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# Grid-Connected PV Systems Design and Installation

## Revisions to the Grid-Connected PV Systems: Design and Installation Australian Edition Version 8.9 Publication

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Following is the summary of changes to the information within Grid-Connected PV Systems Design and Installation Australian Edition Version 8.9, May 2021. Please note that the changes in this document are subject to alterations in newer editions. While all care has been taken to ensure this document is free from omission and error, no responsibility can be taken for the use of this information in the design or installation of any grid-connected PV system.



## Keywords

***Addition:*** *Adding an additional paragraph.*

***Replacement:*** *To entirely replace something.*

***Extension:*** *To add an additional sentence/s onto the end of a sentence or paragraph.*

***Amendment:*** *To modify sections of a paragraph or sentence either by quote or by reviewing the referenced text.*

***Removal:*** *To remove something altogether.*

## Table of Contents



## Introduction

2. **Introduction**

   *Replacement:*

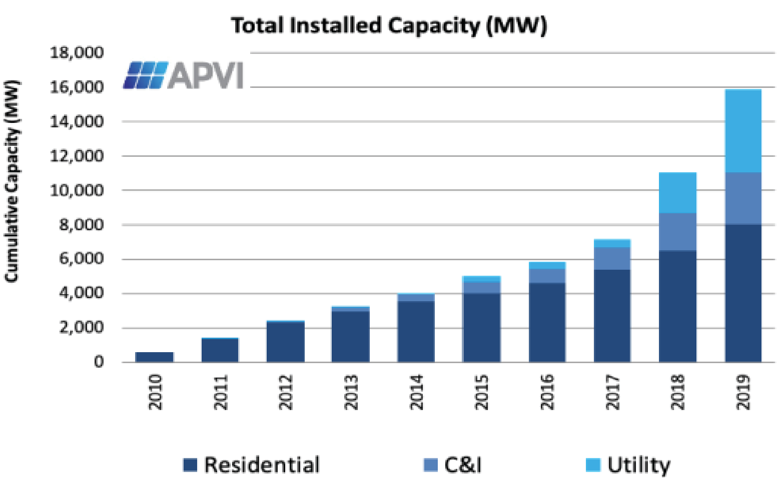


Figure 1. Annual PV installations by sector, where C&I is commercial and industrial.

***Figure i:*** *Australian PV installations by sector.*
*(Source: PV in Australia Report 2019, APVI, July 2020*

## Chapter 2

### 3. Section 2.4 - Summary of DC Electrcity Principles

*Replacement:*

> ***AUSTRALIAN STANDARDS***
>
> The relevant electrical standards for designing and installing a grid-connected PV system are:
>
> ***AS/NZS 3000:2018*** – Wiring rules
>
> ***AS/NZS 3008.1.1:2017*** – Selection of cables (AC only)
>
> ***AS/NZS 4777.1:2016*** – Grid connection of energy systems via inverters, Part 1: Installation requirements
>
> ***AS/NZS 4777.2:2020*** – Grid connection of energy systems via inverters, Part 2: Inverter requirements
>
> ***AS/NZS 5033:2014*** – Installation and safety requirements for photovoltaic (PV) arrays
>
> ***IEC 62305*** –Protection against lightning
>
> ***AS/NZS 1768:2007*** –Lightning Protection

## Chapter 3

### 4. Section 3.1.4 - Solar Radiation that Reaches the Sun's Surface

*Amendment:*

The solar constant ($G_{SC}$) is the amount of solar radiation at the top of the Earth's atmosphere (i.e. extraterrestrial radiation), approximately 1.367 kW/m². Taking into account absorption, reflection and scattering, the amount of solar radiation at sea level on a clear day at AM1 (i.e. with the Sun directly overhead) is approximately 1 kW/m2, which is known as the peak value at sea level ($G_0$).

### 5. Section 3.1.4 - Solar Radiation that Reaches the Sun's Surface

*Addition:*

> **DID YOU KNOW?**
>
> Before sunlight reaches the Earth's atmosphere, it is known as "extraterrestrial irradiation".

## Chapter 5

### 6. Section 5.1.1 - Generation

*Removal:*

e. Under Passive anti-islanding conditions, the inverter must disconnect within 3 seconds (can be specified over a required sampling period).

