WIND LOADING ON SOLAR PANELS

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Abstract

A fully 3D numerical analysis of turbulent flow over a cluster of solar photovoltaic (PV) panels was performed in order to assess the total drag and lift forces, comparing the results with the values from the guidelines of the national standard. A Reynolds-Averaged Navier–Stokes (RANS) model was used in the numerical simulations, considering two acting directions of the wind along the length of the array (0 degree – front, and 180 degrees – reverse direction).

Keywords: *wind load, drag and lift forces, solar photovoltaic panel (PV), Computational Fluid Dynamics (CFD), RANS.*

1. Introduction

The harnessing of solar energy is usually done by using clusters of photovoltaic (PV) panels. The dimensions of these PV panel arrays are determined by the capacity of each panel and by the required amount of energy output. For their structural dimensioning the acting loads should be known. The total drag and lift forces have different values depending on the angle of the panel to the ground surface.

In the past years many researchers have carried out extensive studies of wind loads on PV panels. In some papers only one isolated panel was investigated, but with a large number of hypothesis regarding the wind direction or the angle values for the resultant of wind drag and lift. Such an extensive numerical study was done in [1] considering wind forces with different angles (range of values from 0° to 90°) with 30° inclination angle to the terrain surface (horizontal line). A scaled wind tunnel testing and a numerical simulation was performed by Ogedengbe et al. in [2] for a standalone PV module considering a wide range of wind flow directions from 0° to 180°. In [3, 4, 5] other results of standalone PV panels subjected to wind forces are presented.

Numerical studies and scaled wind tunnel testing on arrays of PV panels were also done by some researchers [6, 7, 8, 9], with similar results. These panel structures appear to be simple only from the point of view of their geometrical shape. The flow of a fluid around them is turbulent, so accurate assessment of the wind induced forces is not easy. There are many parameters that influence the values of the drag forces (ground clearance, the inclination and size of the panels etc.); the most important one is the wind direction. With so many parameters that can change the entire structure's response to the wind load, one might consider it difficult to design and realize a structure in the middle of an empty field on which high wind speeds and gusts can occur. Thus, the design code overrates the total drag forces for this type of structure, for safety reasons. That is why not many structures have collapsed due to local gales.

The values for total drag forces and normal forces in the case of PV panel structures are not fully detailed in current Romanian design codes. Values of the drag coefficients in the case of wind loads can be found both in Eurocode 1 (SR EN 1991-1-4) and in the national standard (CR-1-1-4-2012), but solely for standalone panels subjected

to the wind's action. In this paper two structures were analysed in order to evaluate the drag forces generated by wind pressure on their panels. These structures are more complex considering their response to the wind's action, so, instead of a full structural analysis the goal was set only to evaluate the drag and lift forces on the panels.

The geometry of the structures led us to a very high Reynolds number (in the order of 106), thus a turbulent flow model had to be used.

Wind load parameters for bluff bodies are the main interest in designing the structure for large billboards. Vortexes that appear in the wake of bluff body turbulence are defined by a high Reynolds value which reflects the flow state of a fluid around an obstacle. The geometrical particularities of a bluff body also influence the total drag or pressure coefficients, even if they are small in dimensions, so a full 3D numerical model is imperative whenever possible regarding the computational capabilities.

Starting from the solar intensity map of Romania, shown in [Figure 1.](#), the most suitable sites for placing solar farms made of PV panels can be chosen. While the south part is used mostly for agriculture, our area of interest is in the centre.

where the relief is hillier, thus, the wind velocities are higher than on the flat areas in the southern part of the country.

Solar photovoltaic panel arrays in most cases are made from rectangular panels mounted on steel supports, having an inclination angle in order to be oriented towards the sun ([Figure 2.](#)). There are also more advanced models that follow the sun's path over the sky, the geometrical shape of these PVs is usually a curved one.

2. Numerical model

Two sets of PV panel arrays were considered, first a structure with four parallel panels (case A), and then another structure with seven parallel panels (case B). In both cases, the panels were composed from 24 smaller flat PV elements, with a 2 cm gap between them. Thus, the length of one panel resulted almost 10 m and the width over 3 m ([Figure 3.](#)). These panels were considered to be positioned over the ground with a 25 degree angle inclination, at 5 m from each other ([Figure 4.](#)).

In order to obtain accurate results considering turbulent air flow, a $52 \times 130 \times 10$ m volume domain was modelled in Ansys for the numerical simula-

Figure 1. The solar intensity map of Romania [10]

tions (although, for case A a smaller domain could have been used), as shown in **Figure 5**.

The required mesh for the convergence of the model needed a high number of finite elements, so a structured mesh was used (applying the cut-cell method). The smallest element had edges of $5E-3$ m, with the first layer height $1E-3$ m and a grow rate of 1.2. In the end, the defined mesh domain had $8.7E+6$ nodes and $7.5E+6$ elements overall in case B, considerably more than in case A. **Figure 6** shows the variation of the mesh density near the panels.

