Addressing Barriers to Efficient Renewable Integration

Reconnection Frequency of Inverters v0

Based on Inverter Testing Procedure v0.8

Lead Organisation: University of New South Wales (UNSW)

Project Partners: AEMO, ElectraNet, TasNetworks

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Inverter Bench Testing Results: `http://pvinverters.ee.unsw.edu.au`

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Executive Summary

The increasing penetration of distributed solar PV systems in Australian networks adds to the challenge of managing and operating the electricity network. In order to address challenges that arise, the University of New South Wales (UNSW Sydney) in collaboration with the Australian Energy Market Operator (AEMO), ElectraNet and TasNetworks and supported by ARENA have embarked on a comprehensive test of residential inverters. The tests will identify the response of solar PV inverters in grid disturbances (especially frequency and voltage excursions), their capacity to ride-through network faults and inform the load modelling exercise currently undertaken by AEMO.

This technical report investigates the frequency values, at which the inverters reconnect after an over-frequency or under-frequency event. Two tests are performed on each inverter to find the reconnection frequency of each inverter:

- **Under Frequency**: Initially, the inverter operates at the nominal power and grid voltage and frequency. By decreasing the frequency in a step from 50 Hz to 46.9 Hz, the inverter disconnects from the grid due to the under frequency condition. The grid frequency then increases from 46.9 Hz with steps of 0.1 Hz towards the nominal frequency. The time interval at each step of the frequency is more than 6 minutes, which ensures that the inverter would reconnect at that particular frequency or no. The frequency at which the inverter reconnects to the grid and increases its output power is recorded in the test.

- **Over Frequency**: The inverter initially operates at the nominal power and grid voltage and frequency. By increasing the frequency in a step from 50 Hz to 52.1 Hz, the inverter disconnects from the grid due to the over frequency condition. The grid frequency then decreases from 52.1 Hz with steps of 0.1 Hz towards the nominal frequency. The time interval at each step of the frequency is more than 6 minutes. The frequency at which the inverter reconnects to the grid and increases its output power, is recorded in the test.

Standard Requirement

One of the requirements for connection/reconnection of inverters, based on AS477.2:2015 is:

- The frequency of the grid has been maintained within the range 47.5 Hz to 50.15 Hz for at least 60 s;

Additionally the inverters are required to follow the power ramp rate, after connection/reconnection.

Key Observations

The recorded frequency values, at which the inverters reconnect after a fault is recorded in Table 1.

✓ After an over frequency event, all the tested inverters, follow the standard requirement for the frequency value to reconnect after the fault (51.15 Hz).

✓ After an under frequency event, all the tested inverters, except one (inverter No. 4), follow the standard requirement for the frequency value to reconnect after the fault (47.5 Hz). The frequency reconnection of inverter No. 4 is 47.1 Hz.
It is noted that the compliance test specified in AS/NZS4777.2:2015 does not assess this reconnection frequency after an under frequency event.

The recorded test waveforms for a selection of the tested inverters, including inverter No. 4, are provided in the following sections of this report.

Further information on UNSW's bench testing is available in [1–5].

Table 1: Summary of inverter reconnection frequency values after frequency disturbance.

[1]Inverter description	AS 4777 version	Reconnection frequency after under frequency disturbance (Hz)	Reconnection frequency after under frequency disturbance (Hz)
A, No. 6, 1-phase	2015	47.5 - 47.6	50.1 - 50.2
A, No. 7, 1-phase	2015	47.5 - 47.6	50.1 - 50.2
A, No. 19, 1-phase	2015	47.5 - 47.6	50.1 - 50.2
A, No. 302, 3-phase	2015	47.5 - 47.6	50.1 - 50.2
B, No. 25, 1-phase	2015	47.4 - 47.5	50.1 - 50.2
B, No. 301, 3-phase	2015	47.4 - 47.5	50.1 - 50.2
C, No. 3, 1-phase	2015	47.5 - 47.6	50.1 - 50.2
C, No. 13, 1-phase	2015	47.5 - 47.6	50.1 - 50.2
C, No. 29, 1-phase	2015	47.4 - 47.5	50.1 - 50.2
D, No. 4, 1-phase	2015	47 - 47.1	50.1 - 50.2
E, No. 5, 1-phase	2015	47.5 - 47.6	50.1 - 50.2
H, No. 20, 1-phase	2015	47.5 - 47.6	50.1 - 50.2
J, No. 22, 1-phase	2015	47.4 - 47.5	50.1 - 50.2

[1]Inverter description consists of the following information: Manufacturer, Inverter number, and number of phases.

