A numerical study for wind profile characterisation within and above PV canopies

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Introduction

Photovoltaic (PV) installations are increasingly becoming popular as a means of power generation. However, similar to any roughness element in the Atmospheric Boundary Layer (ABL), they alter the local flow conditions of the environment. Thinking of the PV flow as a Photovoltaic Canopy Layer (PVCL) flow can provide more insights to these effects hence, characterization of the velocity profile is important in order to fully capture the effect of the roughness elements within the canopy and the shearing effect they present to the wind flow. This has already been established for similar canopy studies such as urban and forest canopy [1-2] etc.

Methodology

The commercial Computational Fluid Dynamics (CFD) code, FLUENT was used to carry out the steady state RANS simulation of the $L \times W = 500$ m × 500 m area PV farm in this study. The PV farm is made up of four (4) column of PV panels (*BC*). Each column is made up of three (3) block rows (*BR*) of PV panels. Distance between the columns and blocks is 6 m respectively. The individual PV panels in a PV block row has the following parameters; Tilt (θ) = 25 degrees, row pitch (R) = 7.31 m, PV height (H) = 2.56 m, chord length (L) = 4.98 m.

The domain and boundary conditions are shown in Fig.1. The inlet was specified as a log-law profile using user defined functions (UDF). Standard $\kappa\text{–}\varepsilon$ turbulence model with standard wall treatment was used. SIMPLE algorithm was employed for coupling pressure and velocity as used in related ABL studies [3].

