

The Effect of PV Panel Height on Dust Accumulation in a Two-row Solar Field

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ABSTRACT: In this study, dust accumulation due to dynamic shading in two rows PV panel field is predicted numerically. The main parameters in the simulations are chosen to match typical atmospheric boundary layer conditions in flat landscape. An optimum height to distance between two rows of panels ratio, H/L, is investigated to reduce dead spots, where air would decelerate causing the dust particles to settle on the surface of the panels. The three-dimensional flow field around two panels subjected to atmospheric boundary layer flow is simulated using the finite volume method. A Lagrangian solver was then used to track the movement of dust particles. The H/L = 0.5-0.7 was found to give the least amount of interruption to the flow of air and dust particles.

KEYWORDS: PV panels, dust accumulation, DPM, arid conditions

1. INTRODUCTION

Solar energy is widely used in heating water, dehumidifying air, and generating electrical energy for domestic, agricultural and industrial applications. The solar Photovoltaic (PV) industry has seen worldwide expansion due to technological enhancements and low cost of fabrication compared to other renewable energy devices.

In practice, however, there are many issues that can reduce the efficiency of a PV solar field. A field of solar panels is usually located in an open terrain and it is sensitive to strong winds [1]. The surrounding air is usually turbulent and can affect the optical performance especially if the air is loaded with suspended particles that end up accumulating on the surface of the PV panels.

The subject of Environmental effects on the efficiency of PV cells is not new. It was studied firstly on solar heaters in the 1940's [2]. Jiang et al. [3] studied experimentally the influence of the properties of PV module, such as the cell type and surface material and finishing, on dust deposition and the consequential efficiency degradation. They designed an experimental setup with a sun simulator and a test chamber. They observed that dust pollution has a significant impact on PV module output. For example, increasing dust deposition density from 0 to 22 g/m² causes a corresponding reduction of PV output of 26%.

In this study, we will be investigating one aspect of the PV panel configuration, i.e. height of the panel off the ground. The preferred height would minimize the size of the low-pressure pockets behind the panel and offers the least disturbance to the flow of dust particles.

II. RELATED WORK

Piliouguine et al. [4] made a comparative evaluation of the energy produced by photovoltaic modules with and without anti-soiling coating. They tested six PV modules of the same type, three with coated surfaces and three without, for one year in Spain. They showed that dust accumulation on the surface of the module reduces the performance in terms of energy and power output. The non-homogeneity of the distribution of dust on the surface of the module causes additional power losses. They also noted that in dry periods of the year, energy losses are much higher.

Goossens and Kerschaever [5] studied experimentally in a wind tunnel the effect of wind velocity and dust suspension

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concentration on the drop of PV cell efficiency. They found that the drop in PV cell efficiency due to dust accumulation is larger as wind speed increases. Hegazy [6] studied dust accumulation on glass plates, experimentally, with different inclination angles and the associated reduction in solar transmittance over a period of one year under the climate conditions of Egypt. He allowed the dust to accumulate on the glass plates for one month without cleaning. He observed that the fractional reduction in glass normal transmittance depends on dust deposition in conjunction with plate inclination angle, exposure period and site climate conditions.

Biryukov et al. [7] described a computerized microscope system to study the physics of dust particles, which adhere to various kinds of surfaces including those of solar collectors. They gave some examples for the use of such measuring system for the study of PV surfaces. Many other studies on the effects of environmental factors on solar energy technologies are found in the literature [8-11] and mostly are experimental studies.

There are only few numerical studies on environmental effects of dust on solar technologies in the literature. Hachicha et al. [12] studied numerically wind flow around a parabolic trough solar collector. In their work, they used a numerical aerodynamic and heat transfer model based on the Large Eddy Simulation (LES) method. They simulated Eurotrough solar collector and studied the fluid flow and heat transfer around it and on its receivers. The aerodynamic coefficients were calculated around the solar collector and validated with measurements performed in wind tunnel tests.

