School of Electrical Engineering and Telecommunications
Real-time Digital Simulations Laboratory

Submission to 2021 Market Ancillary Service Specification Consultation

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UNSW Sydney welcomes the opportunity to make a submission to the Australian Energy Market Operator's (AEMO) *Market Ancillary Service Specification Consultation January 2021*, Issue paper (The MASS consultation document). We also support AEMO's initiatives to request feedback and improve stakeholder engagement in the area of DER participation in Market Ancillary Services.

UNSW Sydney, under the ARENA funded project 'Addressing Barriers to Efficient Renewable Integration' and together with its project partners, AEMO, TasNetworks and ElectraNET has been engaging in comprehensive bench-testing of commercially available, residential-scale solar PV inverters in order to evaluate the performance of solar PV inverters, assist with the modelling task of solar PV generation and provide input to the improvement of standards. Up to date, we have completed tests in more than 30 single-phase and three-inverters. Details about the project can be found in Section 2.

Based on our experience in testing solar PV inverters, we would like to provide answers to the questions raised in the MASS consultation document regarding DER participation. Please feel free to contact us if there are any questions or if you wish to discuss any matter with respect to this submission via e-mail to:
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1. Consultation questions for DER participation

1. *Which option for the ongoing measurement requirements for DER described in Section 2.3 do you want AEMO to implement and why? Should any other options be considered?*

   We do not have a specific preference on potential implementations from AEMO to the ongoing measurement requirements for DER. There are product solutions that are currently available in the market and that are technically capable of providing the required 50 ms data capture for all systems, even those rated at a few kWs. However, a balance between appropriate data resolution to confirm provision of service and the amount of data stored does provide the best possible approach.

2. *Which option do you think is more consistent with the NEO, and why?*

   Given the availability of devices that can capture and store disturbance data at 50 ms intervals, the relatively small incremental cost for the inclusion of such devices and with the aim of future-proofing the system (as captured data can be used for other functions beyond FCAS delivery validation), we believe that Option 1 is more consistent with the National Electricity Objectives.

3. *Should AEMO consider any principles other than those described in Section 2.4 to guide its assessment?*

   No comment.

4. *What is the difference in implementation costs,such as updating the communication links or installing additional equipment,forcapturing data at a resolution of either 50 ms or 1 second for every NMI for different VPP facility types? Do you consider the cost difference to be prohibitive for participating in the Contingency FCAS markets? Please provide examples or analysis if possible.*

   No comment.

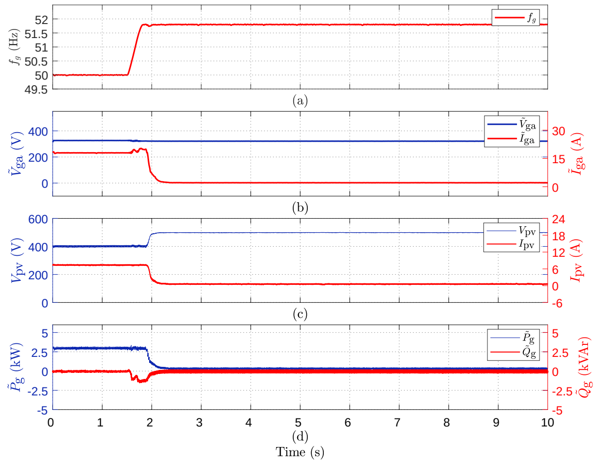
5. *Do you think that either of the options presented will result in more or less competition in the Contingency FCAS markets?*

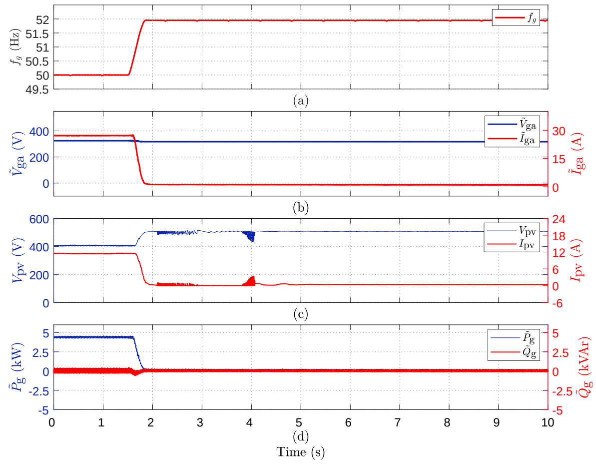
   No comment.

