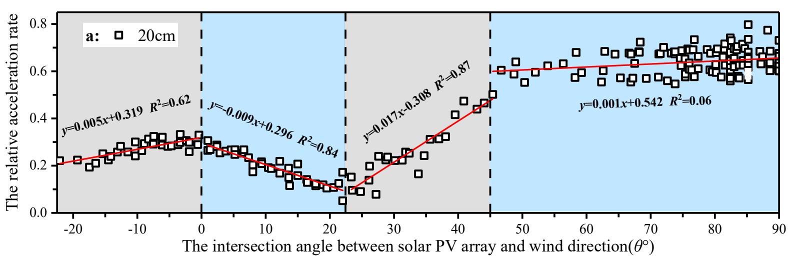
We designated W wind direction as parallel solar PV array, that is, the intersection angle (θ°) between solar PV array and wind direction is 0°. N or S wind direction is vertical PV array, that is, the intersection angle is ±90°. The R_u is positive indicates that the solar PV array can reduce the near surface wind speed, and the greater the value, the greater the wind speed attenuation degree, and vice versa.

The relative acceleration rate of the wind speed provides a measure for evaluating the effect of the solar PV array on the near-surface wind velocity (Jackson et al. 1975), where R_u is the relative acceleration rate; u_z is the measured velocity at height z above the shifting dunes (m/s); u'_z is the measured velocity at height z in the solar PV array (m/s); z is the measured height (m).

$$R_u = \frac{u_z - u'_z}{u_z} \quad (1)$$

3. RESULTS

Our results showed that the existence of solar PV array has a weakening effect for the surface wind speed, and this action intensity was affected significantly by the intersection angle (Fig. 1). When the intersection angle θ° is around 22.5° the reduction of wind speed in the near ground layer within the PV array is the smallest. When the intersection angle is close to 90°, the wind speed in the PV array near the ground layer is reduced the most, calculate the average value of relative acceleration rate in the case of intersection angle greater than 85° and less than 90°, 20cm, 50cm, 100cm and 200cm height are 0.65, 0.67, 0.64 and 0.61 respectively.



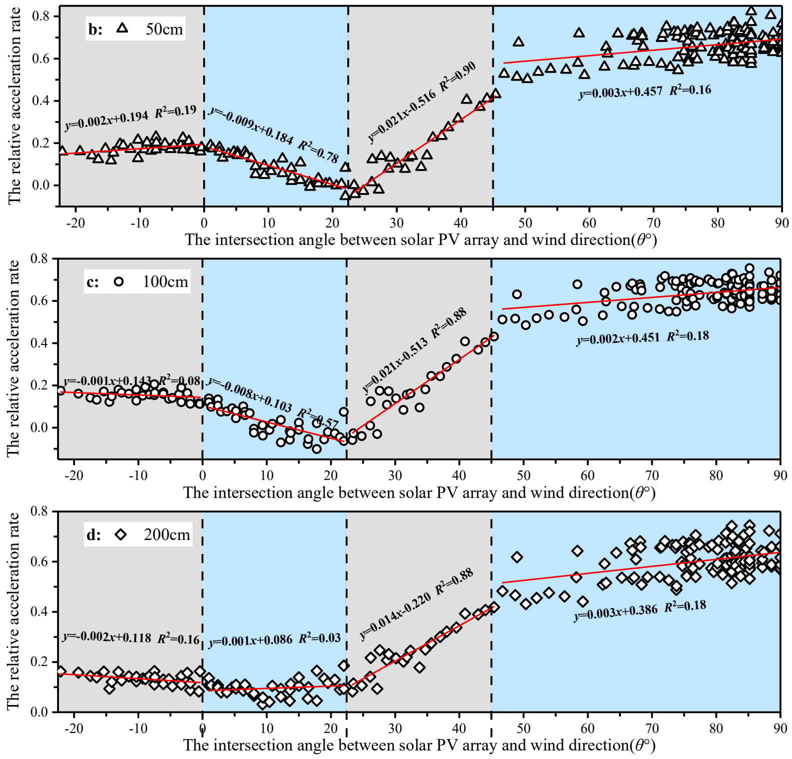
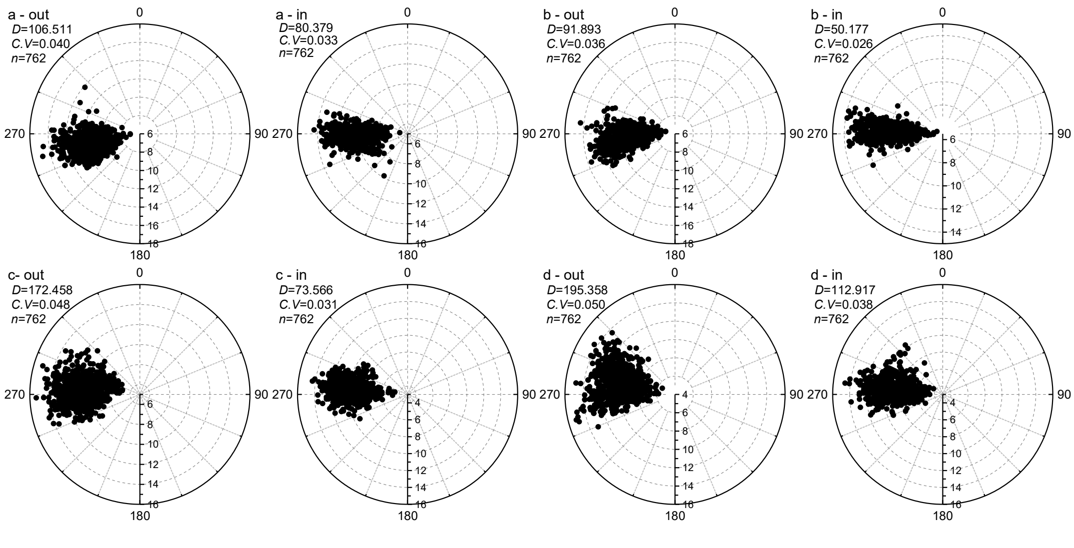


