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Base on DPM model to simulation Sand erosion on PV modules surface

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Abstract: The erosion wear behavior of dust on the surface of PV modules in desert aeolian gas-solid two-phase flow was analyzed by discrete phase model.This paper investigated the effect of the tilt angle、the wind speed、the particle size、the mass flow to erosion on PV modules surface.The conclution showed that the tilt angle and the wind speed are the major factors to effect the maximum and average erosion rate on PV modules surface. In especially,the effect of wind speed on the surface erosion rate of PV modules varies exponentially.

1. Introduction

The country's most abundant resource of solar radiation distributing in most areas of western China, including Inner Mongolia, Gansu, Qinghai, etc.[1].The rich solar energy resources and the cheap land have provided a convenient condition for the large-scale development of the photovoltaic industry. However,these places are located in Central Asia sandstorm area which is one of the most active regions of dust activity.These areas are mostly wasteland, sand, gobi, desert and where is a frequent area of sandstorms.The dust particle impacted on the surface of PV modules to reduce the power generation efficiency of PV modules and reduce their service life, will have a significant impact on the operation of PV solar power plants, especially for the PV modules. According to the above,to extended the service life and guarantee the long-term efficient operation of solar photovoltaic power generation system,the durability of the components is of major importance.Many scholars have studied the influencing factors of surface erosion. Dong Xiaofeng[2] Based on the natural environment of Xinjiang, the paper analyzes the erosion and wear of wind turbine blades in poor environmental conditions. The effects of impact speed, impact angle, particle size and other factors on erosion and wear of wind turbine blade material were analyzed. Lin Nan[3] used the numerical simulation method to study the influence of the elbow size and the incident angle of the solid particles on the erosion and wear, and the angle of incidence was the important factor affecting the erosion and erosion of the pipe. The experiment also got the same result. Numerical simulation was carried out. This study was to investigate the effect of the different tilt angle、the different wind speed、the different dust particle size and the different mass flow to the erosion phenomenon on PV modules surface.

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2. Calculation model And methods

2.1 Theoretical basis

2.1.1 *Continuity equation and momentum equation*
(1) .Continuity Equation of Sand Particle Phase:

$$\frac{\partial(\varphi_p \rho_p u_x)}{\partial x} + \frac{\partial(\varphi_p \rho_p u_y)}{\partial y} = 0 \qquad (1)$$

(2) .Momentum Equation of Sand Particle Phase:

$$\frac{\partial}{\partial t}(\varphi_p \rho_p U_p) + \nabla(\varphi_p \rho_p U_p U_p) = -\varphi_p \nabla p - \nabla p_p + \nabla \tau_p + \varphi_p \rho_p g + f_{fp} \qquad (2)$$

In formula (1) (2), φ_p and ρ_p represent the volume fraction of the particulate phase density, in units of kg/m^3; U_p is the velocity of the dust particles; p_p is the dust pressure of the dust particles; τ_p is the stress of the dust particles; g is the gravitational acceleration, where g = 9.8 m/s^2; f_{fp} is the interphase force between the gas and the dust particles, which is ignored in this paper.

2.1.2 Erosion theory In calculation of Erosion wear, according to MCLAURYBS proposed wear model to calculate,the equation is as follows:

$$ER = CF_S U_p^{1.73} f(\theta) \qquad (3)$$

C is constant, is related to the selected material; U_p is the velocity at which the particles collide with the wall; $f(\theta)$ is the impact angle function, and θ is the angle of the particle collision.

In the numerical simulation, the following formula is used to calculate the wear, and the simulation is carried out using Fluent：

$$R_{erosion} = \sum_{i=1}^{N_{particle}} \frac{m_p C(d_p) f(\theta) U_p^n}{A_{face}} \qquad (4)$$

$R_{erosion}$ is the area of the wall of the wear rate of the unit, the unit kg/(m^2 s), also known as wear rate. A_{face} is the area of the material wall calculation unit. $N_{psrticle}$ is the number of particles colliding on the surface of the component per unit area. m_p is the mass flow rate of particles in the process of wall collision. n is the relative exponent of the velocity of the particles relative to the velocity of the gas. θ is the incident angle of impacted when the particles collide PV modules.

