Effect of panel tilt, row spacing, ground clearance and post-offset distance on the vortex induced dynamic loads on fixed tilt ground mount photovoltaic arrays

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1 INTRODUCTION

Many wind loading standards including ASCE 7-10 [1] define flexible structures, having susceptibility to dynamic effects, as being those that have a fundamental natural frequency less than a threshold value of 1 Hz. In the context of small structures such as ground mounted photovoltaic (PV) panels in arrays, Strobel and Banks [2] have previously demonstrated this definition to be questionable, since these structures have been shown to exhibit buffeting response from upwind panels at frequencies well above this threshold value. This can result in dynamic loads that are well above the loads for an assumed rigid structure for both serviceability and design level wind events. For example, proprietary studies performed by CPP have shown that for typical ground mount systems with chord lengths between 2 and 4 m and tilts between 10º and 45º, an increased dynamic loading corresponding to the vortex shedding frequency of the system can be produced by wind events containing 3-second gusts of 15 m/s (35 mph) to 30 m/s (70 mph). This will have important ramifications for load resistance as well as fatigue design of the racking system, since PV panels are primarily installed in open country terrain where such critical wind speeds are expected to occur several times annually.

The current paper attempts to systematically investigate the extent of this dynamic loading on the ground mount PV panels at different locations in an array for a range of parameters including the tilt angle, row-to-row spacing, low edge ground clearance and the post location along the chord. Each of these parameters affects the formation, strength and frequency of vortex shedding from upwind rows by altering the aerodynamic characteristics of flow around the panels, thereby influencing the resultant dynamic load (as well as the response) on downwind panels in the array.

To investigate this effect, a series of boundary layer wind tunnel tests was conducted on scale models of an array of a generic PV racking system. The parameters described above were systemically varied to obtain static loads on panels at different array locations and wind directions. The relevant static loads so obtained were combined with a representative mode shape to estimate the resulting static-equivalent dynamic response of the system. The mode shape considered in this paper is the tipping (or overturning) moment about the base of the post. This is representative of the typical north-south (or front to back) sway mode (which can also be termed as a "rocking mode") that is commonly exhibited by such systems. Further theoretical details pertaining to the method of evaluating the dynamic loads will be presented in the full paper.

2 RESULTS AND DISCUSSION

The worst static loads (normal force on the modules and the associated moment at the base of the post) are typically found to occur on the perimeter racks (and the supporting post) of the first north row (in the northern hemisphere, where the panels face south) due to cornering (north east or north west) winds. The worst dynamic loads however are typically observed in the second north row due to straight (north) winds. This corresponds to a narrow vortex shedding hump seen in the spectrum of the static loading on the second row resulting from periodic shedding of vortices by the upwind row of panels. A significant dynamic loading and resonant response can be expected to occur when at a given wind speed, the vortex shedding peak matches a natural frequency of the racking system with modal displacement excitable by this type of loading. Further into the array, this periodic buffeting of the panels tends to gradually reduce due to a decrease in mean wind speed at module height as is exhibited by a reduced but much broader hump in the spectrum of the assumed-static loads. Such spectra of static base moment coefficients (CM_y) measured at an interior post of the first north row, the second north row, and a row in the array interior is presented in Figure 1 as a function of the reduced frequency (fD/U).

Here the characteristic length, D, has been considered to be the vertical projected height of the panels whereas U is the mean wind speed approaching at the mid-chord height of the panels. The hump in the spectra in Figure 1 in the (reduced) frequency range of 0.1-0.15 corresponds to the periodicity of vortex shedding. As described earlier, this hump is particularly significant for the second north row and much less pronounced for the interior row. This demonstrates the possibility of a severe dynamic response, particularly in the second row if the periodicity of vortex shedding from the upwind row matches the natural frequency of the racking system. Additionally, the severity of response will depend on the fundamental mode shape and on the system damping.

The extent of this amplified dynamic loading at resonance on an interior post in the second north row is systematically investigated for a range of tilts and row spacings in Figure 2(a) and 2(b) respectively. An assumed system damping of 2%, typical of common ground mount systems, is used for this analysis.

The dynamic loads are higher than the corresponding static loads for all but the lowest 5º tilt. The amplification is found to be particularly severe between the 15 to 30º tilt ranges with the peak amplification observed at around 22.5º.

Similarly, the dynamic amplification for a given tilt (22.5º in this case) is found to be the maximum when the row spacing is approximately 2.5 to 3 times the vertical projected height of the chord [*C*sin(Tilt), *C* being the chord length]. This is usually the row spacing range used for most ground mount fixed tilts in the US.

