Addressing Barriers to Efficient Renewable Integration

Dynamic Response of Inverter Volt-VAr Power Quality Mode v3

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), TasNetworks and ElectraNet 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 demonstrates the Volt-VAr dynamic behavior of inverters, based on inverter testing procedure v0.8. A step increase/decrease in the grid voltage is applied such that the inverter should adjust its reactive power output based on the standard. The aim is to check the inverter response time in regulating the output active/reactive powers based on the requirements of the standard, under sudden changes of grid voltage.

Two tests are performed on each inverter to find the Volt-VAr dynamic response of the inverter at the beginning of an over- or under-voltage disturbance:

- Grid voltage step increase from 1 pu to 1.12 pu
- Grid voltage step decrease from 1 pu to 0.9 pu

Furthermore, Two tests are performed on each inverter to find the recovery dynamic response of the inverter at the end of an over- or under-voltage disturbance:

- Grid voltage step recovery from 1.12 pu to 1 pu
- Grid voltage step recovery from 0.9 pu to 1 pu

Key Observations

The main observations from the tests, reported in this document, can be summarized as follows:

✓ For a grid voltage step increase from 1 pu to 1.12 pu, 5 out of 6 inverters follow the standard Volt-VAr response curve, noting that the compliance test specified in AS/NZS4777.2:2015 does not asses this function.
The average response time for the five inverters using their default settings for the Volt-VAr response time:
Min = 1 s

Average = 6.2 s
Max = 10 s

✓ For grid voltage step decrease from 1 pu to 0.9 pu, all inverters follow the standard Volt-VAr response curve.
The average response time for the six inverters using their default settings for Volt-VAr response time:
Min = 1 s
Average = 6.2 s
Max = 10 s

Inverter Settings

In some inverters, there is a time setting parameter for the dynamic response of the inverter, as follows:

- **Manufacturer A, Inverter 302:** The default value of the Volt-VAr response time setting is 5 s. The minimum value of this time can be set as 0.01 s; and it can be set up to 16 minutes. Additionally, this brand has a parameter setting for the maximum reactive power injection. The default value of this parameter is 0, which means no reactive power injection to the grid. For the test results in this report, this parameter is set to 50% of the nominal power of the inverter. Furthermore, the setting of this inverter has a parameter for reactive power ramp rate, which is kept at its default value for the tests in this report. The tests for this inverter are performed in two conditions: a) The Volt-VAr response time parameter is set to its minimum possible value (0.01 s), and b) the Volt-VAr response time parameter is set to 5 s.
- **Manufacturer B, Inverters 25 and 301:** The default value of the Volt-VAr response time setting is 5 s. The minimum value of this parameter can be set as 0.01 s, while it can increased to more than 16 minutes. The tests for this inverter are performed in two conditions: a) This Volt-VAr response time parameter is set to its minimum possible value (0.01 s), and b) this parameter is set to 5 s.
- **Manufacturer C, Inverter 13:** There is no “Volt-VAr response time parameter” in the setting of this inverter. Only, the Volt-VAr and Volt-Watt set points can be modified by the installer. The Volt-VAr requirement for Horizon Power is set in the inverter setting for the tests in this report.
- **Manufacturer D, Inverter 29**: There is no “Volt-VAr response time parameter” in the setting of this inverter. Only, the country/area can be selected in the installer. Horizon

Power is set as the country/region in the inverter setting for the tests in this report.

- **Manufacturer E, Inverter 5:** There is no "Volt-VAr response time parameter" in the setting of this inverter. Only, the Volt-VAr and Volt-Watt set points can be modified by the installer. As an example for the test, the Volt-VAr requirements for Horizon Power are set in the inverter setting for the tests in this report.
- **Manufacturer J, Inverters 22:** In the setting of this inverter, there is a parameter for setting the time of Volt-VAr response. The behavior of the inverter is tested with considering two different time values for this setting: 0 s (which is the default value) and 5 s. The Volt-VAr and Volt-Watt settings are based on Horizon Power.
- **Manufacturer K, Inverter 23:** In the updated firmware of the inverter, Volt-VAr and Volt-Watt settings are enabled based on the DNSP requirements. The inverter behavior is tested under two DNSP settings (as two examples): Horizon Power and Western Power. The Volt-VAr and Volt-Watt set points are based on the selected DNSP region and the installer cannot modify the individual settings, only the region. Furthermore, there are no time settings in the inverter that can be changed by the installer.
- **Manufacturer L, Inverter 28**: There is no "Volt-VAr response time parameter" that can be modified in this inverter. However, based on our testing, the inverter takes 5 s to change its output reactive power to the new set point based on the grid voltage and the Volt-VAr curve requirement

The inverters Volt-VAr response time for five tested inverters is summarized in Table 1. It is seen that the dynamic response of inverters varies by changing the setting time parameter in the inverter. Additionally, the recovery response time differs from the response time at the beginning of the disturbance.

DNSP Requirements

It should be mentioned that the following DNSP documents are checked in order to find out whether they impose any response time for the PV inverters. **It is seen that none of them impose a value for the volt-var response time of the inverters.**

- Endeavour Energy - Grid connection of embedded generation through inverters, Document No.: MDI 0043, Amendment No: 1 - Approval date: 25/07/2017.
- Horizon Power - Basic micro EG connection technical requirements - Standard No.: HPC-9DJ-13-0001-2019 - Approval date: 07/06/2019.

- Ausgrid - NS194 secondary systems requirements for embedded generators - Document No.: NW000-S0048 - Approval date: 03/10/2018.
- Evonergy - Evoenergy micro embedded generation technical requirements - Document No.: 2020 . PO0845 . V2.2.
- SA Power Networks - Technical Standard TS129 - Small EG Connections, Capacity not exceeding 30kW - Published: May 2019.
- PowerWater - Basic micro EG connection technical requirements specification, less than or equal to 30 kVA - Document No.: D2020/380910 - October 2020.

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

Table 1: Summary of inverter dynamic Volt-VAr response time

[1]Inverter description	AS 4777 version	[2]Response time programmed in inverter (s)	[3]Volt-VAr response time (s)	[4]Volt-VAr recovery response time (s)
A, No. 302, 3-phase	2015	0.01 ***5***	Over volt.: 2, Under volt.: 1 Over volt.: 5, Under volt.: 5	Over volt.: 2, Under volt.: 1 Over volt.: 2, Under volt.: 1
B, No. 301, 3-phase	2015	0.01 ***5***	Over volt.: 0.1, Under volt.: 0.1 Over volt.: 10, Under volt.: 10	Over volt.: 0.1, Under volt.: 0.1 Over volt.: 10, Under volt.: 10
B, No. 25, 1-phase	2015	0.01 ***5***	Over volt.: 0.1, Under volt.: 0.1 Over volt.: 10, Under volt.: 10	Over volt.: 0.1, Under volt.: 0.1 Over volt.: 10, Under volt.: 10
C, No. 13, 1-phase	2015	Not Available	Over volt.: 1, Under volt.: 1	Over volt.: 1, Under volt.: 1
D, No. 29, 1-phase	2015	Not Available	Over volt.: 0.5, Under volt.: 0.7	Over volt.: 0.4, Under volt.: 0.1
E, No. 5, 1-phase	2015	Not Available	Over volt.: 0.8, Under volt.: 1	Over volt.: 0.9, Under volt.: 1.1
J, No. 22, 1-phase	2015	***0*** 5	Over volt.: 3, Under volt.: 3 Over volt.: 7, Under volt.: 6	Over volt.: 2.5, Under volt.: 3 Over volt.: 7, Under volt.: 10
K, No. 23, 1-phase	2015	AU Horizon Western Power	Over volt.: 1.5, Under volt.: 3 Over volt.: 1, Under volt.: 1	Over volt.: 2, Under volt.: 3 Over volt.: 1, Under volt.: 1
L, No. 28, 1-phase	2015	Not Available	Over volt.: 5, Under volt.: 5	Over volt.: 5, Under volt.: 5

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

[2]Some inverter have Volt-VAr response time in the setting, which can be modified by the installer. The numbers in ***bold and italic*** are the default values for each inverter. Please refer to Executive Summary section for detailed information.

[3]Volt-VAr response time is measured under two test conditions: a) **Over-voltage**, which is a step increase in the grid voltage from 1 p.u to 1.12 p.u, and b) **Under-voltage**, which is a step decrease in the grid voltage from 1 p.u to 0.9 p.u.

[4]Recovery response time is measured under two test conditions: a) Recovery from **over-voltage**, which is the recovery of the grid voltage as a step from 1.12 p.u to 1 p.u, and b) Recovery from **under-voltage**, which is the recovery of the grid voltage as a step from 0.9 p.u to 1 p.u,

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1.1 Three-Phase Inverters

1.1.1 Manufacturer A - Inverter 302 - Three-Phase - AS4777.2:2015

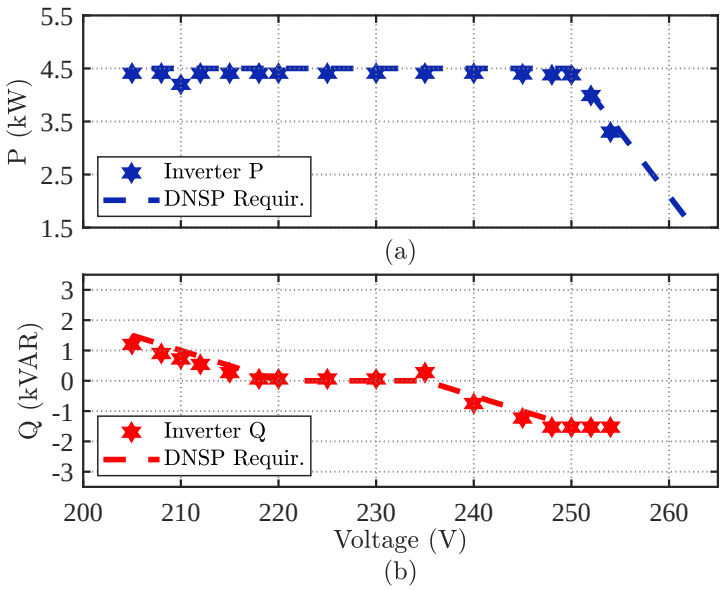

Figure 1: Inverter 302 - Steady-state Volt-VAr and Volt-Watt response.

1.1.2 Manufacturer B - Inverter 301 - Three-Phase - AS4777.2:2015

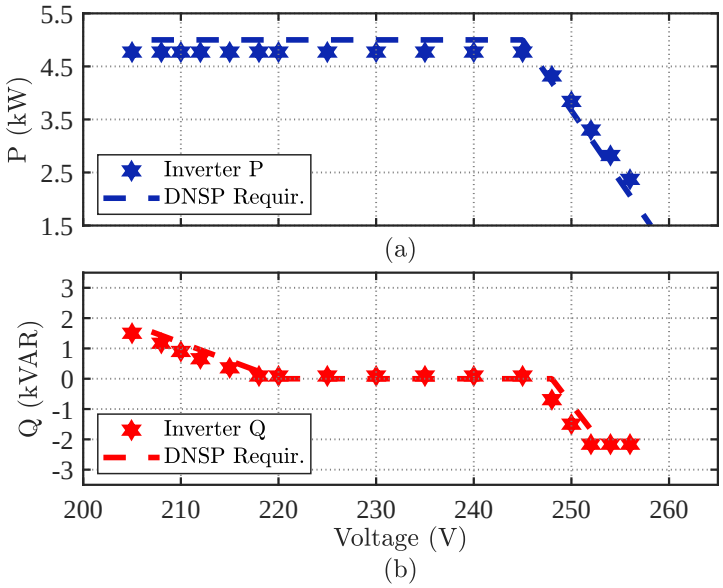

Figure 2: Inverter 301 - Steady-state Volt-VAr and Volt-Watt response.

1.2 Single-Phase Inverters

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

In the setting of this inverter, there is a parameter for setting the time of Volt-VAr response. The behavior of the inverter is tested with considering two different time values for this setting: **0.01 s (which is the minimum value that can be used for this setting) and 5 s**.

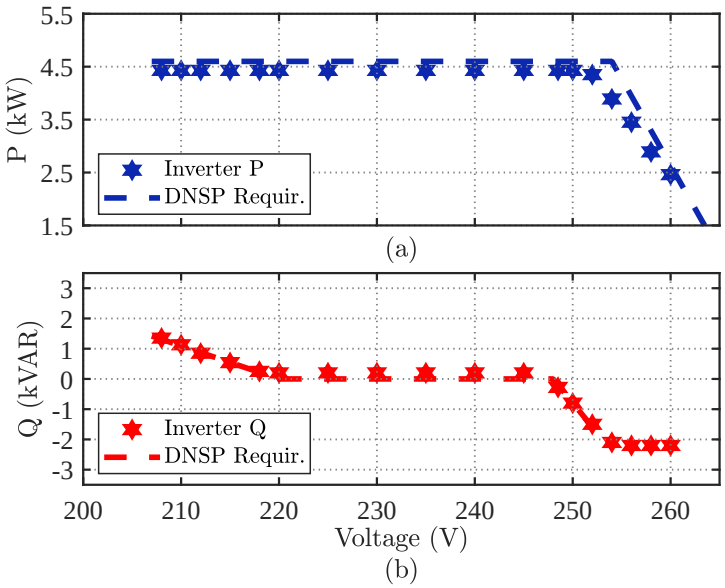

Figure 3: Inverter 25 - Steady-state Volt-VAr and Volt-Watt response.

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

There is no “Volt-VAr response time parameter” in the setting of this inverter. Only, the Volt-VAr and Volt-Watt set points can be modified by the installer. The Volt-VAr requirements for Horizon Power are set in the inverter setting for the tests in this report.

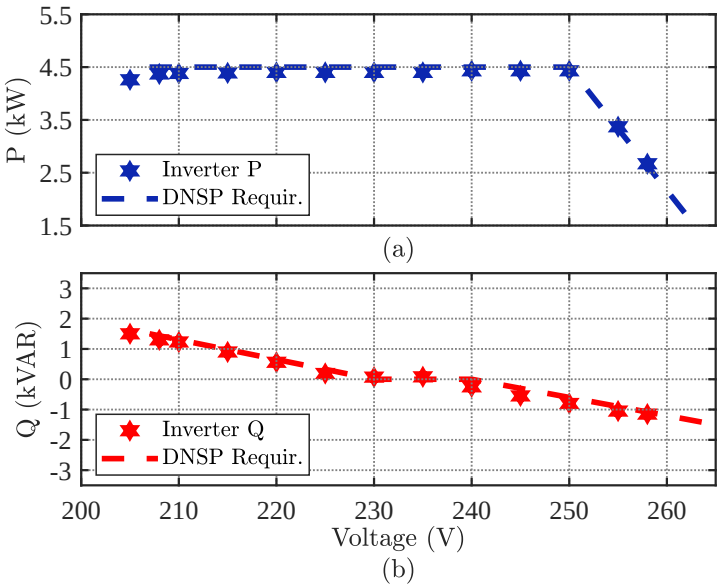

Figure 4: Inverter 13 - Steady-state Volt-VAr and Volt-Watt response.

1.2.3 Manufacturer D - Inverter 29 - Single-Phase - AS4777.2:2015

There is no “Volt-VAr response time parameter” in the setting of this inverter. Only, the country/area can be selected in the installer. Horizon Power is set as the country/region in the inverter setting for the tests in this report.

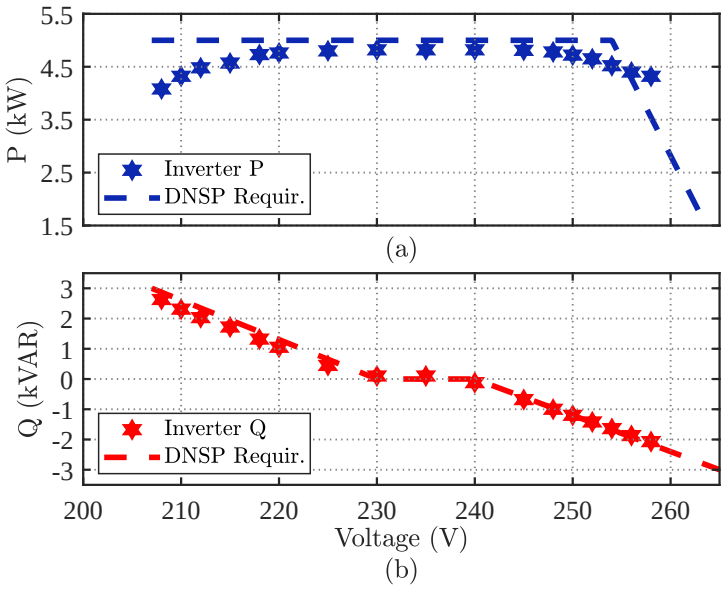

Figure 5: Inverter 29 - Steady-state Volt-VAr and Volt-Watt response.

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

There is no “Volt-VAr response time parameter” in the setting of this inverter. Only, the Volt-VAr and Volt-Watt set points can be modified by the installer. The Volt-VAr requirements for Horizon Power are set in the inverter setting for the tests in this report.

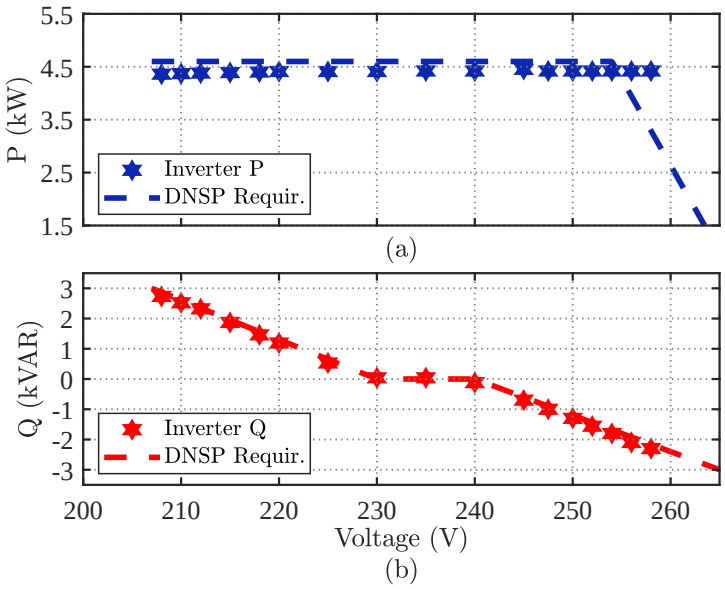

Figure 6: Inverter 5 - Steady-state Volt-VAr and Volt-Watt response.

1.2.5 Manufacturer J - Inverter 22 - Single-Phase - AS4777.2:2015

In the setting of this inverter, there is a parameter for setting the time of Volt-VAr response. The behavior of the inverter is tested with considering two different time values for this setting: **0 s (which is the default value) and 5 s**. The Volt-VAr and Volt-Watt settings are based on Western Australia (Horizon Power).

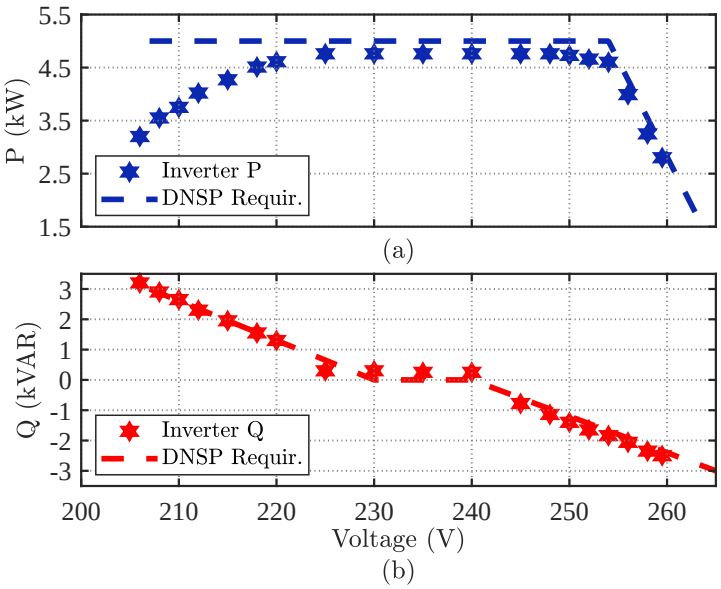

Figure 7: Inverter 22 - Steady-state Volt-VAr and Volt-Watt response.

1.2.6 Manufacturer K - Inverter 23 - Single-Phase - AS4777.2:2015

This inverter initially had an old firmware, in which Volt-VAr was not enabled. The Volt-VAr and Volt-Watt response of the inverter for the old firmware are shown in the following figure. The firmware is then updated to the latest version, in which Volt-VAr and Volt-Watt setting are enables based on the DNSP requirements. The stead-state response for AU Horizon and Western Australia DNSPs are shown in the following figures.

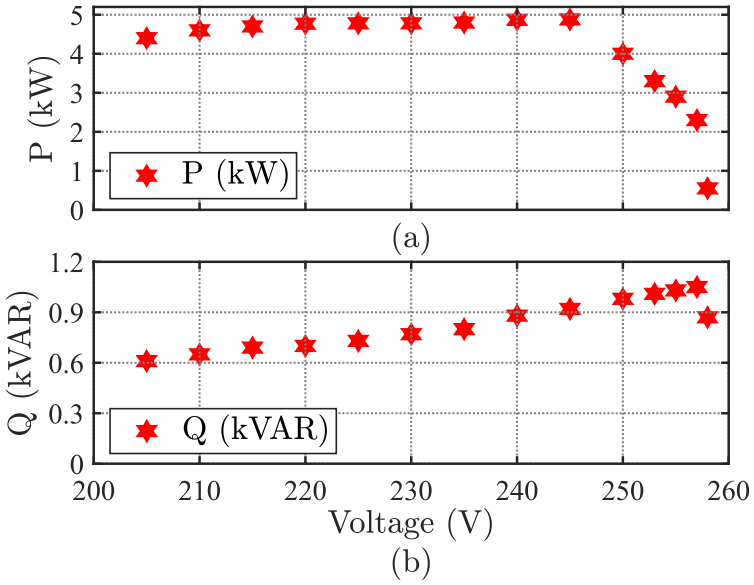

Figure 8: Inverter 23 - Steady-state Volt-VAr and Volt-Watt response for OLD FIRMWARE, in which Volt-VAr response is not available.

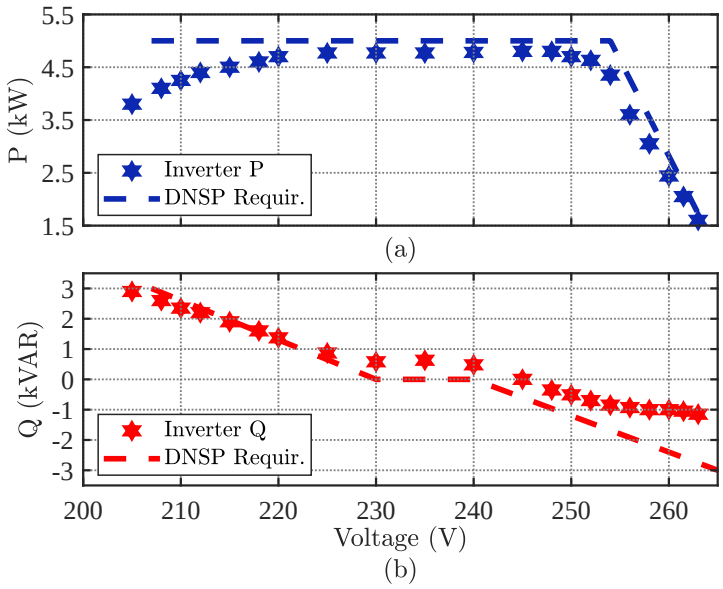

Figure 9: Inverter 23 - Steady-state Volt-VAr and Volt-Watt response for new firmware based on AU Horizon requirements.

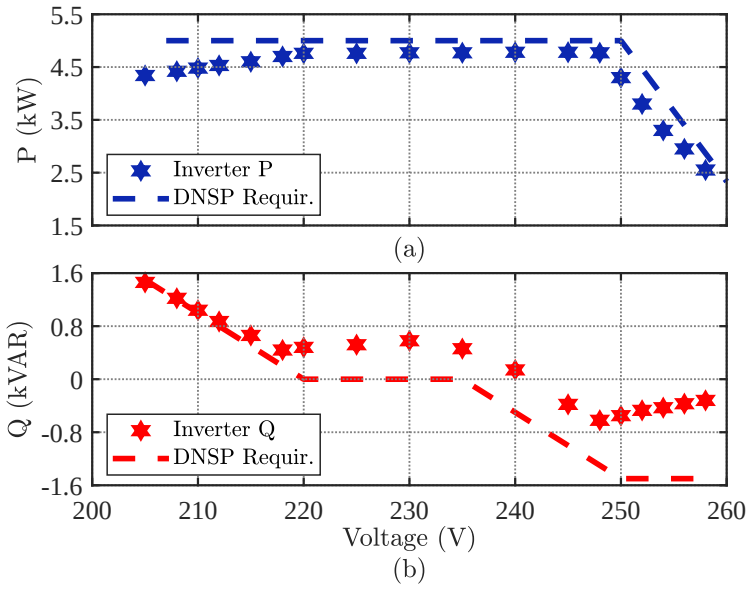

Figure 10: Inverter 23 - Steady-state Volt-VAr and Volt-Watt response for new firmware based on Western Power requirements.