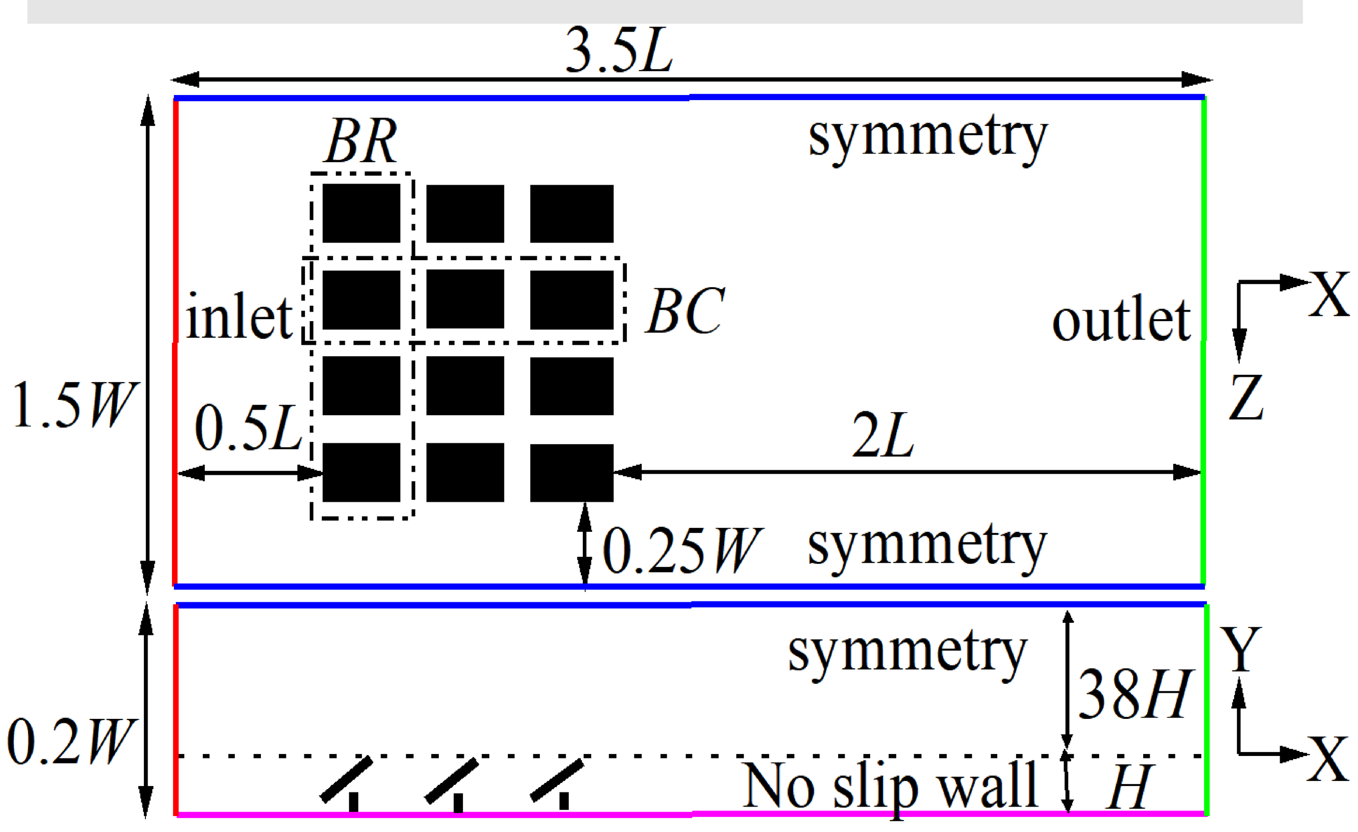

Fig.1. Showing PV farm parameters

Discussions

i. Flow evolution across the PV farm

Fig. 2 shows the flow evolution across the PV farm. Location X/H = -0.55 corresponds to the undisturbed flow ahead of the PV panels. As shown, the flow is sheared close to the ground for locations X/H = 65.76, 132.68, 196.75 behind the first, second and third PV row blocks respectively.

At locations X/H = 235.82, 313.94, velocity decay can be seen downstream of the PV farm. Furthermore, around z/H = 15, self-similarity can be observed. At this height, the vertical influence of the PV is minimal. The flow is said to have achieved homogenous stability typical of the inertial sublayer (ISL).

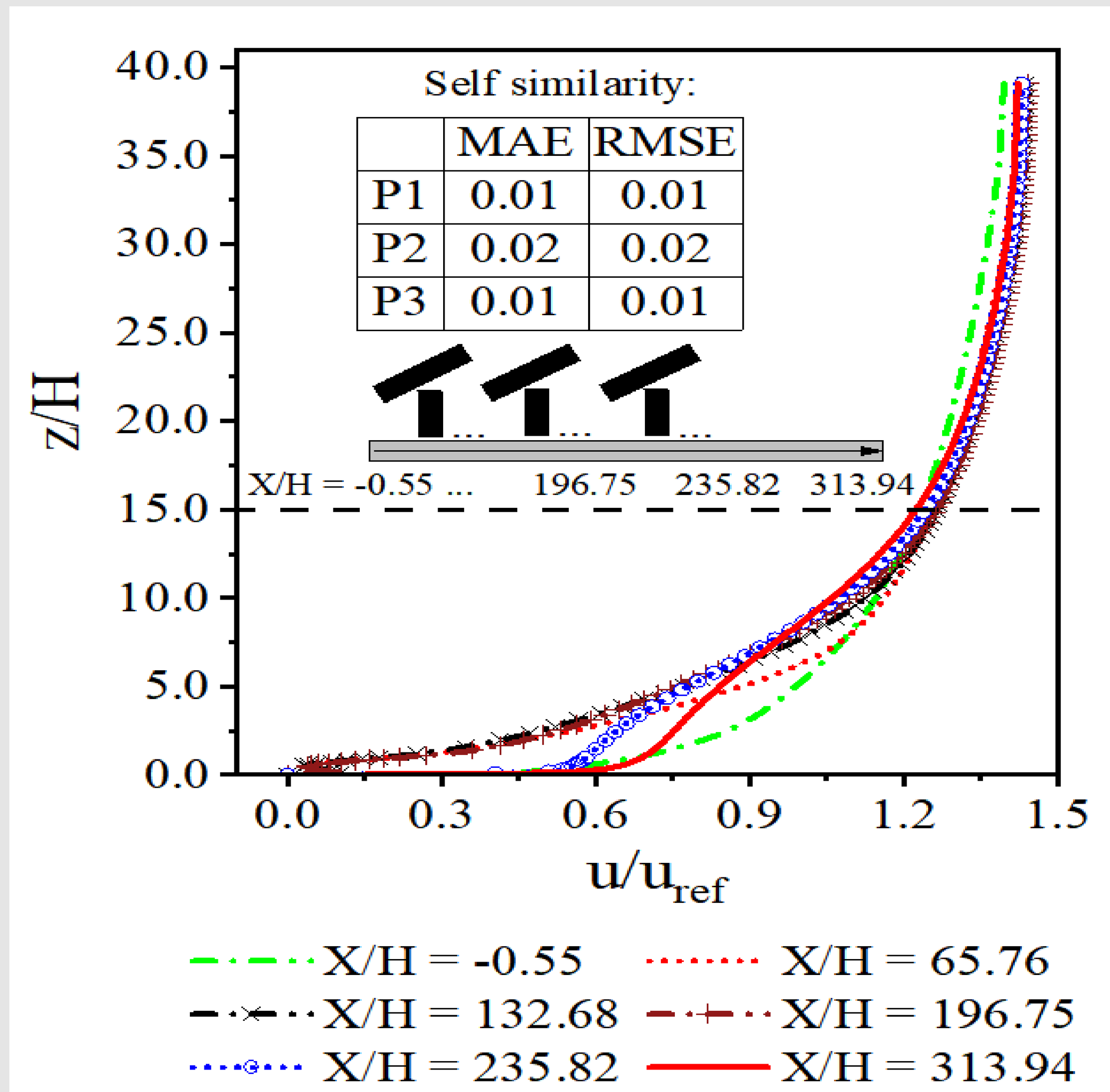

Fig.2. Flow evolution across the PV farm

ii. Profile within the canopy layer

For flows within the canopy layer i.e., $0 \leq z/H < 1$, the exponential equation in Eq,(1). was presented by Inoue [4] for the analytical representation of canopy mean wind flows. Similarly, Eq,(2). was presented by Cowan [5] to account for the close to the ground velocity effects.