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1 Manufacturer B - Inverter 25 - Single-Phase - AS4777.2:2015

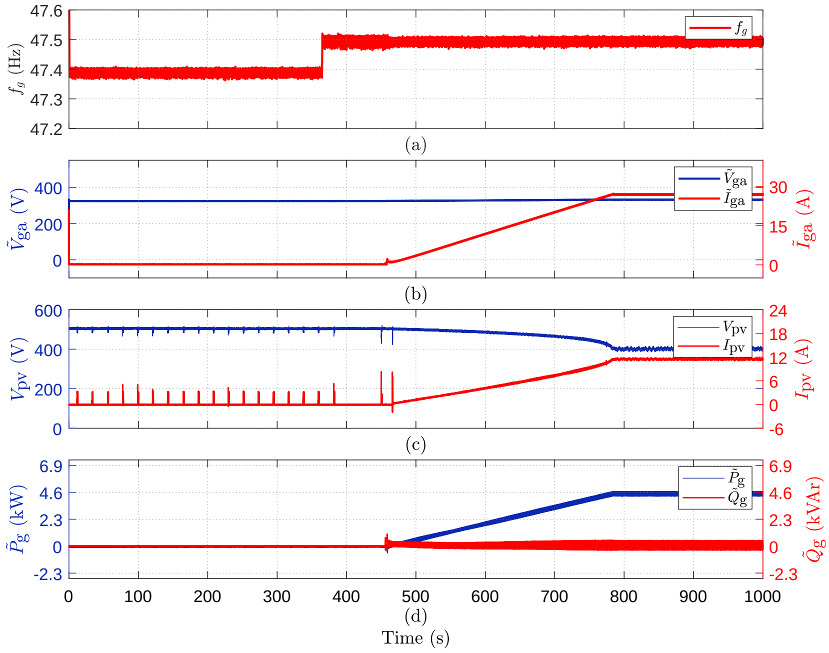

Figure 1: Inverter 25 - Reconnection frequency after an under-frequency fault.

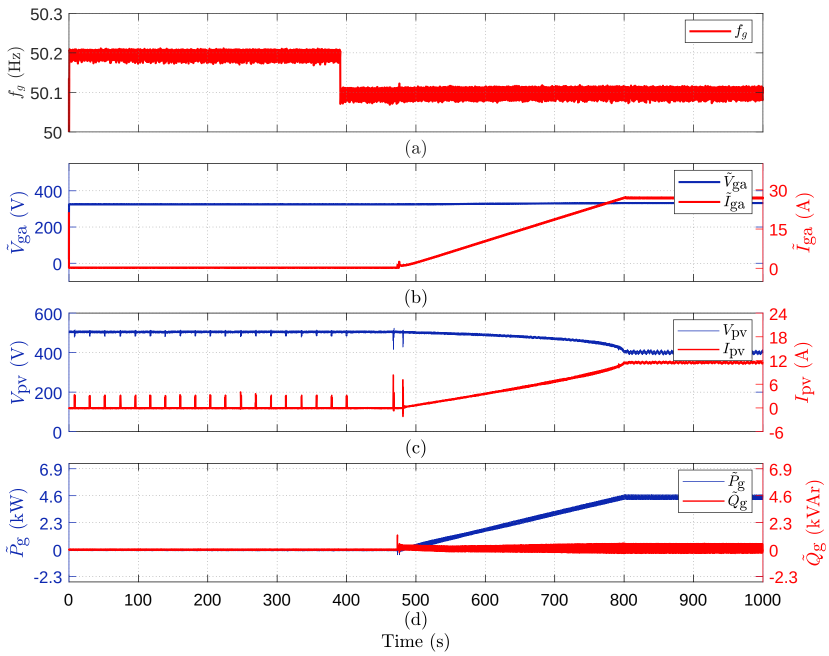

Figure 2: Inverter 25 - Reconnection frequency after a over-frequency fault.