1.2.7 Manufacturer L - Inverter 28 - Single-Phase - AS4777.2:2015

This inverter does not have any time setting parameter. Accordingly, the results are only taken with the default parameters of the inverter.

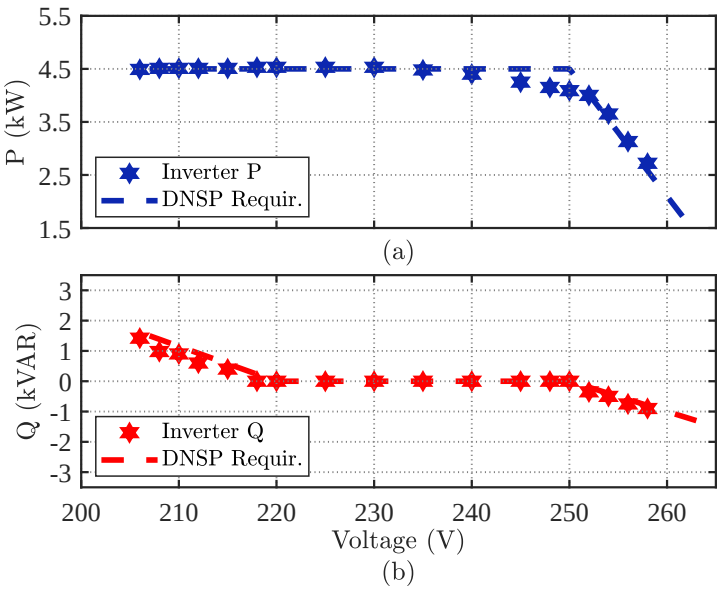

Figure 11: Inverter 28 - Steady-state Volt-VAr and Volt-Watt response.

2 Dynamic Volt-VAr Response

2.1 Three-Phase Inverters

2.1.1 Manufacturer A - Inverter 302 - Three-Phase - AS4777.2:2015

In the setting of this inverter, there is a parameter for setting the time of Volt-VAr response. The behavior of the inverter is tested with considering two different time values for this setting: **0.01 s (which is the minimum value that can be used for this setting) and 5 s**.

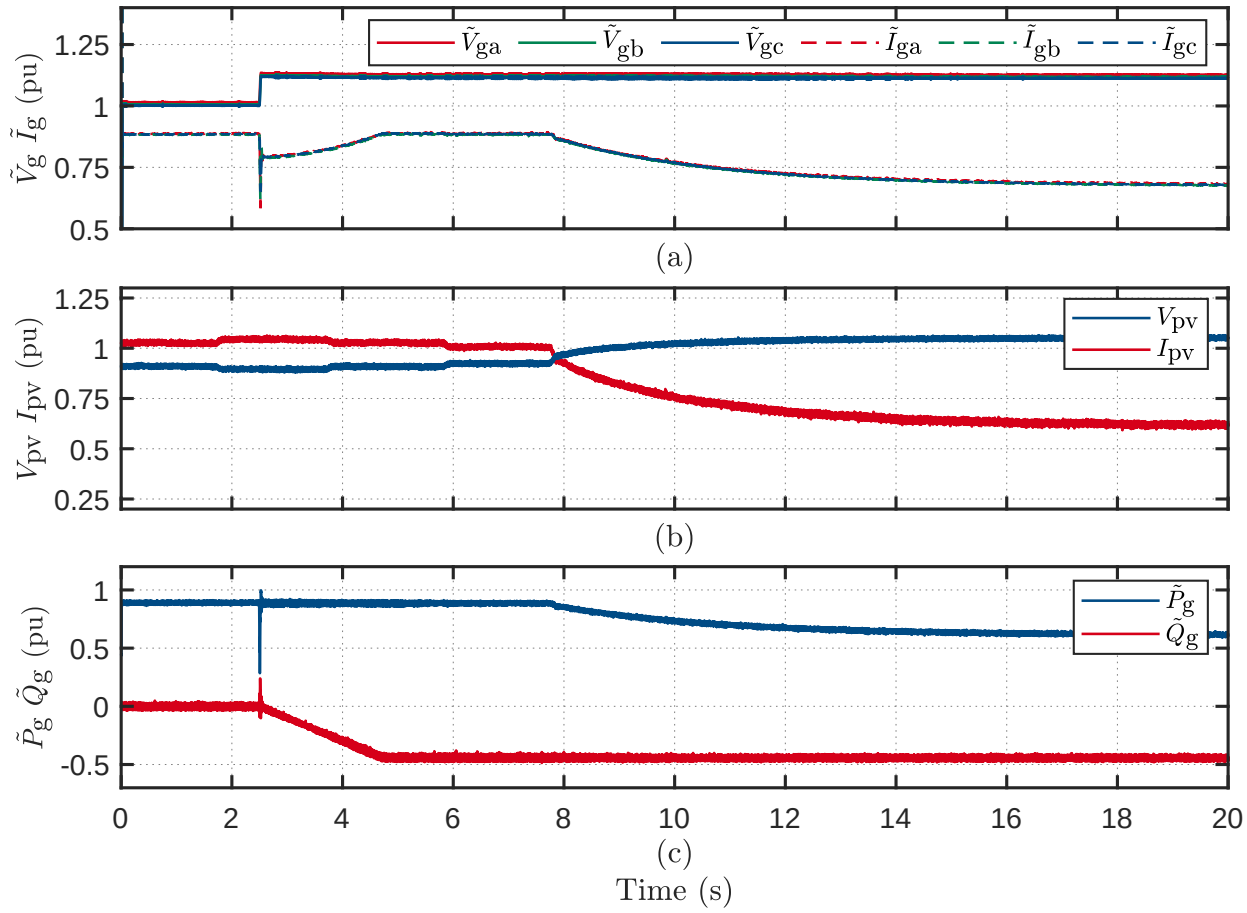

Figure 12: Inverter 302 - Volt-VAr response under step variation of grid voltage from 1 pu to 1.12 pu, with time setting set to 0.01 s.

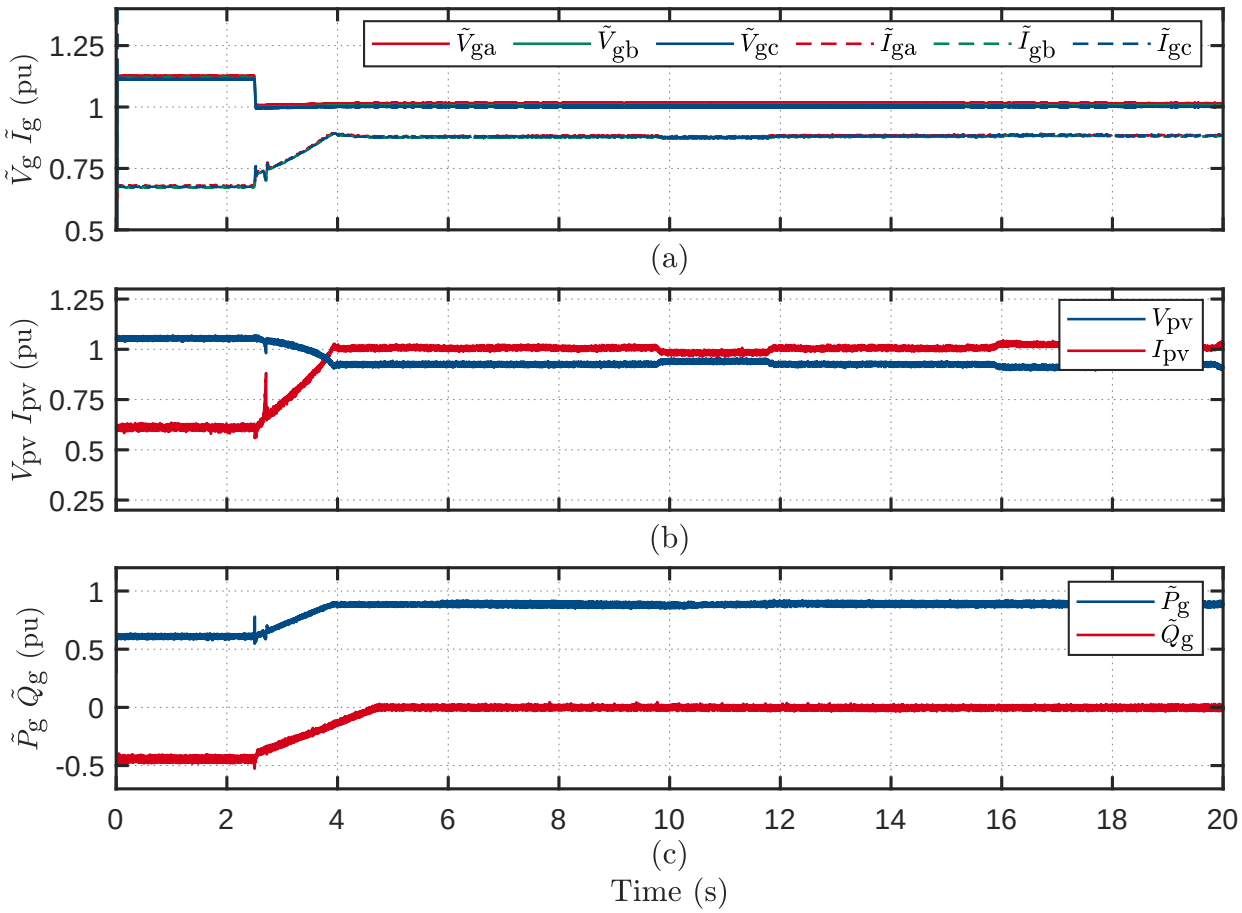

Figure 13: Inverter 302 - Volt-VAr response under step variation of grid voltage from 1.12 pu to 1 pu (recovery), with time setting set to 0.01 s.

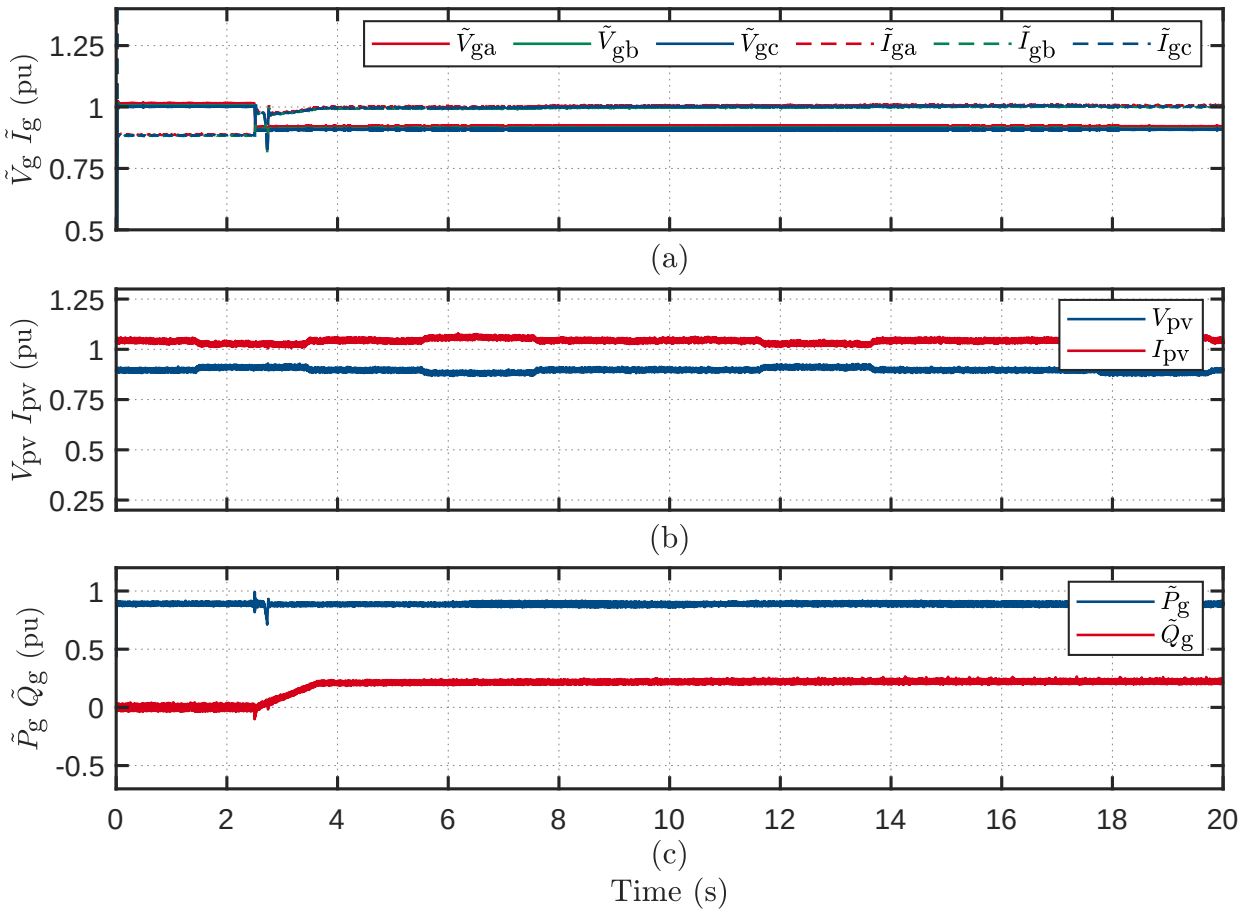

Figure 14: Inverter 302 - Volt-VAr response under step variation of grid voltage from 1 pu to 0.9 pu, with time setting set to 0.01 s.

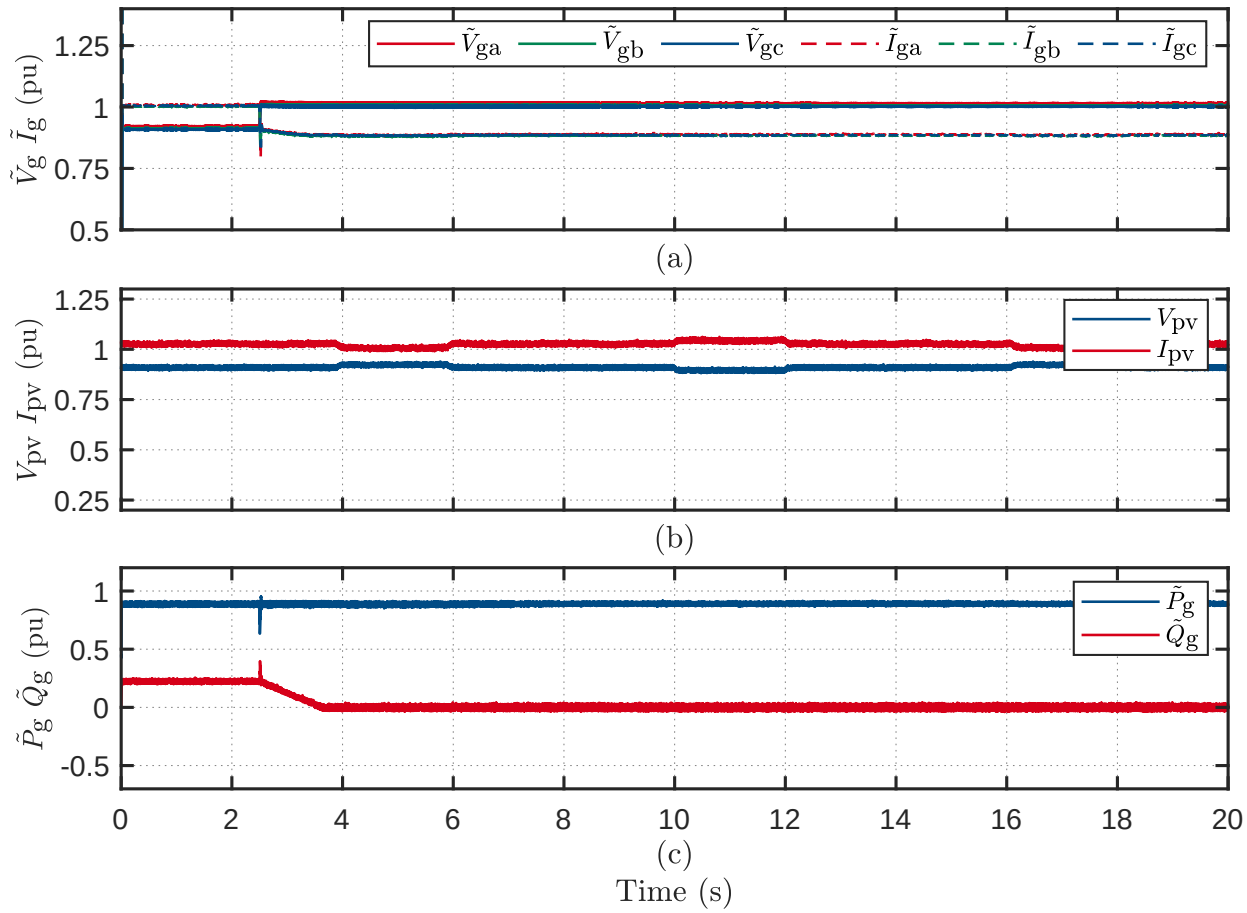

Figure 15: Inverter 302 - Volt-VAr response under step variation of grid voltage from 0.9 pu to 1 pu (recovery), with time setting set to 0.01 s.

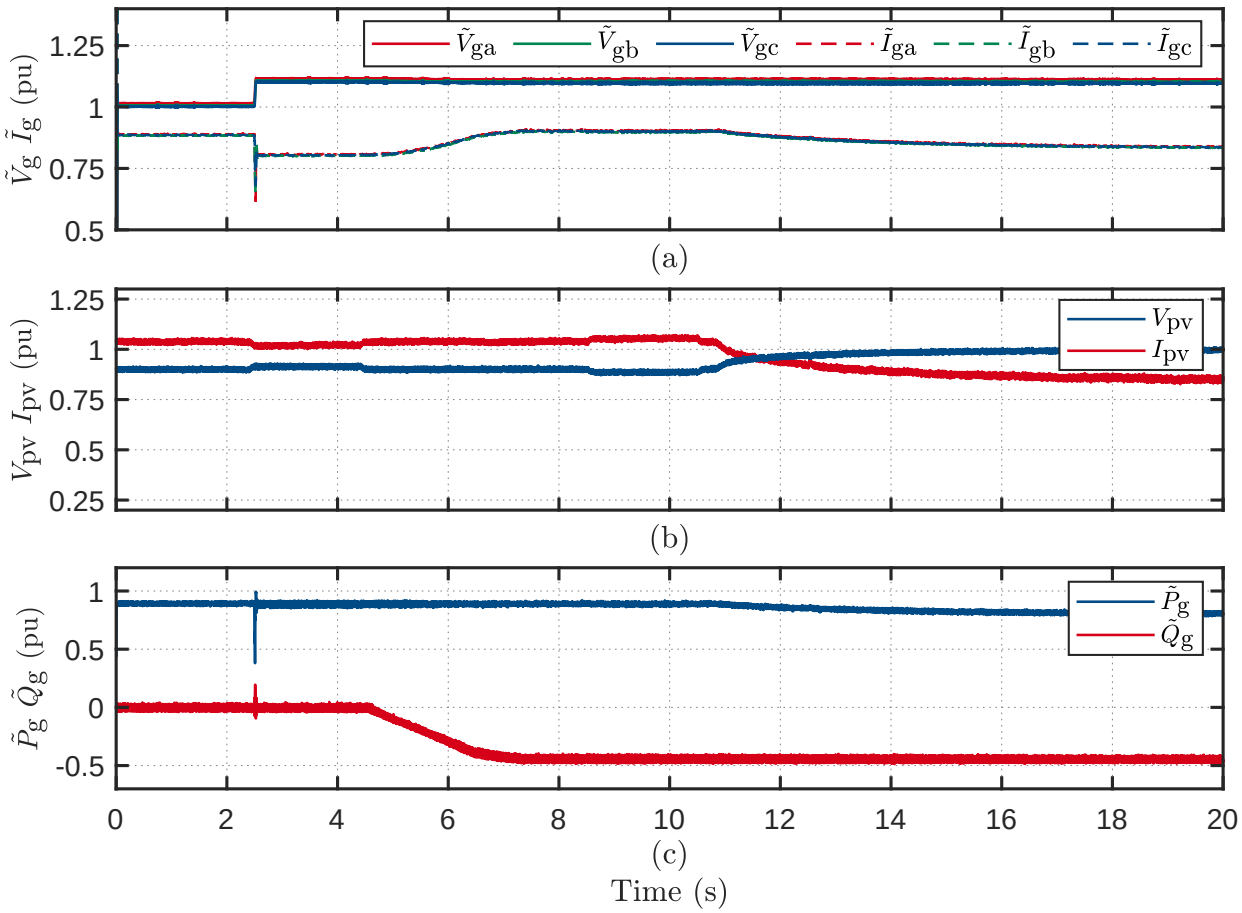

Figure 16: Inverter 302 - Volt-VAr response under step variation of grid voltage from 1 pu to 1.12 pu, with time setting set to 5 s.

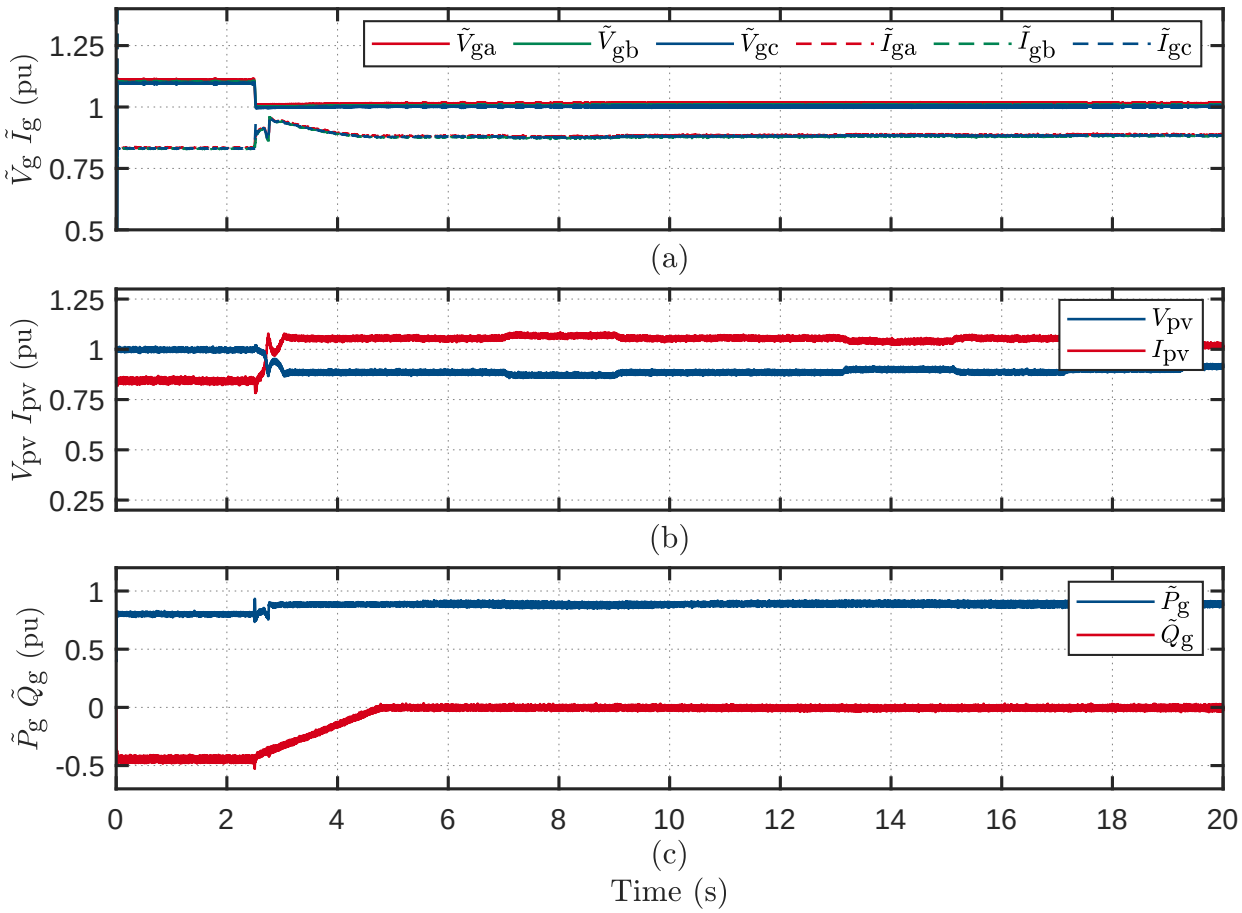

Figure 17: Inverter 302 - Volt-VAr response under step variation of grid voltage from 1.12 pu to 1 pu (recovery), with time setting set to 5 s.

