A numerical study on the aerodynamic influences of the boundary layer from various PV canopy configuration

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Introduction

Already, existing research reported some changes in climatic factors such as temperature, relative humidity, and wind speed in PV sites using field observation or parameterizations based on energy balancing [1,2]. We hypothesize that PV geometry and their arrangement in the PV farm will impact airflow and overall drag coefficient. So, our work seeks to study the possible impacts based on the following parameters; Ground coverage ratio (GCR), Frontal Area Density (λ_f), and farm layout. Similar study has been carried out and already established for the urban canopy [3].

Defining the PV farm Geometric Parameters

(i) Ground cover ratio (GCR), is the ratio of the area covered by the panel (PA) to the system area (*SA*). Alternatively, it can be defined as the ratio of the PV array length (*L*) to the row pitch (R_p). See Fig. 1 for the PV farm parameters.

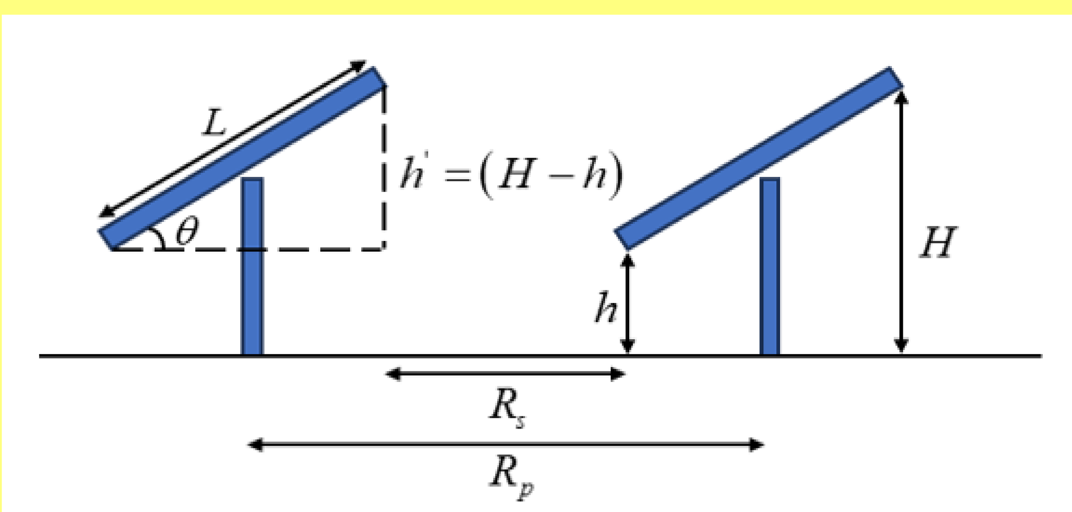

Fig.1. Showing PV farm parameters

$$GCR = \frac{PA}{SA} = \frac{L}{R_p} \qquad (1)$$

Using trigonometry, the PV array length (*L*) and height difference (h') are respectively given as Eq. (2) – (3).

$$L = h'/\sin\theta \qquad (2)$$

$$h' = L \times \sin\theta \qquad (3)$$

Where θ is the tilt angle.

(ii) The Frontal density (λ_f) is given by Eq. (4)

$$\lambda_f = GCR \times (h'/R_p) \qquad (4)$$

(iii) PV farm layout: Fig. 2 shows 500 m by 500m grid size measurement of the farm layouts found around the world.

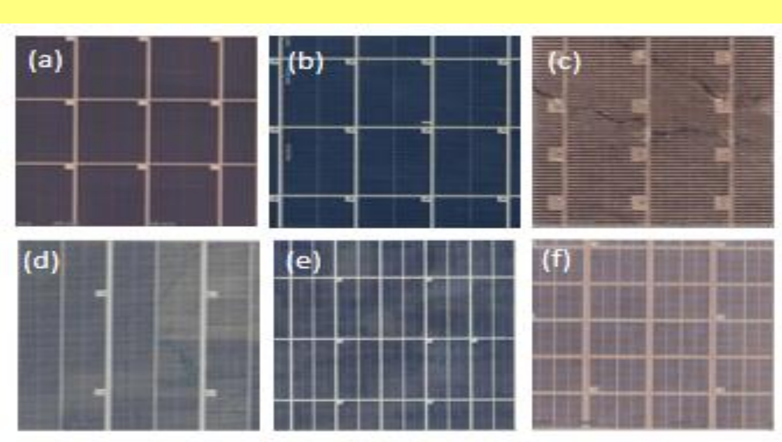

Fig.2. (a) Mount Signal Solar, USA (b) Villanueva Solar, Mexico (c) Jinchuan Solar, China (d) Desert Sunlight Solar, USA (e) Solar Star (I and II), USA (f) Mount Signal Solar,USA

The PV farm layouts above are hence summarized into 3 main types namely; (i) Regular (a, b) , (ii) Column (c, d) and, (iii) Modular grid respectively.