Fig.1 Relationship between the relative acceleration rate at heights of **a**:20, **b**:50, **c**:100 and **d**:200cm above the surface and the intersection angle between wind direction and solar PV array. In the picture, Equation : $y=ax+b$, R^2 is the regression goodness of fit.

When the intersection angle was small (-22.5° to 22.5°), the wind direction in the solar PV array is more concentrated than in the shifting dunes. The variance of the wind direction data set becomes smaller, the coefficient of variation becomes smaller (Fig. 2a-e). As the intersection angle increases, the convergence effect of the PV array becomes weaker for wind direction (Fig. 2f-g). When the intersection angle was close to 45°(Fig. 2h), the wind direction within the PV array was unstable, the wind direction is more dispersed than in flowing sands, the variance of the wind data set becomes larger, and the coefficient of variation becomes larger (Fig. 2i-j).



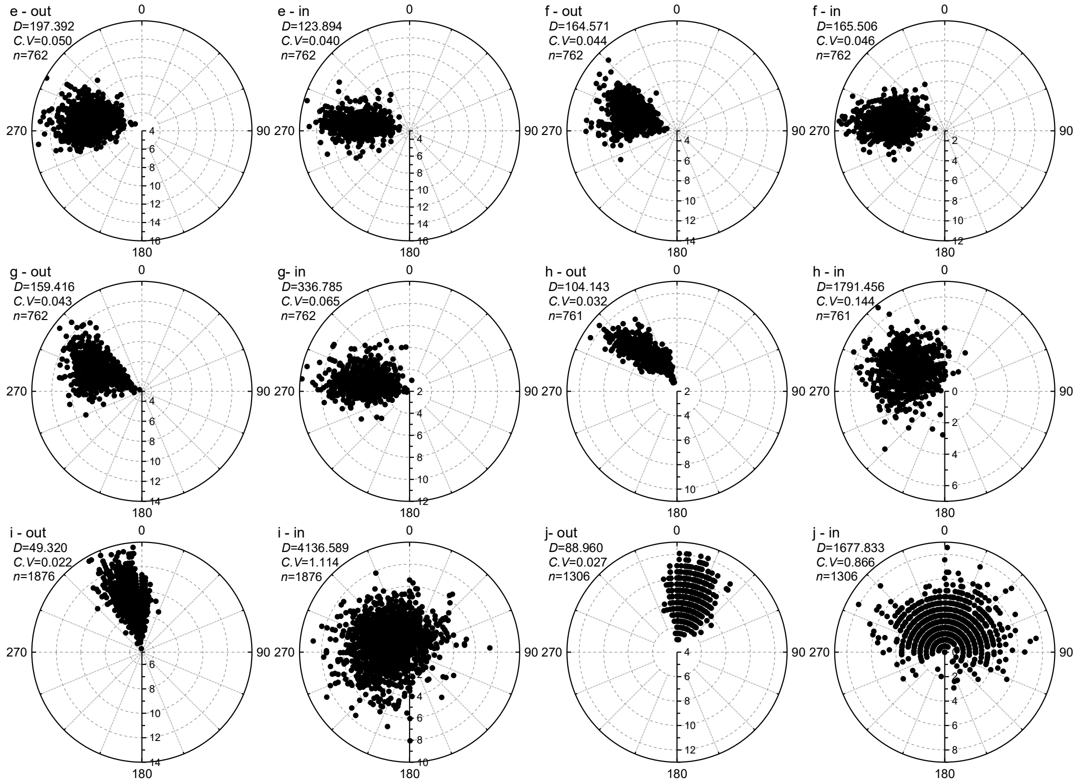


Fig.2 Wind roses in the solar PV array in response to wind conditions at the shifting dunes station. In the picture, a-j represent different intersection angle conditions, *D* is variance, *C.V* is coefficient of variation, *n* is sample size.

4. CONCLUSION

The airflow interference effect commonly occurs at the near-surface of solar PV array after the construction of the solar PV power station, the main performance of this effect was the shelter efficacy for wind speed and convergence effect for wind direction, and it has a significant correlation with the intersection angle between PV array and wind direction.

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