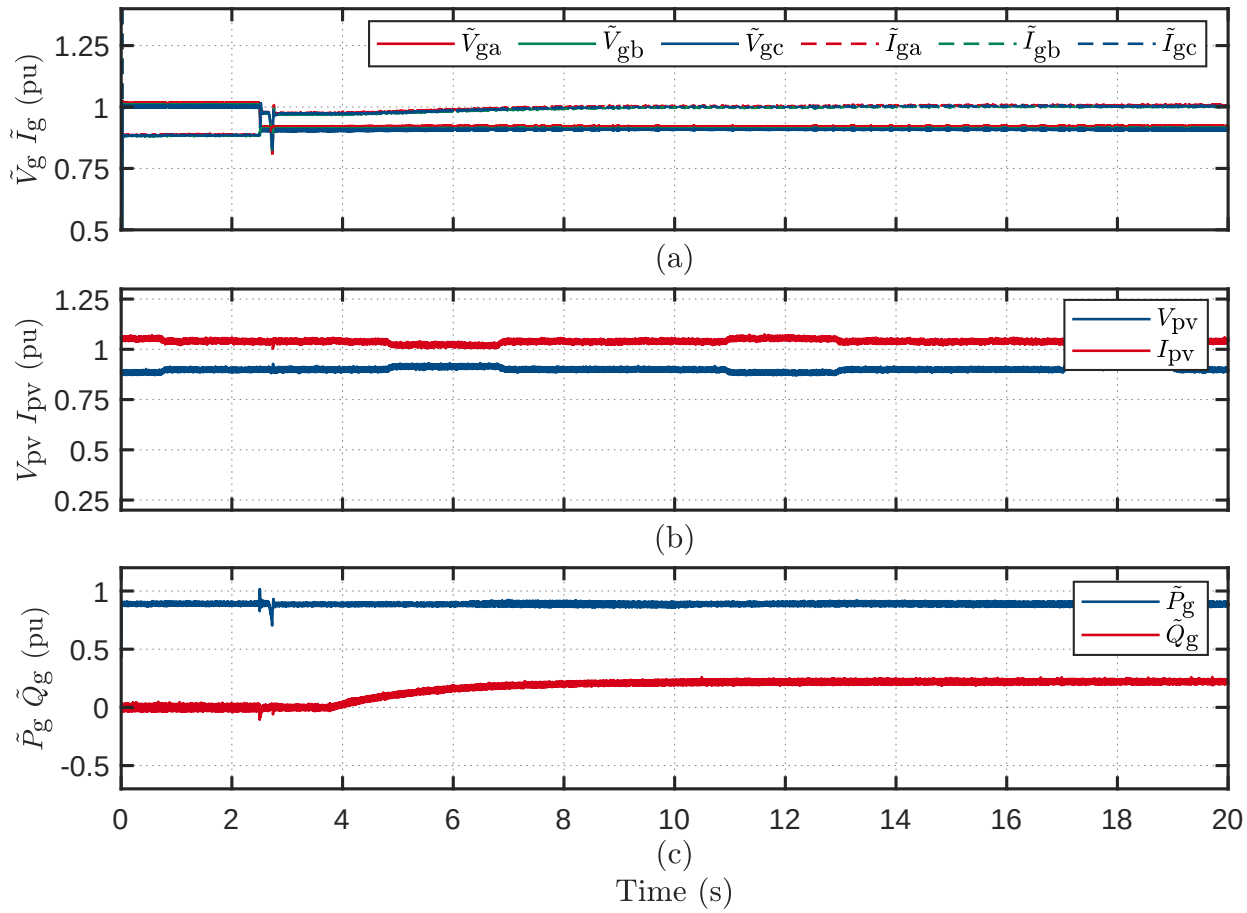

Figure 18: Inverter 302 - Volt-VAr response under step variation of grid voltage from 1 pu to 0.9 pu, with time setting set to 5 s.

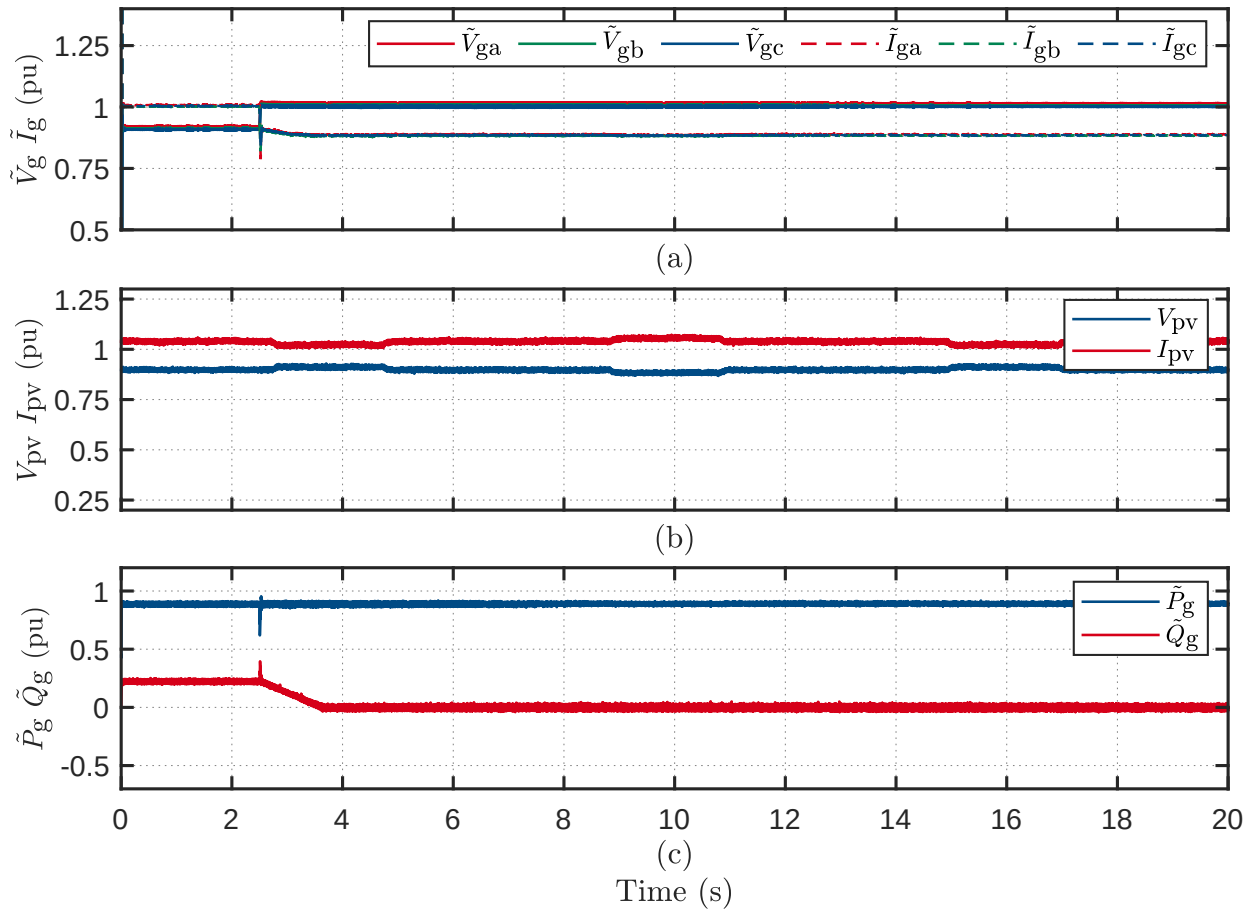

Figure 19: Inverter 302 - Volt-VAr response under step variation of grid voltage from 0.9 pu to 1 pu (recovery), with time setting set to 5 s.

2.1.2 Manufacturer B - Inverter 301 - Three-Phase - AS4777.2:2015

In the setting of this inverter, there is a parameter for setting the time of Volt-VAr response. The behavior of the inverter is tested with considering two different time values for this setting: **0.01 s (which is the minimum value that can be used for this setting) and 5 s**.

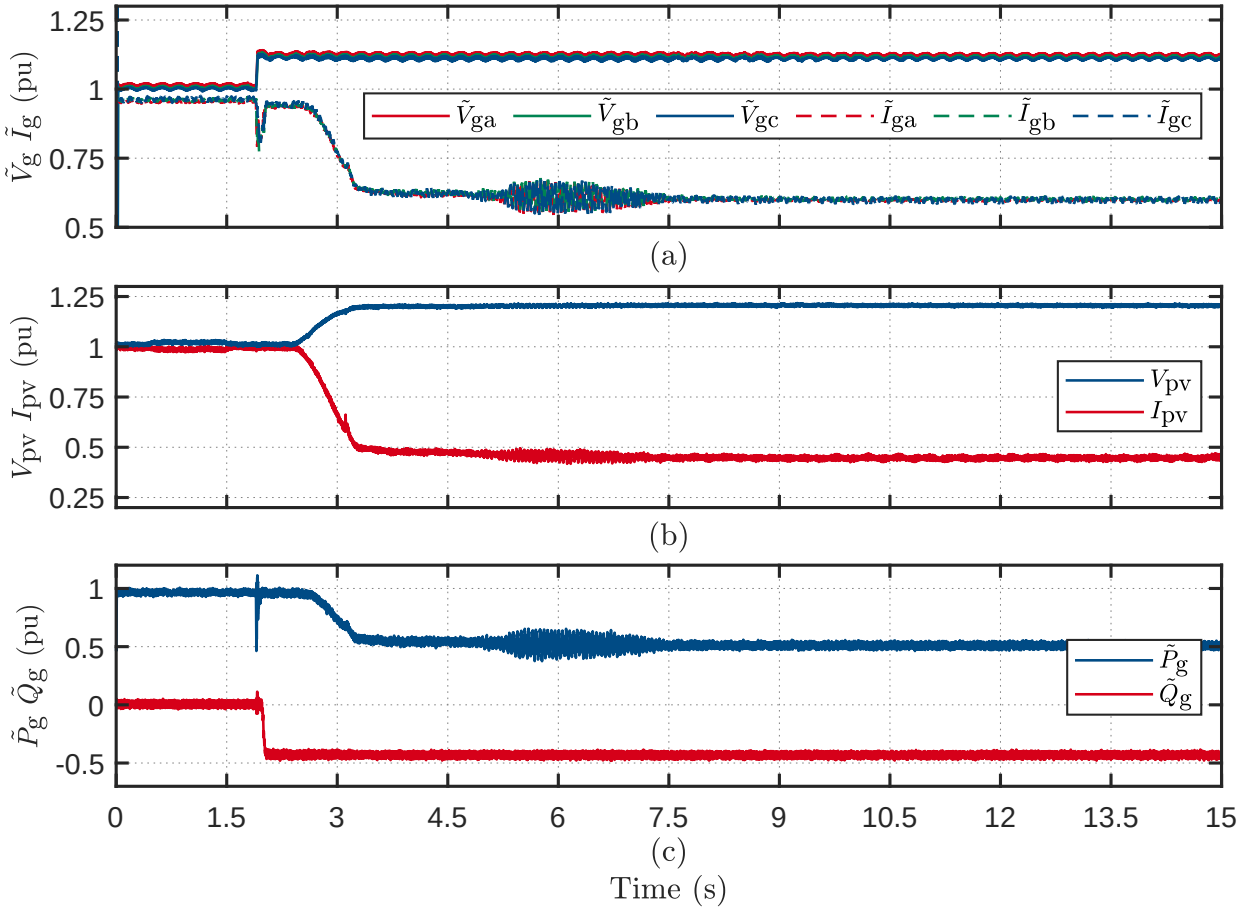

Figure 20: Inverter 301 - Volt-VAr response under step variation of grid voltage from 1 pu to 1.12 pu, with time setting set to 0.01 s.

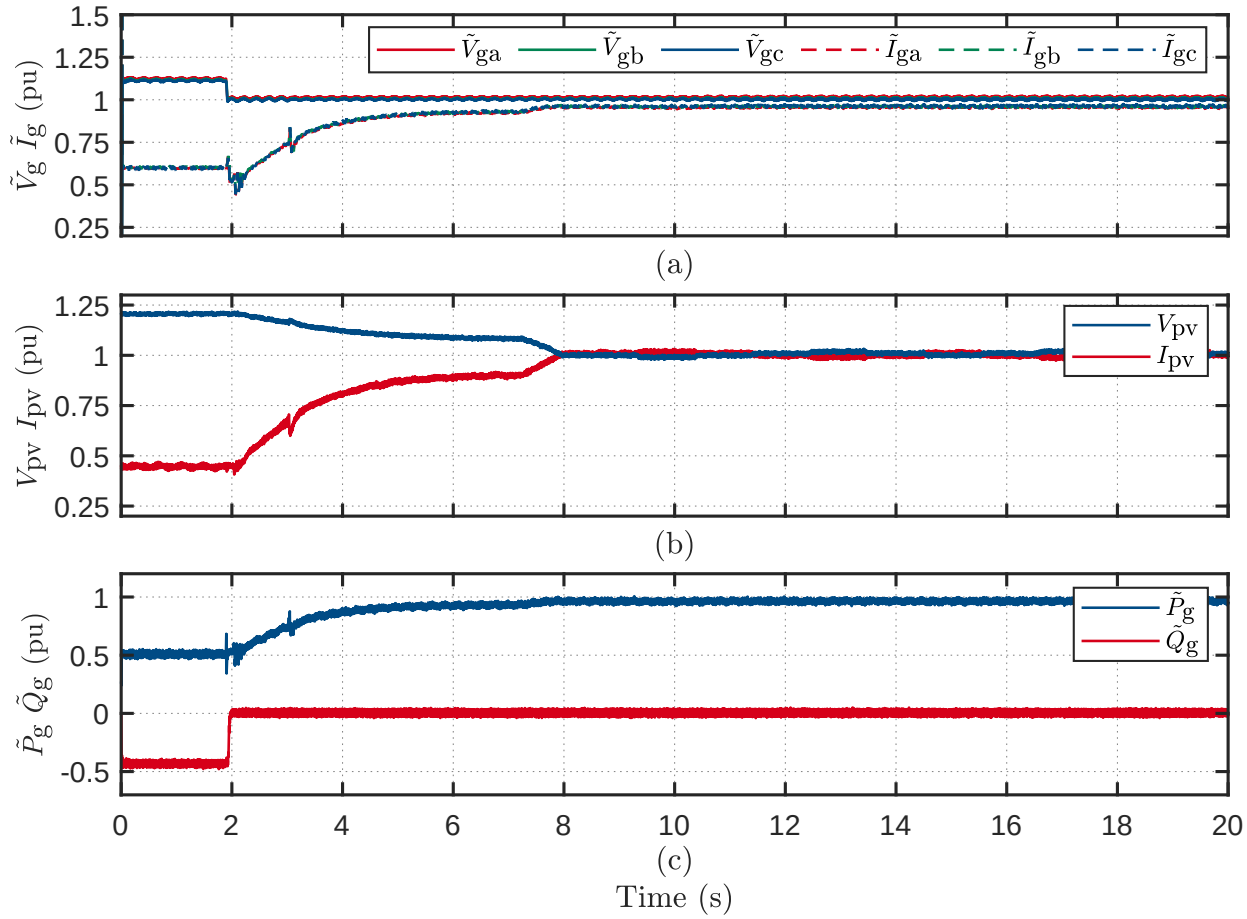

Figure 21: Inverter 301 - Volt-VAr response under step variation of grid voltage from 1.12 pu to 1 pu (recovery), with time setting set to 0.01 s.

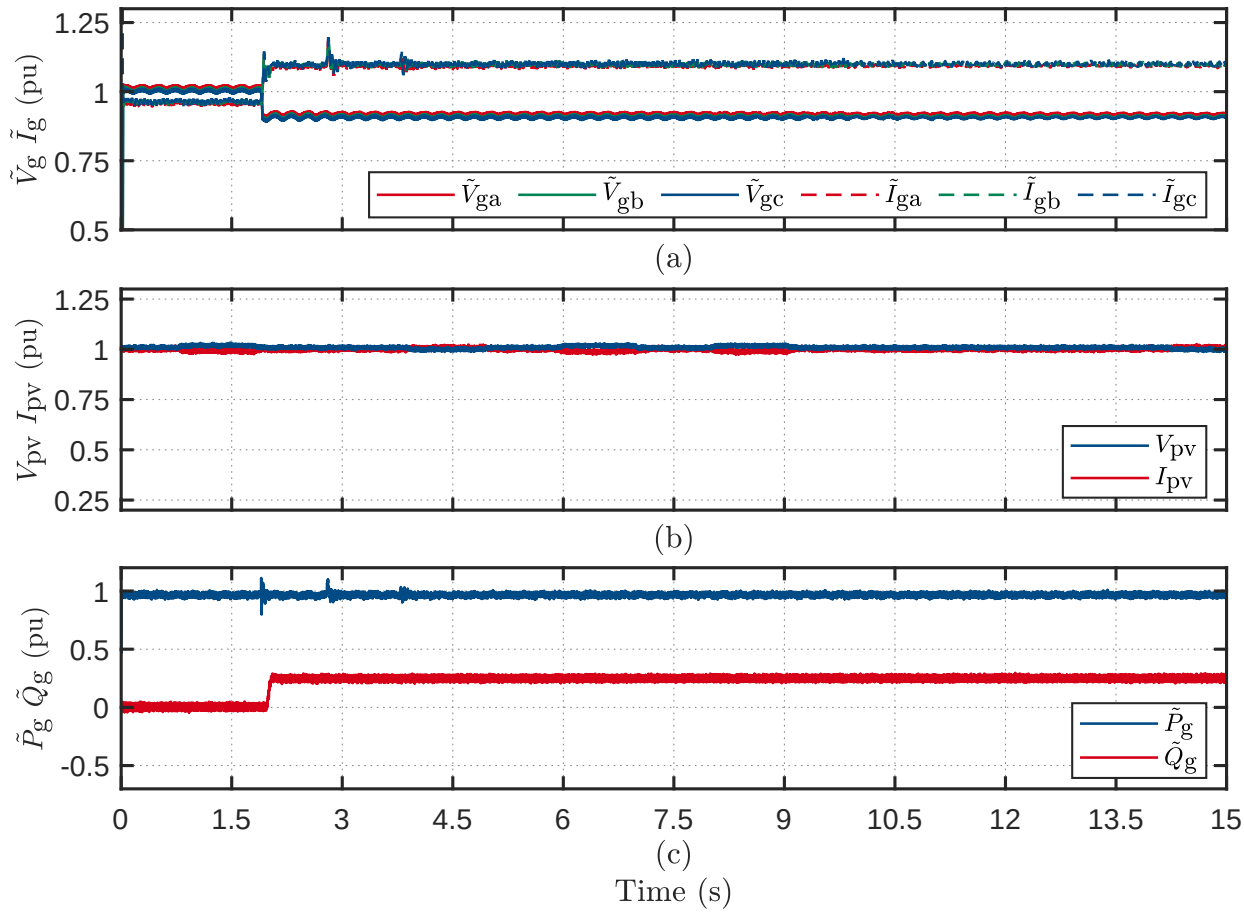

Figure 22: Inverter 301 - Volt-VAr response under step variation of grid voltage from 1 pu to 0.9 pu, with time setting set to 0.01 s.

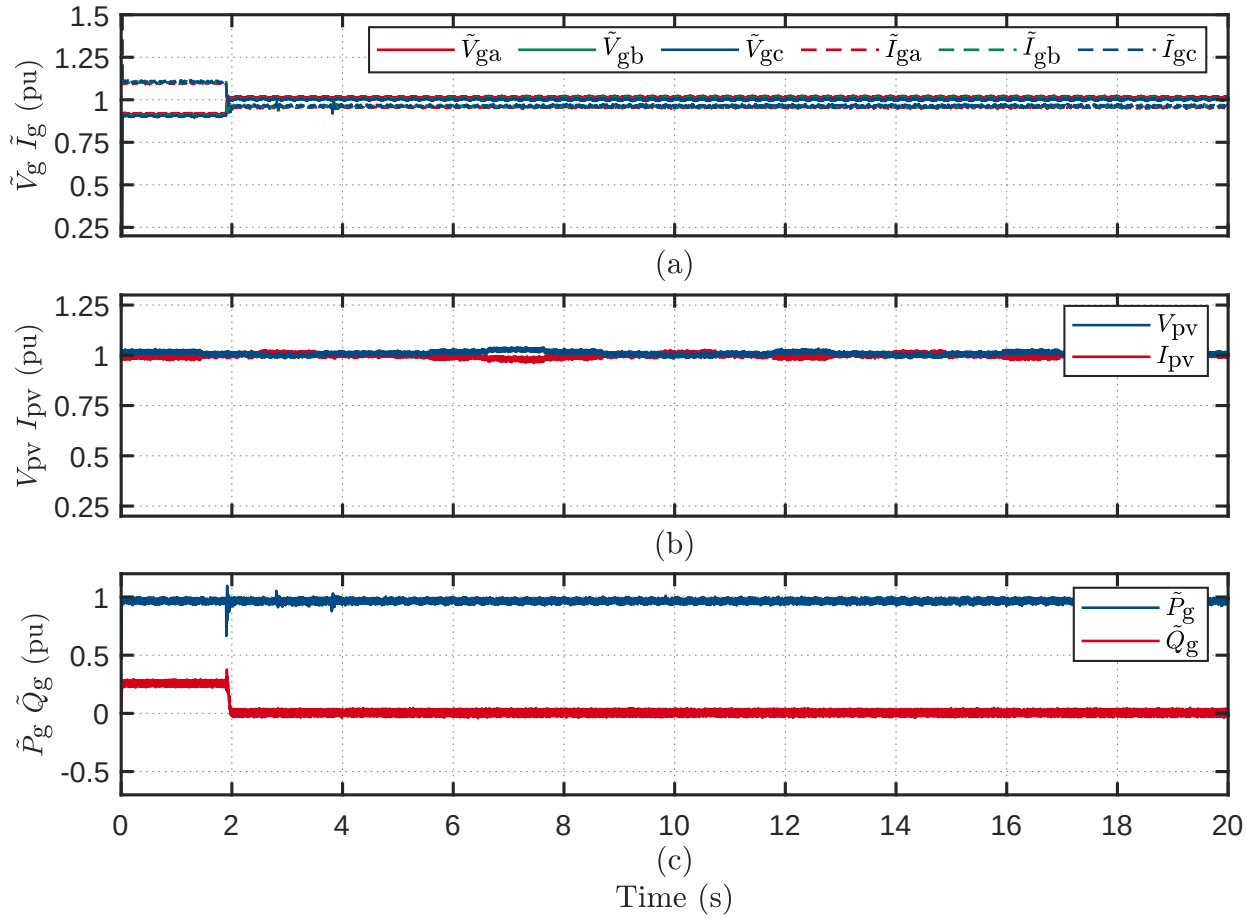

Figure 23: Inverter 301 - Volt-VAr response under step variation of grid voltage from 0.9 pu to 1 pu (recovery), with time setting set to 0.01 s.

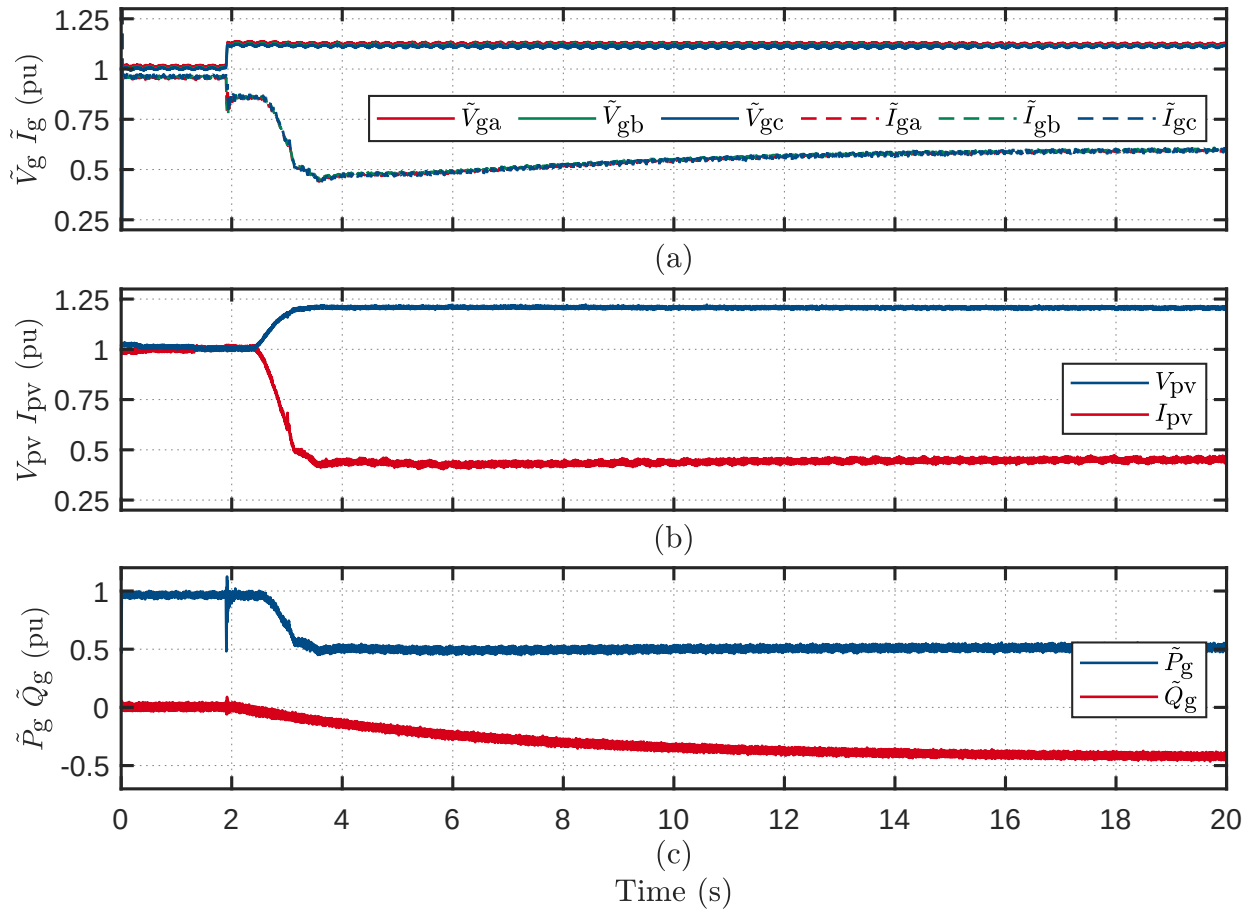

Figure 24: Inverter 301 - Volt-VAr response under step variation of grid voltage from 1 pu to 1.12 pu, with time setting set to 5 s.