Farm parameters were obtained from different PV farms around the world. The obtained Ground cover ratio and Frontal density are listed in Table 1.

Table 1. Showing PV farm sites and the farm characteristics

S/No.	Site	Tilt	Row spacing (R_s)	Row pitch (R_p)	Array length (L)	Ground cover ratio (GCR)	Frontal density (λ_f)
		°	m	m	m	-	-
1	UiTM Gambang, Malaysia	10.00	2.50	6.44	4.00	0.621	0.093
2	Stateline solar, California	25.00	2.80	7.31	4.98	0.681	0.288
3	Wujiaqu, Xinjiang	37.00	7.50	10.14	3.30	0.326	0.197
4	Soroti PV plant, Eastern Uganda	10.00	2.00	5.87	3.93	0.669	0.116
5	Sourdon PV plant, France	25.00	5.20	8.79	3.96	0.451	0.190
6	Sheikh Zayed Solar Plant, Nouakchott, Mauritania	10.00	2.50	7.62	5.20	0.682	0.118
7	NTC solar power	33.75	2.37	4.00	1.96	0.490	0.272
8	El Abiodh Sidi Cheikh Solar plant, Algeria	15.00	6.00	9.79	3.93	0.401	0.104
9	JUST solar park, Irbid, Jordan	15.00	2.00	5.79	3.97	0.685	0.177
10	Quaide Azam Solar Power Plant, Pakistan	28.00	3.00	4.75	1.98	0.417	0.196
11	Appolo Solar power plant, Pakistan	25.00	3.80	5.60	1.98	0.354	0.150

Classification of PV farm road spacings

Bascially, the spacings in a PV farm includes (i) distance between adjacent PV tables (ii) Walkways, to allow for humman movement and, (iii) Roadways, to allow for maintainance and emergency vehicles.

In our work, aproximate distance measurements from various PV farms were obtained using Google earth. We classified the spacings into the following namely; Walkway, one lane, two lane, three lane etc. as shown in Table 2.

Table 2. Classification of PV farm spacings.

	Walkway width	One-lane Road width	Two-lane Road width	Three-lane Road width	Four-lane Road width	Five-lane Road width	Others
	$(1\pm0.5)m$	$(3\pm1)m$	$(6\pm1)m$	$(9\pm1)m$	$(12\pm1)m$	$(15\pm1)m$	$>(15\pm1)m$
Number of observations	15	13	31	15	15	8	5

Method

For the preliminary calulations presented here, the Stateline Solar Califormnia case with row spacing, tilt, row pitch, GCR and Frontal density of 2.8 *m*, 25.00 degrees, 7.31 *m*, 0.681 and 0.288 respectively. The regular grid was selected see Fig. 3(a-b). Fig. 3c includes the addition of 1 m walkway.

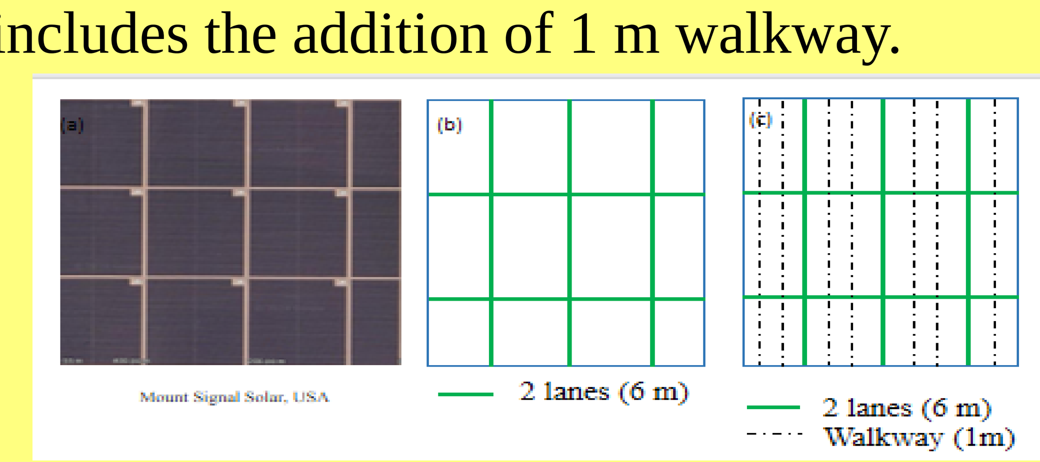

Fig.3. Regular grid layout

The ANSYS Fluent Computational Fluid Dynamics (CFD) software is used to carry out the calculations. The SST κ-ω turbulence model similarly employed in other PV studies [4] was used in the steady state simulation.