2 Manufacturer C - Inverter 13 - Single-Phase - AS4777.2:2015

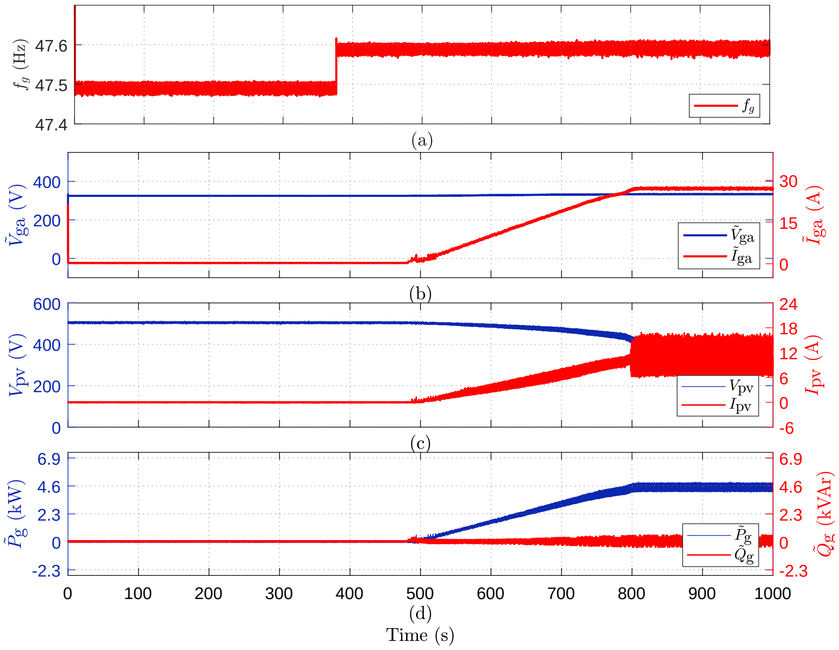

Figure 3: Inverter 13 - Reconnection frequency after an under-frequency fault.

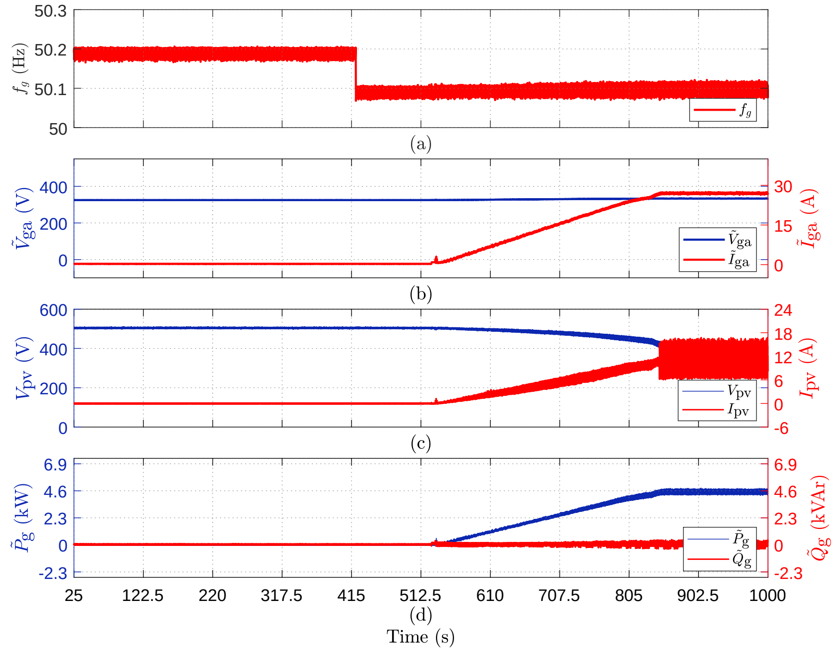

Figure 4: Inverter 13 - Reconnection frequency after an over-frequency fault.

