AS/NZS 4777.2:2015

Australian/New Zealand Standard™

Grid connection of energy systems via inverters

Part 2: Inverter requirements





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Australian PV Association
Australian Solar Council
Clean Energy Council
Clean Energy Regulator
Consumer Electronics Suppliers Association
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Australian/New Zealand Standard™

Grid connection of energy systems via inverters

Part 2: Inverter requirements

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PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee EL-042, Renewable Energy Power Supply Systems and Equipment, to supersede AS 4777.2—2005, *Grid connection of energy systems via inverters*, Part 2: *Inverter requirements*, and AS 4777.3—2005, *Grid connection of energy systems via inverters*, Part 3: *Grid protection requirements*, twelve months after its publication. During this twelve month period, this edition or AS 4777.2—2005 and AS 4777.3—2005 may be utilized.

The objective of this Standard is to specify minimum performance and safety requirements for the design, construction and operation of inverters intended for use in inverter energy systems for the injection of electric power through an electrical installation into the grid.

This Standard is part of a series on the grid connection of energy systems via inverters. The series is as follows:

AS/NZS	
4777	Grid connection of energy systems via inverters
4777.1	Part 1: Installation requirements
4777.2	Part 2: Inverter requirements (this Standard)

There are many differences between this and the previous edition. They include but are not limited to the following:

(a) Inclusion of a balance requirement for multiple phase systems.

(b) Revised set-points and limits to match electricity distributor requirements.

(c) Inclusion of provisions for demand response and power quality response modes.

NOTE: The demand response provisions in this Standard follow the framework in the AS/NZS 4755 series demand response capabilities and supporting technologies for electrical products. At present there is no overlap in the scope of AS/NZS 4777.2 and AS/NZS 4755. However, if in future a new part of the AS/NZS 4755 series is to be published that covers some of the products or functions within the scope of this Standard, it is intended that the coverage of the demand response aspects of those products or functions will then reference the relevant parts of AS/NZS 4755. This would be achieved by a future amendment to AS/NZS 4777.2.

(d) Inclusion of requirements for electrical safety in accordance with IEC 62109-1 and IEC 62109-2.

(e) Inclusion of requirements for multiple mode inverter operation and requirements for systems with energy storage to meet electrical safety requirements in accordance with AS 62040.1.1.

The terms ‘normative’ and ‘informative’ have been used in this Standard to define the application of the appendix to which they apply. A ‘normative’ appendix is an integral part of a Standard, whereas an ‘informative’ appendix is only for information and guidance.

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FOREWORD

This Standard necessarily deals with existing types of inverter energy systems, but is not intended to discourage innovation or to exclude materials, equipment and methods that may be developed in the future. Revisions will be made from time to time in view of such developments, and amendments to this edition will be made when necessary.

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STANDARDS AUSTRALIA/STANDARDS NEW ZEALAND

Australian/New Zealand Standard
Grid connection of energy systems via inverters

Part 2: Inverter requirements

1 SCOPE

This Standard specifies requirements and tests for low voltage inverters for the injection of electric power through an electrical installation into the grid at low voltage. This Standard applies to inverters that have power flow in either direction between the energy source and the grid. General requirements relating to the test methods set out in Appendices B to J are specified in Appendix A.

NOTE: This Standard does not include the regulatory requirements mandated in Australia by the Australian Communications Media Authority (ACMA) and in New Zealand by Radio Spectrum Management. Refer to ACMA *Electromagnetic Compatibility—Information for suppliers of electrical and electronic products in Australia and New Zealand* for guidance.

2 APPLICATION

This Standard needs to be read in conjunction with the regulations, service and installation rules of the electricity distributor approving the connection. This Standard should also be read in conjunction with AS/NZS 3000.

3 NORMATIVE REFERENCES

The following are the normative documents referenced in this Standard:

NOTES:

1 Documents referenced for informative purposes are listed in the Bibliography.

2 Documents referred to in the preparation of this Standard are listed in Appendix K.

AS

60038 Standard voltages

62040 Uninterruptible power systems (UPS)

62040.1.1 Part 1.1: General and safety requirements for UPS used in operator access areas

AS/NZS

3000 Electrical installations (known as the Australian/New Zealand Wiring Rules)

3112 Approval and test specification—Plugs and socket-outlets

4777 Grid connection of energy systems via inverters

4777.1 Part 1: Installation requirements

5033 Installation and safety requirements for photovoltaic (PV) arrays

60320 Appliance couplers for household and similar general purposes

60320.1 Part 1: General requirements

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IEC		
61000	Electromagnetic compatibility (EMC)	
61000.3.3	Part 3.3:	Limits—Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection
61000.3.11	Part 3.11:	Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems—Equipment with rated current less than or equal to 75 A and subject to conditional connection
60038	IEC standard voltages	
60309	Plugs, socket-outlets and couplers for industrial purposes	
60309-1	Part 1:	General requirements
62109	Safety of power converters for use in photovoltaic power systems	
62109-1	Part 1:	General requirements
62109-2	Part 2:	Particular requirements for inverters
62116	Utility-interconnected photovoltaic inverters—Test procedure of islanding prevention measures	

4 DEFINITIONS

For the purpose of this Standard, the following definitions and those of AS/NZS 3000 apply.

4.1 Active anti-islanding protection

A method of preventing islanding by actively varying the output of the inverter.

4.2 Displacement power factor

The cosine of the angle (φ) between the fundamental voltage and the fundamental current.

NOTE: Lagging power factor is defined to be when the inverter sinks reactive power from the grid; that is, when the inverter acts as an inductive load from the perspective of the grid. Leading power factor is defined to be when the inverter sources reactive power to the grid; that is, when the inverter acts as a capacitive load from the perspective of the grid.

4.3 Fixed equipment

Equipment fastened to a support, or otherwise secured in a specific location.

[IEV 826-07-07].

4.4 Grid

The portion of the electrical distribution system that is operated by an electrical distributor.

NOTE: An alternative term for ‘grid’ is ‘electricity distribution network’.

4.5 Grid interactive inverter

An inverter or inverter function intended to operate in parallel to the grid for export or self-consumption of energy generated by the inverter energy system.

4.6 Grid test voltage

The voltage applied for testing of an inverter to this Standard.

4.7 Inverter

A device that uses semiconductor devices to transfer power between a d.c. source or load and an a.c. source or load.

NOTE: For the purposes of this Standard, a.c. to a.c. convertors transferring power between non-grid energy sources and an a.c. source or load that use semiconductor devices are considered to be inverters.

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4.8 Inverter energy system

A system comprising of one or more inverters together with one or more energy sources (which may include batteries for energy storage), and controls, which satisfies the requirements of this Standard.

4.9 Islanding

Any situation where the electrical supply from a grid is disrupted or fails and one or more inverters maintains any form of electrical supply, be it stable or not, to any section of that grid or within the electrical installation.

NOTE: Prevention of the injection of energy and prevention of an unintentional island with the grid or part thereof when supply is disrupted is key to maintaining safety on the grid and within the electrical installation.

4.10 Multiple mode inverter (MMI)

An inverter that operates in more than one mode, for example having grid-interactive functionality when grid voltage is present and stand-alone functionality when the grid is de-energized or disconnected.

NOTES:

1 Inverters with battery storage ports are also considered multiple mode inverters.

2 As defined in IEC 62109-2, Clause 3.107.

4.11 Passive anti-islanding protection

A method of preventing islanding based on monitoring the grid.

4.12 Permanently connected

Electrically connected by means which can be detached only by the use of a tool.

NOTE: As defined in IEC 62109-1, Clause 3.53.

4.13 Pluggable equipment type A

Equipment which is intended for connection to the building installation wiring via a non-industrial plug and socket-outlet or a non-industrial appliance coupler, or both.

NOTE: As defined in IEC 62109-1, Clause 3.57.

4.14 Pluggable equipment type B

Equipment which is intended for connection to the building installation wiring via an industrial plug and socket-outlet or an appliance coupler, or both, complying with IEC 60309-1 or with a comparable national standard.

NOTES:

1 For the purposes of this Standard, appliance couplers and connectors within the scope of IEC 60320 or AS/NZS 60320 are not equivalent connectors to those complying with IEC 60309-1.

2 PV circuits that use connectors are considered pluggable type B or fixed equipment.

3 As defined in IEC 62109-1, Clause 3.57.

4.15 Port

Location giving access to a device or network where electromagnetic energy or signals may be supplied or received or where the device or network variables may be observed or measured.

NOTE: As defined in IEC 62109-1, Clause 3.64.

4.16 Portable equipment

Pluggable equipment intended to be moved from place to place.

NOTE: As defined in IEC 62109-1, Clause 3.65.

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4.17 Rated

Value assigned, generally by a manufacturer, to a specified operating condition of an inverter.

[IEV 151-04-03].

4.18 Rated apparent power

The output apparent power of the inverter which is the product of the rated current and rated voltage.

NOTE: The SI unit is the volt ampere. Typically inverters are rated in kilovolt amperes, which is written as kVA.

4.19 Rated current

The output current of the inverter which can be supplied continuously for 7 h at the rated voltage when the input power to the inverter does not exceed the maximum input limits.

NOTE: For purposes of equipment marking, the maximum continuous current of IEC 62109-1 can be considered equivalent to the rated current.

4.20 Ripple control

A means of one-way communication based on transmitting audio-frequency electrical signals over a grid.

4.21 Single-phase

Connection between the active of a phase and the neutral.

4.22 Stand-alone functionality

An inverter function intended to supply a.c. power to a load that is not connected to the grid.

NOTE: Based on IEC 62109-2, Clause 3.109.

4.23 Three-phase

System either connected to all phases and neutral (i.e. star connected) or connected between phases (i.e. delta connected).

5 GENERAL REQUIREMENTS

5.1 Electrical safety

Inverters for use in inverter energy systems with photovoltaic (PV) arrays shall comply with the appropriate electrical safety requirements of IEC 62109-1 and IEC 62109-2, and the requirements within this Standard.

Inverters for use in inverter energy systems that have energy storage (batteries) as the only possible energy source shall comply with the electrical safety requirements of AS 62040.1.1, and the requirements within this Standard.

Inverters for use in inverter energy systems that incorporate energy sources other than photovoltaic (PV) arrays or batteries shall comply with the applicable electrical safety requirements of IEC 62109-1 and IEC 62109-2, and the requirements within this Standard. However, for energy source inputs other than PV arrays or batteries, the requirements of IEC 62109-1 and IEC 62109-2 shall be applied with consideration of the inverter topology, the energy source voltage, installation requirements and potential faults which could present a hazard.

NOTE: The application of appropriate electrical safety standards for various energy source types is currently under consideration. The requirements of IEC 62109-1 and IEC 62109-2 may be of some use in identifying potential hazard and risk mitigation methods.

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Throughout IEC 62109-1 and IEC 62109-2, the term ‘power conditioning equipment (PCE)’ is used. For the purposes of this Standard, ‘PCE’ shall be replaced with the term ‘inverter’.

5.2 Provision for external connections

Inverters shall be used and installed as fixed equipment only. Inverters shall not be used as portable equipment.

Inverter provisions for external connection—

(a) shall be for fixed equipment only; and

(b) shall provide for safe and reliable connection to any d.c. source or load or any a.c. source or load.

All inverter ports (except communications ports) shall incorporate connection types for either—

(i) permanently connected equipment; or

(ii) pluggable type B equipment.

Inverter source or load connections shall not incorporate connection types for pluggable type A equipment.

Permanently connected inverters shall have suitable terminals for connection to fixed installation wiring.

Pluggable type B equipment shall have one of the following means of connection:

(A) A non-detachable cord for connection to the supply by means of a connector.

(B) An appliance inlet suitable for connection to a matching connector.

Pluggable type B equipment shall not incorporate—

(1) a connection by a connector or inlet complying with any of the dimensional sheets of AS/NZS 60320.1;

(2) a connection by a plug conforming to AS/NZS 3112; or

(3) a connection by a connector or inlet where hazardous voltages are accessible by the standard test finger.

NOTE: The standard test finger is the same as that used in IEC 62109-1.

5.3 Photovoltaic (PV) array earth fault/earth leakage detection

For inverter energy systems used with PV array systems that require earth fault detection and a residual current detection, either internal or external to the inverter, the type of detection used shall be declared in accordance with IEC 62109-1 and IEC 62109-2.

If an external residual current device (RCD) is required, the manufacturer’s installation instructions shall state the need for an RCD and shall specify its rating, type and required circuit location in accordance with Clause 9.

Compliance shall be checked by inspection of the inverter’s markings and manufacturer’s documentation, and testing in accordance with IEC 62109-2.

Where the additional detection for functionally earthed PV arrays, as required by AS/NZS 5033, is present in the inverter, this additional detection shall, before start-up of the system—

(a) open circuit the functional earth connection to the PV array;

(b) measure the resistance to earth of each conductor of the PV array;

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(c) if the earth resistance is above the resistance limit (R_{iso} limit) threshold specified in Table 1, the system shall reconnect the functional earth and shall be allowed to start; and

(d) if the earth resistance is equal to or less than the resistance limit (R_{iso} limit) threshold specified in Table 1, the inverter shall shut down and initiate an earth fault alarm in accordance with the requirements of IEC 62109-2.

NOTES:

1 Direct functional earthing of systems is not recommended. Functional earthing via a resistor is a safer option wherever it is possible.

2 R_{iso} limit is the same as in AS/NZS 5033.

TABLE 1

PV ARRAY TO EARTH INSULATION RESISTANCE (R_{iso}) LIMITS FOR INVERTER RATINGS

Inverter rating kVA	$R_{iso\ limit}$, kΩ
≤20	30
>20 to ≤30	20
>30 to ≤50	15
>50 to ≤100	10
>100 to ≤200	7
>200 to ≤400	4
>400 to ≤500	2
>500	1

5.4 Compatibility with electrical installation

The inverter shall be compatible with wiring practices for LV electrical installations of AS/NZS 3000 and variations as required in AS/NZS 4777.1. The inverter a.c. voltage and frequency operation shall comply with the limits specified in AS 60038 (for Australia), or IEC 60038 (for New Zealand).

NOTE: The inverter needs to have a.c. voltage and frequency ratings compatible with Australian and New Zealand electrical supply regulations. In Australia, the voltage ranges present on electrical distribution networks may be in accordance with AS 61000.3.100.

5.5 Power factor

The displacement power factor of the inverter, considered as a load from the perspective of the grid, shall, for all current outputs from 25% to 100% of rated current, operate at unity power factor within the range 0.95 leading to 0.95 lagging.

NOTE: For all inverter current outputs below 25% of rated current, it is acceptable for the displacement power factor to be controlled such that the vars supplied or drawn are less than the amount of vars supplied or drawn at 25% current output.

Operation at power factor other than unity is acceptable where the inverter operates in power quality response modes. Additional requirements for displacement power factor control apply for inverters that are capable of operating in power quality response modes. See Clause 6.3.

Compliance shall be determined by type testing in accordance with the power factor test specified in Appendix B.

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5.6 Harmonic currents

The harmonic currents of the inverter shall not exceed the limits specified in Tables 2 and 3 and the total harmonic current distortion (I_{THD}) to the 50th harmonic shall be less than 5%.

Compliance shall be determined by type testing in accordance with the harmonic current limit test specified in Appendix C.

NOTE: The inverter should not significantly radiate or sink frequencies used for ripple control by the local electrical distributor. The distributor should be consulted to determine which frequencies are used. Fitting of additional filtering components may be required in some grid areas.

TABLE 2

ODD HARMONIC CURRENT LIMITS

Odd harmonic order number	Limit for each individual odd harmonic based on percentage of fundamental
3, 5, and 7	4%
9, 11, and 13	2%
15, 17, and 19	1.0%
21, 23, 25, 27, 29, 31 and 33	0.6%

TABLE 3

EVEN HARMONIC CURRENT LIMITS

Even harmonic order number	Limit for each individual even harmonic based on percentage of fundamental
2, 4, 6 and 8	1%
10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30 and 32	0.5%

5.7 Voltage fluctuations and flicker

The inverter shall conform to the voltage fluctuation and flicker limits specified in AS/NZS 61000.3.3 for equipment with rated current less than or equal to 16 A per phase (a.c.).

For equipment with rated current greater than 16 A per phase (a.c.), if the inverter cannot meet the requirements of AS/NZS 61000.3.3, the maximum permissible connection point impedance (Z_{max}) shall be determined such that the voltage fluctuation and flicker limits specified in AS/NZS 61000.3.3 can be met. The impedance shall be determined in accordance with the methods given in AS/NZS 61000.3.11. The values of P_{st} and P_{lt}, when tested using Z_{ref}, and the network impedance value (Z_{max} or Z_{ref}) required for compliance shall be included in the inverter documentation.

NOTE: Definitions of P_{st} and P_{lt} and the value of Z_{ref} are given in AS/NZS 61000.3.3.

Compliance shall be determined by testing in accordance with the appropriate Standard. The inverter shall remain connected throughout the test and the automatic disconnection device shall not operate.

5.8 Transient voltage limits

To prevent damage to electrical equipment connected to the same circuit as the inverter, disconnection of the inverter from the grid shall not result in transient overvoltages beyond the limits specified in Table 4.

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Compliance shall be determined by type testing in accordance with the transient voltage limit test specified in Appendix D. The voltage-duration curve is derived from the measurements taken at the grid-interactive port of the inverter.

The transient voltage limits listed in Table 4 are graphically illustrated in Figure 1.

TABLE 4

TRANSIENT VOLTAGE LIMITS

Duration	Instantaneous voltage	
	Line-to-neutral	Line-to-line
s	V	V
0.0002	910	1580
0.0006	710	1240
0.002	580	1010
0.006	470	810
0.02	420	720
0.06	390	670
0.2	390	670
0.6	390	670

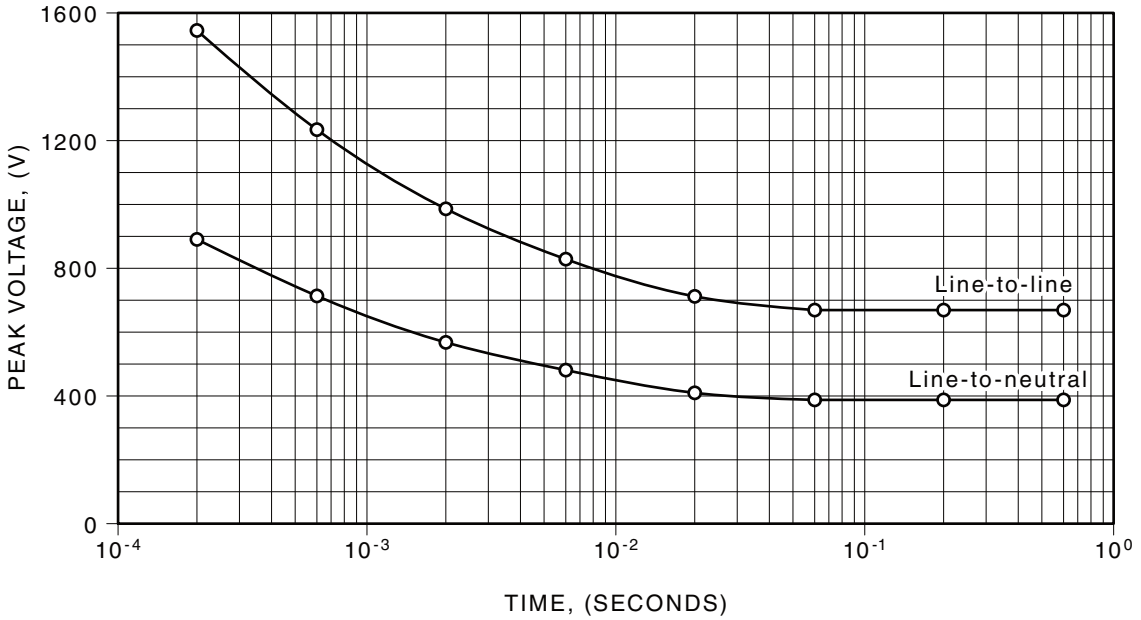


FIGURE 1 VOLTAGE-DURATION CURVE OF TRANSIENT VOLTAGE LIMITS

5.9 D.C. current injection

In the case of a single-phase inverter, the d.c. output current of the inverter at any a.c. port including the grid-interactive and/or stand-alone port shall not exceed 0.5% of the inverter's rated current or 5 mA, whichever is the greater.

