Journal of Wind Engineering & Industrial Aerodynamics 179 (2018) 483–502

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Near-ground impurity-free wind and wind-driven sand of photovoltaic power stations in a desert area

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ARTICLE INFO

Keywords:
Desert area
Photovoltaic power station
Near-ground wind field
Wind-driven sand flow field
Wind-driven sand loads
Field measurement
Wind tunnel test

ABSTRACT

The ground mounted photovoltaic panel in desert areas is one of the best methods to get the solar energy. Unfortunately, there are no existing wind codes and standards to show the effect of impurity-free wind loads and wind-driven sand loads on ground mounted photovoltaic panels. It is necessary to investigate the characteristics of the impurity-free wind and wind-driven sand flow in desert areas. The characteristics of mean and fluctuating wind data are obtained from a 10 m-high tower set up in a desert photovoltaic power station, Zhongwei, China. The wind-driven sand flow fields in sandstorm climate are built to obtain the sand concentration profile and the impact pressure profile of sand particles using the wind tunnel testing. The sand concentration decreases exponentially with height under the lower wind speed and appears in the form of reverse "*S*" when the wind speed increases. The sand particles movement in the wind-driven sand flow reduces the wind speed and increases the turbulence intensity. To improve the output power and service life of photovoltaic panels in sandstorm climate, it is recommended that the installation height of photovoltaic panels should be 2 m.

1. Introduction

Solar energy has attracted much attention due to the recent energy crisis and the imperative need for clean energy. A remarkable design of photovoltaic panels can optimize the efficiency of the solar energy conversion. In general, solar photovoltaic panels can be divided into two families namely ground mounted photovoltaic panels and roof mounslbted photovoltaic panels. The ground mounted photovoltaic panel is used in an open desert area to obtain unobstructed sunlight which makes the panel experience high wind loads or wind-driven sand loads. As a result, wind loads or wind-driven sand loads become the dominant loads in the structural design of the solar photovoltaic panels (Gong et al., 2012; Jubayer and hangan, 2014; Zou et al., 2015). However, the existing wind codes and standards are not including the impurity-free wind and wind-driven sand impact on the structures, also the comprehensive design guidelines. Studies on wind loads acting on ground mounted photovoltaic panels (Bitsuamlak et al., 2010; Abiola-Ogedengbe, 2013; Shademan et al., 2014; Stathopoulos et al., 2014; Aly, 2016; Jubayer and hangan, 2014, 2016) have been reported. The influences of photovoltaic panel geometry (aspect ratio, gaps between panels, gaps between arrays, panel tilt angle, etc.), scale ratio of the model and inflow turbulence on wind loads of panels with methods of numerical simulation and wind tunnel test have been discussed. As the most direct and reliable method to evaluate the structural wind effect, field measurement method is rarely applied to wind loads research of photovoltaic panels. Some researches show the influence of dust cleaning cycle, chemical composition and particle size on the photoelectric conversion efficiency, especially the impact of dust accumulation on the output power of photovoltaic panels (Said, 1990; Jiang et al., 2011; Kaldellis and kapsali, 2011; Pravan et al., 2011; Sarver et al., 2013; Darwish et al., 2015). For solar power stations in desert areas, the wind-driven sand loads of photovoltaic panels, heliostats and concentrators have been presented, but only the sand abrasion on the surface layer is considered (Nelson et al., 2011; Lopez-Martin et al., 2011; Holze and brucks 2012, 2014; Gong et al., 2017). That means the effect of impact loads from sand particles on the structural design is ignored in the existing studies, which creates an unsafe condition for solar power generation systems.

To obtain wind loads and wind-driven sand loads by means of wind tunnel test or numerical simulation, fundamental laws of similitude should be employed, namely the similarity of test model, approaching wind and wind-driven sand to those in full-scale conditions (Plate, 1982).

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https://doi.org/10.1016/j.jweia.2018.06.017
Received 13 January 2018; Received in revised form 23 June 2018; Accepted 24 June 2018

0167-6105/

Therefore, obtaining wind and wind-driven sand characteristics are a fundamental task in the study of wind loads and wind-driven sand loads on photovoltaic panels. However, only limited researches on wind characteristics in desert areas are reported. The study on the characteristics of wind-driven sand flow field is mainly focused on the physical characteristics of sand particles movement and the transport characteristics of wind-driven sand two-phase flow within 2 m height of the surface (vertical distribution of sediment flux, sand transport rate model, threshold shear velocity, wind profile, distribution of sand particle velocity, etc.) (Zou et al., 2001; Dong et al., 2004; Liu et al., 2006; Shi and huang 2012; Raffaele et al., 2016; Zhang et al., 2017). Table 1 shows that further researches are required in this field to provide more theoretical fundamental in wind-driven sand loads design of engineering structures.

