Static wind loading of utility sized modules mounted using 5B's rapid deployment system

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Introduction

Wind loading is an important issue for Australian solar farms, especially as there are drastically increased PV module sizes entering the market with lengths of up to 2384 mm and widths of up to 1303 mm. These "utility" solar modules, with power outputs over 600W, are more than 40% larger than the previously standard module size of 998 x 1996 mm, and ITRPV expects sizes to keep increasing [1]. This has major implications for dynamic and static wind loads experienced in the field, potentially impacting module performance and reliability. The standard covering static module loading, IEC 61215, only assesses loading impacts against the narrow criteria of power loss; there is no information in the public domain regarding the wider behaviour of large format modules under standard test loads or reasonably expected fielded wind loads. Sydney company 5B manufacture a novel pre-fabricated solar array structure designed for rapid deployment in the field [2]. 5B's solar array, known as MAVERICK (MAV) is not susceptible to dynamic effects due to its resonant frequency being > 1Hz. There are unknowns regarding the behaviour of large modules under static load when using non-standard mounting configurations such as happens in 5B's MAV's. The primary concern with module loading is typically related to module microcracks. Cracks in modules can readily propagate due to wind loading on the face of the module [3]. 5B's prefabricated arrays (Fig 1) are inherently aerodynamic and not subject to high static wind loading, however, experience different mechanical stresses due to the mounting system based on hinged corner clamping. Here, we present some initial studies developing testing capabilities to investigate the electrical impact of reasonable static wind loads, as well as how much load is needed to reach failure for utility sized modules mounted using 5B's mounting system. We also present some initial finite element modelling being developed to better predict mechanical stresses on modules and the cells inside under wind loads.

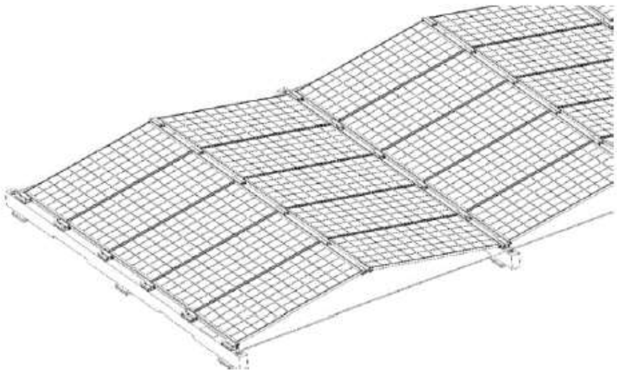

Figure 1: 5B's corner hinge mounted prefabricated array.

Test setup validation: initial corner point supported testing of standard size module

To ascertain the magnitude of deflection that would need to be accounted for, a very crude initial test was conducted on a typical 1675 x 997 mm module with front glass, rear polymer backsheet and 38 mm frame. Figure 2(a) shows the set-up consisting of car jacks to support the module at the corners (no fixings) and 320 kg of sand loaded onto the module. The deflection at the centre was ~90 mm. Despite the frame bending beyond the point of plastic deformation and remaining bent (see picture of bent module in IV tester Fig. 2(b)), no microcracks were observed to have developed and there was no measurable impact to the electrical performance of the module.

Figure 2: Standard sized module (a) corner mounted and loaded with 320 kg of sand; (b) plastically deformed (bent) after the load was removed.

Test setup 1: Utility sized module mounted using 5B mounting version 1, to expected wind pressures

A 2256 x 1133 mm bifacial glass-glass half-cell module with 35 mm frame was used for this test. Loads were selected to correspond with maximum pressures expected for Wind Region A (multiplied by a safety margin), as derived from Australian Standards (AS/NZS 1170), and from 5B's own wind tunnel test conducted by international wind tunnel consultants CPP. The module was characterised using a Spire module IV flash tester (in halves due to its size) and BT imaging LIS-M1 tester [4] for module PL/EL before and after each load test. The peak load in a 5B array is an uplift wind load. The module was first mounted face down, and loaded uniformly with 210 kg (805Pa) of sand, equivalent to a wind uplift pressure of 1053 Pa when accounting for the weight of the module (32.3kg) (Fig 3(a)). The module deflection at the centre of the long edge while loaded was ~48 mm. After an hour the sand was unloaded and module measured. The module was then installed face up, and the module loaded with 129 kg (494 Pa) of sand (Fig 3(b)) and left for an hour prior to unloading and measurement; the loaded module deflection was ~40 mm. The electrical connectivity of the module was monitored and remained continuous throughout testing. The module returned to its original shape, with no plastic deformation.

Figure 3: Utility sized module mounted using 5B corner hinges and loaded (a) from the rear with 202 kg (777 Pa), (b) on the front with 129 kg (494 Pa)

No changes were observed in either the PL or IV measurements as a result of the testing. Figure 4(a) shows the final PL image of the module after all loading with no microcracks, while 4(b) shows the IV curves for one half of the module as received (AR), after backside loading (BL), and after frontside loading (FL).