In the case of a three-phase inverter, the d.c. output current of the inverter at any a.c. port, including the grid-interactive and/or stand-alone port, measured in each of the phases, shall not exceed 0.5% of the inverter's per-phase rated current or 5 mA, whichever is the greater.

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If the inverter does not incorporate a mains frequency isolating transformer or is not used with a dedicated external isolation transformer, it shall be type tested to ensure the d.c. output current at any a.c. port of the inverter is below the limits specified above at all output current levels.

Compliance shall be determined by type testing in accordance with the d.c. current injection test specified in Appendix E.

NOTE: For any inverter capable of injecting d.c. fault current into the electrical installation the selection of an RCD, where required, needs to be such that the RCD operates correctly with the level of d.c. fault current being injected.

5.10 Current balance for three-phase inverters

In the case of a three-phase inverter the a.c. output current shall be generated and injected into the three-phase electrical installation as a three-phase balanced current.

Compliance shall be determined by type testing in accordance with the following requirement. The a.c. output current for each phase for three-phase balanced current shall be within 5% of the measured value of the other phases at rated current when injected into a balanced three phase voltage.

Inverters which can be used in a voltage balance mode, as defined in Clause 6.3.2.4, are allowed to generate unbalanced currents.

6 OPERATIONAL MODES AND MULTIPLE MODE INVERTERS

6.1 General

Unless otherwise stated, the modes in the following Clauses are for the grid-interactive port of the inverter.

6.2 Inverter demand response modes (DRMs)

6.2.1 *General*

The inverter shall support the demand response mode DRM 0 of Table 5. The inverter should support the other demand response modes of Table 5.

NOTE: The only mandatory demand response mode is DRM 0. Support for other demand response modes is optional and may not be applicable for all sizes of inverters.

The inverter shall detect and initiate a response to all supported demand response commands within 2 s. The inverter shall continue to respond while the mode remains asserted.

The inverter shall comply with the relevant requirements of Clause 5 and this Clause (6), and with all of the requirements of Clause 7, while any demand response mode is asserted.

Compliance shall be determined by testing as specified in Appendix I.

NOTE: The demand response modes may be provided via an integrated device or an external device, as long as DRM 0 meets the requirements of Clause 7.1. Only integrated devices and external devices providing DRM 0 are considered for testing in this Standard.

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TABLE 5

DEMAND RESPONSE MODES (DRMs)

Mode	Requirement
DRM 0	Operate the disconnection device
DRM 1	Do not consume power
DRM 2	Do not consume at more than 50% of rated power
DRM 3	Do not consume at more than 75% of rated power AND Source reactive power if capable
DRM 4	Increase power consumption (subject to constraints from other active DRMs)
DRM 5	Do not generate power
DRM 6	Do not generate at more than 50% of rated power
DRM 7	Do not generate at more than 75% of rated power AND Sink reactive power if capable
DRM 8	Increase power generation (subject to constraints from other active DRMs)

NOTE: Demand response modes of Table 5 are as described in AS/NZS 4755.3 series of Standards.

6.2.2 *Interaction with demand response enabling device (DRED)*

The inverter shall have a means of connecting to a DRED. This means of connection shall include a terminal block or RJ45 socket. The terminal block or RJ45 socket shall comply with the minimum electrical specifications in Table 6. The terminal block or RJ45 socket may be physically mounted in the inverter or in a separate device that remotely communicates with the inverter.

NOTES:

1 In the absence of a DRED, it is acceptable for the inverter to be fitted with a DRED bypass device.

2 RJ45 is the common name for the 8P8C modular connector specified in ISO/IEC 8877, which is generally used to terminate communications cables.

3 Where a separate device that remotely communicates with the inverter is used then other methods are possible using a range of different communications systems and protocols in the inverter or external. Provided that this still allows the inverter to interact with the DRED.

TABLE 6

RJ45 SOCKET AND TERMINAL BLOCK SPECIFICATIONS

Property	Value	Symbol
Current rating	≥1.5	A
Voltage rating (V r.m.s.)	≥125	V
Dielectric strength (V r.m.s. 50 Hz, 1 min)	≥1000	V
Insulation resistance (MΩ min 500 V)	≥500	MΩ

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The DRED asserts demand response modes by shorting together terminals or pins as specified in Table 7. In detecting the state of the DRED, the inverter shall comply with the following requirements:

(a) The inverter shall not inject more than 30 mA (d.c. or a.c.) into—

  (i) terminals 'DRM1/5', 'DRM2/6', 'DRM3/7' or 'DRM4/8', where a terminal block is used; or

  (ii) pins 1, 2, 3 or 4, where an RJ45 socket is used.

(b) The inverter shall allow for a drop of up to 1.6 V across the DRED and associated wiring when nominally shorted.

(c) The inverter shall not supply more than 34.5 V (d.c. or a.c.) to any terminal of the terminal block or RJ45 socket.

(d) If the impedance between pins 5 and 6 is detected to be above 20 kΩ, the inverter shall fail-safe to DRM 0 asserted.

TABLE 7

METHOD OF ASSERTING DEMAND RESPONSE MODES

Mode	RJ45 socket Asserted by shorting pins:		Terminal block Asserted by shorting terminals marked:	
DRM 0	5	6	'REF GEN/0' or 'RG/0'	'COM LOAD/0' or 'CL/0'
DRM 1	1	6	'DRM1/5' or '1/5'	
DRM 2	2	6	'DRM2/6' or '2/6'	
DRM 3	3	6	'DRM3/7' or '3/7'	
DRM 4	4	6	'DRM4/8' or '4/8'	
DRM 5	1	5	'DRM1/5' or '1/5'	'REF GEN/0' or 'RG/0'
DRM 6	2	5	'DRM2/6' or '2/6'	
DRM 7	3	5	'DRM3/7' or '3/7'	
DRM 8	4	5	'DRM4/8' or '4/8'	

The RJ45 socket pin assignments for demand response modes are as specified in Table 8.

TABLE 8

RJ45 SOCKET PIN ASSIGNMENT

Pin	Assignment for inverters capable of both charging and discharging
1	DRM 1/5
2	DRM 2/6
3	DRM 3/7
4	DRM 4/8
5	RefGen
6	Com/DRM0
7	V+
8	V–

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The DRED may assert more than one DRM at a time, in which case the requirements of every active DRM that is supported by the inverter shall be simultaneously satisfied.

The inverter shall detect the assertion of any combination of DRMs which result in terminal 5 and 6 being shorted simultaneously as assertion of DRM 0.

Where DRM 3 or DRM 7 are supported, the reactive power set-point shall be set by default to operate at unity power factor. The reactive power set-point should be adjustable up to a minimum of 60% of the inverter's kVA rating.

The inverter may optionally provide a power supply for use by the DRED. If included this shall be d.c. and of a voltage less than 34.5 V.

Where an RJ45 socket is used, pins 7 and 8 may be utilized as positive and negative DRED power supply pins respectively. The power supply shall be capable of delivering at least 0.5 A at a minimum of 6 V d.c., otherwise the inverter shall short pins 7 and 8 together.

Where a terminal block is used, only those terminals needed for the supported DRMs are required.

6.3 Inverter power quality response modes

6.3.1 *General*

The inverter may have the capability of operating in modes which will—

(a) contribute to maintaining the power quality at the point of connection with the customer installation; or

(b) provide characteristics which are outside the typical operation of an inverter for the purpose of providing support to a grid.

These various operating modes may be enabled or disabled in an inverter and may include the following:

(i) Volt response modes.

(ii) Fixed power factor or reactive power mode.

(iii) Power response mode.

(iv) Power rate limit.

If these power quality response modes are available in the inverter, the inverter shall comply with the relevant requirements of this Clause (6) and Clause 5, and all of the requirements of Clauses 7 and 8, when these modes are enabled or disabled.

Compliance shall be determined by type testing as specified in Appendix I with the applicable modes disabled and enabled.

If these power quality response modes of operation are controlled by an external device, the external device shall not interfere with the inverter complying with the relevant requirements of this Clause (6) and Clause 5, and all of the requirements of Clauses 7 and 8, when the external device is controlling these modes.

The required characteristics of the power quality response modes are specified below.

NOTES:

1 These requirements are intended to facilitate consistency of application and the development of consistent approaches to managing the use of these modes in electrical installations and the local grid.

2 These modes are generally applicable to inverters operating as generators. Additional requirements in 6.4.3 are for inverters that have energy storage and when operating in charging modes.

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6.3.2 *Volt response modes*

6.3.2.1 *General*

The intent of including the volt response modes, which respond to voltage changes at the inverter terminals, is to increase the number of systems which can be connected at a point on the grid without adversely affecting the voltage within an electrical installation.

The volt–watt and volt–var response modes specified in Clause 6.3.2.2 and Clause 6.3.2.3 shall use the volt response reference values specified in Table 9. Each volt response mode may have volt response reference values which are independent of other volt response modes. This is to allow different volt response curves for different volt response modes.

TABLE 9

VOLT RESPONSE REFERENCE VALUES

volts

Reference	Aus. default value	NZ default value	Range
V_1	207	207	Not applicable
V_2	220	220	216 to 230
V_3	250	244	235 to 255
V_4	265	255	244 to 265

6.3.2.2 *Volt–watt response mode*

The volt–watt response mode varies the output power of the inverter in response to the voltage at its terminal. The inverter should have the volt–watt response mode. If this mode is available, it shall be enabled by default.

The response curve required for the volt–watt response mode is defined by the volt response reference values in Table 9 and corresponding power levels. The default values are listed in Table 10 and example response modes are shown in Figure 2(A) for Australia and Figure 2(B) for New Zealand.

TABLE 10

VOLT–WATT RESPONSE
MAXIMUM SET-POINT VALUES
FOR REFERENCE VOLTAGES

Reference	Maximum value (P/P_{rated}), %
V_1	100%
V_2	100%
V_3	100%
V_4	20%

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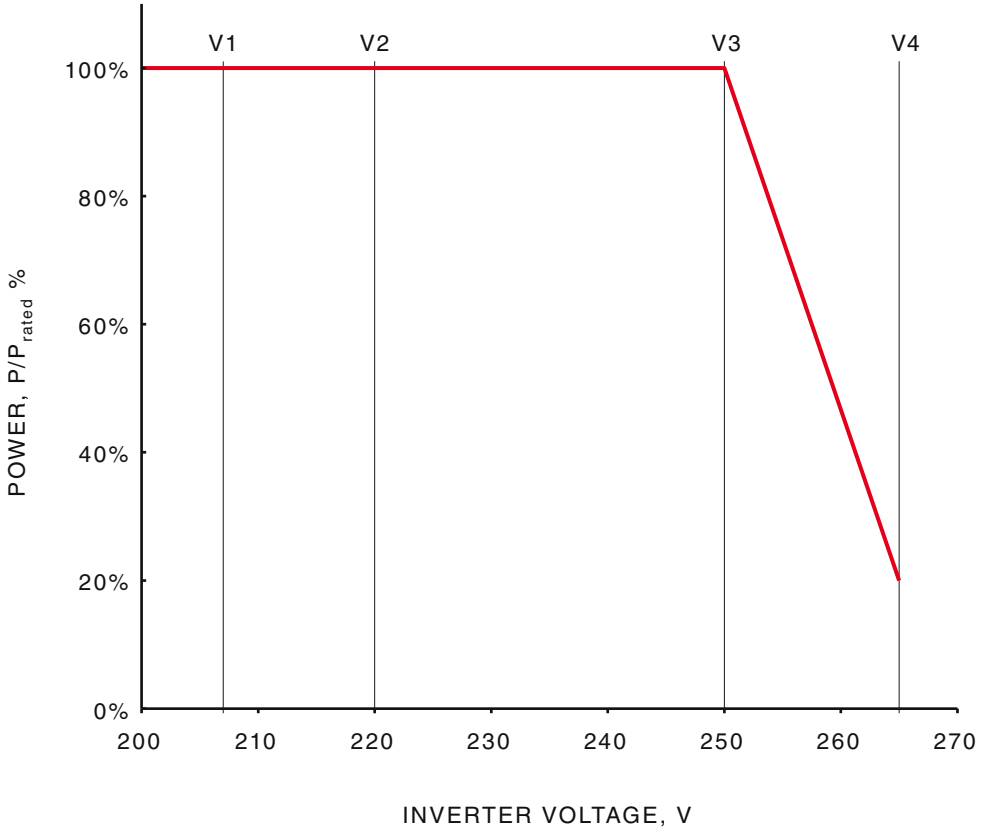


FIGURE 2(A) EXAMPLE CURVE FOR A VOLT–WATT RESPONSE MODE (AUSTRALIA)

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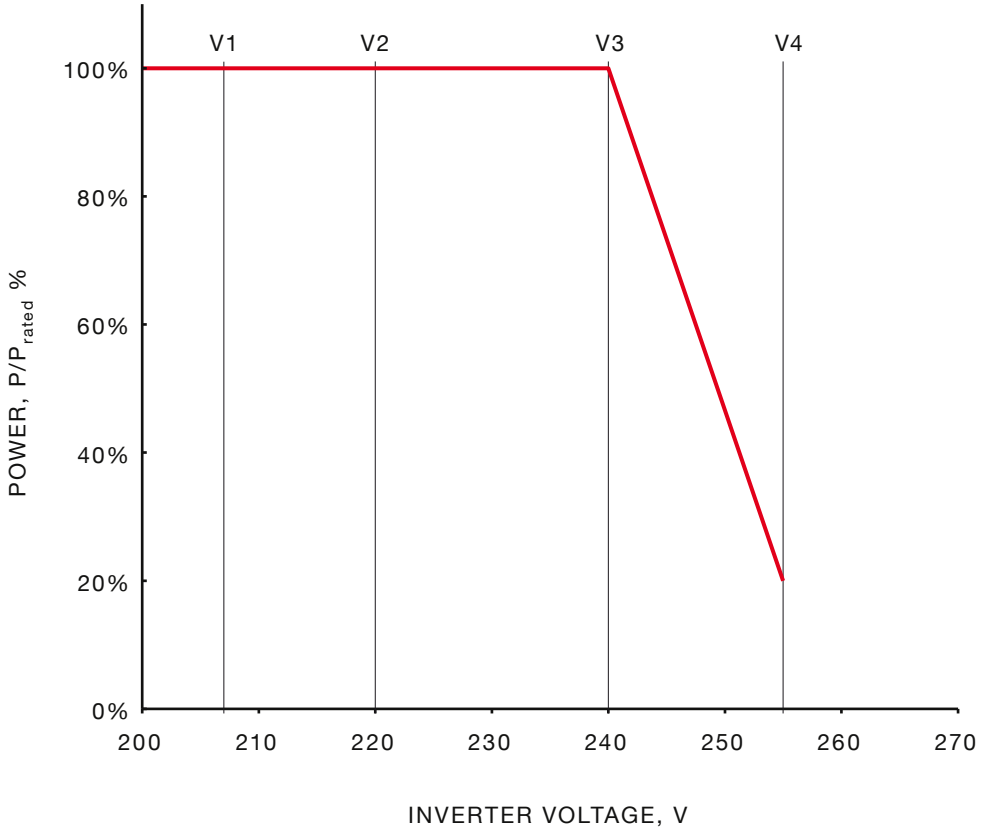


FIGURE 2(B) EXAMPLE CURVE FOR A VOLT–WATT RESPONSE MODE (NEW ZEALAND)

6.3.2.3 *Volt–var response mode*

The volt–var response mode varies the reactive power output of the inverter in response to the voltage at its grid-interactive port. The inverter should have the volt–var response capability. If this mode is available, it shall be disabled by default.

The response curve required for the volt–var response is defined by the volt response reference values specified in Table 9 and corresponding var levels. The default values are listed in Table 11 and shown in Figure 3.

TABLE 11

VOLT–VAR RESPONSE SET-POINT VALUES FOR REFERENCE VOLTAGES

Reference	Default values for var level (var % rated VA)	Minimum range
V_1	30% leading	0 to 60% leading
V_2	0%	0%
V_3	0%	0%
V_4	30% lagging	0 to 60% lagging

NOTES:

1 The percentage var/VA level leading is the inverter sourcing vars to the grid, whereas the percentage var/VA level lagging is the inverter sinking vars from the grid.

2 Inverters may provide a range up to 100% leading or lagging.

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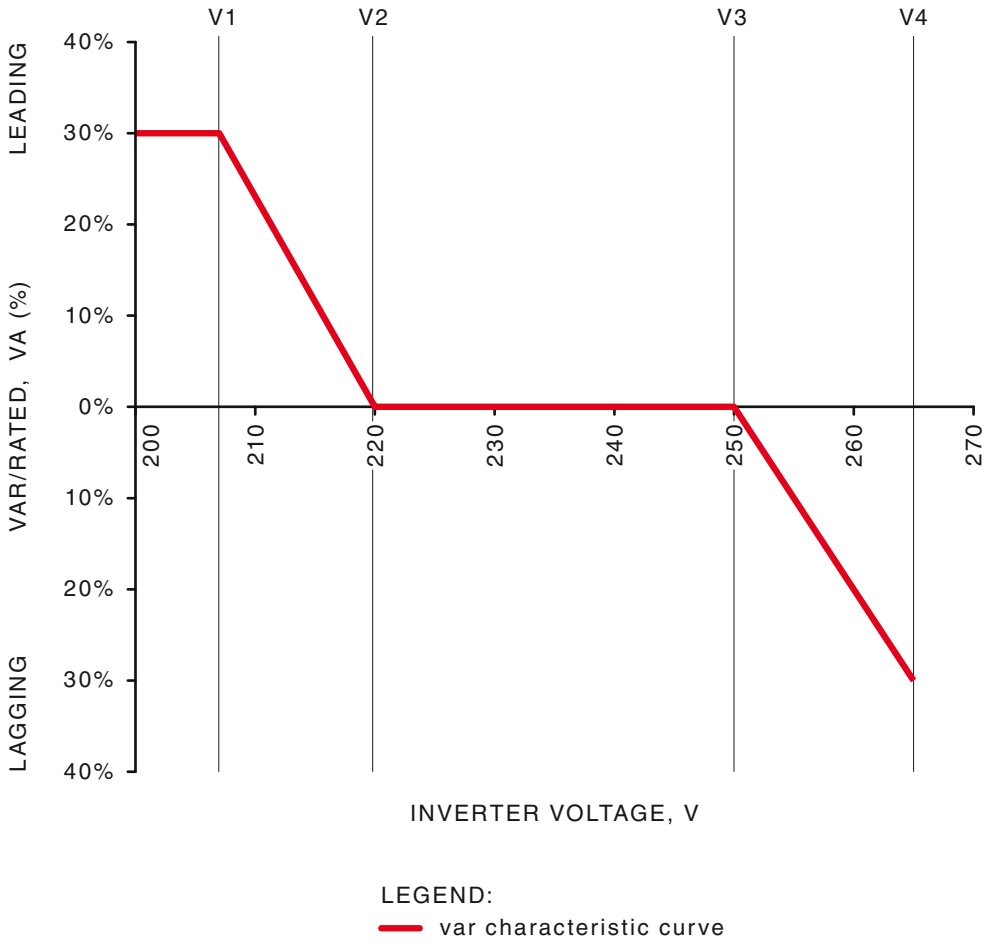


FIGURE 3 EXAMPLE CURVE FOR A POSSIBLE VOLT–VAR CONTROL MODE (AUSTRALIA)

6.3.2.4 *Voltage balance modes*

A voltage imbalance between phases may occur in an electrical installation that presents a load that is not balanced across the phases. Three-phase inverters, or single-phase inverters used in a three-phase combination may be used for voltage balancing between phases by injecting unbalanced three-phase currents into the electrical installation.

If the voltage balance mode is available, the following requirements apply:

(a) The voltage balance mode shall be disabled by default.

(b) For single-phase inverters used in a three-phase combination, the requirements of Clause 8.2 apply.

(c) The voltage balancing mode shall be able to—

(i) operate correctly with a single fault applied;

(ii) detect the fault or loss of operability and cause the inverter to revert to injecting current into the three-phase electrical installation as a three-phase balanced current; or

(iii) detect the fault or loss of operability and disconnect the inverter from the electrical installation.

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6.3.3 *Fixed power factor mode and reactive power mode*

The fixed power factor mode and the reactive power mode may be required in some situations by the electrical distributor to meet local grid requirements. These modes shall be disabled by default.

If the inverter is capable of operating with reactive power mode, the maximum ratio of reactive power (vars) to rated apparent power should be 100%. The reactive power modes may be required to be fixed at a constant reactive power by the electrical distributor.