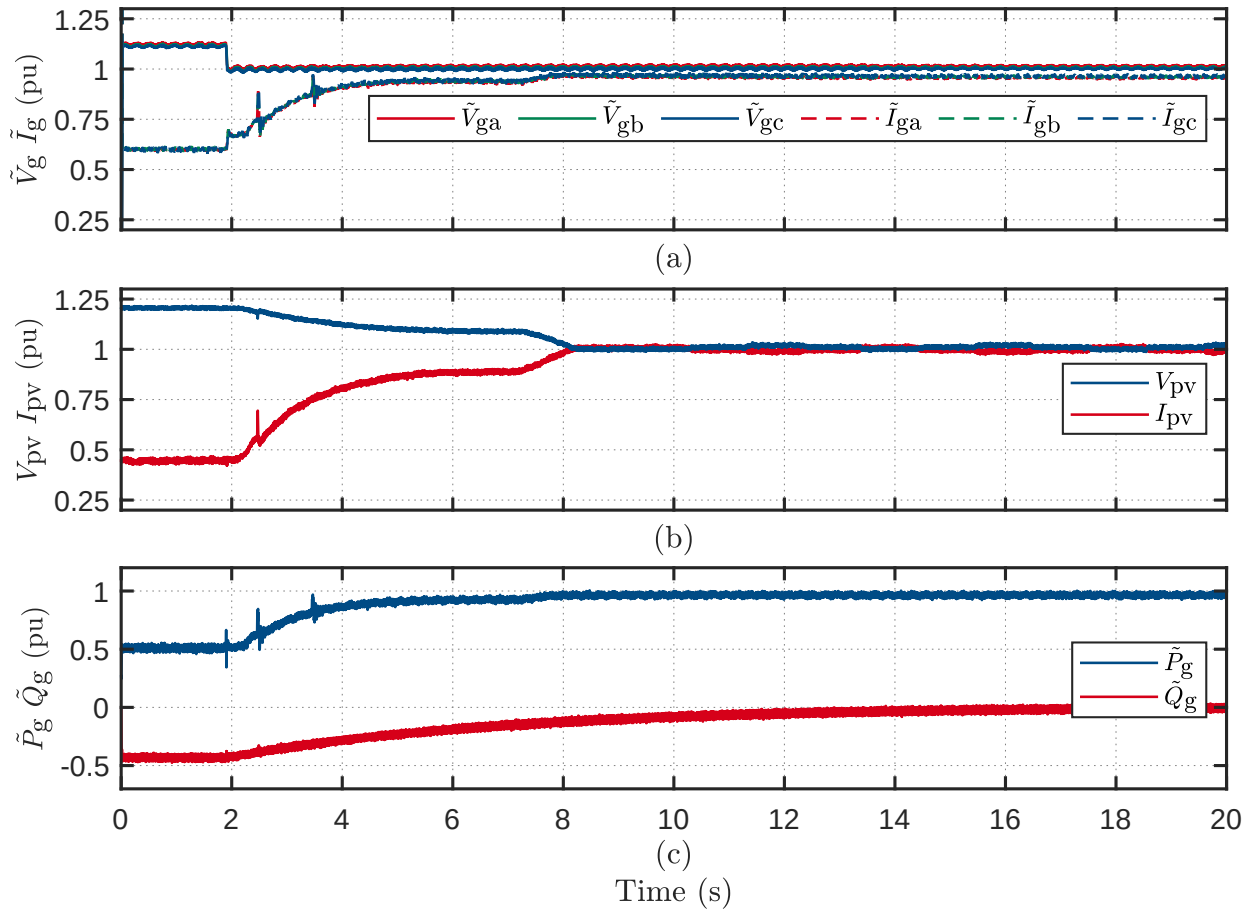

Figure 25: Inverter 301 - Volt-VAr response under step variation of grid voltage from 1.12 pu to 1 pu (recovery), with time setting set to 5 s.

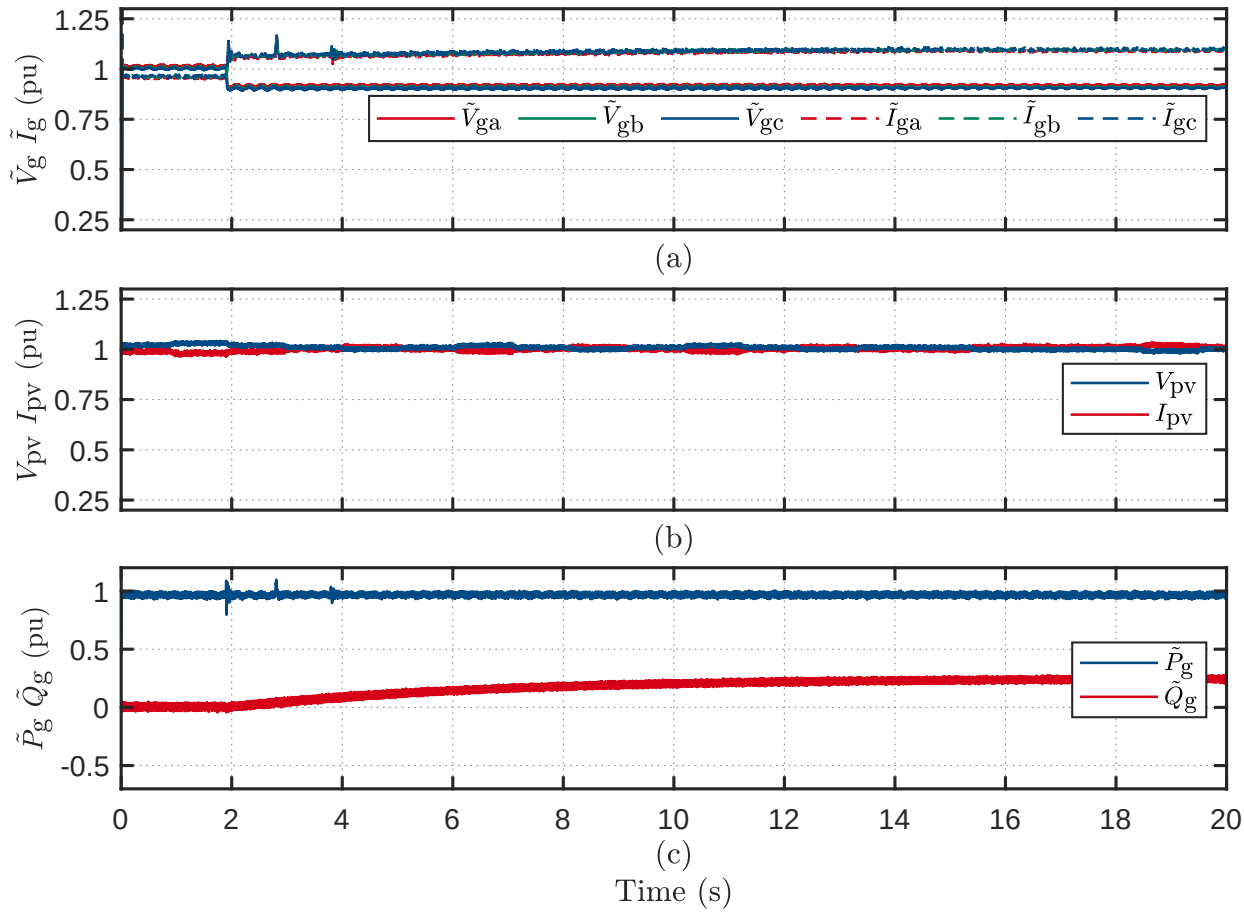

Figure 26: Inverter 301 - Volt-VAr response under step variation of grid voltage from 1 pu to 0.9 pu, with time setting set to 5 s.

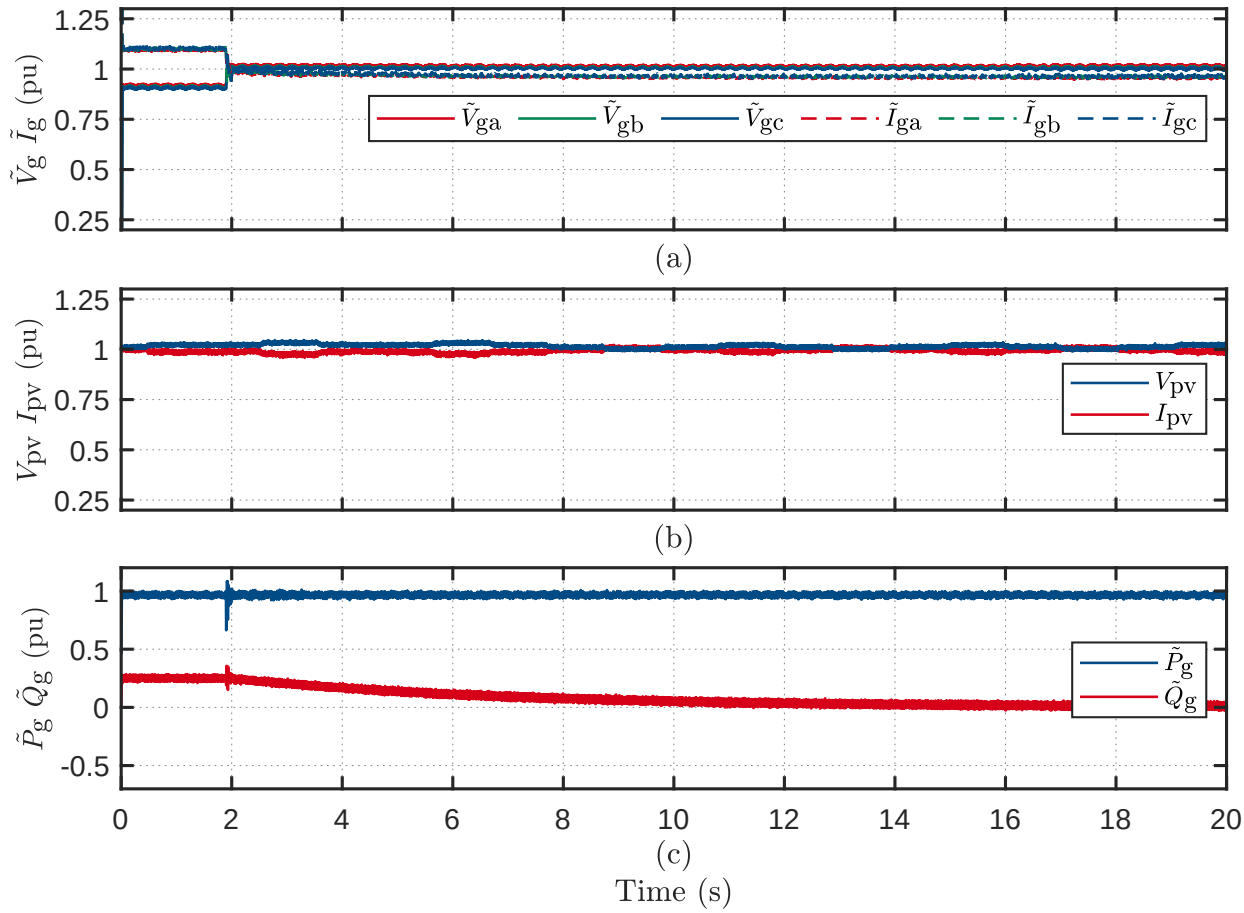

Figure 27: Inverter 301 - Volt-VAr response under step variation of grid voltage from 0.9 pu to 1 pu (recovery), with time setting set to 5 s.

2.2 Single-Phase Inverters

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

In the setting of this inverter, there is a parameter for setting the time of Volt-VAr response. The behavior of the inverter is tested with considering two different time values for this setting: **0.01 s (which is the minimum value that can be used for this setting) and 5 s**.

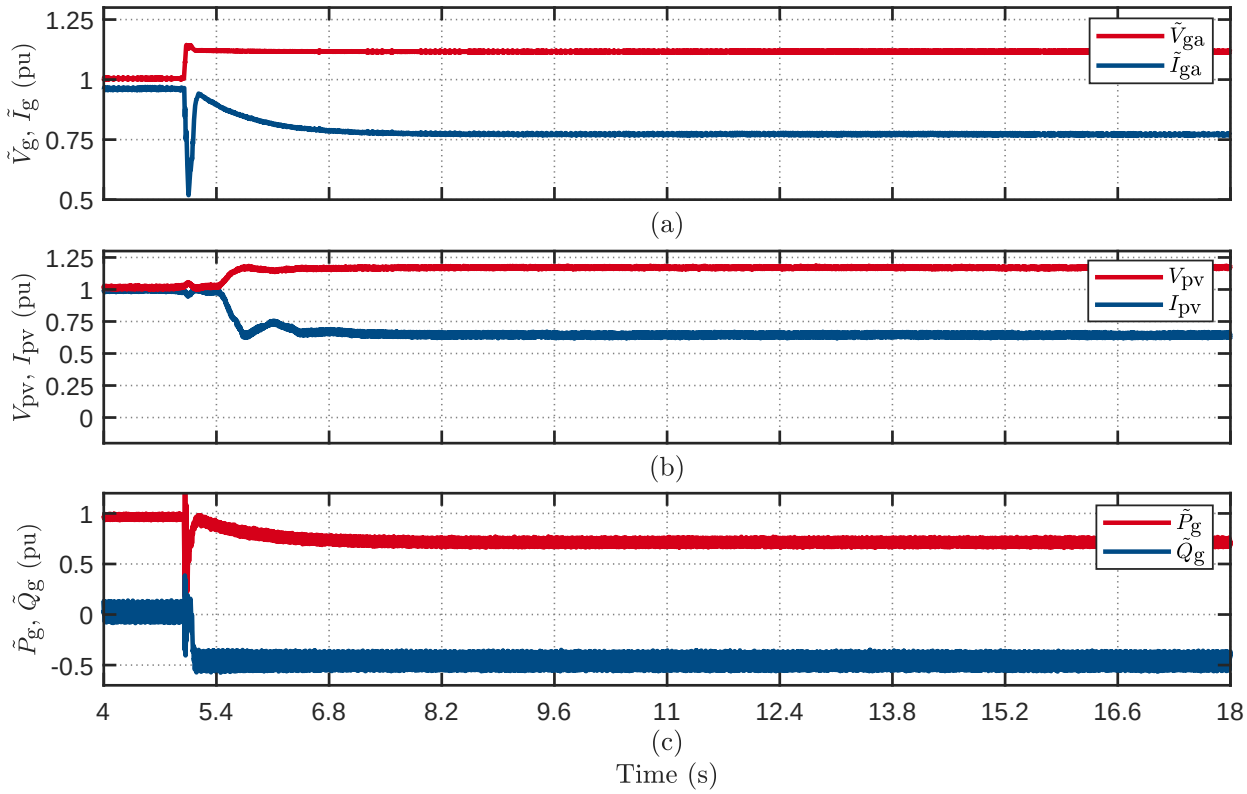

Figure 28: Inverter 25 - Volt-VAr response under step variation of grid voltage from 1 pu to 1.12 pu, with time setting set to 0.01 s.

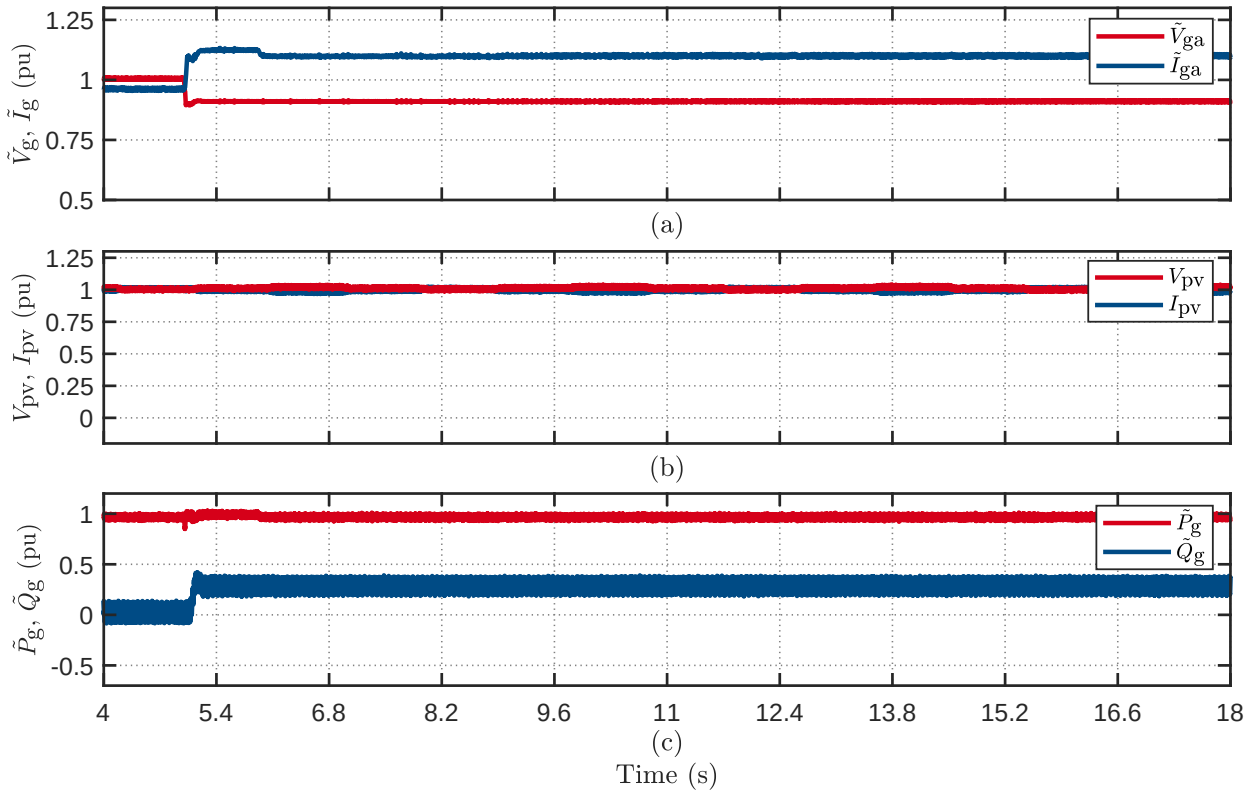

Figure 29: Inverter 25 - Volt-VAr response under step variation of grid voltage from 1 pu to 0.9 pu, with time setting set to 0.01 s.

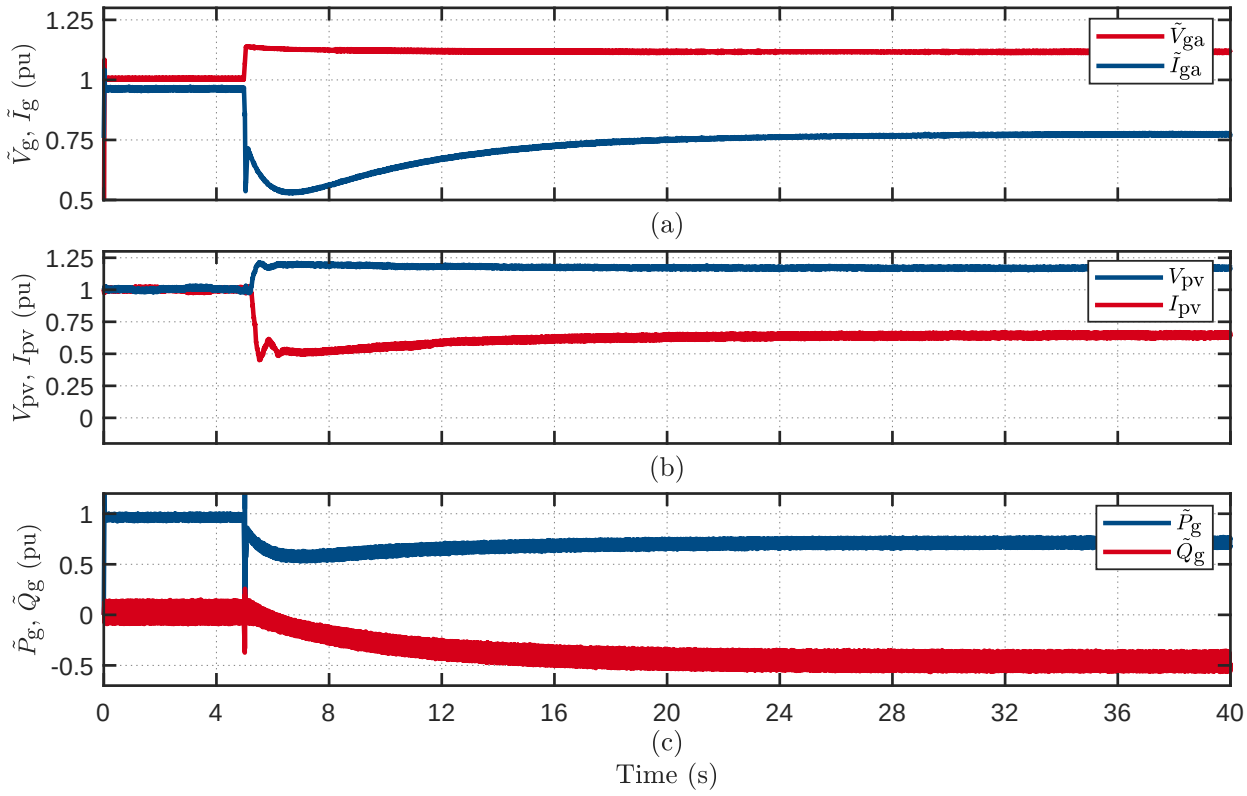

Figure 30: Inverter 25 - Volt-VAr response under step variation of grid voltage from 1 pu to 1.12 pu, with time setting set to 5 s.

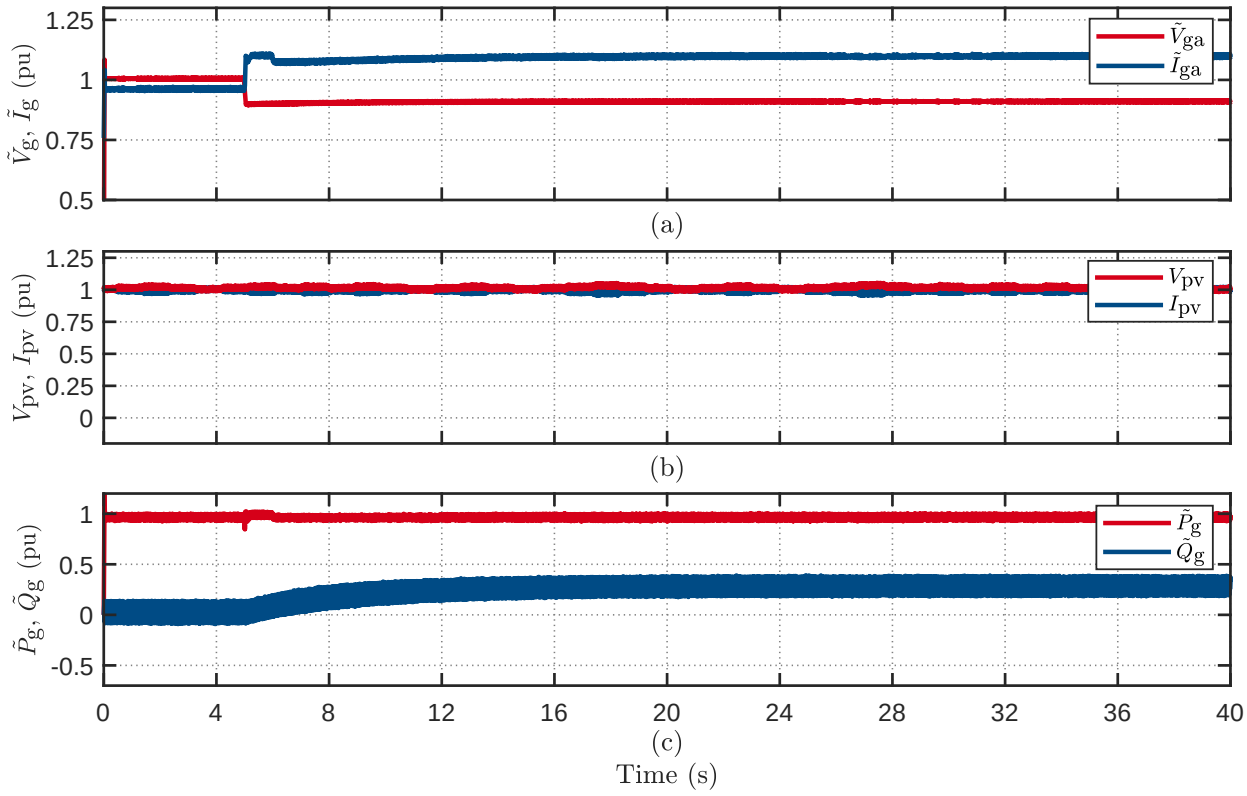

Figure 31: Inverter 25 - Volt-VAr response under step variation of grid voltage from 1 pu to 0.9 pu, with time setting set to 5 s.