Boundary condition

The logarithmic inlet boundary condition was used $u = \frac{u^*}{k}\ln\left(\frac{y}{Z_0}\right)$

The turbulent kinetic energy profile, $k(z)$ and turbulent dissipation rate, $\varepsilon(z)$ are respectively given as

$$k(z) = \frac{(u^*)^2}{\sqrt{c_\mu}} \qquad \varepsilon(z) = \frac{(u^*)^3}{k(y + Z_0)}$$

Friction velocity, surface roughness, von karman constant and model constant are listed below;

$$u^* = 4.12 m/s, Z_0 = 0.03 m, k = 0.4, c_\mu = 0.09$$

Symmetry condition was applied on the top and side boundaries, the outlet is specified as pressure outlet. The ground has a roughness height and constant of 0.03 m and 0.5 respectively. The panels were specified as walls.

Results

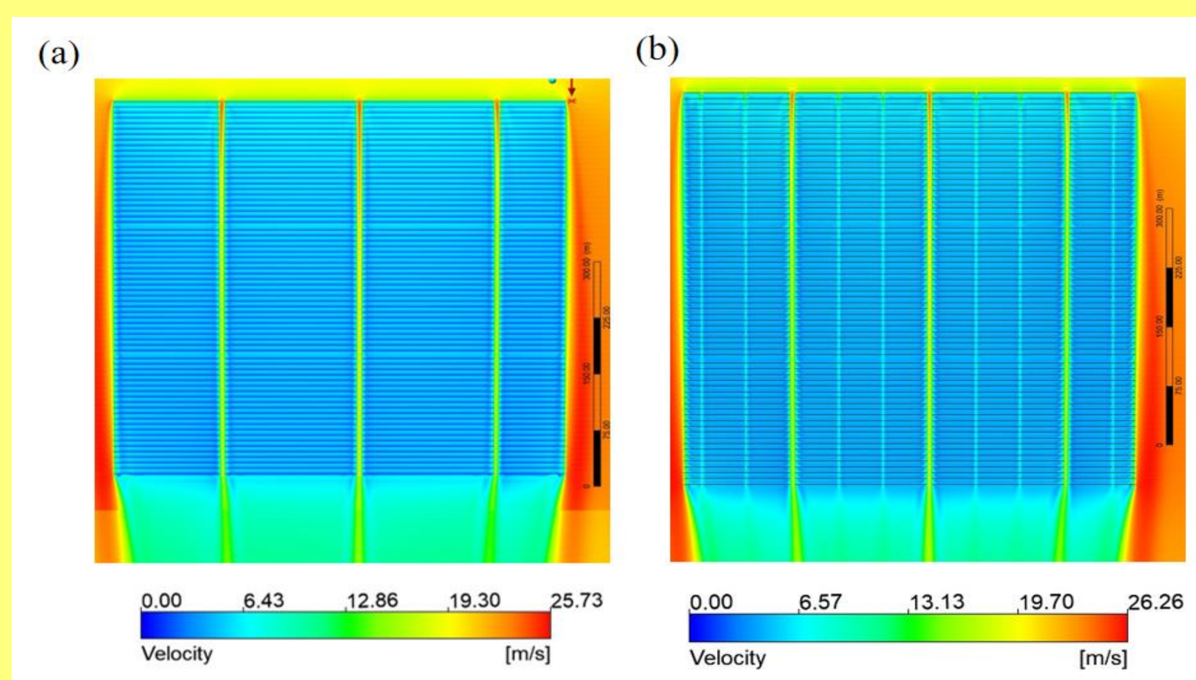

Fig.4. Velocity contour **(a)** Regular grid layout (b) Regular grid layout with 1m walkway

Conclusions

This study is an ongoing work. Preliminary results show that there might be some effects added to the aerodynamics of the PV farm based on the parameters introduced in this study.

References

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