If the inverter is capable of operating with fixed power factor mode, the minimum range of settings should be 0.8 leading to 0.8 lagging. The fixed power factor mode is for control of the displacement power factor over the range of inverter power output.

NOTE: When operating in this mode for all inverter current outputs below 25% of rated current, it is acceptable for the displacement power factor to be controlled such that the vars supplied or drawn are less than the amount of vars supplied or drawn at 25% current output.

6.3.4 *Characteristic power factor curve for cos φ (P) (Power response)*

The characteristic power factor curve for cos *φ (P)* (Power response) mode varies the displacement power factor of the output of the inverter in response to changes in the output power of the inverter, i.e. cos *φ (P)* modes. If this mode is available, it shall be disabled by default.

NOTE: When operating in this mode for all inverter current outputs below 25% of rated current, it is acceptable for the displacement power factor to be controlled such that the vars supplied or drawn are less than the amount of vars supplied or drawn at 25% current output.

The response curve required for the cos *φ (P)* response should be defined within displacement power factor range of 0.9 leading to 0.9 lagging. One possible cos *φ (P)* curve is shown in Figure 4.

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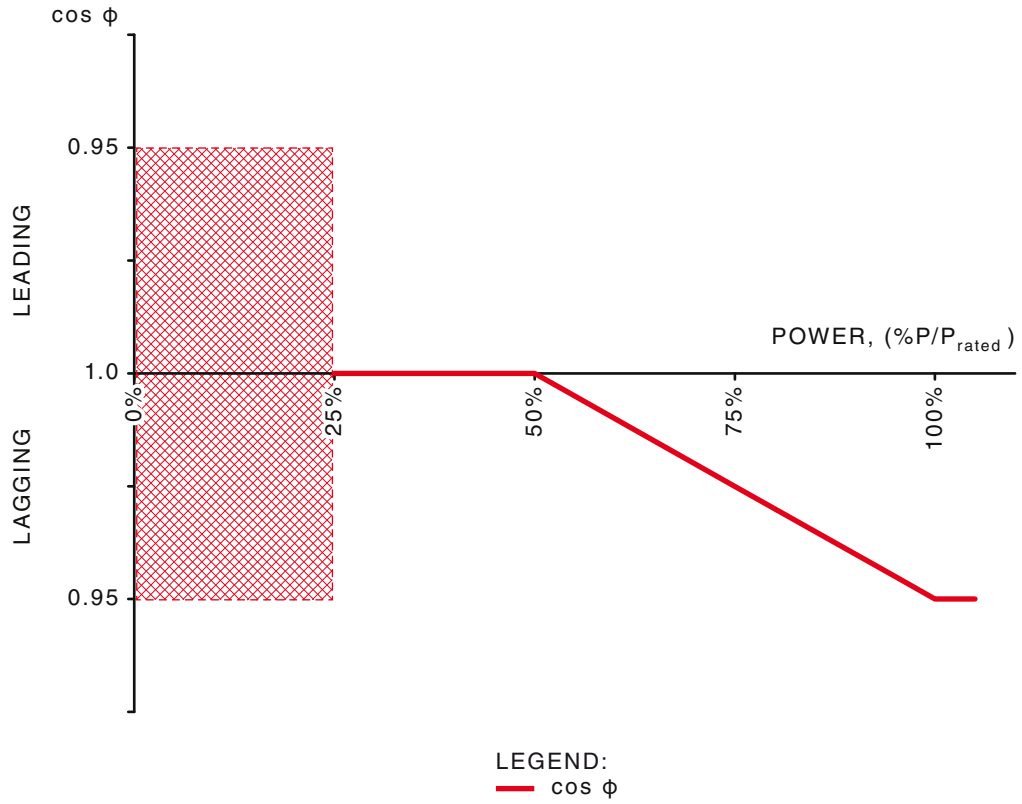


FIGURE 4 EXAMPLE OF A CHARACTERISTIC POWER FACTOR [I.E. COS Φ (P)] CURVE

6.3.5 *Power rate limit*

6.3.5.1 *General*

The power rate limit for an inverter is a power quality response mode. The inverter shall have the capability to rate limit changes in power generation through the grid-interactive port. Inverters capable of multiple mode operation should have the capability to rate limit changes in power consumption (for example increasing/decreasing of charging rates of connected energy storage).

The power rate limit only applies to the changes specified in Clause 6.3.5.3.

The power rate limit does not apply when the inverter disconnection device is required to operate (i.e. to disconnect).

NOTE: The power rate limit causes the inverter power output to either ramp up or ramp down smoothly as it transitions from one power output level to another power output level. These changes in power output level are constrained by several factors such as the type of energy source connected, energy storage and operating state of the inverter. For example, an inverter without energy storage may not be able to ramp down when required if the energy source ceases suddenly or conversely may not be able to ramp up if the energy source is not able to deliver more power. Likewise, when the inverter is outputting its maximum power, it can ramp down but cannot ramp up, while an inverter capable of multiple mode operation with a completely charged storage system may ramp up (discharge power) but cannot ramp up consumption of power (charge power).

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6.3.5.2 *Gradient of power rate limit*

The power rate limit (W_{Gra}) is the ramp rate of real power output in response to changes in power and is defined as a percentage of rated power per minute. The nominal ramp time (Tn) is the nominal time for a 100% change in output power with a power rate limit of W_{Gra}. An inverter shall have an adjustable power rate limit (W_{Gra}) which limits the change in power output to the set power rate limit. The default setting for the power rate limit (W_{Gra}) for increase and decrease shall be 16.67% of rated power per minute which is a nominal ramp time of 6 min.

$$W_{Gra} = \frac{100\%}{Tn}$$

where

Tn = nominal ramp time in minutes (default value is 6 min)

100% = total change from no output to rated power output or from rated power output to no output.

The power rate limit (W_{Gra}) shall be adjustable within the range 5% to 100% of rated power per minute. It is acceptable to have two separate power rate limits for increase and decrease in output power, as follows:

(a) To rate limit an increase in power ($W_{Gra}+$).

(b) To rate limit a decrease in power ($W_{Gra}-$).

6.3.5.3 *Power rate limit modes*

6.3.5.3.1 *General*

The inverter power rate limit (W_{Gra}) is applicable to operate in the following modes:

(a) Soft ramp up after connect or reconnect.

(b) Changes in a.c. operation and control.

(c) Changes in energy source operation.

The following subclauses provide operation information for each mode.

6.3.5.3.2 *Soft ramp up after connect or reconnect*

All inverters shall have this mode. This mode shall be enabled as per Clause 7.7 and for the increase in power required by Clause 7.5.3 after frequency decreased to the required limit.

6.3.5.3.3 *Changes in a.c. operation and control*

If available, this mode shall be enabled for a change in a demand response mode of Clause 6.2 (except for DRM 0). When a demand response mode of Clause 6.2 (except for DRM 0) is asserted or unasserted the power rate limit (W_{Gra}) shall apply to the increase or decrease in power generation or consumption and the transitions between power output levels.

NOTE: Changes in DRM modes (except for DRM 0) are dependent on the availability of the energy source or energy storage to respond. For example an increase in power is not possible if the required increase cannot be met by the available energy resource situation.

The power rate limit for changes in a.c. operation and control does not apply to those inverters that are correcting for sags and swells of less than 1 min.

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6.3.5.3.4 *Changes in energy source operation*

This mode only applies to multiple mode inverters with energy storage. It operates when there is a change in the energy resource available to the inverter, which causes a change in output through the grid-interactive port. For this mode the power rate limit (W_{Gra}) should apply to the increase or decrease in power generation or consumption, and to the transitions between power output levels. For this mode, the power rate limit (W_{Gra}) should be able to be enabled or disabled. The power rate limit shall be disabled by default. The increase or decrease for transitions between power output levels is contingent on external situations (such as amount of available solar energy, wind energy or discharge capacity). Only for increases or decreases in the output which are faster than the power rate limit (W_{Gra}) does a control action to limit the ramp rate apply.

6.3.5.4 *Nonlinearity of power rate limit changes*

The nonlinearity (NL) of the power rate limit (W_{Gra}) in response to an increase of the inverter power output, as defined by the characteristic curve depicted in Figure 5, shall be less than 10%.

The following equation shall be used to calculate the maximum nonlinearity:

$$NL = \frac{(100 \times \Delta)}{Tn}$$

where

NL = maximum nonlinearity

Δ = allowed deviation from the characteristic curve

Tn = nominal ramp time

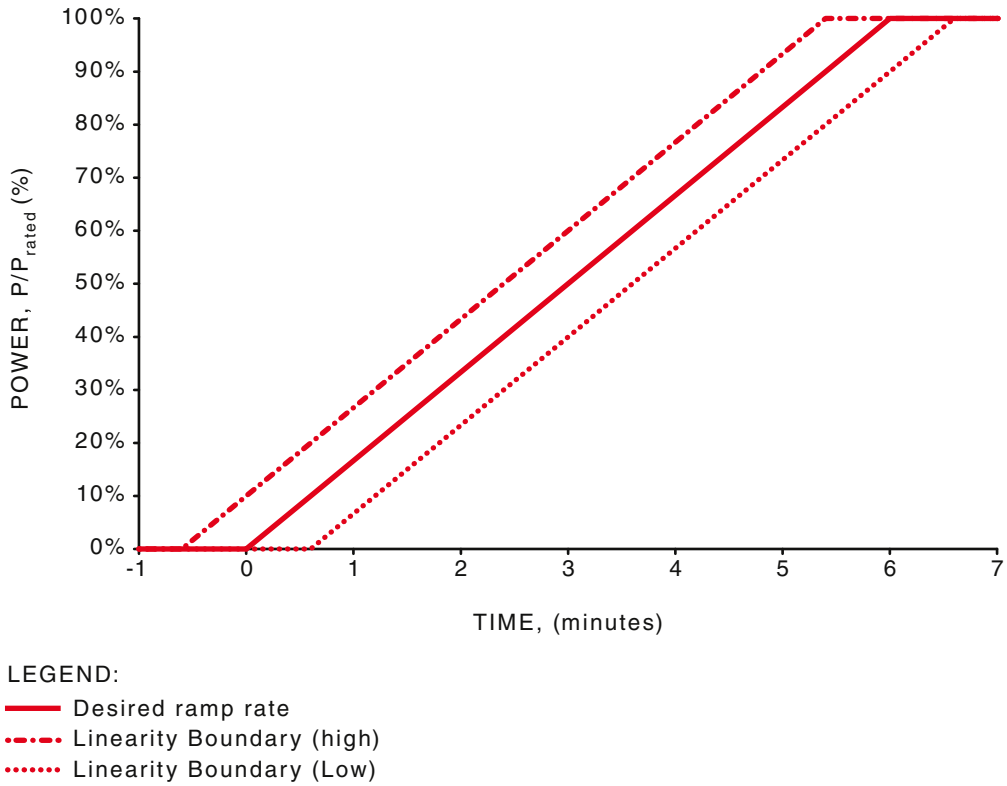


FIGURE 5 NONLINEARITY OF RAMP RATE (W_{Gra} = DEFAULT VALUE)

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6.4 Multiple mode inverter operation

6.4.1 *General*

The requirements in this Clause for multiple mode inverters are in addition to the requirements for inverters.

When the multiple mode inverter is disconnected from the grid any stand-alone port shall ensure that all active conductors are also isolated from the grid-interactive port.

Multiple mode inverters shall be arranged to ensure that the continuity of the neutral conductor to the load from the electrical installation is not interrupted when the inverter disconnects from the grid and supplies a load via the stand-alone port.

NOTE: The requirements for the disconnection device in Clause 7.2 are intended to ensure that at least basic insulation or simple separation is maintained between the energy source port, the grid-interactive port and stand-alone ports when the inverter ceases to operate.

Multiple mode inverters shall be arranged such that only the allowed installation methods of AS/NZS 3000 and AS/NZS 4777.1 can be used.

When the multiple mode inverter is providing the stand-alone function and is disconnected from the grid, the stand-alone port shall comply with the requirements for d.c. current injection (refer to Clause 5.9) into the connected load circuits. The type of RCD compatible with and for use on the stand-alone function outputs shall be declared.

6.4.2 *Sinusoidal output in stand-alone mode*

The a.c. output voltage waveform of a stand-alone port of a multiple mode inverter operating in stand-alone mode, shall comply with the requirements of this Clause (6.4.2). The a.c. output voltage waveform of a stand-alone mode shall have a voltage total harmonic distortion (THD) not exceeding of 5% and no individual harmonic at a level exceeding 5%.

Compliance shall be checked by measuring the THD and the individual harmonic voltages with the inverter delivering 5% power or the lowest continuous available output power greater than 5%, and 50% and 100% of its continuous rated power, into a resistive load, with the inverter supplied with nominal d.c. input voltage. The THD measuring instrument shall measure the sum of the harmonics from $n = 2$ to $n = 50$ as a percentage of the fundamental ($n = 1$) component at each load level.

6.4.3 *Volt–watt response mode for charging of energy storage*

The volt–watt response mode for charging of energy storage varies the power input of the inverter from the grid in response to the voltage at its grid-interactive port. A multiple mode inverter with energy storage which can be charged from the grid shall have this volt–watt response mode. This volt–watt response mode is only active when power from the grid is required to charge the energy storage.

The response curve required for the volt–watt response is defined by the volt response reference values in Table 9 and corresponding power consumption from the grid through the grid-interactive port for charging energy storage. The default values are listed in Table 12 and shown in Figure 6.

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TABLE 12

VOLT–WATT RESPONSE SET-POINT VALUES FOR REFERENCE VOLTAGES FOR MULTIPLE MODE INVERTERS

Reference	Maximum value (P/P_{rated}), %
V_1	0%
V_2	100%
V_3	100%
V_4	100%

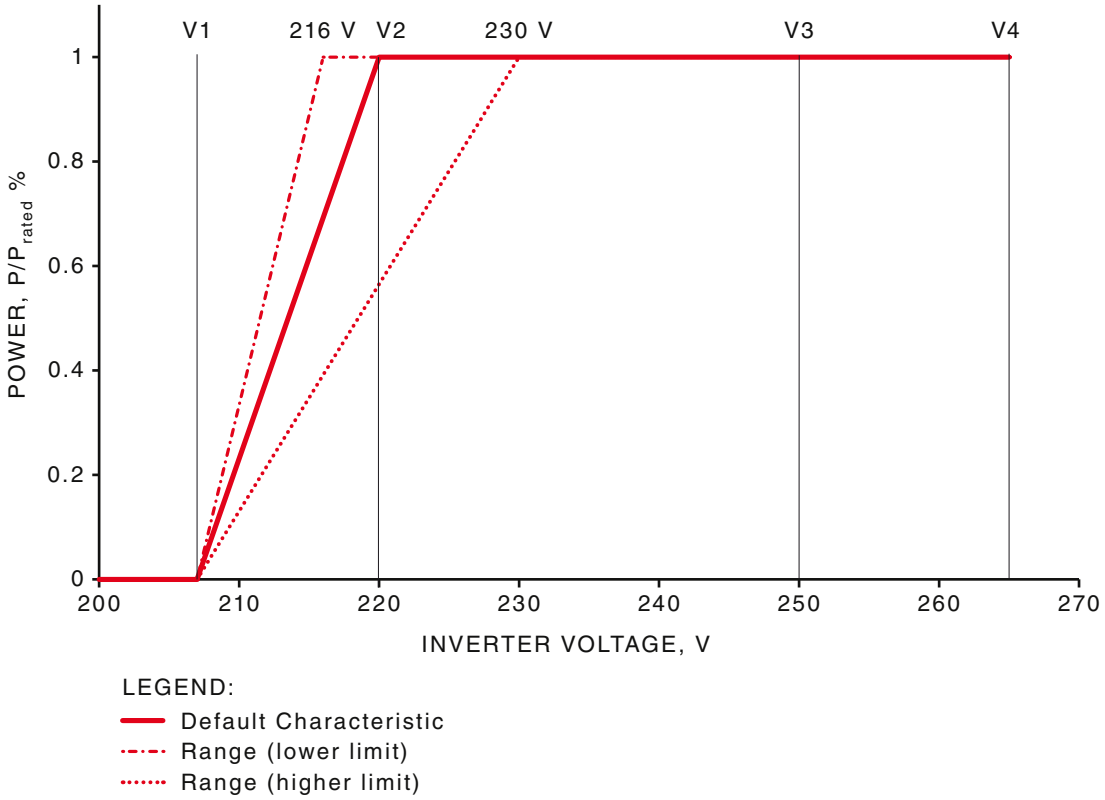


FIGURE 6 EXAMPLE CURVE FOR A BATTERY CHARGING VOLT–WATT RESPONSE MODE

6.5 Security of operational settings

The internal settings of the demand response or power quality response modes of the inverter shall be secured against inadvertent or unauthorized tampering. Changes to the internal settings shall require the use of a tool and special instructions not provided to unauthorized personnel.

NOTE: Special interface devices and passwords are regarded as tools.

The installer-accessible settings shall be capable of being adjusted within the values specified in this Clause (6).

Compliance shall be determined by inspection.

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7 PROTECTIVE FUNCTIONS FOR CONNECTION TO ELECTRICAL INSTALLATIONS AND THE GRID

7.1 General

There shall be an automatic disconnection device to prevent injection of energy into the point of supply and prevent the formation of an unintentional island with the grid or part thereof when supply is disrupted from the grid.

NOTE: This includes preventing the formation of an island within any part of the electrical installation, which is normally connected to the grid.

The automatic disconnection device shall operate—

(a) if supply from the grid is disrupted;

(b) when the grid goes outside preset parameters (e.g. undervoltage/overvoltage, under-frequency/over-frequency); or

(c) when the demand response mode DRM 0 (see Clause 6.2) is asserted.

For inverter energy systems connected to multiple phases the automatic disconnection device shall operate if any of the above conditions is met on any phase.

The automatic disconnection device may be within the inverter or a separate device.

Compliance with this Standard shall be determined by type testing the automatic disconnection device within the inverter or combined with the inverter. Where the automatic disconnection device is separate to the inverter (or inverters), the inverter (or inverters) and the automatic disconnection device shall be tested together as though they are one inverter. Compliance of one combination of inverter and automatic disconnection device does not ensure compliance of either device as part of a different combination. Specific requirements are specified in Clauses 7.2 to 7.8.

7.2 Automatic disconnection device

The automatic disconnection device shall prevent power (both a.c. and d.c.) from entering the grid when the automatic disconnection device operates.

NOTE: The automatic disconnection device need not disconnect sensing circuits.

The automatic disconnection device shall provide isolation in all live conductors.

Automatic disconnection devices for isolation shall comply with the following requirements:

(a) They shall be capable of withstanding an impulse voltage likely to occur at the point of installation, or have an appropriate contact gap.

(b) They shall not be able to falsely indicate that the contacts are open.

(c) They shall be designed and installed so as to prevent unintentional closure, such as might be caused by impact, vibration or the like.

(d) They shall be devices that disconnect all live conductors (active and neutral) of the inverter from the grid-interactive port.

Exception: For multiple mode inverters with stand-alone function, which comply with AS 62040.1.1, the automatic disconnection device for isolation shall be a device that disconnects active conductors of the multiple mode inverter from the grid-interactive port.

(e) They shall be such that with a single fault applied to the automatic disconnection device or to any other location in the inverter, at least basic insulation or simple separation is maintained between the energy source port and the grid-interactive port when the means of disconnection is intended to be in the open state.

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(f) They shall be such that with a single fault applied to the automatic disconnection device or to any other location in the inverter, power is prevented from entering the grid.

NOTE: In the case of a non-isolated inverter, the prevention of power entering the grid can be achieved by two mechanical automatic disconnection devices in series in each live conductor. In the case of an isolated inverter, the prevention of power entering the grid can be achieved by a single mechanical automatic disconnection device and a semiconductor device (or semiconductor devices) in each live conductor.

The automatic disconnection device shall be capable of interrupting at least the rated current.

The settings of the automatic disconnection device shall not exceed the capability of the inverter.

A semiconductor (solid-state) device shall not be used for isolation purposes.

7.3 Active anti-islanding protection

The automatic disconnection device shall incorporate at least one method of active anti-islanding protection.

NOTE: Examples of such methods include—

(a) shifting the frequency of the inverter away from nominal conditions in the absence of a reference frequency (frequency shift);

(b) allowing the frequency of the inverter to be inherently unstable in the absence of a reference frequency (frequency instability);

(c) periodically varying the output power of the inverter (power variation); and

(d) monitoring for sudden changes in the impedance of the grid by periodically injecting a current pulse (current injection).