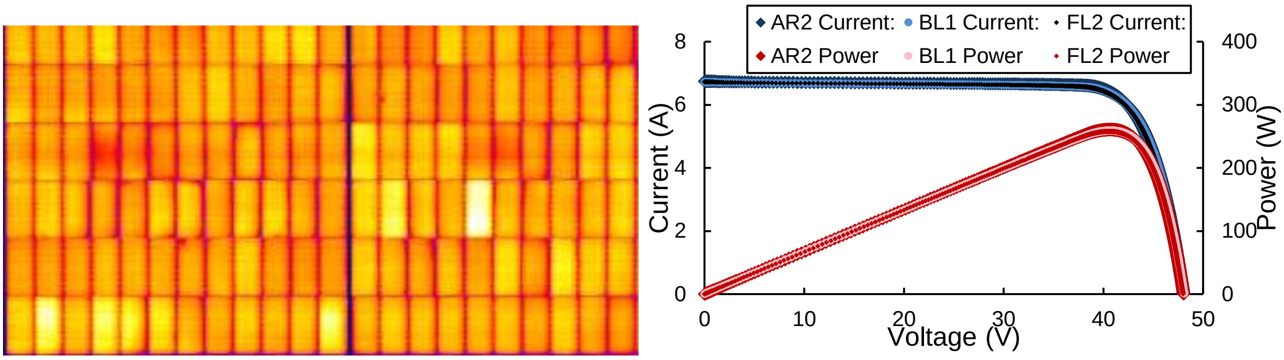

Figure 4: (a) PL image after wind load testing from the front and rear with no microcracks, (b) half-module IV curves as received (AR), after backloading (BL) and front loading (FL)

Test setup version 2: Jig to mount modules with 5B mounting version 1, loaded to fail.

A specialised solid steel test jig (Fig. 5) was designed and built to enable modules to be mounted using 5B's mounting system. The test jig also allows horizontal movement and hinge rotation under load to more accurately reflect real-life installation.

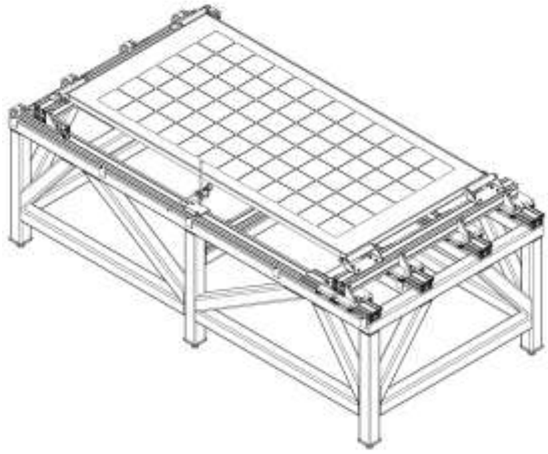

Figure 5: Solid steel test jig designed to enable 5B and standard module mounting configurations

Testing utility sized modules to failure

A 540W single glass half-cell module measuring 2279 x 1134 mm with a 35 mm frame was mounted face up on the test jig. The module was loaded with ~335 kg (1270 Pa) leading to 148 mm deflection at the centre (Fig 6(a)). This load resulted in complete failure, firstly of the frame, and secondly of the glass laminate (Fig 6(b)). This load is well in excess of the expected peak downward load in Wind Region B of AS/NZS 1170.

Figure 6: Utility sized module under 335 kg load, (a) before and (b) after failure.

Finite Element Modelling (FEM)

Uplift loading of a 2256 x 1133 mm glass-glass module with 35 mm frame was investigated using FEM. One quarter of the module was modelled with the assumption that deformation was symmetric along both short and long edges. The module corner was clamped to a corner hinge of which the outer edge was free to rotate; free to move in the direction of the long edge, but zero displacement along the short edge or vertically. Gravitational effect was not included in the simulation, which was carried out using material properties summarised in Table 1.

Table 1. Material properties used in the FEM of module loading.

Material	Density (kg/m^3)	Young's modulus (GPa)	Poisson ratio	Yield strength (MPa)
Glass	2500	73	0.23	-
EVA	960	0.025	0.4	-
Si	2329	Anisotropic	-	-
Frame	2700	70	0.334	215
Sealant	67	0.0074	0.3	-

Figure 7(a) shows the maximum deflection of the module with uplift loading. At a pressure of 1050 Pa, a module deflection of 41 mm was simulated, which is lower than the measured deflection of 48 mm at 1053 Pa. The difference between simulation and actual measurement requires further investigation. Figure 7(b) shows maximum von-Mises stress in the Al frame increases linearly with uplift pressure until the frame starts to experience plastic deformation (>630 Pa) after which the module deflection increases faster. The observed plastic deformation of the frame occurred at much higher loads.