# Chapter 6

**7. Section 6.4.1 - Bypass Diodes**

*Amendment in Half-cut Cells:*

In some shading situations, particularly localised shading, a conventional modue and half-cut cell module will perform similarly (Figure 6.21a). However, in some cases, for example where the bottom half of the module is shaded, the bypass diodes in a half-cut cell module will not activate and the half-cut cell module will perform better than a conventional module (Figure 6.21b).

**8. Section 6.4.1 - Bypass Diodes**

*Replacement:*

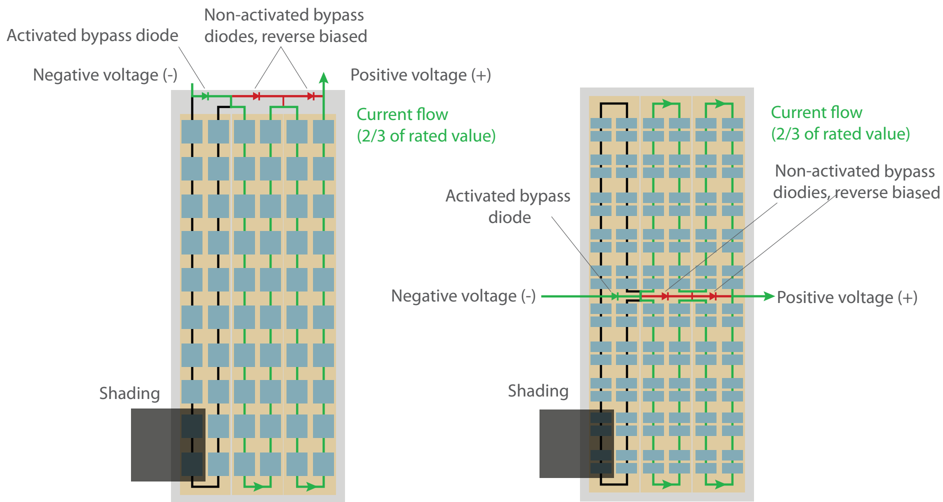


***Figure 6.21a:*** *An example of shading where a conventional module and a half-cut cell module are similarly affected.*

# Chapter 7

**9. Introduction**

*Replacement:*

***AUSTRALIAN STANDARDS AND GUIDELINES***

Grid-connected inverters for use in Australia must comply with the prescribed Australian Standards.

***AS/NZS 4777.1:2016***

***AS/NZS 4777.2:2020***

***AS/NZS 5033:2014*** calls up ***IEC 62109:2010*** Parts 1 & 2 and ***AS/NZS 3100:2017***.

The Clean Energy Council (CEC) provides a list of these approved inverters. The CEC list is regularly updated and can be found on the CEC website:

www.cleanenergycouncil.org.au

 

**10. Section 7.2.2 - AC Specifications**

*Replacement:*

> ***AUSTRALIAN STANDARDS AND GUIDELINES***
>
> ***AS/NZS 4777.2:2020*** outlines the AC output specifications of a grid-connect inverter so that it is compatible with the Australian grid.
>
> Inverters installed in Australia connected to the grid must be compliant to this standard. This document sets out the inverter's required behaviour under abnormal grid conditions such as when the voltage of the grid is lower or higher than prescribed settings, as well as behaviour to prevent islanding.
>
> The CEC's Design Guidelines for Accredited Installers state that the AC output of the inverter must not be less than 75% of the array output

**11. Section 7.2.2 - AC Specifications**

*Amendment:*

**Inverter's Power Factor**

Most inverters are able to customise the power factor of the output AC signal (see Chapter 5 for more on power factor).

**12. Section 7.2.2 - AC Specifications**

*Addition:*

> ***AUSTRALIAN STANDARDS***
>
> ***AS/NZS 4777.2:2020*** Clause 2.7 requires that the total harmonic current distortion of the inverter is less than 5%.

**13. Section 7.2.2 - AC Specifications**

*Replacement:*

> **DID YOU KNOW?**
>
> The ability of the inverter to supply and absorb reactive power is set out by ***AS/NZS 4777.2:2020***.