The method used to provide active anti-islanding protection shall be declared.

NOTE: Active anti-islanding protection is required in addition to the passive anti-islanding protection specified in Clause 7.4 to prevent a situation where islanding may occur because multiple inverters and/or other generators are providing a frequency and voltage reference for one another and/or because load and generation is balanced.

To prevent islanding, the active anti-islanding protection system shall operate the automatic disconnection device (see Clause 7.2) within 2 s of disruption to the power supply from the grid.

Compliance shall be determined by type testing in accordance with the active anti-islanding tests specified in Appendix F or IEC 62116.

NOTE: IEC 62116 scope is for PV inverters however for purposes of this Standard the test is applicable to other inverter energy systems.

7.4 Voltage and frequency limits (passive anti-islanding protection)

The automatic disconnection device shall incorporate the following forms of passive anti-islanding protection:

(a) Undervoltage and overvoltage protection.

(b) Under-frequency and over-frequency protection.

For sustained variation of the voltage and frequency beyond each limit specified in Table 13, the automatic disconnection device (see Clause 7.2) shall operate no sooner than the required trip delay time and before the maximum disconnection time.

This requires the inverter to remain in continuous, uninterrupted operation for voltage variations with a duration shorter than the trip delay time specified in Table 13.

NOTE: When voltage falls below the undervoltage limit of Table 13 it is permissible to continue, reduce or stop the inverter output during the trip time delay and if voltage returns above the limit during the trip time delay period it may resume normal operation.

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TABLE 13

PASSIVE ANTI-ISLANDING SET-POINT VALUES

Protective function	Protective function limit	Trip delay time	Maximum disconnection time
Undervoltage (V<)	180 V	1 s	2 s
Overvoltage 1 (V>)	260 V	1 s	2 s
Overvoltage 2 (V>>)	265 V	—	0.2 s
Under-frequency (F<)	47 Hz (Australia) 45 Hz (New Zealand)	1 s	2 s
Over-frequency (F>)	52 Hz	—	0.2 s

Each protective function limit shall be preset and secured against change.

NOTE: It is acceptable for these limits to be part of a country-specific set-up, selected at installation.

Compliance shall be determined by type testing in accordance with the voltage and frequency limits tests specified in Appendix G.

7.5 Limits for sustained operation

7.5.1 *General*

The inverter or inverter energy system shall remain connected over the range of voltages and frequencies that it is required to be compatible with. Refer to Clause 5.4.

7.5.2 *Sustained operation for voltage variations*

The inverter shall operate the automatic disconnection device (see Clause 7.2) within 3 s when the average voltage for a 10 min period exceeds the V_{nom_max}, where $V_{nom\text{-}max}$ lies in the range 244–258 V.

The sustained operation for voltage variations shall not interfere with the active and passive anti-islanding requirements of Clauses 7.3 and 7.4.

The limit $V_{nom\text{-}max}$, shall be preset to the default set-point and may be programmable up to the maximum 258 V. The default set-point for $V_{nom\text{-}max}$ shall be as follows:

(a) In Australia: 255 V.

(b) In New Zealand: 248 V.

NOTE: The default set-point is set to allow for some voltage drop from the inverter grid-interactive port to the point of supply, preventing voltage rise above the upper voltage limits for all output levels of the inverter. The default set-points for Australia are 2 V above the upper limit specified in AS 60038 (for Australia). The default set-point for New Zealand is 4 V above the upper limit in IEC 60038 required at the point of supply in New Zealand.

The 10 min average value shall be compared against the limit $V_{nom\text{-}max}$ at least every 3 s to determine when to disconnect.

NOTE: The 10 min average value needs to be calculated for the preceding 10 min based on measurements at the inverter's terminals or another external measurement position.

Compliance shall be determined by type testing in accordance with the sustained operation for voltage variations test specified in Appendix H.

7.5.3 *Sustained operation for frequency variations*

7.5.3.1 *Response to an increase in frequency*

The inverter shall be capable of supplying rated power between 47 Hz and 50.25 Hz for Australia.

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The inverter shall be capable of supplying rated power between 45 Hz and 50.25 Hz for New Zealand.

When a grid frequency disturbance results in an increase in grid frequency which exceeds 50.25 Hz, the inverter shall reduce the power output linearly with an increase of frequency until f_{stop} is reached, where f_{stop} lies in the range 51–52 Hz.

The power level present at the time the frequency reaches or exceeds 50.25 Hz shall be held as the reference power level used to calculate the required response to the increasing frequency.

This is expressed in the equation below:

$$P_{out} = P_{ref}\left[1-\frac{(f-50.25)}{(f_{stop}-50.25)}\right]$$

where

P_{out} = required output for a frequency between 50.25 Hz and f_{stop}

P_{ref} = reference power level when the frequency reaches or exceeds 50.25 Hz

f = frequency between 50.25 Hz and f_{stop}

When the frequency exceeds f_{stop} the inverter power output shall be ceased (i.e. 0 W). The default set-point for f_{stop} shall be 52 Hz.

The output power shall remain at or below the lowest power level reached in response to an over-frequency event between 50.25 Hz and f_{stop}. This is to provide hysteresis in the control of the inverter. When the grid frequency has decreased back to 50.15 Hz or less for at least 60 s, the power level shall be increased at a rate no greater than the power rate limit (W_{Gra}) of Clause 6.3.5 until the available energy source power is reached. Figure 7(A) shows this.

Unconstrained power operation may recommence 6 min after the frequency returns to and remains at less than 50.15 Hz.

NOTE: No delay in response to a frequency change is required although it is acceptable to have a delay due to an inherent inverter system control mechanism.

Compliance shall be determined by type testing in accordance with the sustained operation for frequency variations test specified in Appendix H.

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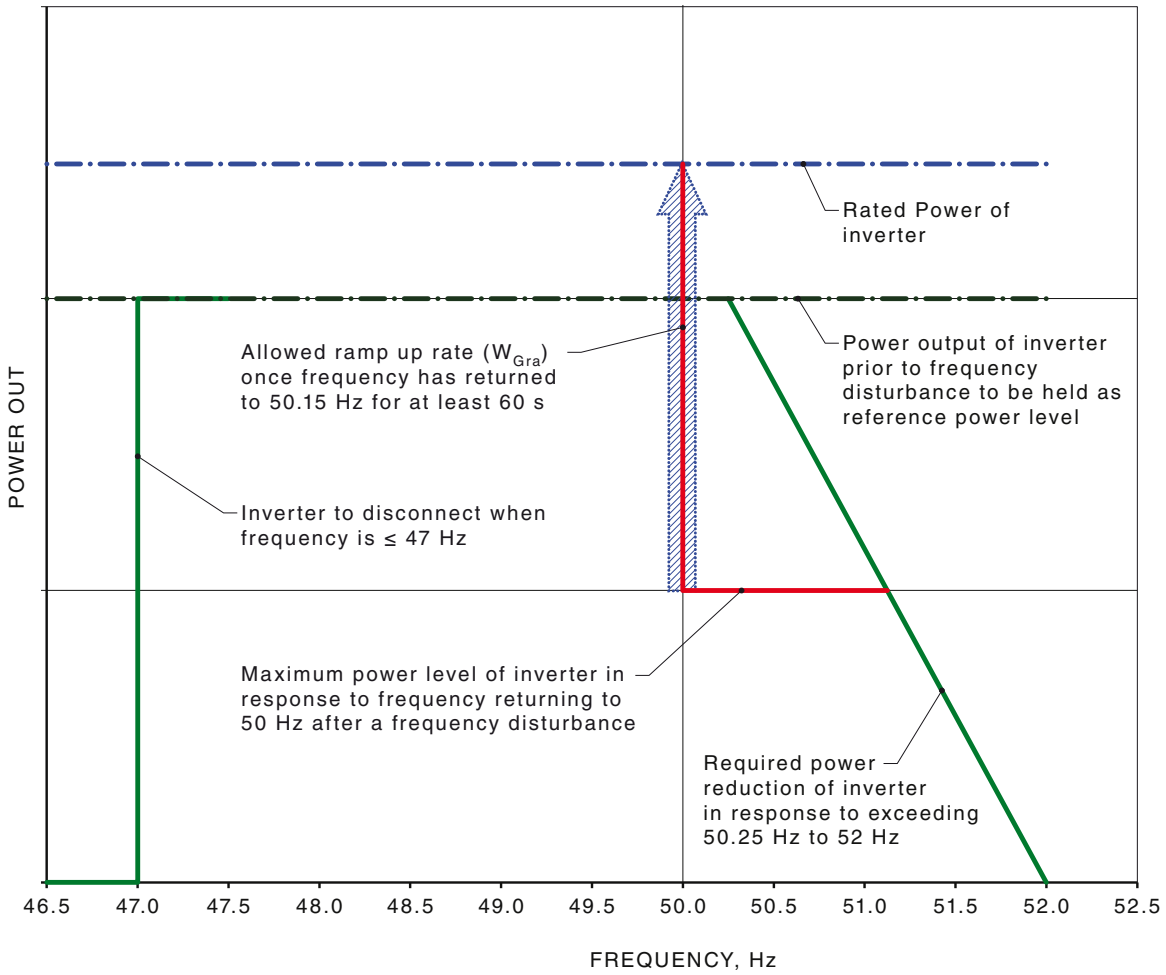


FIGURE 7(A) EXAMPLE FREQUENCY RESPONSE FOR OVER-FREQUENCY CONDITIONS FOR f_{stop} OF 52 Hz

7.5.3.2 *Response to a decrease in grid frequency*

This requirement applies only to inverters with energy storage.

The inverter shall be capable of charging the energy storage between 49.75 Hz and 52.0 Hz.

When a grid frequency disturbance results in a decrease in grid frequency which falls below 49.75 Hz, an inverter with energy storage which is charging from the grid port should reduce the power input for charging linearly with a decrease of frequency until $f_{stop\text{-}CH}$ is reached, where $f_{stop\text{-}CH}$ lies in the range 47–49 Hz.

The power input level for charging present at the time the frequency reaches or falls below 49.75 Hz shall be held as the reference charge rate used to calculate the required response to the decreasing frequency.

This is expressed in the equation below:

$$P_{charge} = P_{ref}\left[1-\frac{(49.75-f)}{(49.75-f_{stop-CH})}\right]$$

where

P_{charge} = charge rate of the storage element for a frequency between 49.75 Hz and $f_{stop\text{-}CH}$

$P_{ref\text{-}CH}$ = charge rate of the storage element when the frequency reaches or falls below 49.75 Hz

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f = frequency between 49.75 Hz and $f_{stop-CH}$

When the frequency falls below $f_{stop-CH}$, the inverter should have ceased charging the storage element (i.e. 0 W). The default set-point for $f_{stop-CH}$ should be 49 Hz.

The power input level for charging of the storage element shall remain at or below the lowest charge rate reached in response to a low-frequency event between $f_{stop-CH}$ and 49.75 Hz. This is to provide hysteresis in the control of the inverter.

When the grid frequency has increased back to 49.85 Hz or more for at least 60 s, the charge rate of the storage element may be increased at a rate no greater than the power rate limit (W_{Gra}) of Clause 6.3.5 until the charge rate present at the time of the frequency disturbance is reached. Figure 7(B) shows this.

Unconstrained charging of the storage element may recommence 6 min after the frequency returns to and remains above than 49.85 Hz.

NOTE: No delay in response to a frequency change is required, although it is acceptable to have a delay due to an inherent inverter system control mechanism.

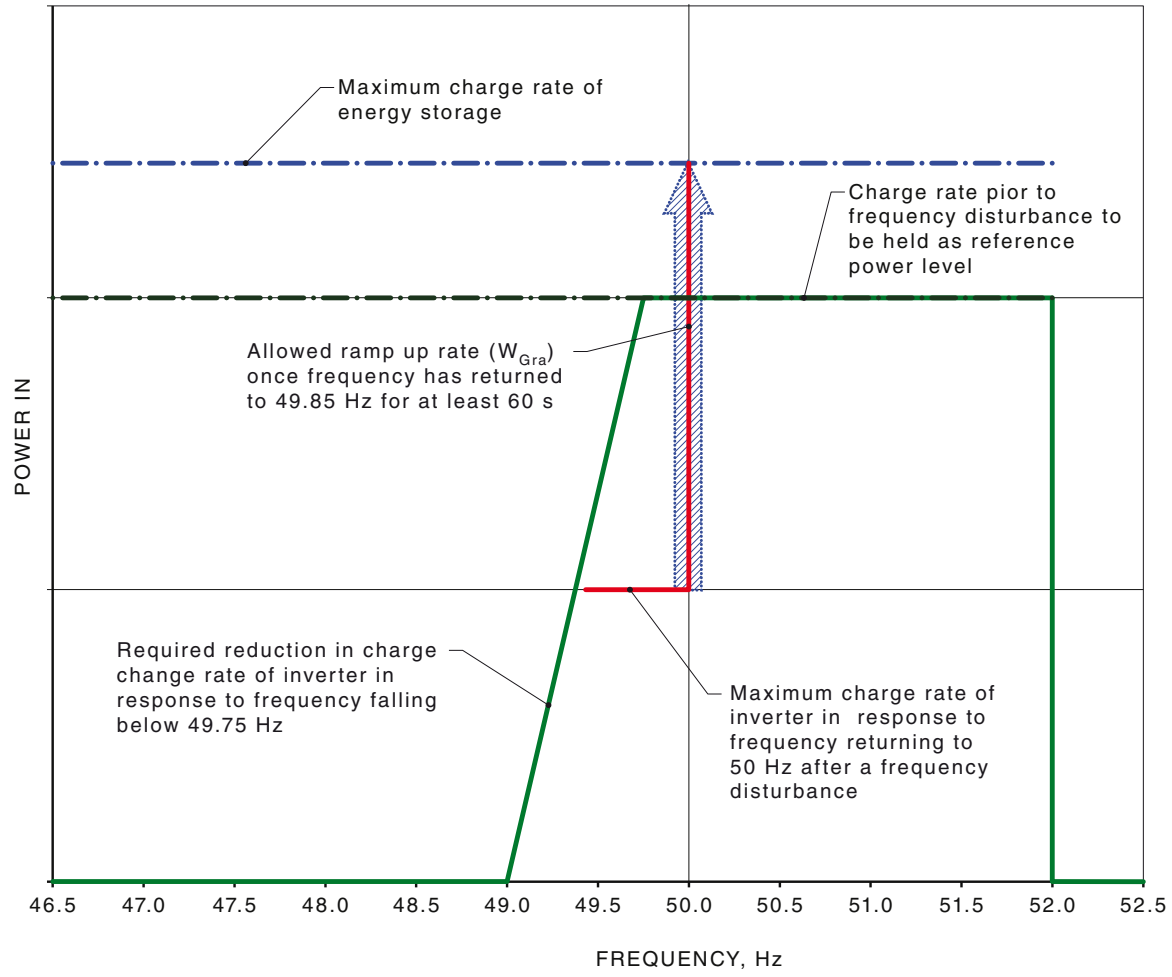


FIGURE 7(B) EXAMPLE FREQUENCY RESPONSE FOR UNDER-FREQUENCY CONDITIONS FOR $f_{stop-CH}$ OF 49 HZ

Compliance shall be determined by type testing in accordance with the sustained operation for frequency variations test specified in Appendix H.

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7.6 Disconnection on external signal

The automatic disconnection device shall incorporate the ability to disconnect on an external signal.

If an external signal or demand response 'DRM 0' condition is asserted, the automatic disconnection device shall operate within 2 s.

Compliance shall be determined by type testing as specified in Appendix I.

7.7 Connection and reconnection procedure

Only after all of the following conditions have been met shall the automatic disconnection device operate to connect or reconnect the inverter to the grid—

(a) the voltage of the grid has been maintained within the limits of AS 60038 (for Australia) or IEC 60038 (for New Zealand) for at least 60 s;

(b) the frequency of the grid has been maintained within the range 47.5 Hz to 50.15 Hz for at least 60 s;

(c) the inverter and the grid are synchronized and in-phase with each other; and

(d) no external signal is present or DRM 0 asserted requiring the system to be disconnected.

After the automatic disconnection device operates to connect or reconnect the inverter the output shall rate limit increase in power generation to the set power rate limit (W_{Gra}) for increase in power of Clause 6.3.5. Unconstrained power operation may recommence after the automatic disconnection device operates to connect or reconnect the inverter, when either the rated power output is reached or the required output power level of the inverter exceeds the available energy source.

Compliance shall be determined by type testing in accordance with the tests as specified in Appendix F and Appendix G.

7.8 Security of protection settings

The internal settings of the automatic disconnection device shall be secured against inadvertent or unauthorized tampering. Changes to the internal settings shall require the use of a tool and special instructions not provided to unauthorized personnel.

NOTE: Special interface devices and passwords are regarded as tools.

The installer-accessible settings of the automatic disconnection device shall be capable of being adjusted within the limits specified in Clause 7.5.

The manufacturer settings of the automatic disconnection device, specified in Clause 7.4, shall be secured against changes.

NOTE: It is acceptable for the manufacturer settings to be part of a country-specific set-up, selected at installation.

Compliance shall be determined by inspection.

8 MULTIPLE INVERTER COMBINATIONS

8.1 General

There are installations where multiple inverter energy systems are used and the electrical installation connects at a single point of supply to the grid. Inverter energy systems are often comprised of multiple inverters used in combination to provide the desired inverter energy system capacity or to ensure that voltage balance is maintained in multiple phase connections to the grid.

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This Clause (8) specifies the requirements and tests for inverter energy systems used in such combinations. If a combination is not tested, it should not be used or external devices should be used in accordance with the requirements of AS/NZS 4777.1.

Possible combinations are single-phase inverters used in parallel, single-phase inverters used in multiple phase installations and three-phase inverters used in parallel.

8.2 Inverter current balance across multiple phases

In a three-phase inverter system comprised of individual single-phase inverters the a.c. output current should be generated and injected into the three-phase electrical installation as a three-phase balanced current. The maximum current imbalance in a three-phase inverter system comprised of individual single-phase inverters shall be no more than 21.7 A.

NOTE: Provisions for current balance of three-phase inverters are given in Clause 5.10.

8.3 Grid disconnection

When any inverter within the inverter energy system disconnects as required by Clause 7, all inverters within the inverter energy system shall disconnect within 2 s of the first inverter disconnecting. This applies to all inverters used in combination for single-phase or multiple phases.

8.4 Grid connection and reconnection

When multiple inverters are used together in a multiple phase combination, only after all the conditions of Clause 7.7 have been met on all connected phases shall the automatic disconnection device operate to connect or reconnect any inverter of the multiple phase combination to the grid.

Where any inverter used in a multiple phase combination has a rated current exceeding 21.7 A per phase, the requirement of Clause 8.2 shall be met when connecting or reconnecting.

8.5 Testing combinations

8.5.1 *Single-phase combinations*

Single-phase parallel combinations of inverters shall be tested for combinations with total rated current (I_{rated}) equal to or up to the maximum of 6 A per phase.

To determine the number of inverters to be tested, the following equation shall be used:

$$N = \frac{6}{I_{rated}}$$

where

N = number to be tested, rounded up to next whole number

I_{rated} = rating of the inverter in amperes

If $N \geq 2$, the minimum number of inverters to be tested shall be N. If $N > 6$, the maximum number of inverters to be tested in a combination shall be 6.

8.5.2 *Single-phase inverters used in three-phase combinations*

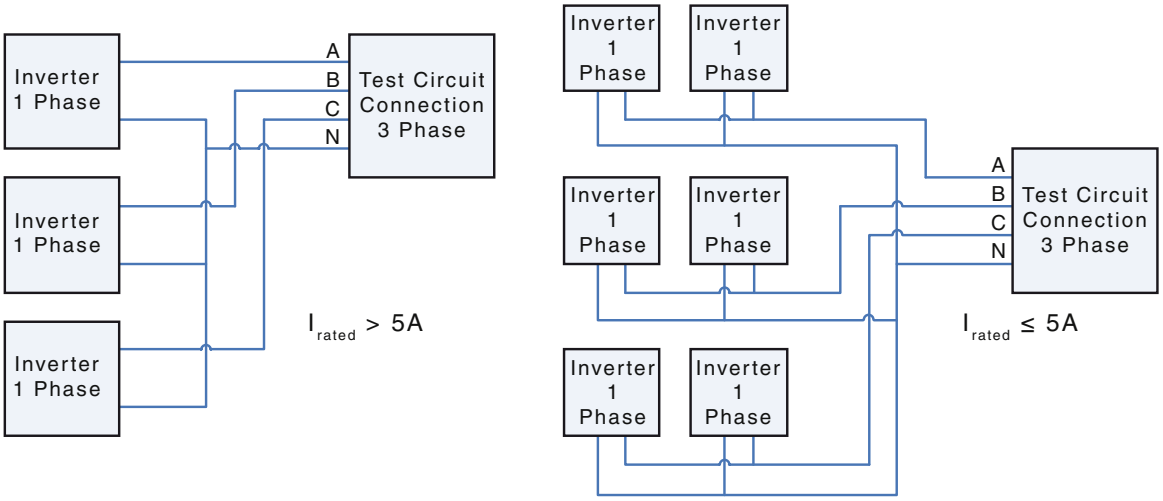
For single-phase inverters with rated current (I_{rated}) greater than or equal to 5 A used in three-phase combinations, three inverters shall be tested in a three-phase arrangement [refer to Figure 8(a)].