A comprehensive review of the history and status of research on dust effect on the use of solar energy was published by Sarver et al. [13]. They classified the dust accumulation mitigation methods into two classes; restoration and prevention. The restoration is carried out mainly by washing, and in dry tropical climates it is advised to wash the panels at least once a week [14]. For example, at KACST's Solar Village, in the central region of Saudi Arabia, washing is carried out with a portable tank and a hose about twice a week [15]. While washing is a simple and effective way for cleaning the panels, it does come with its own problems. First, water in dry tropical climates is scarce, and wasting it on washing makes the PV field less sustainable. Second, carrying out the washing adds to the running cost of a solar field in terms of manpower and equipment.

The prevention of dust accumulation can be achieved by PV panel surface modification and coating. Implementing surface coating increases the initial cost of a PV panel, and dust storm events, which happen regularly in arid climates, can damage the coating and decrease its effectiveness.

Another prevention technique that needs extensive development is aerodynamic sweep of dust [13]. In this method, the surface shape of the panel and the relative location of the panels within the field are designed in such a way that causes minimum deposition of dust on the panels and help sweeping the already settled dust particles, or at least maintain enough energy in the air to prevent new dust settlement events.

III. METHODOLOGY

In this study, we investigate numerically the flow around a row of two PV panels at different heights above the ground, H/L (figure.1). The dynamic shading of the front panel on the back panel at different heights off the ground is investigated. The back panel is in the wake of the front panel, which is a region of low pressure and it is where the dust particles are more likely to adhere to the surface of the panel. The wake region can be assessed based on pressure or velocity deficit. In this study we will observe the negative gage pressure behind the panel to determine the wake region.

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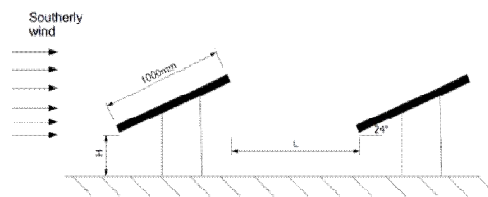


Figure 1. PV panels configuration.

Dust particles in this study is taken to be of spherical shape with uniform diameter of 80 microns. 21000 of these dust particles are injected at the inlet where they would ride along with the air and assumed to have no effect on the air motion. The location of dust particles is updated every 10 iterations of the air, Eulerian, solver and reflects the distance the particle moved and direction of that motion. The particles are kept suspended in the air due to lift forces which is a function of the velocity of the air. If the kinetic energy of the air drops below a certain point, the dust particles are more likely to drop. No adhesion model was added at this point to determine quantitatively how many particles slid off and how many actually stuck to the surface. This could be the subject of a follow-up study and requires extensive experimental work on the specific type of dust that exists in a certain region and a specific type of PV surface.

The panels in a field are affected by the atmospheric boundary layer, ABL, which is highly turbulent. In this study, we will limit our investigations to averaged values of the velocity and pressure. For this purpose, we choose a two-equation turbulence model to simulate the flow, namely the $k-\omega$ SST model. In this model, the Reynolds averaged equations for mass and momentum in addition to turbulent kinetic energy and rate of dissipation are solved to obtain time-averaged quantities. The method is described in details in the work of Menter [18]. The inlet velocity condition is obtained from the literature for open terrain and it takes a power law shape [16],

$$u(y) = 43 * \left(\frac{y}{300}\right)^{0.16} \quad (1)$$

where u is the velocity at the inlet of the domain and y the height off the ground. The inlet k and ω values are taken from the work of Blocken et al. [17].

The computation domain is shown in figure 2. The ground and the surfaces of the panel are all considered no-slip walls. The top and side surfaces are modelled as a slip wall with zero shear to mimic an open surface. The outlet is modelled as a pressure outlet. The model equations are discretized and solved using the finite volume method. The Semi-implicit method for pressure linked equations, SIMPLE, is used for the pressure term and the governing equations are discretized with the second order upwind scheme. A commercial package was used for the discretization and solution of the equations.