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

This inverter does not have any time setting parameter. Accordingly, the results are only taken with the default parameters of the inverter. Only, the Volt-VAr and Volt-Watt set points can be modified by the installer. The Volt-VAr requirements for Horizon Power are set in the inverter setting for the tests in this report.

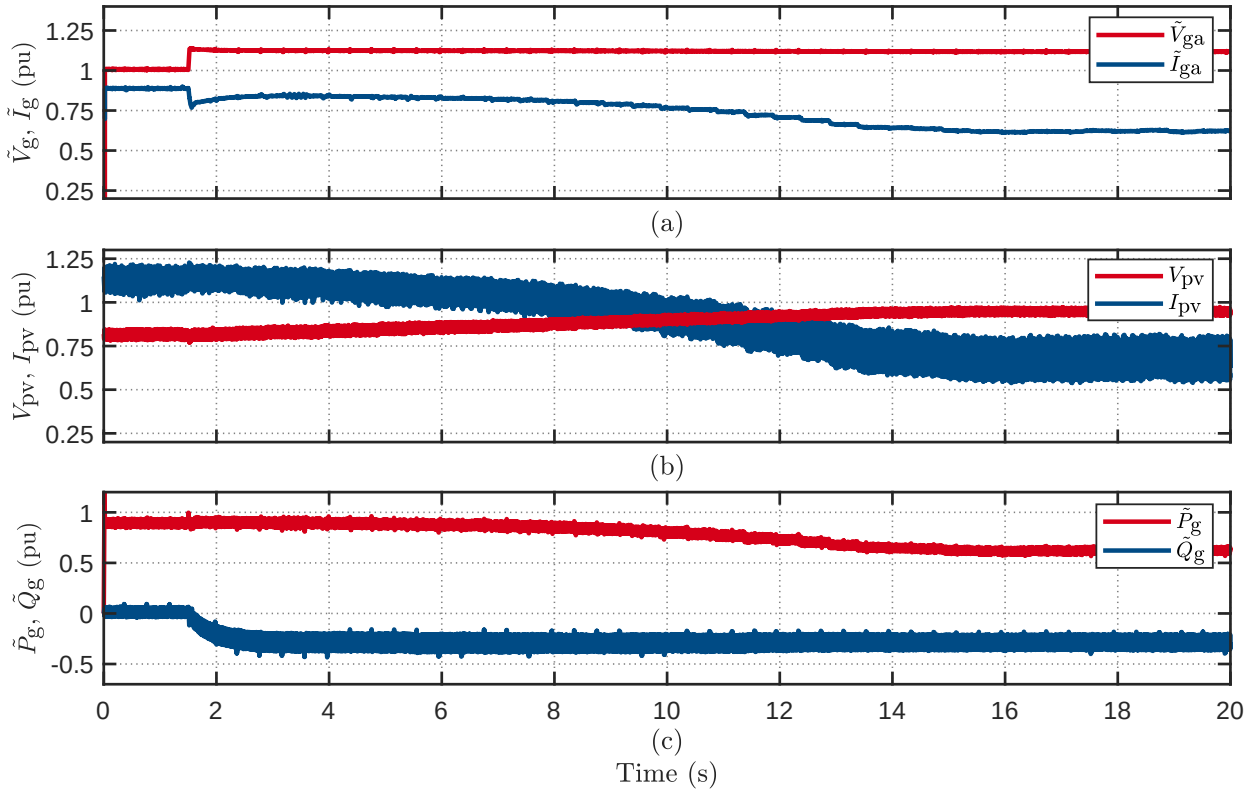

Figure 32: Inverter 13 - Volt-VAr response under step variation of grid voltage from 1 pu to 1.12 pu.

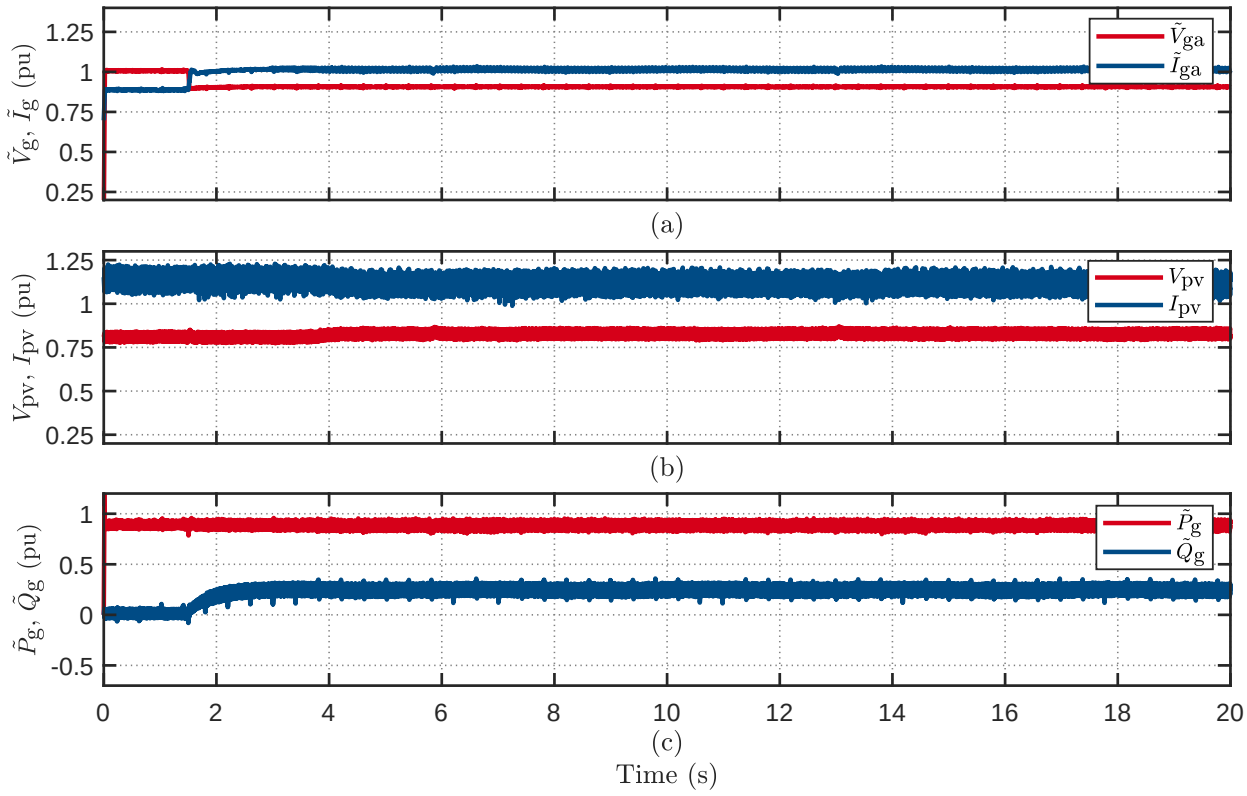

Figure 33: Inverter 13 - Volt-VAr response under step variation of grid voltage from 1 pu to 0.9 pu.

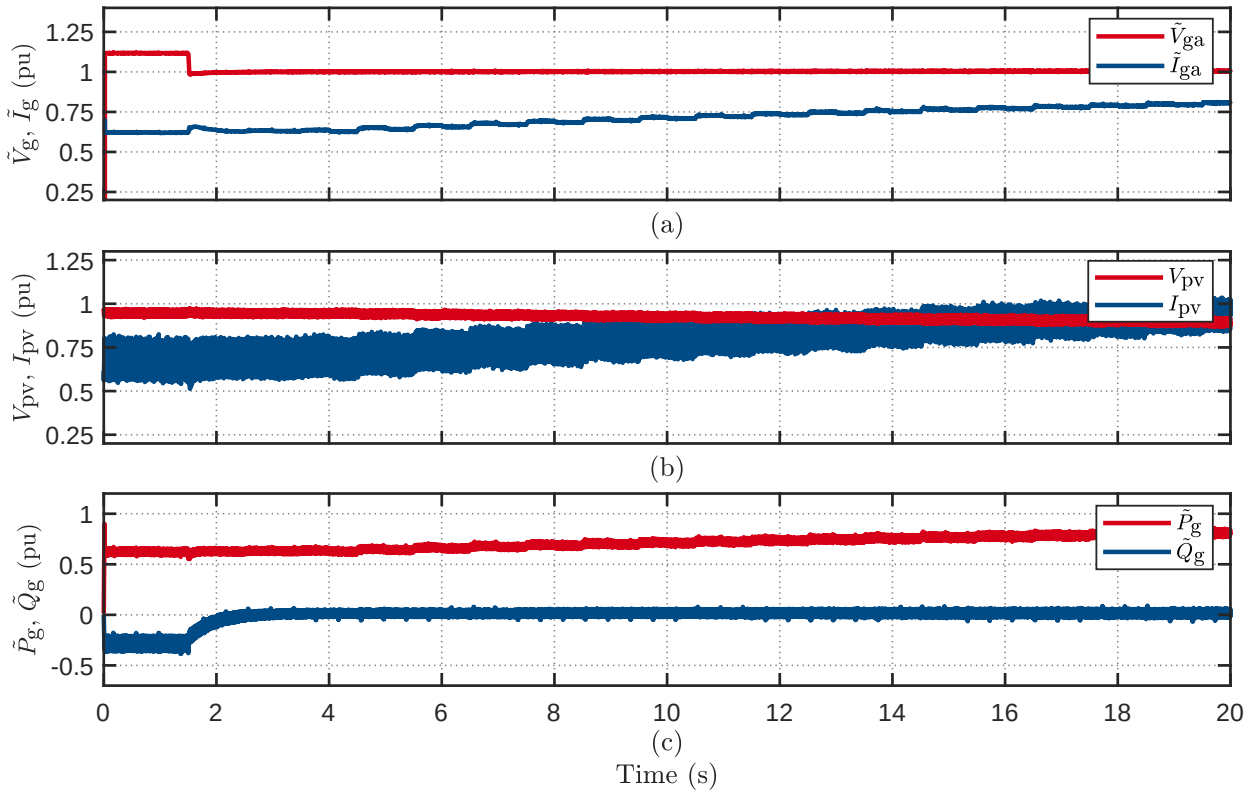

Figure 34: Inverter 13 - Volt-VAr response under step variation of grid voltage from 1.12 pu to 1 pu (recovery).

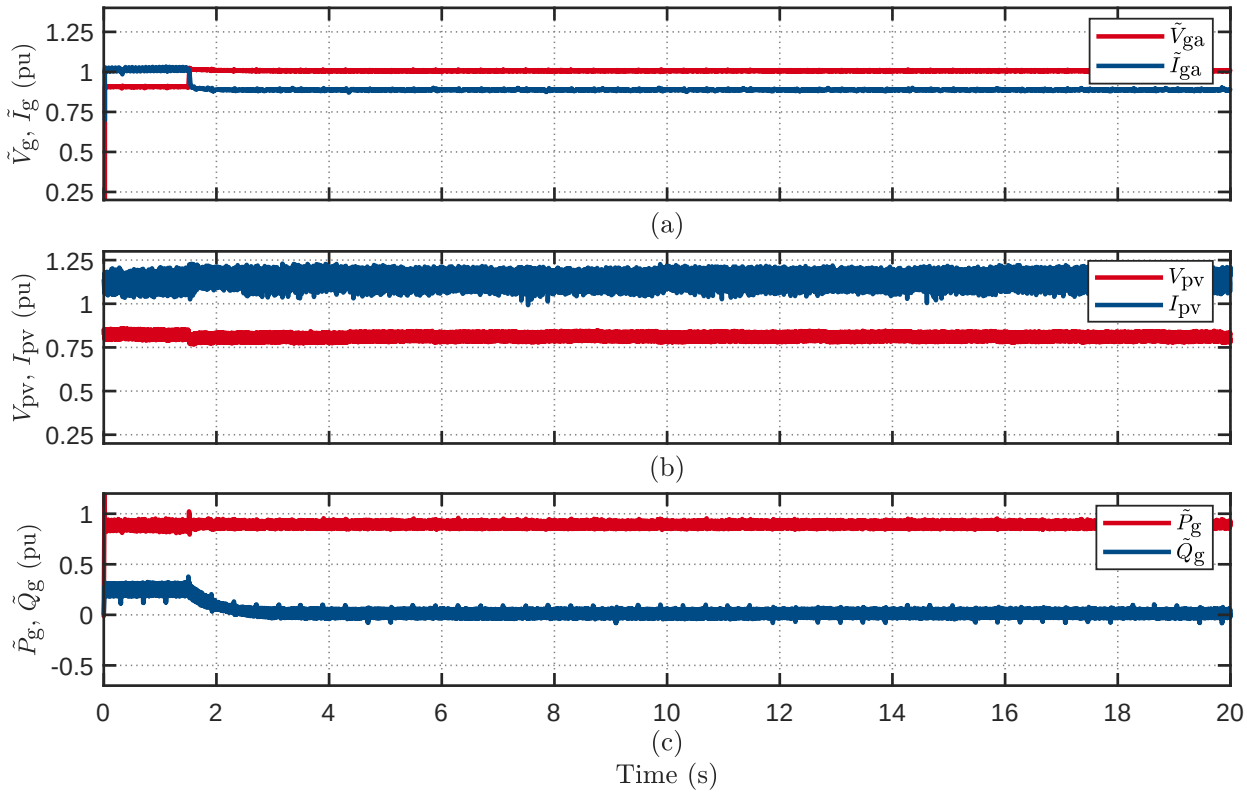

Figure 35: Inverter 13 - Volt-VAr response under step variation of grid voltage from 0.9 pu to 1 pu (recover).

2.2.3 Manufacturer D - Inverter 29 - Single-Phase - AS4777.2:2015

There is no “Volt-VAr response time parameter” in the setting of this inverter. Only, the country/area can be selected in the installer. Horizon Power is set as the country/region in the inverter setting for the tests in this report.

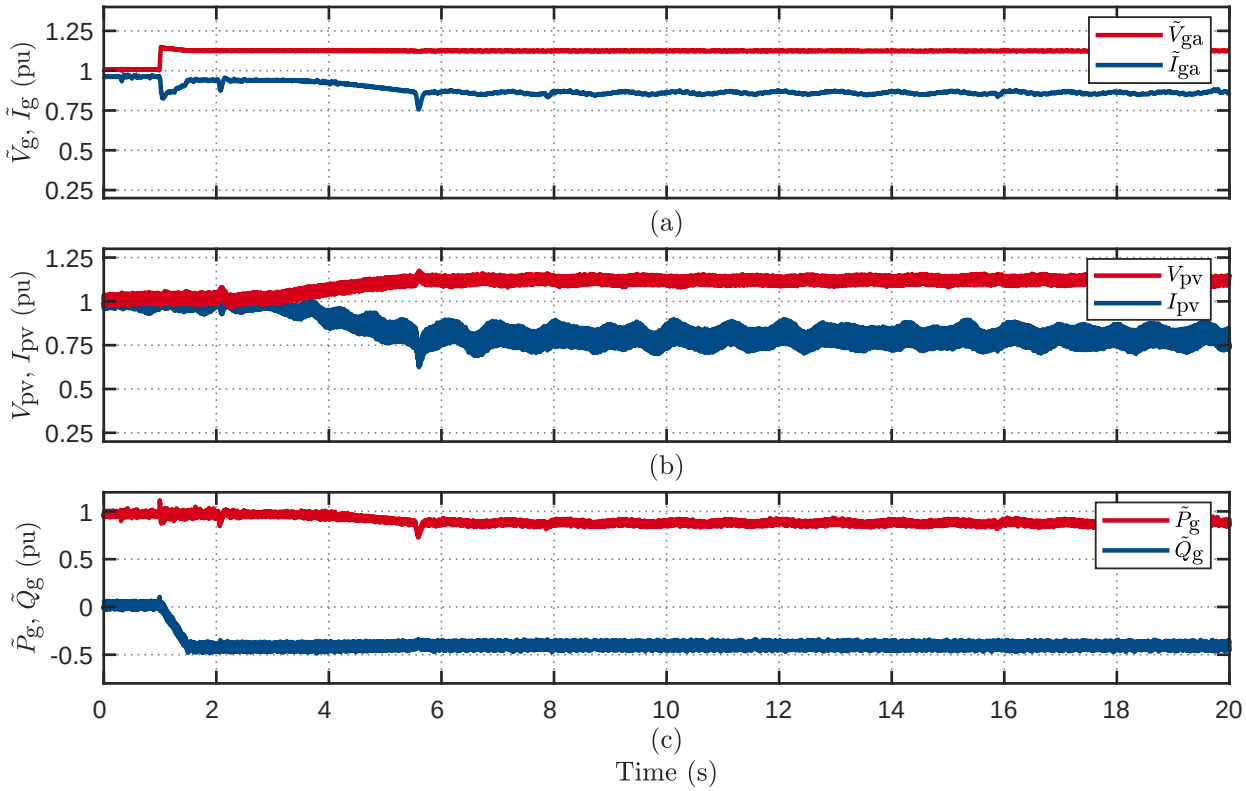

Figure 36: Inverter 29 - Volt-VAr response under step variation of grid voltage from 1 pu to 1.12 pu.

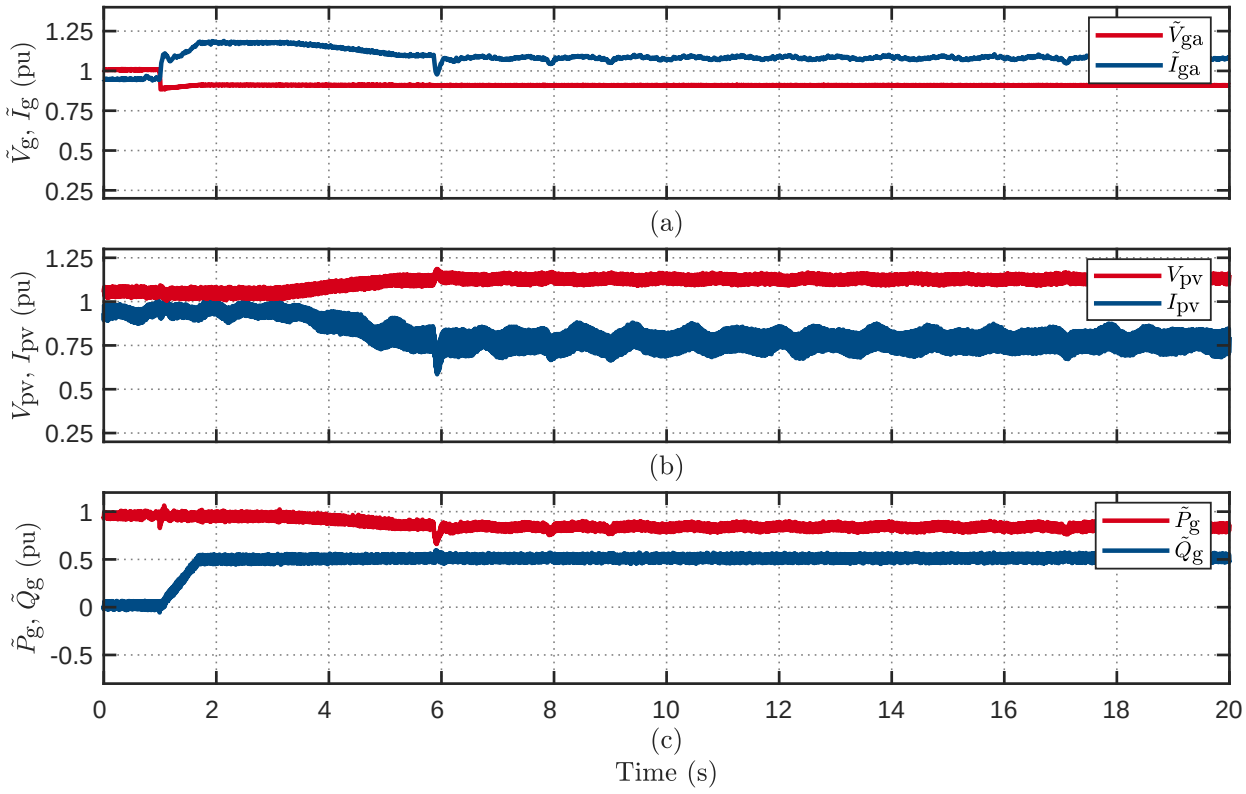

Figure 37: Inverter 29 - Volt-VAr response under step variation of grid voltage from 1 pu to 0.9 pu.

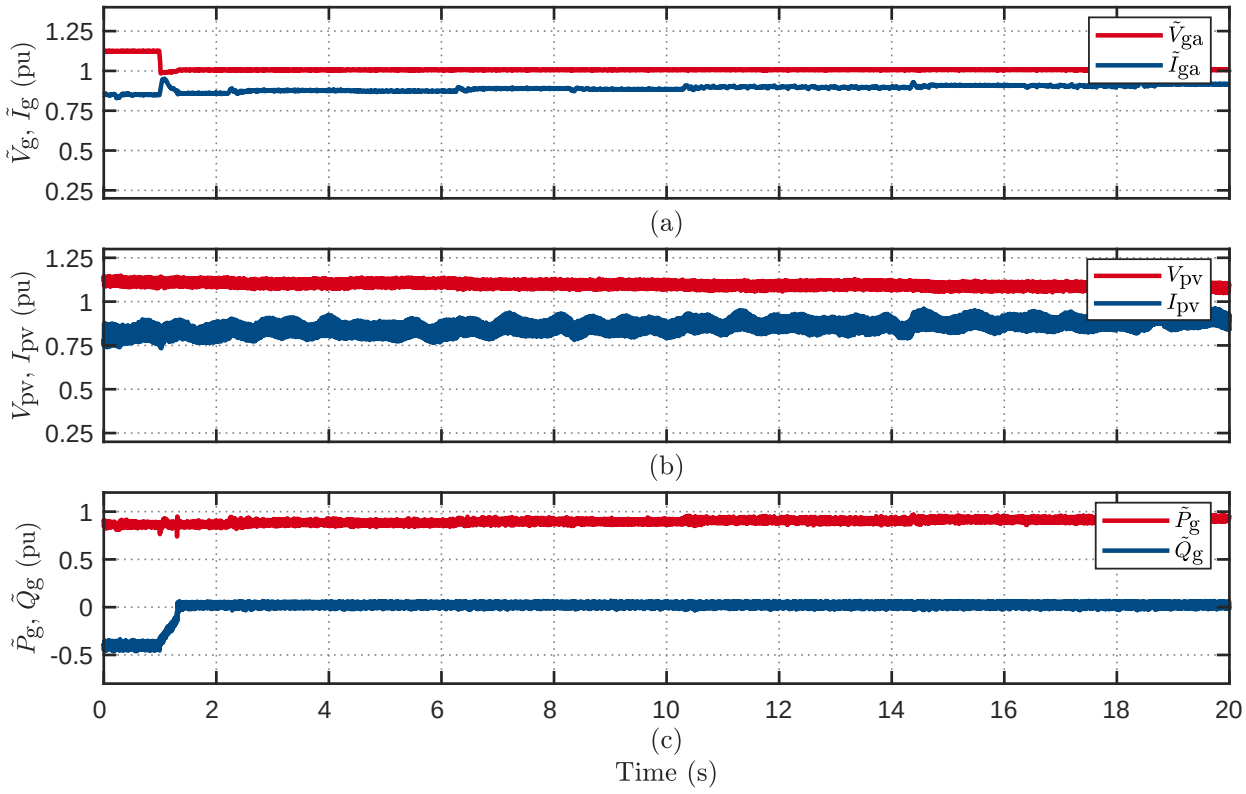

Figure 38: Inverter 29 - Volt-VAr response under step variation of grid voltage from 1.12 pu to 1 pu (recovery).