Single-phase inverters with rated current less than 5 A and to be used in three-phase combinations shall be tested in combination with at least two inverters per phase [refer to Figure 8(b).

NOTE: Testing of combinations is not required if the test combination is not allowed by the inverter manufacturer's installation instructions or similar documentation.

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(a) Three single phase inverters in three phase arrangement

(b) Six single phase inverters (< 5A) in three phase arrangement)

FIGURE 8 SINGLE-PHASE INVERTERS IN THREE-PHASE COMBINATIONS

8.5.3 *Required tests for multiple inverter combinations*

Any single-phase inverter used in a multiple inverter combination shall be tested individually and meet all the requirements of this Standard. Any single-phase inverter which is to be used as part of a multiple inverter combination shall be tested in combination as specified in Clauses 8.5.1 and 8.5.2.

The tests specified in Table 14 for multiple inverter combinations shall be performed.

TABLE 14

REQUIRED TESTS FOR MULTIPLE INVERTER COMBINATIONS

Test required	Single-phase combinations (Clause 8.5.1)	Single-phase inverters used in three-phase combinations (Clause 8.5.2)
Active anti-islanding (Clause 7.3 and Appendix F)	Test required	Test required
V and freq. limits (Clause 7.4 and Appendix G)	Not required	Test required
Balance (Clause 8.2)	Not applicable	Test required

Compliance shall be determined by type testing as specified in Appendix J.

8.5.4 *Multiple inverters with one automatic disconnection device*

Where the inverter does not have an internal automatic disconnection device, or requires an external automatic disconnection device to provide the required disconnection function, or both, testing shall be conducted with the automatic disconnection device and with either the number of inverters required by Clause 8.5.1 and 8.5.2 or with the automatic disconnection device configured with the number of inverters specified by the manufacturer's instructions.

Compliance shall be determined by performing all of the type tests specified in Clause 5.

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9 INVERTER MARKING AND DOCUMENTATION

9.1 General

The inverter shall comply with the marking and documentation requirements of IEC 62109-1 and IEC 62109-2, as varied by this Clause (9).

All markings and documentation shall be in the English language.

NOTE: It is acceptable for the marking and documentation to be written in other languages in addition to English.

9.2 Marking

9.2.1 *General*

The following variations apply to the marking requirements of IEC 62109-1 and IEC 62109-2:

(a) Inverters that are designated for use in inverter energy systems incorporating energy sources other than PV arrays or batteries shall bear additional or alternative markings appropriate to the energy source.

(b) Inverters that are designated for use in closed electrical operating areas shall be marked with a warning stating that they are not suitable for installation in households or areas of a similar type or use (i.e. domestic).

NOTE: This requirement is derived from the Cooling system failure—Blanketing test of IEC 62109-2. It is intended to ensure that inverters for closed electrical operating areas are not installed in areas where the intended ventilation may be blocked after installation due to shared access and use. For example, an inverter may be installed with correct ventilation in a storage area, but over time the area may become cluttered with material that blocks required ventilation and rests against the heat sink, preventing adequate cooling of the device.

9.2.2 *Equipment ratings*

The inverter shall be marked with its ratings and the ratings of each port, as specified in Table 15. Only those ratings that are applicable to the type of inverter are required. The ratings shall be plainly and permanently marked on the inverter, in a location that is clearly visible after installation.

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TABLE 15

INVERTER RATINGS—MARKING REQUIREMENTS

Port (all that apply)	Parameter	Marking value or symbol	Units
Photovoltaic	Vmax PV (absolute maximum)		d.c. V
	Isc PV (absolute maximum)		d.c. A
Wind (a.c. or d.c.)	Voltage (nominal or range)		a.c V or d.c. V
	Rated current (maximum continuous)		a.c A or d.c. A
	Frequency (nominal or range) (a.c. wind only)		Hz
Energy storage ports	Voltage (nominal)		d.c. V
	Voltage (range)		d.c. V
	Rated current (maximum continuous)		d.c. A
	Storage type	e.g. lead acid batteries	
Other energy sources or inputs (a.c. or d.c.)	Voltage (nominal or range)		a.c V or d.c. V
	Rated current (maximum continuous)		a.c A or d.c. A
	Power factor (range)		
	Frequency (nominal or range) (a.c. sources only)		Hz
a.c. output ratings (for each port)	Voltage (nominal or range)		a.c. V
	Rated current		a.c. A
	Frequency (nominal or range)		Hz
	Rated apparent power		VA
	Power factor range		
d.c. output ratings	Voltage (nominal or range)		d.c. V
	Rated current		d.c. A
Inverter topology		Isolated or non-isolated Or symbol	
Protective class (I, II or III)		I, II or III Or symbol	
Ingress protection (IP) rating		IPXX	

NOTE: Table 15 is based on the requirements of IEC 62109-2.

9.2.3 *Ports*

Each port shall be marked with its classification and indicate whether a.c or d.c. voltage as appropriate.

Typical classifications include the following:

(a) PV (photovoltaic).

(b) Wind turbine.

(c) Energy storage.

(d) Battery.

(e) Generator.

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(f) Grid-interactive.

(g) Stand-alone.

(h) Communications (type).

(i) DRM.

(j) Load.

9.2.4 *External and ancillary equipment*

If the inverter requires external or ancillary equipment for compliance with this Standard, the requirement for any such equipment shall be marked on the inverter along with the following or an equivalent statement: 'Refer to the installation instructions for type and ratings' or symbol.

NOTE: External or ancillary equipment includes external automatic disconnection devices, external isolation transformers and external RCDs.

Any external or ancillary equipment shall be marked in accordance with this Clause (9).

9.2.5 *Residual current devices (RCDs)*

Inverter energy systems used with PV array systems require residual current detection in accordance with IEC 62109-1 and IEC 62109-2. The requirements can be met by the installation of a suitably rated RCD external to the inverter or by an RCMU integral to the inverter.

Where an external RCD is required, the inverter shall be marked with a warning along with the rating and type of RCD required. The warning shall be located in a prominent position and written in lettering at least 5 mm high. It shall contain the following or an equivalent statement:

WARNING: AN RCD IS REQUIRED ON THE [*NAME*] PORTS OF THE INVERTER

If the inverter energy system requires a Type B RCD, the inverter shall be marked with a warning. The warning shall be located in a prominent position and written in lettering at least 5 mm high. It shall contain the following:

WARNING: A TYPE B RCD IS REQUIRED ON THE [*NAME*] PORTS OF THE INVERTER

9.2.6 *Demand response modes*

The demand response modes supported by the inverter should be permanently marked on the name plate or on a durable sticker located on or near the demand response interface port to indicate the demand response modes of which the unit is capable.

NOTE: It is acceptable for a durable sticker to be supplied by the manufacturer.

Figure 9 illustrates an acceptable form of marking. If this form of marking is used, each box shall contain a tick or a cross (if the inverter has that capability) or remain blank (if it does not have that capability). Alternatively, only the modes supported may be marked.

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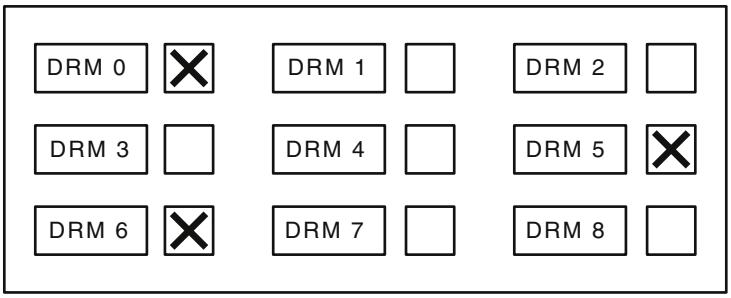


FIGURE 9 EXAMPLE OF DRM PORT MARKING ON INVERTER

If the physical interface is a terminal block, then—

(a) the terminals shall be engraved or otherwise durably marked; or

(b) a permanent label with 'DRM Port' shall be affixed near the terminal block.

The marking shall indicate which terminal corresponds to which demand response mode. The range of markings is indicated against Pins 1 to 6 in Table 7.

NOTE: It is acceptable for a durable sticker to be supplied by the manufacturer.

The following contractions are permitted:

(i) 'DRM' may be omitted, e.g. the terminal corresponding to DRM 1 may be marked '1' and the terminal corresponding to DRM 1/5 may be marked '1/5'.

(ii) 'Common' may be contracted to 'C'.

(iii) 'RefGen' may be contracted to 'Gen'.

(iv) 'Com/DRM 0' may be contracted to 'CD0'.

9.3 Documentation

9.3.1 *General*

The documentation supplied with the inverter shall provide all information necessary for the correct installation, operation and use of the system and any required external devices including information specified in Clause 9.2.

All inverters, including those intended for use in systems incorporating energy sources other than PV arrays or batteries, shall comply with the documentation requirements of IEC 62109-1 and IEC 62109-2.

9.3.2 *Equipment ratings*

The documentation supplied with the inverter shall state the ratings of the inverter and the ratings for each port, as specified in Table 16. Only those ratings that are applicable to the type of inverter are required.

For equipment with rated current greater than 16 A per phase, additional documentation requirements apply. See Clause 5.7.

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TABLE 16

INVERTER RATINGS DOCUMENTATION REQUIREMENTS

Port (all that apply)	Parameter	Value	Units
Photovoltaic	Vmax PV (absolute maximum)		d.c. V
	PV input operating voltage range		d.c. V
	Maximum operating PV input current		d.c. A
	Isc PV (absolute maximum)		d.c. A
	Maximum inverter backfeed current to array		a.c A or d.c. A
Wind (a.c. or d.c.)	Voltage (nominal or range)		a.c V or d.c. V
	Rated current (maximum continuous)		a.c A or d.c. A
	Current (inrush)		a.c A or d.c. A (peak and duration)
	Frequency (nominal or range) (a.c. wind only)		Hz
Energy storage ports	Voltage (nominal or range)		d.c. V
	Nominal battery voltage		d.c. V
	Rated current (maximum continuous) input and output		d.c. A
	Storage type		
Other energy sources or inputs (a.c. or d.c.)	Voltage (nominal or range)		a.c V or d.c. V
	Rated current (maximum continuous)		a.c A or d.c. A
	Power factor (range)		
	Frequency (nominal or range) (a.c. sources only)		Hz
a.c. output ratings (for each port)	Voltage (nominal or range)		a.c. V
	Rated current		a.c. A
	Current (inrush)		a.c. A (peak and duration)
	Frequency (nominal or range)		Hz
	Rated apparent power		VA
	Power factor range		
	Maximum output fault current		a.c. A (peak and duration) or RMS
	Maximum output overcurrent protection		
d.c. output ratings	Voltage (nominal or range)		d.c. V
	Rated current		d.c. A
	Inverter topology	Isolated or non-isolated	
	Active anti-islanding method	Specify type name	
	Protective class (I, II or III)	I, II or III	
	Over voltage category	OVC I, II, III or IV	
	Ingress protection (IP) rating	IPXX	
	Temperature operating range	Min. to max. (°)	

NOTE: Table 16 is based on the requirements of IEC 62109-2.

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9.3.3 *Ports*

In addition to the requirements of Clause 9.3.2, the documentation supplied with the inverter shall state the following for each port, as a minimum:

(a) Means of connection.

(b) For pluggable equipment type B, the type of matching connectors to be used.

NOTE: For some ports, the specific manufacturer of the connector type may also need to be specified to ensure correct mating connectors.

(c) External controls and protection requirements.

(d) Explanation of terminals or pins used for connection including polarity and voltage.

(e) Tightening torque to be applied to terminals.

(f) Instructions for protective earthing.

(g) Instructions for connection of loads and installation of RCD protection to stand-alone ports.

(h) The decisive voltage class (DVC).

NOTE: The DVC is the voltage of a circuit which occurs continuously between any two live parts in the worst-case rated operating condition when used as intended.

9.3.4 *External and ancillary equipment*

Where an inverter or multiple inverter combinations requires external or ancillary equipment for compliance with this Standard, the documentation shall—

(a) state the requirement for any such equipment;

(b) provide sufficient information to identify the external or ancillary equipment, either by manufacturer and part number or by type and rating; and

(c) specify assembly, location, mounting and connection requirements.

9.3.5 *RCDs*

Where an external RCD is required, the following or an equivalent statement shall be included in the documentation: ‘External RCD Required’. The documentation shall also state the rating and type of RCD required and provide instructions for the installation of the RCD.

9.3.6 *Multiple mode inverters*

Where the inverter is capable of multiple mode operation, the documentation shall include the following:

(a) Ratings and means of connection to each source of supply to the inverter or output from the inverter.

(b) Any requirements related to wiring and external controls, including the method of maintaining neutral continuity within the electrical installation to any stand-alone ports as required.

(c) Disconnection means and isolation means.

(d) Overcurrent protection needed.

9.3.7 *Multiple inverter combinations*

Where an inverter has been tested for use in a multiple inverter combination as per Clause 8, the documentation shall include the following:

(a) Valid combinations of inverters.

(b) Installation instructions for correct operation as a multiple inverter combination.

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APPENDIX A

GENERAL TEST AND REPORTING REQUIREMENTS

(Normative)

A1 GENERAL

This Appendix specifies requirements for the configuration of the equipment under test, the real test grid or simulated test grid, and the reporting of results in test reports.

A2 TEST CONDITIONS

Unless otherwise specified by the test procedure, the testing conditions for each test shall be such that—

(a) the average r.m.s. current on each phase is within ±5% of the intended test point; and

(b) the average r.m.s. voltage on each phase is within ±5% of the grid test voltage.

In the case of a three-phase supply, the angle between the fundamental voltages of each pair of phases shall be maintained at 120 ±1.5°. The average r.m.s. voltages between each pair of phases shall be maintained within ±1%.

The grid test voltage shall be 240 V a.c. phase to neutral 50 ±0.1 Hz, unless otherwise specified.

NOTE: The test voltage specified is aligned with the approaches used in AS/NZS 60335.1 and other related standards, and is similar to normal operating voltage levels on Australian and New Zealand networks.

A3 INVERTER SET-UP

Each inverter that is to be tested shall have its internal settings and configurations set to the default set-points required by this Standard, as they would be for operation in an installation.

For inverters that have configurations or functionality that can be enabled or disabled and which may have an impact on the test results, the test shall be either repeated with the valid configurations enabled and disabled or be carried out with the least favourable settings.

NOTE: This is so that any functionality that is enabled or disabled is proven not to compromise the safe operation of the inverter in all possible operational modes.

Each valid configuration that is tested shall be listed in the test report and the test results indicated. This includes testing with different demand response modes enabled and disabled and different power quality response modes enabled and disabled.

If the inverter is required to be used with an external device or devices, such as external automatic disconnection devices or dedicated isolation transformers, the inverter shall be tested in combination with these devices for all tests.

The combinations tested shall be documented in the test report.

Before commencement of the test, all model information and specific information concerning the version of software, firmware and hardware used by the inverter shall be recorded. This information shall be provided in the test report.

Sufficient records shall be kept and photographs taken so that the model tested can be verified by a certification agency, and if required, by field inspectors.

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Different configurations and default settings may be required for Australia and New Zealand. Testing shall be performed for the market intended and this shall be recorded in the test report.

A4 GRID SOURCE

Either a real grid or a simulated test grid shall be used in the testing.

Whether a real grid or simulated test grid is used, the impedance of the test point shall be rated appropriate to the rating of the inverter or combination of inverters under test. Impedances of the test connection are specified in Paragraph A5.

NOTE: This is to ensure that the application of the inverter in a customer installation will not adversely affect the quality of supply to the customer.

The type of source and the impedance of the source shall be declared in the test report for each test performed.

During the tests, the steady-state voltage of the real or simulated test grid shall not vary by more than ±1% of the nominal voltage. The grid test voltage shall be set as required by each test.

For tests requiring step changes in voltage and/or frequency, the simulated test grid shall be at least capable of being stepped at 0.5 times the smallest step required for testing, to determine the set-points with required accuracy.

The real grid or a simulated test grid needs to be free from harmonic distortion which could interfere with testing. The voltage harmonic distortions of the real or simulated test grid shall be less than the limits specified in Table C1 in Appendix C.

A5 REFERENCE NETWORK IMPEDANCE

A reference network impedance is required to be used in the testing circuit for the associated tests. This reference network impedance simulates the impedance of the grid.

For single-phase and three-phase inverters with rated current less than 21.7 A per phase, the impedance of the reference network impedance shall be 0.24 Ω + j0.15 Ω for each phase conductor and 0.16 Ω + j0.10 Ω for the neutral conductor.

For inverters with rated current greater than 21.7 A per phase, the impedance of the reference network impedance shall be 0.15 Ω + j0.15 Ω for each phase conductor and 0.1 Ω + j0.1 Ω for the neutral conductor.

For inverters with rated current greater than 75 A per phase, the source impedance of the network shall be no less than 5% of the source impedance of the inverter, where the source impedance of the inverter is assumed to be the rated voltage divided by the rated current.

NOTE: When using a real test grid, the source impedance of the connection needs to be considered when setting up the test circuit with the required reference impedance value.

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APPENDIX B

POWER FACTOR TEST

(Normative)

B1 TEST PROCEDURE

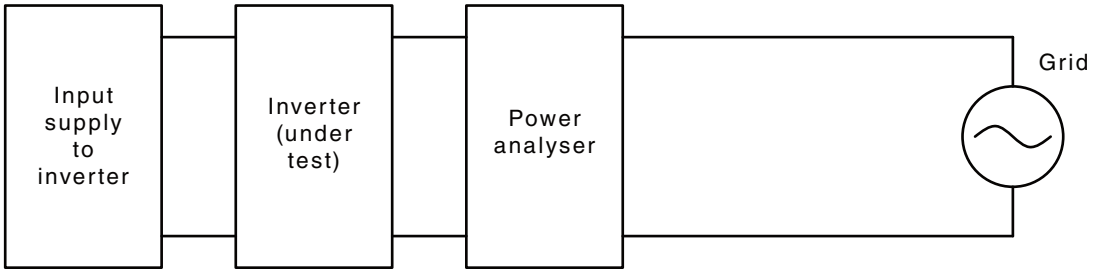
The procedure shall be as follows:

(a) The inverter shall be connected into a test circuit equivalent to that shown in Figure B1. The voltage shall equal the grid test voltage.

(b) The simulated source supply shall be varied until the a.c. output of the inverter equals 15 ±5% of its rated current output.

(c) The displacement power factor of the inverter output shall be measured.

(d) Steps (b) and (c) shall be repeated with the inverter operating at 25 ±5%, 50 ±5%, 75 ±5% and 100 ±5% of its rated current output.



NOTE: This test circuit applies to a single-phase system. To test a three-phase system, an equivalent three-phase circuit is required.

FIGURE B1 CIRCUIT FOR POWER FACTOR TEST

B2 POWER FACTOR LIMITS

When subjected to the test specified in Paragraph B1, the displacement power factor shall comply with the limits specified in Clause 5.5 with an initial setting of the power factor at unity. If the inverter is capable of different displacement power factor settings, the test shall also be performed at the limits of the adjustable range.

The required accuracy for the measurement and reporting of results is ±0.01 PF. For testing at limits or in other modes, results shall be ±0.01 of the required limit, i.e. for a limit of 0.95, values equal to 0.94 to 0.96 are acceptable. The vars at the 15% test point are required to be the same or less than the vars at the 25% test point when operating at unity power factor.

When the power factor or reactive power of the inverter can be set according to a mode specified in Clause 6.2 or 6.3, this test shall be repeated for each possible mode and at the limits of the adjustable range.