$f(\theta)$ is an impact angle function, which is defined as the following equation：

$$f(\theta) = \begin{cases} 22.7\theta - 38.4\theta^2 & \theta \le 0.267rad \\ 2.0 + 6.80\theta - 7.50\theta^2 + 2.25\theta^3 & \theta > 0.267rad \end{cases} \qquad (5)$$

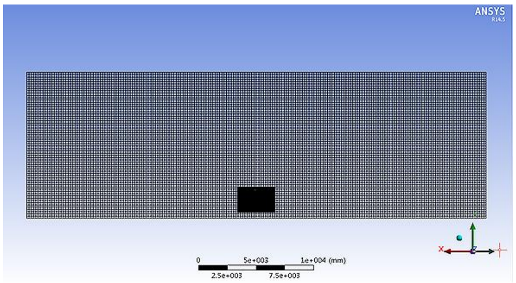
$C(d_p)$ is a function related to particle diameter, and its expression is ：

$$C(d_p) = 1.559 \times 10^{-6} B^{-0.59} F_S \qquad (6)$$

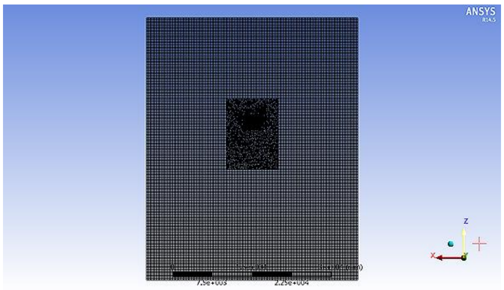
B is Brinell hardness of the be eroded material, which material in this paper is solar photovoltaic glass, a value of 6.5； F_S is the particle shape factor, when the particles are spherical to take 0.2, hemispherical when the 0.5, more sharp when taken 1[4,5],Dust particles are herein assumed rule spherical particles, so a value of 0.2.

2.2 Model establishment

Based on the size of standard solar PV modules, The dimensions of the monolithic components are 1580mm×808mm×40mm.The final model has eight PV modules, up and down two rows of installation, each row of four,the size is 3232mm×3160mm×40mm,and the model is 500mm from the ground. The hybrid model of tetrahedron and hexahedron were chosen to mesh the established model,the eventually get the number of grid is about 4.34 million and the number of nodes is about 3.25 million,as shown in Figure 1.



(a).Grid model front view



(b).Grid model top view

Figure.1 The model geometry and meshing

2.3 Solution setting

In the DPM model, Assume that the discrete phase is very sparse,thus, The effect of particle-particle interaction and particle volume fraction on the continuous phase were neglected.In this model, First, the flow field of the continuous phase was solved,and then add the discrete phase of the dust particles in this paper phase, set the continuous phase to calculate the iterative calculation of a discrete phase for every 5 steps. The parameter settings are shown in Table 1.

Table 1. Parameter setting in erosion simulation

Boundary Conditions	
Import Speed	5m/s, 10 m/s, 15 m/s, 20 m/s
Gas Density	1.225kg/m^3
Particle Density	2650 kg/m^3
Particle Diameter	10μm~60μm
Mass Flow Rate	0.05kg/s~0.4kg/s
The Sand Incidence Mode	surface

3. Simulation results and analysis

Erosion wear is a type of wear caused by damage to the surface of the material due to the impact of tiny and loose motion particles [6].The factors affecting the erosion are impact angle, abrasive grain velocity, abrasive grain shape, ambient temperature, material structure and so on. In this paper, only the abrasive grain velocity, impact angle, abrasive grain size and abrasive grain mass flow, In the simulation process, the ambient temperature, sand shape, PV modules surface materials, etc. do not change.

By simulation, the maximum erosion rate of the component surface often occurs at the bottom edge of the assembly, and there is also a distribution of erosion rates in other areas of the module. Take the inclination angle of 45 °, wind speed 10m/s and particle size 10μm as an example,the surface of the erosion rate distribution shown in Figure 2,the proportions of the various erosion rates on the surface of the module are shown in Table 2.