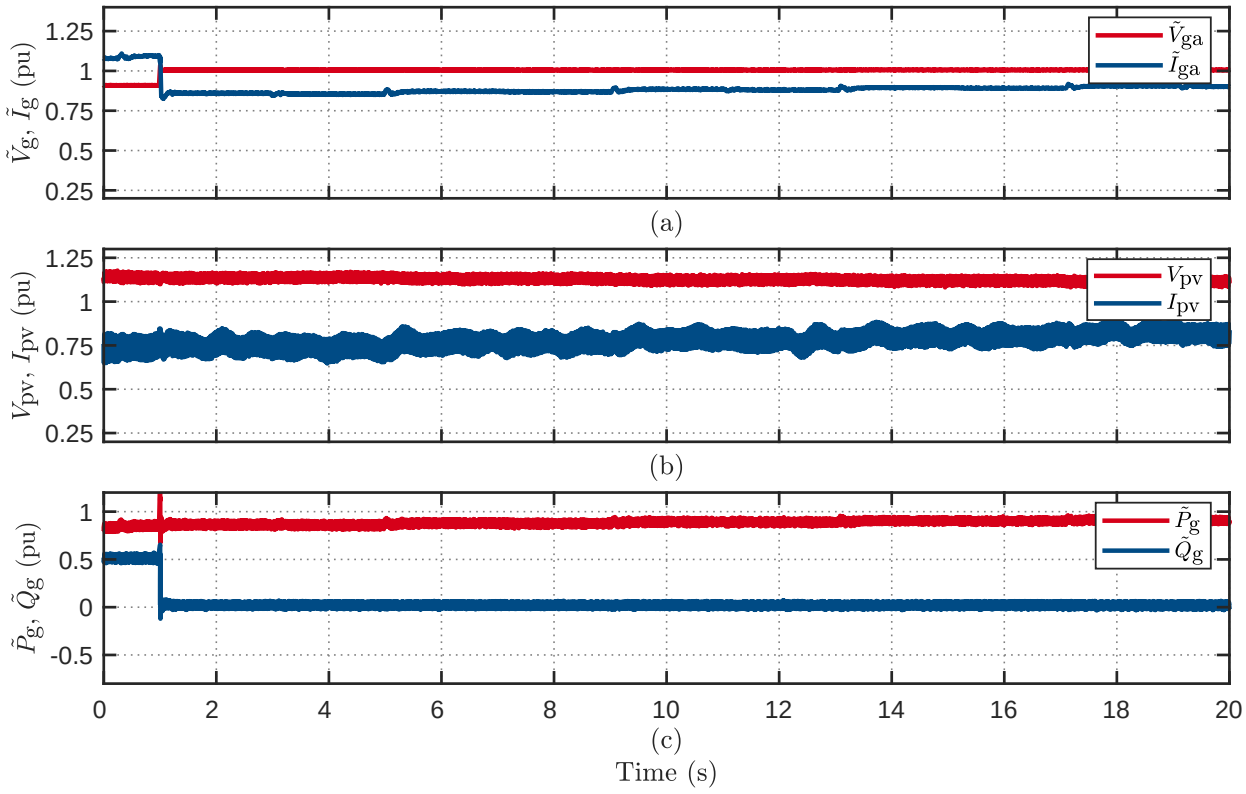

Figure 39: Inverter 29 - Volt-VAr response under step variation of grid voltage from 0.9 pu to 1 pu (recover).

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

There is no “Volt-VAr response time parameter” in the setting of this inverter. Only, the Volt-VAr and Volt-Watt set points can be modified by the installer. The Volt-VAr requirements for Horizon Power are set in the inverter setting for the tests in this report.

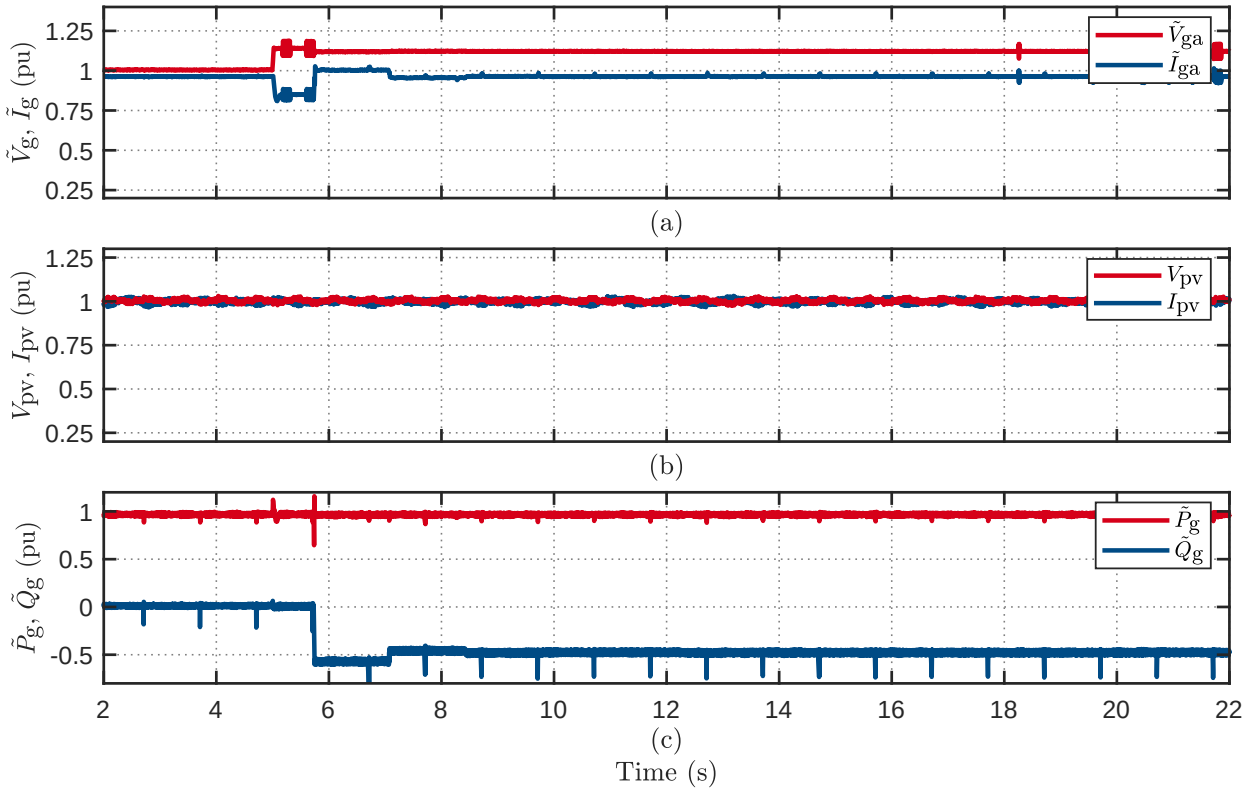

Figure 40: Inverter 5 - Volt-VAr response under step variation of grid voltage from 1 pu to 1.12 pu.

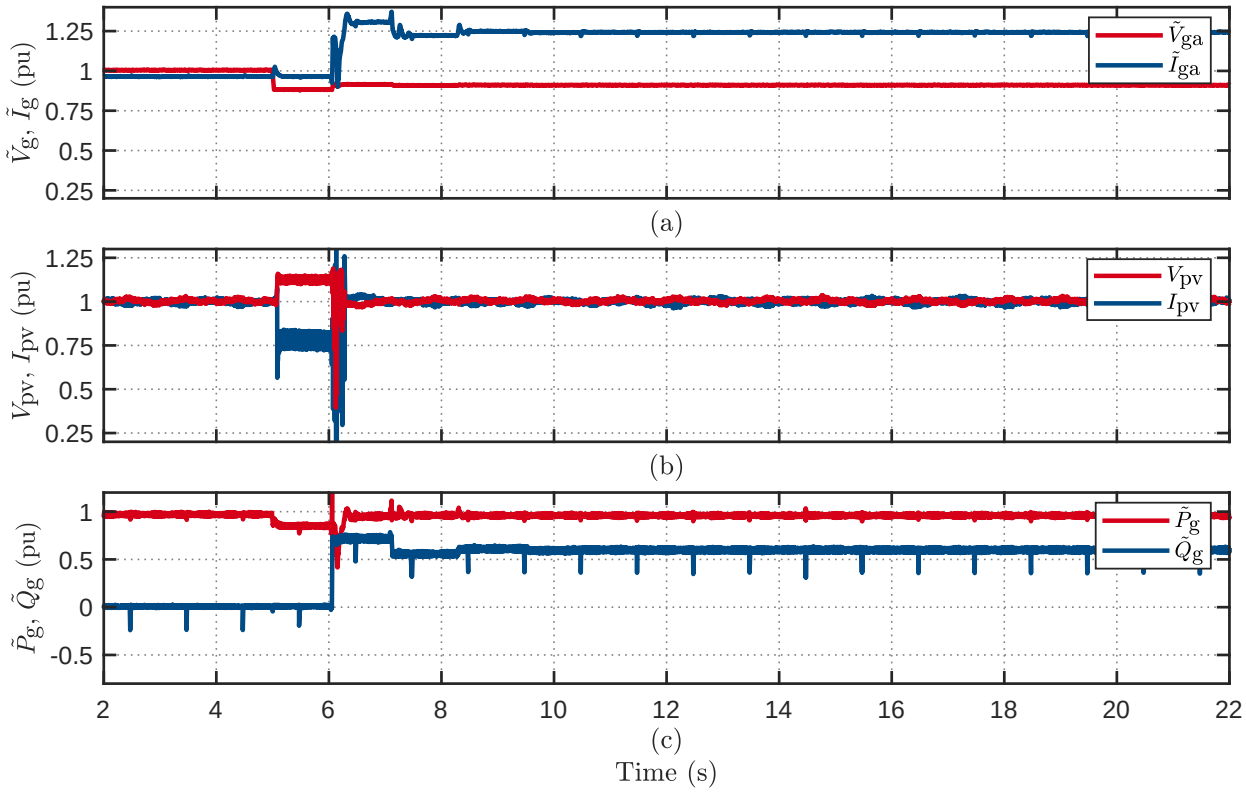

Figure 41: Inverter 5 - Volt-VAr response under step variation of grid voltage from 1 pu to 0.9 pu.

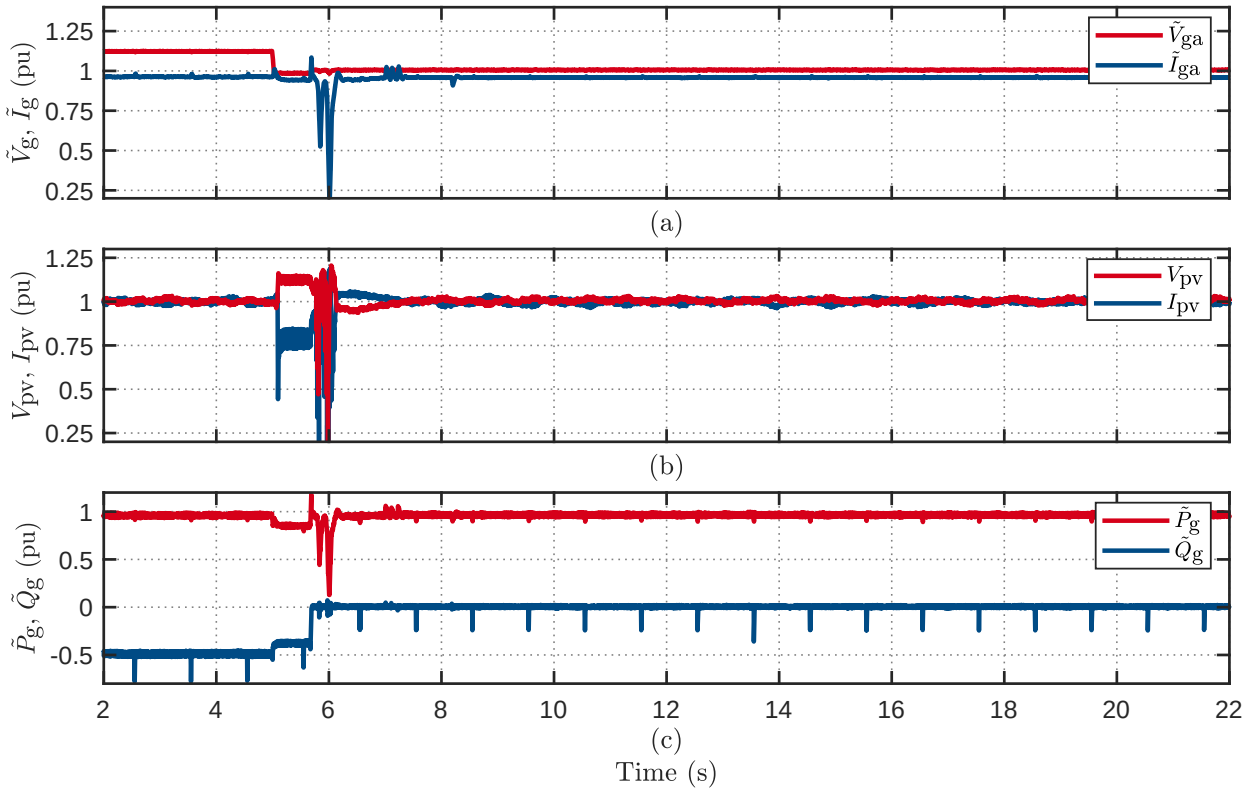

Figure 42: Inverter 5 - Volt-VAr response under step variation of grid voltage from 1.12 pu to 1 pu (recovery).

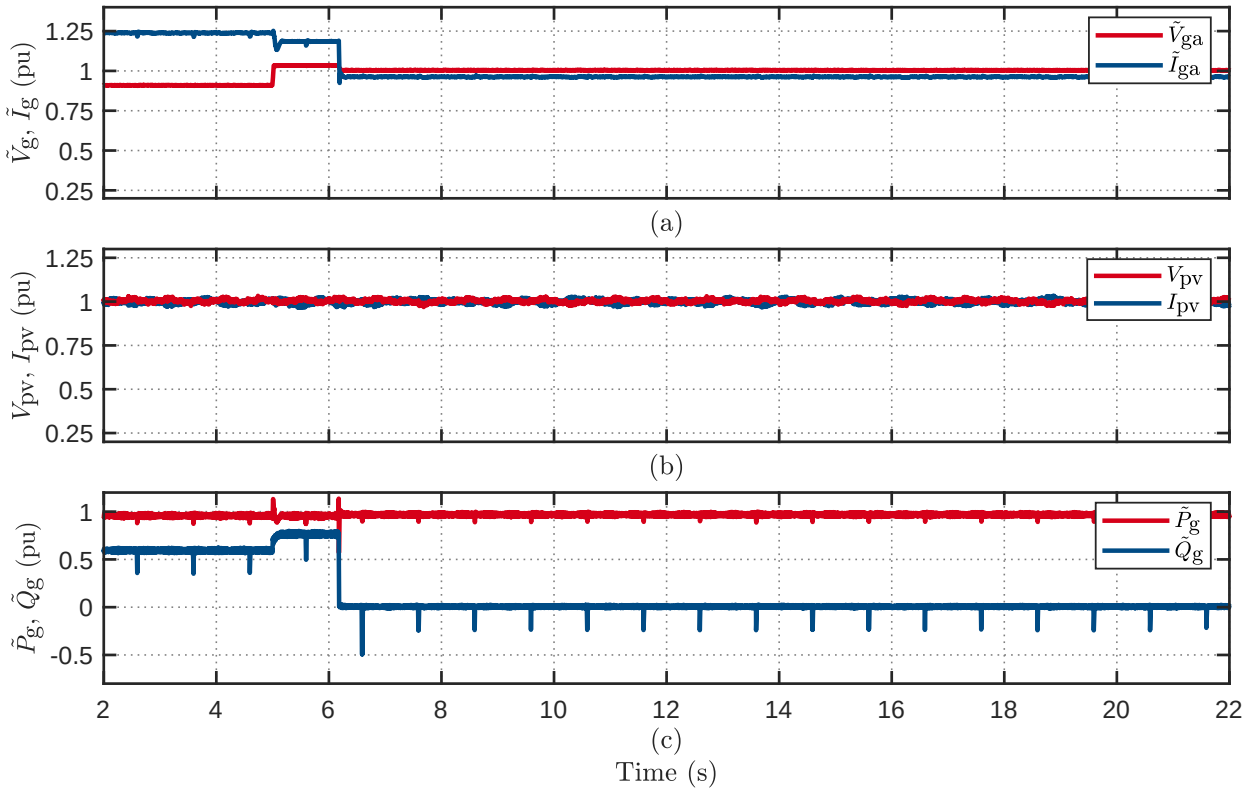

Figure 43: Inverter 5 - Volt-VAr response under step variation of grid voltage from 0.9 pu to 1 pu (recovery).

2.2.5 Manufacturer J - Inverter 22 - Single-Phase - AS4777.2:2015

In the setting of this inverter, there is a parameter for setting the time of Volt-VAr response. The behavior of the inverter is tested with considering two different time values for this setting: **0 s (which is the default value) and 5 s**. The Volt-VAr and Volt-Watt settings are based on Western Australia (Horizon Power).

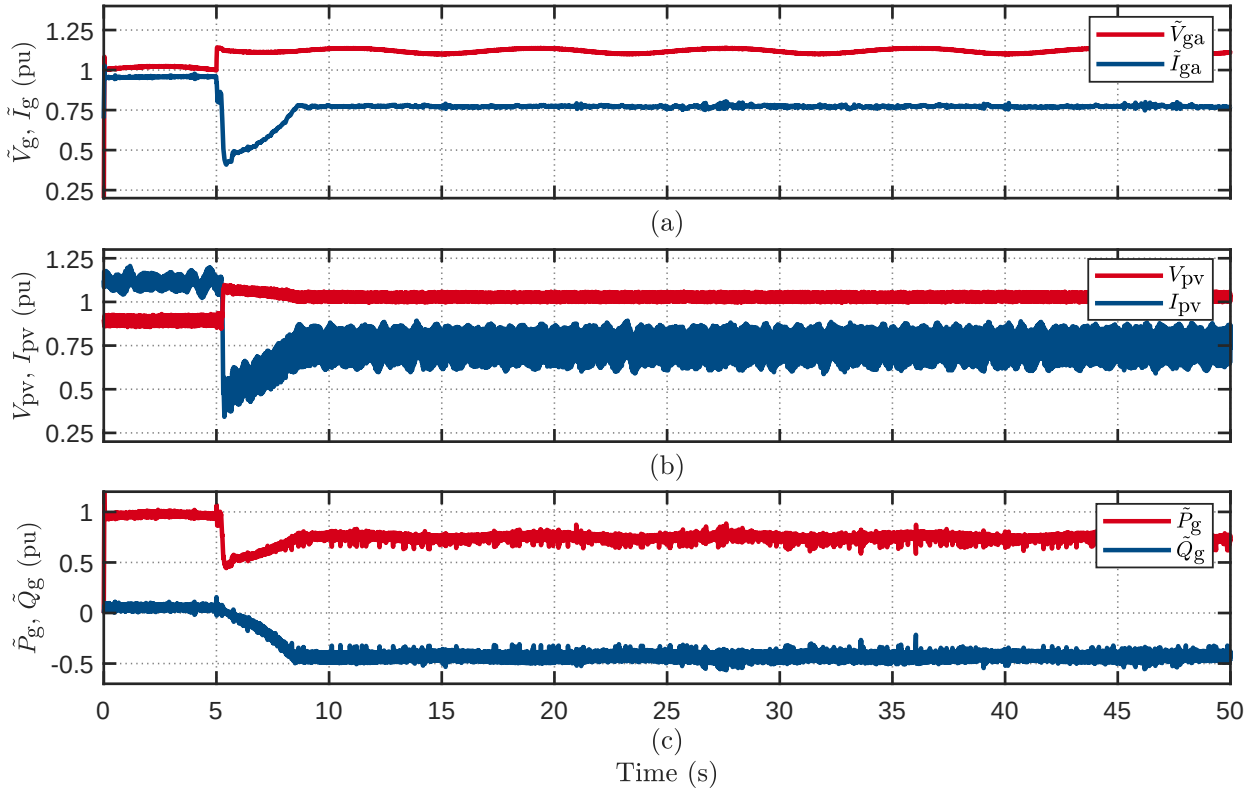

Figure 44: Inverter 22 - Volt-VAr response under step variation of grid voltage from 1 pu to 1.12 pu, with time setting set to 0 s.

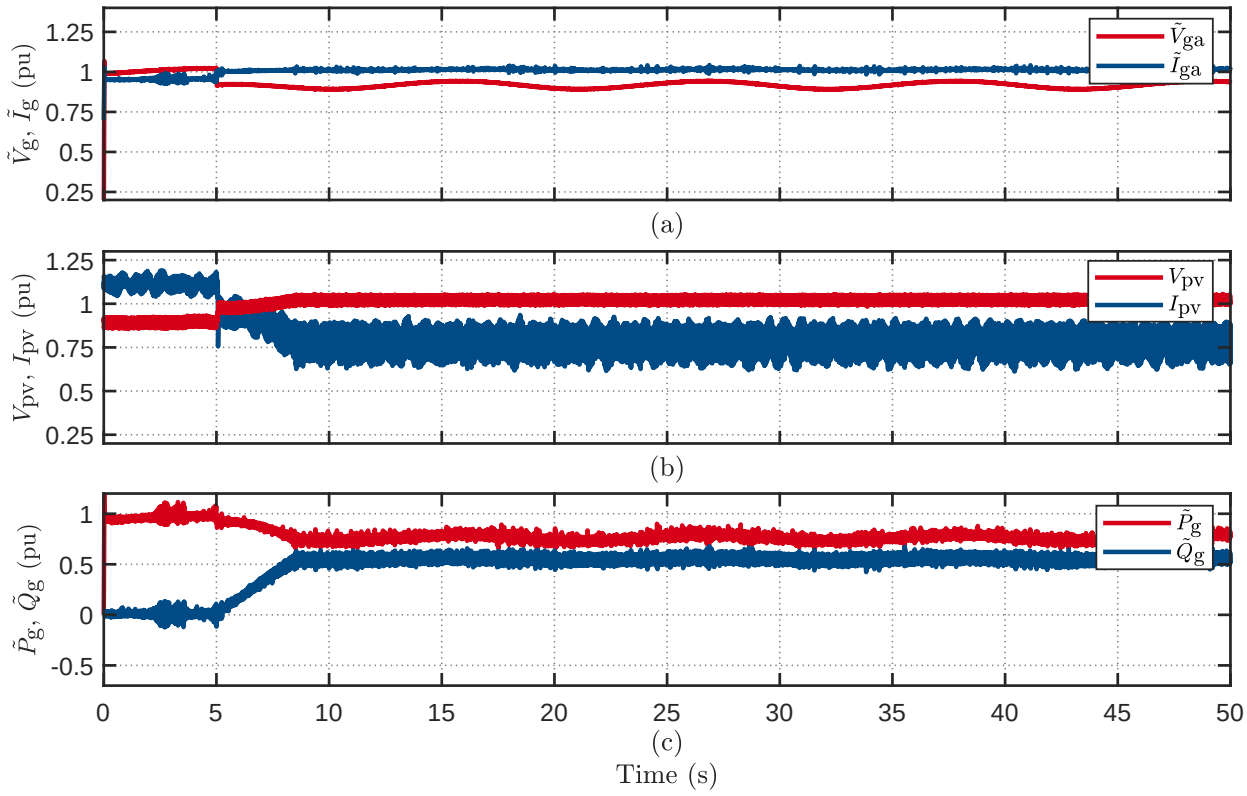

Figure 45: Inverter 22 - Volt-VAr response under step variation of grid voltage from 1 pu to 0.9 pu, with time setting set to 0 s.

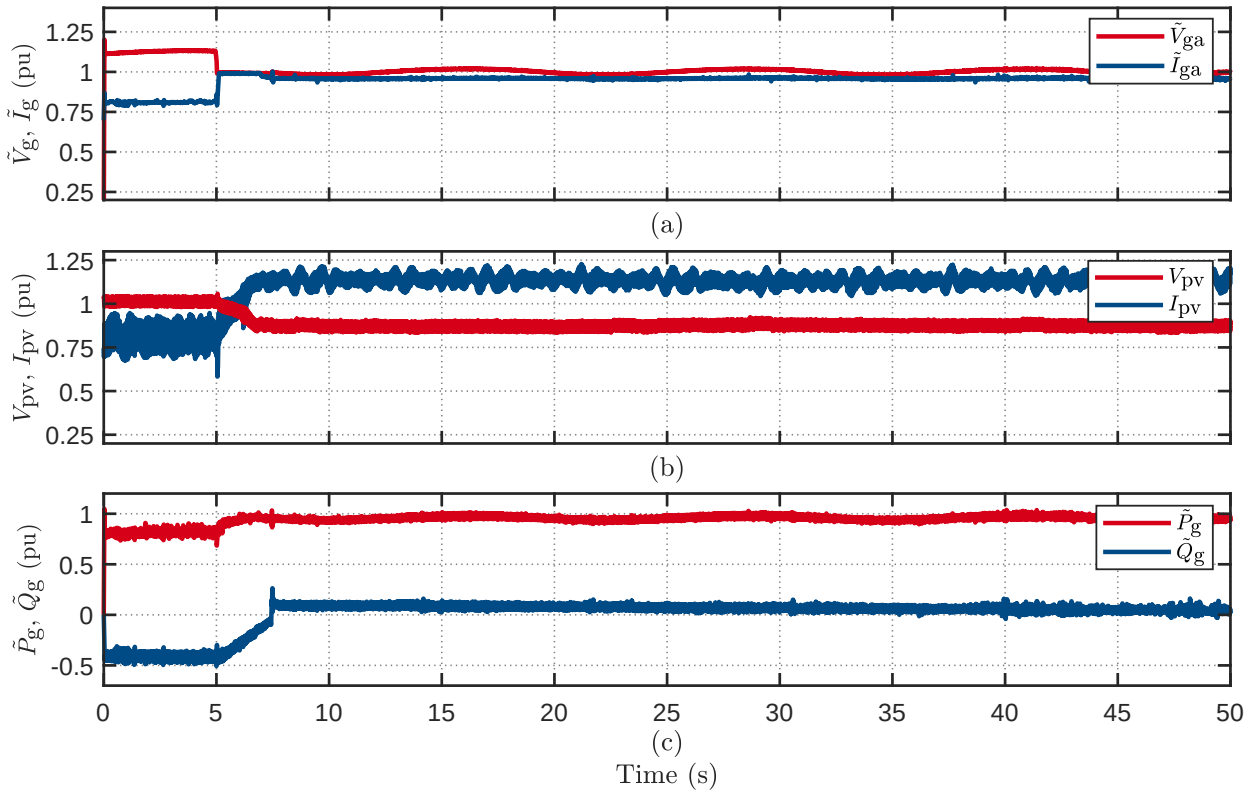

Figure 46: Inverter 22 - Volt-VAr response under step variation of grid voltage from 1.12 pu to 1 pu, with time setting set to 0 s (recovery).