B3 TEST REPORT

The measured values for the displacement power factor shall be reported in a table format for each point measured and for each mode of operation. Table B1 is an example.

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TABLE B1
DISPLACEMENT POWER FACTOR REPORTING TABLE

Mode	Measurement	15%	25%	50%	75%	100%
Unity	Power (watts)					
	Reactive power (var)					
	PF cos (phi)					
	Lead/lag					
Lag limit	Power (watt)					
	Reactive power (var)					
	PF cos (phi)					
Lead limit	Power (watt)					
	Reactive power (var)					
	PF cos (phi)					
Modes	Power (watt)					
	Reactive power (var)					
	PF cos (phi)					

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APPENDIX C
HARMONIC CURRENT LIMIT TEST
(Normative)

C1 TEST PROCEDURE

The procedure shall be as follows:

(a) The inverter shall be connected into a test circuit equivalent to that shown in Figure C1.

(b) The simulated source supply shall be varied until the a.c. output of the inverter, measured in amperes, lies in the range 100 ±5% of the inverter's rated current output.

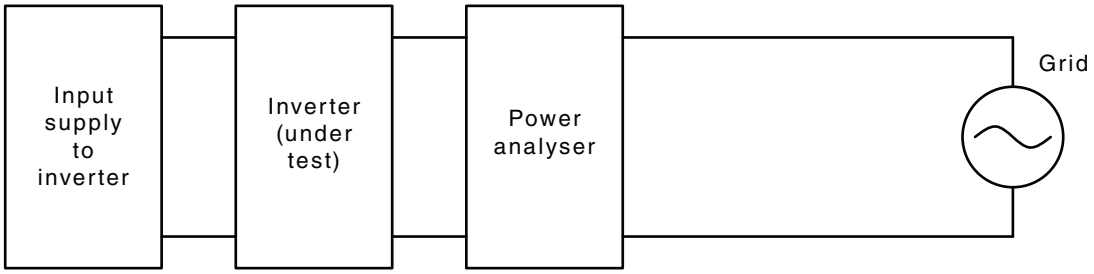
NOTE: The required conditions for the grid source are specified in Paragraph C3.

(c) The harmonic current content of the inverter output shall be measured and recorded.

(d) The simulated source supply shall be varied until the a.c. output of the inverter, measured in amperes, lies in the range 50 ±5% of the inverter's rated current output.

(e) The harmonic current content of the inverter output shall be measured and recorded.

(f) The total impedance of the a.c. source and reference impedance that simulates a grid shall be in accordance with Paragraph A5 of Appendix A.



NOTE: This test circuit applies to a single-phase system. To test a three-phase system, an equivalent three-phase circuit is required.

FIGURE C1 CIRCUIT FOR HARMONIC CURRENT LIMIT TEST

C2 HARMONIC CURRENT LIMITS

When the inverter is subjected to the test specified in Paragraph C1 above, the harmonic currents of the inverter shall not exceed the limits specified in Table 2 and Table 3 of Clause 5 for all points tested.

C3 GRID SOURCE DURING HARMONIC TEST

While the harmonic current measurements are being made, the test voltage at the a.c. terminals of the inverter shall meet the following requirements:

(a) The test voltage and frequency shall be maintained at the grid test voltage.

(b) In the case of a three-phase supply, the angle between the fundamental voltages of each pair of phases shall be maintained at 120 ±1.5°.

(c) The impedance of the supply source shall be as specified in Paragraph A5.

(d) The harmonic ratios of the grid test voltage shall not exceed the limits specified in Table C1.

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TABLE C1

VOLTAGE HARMONIC LIMITS OF TEST GRID

Harmonic order number	Limit based on percentage of fundamental
3	0.9%
5	0.4%
7	0.3%
9	0.2%
Even harmonics 2–10	0.2%
11–50	0.1%
Total harmonic distortion (to the 50th harmonic)	5%

C4 TEST REPORT

The measured values for harmonic current shall be reported in a table format for each point measured. The table shall contain all measured harmonic components as a current reading and as a percentage of the fundamental with a comparison against the limit for the component. Table C2 is an example.

The test report shall also include—

(a) the reference impedance value used for the test circuit; and

(b) the background voltage harmonics present at the time of the test.

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TABLE C2

EXAMPLE OF TABLE FOR REPORTING HARMONIC LIMITS

Component	Limit	50% of rated current			100% of rated current		
	% of fundamental	Value A	Angle degrees	% of fundamental	Value A	Angle degrees	% of fundamental
0	0.5%						
1	100%						
2	1%						
3	4%						
4	1%						
5	4%						
6	1%						
7	4%						
8	1%						
9	2%						
10	0.5%						
11	2%						
12	0.5%						
13	2%						
14	0.5%						
15	1%						
16	0.5%						
17	1%						
18	0.5%						
19	1%						
20	0.5%						
21	0.6%						
22	0.5%						
23	0.6%						
24	0.5%						
25	0.6%						
26	0.5%						
27	0.6%						
28	0.5%						
29	0.6%						
30	0.5%						
31	0.6%						
32	0.5%						
33	0.6%						
Total harmonic distortion (to 50th component)							

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APPENDIX D

TRANSIENT VOLTAGE LIMIT TEST

(Normative)

D1 GENERAL

The purpose of this test is to verify that the inverter complies with the transient voltage limits specified in Clause 5.8 when the grid is disconnected from the inverter.

For inverters with rated apparent power not more than 5 kVA, the test load shall be as described in Figure D1 with the resistor value (R) indicated. For all other inverters, the resistor value (R) shall be calculated such that the total resistive load connected per phase is equivalent to 0.1% of the rated apparent power of the inverter.

NOTE: When choosing a resistor value, the resistive load may be calculated based on the nearest standard resistor value with an appropriate power rating, as long as the resistive load is within 20% of the required value.

D2 TEST PROCEDURE

The procedure shall be as follows:

(a) The inverter shall be placed in a test circuit equivalent to that shown in Figure D1, with modification of the resistor value (R) if required (see Paragraph D1).

(b) Before the switch is opened, the voltage at the grid-interactive port of the inverter shall be maintained at the grid test voltage.

(c) The simulated source supply shall be varied until the apparent power output of the inverter equals 10 ±5% of its rated apparent power.

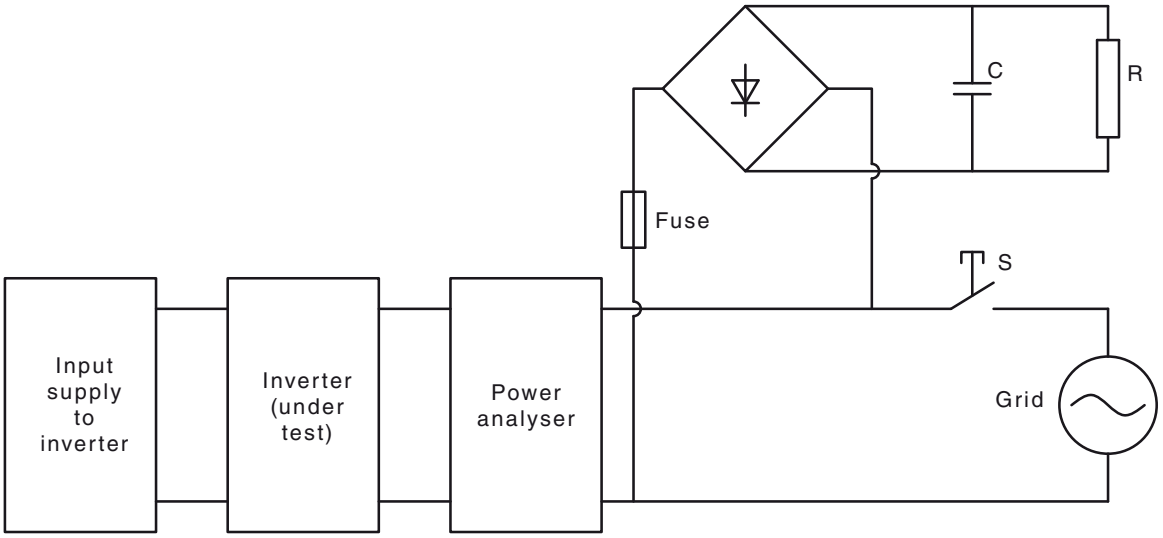
(d) The switch (S) shall be opened.

(e) The voltage across the grid-interactive port of the inverter shall be recorded at a sample frequency of at least 10 kHz.

(f) Steps (b) to (e) shall be repeated with the inverter operating at 50 ±5% and 100 ±5% of its rated current output.

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NOTE: This test circuit applies to a single-phase system. To test a three-phase system, an equivalent three-phase circuit is required.

FIGURE D1 CIRCUIT FOR TRANSIENT VOLTAGE LIMIT TEST

D3 TRANSIENT VOLTAGE LIMITS

When subjected to the test specified in Paragraph D2, the voltage-duration curve shall be derived from the measurements sampled for the a.c. voltage at the grid-interactive port.

A voltage-duration curve shall be calculated using the sampled instantaneous voltage over the complete trip time of the inverter. For each voltage (maximum voltage step 10 V), the number of samples greater than that voltage are counted. This number is then multiplied by the sample interval to derive the duration for that voltage. The voltage-duration curve is the locus of all points derived from this process. The inverter is deemed to comply with the transient voltage limit test if the derived voltage-duration curve lies beneath the curve of Figure 1 at all points.

The values obtained shall not exceed the limits specified in Table 4.

D4 TEST REPORT

The results recorded shall be provided in tabular and graphical formats.

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APPENDIX E

D.C. INJECTION TEST

(Normative)

E1 GENERAL

The purpose of this test is to verify that the inverter complies with the d.c. current injection limit specified in Clause 5.9 when it connects to the grid. This test is required for inverters that do not incorporate a mains frequency isolating transformer either internally or externally.

The inverter shall be placed in a test circuit equivalent to that shown in Figure C1. For three-phase systems, current shall be measured in each phase conductor. For single-phase inverters, either the active or neutral current may be measured.

If used, the simulated test grid shall meet the requirements of Appendix A and shall have negligible d.c. offset before the test commences.

E2 TEST PROCEDURE

The procedure shall be as follows:

(a) Operate the inverter at 20% of its rated current and at rated power factor. The inverter shall operate for at least 5 min prior to taking any test measurements (or until the inverter temperature stabilizes). The inverter shall operate at the specified current for the period of the measurement

(b) At the inverter output, measure the r.m.s. voltage, r.m.s. current, and d.c. component (frequency less than 1 Hz) of current on all phases. The average value of 180 consecutive readings of the d.c. component with a measurement period of 1 s for each reading shall be calculated. The inverter passes the requirement of this Standard if the average of the 180 consecutive readings is below the limit specified in Clause 5.9. For each 1 s sample, the absolute value (i.e. unsigned value) shall be used to calculate the 180 s average.

(c) Repeat Steps (a) and (b) with the inverter operating at 60% and 100% of its rated current.

(d) Divide the calculated average values for the magnitude of the d.c. component of current by the rated current of the inverter and derive the value of the d.c. current injection as a percentage. This shall be done for 3 test points (20%, 60% and 100%) and for each phase and/or neutral measurement. Record the final calculated values as the percentage of d.c. current injection for each phase.

E3 D.C. CURRENT LIMITS

All d.c. current injection levels, calculated as percentages, shall be within the limit specified in Clause 5.9.

The resolution of the d.c. component measurement shall be 1 mA or 5% of the applicable limit, whichever is greater, as specified in Clause 5.9.

E4 TEST REPORT

The measured values shall be reported in a table format for 20%, 60% and 100% of the rated current. Table E1 is an example.

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TABLE E1

EXAMPLE REPORTING TABLE FOR D.C. INJECTION TEST

		20%	60%	100%
Inverter current, A	Setting			
	Actual			
Limit	0.5% × I_{rated}			
Result	A			
Compliance	(P/F)			

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APPENDIX F

ACTIVE ANTI-ISLANDING TEST

(Normative)

F1 GENERAL

For the active anti-islanding test, the inverter and automatic disconnection device shall be connected into a test circuit equivalent to that of Figure F1.

F2 LOAD CONDITIONS

F2.1 General

The test shall be carried out using three different load conditions as follows:

(a) A—light electronic load.

(b) B—load match.

(c) C—load match plus 10%.

F2.2 Load condition A

For load condition A, a test load circuit equivalent to that shown in Figure F2 shall be used. This consists of a full-wave rectifying bridge connected to a 100 μF capacitive element and a 560 kΩ resistive element in parallel. This load is applicable for inverters with rated apparent power not more than 5 kVA. For all other inverters, the resistor shall be replaced by a resistive load equal to 0.1% of the rated apparent power of the inverter.

NOTE: When choosing a resistor value, the resistive load may be calculated based on the nearest standard resistor value with an appropriate power rating, as long as the resistive load is within 20% of the required value.

F2.3 Load conditions B and C

F2.3.1 *General*

For load conditions B and C, a test load circuit equivalent to that of Figure F3 shall be used. This consists of resistive, inductive and capacitive loads and the resonant load in parallel. For load condition B, the resistive load shall be chosen such that it draws a load equal to the real power output of the inverter. For load condition C, the resistive load shall be chosen such that it draws a load that exceeds the real power output of the inverter by 10%. In both load conditions B and C, an additional inductive or capacitive load shall be chosen to sink or source the reactive power (var) output from the inverter. In Figure F3, these are shown as variable inductive and capacitive loads and are indicated by C_v and L_v.

F2.3.2 *Resonant load*

For both load conditions B and C, an additional fixed resonant load shall be chosen which has an inductive load such that it draws var from the grid and a capacitive load such that it supplies var to the grid. The fixed resonant load shown in Figure F3 shall be a separate load included in addition to the variable capacitive (C_v) and inductive (L_v) loads used for achieving required load match conditions for the test.

The value of the capacitive and inductive parts of the resonant load shall be increased based on the apparent power rating of the inverter per phase in accordance with Table F1.

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TABLE F1

RESONANT LOAD SELECTION OF VAR (Q) VALUES

Apparent power rating/phase kVA	Reactive power rating (var) $Q_c = Q_l$
≤5	100
≤10	200
≤20	400
≤30	600
≤40	800
≤50	1000
≤100	2000
>100	3000

For the fixed resonant load, values for L and C can be calculated using the values for Q_c and Q_l in Table F1 and the following equation:

$$L = \frac{V^2}{2\pi f \times Q_l}$$

$$C = \frac{Q_l}{2\pi f \times V^2}$$

where

V = grid test voltage = 240 V

f = grid frequency = 50 Hz

C = capacitance

L = inductance

To determine that the resonant load is correctly established for each of the chosen test values, the resonant load shall be tested connected to a voltage equal to the test grid voltage and then disconnected by a switch. The resonant load shall meet the following criteria:

(a) There shall be a minimal internal resistance such that the resonant load has an underdamped resonant behaviour.

(b) The voltage seen at the resonant load terminal after the switch disconnects it from the test grid voltage shall oscillate at the resonant frequency 50 Hz.

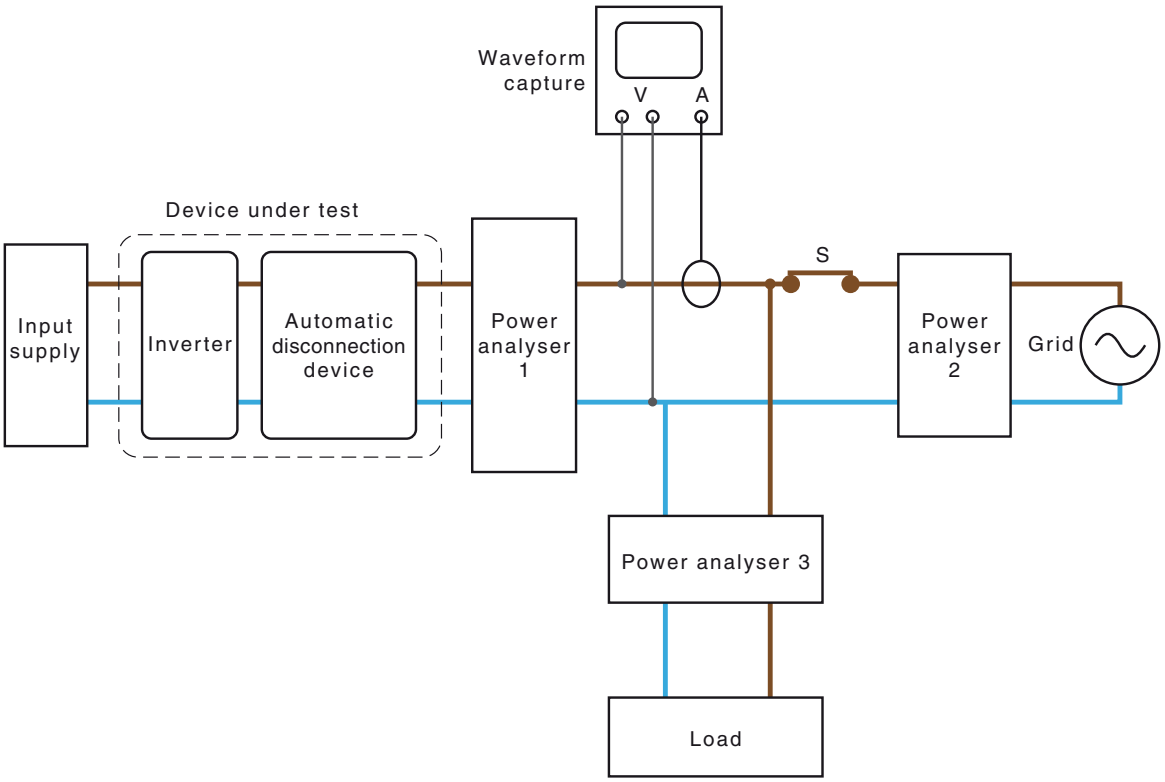
NOTE: As the resonant frequency is dependent on inductors and capacitors, the allowable range for the measured resonance after disconnection is 48 Hz to 50.25 Hz.

(c) When the resonant load is tested with no other loads or sources, after the switch disconnects the resonant load the measured peak voltage value of the second peak shall be more than 90% of the measured first peak value cycle after the resonant load is disconnected from a source set at the grid test voltage.

The load and resonant load are based on the per phase rating of the inverter and the load conditions for a three-phase system are the same as for a single-phase system. The load and resonant load shall be connected between the neutral and active terminals of the grid interactive port.

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NOTE: This load applies to a single-phase system. To test a three-phase system, an equivalent three-phase load is required.

FIGURE F1 CIRCUIT FOR ACTIVE ANTI-ISLANDING TEST

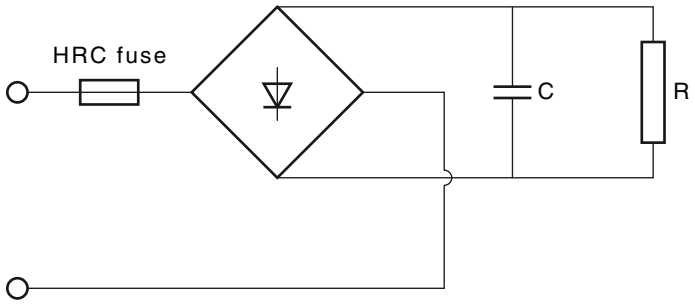


FIGURE F2 TEST LOAD FOR GRID TRIP TEST UNDER LOAD CONDITION (A)

F3 TEST UNDER LOAD CONDITION A

The procedure shall be as follows:

(a) The inverter and automatic disconnection device shall be connected into a test circuit equivalent to that shown in Figure F1 with a load equivalent to that shown in Figure F2. The grid voltage shall equal the grid test voltage.

(b) The input supply to the device under test shall be varied until the a.c. output of the device under test equals 10 ±5% of its rated current output.

(c) The switch (S) shall be opened and the time for the device under test to disconnect from the test circuit shall be recorded.

(d) The switch (S) shall be closed and after the device under test reconnects, the input supply to the device under test shall be varied until the a.c. output of the device under test equals 50 ±5% of its rated current output.

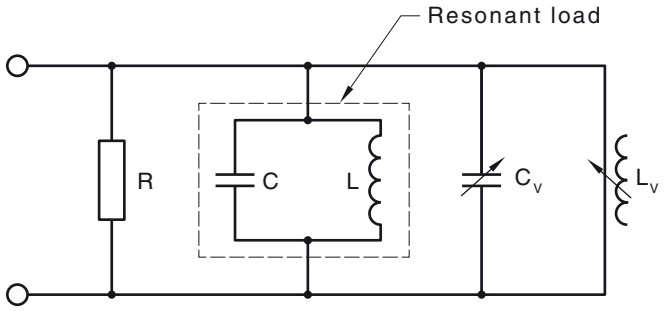
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(e) Step (c) shall be repeated.