The computation domain is 10 meters long, 5 meters high and 4 meters wide. The first panel is placed two meters from the inlet and the second panel is two meters behind the first. This leaves 4 meters for the wake of the second panel to leave the domain without causing numerical reflections. The back surface is a symmetry plane. The panel is 2 meters wide and 1 meter high. However, utilising symmetry allows us to model half the panel, i.e. 1x1 meter. The panels have a thickness of 4 cm and tilted to an angle of 24 from the horizontal which is the angle of PV panels in non-tracking fields in tropical regions.

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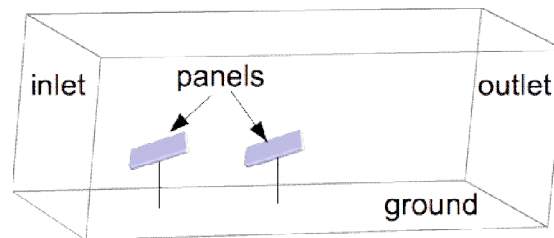


Figure 2. The computational domain.

Five panel heights are tested, namely, $H/L = 0, 0.2, 0.4, 0.6$ and 0.8 , and the results of the simulations are analysed and conclusions are drawn.

A. GRID ANALYSIS

Three unstructured grids were generated to check for grid independence as shown in table 1. The table shows the pressure force on the front face of the back panel obtained from the solution of the governing equations over the different grids. Grid independence can be noted between 2 and 3, so grid 3 was used for this study. Figure 3 shows a section of the mesh around the panels.

Table 1. Grid independence trials.

Grid #	No. of Elements	Back panel press. force (N)	Front panel press. force (N)
1	1770000	2.14	5.86
2	4200000	7.38	8.01
3	5600000	7.39	8.17

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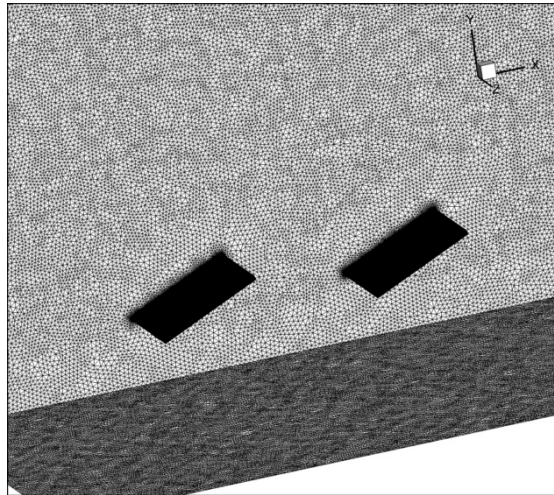


Figure 3. Meshing around the panels, on the symmetry plane and on the ground.

B. VALIDATION

The results obtained by grid 3 was validated using the published experimental data of Ortiz, et. al. [18]. The drag coefficient over 24 degrees inclined panel in the published data matched the drag coefficient in this study over the first panel in the highest panel position. Both the published C_d and the computed one was found to be equal to 0.4.

IV. RESULTS AND DISCUSSION

First, wall distance, y^+ , at the top surface of the panel is checked to make sure that the grid density is adequate for the chosen model. y^+ is found to have values ranging between 20-120 which is reasonable for $k-\omega$ with wall function.

Figures 4-8 show pressure contours on the symmetry plane, the ground and the panels surfaces. The negative pressure contours are marked with dashed lines. Negative pressure regions are regions where dust particles are more likely to be sucked into. Figure 4 shows the case where the panel is touching the ground, i.e. $H/L = 0$. This is the worst of the cases in this study since the wake of the front panel is touching the top surface of the back panel. This wake is a low-pressure region and could suck in more dust particles to the panel's surface. Also, at the leading edge of the panel, a very small region of dead air is formed. Again, this will accumulate dust and become a source of soiling. Sand particles that slide down the panel end up in this region and is blown again over the panel. In fact, installing PV panels in this configuration is not recommended for reasons other than dust accumulation. Possible issues include being shaded by vegetation, soiled by animals and heated by radiation and convection from the ground.