### 14. Section 7.2.4 - Physical Specifications

*Addition:*

***Table 7.1:*** *IP rating classifications.* (Source: IEC 60529:2001 Clause 4.2)

| Element | Numerals | Meaning for the Protection of Equipment |
|---|---|---|
| First characteristic numeral (against ingress of solid foreign objects) | 0 | (non-protected) |
| | 1 | ≥ 50 mm diameter |
| | 2 | ≥ 12.5 mm diameter |
| | 3 | ≥ 2.5 mm diameter |
| | 4 | ≥ 1.0 mm diameter |
| | 5 | dust-protected |
| | 6 | dust-tight |
| Second characteristic numeral (against ingress of water with harmful effects) | 0 | (non-protected) |
| | 1 | vertically dripping |
| | 2 | dripping (15° tilted) |
| | 3 | spraying |
| | 4 | splashing |
| | 5 | jetting |
| | 6 | powerful jetting |
| | 7 | temporary immersion |
| | 8 | continuous immersion |

### 15. Section 7.3.1 - Grid-connect, Standalone, and Multimode Inverters

*Replacement:*

***AUSTRALIAN STANDARDS***

Stand-alone inverters are covered by ***AS/NZS 4509.1:2009***, and multimode inverters also need to provide certification to ***AS/NZS 4777.1:2016***, ***AS/NZS 4777.2:2020*** and ***AS 62040:2003*** or ***IEC 62109:2010***.

### 16. Section 7.4 - Grid-connect Inverter Protection System

*Amendment:*

***AUSTRALIAN STANDARDS***

***AS/NZS 4777.1:2016***
***AS/NZS 4777.2:2020***
***AS/NZS 5033:2014*** calls up
***IEC 62109:2010*** Parts 1 & 2 and
***AS/NZS 3100:2017***.

 

## 17. Section 7.4.2 - Passive Protection

*Replacement:*

> *EXAMPLE*
>
> The characteristics of the supply voltage are defined by the relevant standards and network operators.
>
> In Australia, the permitted voltage ranges are defined by AS 60038:2012 to be +10% and –6% of the nominal supply voltage. With a supply voltage of 230 $V_{RMS}$, this corresponds to:
>
> VMIN = 216 V
>
> VMAX = 253 V
>
> The permitted frequency ranges of the electricity supply in Australia are defined by the ***AEMC Frequency Operating Standard*** as:
>
> $f_{MIN}$ = 47 Hz
>
> $f_{MAX}$ = 52 Hz (mainland) 55 Hz (Tasmania)

## 18. Section 7.4.3 - Active Protection

*Replacement:*

> ***AUSTRALIAN STANDARDS***
>
> ***AS/NZS 4777.2:2020*** Clause 4.3 states that an inverter must have at least one method of active anti-islanding protection.

## 19. Section 7.6 - Demand Response Management (DRM)

*Replacement:*

> ***AUSTRALIAN STANDARDS***
>
> ***AS/NZS 4755*** series of standards provides full details on the various Demand Response Modes for various equipment, ***AS/NZS 4755.3*** in particular deals with Energy Storage Systems. ***AS/NZS 4777.2:2020*** Section 3 covers the operational mode requirements for grid-connected inverters or the grid-connected port of multiple mode inverters.

## 20. Section 7.6 - Demand Response Management (DRM)

*Replacement:*

***Table 7.3:*** *Demand Response Modes (DRMs).*

*(Source: **AS/NZS 4777.2:2020** Table 3.1)*

## 21. Section 7.7.1 - Automatic Disconnection Device

*Replacement:*

> ***AUSTRALIAN STANDARDS***
>
> The requirement for the automatic disconnection device to operate when DRM 0 is activated was a new function in ***AS/NZS 4777.2:2015***. It continues to be a requirement in ***AS/NZS 4777.2:2020***.

