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Simulation Study on the Deposition Characteristics of Particles on the Surface of Solar Photovoltaic Panel at Different Wind Speeds

HuadongYang *, HuiWang
[*1](*Department of Mechanical Engineering, North China Electric Power University, Baoding, China, 071000)*

Abstract
Dust deposition on the photovoltaic panel affects the stability of the photovoltaic panel system, resulting in a decrease in the power generation efficiency of the photovoltaic panel.Therefore, in this paper, a geometric model of the distribution form of the three-dimensional photovoltaic panel array is constructed, and the SST turbulence model and the discrete phase model (DPM) are used to simulate the deposition characteristics of particles on the photovoltaic panel, and the influence of different wind speeds on the particle deposition is analyzed.The results show that with the increase of wind speed, the particle deposition amount on the first row of photovoltaic panels gradually increases, and the particle deposition amount on the last two rows of photovoltaic panels gradually decreases.And the particle deposition on the photovoltaic panel is no longer evenly distributed, and more particles are deposited in the lower part of the panel;When the wind speed is small (2.6m/s), the particles are evenly distributed on the photovoltaic panels, and the deposition amount of particles on the first row of photovoltaic panels is much larger than that of the last two rows of photovoltaic panels;

Keywords:*particle, gas-solid two-phase flow, deposition characteristics, Different wind speed*

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I. INTRODUCTION

With the development of the global economy, the demand for energy in various countries has gradually increased, and the development and utilization of renewable energy has become a global development trend. Facing the current global energy crisis and environmental pollution problems, solar energy is one of the most promising renewable energy sources to solve the problem [1]. In the future long-term strategic planning, solar energy plays an important role [2]. By 2020, the global demand for new solar photovoltaic modules will reach 142 GW, showing the potential of solar energy to replace traditional energy in the coming decades [3-4]. However, the dust deposition on the solar photovoltaic panel is very serious, which has a great negative impact on the power generation efficiency of the photovoltaic panel. Therefore, it is very important to study the characteristics of particle deposition on the surface of photovoltaic panels.

A large number of related studies have reported that dust deposition can reduce the power generation efficiency of photovoltaic panels [5-8]. Khazaee et al. [9] found through experiments that when the dust density reached 6.0986g/m2, the power generation decreased by 21.47%. Goossens et al. [10]studied the effect of wind speed on the dust deposition characteristics of photovoltaic cells. They found that the higher the wind speed and the higher the dust deposition density, the greater the reduction in solar photovoltaic efficiency. Jaszczur et al. [11] studied the effects of PV module temperature and natural dust deposition on the performance of PV systems. The results show that the photovoltaic efficiency decreases significantly when the mass is deposited or the temperature is increased. In addition, a large number of scholars have used CFD numerical simulation method to study the characteristics of dust deposition. Lu et al. [12] used the CFD method to study the effects of wind speed and photovoltaic module inclination angle on airflow characteristics and dust deposition state. The study found that the dust accumulation rate of the photovoltaic system increased first and then decreased with the increase of the dust diameter. In addition, with the increase of the inclination angle of the photovoltaic panel, the deposition rate also increased. Liu et al. [13] used the CFD-DEM method to study the gas phase motion characteristics and charging mechanism of dust particles on a single solar photovoltaic panel, and also discussed the mechanism and characteristics of dust deposition in solar photovoltaic modules dominated by electrostatic force. The study found that the dust accumulation mechanism on solar photovoltaic modules is a gas-solid-electric multidirectional coupling process. The presence of large electrostatic fields near solar photovoltaic glass results in the deposition of charged dust particles. Raillani et al. [14] studied the effect of windshield height on the dust accumulation rate of ground-mounted photovoltaic panels, and the results showed that gravity has a considerable influence on the behavior of dust. For small particles, this effect is negligible, while for large particles there is a completely different behavior.

Therefore, it can be seen that in the past experimental studies and numerical simulation studies, more focus was placed on the power generation efficiency and the trajectory of dust particles. In order to study the distribution of particles deposited on photovoltaic panels, a three-dimensional photovoltaic panel model was established in this paper and distributed in a 3×3 array. The effects of different wind speeds, particle sizes, and wind direction angles on the dust deposition process were mainly discussed. And further analysis of the impact of the front and rear photovoltaic panels on particle deposition has important theoretical significance and reference value for the distribution of photovoltaic panels in photovoltaic power plants and the development of photovoltaic industry.