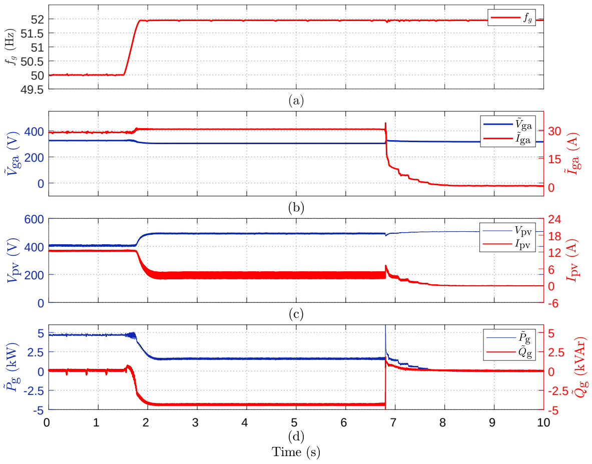
6. *Are there any technical risks that you envisage if the Option 2 measurement requirements are allowed? How material do you consider those risks and how could they be efficiently mitigated?*

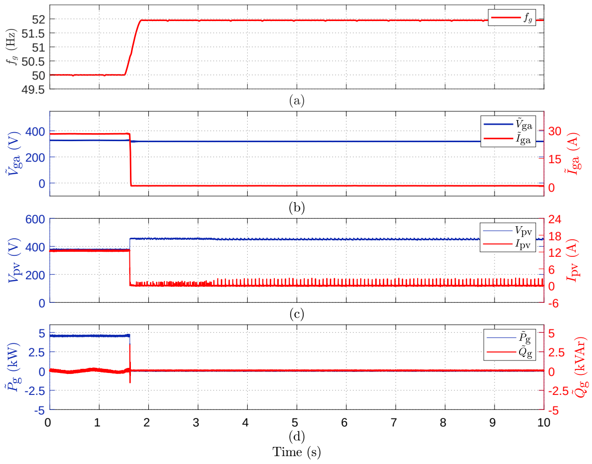
   In order to mitigate technical risks under Option 2, AEMO should consider not only the number of VPP trials conducted, but also the number and different models of inverters that will be part of the future fleet of inverters participating in VPPs. This should include both the inverter model as well as the specific firmware and inverter settings that the inverter was tested under and confirming that the same firmware and parameters are used in the actual installation after commissioning.

   Based on our inverter bench-testing (See details in Section 2), we have observed a broad range of responses from inverters to frequency and voltage variations. The following figures show a sample of four inverter responses to a frequency increase with a Rate of Change of Frequency (RoCoF) of 10 Hz/s. In each case, the top figure shows the grid frequency[1], while the bottom figure shows the power[2].









If Option 2 is selected, it is critical to establish a detailed and comprehensive set of tests that the participating inverters will be validated against. We have found that a single test or a single frequency injection might not be fully representative of the inverter response and additional tests (e.g. Freqeuncy steps, RoCoF events, slow and fast frequency modulation tests, combined voltage and frequency tests) would help provide a more accurate picture of an inverter response.

We would also recommend that, although the data for DERMASS is sampled at 50 ms, the inverter response is captured at significantly higher resolution during inverter testing.

7. Does the sampling rate of one second rather than 50 ms for Fast Contingency FCAS under Option 2 and the determination of the FCAS delivery at the inverter/controllable device level create market distortion or negatively impact the FCAS markets?

As commented above, data for tests under Option 2 should be captured at significantly higher resolution.

[1] The frequency is common for all tests

[2] Instantaneous calculation of power is used in all our measurements and results

8. *If Option 2 was adopted, should the changes to the measurement requirements of the MASS be limited to small-scale DER (under 1 MW per NMI), or should a different threshold apply,such as 5MW? For example, what do you see as the risks and benefits of expanding these measurement requirements to other FCAS providers and in what circumstances might that be appropriate?*

   We believe that a more cautions approach is preferable, as the increase of DG in the grid together with changes in the generation fleet across the NEM will result in reduced inertia, higher RoCoF events and generally expectations to provide frequency ancillary functions at a more consistent rate in a more challenging environment.

   Another point for consideration should be the provision of inertia from other forms of distributed generation participating in VPP operation, such as solar PV systems. There are current technical solutions to allow PV inverters to provide such functionality (see [1] for example). Such approaches may affect future registration and operation of VPPs with multiple sources of FCAS.

2. About UNSW's ARENA funded "Addressing Barriers to Efficient Renewable Integration" Project

With the scope of unveiling potential vulnerability of commercial rooftop PV inverters, thus helping the modeling task and feeding inputs to the improvement of standards, extensive inverter bench-testing has been performed on several off-the-shelf rooftop inverters under UNSW's ARENA funded "Addressing Barriers to Efficient Renewable Integration" project.

Creation of a DER model for PV inverters requires an understanding of the behavior of the inverters when these are subjected to voltage and frequency disturbances. The connection between the grid voltage and frequency variations with the active and reactive power delivered by the inverter is fundamental to developing a useful DER model.

The scope of the bench testing is to observe the response of commercial PV inverters under different types of grid disturbances. The motivation of the bench testing is:

- To utilise these results to assist in the development of a DER model.
- To assess whether inverters are 'robust' to grid disturbances.
- To benchmark the inverters against the standard enforced at the time.
- To identify possible enhancements to future standards.
- To attempt to confirm/refute common perceptions around small-scale inverters.