The trend presented above can be a consideration when making decisions about the design of a racking system vis a vis other non-wind related factors. A cost-benefit analysis regarding choice of the above parameters appears necessary to ensure a profitable outcome, else the design cost required to safeguard against high wind loads may negate other benefits.

Some proprietary studies carried out by CPP also involved designs with the post location set off from the center of the chord, usually towards the high side. Given the unique nature of the wind load distribution on the panels, this could increase or decrease the static and dynamic load (read base moments) on the system. Figure 3 presents a parametric study of the effect of post location along the chord on static and dynamic base moments at interior posts in three array locations (north row, second north row, and interior row) as in Figure 1 for a damping of 1.5%. It is interesting to note that both the static and dynamic loads are significantly reduced when the post location is offset by about 5-10% from the center towards the high edge. The dynamic loading as expected is significantly higher in the second row compared to other locations. The dynamic amplification could be as much as 4 for a limiting case of the post located right at the edge of the panel low side caused by a huge lift due to a wind coming into the high edge. This particular configuration is however unrealistic from a design perspective.

A further parametric study of the effect of different factors including the ones already discussed here briefly, as well as the low edge ground clearance gap, on the effect of dynamic loading on fixed tilt PV racking systems will be reported and discussed at length in the full paper.

This will hopefully allow the designers and stakeholders to make an informed decision regarding the range of parameters for their system from a wind loading perspective and pave the way for a safe, reliable, and profitable system.

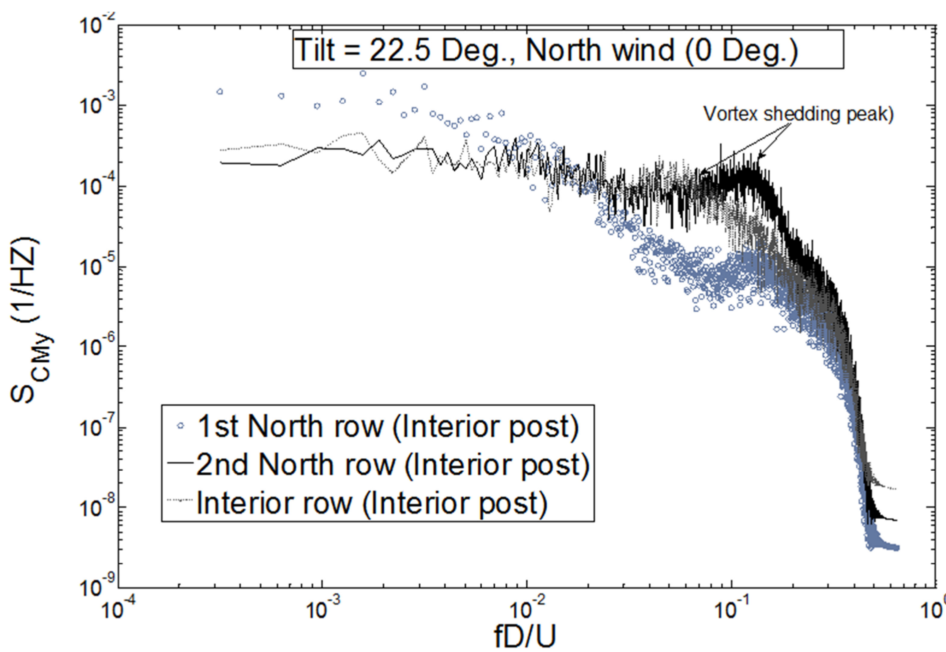

Figure 1. Spectra of static base moment coefficients (CMy) for different array locations.