II. NUMERICAL SIMULATION MODEL

2.1 GEOMETRIC MODEL

In this paper, SolidWorks is used to establish the model. The photovoltaic panel is regarded as a flat plate in the modeling process, and the distribution law of dust particles on the photovoltaic panel is studied by CFD numerical simulation.

The size of the solar photovoltaic panel model adopts the typical size of a photovoltaic power station 1990mm×990mm×50mm. This paper selects a 3×3 array of solar photovoltaic panels. The solar photovoltaic panel is numbered as shown in Figure 1. Finally, the inclination angle of the solar photovoltaic panel is determined to be 36.39°[15].

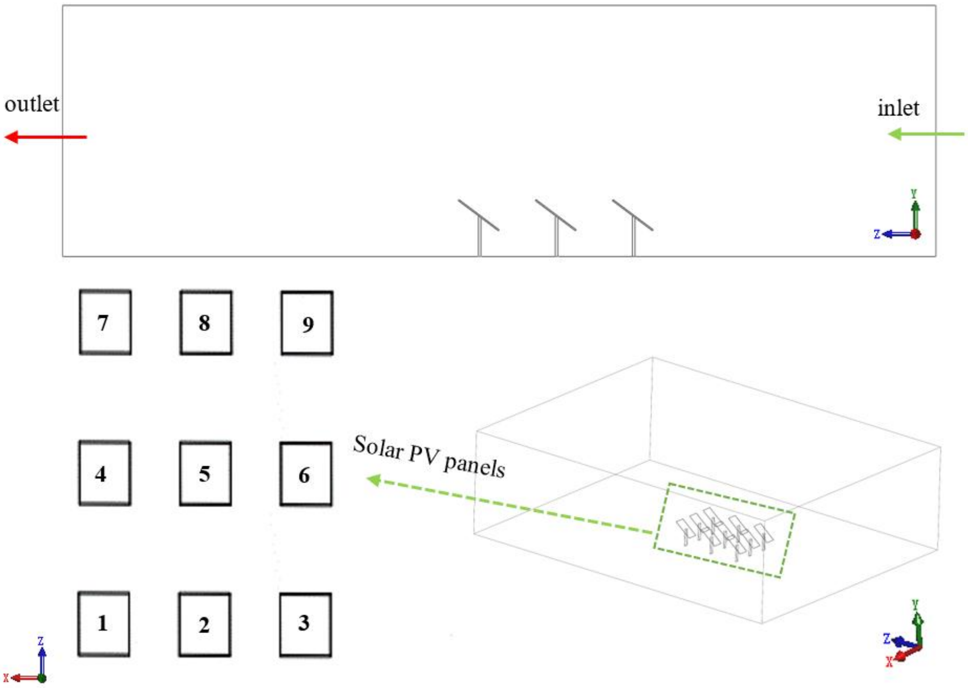


Figure1: Schematic diagram of the model

In order to make the simulation environment close to the real environment, the computational domain should be kept large enough to ensure that the boundary is far enough from the model, thereby reducing the simulation error and improving its authenticity. However, if the computational domain is too large, the number of grids will increase, which will increase the computational burden, and sometimes even lead to computational errors. Therefore, in the numerical simulation, the size of the blocking rate [16] is used to measure whether the computational domain meets the simulation requirements, as shown in formula (1).

$$\varepsilon = \frac{s_1}{s_2} \quad (0)$$

In which, s1 is the maximum windward area of the solar panel, s2 is the cross-sectional area of the computational domain.

In addition to this, the placement of the model in the computational domain also needs to be considered. Through the calculation, the size of the computational domain is obtained, the height of the computational domain is H=9.8m, the width of the computational domain is B=26m, the distance from the model to the entrance L1=11m, the distance from the model to the exit L2=17m, the distance between the model and the ground h=1m ,According to the calculation of the blocking rate formula, the blocking rate is 2.32%, which is less than 3%, which meets the simulation requirements.

For photovoltaic panels distributed in an array, it is necessary to avoid shadow effects during installation, and there should be sufficient distance between the front and rear of each photovoltaic panel to ensure that there is no shadow blocking of photovoltaic modules from 9:00 to 15:00 local time every day, such as Equation (2) is shown. After calculation, the minimum distance between the front and rear of the photovoltaic panel is designed to be D=3.02m.

$$D = \frac{0.707h}{\tan[\sin^{-1}(0.648\cos\varphi - 0.399\sin\varphi)]} \quad (0)$$

In which, $\varphi$is the latitude, latitude 40° (Beijing city) is chosen in this paper. h is the height difference between the photovoltaic array and the bottom edge of the module that may be shaded.