## 22. Section 7.8 - Inverter Power Quality Response Mode

*Removal:*

i. Volt response modes;
ii. Fixed power factor or reactive power mode;
iii. Power response modes
iv. Power rate limit;

## 23. Section 7.8.1 - Volt Response Modes

*Removal:*

***Table 7.4:*** *Volt response reference values.*
*(Source: AS/NZS 4777.2:2015 Table 9)*

| Reference | Australian default value (V) | Range (V) |
|---|---|---|
| V1 | 207 | N/A |
| V2 | 220 | 216 to 230 |
| V3 | 250 | 235 to 255 |
| V4 | 265 | 244 to 265 |

## 24. Section 7.8.1 - Volt Response Modes

*Addition:*

***AUSTRALIAN STANDARDS***

Setpoints are defined by region of installation. The regions are:

- **Australia A:** For large interconnected power systems, e.g. the National Energy Market (NEM)
- **Australia B:** For small interconnected systems, e.g. the South West Interconnected System (SWIS) in Western Australia
- **Australia C:** For isolated or remote power systems, e.g. Horizon Power in Western Australia
- **New Zealand:** All systems in New Zealand

As ***AS/NZS 4777.2:2020*** does not explicitly define the difference between large and small interconnected systems, network operators (DNSPs) will decide which regions their networks fall under. Therefore, it is possible that specific DNSPs can request setpoints that do not correspond to the examples provided in the list.

 

**25. Section 7.8.1 - Volt Response Modes**

*Replacement:*

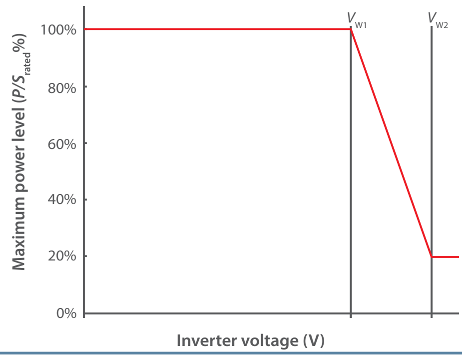


*Figure 7.38: Example curve for a volt-watt response mode (Australia).*
(*Source: AS/NZS 4777.2:2020 Figure 3.1*)

**26. Section 7.8.1 - Volt Response Modes**

*Replacement:*

## Volt-var Response Mode

In this mode, the reactive power output of the inverter is varied in response to the voltage at its grid interactive port. This feature is enabled by default.

**27. Section 7.8.1 - Volt Response Modes**

*Replacement:*

***Table 7.5:*** *Volt-var response set-point values for reference voltages.*

(*Source: AS/NZS 4777.2:2020 Table 3.7*)

| Region | Default value | $V_{V1}$ | $V_{V2}$ | $V_{V3}$ | $V_{V4}$ |
|---|---|---|---|---|---|
| Australia A | Voltage | 207 V | 220 V | 240 V | 258 V |
| | Inverter reactive power level (Q) % of $S_{rated}$ | 44% supplying | 0% | 0% | 60% absorbing |
| Australia B | Voltage | 205 V | 220 V | 235 V | 255 V |
| | Inverter reactive power level (Q) % of $S_{rated}$ | 30% supplying | 0% | 0% | 40% absorbing |
| Australia C | Voltage | 215 V | 230 V | 240 V | 255 V |
| | Inverter reactive power level (Q) % of $S_{rated}$ | 44% supplying | 0% | 0% | 60% absorbing |
| New Zealand | Voltage | 207 V | 220 V | 235 V | 244 V |
| | Inverter reactive power level (Q) % of $S_{rated}$ | 60% supplying | 0% | 0% | 60% absorbing |
| Allowed range | Voltage | 180 to 230 V | 180 to 230 V | 230 to 265 V | 230 to 265 V |
| | Inverter reactive power level (Q) % of $S_{rated}$ | 30 to 60% supplying | 0% | 0% | 30 to 60% absorbing |