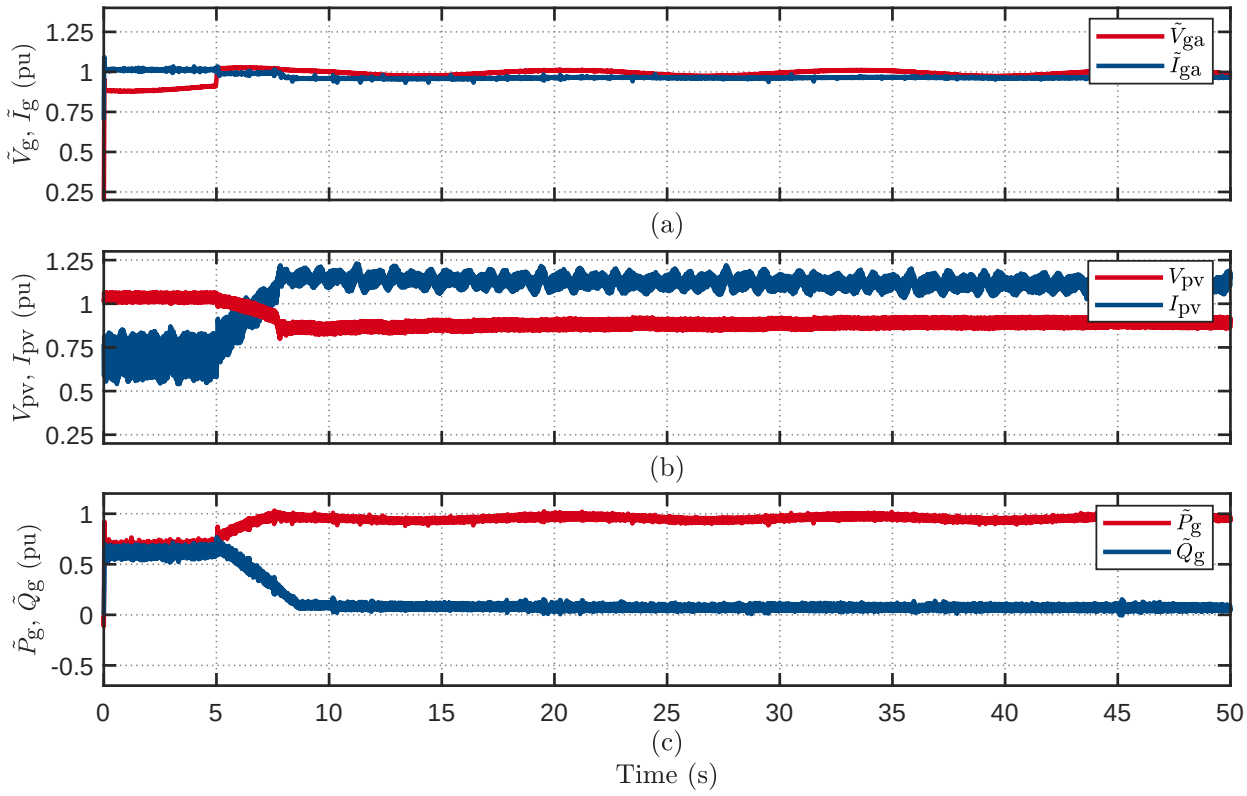

Figure 47: Inverter 22 - Volt-VAr response under step variation of grid voltage from 0.9 pu to 1 pu, with time setting set to 0 s (recovery).

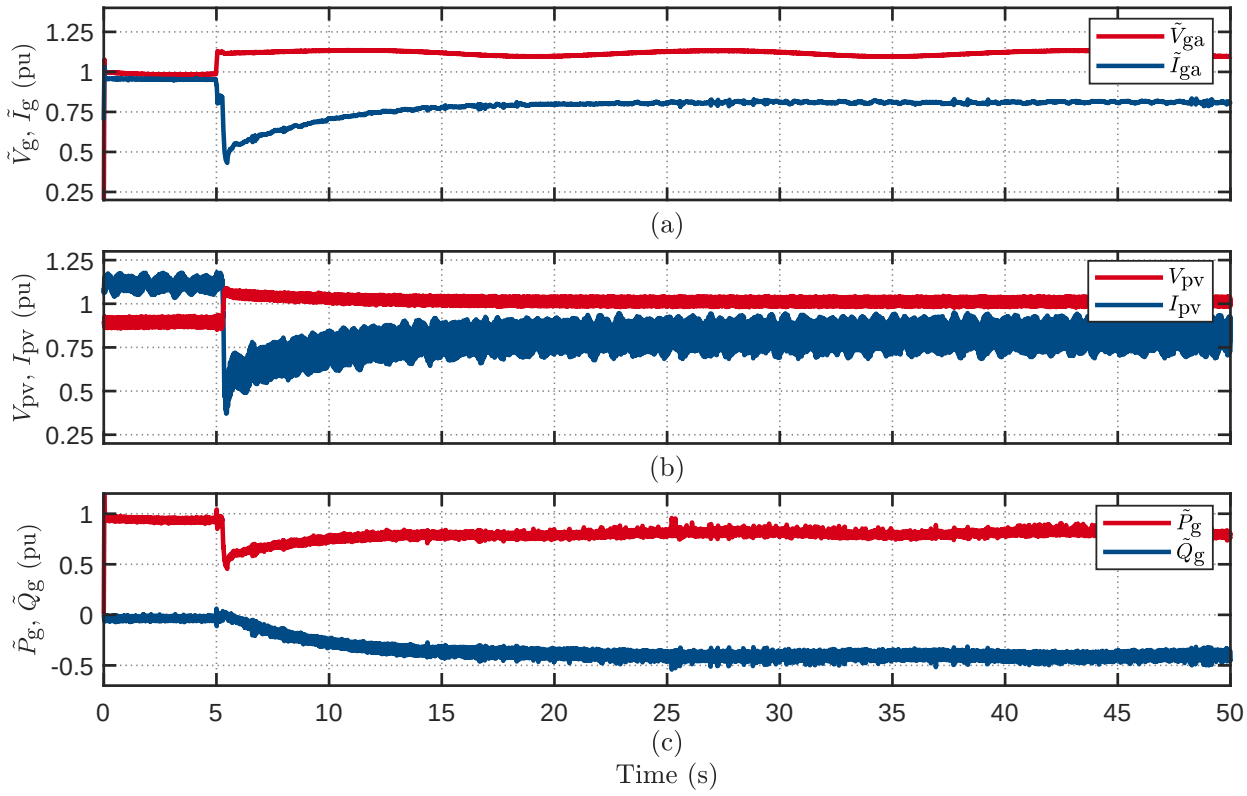

Figure 48: Inverter 22 - Volt-VAr response under step variation of grid voltage from 1 pu to 1.12 pu, with time setting set to 5 s.

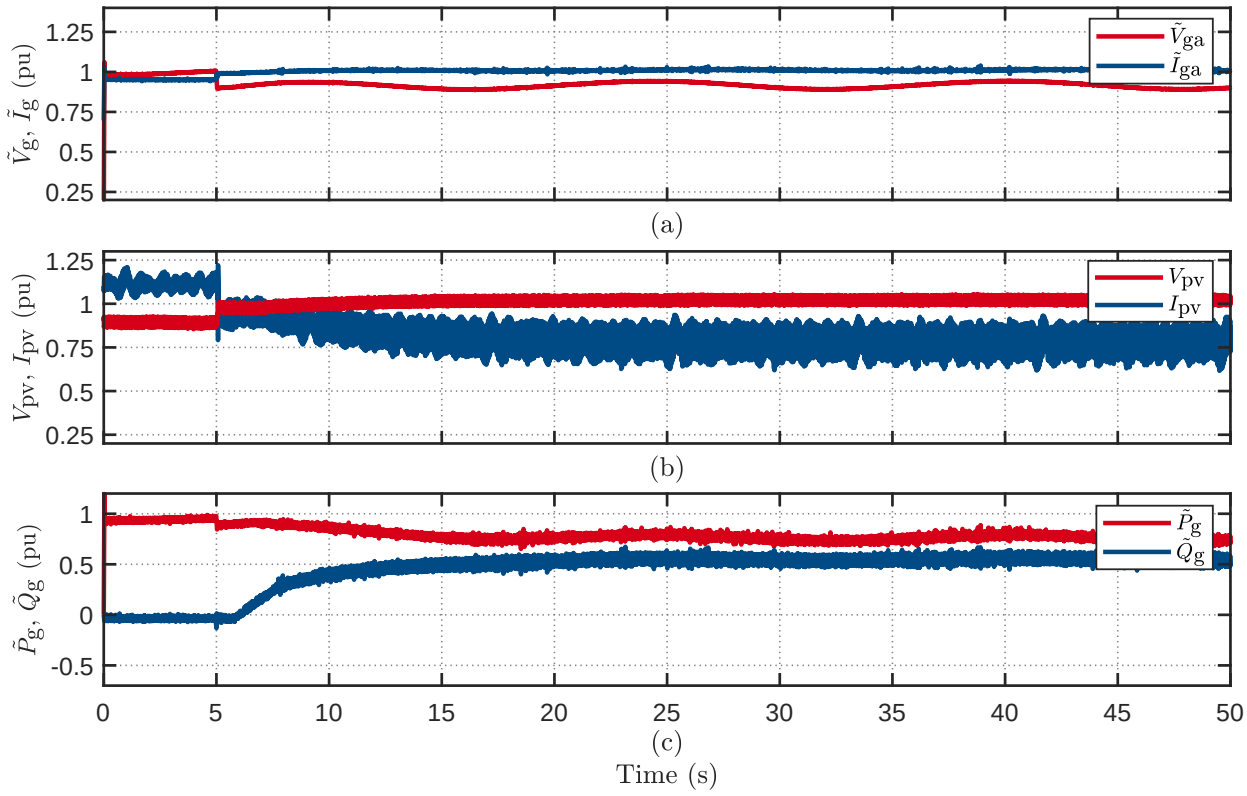

Figure 49: Inverter 22 - Volt-VAr response under step variation of grid voltage from 1 pu to 0.9 pu, with time setting set to 5 s.

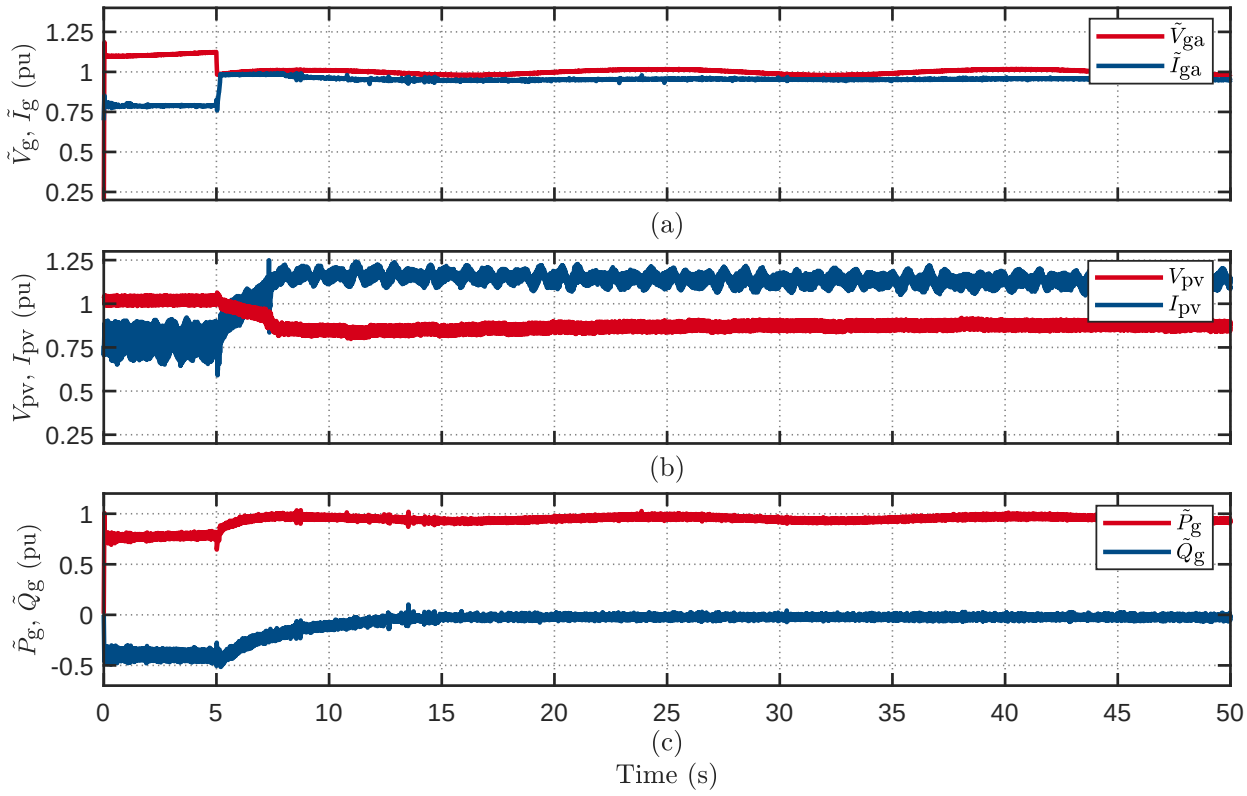

Figure 50: Inverter 22 - Volt-VAr response under step variation of grid voltage from 1.12 pu to 1 pu, with time setting set to 5 s (recovery).

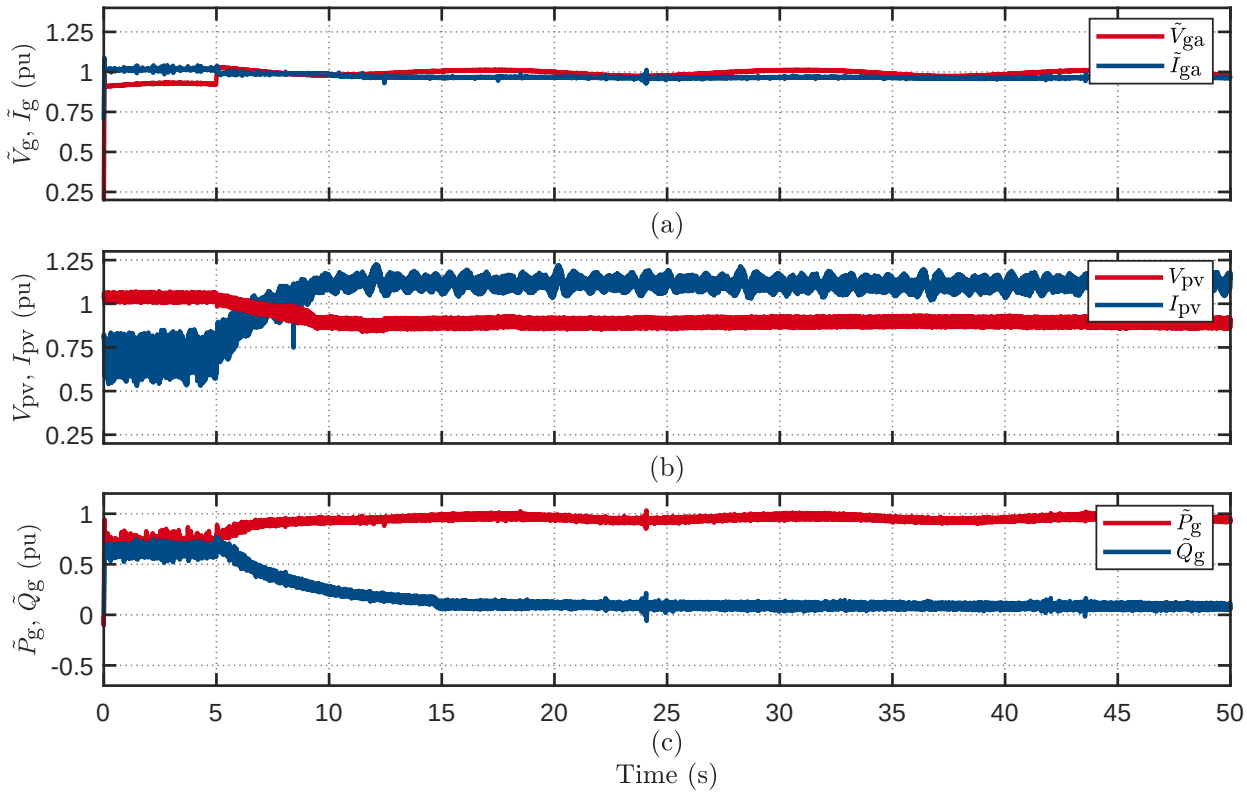

Figure 51: Inverter 22 - Volt-VAr response under step variation of grid voltage from 0.9 pu to 1 pu, with time setting set to 5 s (recovery).

2.2.6 Manufacturer K - Inverter 23 - Single-Phase - AS4777.2:2015

The firmware is updated to the latest version, in which Volt-VAr and Volt-Watt setting are enabled based on the DNSP requirements. The stead-state response for AU Horizon and Western Australia DNSPs are shown in the following figures.

Remark: This inverter does not have any time setting parameter. Accordingly, the results are only taken with the default parameters of the inverter.

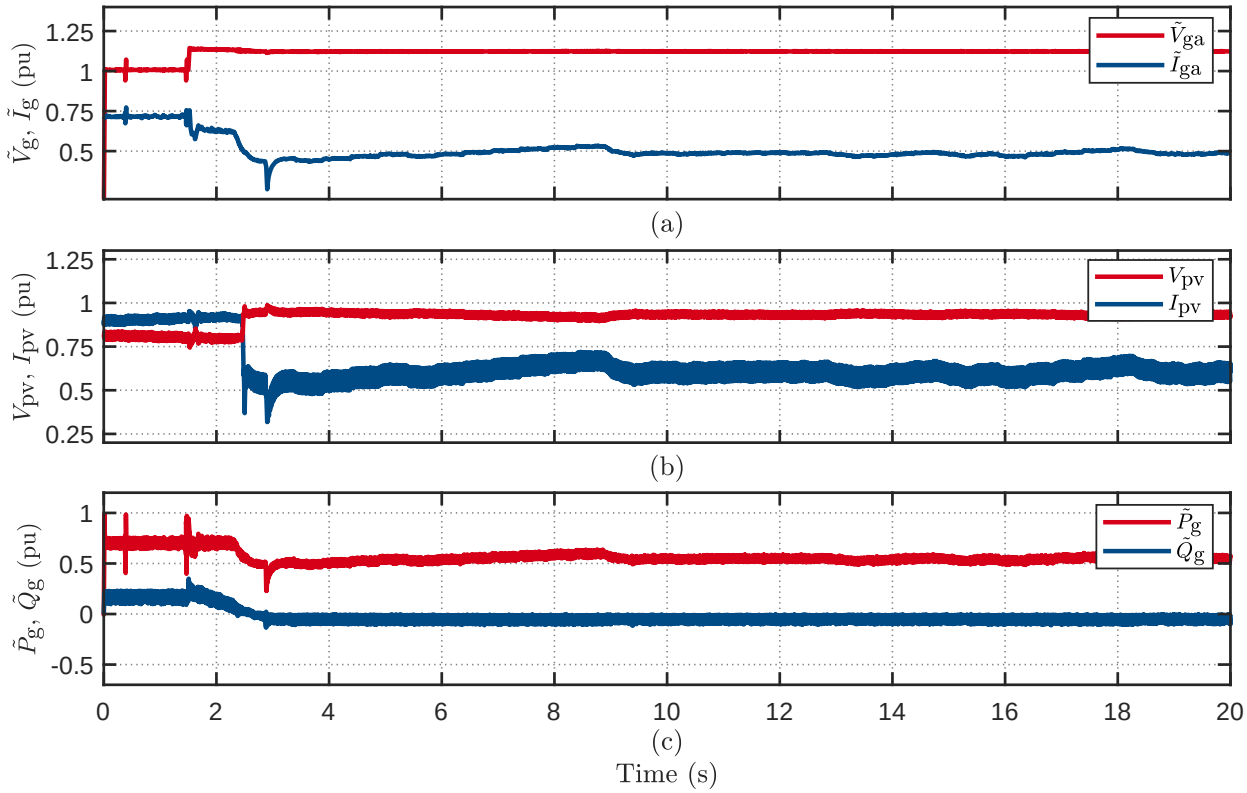

Figure 52: Inverter 23 - Western Power - Volt-VAr response under step variation of grid voltage from 1 pu to 1.12 pu.

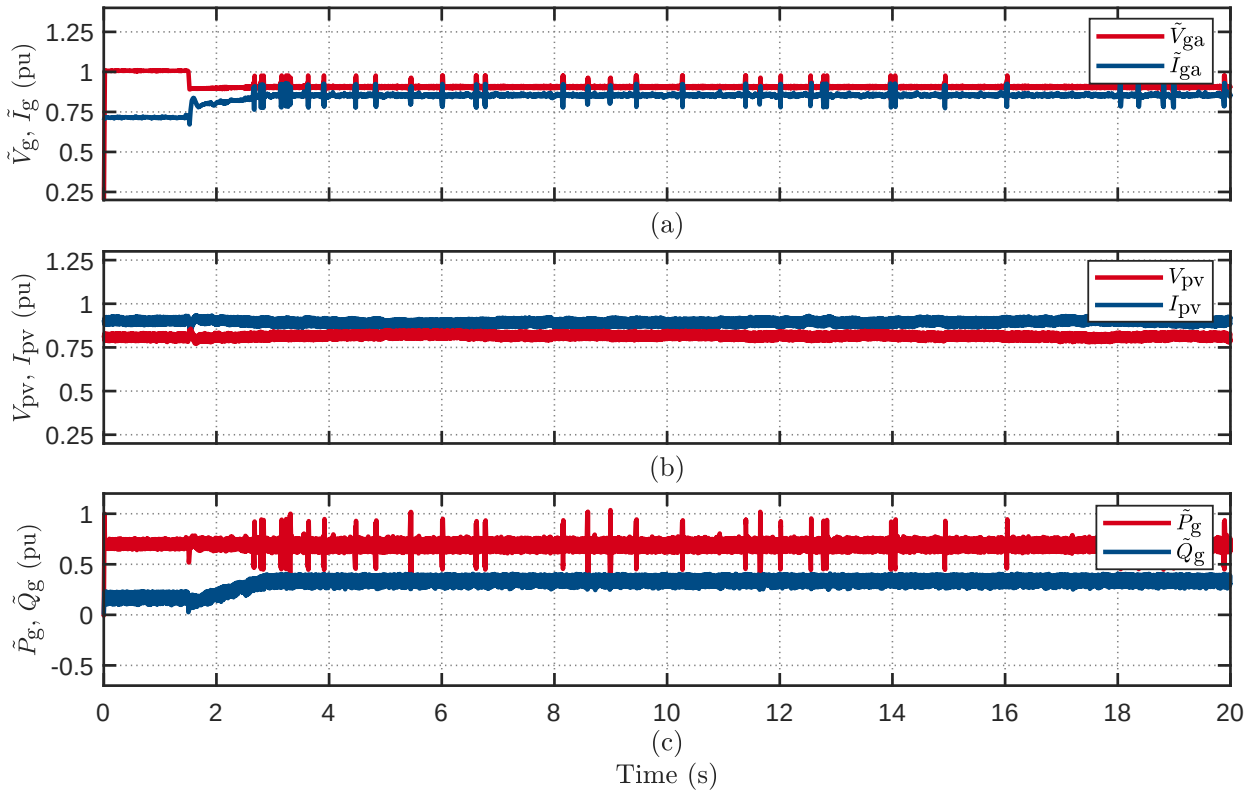

Figure 53: Inverter 23 - Western Power - Volt-VAr response under step variation of grid voltage from 1 pu to 0.9 pu.