3 Manufacturer D - Inverter 4 - Single-Phase - AS4777.2:2015

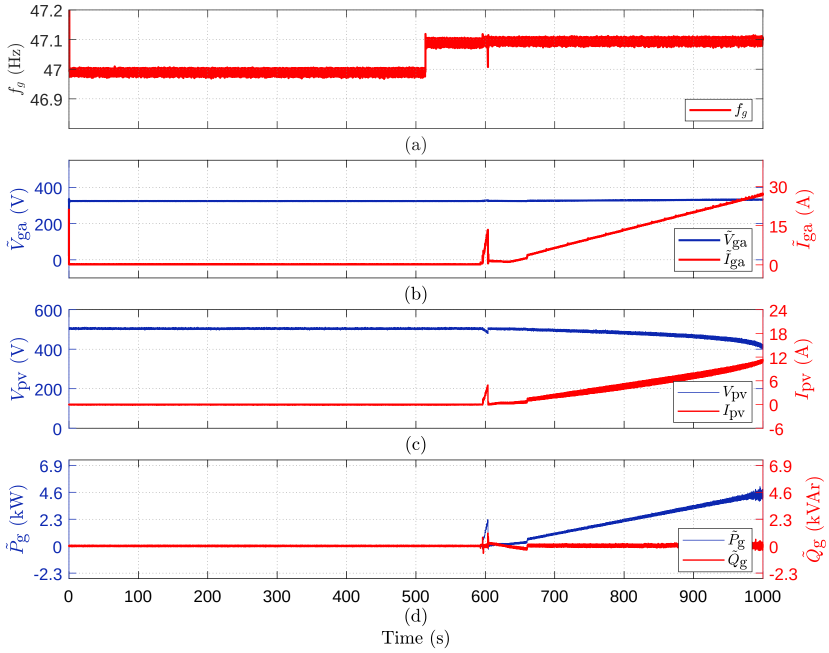

Figure 5: Inverter 4 - Reconnection frequency after an under-frequency fault.

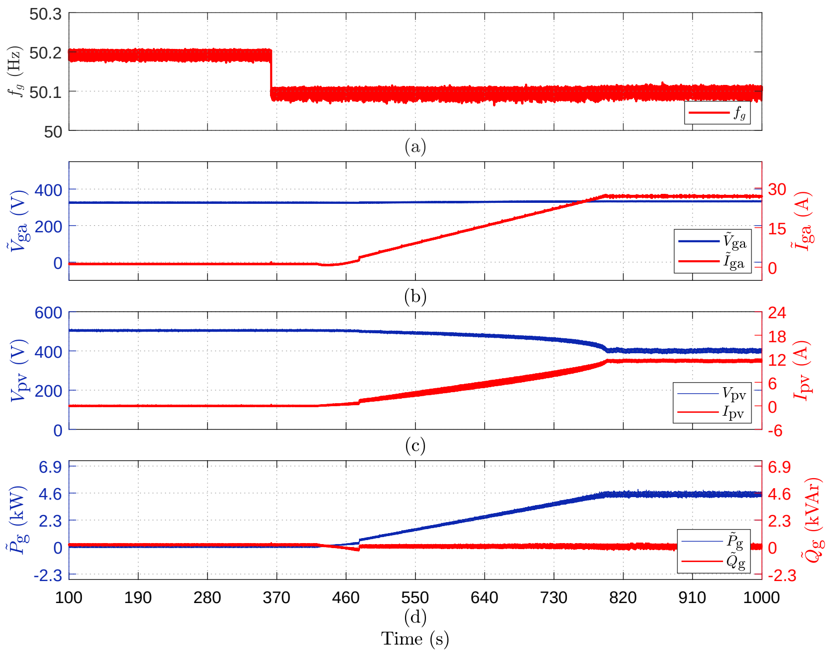

Figure 6: Inverter 4 - Reconnection frequency after an over-frequency fault.

