Postprint: Wind Speed Fluctuation Characteristics of an Ecological Photovoltaic Power Station in the Kubuqi Desert

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Abstract

This study investigates the characteristics of wind speed fluctuations under the disturbance of photovoltaic panels in sandy areas to understand the patterns of wind erosion and sand burial in photovoltaic power stations. Two cross-sections within an ecological photovoltaic power station were selected to measure wind speeds at five heights (20, 50, 80, 100, and 200 cm) at typical locations including beneath, in front of, and between panel arrays, and the wind flow field and fluctuation characteristics of the photovoltaic power station were analyzed. The research results indicate: The wind speed at the upwind edge of the photovoltaic panels is maximal, gradually decreasing through the array, with wind speed in the interior of the photovoltaic array significantly reduced, particularly in the near-surface layer. Compared with the average wind speed in the interior of the panel array, the average wind speeds at 20 cm beneath, in front of, and between panels increased by 44.7%, 54.8%, and 7.2%, respectively. At three upwind positions of the photovoltaic panels, wind speed fluctuation and wind speed fluctuation intensity exhibit a trend of first decreasing then increasing with height, while the interior panels show a decreasing trend with increasing height, with the most intense turbulence occurring in the 20–80 cm range. Compared with the control, turbulence intensity at the upwind edge of the photovoltaic panels shows an increasing trend with height at positions beneath and in front of the panels. Wind speed fluctuations around the photovoltaic panels constitute the primary driving force for vortex formation beneath and in front of the panels, thereby causing foundation undercutting of the PV panels and development of sand accumulation belts between panels.

Full Text

Study Area

The study area is located in a photovoltaic (PV) power station on the eastern margin of the Kubuqi Desert (37°20 -39°50 N, 107°10 -111°45 E). This region is characterized by a temperate continental climate. Meteorological data indicate an average annual precipitation of 2400 mm, mean annual temperature of 5.7°C, average wind speed of 3.5 m · s ¹, and annual evaporation of 258.3 mm. The windy season typically occurs from March to May [?], with wind speeds reaching 25–35 m · s ¹. The PV power station was constructed on June 16, 2016, covering an area of 6.67 km².

Methods

Two representative sections were selected within the eco-photovoltaic power station for wind speed measurements. The PV panels were oriented at a 37° tilt angle, facing south. The experimental design included three measurement positions: under the panels (A1, A2), between panels (B1, B2), and in front of the panels (C1, C2). Wind speeds were measured at heights of 20 cm, 50 cm, 80 cm, 100 cm, and 200 cm using HOBO anemometers. The measurement protocol consisted of 5-second intervals over 30-minute periods, with four replicates per location.

[Figure 1: see original paper] Schematic diagram of wind measurement positions at the experimental site

2.1 Wind Speed Measurements

At position C1 (20 cm height), the average wind speed was 7.95 m · s ¹. The wind speeds at 20 cm height under the panels (A1, B1) showed reductions of 31.8% and 40.4%, respectively, compared to C1. The wind speed reduction at 20 cm height for measurement point 1 was 35.0%. At heights of 50 cm, 80 cm, 100 cm, and 200 cm, the differences between measurement points 1 and 2 were not statistically significant. At 200 cm height, the wind speed reduction was minimal, with only a 1.3% difference. For measurement point 2, the wind speed between panels was lower, with the reduction at 20 cm height following the relationship: $v = 0.78v_0$, where v_0 is the reference wind speed at C2. Measurement point 2 showed reductions of 27.7%, 53.8%, and 83.0% at various heights.

2.2 Wind Speed Fluctuation Analysis

The relative intensity of wind speed fluctuation (turbulence intensity) was calculated using the formula:

$$I = \frac{\sigma}{\bar{v}}$$

where σ is the standard deviation of wind speed and $\bar{v}$ is the mean wind speed. The analysis revealed that turbulence intensity first decreased then increased with height, with the most severe turbulence occurring at 20–80 cm height. Compared to the control, turbulence intensity under and in front of the PV panels increased with height.

The wind speed fluctuation around the PV panels was the primary driving force for vortex formation both under and in front of the panels. This vortex formation resulted in erosion at the PV panel bases and contributed to sand accumulation between panels. The average wind speeds at 20 cm height under the panels, at the front, and between panels increased by 44.7%, 54.8%, and 7.2%, respectively, compared to reference conditions.

[Figure 8: see original paper] Wind speed field of section 1
[Figure 9: see original paper] Wind speed field of section 2

Discussion

The PV array layout significantly altered near-surface wind fields. The wind speed at the panel margins was highest, while the leeward side showed significant reduction, particularly near the ground surface. The complex airflow patterns created by the panels included acceleration at panel edges, flow separation, and vortex development in the wake region. These aerodynamic effects are consistent with previous studies on flow around surface-mounted obstacles [**?**, **?**].