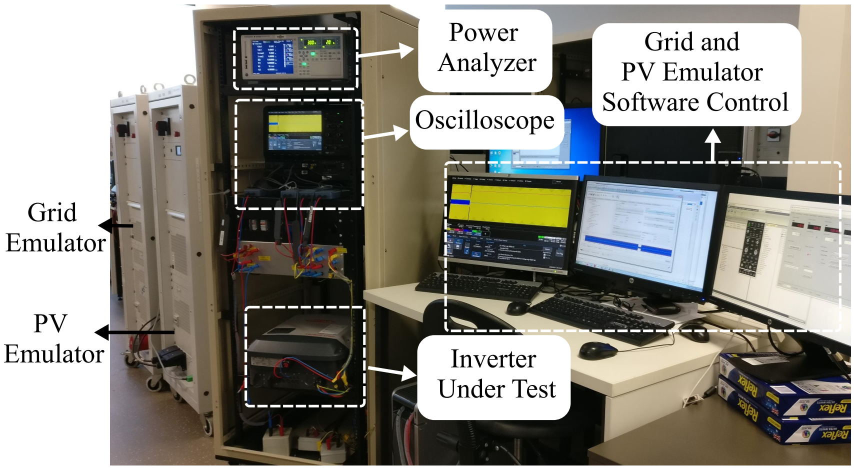
Observing the response of the inverter in terms of active and reactive power, when the grid voltage and frequency are varied according to specific patterns is the tool which is used to infer the dynamic behavior of the inverters and for creating a DER model.

The tests carried out entailed application of voltage and frequency disturbances to the inverter, emulating abnormal conditions in the grid, which may arise for instance due to sudden loss or surplus of power generation, or short-circuit faults. The results identify vulnerabilities of certain inverter models, abruptly disconnecting from the grid or undesirably curtailing their output power upon application of voltage sags, phase-angle jumps, and rate of change of frequency.

Power electronic inverters inverters process the energy produced by PV systems and must ensure continuity of operation under a range of grid disturbances, impacting voltage and frequency at the point of interconnection with the grid. Inverter bench testing has the scope of verifying the inverter response to a variety of events which can occur in the grid. Understanding the behaviour of PV inverters during grid disturbances has multiple benefits, among which are the insights given towards improving existing load models, the information provided to grid operators to manage loads and generation contingencies, and the development of better product standards. The results given by the test benching procedure have highlighted different inverter behaviors in response to specific grid disturbances, the most relevant being described in the coming paragraphs.

The bench testing setup schematic is displayed in Fig. 1. By means of the grid emulator, represented by the ac voltage source vemu, it is possible to change amplitude, frequency and phase parameters of the voltage at the ac connection point of the inverter, v_g.

The inverters which have been tested so far represent about 20% of all rooftop PV capacity in Australia, are from globally recognizable manufacturers, and are among the most common models



installed across the nation.

Details of the inverter bench-testing report, milestone reports and all related publications to the project can be found at our project website: http://pvinverters.ee.unsw.edu.au/. This website provides a comprehensive database of inverter bench testing results, plotting inverter responses to a variety of stimuli. For each inverter, the plots show input and output voltage and current, as well as output active and reactive power. The left hand side dropdown menu allows to choose the inverter tested, while the right hand side dropdown menu selects the test performed. A summary page tabulates the results from testing, highlighting the behaviour of each inverter tested, and reporting the capacity installed for each inverter vulnerable to selected grid disturbances. The information reported on this website ultimately provides useful insights on understanding effects of grid disturbances on rooftop PV inverters, on an individual and aggregate basis.

3. Acknowledgment

UNSW Sydney received funding as part of the project ‘Addressing Barriers to Efficient Renewable Integration’ funded by the Australian Renewable Energy Agency (ARENA) under grant number G00865.

4. References

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[2] PV inverter testing website: Addressing Barriers to Efficient Renewable Integration http://pvinverters.ee.unsw.edu.au/

[3] UNSW Addressing Barriers to Efficient Renewable Integration - Australian Renewable Energy Agency (ARENA), Project website https://arena.gov.au/projects/addressing-barriers-efficient-renewable-integration/

[4] L. Callegaro, G. Konstantinou, C. A. Rojas, N. F. Avila and J. E. Fletcher, “Testing Evidence and Analysis of Rooftop PV Inverters Response to Grid Disturbances,” *IEEE Journal of Photovoltaics*, vol. 10, no. 6, pp. 1882-1891, Nov. 2020.

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[6] N. F. Avila, L. Callegaro and J. E. Fletcher, "Measurement-Based Parameter Estimation for the WECC Composite Load Model with Distributed Energy Resources," in *Proc. of IEEE PESGM*, pp. 1-5, 2020.