Wind loads on ground-mounted, isolated and array of solar panels using Large-eddy simulation

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SUMMARY:
Wind loading and wind-related damage and failure are significant concerns for the solar industry. Therefore, a proper wind load evaluation on ground-mounted solar panels is paramount. The relatively small size of solar panels requires a large model, which in turn leads to discrepancy of turbulence scaling in wind tunnels. This study presents a computational modelling approach using large-eddy simulation (LES) to analyse flow past isolated and arrayed solar panels. We validated the LES output for input wind field, pressure coefficients, and aerodynamic loads using boundary layer wind tunnel (BLWT) data for the isolated panel configuration. The results show good agreement with the experimental data. Our study demonstrates the potential of using LES for detailed analysis of the aerodynamic flow features around solar panels, which can contribute to improving the design and safety of these systems. In future work, we plan to conduct independent experimental testing of horizontal-axis solar trackers (HSATs) and use a broader range of LES simulations to validate our results further.

Keywords: Large-eddy simulation, Solar panel, Wind loading

1. INTRODUCTION

With the significant demand for sustainable energy and development of large-scale solar farms, ensuring the safety of solar panels under extreme weather conditions is important. Wind-induced damage is a primary concern for solar panels due to their light weight and large surface area-to-stiffness ratio. Typically, these structures are designed based on aerodynamic loads obtained through wind tunnel (WT) experiments. However, their small size requires large geometric scales, which leads to challenges in modeling turbulence scales and atmospheric boundary layer (ASCE, 2021). Computational fluid dynamics (CFD) has tremendous potential to resolve some of these challenges. Unlimited geometric scales, flow visualization, versatility in setting up geometry and ample output are some of the advantages it offers.

CFD has been applied for wind load evaluation of solar panels (Aly and Bitsuamlak, 2013) conducting both steady and transient simulations validated against WT tests. Although earlier studies (Jubayer and Hangan, 2016; Reina & De Stefano, 2017) focused on obtaining mean aerodynamic loads, recent studies are using unsteady simulations to investigate unsteady flow behavior and obtain peak aerodynamic loads (Wang et al., 2020; Shademan and Naghib-Lahouti, 2020). Considering the various recent developments in CFD, such as synthetic inflow generation methods, solar panel wind loading can be further explored computationally. In this study, we intend to establish a computational modelling approach for Large-eddy simulation (LES) of flow past a ground-mounted solar panel. An isolated case is used to validate the model against wind tunnel, while a preliminary array case is also presented.

2. METHODOLOGY

The primary study case is an isolated solar panel taken from Aly and Bitsuamlak, (2013). The 25degH32 configuration, i.e., $25°$ tilt-angle and $32\ in.$ ground clearance, under wind profile E3 is selected from the four configurations studied by (Aly and Bitsuamlak, 2013) for validation. The solar panel has full-scale dimension of chord width (B) $1.336\ m$ and length (L) $9.144\ m$ and is modeled in $1:20$ geometric scale both in LES and BLWT.

Large-eddy simulation (LES) is used to reproduce the wind tunnel experiments. The computational domain set up and mesh design are shown in Figure 1. A transient velocity is input at the inlet using a synthetic inflow generation technique (CDRFG) proposed by (Aboshosha et al., 2015) with target ESDU profile ($Z_0 = 0.005$) matching the WT data. The mesh was designed following (Geleta and Bitsuamlak, 2022) to carry the turbulence from the inlet and resolve local flows around the panel. The rest of the boundary conditions are pressure outlet at the ends, symmetry planes at the top and sides and no-slip wall for the ground and solar panel surface. Implicit unsteady solver with $0.001\ s$ time-step and WALE sub-grid scale model has been implemented in STAR-CCM+.

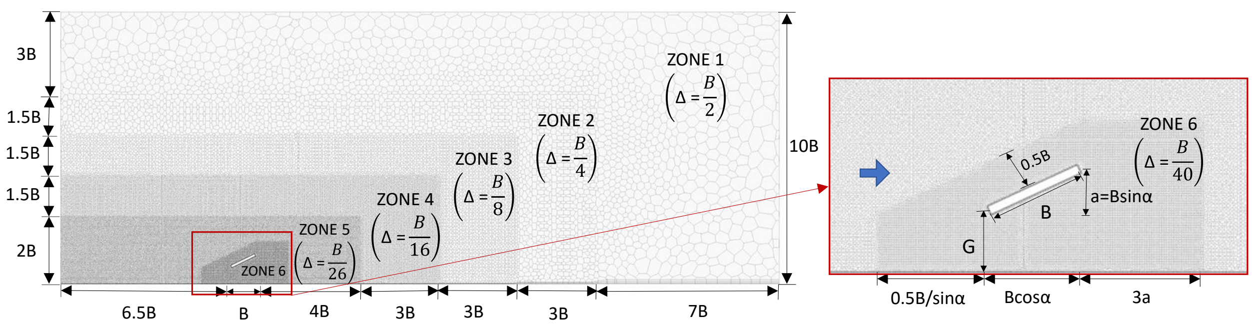

Figure 1. Computational domain and mesh design

3. RESULTS

The LES simulation is conducted in two parts: an empty domain simulation to validate the input wind field and a main simulation to validate the output solar panel aerodynamics. The simulations have been run for 20 seconds so far.