The observed wind speed profiles demonstrate that PV panels act as roughness elements, increasing surface friction and modifying boundary layer dynamics. The turbulence intensity variations indicate that the 20–80 cm height range experiences the most dynamic flow conditions, which has important implications for sand transport and erosion processes. The relationship between wind speed reduction and height follows a logarithmic profile, as described by standard boundary layer theory [**?**, **?**].

The formation of vortices under and between panels creates localized erosion hotspots. This phenomenon is particularly problematic for the stability of PV installations in sandy environments, as it can lead to foundation exposure and structural instability. The sand accumulation patterns observed between panel rows suggest that the array geometry influences sediment transport pathways, with implications for maintenance requirements and long-term operational efficiency.

Conclusion

This study investigated wind speed fluctuation characteristics around photovoltaic panels in the Kubuqi Desert. Key findings include: (1) PV panels significantly reduce wind speeds in their lee, with effects most pronounced near the ground surface; (2) turbulence intensity exhibits a non-linear relationship with height, peaking at 20–80 cm; and (3) wind speed fluctuations drive vortex formation that causes erosion at panel bases and sand accumulation between panels. These results provide a theoretical foundation for developing effective sand disaster prevention and control strategies at photovoltaic power stations in arid regions.

References

[?] Reference text about climate data
[?] Cava D, Schipa S, Giostra U. Investigation of low-frequency perturbations induced by a steep obstacle. *Boundary-Layer Meteorology*, 2005, 115(1): 27-45.
[?] Zheng Xiannian, Yang Xinghua, He Qing, et al. The characteristics of wind pulsation in the near-surface layer under different weather conditions. *Arid Zone Research*, 2019, 36(2): 387-394.
[?] Mao Donglei, Cai Fuyan, Yang Yuhui, et al. Characteristics of wind speed pulsation of four typical underlying surfaces in Cele, Xinjiang. *Arid Zone Research*, 2017, 34(1): 126-135.
[?] Mao Donglei, Lei Jiaqiang, Zeng Fanjiang, et al. Study on the temporal and spatial differences of wind speed profile of different underlying surface of Celle. *Journal of Arid Land Resources and Environment*, 2014, 28(11): 171-177.
[?] Yang Lin. Study on Wind Speed Pulsation Characteristics of Valley Slope under the Condition of Sand and Wind in the Lower Reaches of Laohe River. Changsha: Hunan Normal University, 2015.
[?] Zhang Xiwei, Wang Ji, Hai Chunxing, et al. Characteristics of wind-blown sand flow in the wind-eroded crater of Hulunbeier sandy grassland. *Arid Zone Research*, 2018, 35(6): 1505-1511.
[?] Mei Fanmin, Zhang Ningning, Xi Yuan, et al. Aerodynamic roughness and spatial variability of unified logarithmic region of different underlying surface wind profile. *Journal of Desert Research*, 2018, 38(3): 445-454.
[?] Zhou Jie, Lei Jiaqiang, Zheng Zehao, et al. Frictional wind speed and aerodynamic roughness of different underlying surfaces in the southwestern margin of Tarim Basin. *Bulletin of Soil and Water Conservation*, 2016, 36(1): 1-5, 10.
[?] Dong Zhibao, Qi Nan, Guang Qiang, et al. Turbulence fields in the lee of two-dimensional transverse dunes simulated in a wind tunnel. *Earth Surface Processes and Landforms*, 2009, 34: 204-216.
[?] Guo Caizhen, Han Zhiwen, Li Aimin, et al. The dynamic mechanism of secondary sandstorm hazard in 110 MW photovoltaic base in Kubuqi Desert. *Journal of Desert Research*, 2018, 38(2): 1-8.
[?] Shang Heying, Yin Zhongdong, Zhang Peng, et al. Characteristics of wind velocity in the surface of Gobi surface. *Journal of Nanjing Forestry University (Natural Science Edition)*, 2017, 41(1): 123-128.
[?] Bao Huijuan, Li Zhenshan. Experimental study on longitudinal pulsation of wind speed in wind sands flow. *Journal of Desert Research*, 2004, 24(2): 132-135.
[?] Wang Ping, Zheng Xiaojing. Analysis of pulsating characteristics of wind

and sand flow in the near field. *Journal of Desert Research*, 2013, 33(6): 1622-1628.
[**?**] Zhang Kecun, Qu Jianjun, Dong Zhibao, et al. Preliminary study on wind speed fluctuation characteristics in lattice-shaped sand barriers. *Arid Zone Research*, 2006, 23(1): 93-97.

Note: Figure translations are in progress. See original paper for figures.