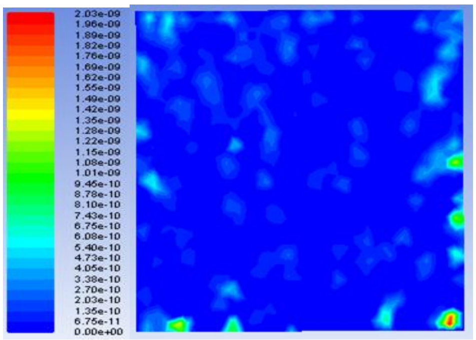


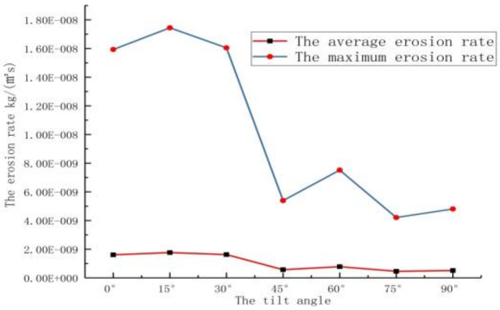
Figure 2. The surface of the module erosion rate distribution

The erosion rate refers to the mass loss of the surface of module material per unit area per unit time in kg/(m^2 s).The erosion rate is calculated by calculating the cumulative damage to the surface of each particle.

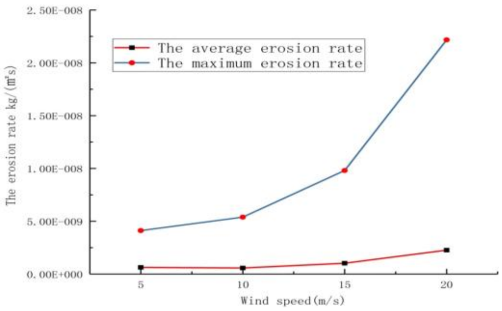
Table.2 Percentage of erosion rate

erosion rate（kg/m^2s）	percentage（%）
0~5.3917e-10	96.5225
5.3917e-10~1.0783e-09	2.2703
1.0783e-09~1.6175e-09	0.5766
1.6175e-09~2.1567e-09	0.2883
2.1567e-09~2.6958e-09	0.1441
2.6958e-09~3.2350e-09	0.0180
3.2350e-09~3.7742e-09	0.0180
3.7742e-09~4.3133e-09	0.0180
4.3133e-09~4.8525e-09	0.0541
4.8525e-09~5.3917e-09	0.0541
5.3917e-09 or more	0

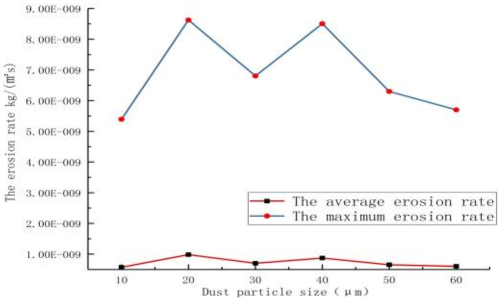
According to Table 2, it can be seen that the main erosion rate of the surface of the module is low,therefore, only the maximum erosion rate of the surface of the module can not objectively reflect the influence of different factors on the surface erosion rate of the module,can only explain the erosion of the largest erosion site,want to know the overall erosion of the components, but also need to use the average erosion rate to describe.Figure 3 shows the comparison between the maximum erosion rate and the average erosion rate of the module surface under various conditions. The unit is kg/(m^2 s).



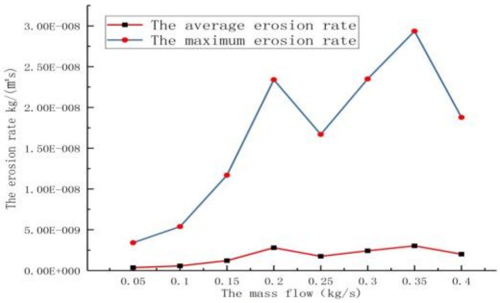
(a). different tilt angle



(b). different wind speed



(c). different particle sizes



(d). different mass flow

Figure.3 The maximum erosion rate and average erosion rate of the surface of PV modules under different conditions

From the maximum erosion rate curve in the graph, the maximum erosion rate increases exponentially with the increase of wind speed when the other conditions are constant. This result is very close to the model results in Finard's theory of erosion. Indicating that particle velocity is one of the important factors affecting erosion.

When the particle size increases, the maximum erosion rate changes little, basically maintained at the same order of magnitude, the results and Huang Si [7] using DPM model simulation centrifugal pump unsteady solid-liquid two-phase flow wear similar results , Indicating that the change in particle size has little effect on the erosion rate.