Figure 2 displays the wind field comparison at the solar panel location using the empty domain simulation output. A very good agreement between LES, BWTL and target ESDU profile is observed for normalized mean velocity (U/U_{ref}), longitudinal turbulence intensity (I_u) and reduced turbulence spectra for U at the reference height $(nS_u/\sigma_u{}^2)$. However, the turbulence intensity is slightly overestimated by LES at the reference height while higher spectral energy at a higher frequency is also observed in the spectra. The expected mesh filtering is also observed.

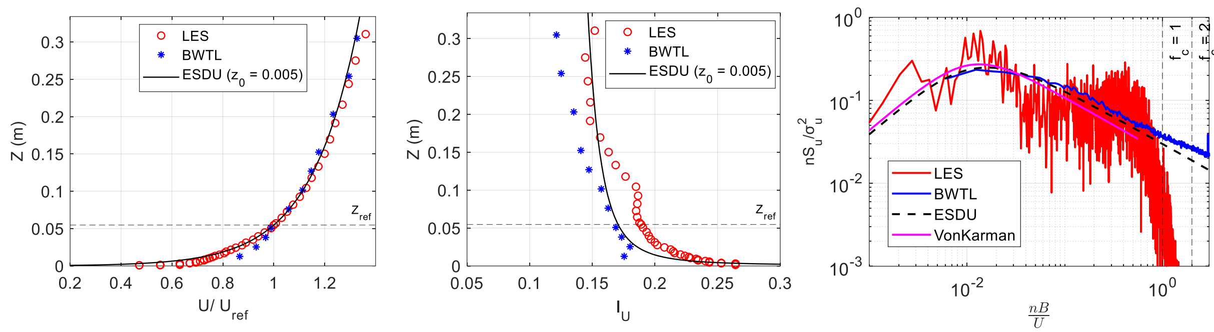

Figure 2. Wind profiles for normalized velocity (left), longitudinal turbulence intensity (centre) and reduced turbulence spectra for U (right)

The solar panel aerodynamics is compared using pressure coefficients, aerodynamic load coefficients (C_D, C_L & C_M) and their spectra. Figure 3 displays mean and peak C_p contour, C_p near the centerline of the solar panel and aerodynamic load coefficients, which are in excellent agreement with BLWT output. Moreover, vortex shedding is observed in the normalized spectra obtained from LES. Difference in C_p values is observed on the bottom surface of the panel where the support structure and pressure tube bundles could disrupt the air flow during the WT tests.