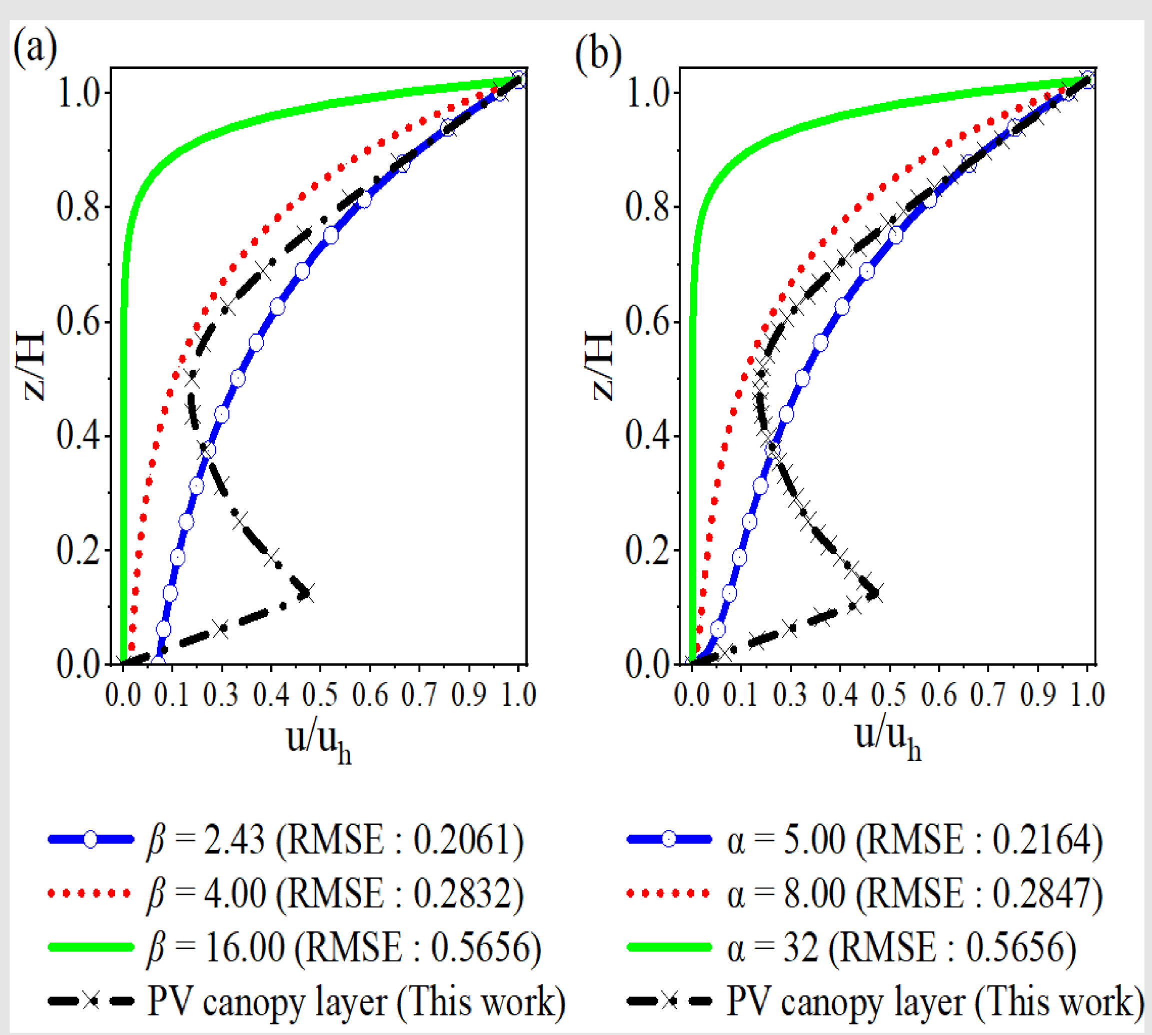

Fig.3. PV canopy using (a) Inoue's equation (b) Cowan's equation

$$u(z) = u_h \cdot e^{-\beta\left(1-\frac{z}{H}\right)} \quad (1)$$

$$u(z) = u_h \cdot \sqrt{\left(\sinh(\alpha \cdot z/H)/\sinh(\alpha)\right)} \quad (2)$$