The desert area with long sunlight period is an ideal site to set up the solar photovoltaic stations. The existing wind codes and standards define the desert area as open, barrier-free and flat terrain, but ignoring the effects of near-ground sand particles movement on the wind field (GB50009-2012, 2012; ASCE/SEI 7-16, 2016; AIJ-2004, 2004; Eurocode 1, 2005; ESDU 85020, 2008; ESDU 82026, 2008; ESDU 83045, 2012). Moreover, there are certain differences in provisions for near-ground impurity-free wind characteristic parameters. For example, exponential law and logarithmic law are two different ways to characterize the ground surface roughness in the existing wind codes and standards. The wind profile uses the exponential law in Chinese, American and Japanese wind codes and standards, and the logarithmic law in European wind code. The minimum height $Z_{\min}$ of the turbulence intensity profile is 2.13 m in America, 1 m in Europe and 5 m in Japan. The influence of the surface roughness Z_0 on the turbulent integral scale empirical formula is considered in European and British wind codes, while it is neglected in American and Japanese wind standards. The von Karman's spectrum is adopted in Japan and UK (AIJ-2004, 2004; ESDU 85020, 2008a), while the Davenport's spectrum, Kaimal's spectrum and Solari's spectrum are adopted in China, America and Europe, respectively (GB50009-2012, 2012; ASCE/SEI 7-16, 2016; Eurocode 1, 2005). The Davenport's spectrum is the wind speed spectrum at the height of 10 m and does not change with the height, while the Kaimal's spectrum, Solari's spectrum and von Karman's spectrum take into account the characteristics of near-ground turbulence integral scale varying with the height. The near-ground wind characteristics in desert areas are obviously different from other landforms, because of its special geological environment and the influence of near-ground sand particles movement on the mean and fluctuating airflow speeds. In addition, the near-ground wind characteristics below 10 m have not been further investigated because of the impact of ground-surface obstacles. Therefore, it is necessary to carry out an intensive study on the near-ground impurity-free wind and wind-driven sand of the desert area.

The height of the ground mounted photovoltaic panel is no more than 10 m. The wind flow is highly turbulent below 10 m (Sun et al., 2014) and the wind loads and wind-driven sand loads acting on the photovoltaic panels are significantly influenced by the turbulent characteristics of the incoming wind. Therefore, the wind and wind-driven sand characteristics surrounding the ground mounted photovoltaic panels deserve an intensive research. This study systematically analyses the mean and fluctuating wind characteristics parameters around photovoltaic panels in desert areas, which are including the mean wind speed, mean wind direction, turbulence intensity, gust factor, turbulence integral scale, coherence function and fluctuating wind spectrum. Three kinds of sandstorm climate are simulated in wind tunnel to compare the characteristics of the impurity-free wind field with the wind-driven sand flow field and the mechanical model of wind-driven sand loads is constructed. This research will contribute to the further understanding of the wind and wind-driven sand in desert areas, and improve provisions of wind codes and standards for guiding the wind tunnel test and numerical simulation. The theoretical fundamental for the wind and wind-driven sand resistance design of photovoltaic panels in desert areas will also be presented.

Table 1
Studies on the characteristics of wind-driven sand flow.

References	Purposes	Methods	The key findings	Limitations
Zou et al., 2001	Study on the distribution of velocity and energy of sand grains within the boundary layer	Wind tunnel test High-speed photography Theoretical analysis	Velocity distribution of sand grains: Pearson Ⅶ distribution pattern Energy distribution of sand grains: Pulsepow law	It does not consider the influence of the actual bed characteristics on the start-up and transport of sand particles.
Liu et al., 2006	Study on the effect of grain sizes on the sand transport rate	Wind tunnel test	A method for fitting experimental data of the blown sand flux	It does not fully consider the turbulent characteristics under the actual terrain conditions.
Dong et al., 2004	To examine the fetch effect of a sandy surface on the blown sand flux	Wind tunnel test	The fetch effect of a sandy surface on the vertical flux profile and the total horizontal flux	It is suitable for wind tunnel test to study the problem of wind-driven sand flow.
Shi and huang, 2012	Study on sand saltation movement under fluctuating wind in a natural field environment	Field measurement Numerical simulation	The effect of turbulent characteristics in real environment on the sand transport rate A numerical model to simulate sand movement under the fluctuating wind	It studies only the situation below 2 m with a low sampling frequency of 1 Hz, which is hard to apply to the actual engineering structure.
Raffaele et al., 2016	Study on fluid threshold shear velocity for sand saltation	Theoretical analysis	A statistical approach to fluid threshold shear velocity for sand saltation	It does not ascertain which source of uncertainty among aleatory and epistemic ones mostly affected the variability of the fluid threshold velocity.
Zhang et al., 2017	Study on the sand transport rate over the dune crest	Field measurement	The relationship between the shear velocity and roughness length expressed by the modified Charnock model The sand transport flux expressed by Exponential function and Gaussian function	It needs to accumulate measured data from several sites for further verification.

2. Design of field measurements

Field measurement is the most direct and reliable method to investigate wind characteristics and evaluate the wind effect. However, due to the unpredictability of sandstorm climate, only the impurity-free wind field data under normal wind climate in desert areas are obtained during