(f) The switch (S) shall be closed and after the device under test reconnects, the input supply to the device under test shall be varied until the a.c. output of the device under test equals 100 ±5% of its rated current output.

(g) Step (c) shall be repeated.



NOTES:

1 This load applies to a single-phase system. To test a three-phase system, an equivalent three-phase load is required.

2 The capacitance (C) and inductance (L) form a resonant load where the reactive power of each component is as specified in Table F1.

3 C_v and L_v are the components used in Steps F4(d) and F5(d) and are not part of the resonant loads.

FIGURE F3 TEST LOAD FOR ACTIVE ANTI-ISLANDING TEST UNDER LOAD CONDITIONS B AND C

F4 TEST UNDER LOAD CONDITION B

The procedure shall be as follows:

(a) The inverter and automatic disconnection device shall be connected into a test circuit equivalent to that shown in Figure F1 with a test load equivalent to that shown in Figure F3. The resistive load shall be chosen to draw a load equal to the real power output of the device under test required in each of the following three test output levels. The fixed resonant load shall be connected for each test and arranged as shown in Figure F3. The grid voltage shall equal the grid test voltage.

(b) The input supply to the device under test shall be varied until the a.c. output of the device under test equals 10 ±5% of its rated current.

(c) The resistive load (R) shall be increased or decreased until the real power consumption of the test load matches the real power output of the inverter to within ±5%.

(d) Either the inductive or capacitive load shall be adjusted until the reactive power consumption of the test load matches the reactive power output of the device under test ($Q_{Load} + Q_{Testload} = Q_{Inverter\ output}$) to ±5%.

NOTES:

1 The purpose of the procedure up to this point is to bring the 50 Hz components of power at the utility disconnection switch to zero.

2 System harmonic voltages will result in harmonic currents in the test circuit. The harmonic currents will typically make it very difficult to make the measurement of power or current flow at the disconnection switch equal to zero.

(e) The switch (S) shall be opened and the time for the device under test to disconnect from the test circuit shall be recorded.

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(f) The switch (S) shall be closed and after the device under test reconnects, the input supply to the device under test shall be varied until the a.c. output of the device under test equals 50 ±5% of its rated current.

(g) Steps (c) to (d) shall be repeated.

(h) The switch (S) shall be closed and after the device under test reconnects the input supply to the device under test shall be varied until the a.c. output of the device under test equals 100 ±5% of its rated current.

(i) Steps (c) to (d) shall be repeated.

F5 TEST UNDER LOAD CONDITION C

The procedure shall be as follows:

(a) The inverter and automatic disconnection device shall be connected into a test circuit equivalent to that shown in Figure F1 with a test load equivalent to that shown in Figure F3. The resistive load shall be chosen to draw a load 1.1 times the real power output of the device under test required in each of the following three test output levels. The fixed resonant load shall be connected for each test and arranged as shown in Figure F3. The grid voltage shall equal the grid test voltage.

(b) The switch (S) shall be closed and after the device under test reconnects the input supply to the device under test shall be varied until the a.c. output of the device under test equals 10 ±5% of its rated current.

(c) The resistive load (R) shall be increased or decreased until the real power consumption of the test load matches 110% of the real power output of the device under test (i.e. overloads the device under test by 10%) to ±5%.

(d) Either the inductive or capacitive load shall be varied until the reactive power consumption of the test load matches the reactive power output of the device under test to ±5%.

NOTES:

1 The purpose of the procedure up to this point is to bring the 50 Hz components of power at the utility disconnection switch to zero.

2 System harmonic voltages will result in harmonic currents in the test circuit. The harmonic currents will typically make it very difficult to make the measurement of power or current flow at the disconnection switch equal to zero.

(e) The switch (S) shall be opened and the time for the device under test to disconnect from the test circuit shall be recorded.

(f) The switch (S) shall be closed and after the device under test reconnects, the input supply to the device under test shall be varied until the a.c. output of the device under test equals 50 ±5% of its rated current.

(g) Steps (c) to (d) shall be repeated.

(h) The switch (S) shall be closed and after the device under test reconnects, the input supply to the device under test shall be varied until the a.c. output of the device under test equals 100 ±5% of its rated current.

(i) Steps (c) to (d) shall be repeated.

F6 DISCONNECTION REQUIREMENTS

For each test performed, each disconnection time shall be less than 2 s.

For inverters that can be operated with different power factors, demand response modes and power quality response modes, the test under load condition B in Paragraph F4 shall be repeated for all valid combinations of modes enabled and disabled.

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For all inverters, each test result shall be examined to determine that the mode of disconnection was due to the active anti-islanding protection functioning and not a result of the unintended passive anti-islanding protection functioning due to incorrect test load conditions.

NOTE: In some cases, if suitably stable and correct test conditions are not established before the switch (S) is operated, an island condition will not be present, either voltage or frequency will rapidly change, and disconnection will occur when the passive anti-islanding set-points are reached. An example would be the disconnection due to undervoltage trip setting when the active anti-islanding method is declared as a frequency shift method which would expect to disconnection on over frequency set points.

F7 TEST REPORT

For each test performed, a voltage waveform shall be provided which shows the time the grid tripped and the cessation of the generation of a.c. waveform and current within 2 s. The presented waveform shall be analysed to determine the cause of disconnection to ensure that the correct conditions were present and that the trip was triggered by the active anti-islanding scheme.

A summary table shall be presented with a result for each test performed.

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APPENDIX G

VOLTAGE AND FREQUENCY LIMITS (PASSIVE ANTI-ISLANDING PROTECTION) TESTS

(Normative)

G1 GENERAL

Voltage and frequency limits which provide passive anti-islanding protection, and the voltage and frequency limits for connection and reconnection and the ramp rate upon reconnection shall be assessed by means of the following tests.

NOTE: The facility performing the test may need to change the operational settings of the inverter from any default mode to determine the overvoltage trip limits. An example of this is to set the sustained overvoltage set-point to 258 V instead of the 255 V default for Australia or the 244 V default for New Zealand. Depending on the speed of the test required, any of the volt response modes may also be disabled to assist in determining the overvoltage limits as appropriate.

The ramp rate for reconnection shall be tested at the default setting of 6 min specified in Clause 6.3.5.2.

NOTE: Each test in this Appendix should be repeated three times to confirm compliance of the limit.

G2 UNDERVOLTAGE AND OVERVOLTAGE TRIP SETTINGS AND RECONNECTION TEST

G2.1 General

This test is used to verify—

(a) the undervoltage and overvoltage trip delay and maximum disconnection times specified in Table 13;

(b) the voltage limits and set power rate limit (W_{gra}), following connection or reconnection, specified in Clause 7.7; and

(c) the nonlinearity requirements of Clause 6.3.5.4 and the default ramp rate of Clause 6.3.5.2.

G2.2 Test procedure

The procedure shall be as follows:

(a) The inverter and automatic disconnection device shall be connected into a test circuit equivalent to that shown in Figure G1.

(b) The variable a.c. supply shall be set so that the voltage at the a.c terminals of the device under test equals the grid test voltage. The energy source supply shall be varied until the a.c. output of the device under test equals 50 ±5% of its rated current output. The voltage at the a.c. terminals shall be maintained for a continuous period exceeding 10 min to ensure that the average voltage for that 10 min period is equal to the grid test voltage.

NOTES:

1 For three-phase inverters or inverter combinations, the required inverter output is based on the per phase inverter current rating.

2 The 10 min interval is set so that the output level reaches the required limit and the inverter's internal measurements for sustained overvoltage approach approximately 240 V. The overall time for the test needs to be considered to ensure that the sustained overvoltage limit does not trip the automatic disconnection device.

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(c) The trip voltage and disconnection time for the protective function overvoltage 2 (V>>) of Table 13 (i.e. 265 V) shall be confirmed.

(d) The variable a.c. supply shall be set so that the voltage at the a.c terminals of the device under test equals 257.5 V (which is just under the sustained overvoltage upper limit).

(e) The voltage shall then be increased to 267.5 V as rapidly as possible but at a rate less than any dV/dt protection incorporated in the device under test. The time interval between the voltage passing through 265 V and the device under test disconnecting from the variable a.c. supply shall be recorded. The voltage at which the device under test disconnects shall also be recorded.

NOTE: For testing of the disconnection time (V>>), the time to perform the test needs to be such that the sustained overvoltage protection and the protective function overvoltage 1 (V>) of Table 13 (i.e. 260 V) does not cause the automatic disconnection device to trip prior to reaching V>> protection function limit.

(f) The reconnection time following connection or reconnection shall be confirmed.

(g) The variable a.c. supply shall be adjusted to return the voltage at the a.c. terminals of the device under test to the grid test voltage. The reconnection time (the time taken for the device under test to reconnect to the variable a.c. supply) shall be recorded.

(h) The conditions of Step (b) shall be re-established.

(i) The disconnection time for the undervoltage (V<) limit (i.e. 180 V) shall be confirmed.

(j) The variable a.c. supply shall be set so that the voltage at the a.c terminals of the device under test equals 182.5 V.

(k) The voltage shall then be decreased in steps of less than 1 V to 177.5 V. The dwell time at each voltage step shall be 5 s. The time interval between the start of a voltage step and the device under test disconnecting from the variable a.c. supply shall be recorded. The voltage at which it disconnects shall also be recorded.

(l) The minimum voltage for reconnection of the automatic disconnection device shall be confirmed as in accordance with Clause 7.7.

(m) The output voltage of the variable a.c. supply shall be set to a voltage equal to the lowest utilization voltage of AS 60038 (for Australia) or IEC 60038 (for New Zealand), minus 2 V. The voltage shall be maintained at this level for a period of two (2) times the reconnection time measured at Step (f). The device under test shall not reconnect for the duration of this period.

(n) The variable a.c. supply shall be adjusted to return the voltage at the a.c. terminals of the device under test to the grid test voltage. The reconnection time (the time taken for the device under test to reconnect to the variable a.c. supply) shall be recorded.

(o) The trip voltage and disconnection time for the overvoltage 1 (V>) (i.e. 260 V) shall be confirmed.

(p) The conditions of Step (b) shall be re-established.

(q) The variable a.c. supply shall be set so that the voltage at the a.c. terminals of the device under test equals 257.5 V.

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(r) The voltage shall then be increased in steps of no more than 1 V to 262.5 V. The dwell time at each voltage step shall be 5 s. The time interval between the start of a voltage dwell time and the device under test disconnecting from the variable a.c. supply shall be recorded. The voltage at which the device under test disconnects shall also be recorded.

NOTE: For testing of the overvoltage 1 (V>) disconnection time, the time to perform the test needs to be such that the sustained overvoltage protection does not cause the automatic disconnection device to trip prior to reaching the V> protection function limit.

(s) The maximum voltage for reconnection of the automatic disconnection device shall be confirmed as in accordance with Clause 7.7.

(t) The output voltage of the variable a.c. supply shall be set to a voltage equal to the highest utilization voltage of AS 60038 (for Australia) or IEC 60038 (for New Zealand), plus 2 V. The voltage shall be maintained at this level for a period of two (2) times the reconnection time measured at Step (n). The device under test shall not reconnect for the duration of this period.

(u) The variable a.c. supply shall be adjusted to return the voltage at the a.c. terminals of the device under test to the grid test voltage. The reconnection time (the time taken for the device under test to reconnect to the variable a.c. supply) shall be recorded.

(v) The real power output shall be recorded at intervals of no more than 15 s until the real power output has stabilized to confirm that the ramp rate on connection or reconnection meets requirements of Clause 6.3.5.

G2.3 Criteria for acceptance

When subjected to the tests specified in Paragraph G2.2, the device under test shall comply with the following:

(a) The voltage recorded at Step (e) for the overvoltage 2 limit (V>>) shall equal 265 ±2 V. The disconnection time recorded at Step (e) shall be equal to or less than 0.2 s.

(b) The disconnection time recorded at Step (r) for the overvoltage (V>) limit shall be greater than the trip delay time of 1 s and less than 2 s. The voltage at which disconnection occurs shall be 260 ±2 V.

(c) The disconnection time recorded at Step (k) for the undervoltage (V<) limit shall be greater than the trip delay time of 1 s and less than 2 s. The voltage at which disconnection occurs shall be 180 ±2 V.

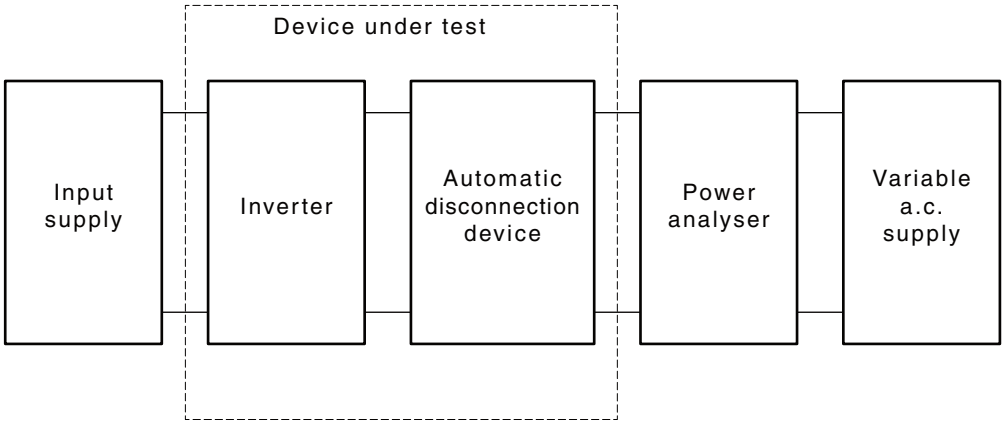
(d) Reconnection shall not occur at Steps (m) and (t).

(e) The reconnection times recorded at Steps (g) and (u) shall each be 60 s or greater.

(f) The real output power for each interval recorded at Step (v) shall comply with the nonlinearity requirements of Clause 6.3.5.4 and the default ramp rate of Clause 6.3.5.2.

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NOTE: The above test circuit applies to a single-phase system. To test a three-phase system, an equivalent three-phase circuit is required.

FIGURE G1 TEST CIRCUIT FOR VOLTAGE AND FREQUENCY LIMITS

G3 UNDER-FREQUENCY AND OVER-FREQUENCY TRIP SETTINGS AND RECONNECTION TEST

G3.1 General

This test is used to verify—

(a) the under-frequency and over-frequency trip delay and maximum disconnection times specified in Table 13; and

(b) the time for reconnection, specified in Clause 7.7.

G3.2 Test procedure

The procedure shall be as follows:

(a) The inverter and automatic disconnection device shall be connected into a test circuit equivalent to that shown in Figure G1.

(b) The variable a.c. supply shall be set so that the voltage at the a.c. terminals of the device under test equals the grid test voltage. The input supply shall be varied until the a.c. output of the device under test equals 50 ±5% of its rated output or 10 A, whichever is the lesser.

NOTE: For three-phase inverters, the required output is based on the per phase rating. For larger inverters, if 10 A is too low for stable operation, the minimum output level at which the inverter operates suitably may be used.

(c) The protective function limit, the trip delay time and disconnection time for the protective function under-frequency (F<) of Table 13 (i.e. 47 Hz or 45 Hz) of the automatic disconnection device shall be confirmed.

(d) The frequency of the variable a.c. supply shall be adjusted slowly to decrease the frequency at the a.c. terminals of the device under test until the device under test disconnects from the variable a.c. supply. The frequency at which disconnection occurs shall be recorded.

(e) The frequency of the variable a.c. supply shall be adjusted to return the frequency at the a.c. terminals of the device under test to 50 ±0.1 Hz. The time taken for the device under test to reconnect to the variable a.c. supply shall be recorded.

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(f) The output frequency of the variable a.c. supply shall be set to a frequency equal to the under-frequency (F<) limit, as recorded at Step (d), plus 0.1 Hz. The frequency shall then be decreased as rapidly as possible but at a rate less than any df/dt protection incorporated in the device under test. The time interval between the frequency passing through the frequency measured at Step (d) and the device under test disconnecting from the variable a.c. supply shall be recorded.

(g) The conditions of Step (b) shall be re-established.

(h) The trip frequency and the disconnection time for the protective function over-frequency (F>) of Table 13 (i.e. 52 Hz) limit of the automatic disconnection device shall be confirmed.

(i) The frequency of the variable a.c. supply shall be adjusted slowly to increase the frequency at the a.c. terminals of the device under test until the device under test disconnects from the variable a.c. supply. The frequency at which disconnection occurs shall be recorded.

NOTE: For testing of the over-frequency (F>) limit, the behaviour of the inverter for sustained over-frequency operation needs to be considered; the output of the inverter before the automatic disconnection device operates may be close to zero, so verification of the disconnection may not be detected by recording the inverter output.

(j) Step (e) shall be repeated.

(k) The output frequency of the variable a.c. supply shall be set to a frequency equal to the over-frequency (F>) limit, as recorded at Step (i), less 0.1 Hz. The frequency shall then be increased as rapidly as possible but at a rate less than any df/dt protection incorporated in the device under test. The time interval between the frequency passing through the frequency measured at Step (i) and the device under test disconnecting from the variable a.c. supply shall be recorded.

G3.3 Criteria for acceptance

When subjected to the test specified in Paragraph G3.2, the device under test shall comply with the following:

(a) The frequency recorded at Steps (d) for the under-frequency (F<) limit shall equal 47 ±0.1 Hz. The disconnection time recorded at Steps (f) shall be greater than the trip delay time of 1 s, and the disconnection time shall be less than 2 s.

NOTE: For New Zealand, 45 Hz.

(b) The frequency recorded at Step (i) for the over-frequency (F>) limit shall equal 52 ±0.1 Hz. The disconnection time recorded at Step (k) shall be less than 0.2 s.

(c) The reconnection times recorded at Steps (e) and (j) shall each be 60 s or greater.

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APPENDIX H

LIMITS FOR SUSTAINED OPERATION

(Normative)

H1 GENERAL

The limits for sustained operation are as specified in Clause 7.5. The purpose of the tests set out in this Appendix is to demonstrate the performance of the inverter in terms of accuracy of set-points and control of output in response to a variation in the grid voltage and frequency.

The inverter and automatic disconnection device shall disconnect correctly in response to the limits and in such a way that no interference with the anti-islanding protection of the inverter occurs.

H2 SUSTAINED OPERATION FOR VOLTAGE VARIATIONS

H2.1 General

When tested in accordance with the following procedure, the device under test shall demonstrate a satisfactory response to a sustained overvoltage event and then a controlled return to normal operation after the voltage has been maintained within the limits of AS 60038 (for Australia) or IEC 60038 (for New Zealand) for at least 60 s.

The test should be performed for the default set-point for both Australia and New Zealand (i.e. 255 V and 246 V respectively).

H2.2 Test procedure

The procedure shall be as follows:

(a) The inverter and automatic disconnection device shall be connected into a test circuit equivalent to that shown in Figure G1.

(b) The sustained operation over-voltage limit (V_{nom_max}) as specified in Clause 7.5.2, shall be confirmed (i.e. V_{nom_max} shall be 255 V or 246 V).

(c) The variable a.c. supply shall be set so that the voltage at the a.c terminals of the device under test equals the grid test voltage. The input supply shall be varied until the a.c. output of the device under test equals 50 ±5% of its rated apparent power.

(d) The output voltage of the variable a.c. supply shall be set to a voltage equal to the V_{nom_max} setting less 1 V. This voltage level shall be maintained for 5 min.

(e) The output voltage of the variable a.c. supply shall be increased by 2 V (i.e V_{nom_max} setting plus 1 V).

(f) The average voltage shall be recorded at the a.c terminals of the device under test such that the average value for the preceding 10 min can be calculated when the device under test disconnects.

NOTE: The disconnection can be determined by the device under test ceasing output and the automatic disconnection device operating (and/or an indication of the automatic disconnection device operating).

(g) The variable a.c. supply shall be adjusted to return the voltage at the a.c. terminals of the device under test to the grid test voltage.

NOTE: Steps (d), (e) and (f) should be repeated at least three times to confirm the set-point.

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(h) After the set-point has been determined, the output voltage of the variable a.c. supply shall be set to a voltage equal to the V_{nom_max} setting. This voltage level shall be maintained for 10 min.

(i) The output voltage of the variable a.c. supply shall be increased by 2 V (i.e. V_{nom_max} setting plus 2 V). The time to disconnect shall be recorded.