**28. Section 7.8.1 - Volt Response Modes**

*Replacement:*

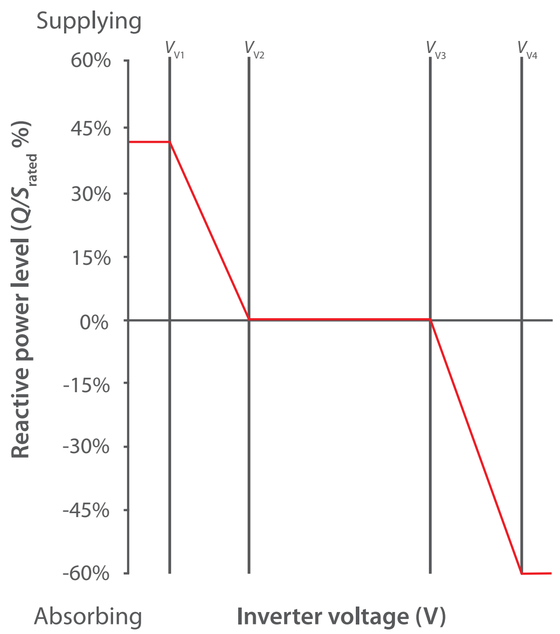


*Figure 7.39: Example curve for a possible volt-var control mode (Australia).*
*(Source: **AS/NZS 4777.2:2020** Figure 3.2)*

**29. Section 7.8.2 - Fixed Power Factor Mode and Reactive Power Mode**

*Amendment:*
If the inverter is capable of operating with reactive power mode, the default ratio of reactive power (var) to rated apparent power (VA) should be 100%.

**30. Section 7.8.3 - Power Rate Limit**

*Replacement:*

> ***AUSTRALIAN STANDARDS***
>
> ***AS/NZS 4777.2:2020*** Clause 4.5.2 details limitations regarding sustained operation for voltage variations.

**31. Section 7.8.3 - Power Rate Limit**

*Replacement:*
The inverter must disconnect from the grid within 3 seconds if the average voltage for a 10 minute period exceeds the nominal maximum voltage setting (default of 258 V in Australia).

**32. Section 7.9.1 - Response to Increase in Frequency**

*Replacement:*
The inverter shall be capable of supplying rated power between 47 Hz and 52 Hz for Australia. An inverter shall reduce the power output linearly with increase in the frequency of the grid. The power level present at the time that frequency reaches or exceeds an acceptable frequency upper limit of continuous operation for the region ($f_{ULCO}$) is used as reference power level to calculate the required response to the increasing frequency. The object of this mode is to avoid forcing up the grid frequency by continuing to supply power into the grid during over-frequency events whilst still allowing the inverter to remain connected to the grid.

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

 

**Where:**

- $P_{out}$ = required power output level for a frequency between $f_{ULCO}$ and $f_{Pmin}$
- $P_{ref}$ = reference power output level when the frequency exceeds $f_{ULCO}$
- $f_{ULCO}$ = upper limit of the continuous operation range for frequency
- $f_{Pmin}$ = frequency where power output is zero
- $f$ = frequency between $f_{ULCO}$ and $f_{Pmin}$ (i.e. $f_{ULCO} \leq f \leq f_{Pmin}$)

**33. Section 7.9.1 - Response to Increase in Frequency**

*Addition:*

> ***AUSTRALIAN STANDARDS***
>
> ***AS/NZS 4777.2:2020*** Tables 4.4 and 4.5 describe the allowable frequency characteristics for specific regions of Australia and New Zealand.