4 Manufacturer E - Inverter 5 - Single-Phase - AS4777.2:2015

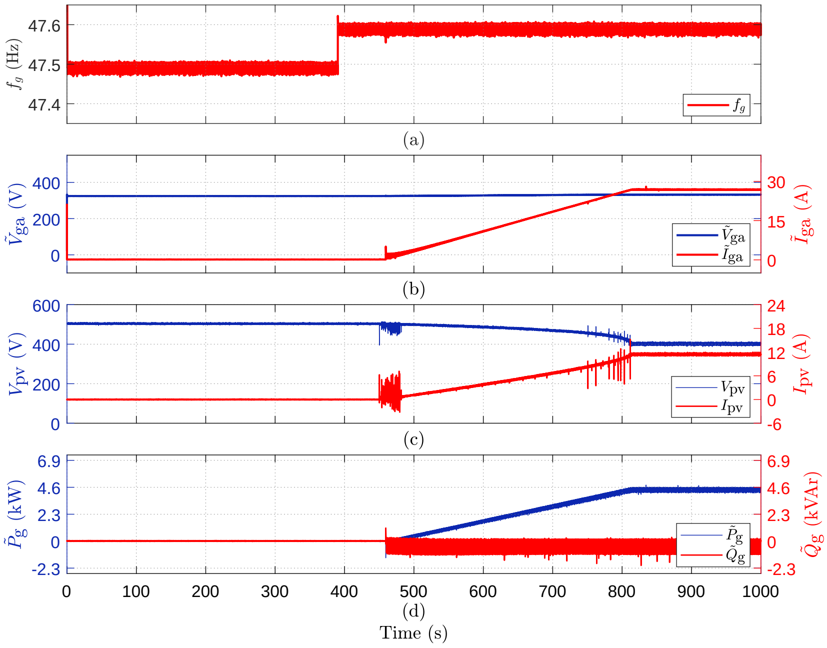

Figure 7: Inverter 5 - Reconnection frequency after an under-frequency fault.

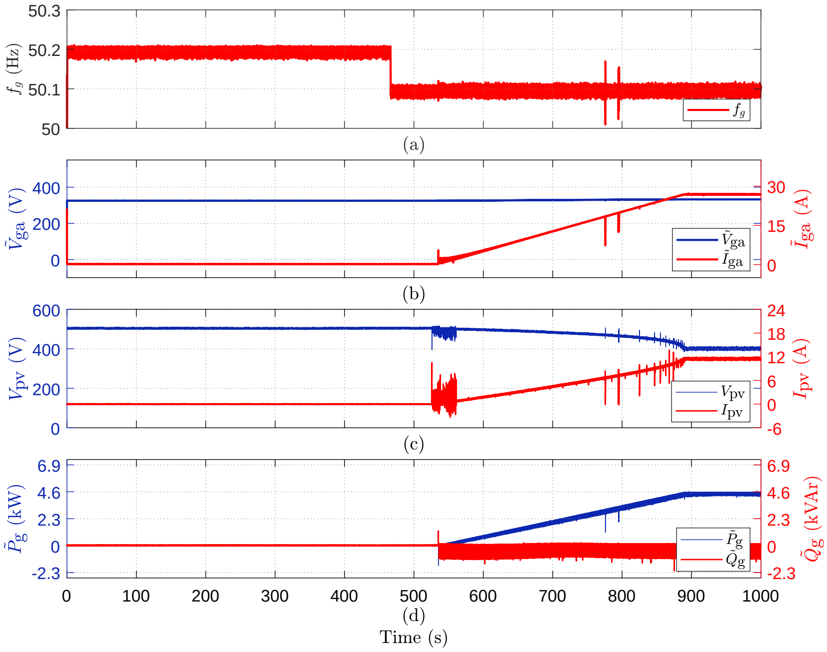

Figure 8: Inverter 5 - Reconnection frequency after an over-frequency fault.