Fig. 3 compares the Inoue and Cowan models for the PV canopy. As shown, these equations do not accurately represent the PV canopy flow. The PV canopy flow is not exponential. In fact, it follows the *S*-profile commonly found in forest canopies.

iii. Profile above the canopy layer

The Profile above the PV canopy layer corresponds to the region at $1 \leq z/H < 15$ and $z/H \geq 15$ respectively. Fig. 4 shows the fitting of the profile to the log-law. Friction velocity (u_*) =0.68 m/s, displacement height (d) = 1.80 m, obtained from empirical relation as 0.7*H*. Roughness length (z_0) = 0.25 m, obtained from empirical relation as 0.1*H*.

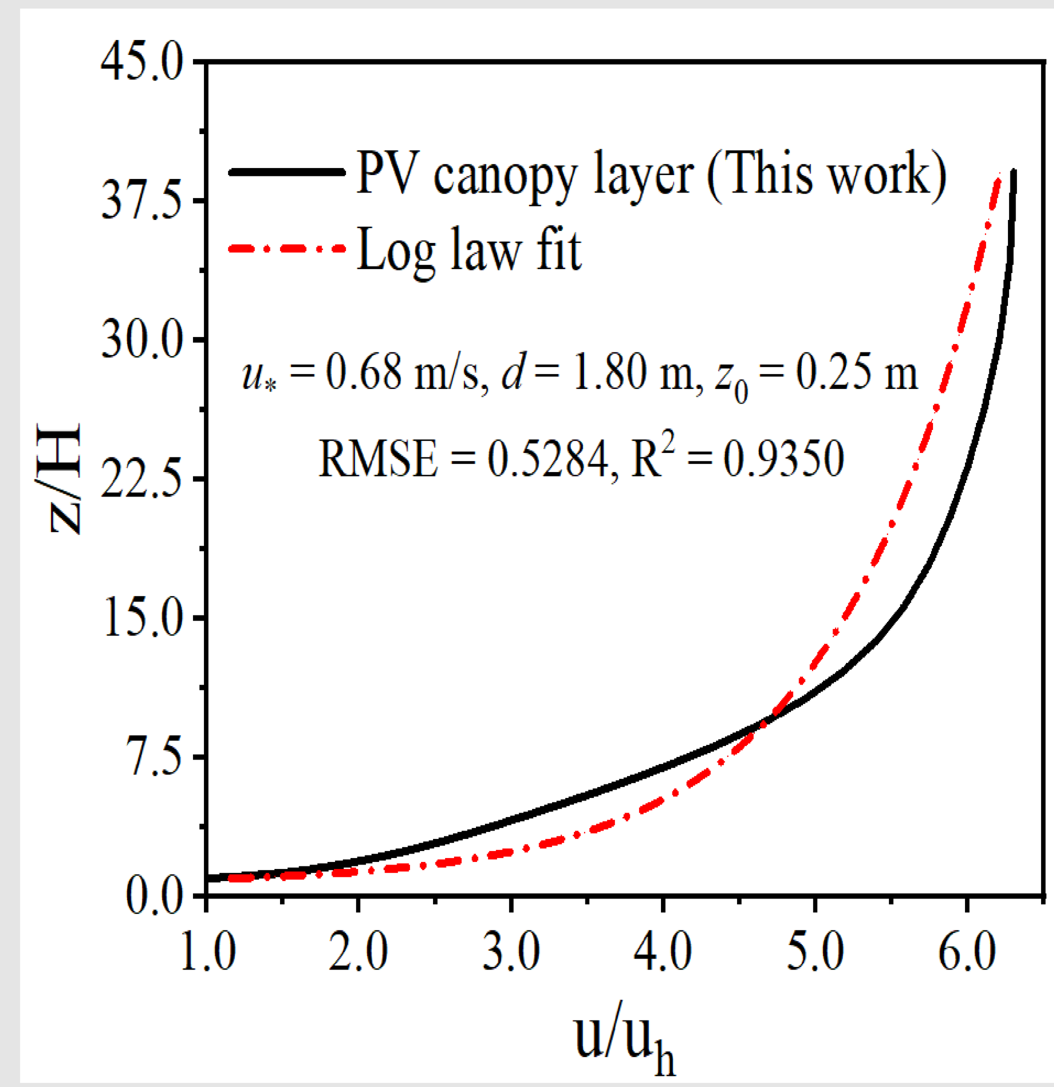

Fig.4. Log law profile fit for above canopy layer

Conclusions

Simulation of a large-scale PV farm has been carried out using the FLUENT software. Derivation of complete PV canopy equations is ongoing.

Acknowledgement

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