(j) The output voltage of the variable a.c. supply shall be decreased so that the voltage at the a.c terminals of the device under test equals the grid test voltage. The time to reconnect shall be recorded.

H2.3 Criteria for acceptance

When subjected to the test specified above, the average of the value for V_{nom_max} determined in Step (f) shall equal the set-point ±1%. The time to detect a sustained overvoltage and disconnect as recorded in Step (i) shall be less than 30 s. The time to reconnect recorded in Step (j) shall be greater than 60 s.

H2.4 Test report

A summary table shall be presented with a result for each step performed, comparing actual test values against set-point values.

H3 SUSTAINED OPERATION FOR FREQUENCY VARIATIONS

H3.1 General

When tested in accordance with the following procedure, the device under test shall demonstrate a satisfactory response to a sustained over-frequency event and then a controlled return to normal operation after the frequency returns to 50 Hz ±0.15 Hz as required by Clause 7.5.3.

The accuracy of the response to an over-frequency event shall be measured at 50% of the rated apparent power. There shall be a tolerance on the output of ±5% of the starting apparent power for each test.

This test is comprised of two parts where frequency is increased at 0.1 Hz steps. First part increases frequency until frequency exceeds F_{stop} and the second part increase frequency to 51.0 Hz. This second part is to check that on return to nominal frequency the hysteresis function holds the apparent power output of the inverter at the same output or below as measured at 51.0 Hz as the frequency is returned to 50 Hz.

After each test, the time taken to return to initial output power shall be timed to ensure that the rate of increase does not exceed requirements of Clause 7.5.3.

H3.2 Test procedure

The procedure shall be as follows:

(a) The inverter and automatic disconnection device shall be connected into a test circuit equivalent to that shown in Figure G1.

(b) The default sustained operation over-frequency limit (F_{stop}), as specified in Clause 7.5.3, shall be confirmed (i.e. F_{stop} shall be 52 Hz).

(c) The variable a.c. supply shall be set so that the voltage at the a.c terminals of the device under test equals the grid test voltage. The input supply shall be varied until the a.c. power output of the device under test equals 50 ±5% of its rated apparent power.

(d) The output voltage of the variable a.c. supply set to the grid test voltage shall be maintained at this level for 5 min. The average inverter power recorded over this period shall be used as the frozen value of power (P_{ref}) when the frequency exceeds 50.25 Hz.

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(e) The output frequency of the variable a.c. supply shall be increased by a 0.1 Hz step in frequency.

(f) The average frequency and average power shall be recorded for each 0.1 Hz step.

(g) After 30 s, Steps (e) and (f) shall be repeated until the F_{stop} + 0.2 Hz is reached. At this frequency, the inverter output shall be 0 W.

(h) The frequency shall be decreased every 30 s in 0.2 Hz decrements until the frequency is less than 50.15 Hz.

(i) The voltage and frequency shall be maintained for 10 min or until the inverter reaches the maximum output power available. The increase in power shall be monitored to determine if the controlled increase in power exceeds the power rate limit (W_{Gra}) of Clause 6.2.5.2.

(j) Steps (c) and (d) shall be repeated for the testing of the hysteresis when frequency does not exceed F_{stop}.

(k) After 30 s, Steps (e) and (f) shall be repeated until the 51.0 Hz is reached.

(l) The average frequency and average power shall be recorded.

(m) The frequency shall be decreased every 30 s in 0.2 Hz decrements until the frequency is less than 50.15 Hz. The average frequency and average power shall be recorded for each 0.2 Hz decrement.

(n) The voltage and frequency shall be maintained for 10 min or until the inverter reaches the maximum output power available. The increase in power shall be monitored to determine if the controlled increase in power exceeds the power rate limit (W_{Gra}) of Clause 6.2.5.2.

H3.3 Criteria for acceptance

When subjected to the tests specified in Paragraph H3.2, the response to the over-frequency condition shall be linear and in accordance with Clause 7.5.3.

The results recorded in Steps (f) and (k) shall be graphed on an x-y axis graph, where the x axis is frequency and the y axis is power output.

The results monitored in Steps (i) and (n) shall be graphed with respect to time. The rate of increase in output power shall not exceed the power rate limit (W_{Gra}).

H3.4 Test procedure for inverters with energy storage

When tested in accordance with the following procedure, the device under test should demonstrate a satisfactory response to a sustained under-frequency event and then a controlled return to normal operation after the frequency returns to 50 Hz ±0.15 Hz.

Two tests are required where frequency is reduced at 0.1 Hz steps until frequency first falls below F_{stop} and the second test is to 49.5 Hz. This second test is to check that on return to nominal frequency the hysteresis function maintains the charge rate at the same level or below as at 49.5 Hz.

After each test, the time taken to return to initial output power shall be timed to ensure that the rate of increase does not exceed requirements.

H3.5 Test procedure

The procedure shall be as follows:

(a) The inverter and automatic disconnection device shall be connected into a test circuit equivalent to that shown in Figure G1.

(b) The default sustained charging under-frequency limit ($F_{stop\text{-}CH}$), as specified in Clause 7.5.3, shall be confirmed (i.e. $F_{stop\text{-}CH}$ shall be 49 Hz).

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(c) The variable a.c. supply shall be set so that the voltage at the a.c terminals of the device under test equals the grid test voltage. Where the charge rate of the storage element can be externally controlled, the charge rate shall be adjusted to 50 ±5% of maximum charge rate. Otherwise the initial charge rate of the storage element should be noted for each test.

(d) The output voltage of the variable a.c. supply set to the grid test voltage shall be maintained at this level for 5 min. The average charge rate over this period shall be used as the frozen value of charge rate ($P_{ref\text{-}CH}$) when the frequency falls below 49.75 Hz.

(e) The output frequency of the variable a.c. supply shall be decreased by a 0.1 Hz step in frequency.

(f) The average frequency and average power shall be recorded for each 0.1 Hz step.

(g) After 30 s, Steps (e) and (f) shall be repeated until the F_{stop} – 0.2 Hz is reached. At this frequency, the charge rate of the storage element shall be 0 W.

(h) The frequency shall be increased every 30 s in 0.1 Hz increments until the frequency is more than 49.85 Hz.

(i) The voltage and frequency shall be maintained for 10 min or until the charge rate of the storage element reaches the maximum available. The increase in charge rate shall be monitored to determine if the controlled increase in charge rate exceeds the power rate limit (W_{Gra}) of Clause 6.2.5.2.

(j) Steps (c) and (d) shall be repeated for the testing of the hysteresis when frequency does not fall below F_{stop}.

(k) After 30 s, Steps (e) and (f) shall be repeated until 49.5 Hz is reached.

(l) The average frequency and average power shall be recorded.

(m) The frequency shall be increased every 30 s in 0.1 Hz increments until the frequency is more than than 49.85 Hz. The average frequency and average charge rate shall be recorded for each 0.1 Hz increment.

(n) The voltage and frequency shall be maintained for 10 min or until the charge rate of the storage element reaches the maximum available. The increase in power shall be monitored to determine if the controlled increase in charge rate exceeds the rate limit (W_{Gra}) of Clause 6.2.5.2.

H3.6 Criteria for acceptance

When subjected to the tests specified in Paragraph H3.5, the response to the under-frequency condition shall be linear and in accordance with Clause 7.5.3.

The results recorded in Steps (f) and (k) shall be graphed on an x-y axis graph, where the x axis is frequency and the y axis is charge rate.

H3.7 Test report

The graphs specified in Paragraphs H3.3 and H3.6 shall be included in the test report.

A summary table shall be presented with a result for each step performed, comparing actual test values against set-point values.

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APPENDIX I

DEMAND AND POWER QUALITY RESPONSE MODE TESTING INCLUDING DISCONNECTION ON EXTERNAL SIGNAL

(Normative)

I1 GENERAL

The purpose of the tests set out in this Appendix is to verify that the demand response and power quality response modes respond as required and that the performance of the anti-islanding protection is not affected when these modes are enabled or disabled.

NOTES:

1 This Standard focuses on the essential requirements of the power quality response modes, i.e. that when enabled the safety and protective functions of the inverter are not comprised. It is left to the manufacturer to determine the other functions and abilities of the power quality response modes and verify the performance of these functions and abilities. The testing of such functions and abilities is complex, as the development of these modes is ongoing and subject to rapid change, and currently under consideration.

2 The Demand Response provisions in this Standard follow the framework in the AS/NZS 4755 series Demand response capabilities and supporting technologies for electrical products. Each part of the AS/NZS 4755 series covers the role of the Demand Response Enabling Device (DRED) in achieving demand response, but at present there is no part of AS/NZS 4755 explicitly covering the design or performance of a DRED.

I2 TEST PROCEDURES

I2.1 Test for demand response and disconnection on external signal

The procedure shall be as follows:

(a) The inverter shall be connected into a test circuit equivalent to that shown in Figure G1. The voltage shall equal the grid test voltage.

(b) The inverter DRED connection (i.e. terminal block or RJ45 socket) shall be connected to a DRED though an auxiliary DRED test circuit, as shown in Figure I1. The following applies:

(i) When measured from the inverter DRED connection point, and with less than 30 mA (a.c. or d.c.) current flow, each DRED switch (S1–S8) and auxiliary DRED test circuit switch (S0) shall have a voltage drop of less than 0.1 V when ‘on’.

(ii) When measured from the inverter DRED connection point, and with less than 30 mA (a.c. or d.c.) current flow, the auxiliary DRED test circuit shall have a voltage drop of 1.5–1.6 V (a.c. or d.c.) between terminals REF GEN/0 and DRM1/5 and COM LOAD/0 and DRM1/5, when auxiliary switches S5a and S1a respectively are ‘on’.

I2.2 Test for disconnection at rated current output

The procedure shall be as follows:

(a) Switch S9 (see Figure I1) shall be closed.

(b) The input supply or inverter set-point shall be varied until the a.c. output of the inverter equals 100 ±5% of its rated current output.

(c) DRED switch S0 (see Figure I1) shall be asserted and the time for the device under test to disconnect shall be measured and recorded.

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(d) Where the inverter supports the provision of d.c. power to the DRED, power to the DRED shall remain after the automatic disconnection device has operated.

(e) The disconnect signal (S0) shall be removed and the inverter shall be allowed to automatically reconnect (see Clause 7.6).

(f) Switch S9 shall be opened and the time for the device under test to disconnect shall be measured and recorded. See Clause 6.2.2(d).

I2.3 Test for standard operation of generator demand response modes

The procedure shall be as follows:

(a) All DRM signals shall be removed and the input supply or inverter set-point shall be varied until the a.c. output of the inverter equals 100 ±5% of its rated current output. The DRM 3 and DRM 7 reactive power limits shall be set to their maximum allowed values (see Clause 6.2).

(b) DRED switch S7 shall be asserted and DRM 7 response assessed over a period of 2 min in accordance with Table I1.

(c) DRED switch S6 shall be asserted and simultaneous DRM 6 and DRM 7 response assessed over a period of 2 min in accordance with Table I1.

(d) DRED switch S7 shall be opened and DRM 6 response assessed over a period of 2 min in accordance with Table I1.

(e) DRED switch S5 shall be asserted and DRM 5 response assessed in accordance with Table I1.

(f) All DRM signals shall be removed and the input supply or inverter set-point shall be varied until the a.c. output of the inverter equals 50 ±5% of the inverter's rated current output and is in a state able to respond to DRM 8.

(g) DRED switch S8 shall be opened and DRM 6 response assessed over a period of 2 min in accordance with Table I1.

I2.4 Test for standard operation of load demand response modes (such as for battery charging)

The procedure shall be as follows:

(a) All DRM signals shall be removed and the input supply or inverter set-point shall be varied until the a.c. draw of the inverter equals 100% of the inverter's rated current input. DRM 3 and DRM 7 reactive power limits shall be set to their maximum allowed values (see Clause 6.2).

(b) DRED switch S3 shall be asserted and DRM 3 response assessed over a period of 2 min in accordance with Table I1.

(c) DRED switch S2 shall be asserted and simultaneous DRM 2 and DRM 3 response assessed over a period of 2 min in accordance with Table I1.

(d) DRED switch S3 shall be opened and DRM2 response assessed over a period of 2 min in accordance with Table I1.

(e) DRED switch S1 shall be asserted and DRM 1 response assessed over a period of 2 min in accordance with Table I1.

(f) All DRM signals shall be removed and the input supply or inverter set-point shall be varied until the a.c. draw of the inverter equals 50 ±5% of the inverter's rated current input and is in a state able to respond to DRM 4.

(g) DRED switch S4 shall be opened and DRM 4 response assessed over a period of 2 min in accordance with Table I1.

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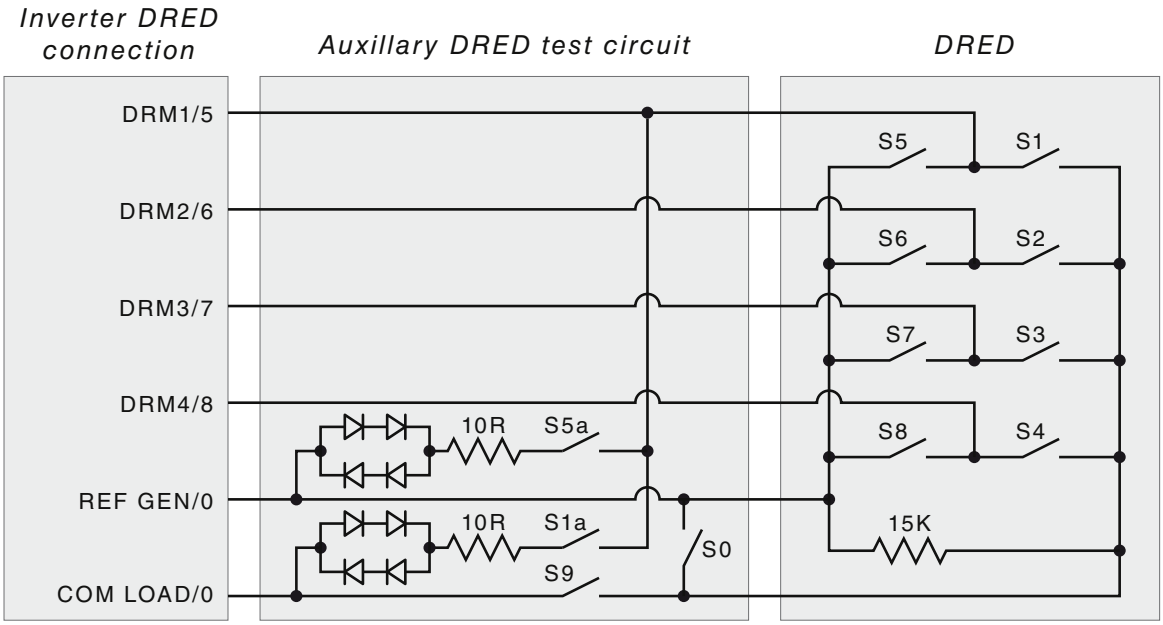


FIGURE I1 DRED CONNECTION CIRCUIT

I3 DEMAND RESPONSE MODE LIMITS

When subjected to the tests specified in Paragraph I2, the inverter shall not exceed the real current limits, reactive current limits, or switching time limits specified in Table I1.

The inverter does not satisfy this test if it—

(a) fails to respond to a DRM instruction of which it is claimed to be capable within the switching time limit;

(b) does not operate in accordance with the requirements for the DRM of Clause 6.1; or

(c) responds to a DRM instruction of which it is not claimed to be capable.

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TABLE I1

CURRENT AND SWITCH TIME LIMITS FOR DRM COMPLIANCE

Demand response mode	Real current limit (referenced to inverter rated per phase current)	Reactive current limit (referenced to inverter rated per phase current)	Switching time limit
DRM 0	0	0	2 s
DRM 1	Import = 0	0	2 s
DRM 2	Import < 50%	As per Clauses 5.5, 6.2 and DRM 3 and DRM 7	2 s
DRM 3	Import < 75%	Within 5% of set-point per Clause 6.2	2 s
DRM 4	Not limited	As per Clauses 5.5, 6.2 and DRM 3 and DRM 7	2 s
DRM 5	Generate = 0	0	2 s
DRM 6	Generate < 50%	As per Clauses 5.5, 6.2 and DRM 3 and DRM 7	2 s
DRM 7	Generate < 75%	Within 5% of set-point per Clause 6.2	2 s
DRM 8	Not limited	As per Clauses 5.5, 6.2 and DRM 3 and DRM 7	2 s

NOTE: For DRM 0, DRM 1 and DRM 5, current draw due to sensing and DRED circuits is allowable (see Clause 7.2).

I4 TEST REPORT

The measured values for switching times and per phase real and reactive current shall be reported in a table format for each stage of the test. See example in Table I2.

TABLE I2

DEMAND RESPONSE MODE REPORTING TABLE

Demand response test	Real current	Reactive current	Switching time	Pass/ Fail
DRM 0 at 100%				
DRM 7				
DRM 6 and DRM 7				
DRM 6				
DRM 5 and DRM 6				
DRM 8				
DRM 3				
DRM 3 and DRM 2				
DRM 2				
DRM 1 and DRM 2				
DRM 4				

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APPENDIX J

MULTIPLE INVERTER TESTING

(Normative)

J1 GENERAL

When multiple inverters are to be used in combination with other inverters to meet the needs of the consumer and provide the desired inverter energy system capacity, they are required to be tested together in combination, as specified in Clause 8. This is to ensure that the operation of the inverters in combination does not compromise inverter performance or safety.

For all tests performed in combination, each inverter in the combination shall have a current output that is equal, within 5%, to the other inverters in the combination.

J2 TEST PROCEDURES

J2.1 Test for single-phase combinations

The procedure shall be as follows:

(a) Determine the number of inverters to be tested in combination in accordance with Clause 8.5.1.

(b) Perform the active anti-islanding test for load condition B set out in Paragraph F4 of Appendix F. The test shall be performed in accordance with Appendix F, with the following variations:

(i) Connect inverters in an equivalent arrangement for testing as shown in Figure F1, but replace the single inverter with the correct number of paralleled single-phase inverters.

(ii) Perform the test as set out in Paragraph F4 for a single inverter for the combination of inverters to be tested.

J2.2 Test for single-phase inverters used in three-phase combination

J2.2.1 *Test procedure*

The procedure shall be as follows:

(a) Determine the number of inverters to be tested in combination in accordance with Clause 8.5.2.

(b) Perform the voltage and frequency limits tests for the inverter combination in accordance with Appendix G. The tests shall be performed such that when any change on any one phase trips any inverter in the combination, all of the other inverters trip within the secondary trip time required by Clause 8.3 (i.e. 2 s). Changes to voltage shall be applied to a single-phase whereas changes to frequency shall be applied to all phases.

(c) Perform the active anti-islanding test for the inverter combination for load combination B in accordance with Appendix F. The test shall be performed such that when any one phase trips any inverter in the combination, all other inverters trip within the secondary trip time required by Clause 8.3 (i.e. 2 s).

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(d) The response of the inverters in a three-phase combination system to a change of output in a single-phase inverter shall be tested by reducing the energy source input on one inverter in the combination to 0% and maintaining the energy source input for the other inverters in the combination at full input. The inverters shall limit the imbalance to 21.7 A between any combination of phases or disconnect all inverters, in accordance with the requirements of Clause 8.2.

J3 TEST REPORT

For each test performed, the results specified in the relevant appendix shall be recorded in the test report for the inverter combination tested.

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APPENDIX K

RELATED DOCUMENTS

(Informative)

Attention is drawn to the following related documents. These documents were used for information and guidance in the preparation of this Standard to ensure that features and requirements were aligned with international developments.

VDE-AR-N 4105:2011-08, *Power generation systems connected to the low-voltage distribution network* (English translation of the VDE application rule VDE-AR-N 4105)

Common functions for smart inverters. EPRI, Palo Alto, CA, 2011. 1023059

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AS	
61000	Electromagnetic compatibility (EMC)
61000.3.100	Part 3.100: Limits—Steady state voltage limits in public electricity systems
AS/NZS	
4755	Demand response capabilities and supporting technologies for electrical products (series)
60335	Household and similar electrical appliances—Safety
60335.1	Part 1: General requirements
ISO/IEC	
8877	Information technology—Telecommunications and information exchange between systems—Interface connector and contact assignments for ISDN Basic Access Interface located at reference points S and T
ACMA	Electromagnetic Compatibility—Information for suppliers of electrical and electronic products in Australia and New Zealand

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