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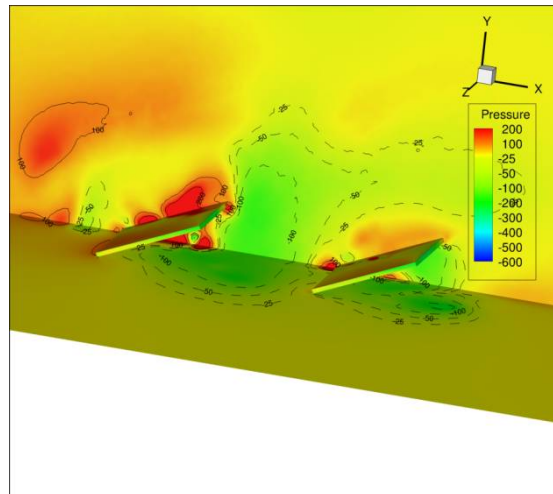


Figure 4 Pressure contours for the case $H/L = 0$. Positive pressure: solid lines; negative pressure: dashed lines.

Figure 5 shows the case where the panels are at a height $H/L = 0.2$. At this height, we notice two large low-pressure areas, one on the ground under the panels and one high above the panels. Here the back panel is not in the wake of the front panel because the air is allowed to flow underneath the front panel and that energizes the flow behind the first panel. However, low pressure still formed above the back panel and can cause deposition.

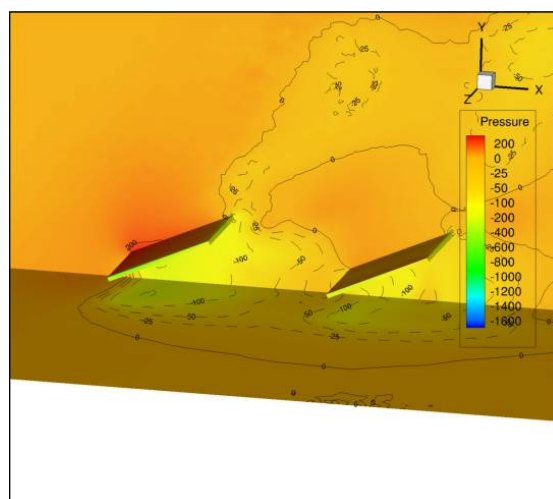


Figure 5. Pressure contours for the case $H/L = 0.2$. Positive pressure: solid lines; negative pressure: dashed lines.

Figure 6 shows the case with $H/L = 0.4$. The negative pressure region right above the back panel disappeared at this height; however, there are still a large low-pressure region over the trailing side of the back panel. Increasing the height further to $H/L = 0.6$ pushes this low-pressure region even further, which should decrease dust deposition as shown in figure 7. Raising the panels higher to $H/L = 0.8$, figure 8, brings back the low-pressure region over the back panel. That could be attributed to the higher wind velocity as we move higher off the ground. This indicates that H/L in the range

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of 0.5 to 0.7 is optimum for two row panel configurations.

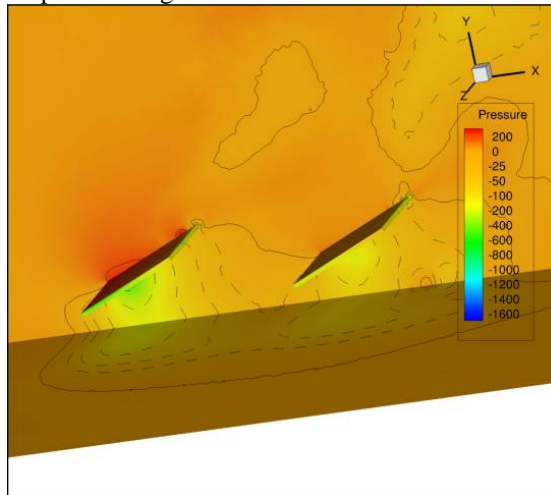


Figure 6. Pressure contours for the case $H/L = 0.4$. Positive pressure: solid lines; negative pressure: dashed lines.