After calculation, the minimum distance between the front and rear of the photovoltaic panel array is designed to be 3.02m

2.2 MESHING

Before numerical simulation, mesh division is very important.In this paper, three different mesh sizes are used for mesh division, and the number of meshes obtained is 1.4 million, 1.9 million, and 2.4 million, corresponding to three types of coarse mesh, medium mesh and fine mesh.And compare the grids and draw a curve graph, as shown in Figure 2.

It can be seen from the figure that there is a big difference between the coarse mesh and the fine mesh. Compared with the medium grid and the fine grid, the two curves basically coincide, but the change of the fine grid is smoother, and the prediction of the wind speed inside the flow field is also more accurate, so this paper chooses the fine grid for simulation.

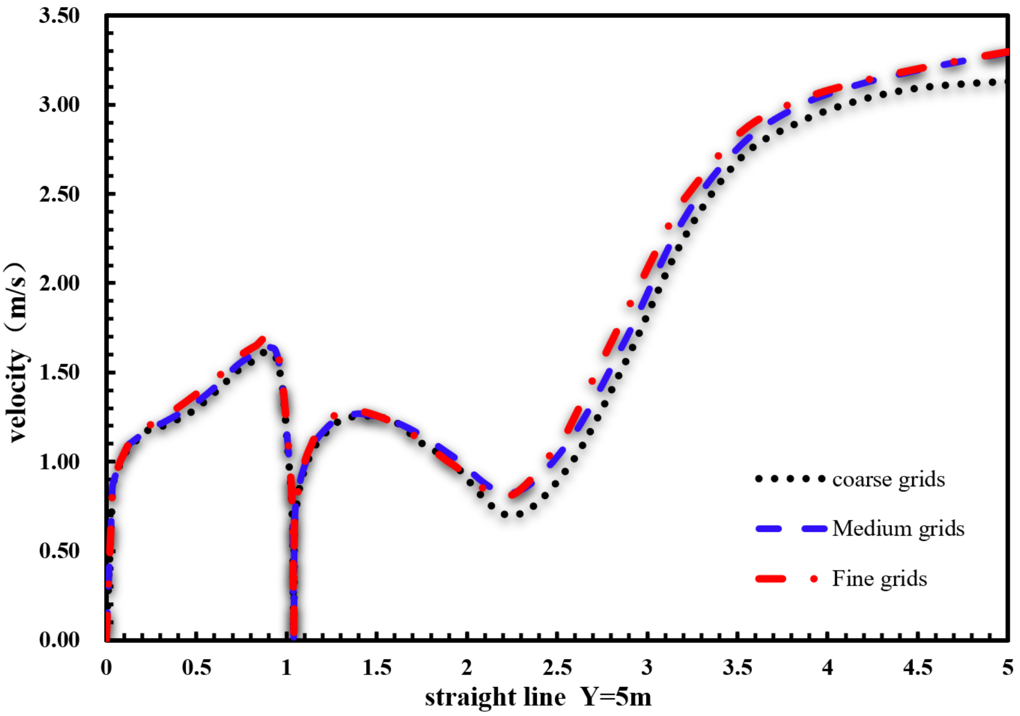


Figure2:Grid independence verification under different grid sizes

2.3 BOUNDARY CONDITION SETTING

In order to accurately simulate the change of the flow field, the DPM model is used to simulate the flow field around the photovoltaic module and the deposition of particles on the module. The bidirectional coupling is selected, and the particle incidence is uniform from the entrance surface of the computational domain. During the numerical simulation, Phase Couple SIMPLE pressure-velocity coupling algorithm, three-dimensional simulation model, and transient solver were used for calculation. The simulation time was set to 20s, and a total of 500g of particles were injected.

Table 1. Boundary condition settings

Name	Boundary condition setting
Inlet	velocity-inlet
Outlet	outflow
Particle gravity	The gravitational acceleration is -9.81m/s^2along the Y-axis
Mass Flow	0.25kg/s
Particle density	2650kg/m^3
Wall condition	Non-slip wall
Variabledensity parameter of unit area condition	air density 1.225 kg/m^3

2.4 MATHEMATICAL MODEL

For solving the problem of multiphase flow, the particle trajectory model (DPM model) is selected. The model is carried out under the Euler-Lagrange theory. The fluid is regarded as a continuous phase and the particles are regarded as discrete phases. The DPM model requires particle volume fraction to be less than 10%, but the mass load of the particles can be greater than 10%. By solving for the force of each particle in the continuous phase, the trajectories of all particles can be analyzed.