5 Manufacturer H - Inverter 20 - Single-Phase - AS4777.2:2015

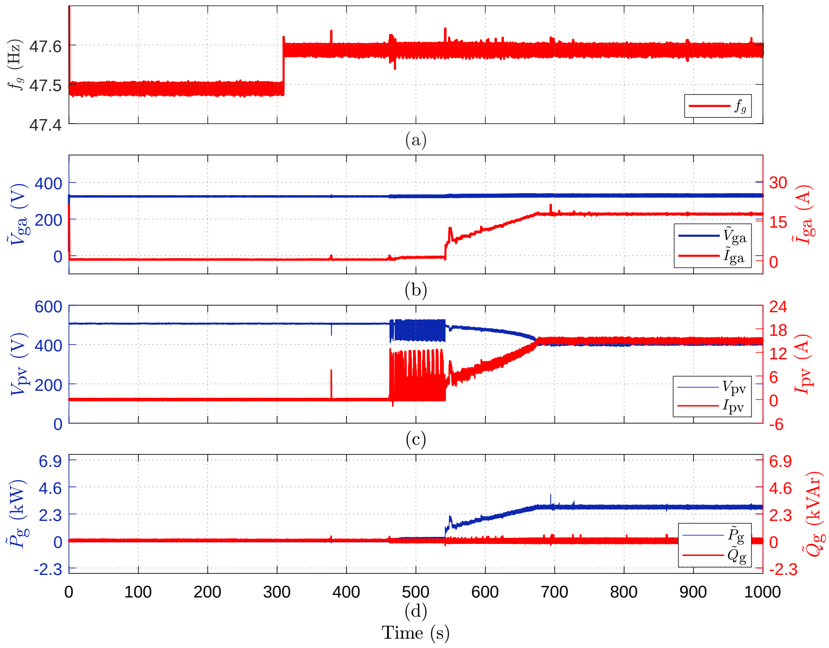

Figure 9: Inverter 20 - Reconnection frequency after an under-frequency fault.

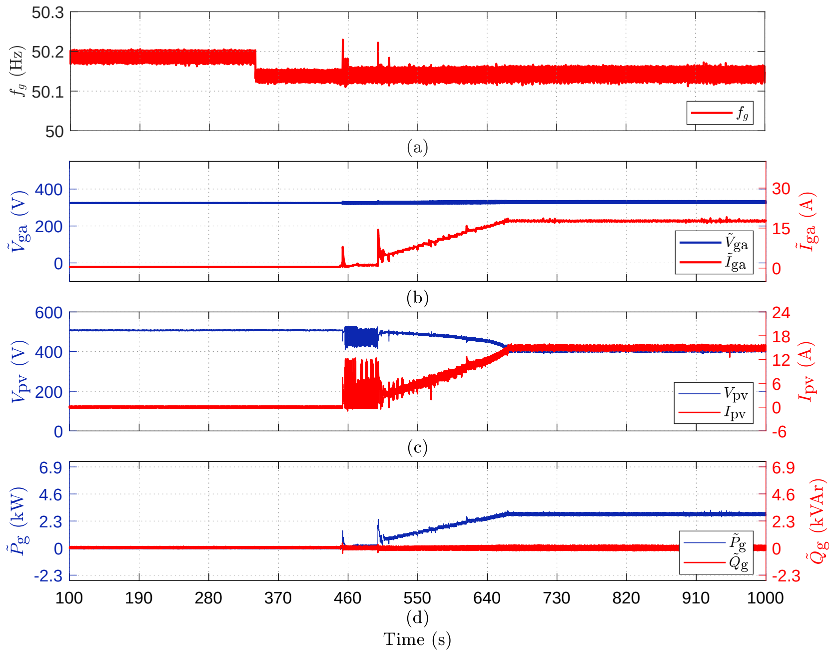

Figure 10: Inverter 20 - Reconnection frequency after an over-frequency fault.

References

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

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

[3] 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.

[4] K. Ndirangu, L. Callegaro, J. E. Fletcher and G. Konstantinou, "Development of an aggregation tool for PV inverter response to frequency disturbances across a distribution feeder," in *Proc. of IECON*, pp. 4037-4042, Oct. 2020.

[5] 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.

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