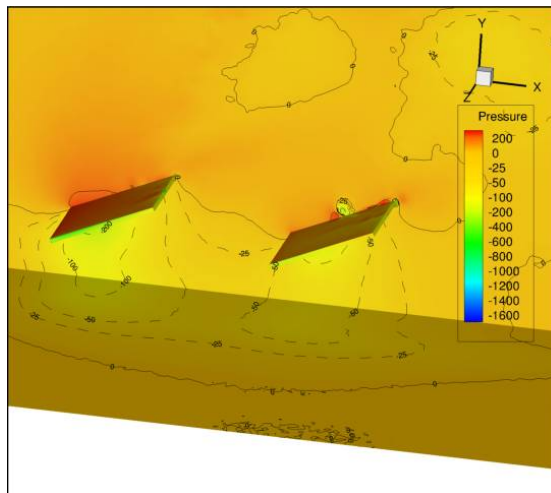


Figure 7. Pressure contours for the case $H/L = 0.6$. Positive pressure: solid lines; negative pressure: dashed lines.

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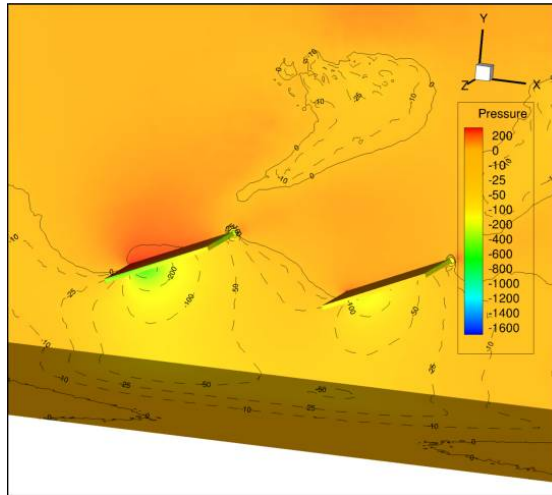


Figure 8. Pressure contours for the case $H/L = 0.8$. Positive pressure: solid lines; negative pressure: dashed lines.

It can also be noted from figures 4-8 that the pressure upstream is getting lower as we increase the height of the panels. That is due to the fact that the air has more room to flow underneath causing the pressure to decrease.

Figures 9-13 show the dust particle traces for all the heights considered in this study. First, figure 9 shows the least amount of disturbance for the particles passing over the panels. The particles passing over the front panel decelerate and then pick up speed as they move around the first panel before decelerating again as they pass over the back panel. Figure 10 shows the particles that hits the first panel continue rising and picking up speed until they leave the computation domain. This agrees with the speculations made regarding the low-pressure area above the panels as was shown in figure 5. The downstream of the back panel shows the particles decelerating which can be a problem for the third row of panels if the field had more than two rows.

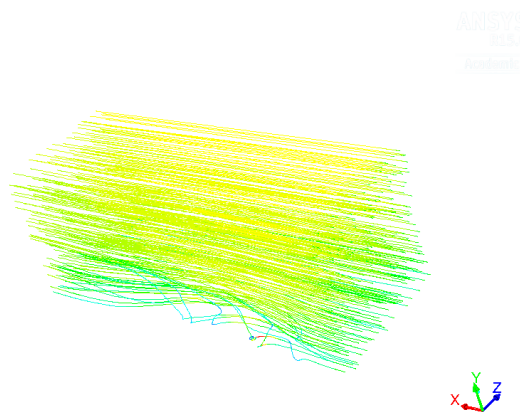


Figure 9. Dust particles colored by the velocity magnitude for the case $H/L = 0$.