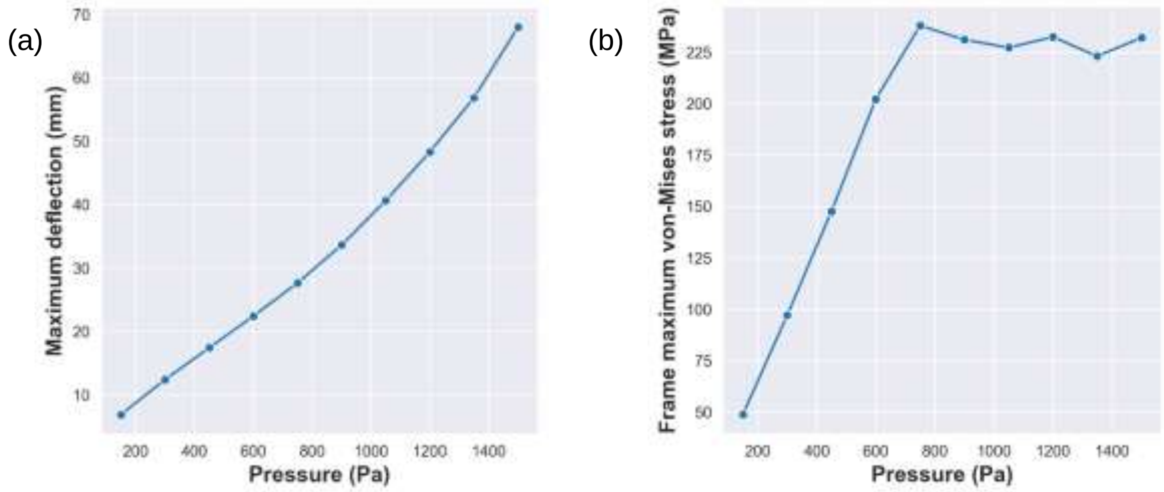

Figure 7: Simulated utility sized glass-glass module under uplift loading test (a) maximum deflection and (b) maximum von-Mises stress in Al frame as a function of load pressure.

The stress distribution on the module under uplift loading at 750 Pa is depicted in Figure 8.

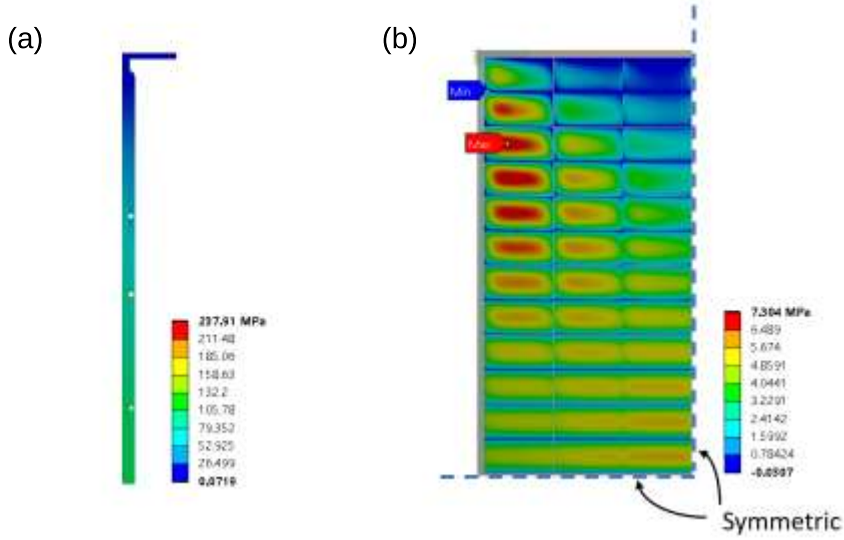

Figure 8: Simulated 2256 x 1133 mm glass-glass module quarter with 35 mm frame loaded with 750 Pa uplift (a) von-Mises stress in Al frame and (b) tensile stress in Si solar cells.

It is revealed in Figure 8(a) that maximum von-Mises stress in Al frame is concentrated locally near the mounting hole closest to the module centre. As the region exceeding yield strength was very localised, the module was restored to original shape after unloading and no permanent deformation was observed. If pressure was further increased, frame damage around the mounting hole(s) would become visible. The corresponding tensile stress induced in Si is shown in Figure 8(b). Attributed to the double glass protection, a maximum tensile stress of 7 MPa was simulated and mainly located in the outer string of cells when subjected to uplift loading of 750 Pa. Such low stress in Si indicates the cells are safe from microcracks, with breakage not expected until pressures exceed 120 MPa for undamaged Cz cells or 20 MPa for an already significantly cracked cell [5].

Summary/Conclusions

- Initial static wind load tests and finite element modelling have been conducted to investigate utility sized modules mounted with 5B's mounting system. A specialised test jig has been built to enable mounting that realistically represents field conditions.
- Both experimentally and via FEM it is seen that the stress on the cells within the module is very low having no impact on electrical performance or formation of microcracks even as the frames of the modules reach plastic deformation and 'fail'. It is a significant result that the frames "fail" before cell damage occurs in the 5B mounting configuration.
- For a utility sized module loaded with expected wind loads there was no plastic deformation and no measurable impact on electrical performance, including no formation of microcracks.
- Simulated module deflection by FEM was smaller than test measurements, which requires further experiments to clarify. Having a reliable and calibrated FEM module is very important for ongoing development of the mounting system.
- These results form the basis for an ongoing project in which more detailed and discrete module deflection will be measured to fine-tune the FEM models and aid predictions.

References

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