III. ANALYSIS OF SIMULATION RESULTS

In the two-phase flow of wind and sand, wind speed has a very important influence on the deposition of particulate matter on photovoltaic panels. In order to further explore the effect of wind speed on particle deposition when the particle size meets the Rosin-Rammler distribution, the initial wind speeds at the top of the photovoltaic panel were selected as 2.6 m/s, 5.2 m/s, and 7.8 m/s. The upper distribution law is simulated and analyzed.

It can be seen from Figure 3 that the change of the flow field is quite complicated with the change of the inlet velocity. When the wind passes through the photovoltaic panel, a diversion is formed at the top and bottom of the photovoltaic panel. As the wind speed increases, the diversion trend and the eddy current formed at the bottom of the photovoltaic panel are more obvious. Due to the blocking effect of photovoltaic panels, the surface wind speed of the second and third rows of photovoltaic panels was significantly lower than that of the first row of photovoltaic panels, and the wind speed in the leeward area was significantly reduced, indicating that the change of wind speed would have a certain impact on the deposition of particulate matter.

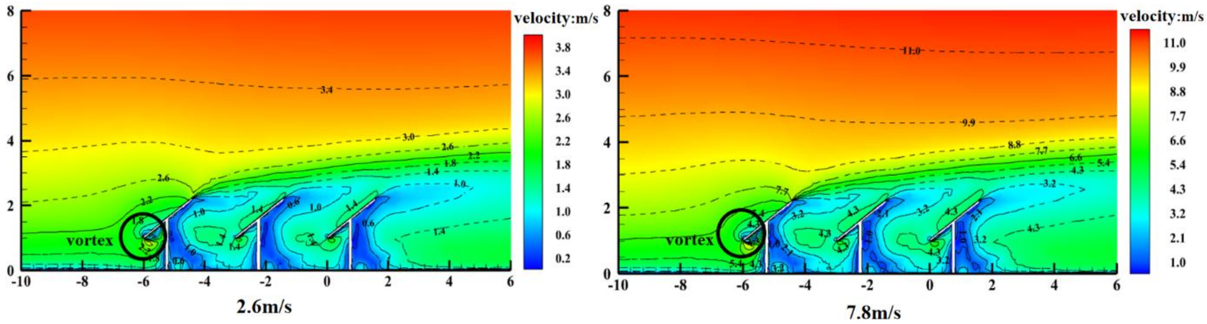
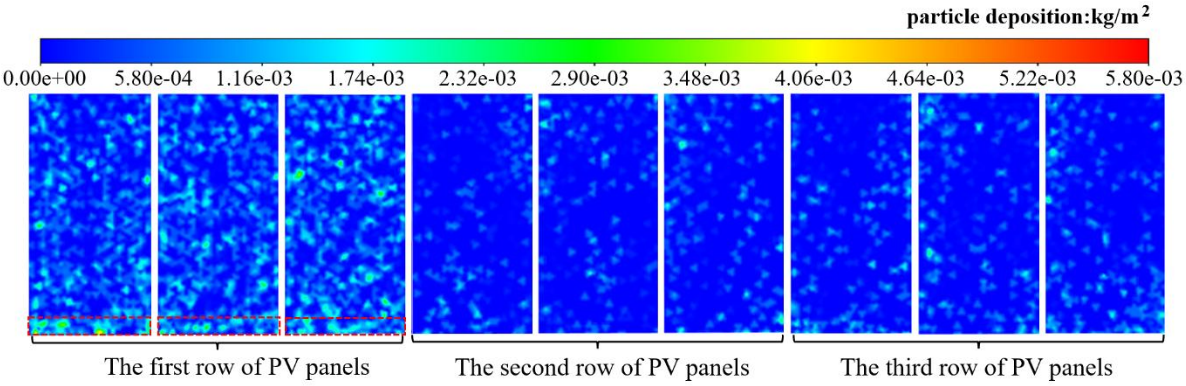