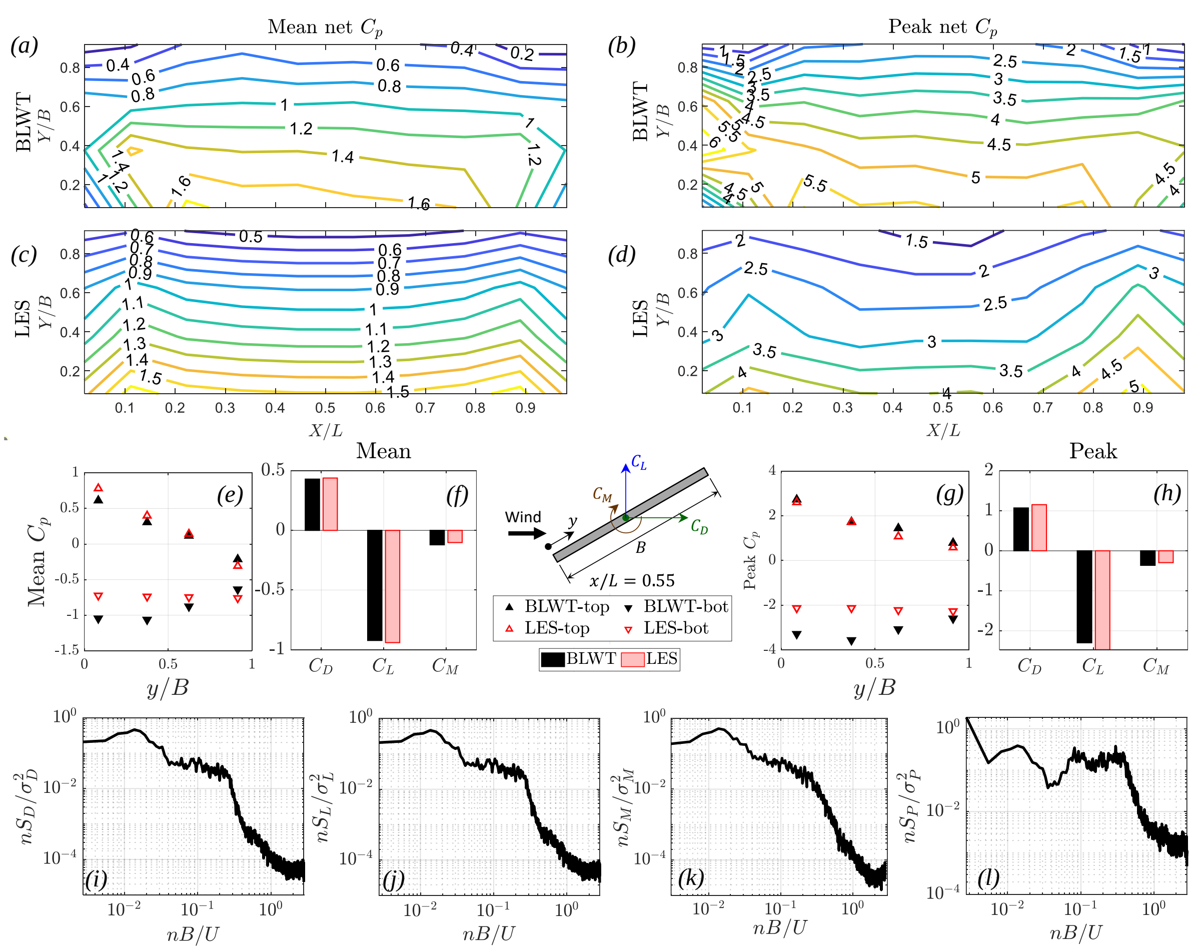

Figure 3. Comparison C_p between BLWT and LES. (a) mean net C_p of BLWT, (b) peak net C_p of BLWT, (c) mean

net C_p of LES, (d) peak net C_p of LES, (e) mean C_p along a centre chord-line from BLWT and LES, (f) mean aerodynamic loading ,(g) Peak C_p along a centre chord-line from BLWT and LES, (h) peak aerodynamic loading, normalized spectra (i) for drag, (j) for lift, (k) for moment and (k) pressure at leading edge.

A CFD model with an arrayed configuration as shown in Figure 4 will be conducted concurrently with a WT test to investigate the effect of tilt-angle, ground clearance and array effects on the aerodynamics of solar trackers. The CFD will mainly be used to observe steady and unsteady flow features that explain the pressure distribution and aerodynamic loading.

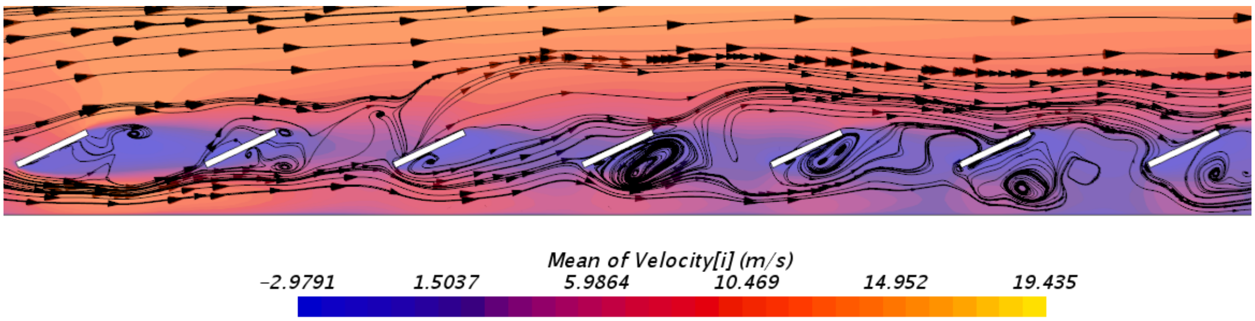

Figure 4. Mean velocity contour and streamlines on a preliminary solar panel array configuration.

4. SUMMARY AND CONCLUSION

In this study, a computational modelling approach for Large-eddy simulation of flow past a ground-mounted solar panel is validated using WT data from (Aly and Bitsuamlak, 2013). The input wind field as well as mean & peak pressure coefficient and aerodynamic loads showed good agreement with BLWT data. Further attempts for validation such as correcting the simulated turbulence intensity and modelling support structures will be carried out. Next, both experimental and computational investigation on an array of HSATs with variable tilt-angle, height, and spacing will be undertaken for a comprehensive understanding on their aerodynamics.

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