When the other conditions are constant, the maximum erosion rate and the average erosion rate are decreasing as a whole as the installation angle increases.The installation angle of the module changes, which is equivalent to changing the impact angle of the sand, According to the erosion theory, the impact angle is another important factor affecting the erosion. When the installation angle of the module is small, The angle between the incident velocity of the sand and the plane of the module is also small,from Figure 3 (a) can be seen when the installation angle of 0 °~30 °, that is the impact angle of 0 °~30 °, the component surface erosion rate of the largest.In the erosion theory , The typical ductile material has the largest erosion rate at an impact angle of 20 ° to 30 °, indicating that the module surface material exhibits the properties of the ductile material.

As shown in Figure.3 (d), with the increase of sand mass flow rate, the maximum erosion rate increases first, and then the curve change is fluctuating, When the mass flow rate of sand is less than 0.2kg/s, the maximum erosion rate increases exponentially with the increase of sand mass flow rate, When the mass flow rate is more than 0.2kg/s, the maximum erosion rate fluctuate with increase of sand mass flow rate of soil, and reaches the maximum value of 2.9355e-08 when the mass flow rate is 0.35kg/s. According to the influence of particle mass flow on erosion rate in erosion theory, when the mass flow reaches a certain value,due to the existence of the flow, the collision and rebound between the sand and the sand will affect the erosion rate of the material, which is also the reason why the module surface erosion rate fluctuates when the mass flow rate is greater than 0.2kg/s.

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4. Conclusion

(1) With the increase of tilt angle, the maximum erosion rate and the average erosion rate showed a decreasing trend.The change in the tilt angle can be seen as changing the impact angle of the sand.This mean that when the impact angle is 0°—30°, the erosion rate of the PV module surface reaches its maximum value.The material of the PV module exhibits the properties of the Plastic material.So, with the change of impact angle, erosion rate change is more obvious, and that is meaning the impcat angle of sand is one of the important factors to the erosion rate of PV surface.

(2) With the increase of wind speed, the maximum erosion rate and the average erosion rate all increase exponentially, and the maximum erosion rate increases greatly, indicating that wind speed is one of the main factors affecting erosion.

(3) With the increase of sand particle size, the change trend of erosion rate on the surface of PV module was not obvious, and the maximum change ratio between each particle size is only 37.5%, which indicates that sand particle size had little effect on the erosion rate of PV module.

(4) When the sand mass flow rate is less than 0.2kg/s, with the increase of sand mass flow rate, the maximum erosion rate and the average erosion rate increase exponentially; when the sand mass flow rate is more than 0.2kg/s, with the increase of mass flow rate, the maximum erosion rate and the average erosion rate had little effect.

Reference

[1] Zhao Mingzhi,Song Shijin,Zhang Xiaoming 2013 Method research of parabolic trough solar thermal power plant site selection *Renewable Energy Resources* **3**(31):18-22.
[2] Dong Xiao-feng.Study on erosion behavior of wind turbine blade material under gas-solid two-phase flow. 2013 *Xinjiang University.*
[3] Lin Nan, Lan Huiqing, Cui Yue, Zhao Chao.Influence of Erosion Angle and Elbow Size on Erosion Wear. *Science Technology and Engineering* 2013 (18): 5135-40.
[4] J.K.Edwards, B.S.Mclaury, S.A.Shirazi.Supplementing a CFD Code with Erosion Prediction Capabilities. *ASME 1998Fluids Engineering Division Summer Meeting* 1998 Washington DC.
[5] Ma Guangfei.The effect of gate position on gas-solid two-phase flow and wear in gate valve 2016 *Zhejiang Sci-Tech University.*
[6] Ma Ying, Ren Jun, Li Yuandong, Chen Tijun, Li Bing.Study on the Research of Erosion Wear. *Journal of Lanzhou University of Science andTechnology*.2005,31: 21-5.
[7] Huang Si, Zou Wenlang, Zhou Jinju, He Dongping, Peng Tianyang.Calculation of Unsteady Solid -liquid Two -phase Flow and Wear Calculation of Centrifugal Pump Based on DPM Model. 2016 *China Rural Water and Hydropower.* (07):103-6.