Figure3:Cloud map of flow field under different wind speeds

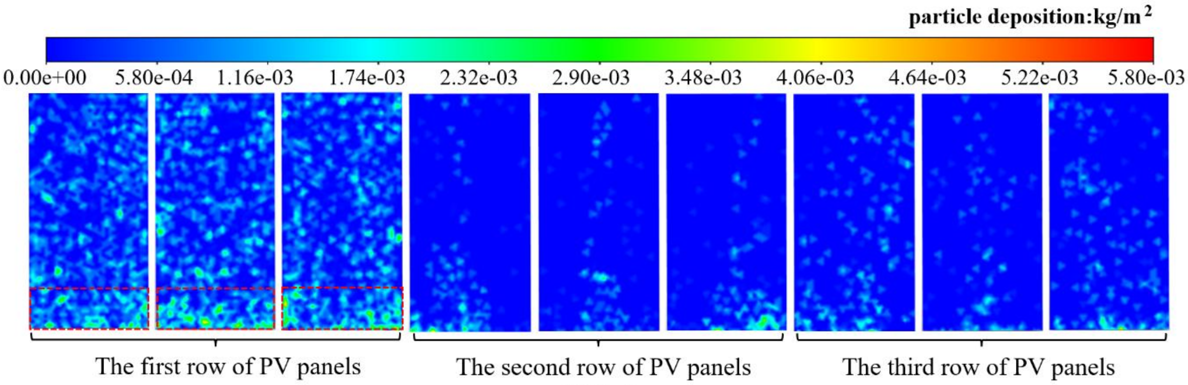
At different wind speeds, the particle deposition distribution is shown in Figure 4.In order to distinguish different photovoltaic panels, the photovoltaic panels are named 1-9 from left to right in this paper. 1-3 represent the first row of photovoltaic panels, 4-6 represent the second row of photovoltaic panels, and 7-9 represent the third row of photovoltaic panels.

It can be seen from the figure that when the wind speed is 2.6m/s, the particles are evenly distributed on the photovoltaic panels, and the deposition amount of particles on the first row of photovoltaic panels is much larger than that of the last two rows of photovoltaic panels.As the wind speed increases, the particles on the first row of photovoltaic panels are gradually deposited on the bottom of the photovoltaic panels.And with the change of wind speed, the deposition amount of the first row of photovoltaic panels gradually increases, while the deposition amount of the last two rows gradually decreases, which is due to the influence of the eddy current at the bottom of the photovoltaic panels.As shown in Figure 3, during the reflow process, the eddy current drives the particles, and the wind speed at the bottom of the photovoltaic panel is relatively small, which leads to a gradual increase in the amount of particles deposited at the bottom of the photovoltaic panel and does not detach with the increase of the wind speed.It can be seen from Figure 4 that with the increase of wind speed, the particle deposition distribution on the photovoltaic panels in the second row and the third row presents different laws.As the wind speed increased, the deposition of particles gradually changed from being more uniformly distributed on the photovoltaic panels to being deposited in the middle and bottom of the photovoltaic panels.

In order to observe the changes of wind speed and turbulent energy at the bottom of the photovoltaic panel more intuitively, this paper intercepts reference lines on both sides of the bottom of the array photovoltaic panel. A total of 6 lines are intercepted, named in the order of line 1 to line 6, and each reference line is taken as 1000 sampling points, respectively output the wind speed and turbulent energy corresponding to different points, and draw them in the graph, as shown in Figure 5, it can be seen that there is a large wind speed and turbulent energy between the edges of the photovoltaic panel. With the increase of turbulent energy, the turbulent energy gradually increases. The enhanced turbulent energy causes the particles deposited at the edge of the photovoltaic panel to regain kinetic energy and separate from the photovoltaic panel, while the particles suspended in the air reduce the deposition on the photovoltaic panel due to the effect of turbulent energy. As a result, the deposition of particles changed from uniform distribution to deposition in the middle and bottom of the photovoltaic panel.