The boundary conditions of the domain are illustrated in **Figure 7**. There was a modification for case A, where the top and the lateral edges of the fluid domain were considered as wall conditions (meaning no slip and no penetration). The

differences between these two approaches were irrelevant in the final results, so we can say, if a sufficient large domain is used, then both conditions are accurate.

The mathematical model used to solve the RANS equations was a $k-\epsilon$ turbulence model with enhanced wall treatment. In both cases only two hypotheses of wind directions angles (0° and 180°) have been considered (as worst case scenario). Thus, the numerical studies were carried out for four hypotheses, further marked as A-front and A-back (case A), B-front and B-back (case B), according to the direction of the wind.

In both cases (case A with four panels and case B with seven panels), the fluid domain settings were the same, the observed fluid flow and the turbulence intensity were similar, only the resulted loading forces had different numerical values

Figure 2. Solar photovoltaic panels arrays [11]

Figure 3. The geometry of a panel (composed from 24 flat PV elements)

Figure 4. Setting of the panels in an array (row)

Figure 5. The numerical modelled domain (case B)

Figure 6. Mesh refinement near the walls boundary conditions (case B)

Figure 7. Boundary conditions of the fluid domain

Figure 8. The wind velocity distribution in case A-front

Figure 9. The wind velocity distribution in case A-back

Table 1. Drag and lift forces [N], case A-front

Panel	Drag (Y axis)	Lift (Z axis)
P1 (windward)	1539.3113	-2887.2343
P2	1529.2392	-2907.2607
P3	607.91867	-949.07348
P4 (leeward)	4422.9963	-8837.388

Table 2. Drag and lift forces [N], case A-back

Panel	Drag (Y axis)	Lift (Z axis)
P1 (leeward)	2885.4727	5840.8222
P2	2276.3627	4602.1176
P3	607.93947	1147.551
P4 (windward)	7325.4916	14972.468

2.1. Case A results

The velocity distribution in a sectional plane through the middle of the domain, parallel with the longitudinal axis (Y in our case), is shown in Figure 8. (case A-front) and Figure 9. (case A-back). The wind direction is always from the left side of the figure, to the right side of the figure. The total drag and lift forces, in case A-front and case A-back are synthesized in Table 1. and Table 2.

2.2. Case B results

The velocity distribution in a sectional plane through the middle of the domain, parallel with the longitudinal axis (Y in our case), is shown in Figure 10. (case B-front) and Figure 11. (case B-back). The wind direction is always from the left side of the figure to the right side of the figure.

The total drag and lift forces, in case B-front and case B-back are synthesized in Table 3. and Table 4. The pressure distribution for case B-front is in Figure 12.

Figure 10. The wind velocity distribution in case B-front

Figure 12. Pressure distribution on panels (case B-front).

Figure 11. The wind velocity distribution in case B-back

Table 3. Drag and lift forces [N], case B-front

Panel	Drag (Y axis)	Lift (Z axis)
P1 (windward)	4613.7123	-9182.1861
P2	583.24925	-1065.778
P3	1330.112	-2601.6572
P4	1172.4369	-2251.5358
P5	1572.6932	-3079.4485
P6	1841.3657	-3654.8858
P7 (leeward)	1934.8247	-3850.5414

Table 4. Drag and lift forces [N], case B-back

Panel	Drag (Y axis)	Lift (Z axis)
P1 (leeward)	2949.8167	5949.4786
P2	2505.5557	5062.3157
P3	2276.3973	4498.6831
P4	2194.8544	4348.1134
P5	2104.1257	4257.0653
P6	316.37399	613.9565
P7 (windward)	7311.7861	15219.223

3. Conclusions

During this study, the wind load was computed through numerical (CFD) simulation applied on two configurations of PV panel arrays, considering front and backward wind directions. In order to compare the numerical results with the values from the design codes, a manual calculation was performed according to CR-1-1-4-2012:

- the reference pressure of the wind, depending on the place of the structures is $q_b=0.5 \text{ kN/m}^2$, from this value the wind velocity can be approximated as $v=28.4 \text{ m/s}$ (the same value as in the numerical simulation);
- the total drag force in the direction of the wind action, considering pressure on the panels, was evaluated at $F_w^{ny} = 10598 \text{ N}$ (10.6 kN);
- the total drag force in the direction of the wind action, considering suction on the panels, was evaluated at $F_w^{sz} = -16957 \text{ N}$ (17.0 kN).

Comparing these results to the values obtained through CFD simulation, it is obvious that the national code overestimates the total drag and lift force, mostly due to the fact that it considers a standalone PV panel. A standalone PV panel takes the whole force of the wind by itself.

The differences between the manual computed values and those obtained through numerical simulation are around 31 % for the drag force and over 10 % for the lift force.

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