**34. Section 7.9.1 - Response to Increase in Frequency**

*Replacement:*

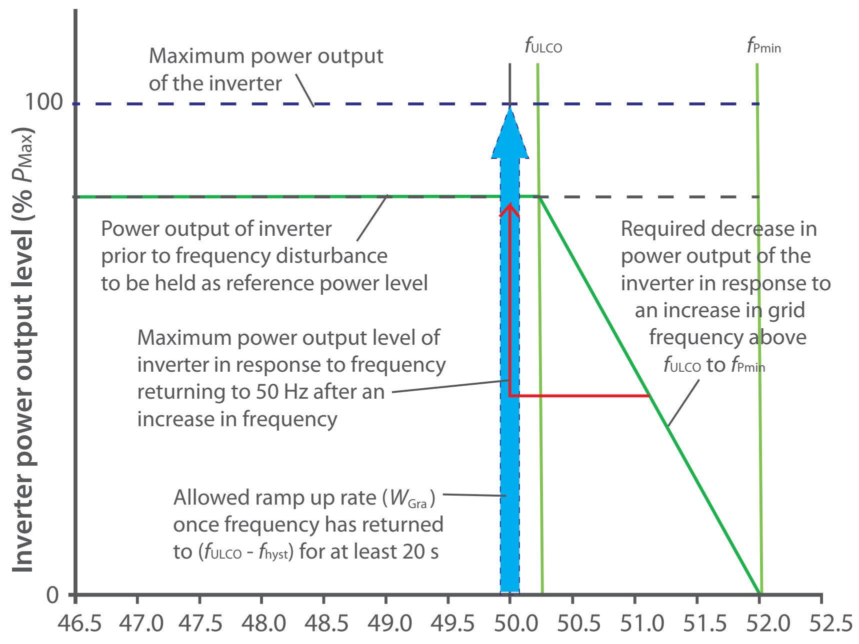


*Figure 7.40: Example frequency response for an increase in frequency for $f_{Pmin}$ of 52 Hz.*
(Source: **AS/NZS 4777.2:2020** Figure 4.3)

**35. Section 7.9.2 - Response to Decrease in Frequency**

*Replacement:*

## 7.9.2 Response to Decrease in Frequency

The inverter shall not reduce power output through the grid-interactive port in response to a decrease in frequency. In addition, if the inverter is not operating at full power due to another response mode, and the grid's frequency drops, the inverter must increase its output linearly to support the grid frequency. The power level present at the time that frequency reaches or exceeds an acceptable frequency upper limit of continuous operation for the region ($f_{ULCO}$) is used as a reference power level to calculate the required response to the increasing frequency.

### 36. Section 7.9.2 - Response to Decrease in Frequency

*Addition:*

$$P_{out} = P_{ref}\left[(P_{max} - P_{ref})\frac{(f_{LLCO} - f)}{(f_{LLCO} - f_{Pmax})}\right]$$

**Where:**

- $P_{out}$ = required power output level for a frequency between $f_{LLCO}$ and $f_{Pmax}$
- $P_{max}$ = maximum power output of the inverter
- $P_{ref}$ = reference power output level when the frequency falls below $f_{LLCO}$
- $f_{LLCO}$ = lower limit of the continuous operation range for frequency
- $f_{Pmax}$ = frequency where power output is maximum
- $f$ = frequency between $f_{LLCO}$ and $f_{Pmax}$ (i.e. $f_{Pmax} \leq f \leq f_{LLCO}$)

Furthermore, charging limits also apply for inverters with energy storage charging capabilities when grid frequency decreases.

### 37. Section 7.10 - Multiple Inverter Combinations

*Replacement:*

> ***AUSTRALIAN STANDARDS***
>
> ***AS/NZS 4777.2:2020*** Section 5 sets out the requirements for inverters that can be used in installations with multiple inverters.

### 38. Section 7.11 - Signage

*Amendment:*

> ***AUSTRALIAN STANDARDS***
>
> In Australia and New Zealand refer to ***AS/NZS 4777.2:2020*** Clause 7.2.5 for detailed information related to warning labels where external RCDs are required by an inverter.

### 39. Section 7.11 - Signage

*Amendment:*

| | | | | | |
|---|---|---|---|---|---|
| DRM 0 | ☐ | DRM 1 | ☐ | DRM 2 | ☐ |
| DRM 3 | ☐ | DRM 4 | ☐ | DRM 5 | ☐ |
| DRM 6 | ☐ | DRM 7 | ☐ | DRM 8 | ☐ |

*Figure 7.41: Sample DRM labelling.*
*(Source: **AS/NZS 4777.2:2020** Figure 7.1)*

 