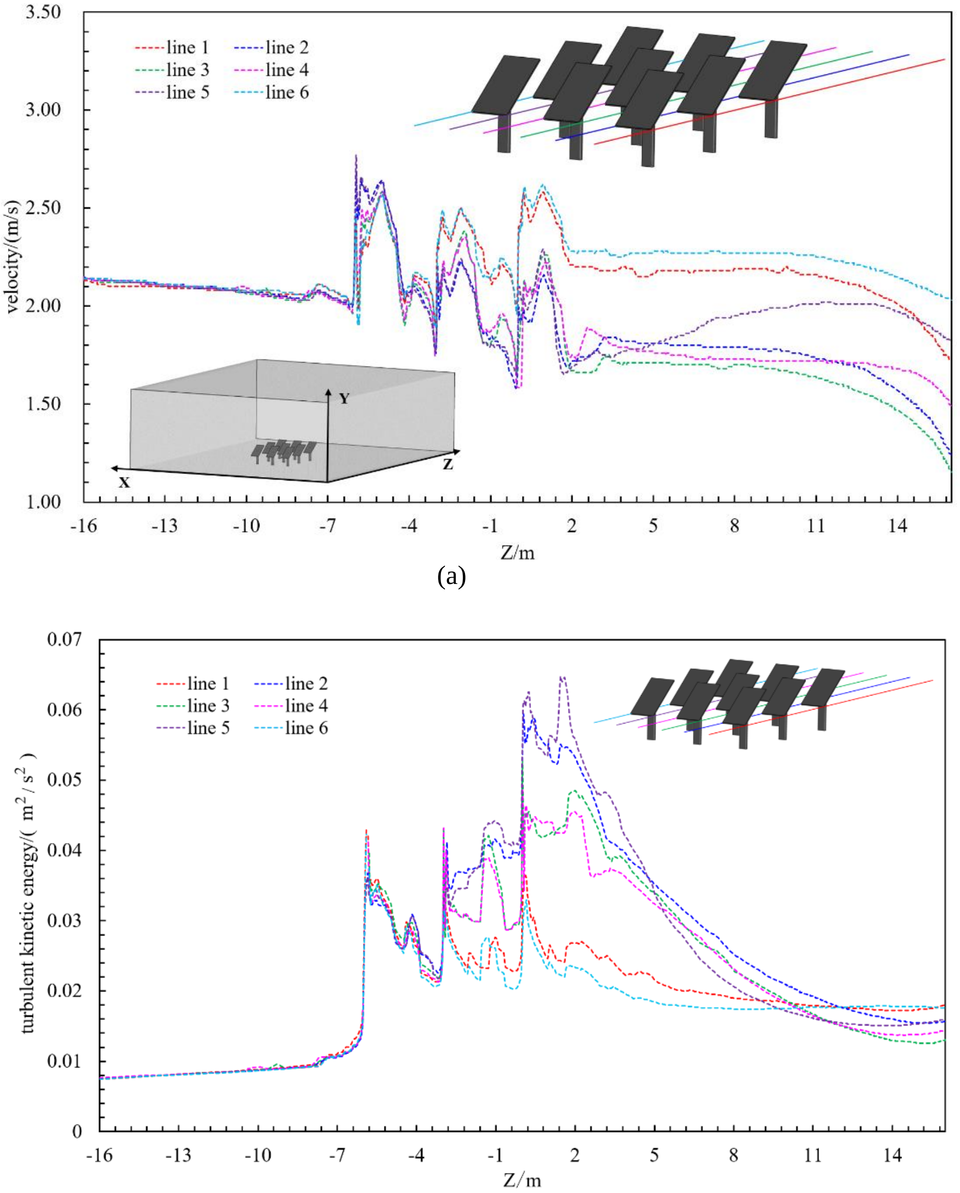


a) 2.6m/s



c) 7.8m/s

Figure4: Cloud map of particle deposition distribution under different wind speeds



(a)

(b)

Figure5: Wind speed (a) and turbulent energy change (b) at both sides of the bottom edge of photovoltaic panel

IV. CONCLUSION

In this paper, the CFD numerical simulation method is used to analyze the deposition characteristics of particles on photovoltaic panels at different wind speeds, different particle sizes, and different wind direction angles. Based on this study, the following conclusions can be drawn:

(1) When the wind speed is small (2.6m/s), the particles are evenly distributed on the photovoltaic panels, and the deposition amount of particles on the first row of photovoltaic panels is much larger than that of the last two rows of photovoltaic panels;

(2) When the wind speed gradually increases, the particle deposition on the solar panel is no longer evenly distributed, and more particles are deposited on the lower part of the panel. This is due to the increased turbulent energy as the wind speed increases, thus depositing more particles in the middle and bottom of the photovoltaic panel.

(3) With the increase of wind speed, the amount of particles deposited on the first row of photovoltaic panels gradually increased, and the amount of particles deposited on the last two rows of photovoltaic panels gradually decreased. This is due to the shading effect of the first row of photovoltaic panels, the increase in wind speed leads to an increase in the kinetic energy of particles, and more particles collide with the first row of photovoltaic panels, increasing the probability of particle deposition.

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