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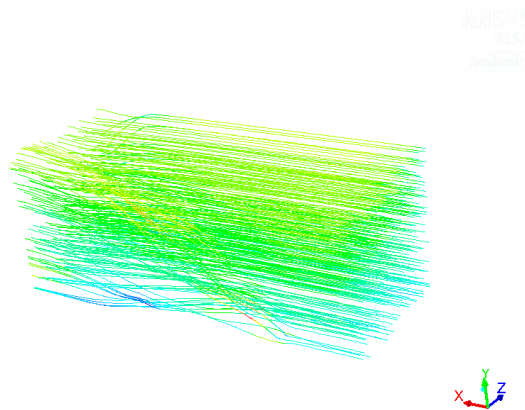


Figure 10. Dust particles traces colored by the velocity magnitude for the case $H/L = 0.2$

Figure 11 shows the case $H/L = 0.4$. In the figure, the particles take off after leaving the first panel at a steeper angle and higher acceleration and the air seems to pass under the panel without much disturbance. At the next height, in figure 12, we can see the least disturbance on the back panel. One can see a little pocket of acceleration in front of the front panel and a lack of speed near the ground which is expected. In the last case, we can see lots of decelerating particles over the width of the domain. This is confirmed by looking at figure 8, which shows the width of the low-pressure area to be the widest of all the cases.

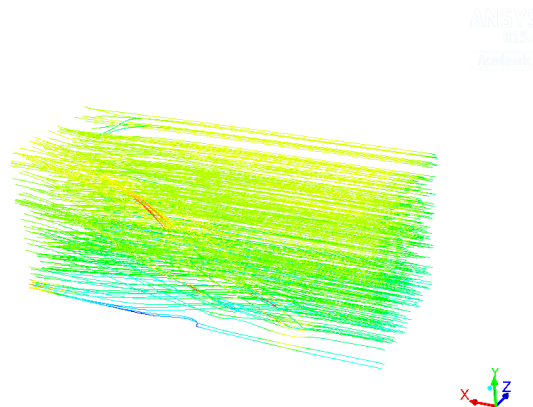


Figure 11. Dust particles traces colored by the velocity magnitude for the case $H/L = 0.4$.

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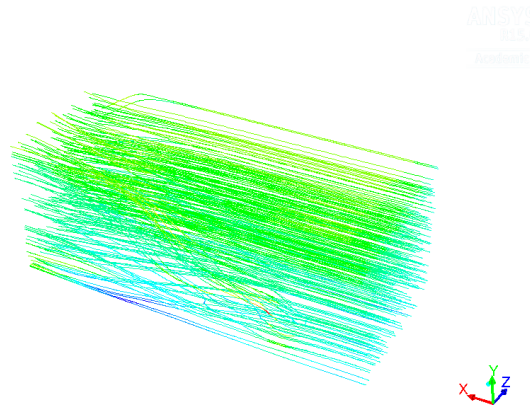


Figure 12. Dust particles traces colored by the velocity magnitude for the case H/L = 0.6.

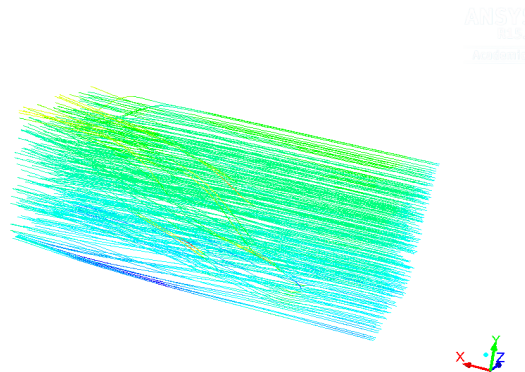


Figure 13. Dust particles traces colored by the velocity magnitude for the case H/L = 0.8.

IV. CONCLUSIONS

In this study, we focused on finding the best height to distance ratio that will lead to minimum dust accumulation on two rows of PV panels. We investigated the flow around two panels under atmospheric turbulent boundary layer conditions. We conclude the following:

- For reduction of dust accumulation on PV panels in tropical areas, where the angle of tilt is around 24, the panels are better installed at a height to distance ratio between 0.5 and 0.7.
- Installing the panels on the ground with no clearance was the worst case since it puts the back panel in the wake of the first panel.
- Increasing the height of the PV installation doesn't always lead to reduced deposition, because the wake widens and that can affect panels in the back right and left.

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