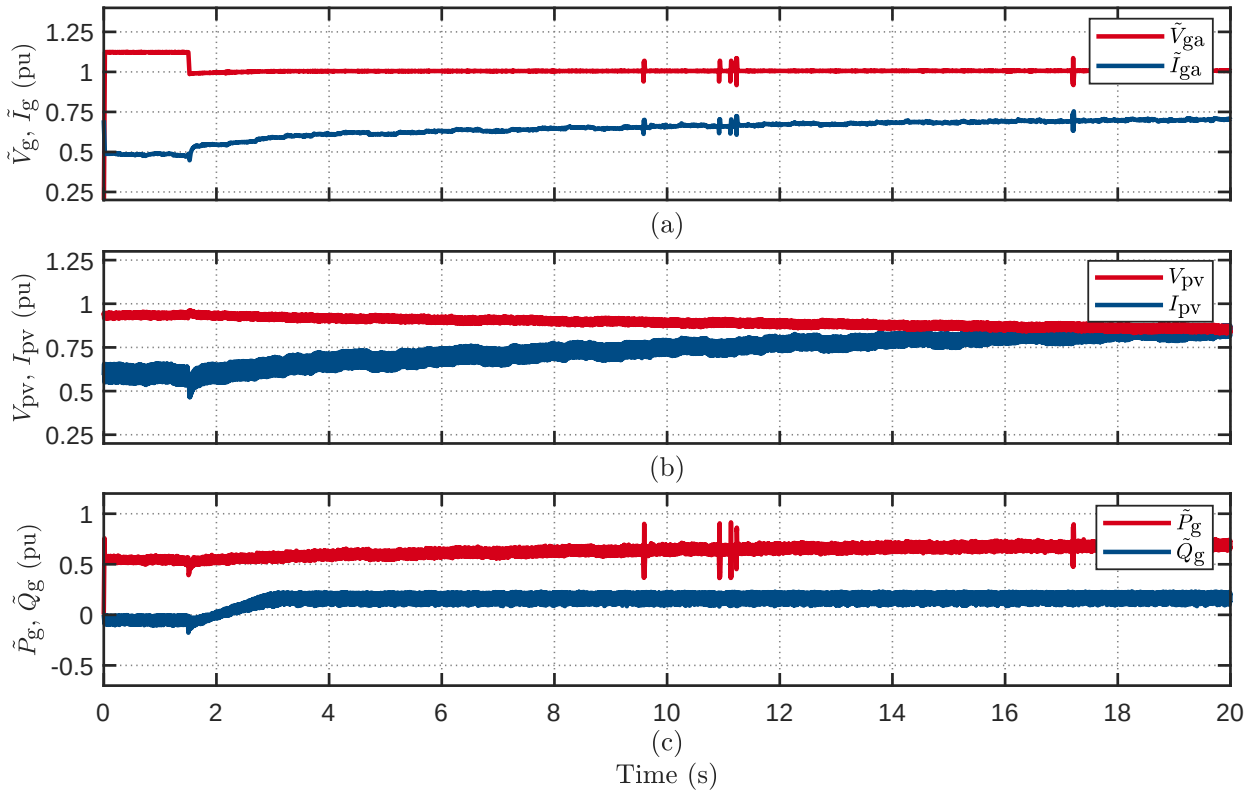

Figure 54: Inverter 23 - Western Power - Volt-VAr response under step variation of grid voltage from 1.12 pu to 1 pu (recovery).

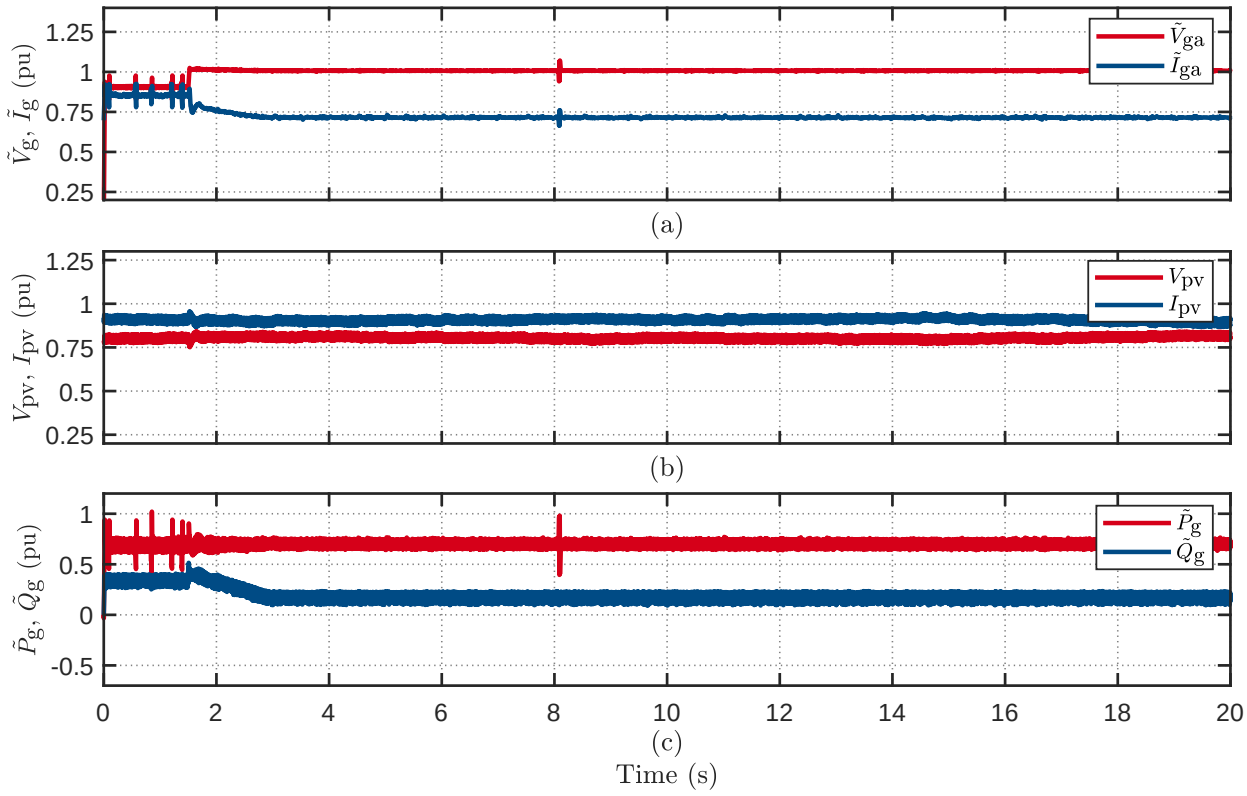

Figure 55: Inverter 23 - Western Power - Volt-VAr response under step variation of grid voltage from 0.9 pu to 1 pu (recover).

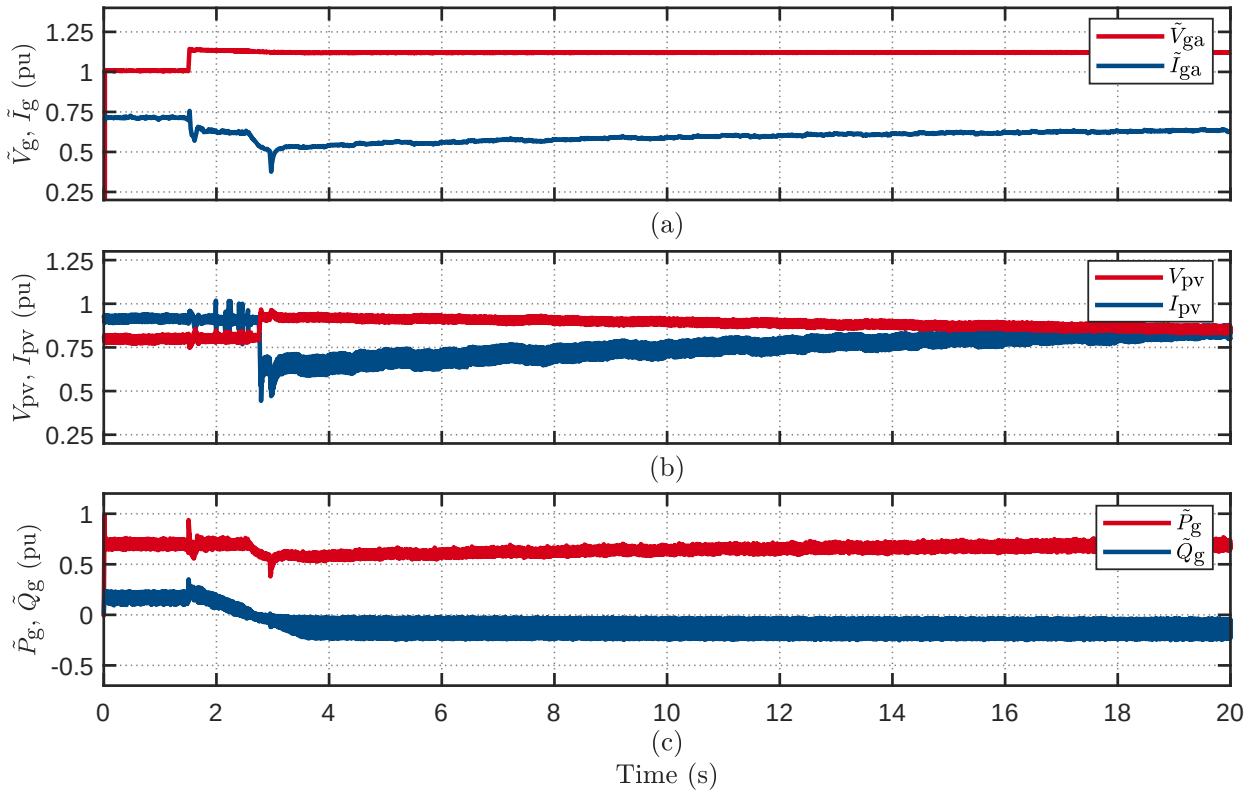

Figure 56: Inverter 23 - AU Horizon - Volt-VAr response under step variation of grid voltage from 1 pu to 1.12 pu.

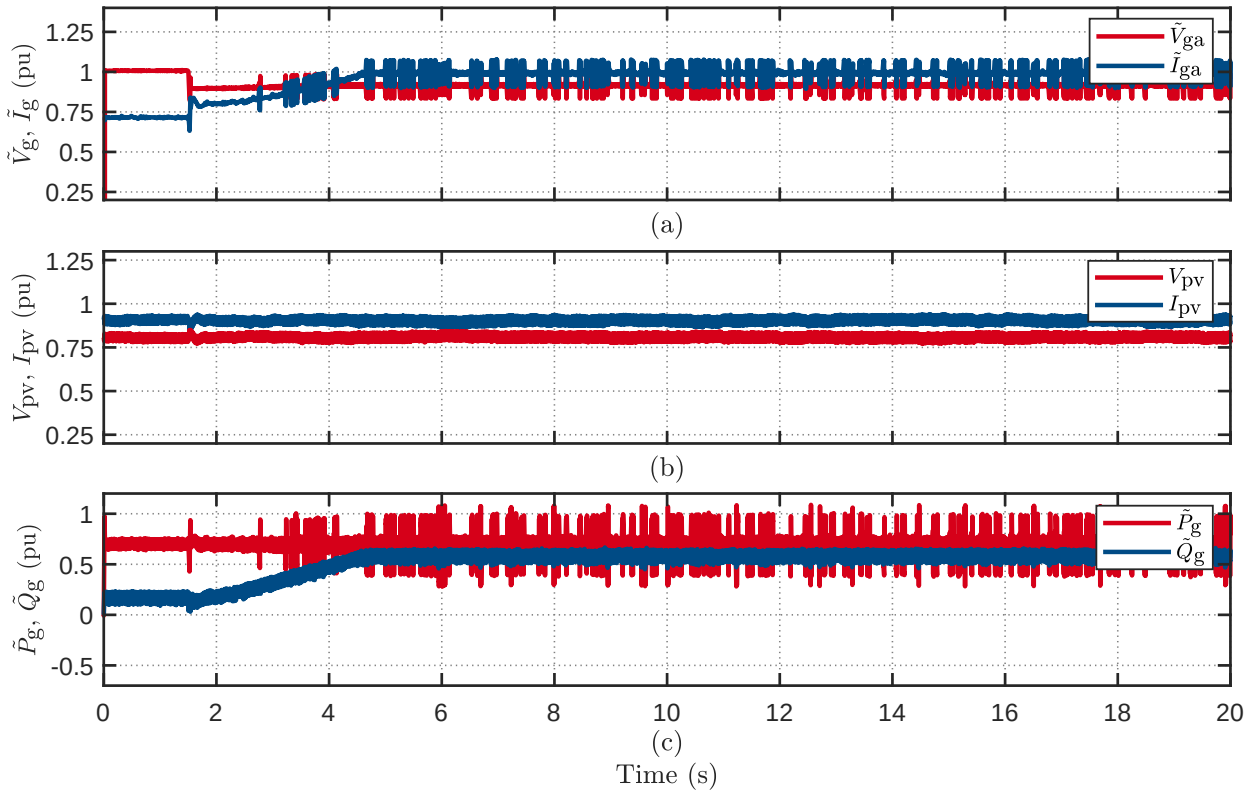

Figure 57: Inverter 23 - AU Horizon - Volt-VAr response under step variation of grid voltage from 1 pu to 0.9 pu.

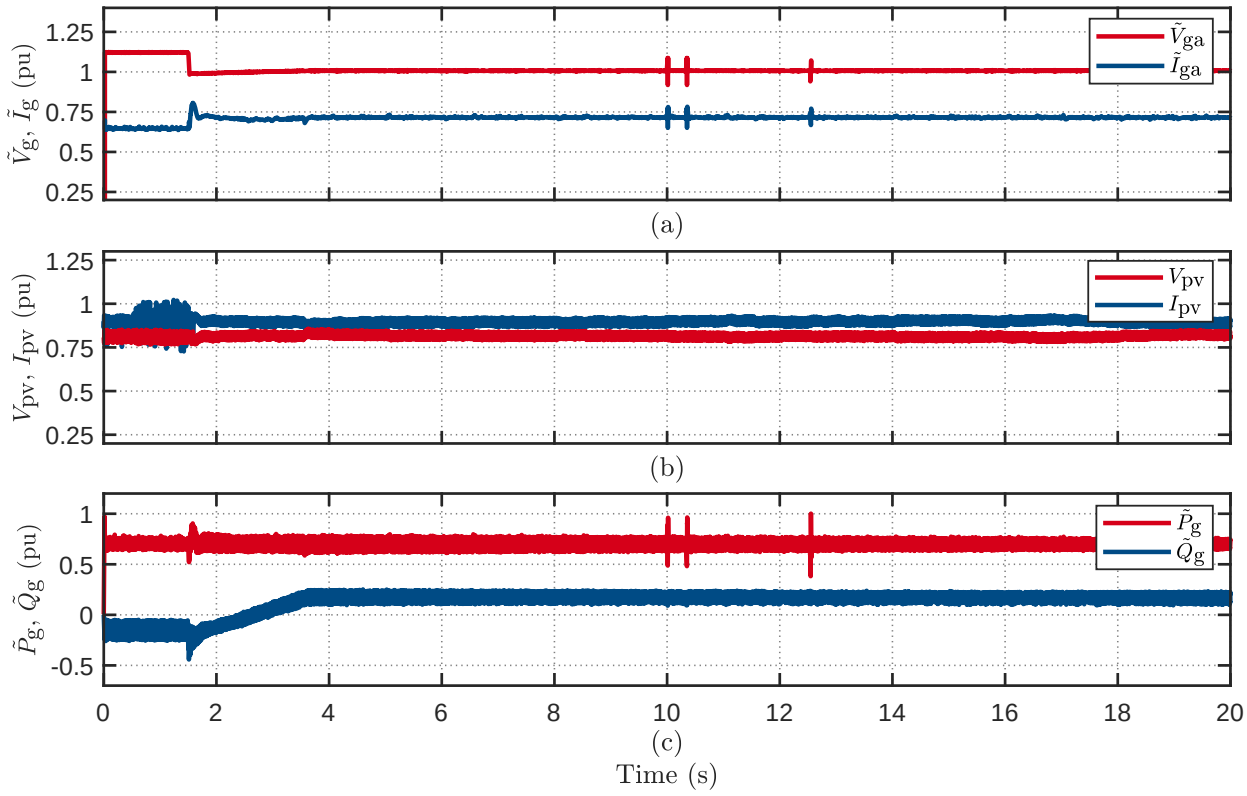

Figure 58: Inverter 23 - AU Horizon - Volt-VAr response under step variation of grid voltage from 1.12 pu to 1 pu (recovery).

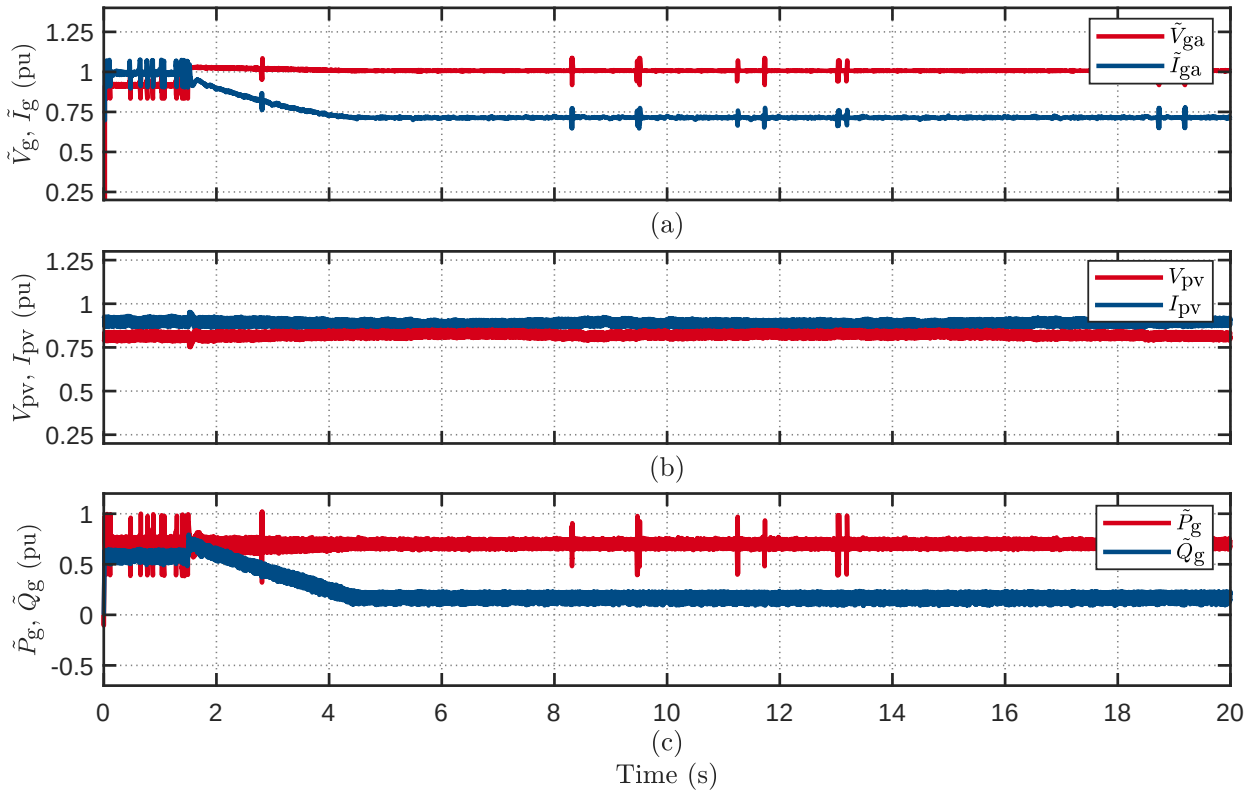

Figure 59: Inverter 23 - AU Horizon - Volt-VAr response under step variation of grid voltage from 0.9 pu to 1 pu (recover).

2.2.7 Manufacturer L - Inverter 28 - Single-Phase - AS4777.2:2015

his inverter does not have any time setting parameter. Accordingly, the results are only taken with the default parameters of the inverter.

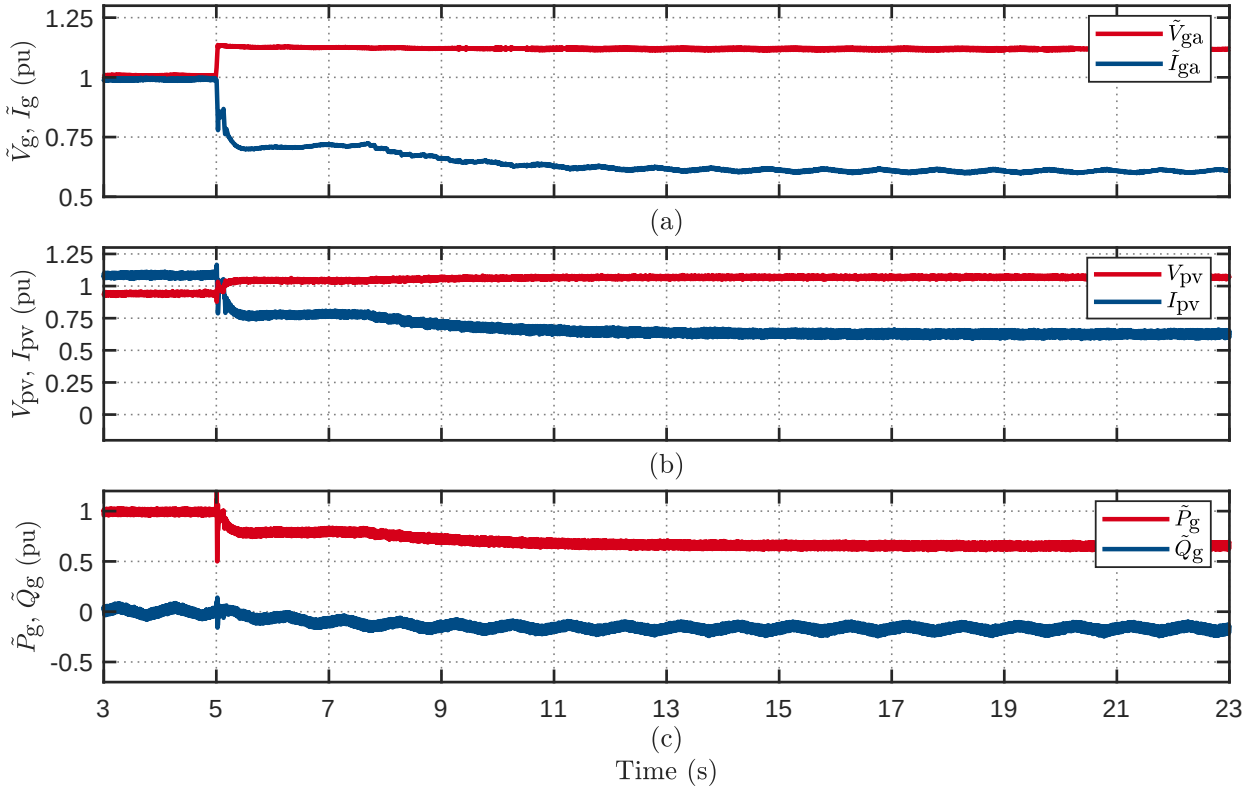

Figure 60: Inverter 28 - Volt-VAr response under step variation of grid voltage from 1 pu to 1.12 pu.

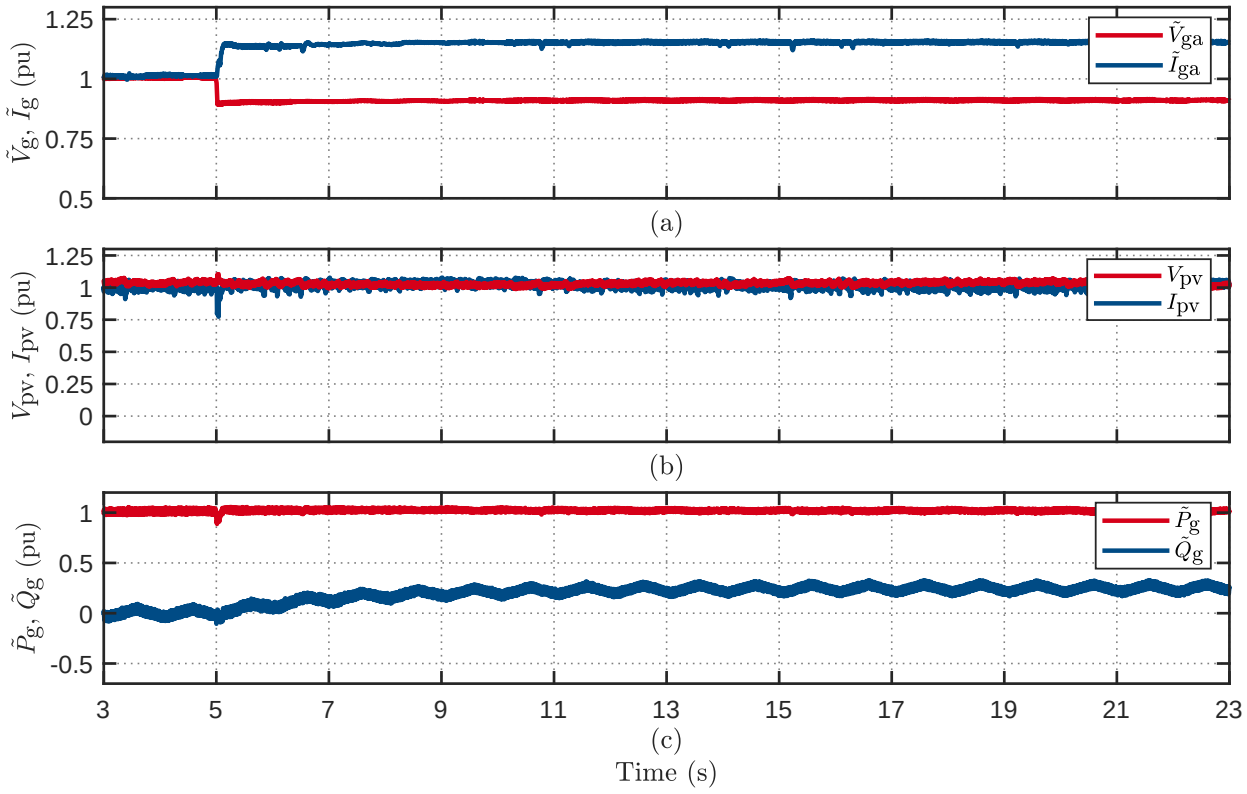

Figure 61: Inverter 28 - Volt-VAr response under step variation of grid voltage from 1 pu to 0.9 pu.

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[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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