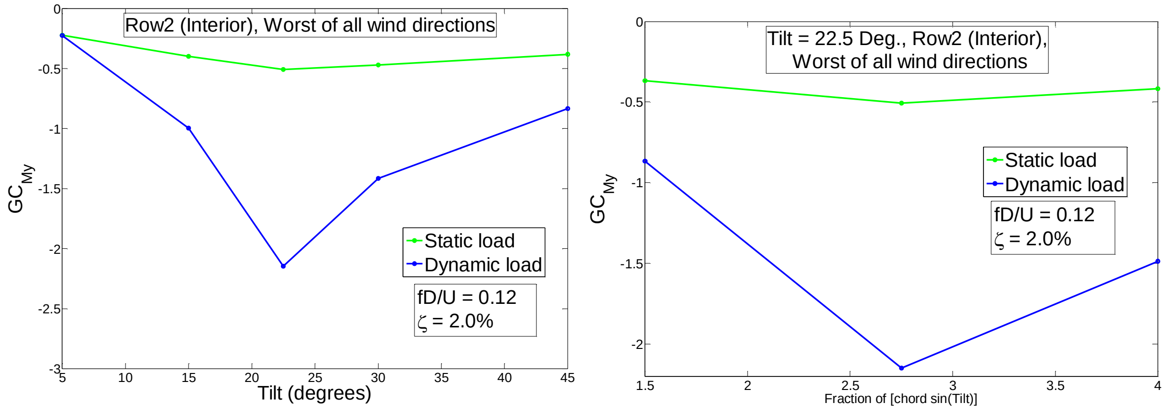

Figure 2. (a) Static and dynamic loading vs. Tilt (b) Static and dynamic loading vs. row spacing.

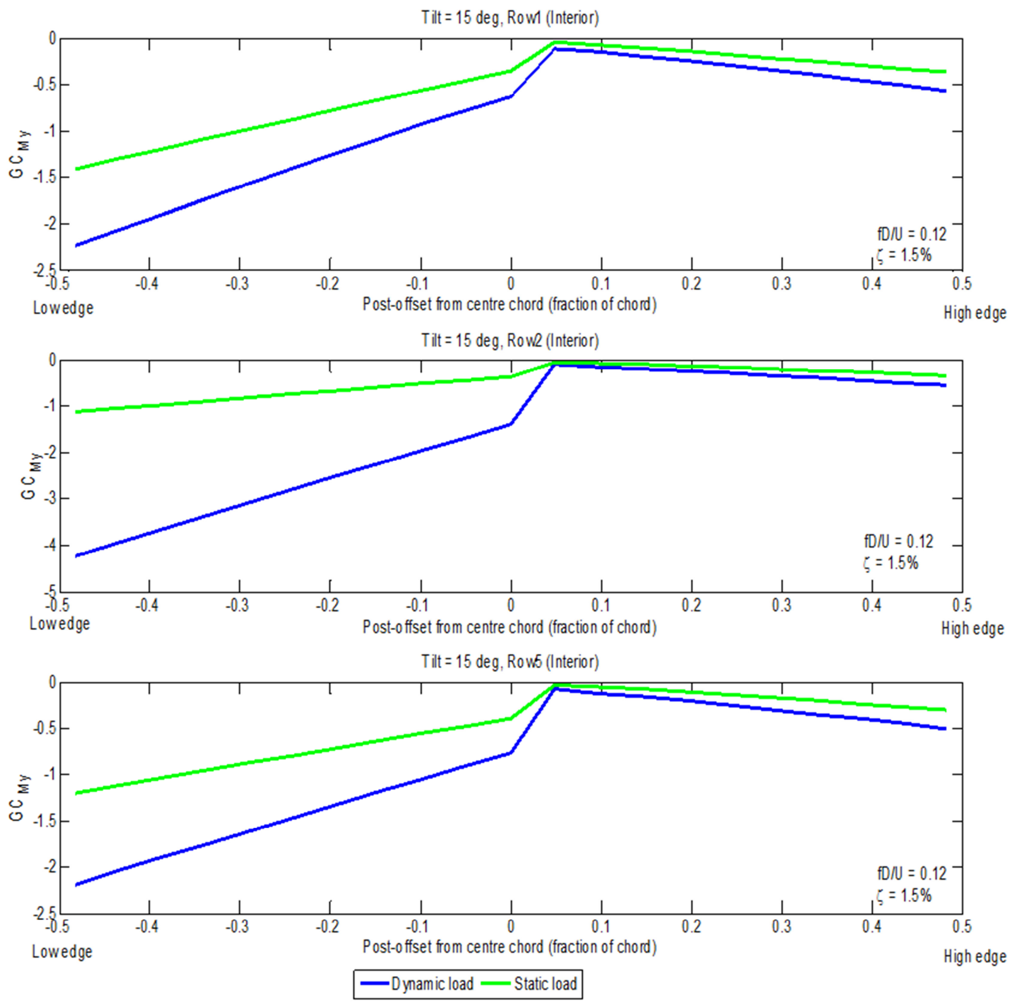

Figure 3. Static and dynamic loading vs. post location along chord.

REFERENCES

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[2] Strobel and Banks, *Effects of Vortex Shedding in Arrays of Long Inclined Flat Plates and Ramifications for Ground-mounted Photovoltaic Arrays*, 12th Americas Conference on Wind Engineering, 2013.