# Chapter 11

### 40. Section 11.6 - Site Assessment of the Grid Connection

*Amendment:*

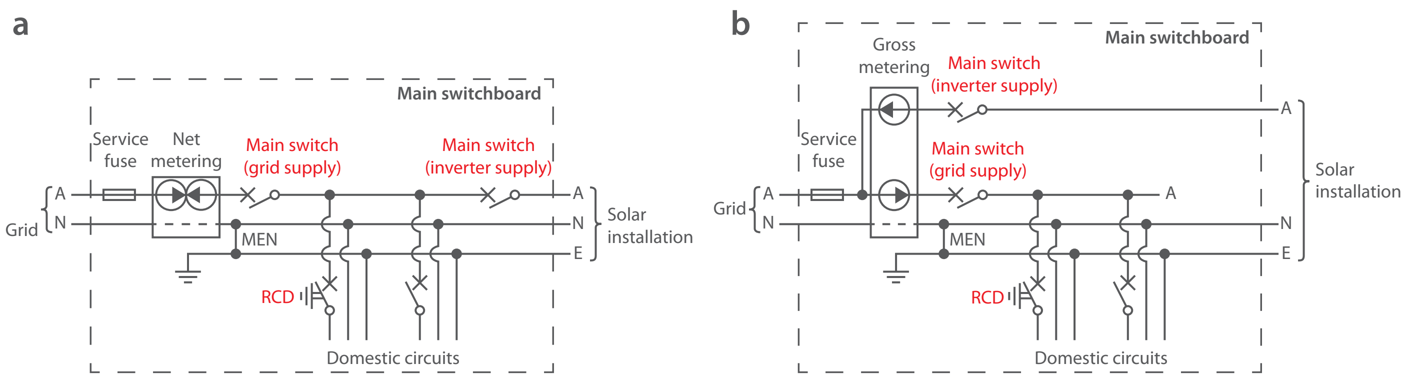


*Figure 11.24: Wiring schematics for a) a net-metering arrangement and b) a gross-metering arrangement. MEN: multiple earth neutral.*

# Chapter 12

### 41. Section 12.3.3 - Calculating Maximum Number of Modules in a String

*Amendment:*

**Maximum MPPT Voltage Threshold**

The MPPT maximum operating voltage is divided by the module's maximum operating voltage.

### 42. Section 12.3.3 - Calculating Maximum Number of Modules in a String

*Amendment:*

**Maximum MPPT Voltage:**

5. Multiply the MPPT maximum operating voltage by 0.95 (5% safety margin)

570 V × 0.95

# Chapter 13

### 43. Introduction

*Amendment:*

***AUSTRALIAN STANDARDS***

System protection design principles have been based on:

***AS/NZS 5033:2014***

***AS/NZS 4777.1:2016***

***AS/NZS 4777.2:2020***

***AS/NZS 3000:2018***

## 44. Section 13.3.4 - Summary of DC Disconnection Devices

*Amendment:*

| Location | Protection/ Disconnection Description | Protection/ Disconnection Device | Protection Sizing and Guidelines | Australian Standards |
|---|---|---|---|---|
| String | String overcurrent protection device (Section 13.2.1) | Fuse (preferred) or circuit breaker | **Required if:** $I_{SC}$ × *(No. of strings - 1) ≥ Module reverse current rating* **Sizing:** $1.5 \times I_{SC\_MOD} < I_{TRIP} < 2.4 \times I_{SC\_MOD}$ AND $I_{TRIP} \leq I_{MOD\_REVERSE}$ | ***AS/NZS 5033:2014*** Clause 3.3.4 and 3.3.5.1 |
| String | String disconnection device (Section 13.3.1) | Switch-disconnector, circuit breaker, or plug and socket | • Can be non-load-breaking<br>• Rated for PV array maximum voltage<br>• Current rating ≥ string overcurrent protection or, if no string overcurrent protection present, current rating ≥ CCC of string cable<br>• No live parts may be exposed at any time | ***AS/NZS 5033:2014*** Clause 4.2, 4.3.5.2 and 4.4.1.3 |
| Sub-array | Sub-array overcurrent protection device (Section 13.2.2) | Fuse or circuit breaker | **Required if:** $1.25 \times I_{SC\ ARRAY}$ > CCC of any sub-array cable, switching and connection device OR More than two sub-arrays are present within the array **Sizing:** $1.25 \times I_{SC\ SUB\text{-}ARRAY} \leq I_{TRIP} \leq 2.4 \times I_{SC\ SUB\text{-}ARRAY}$ | ***AS/NZS 5033:2014*** Clause 3.3.5.2 |
| Sub-array | Sub-array disconnection device (Section 13.3.2) | Switch-disconnector, circuit breaker, or plug and socket (ELV) | • Can be non-load-breaking<br>• Recommended to be load-breaking for LV systems<br>• Rated for PV array maximum voltage<br>• Current rating ≥ sub-array overcurrent protection or, if no sub-array overcurrent protection present, current rating ≥ CCC of sub-array cable<br>• No live parts may be exposed at any time | ***AS/NZS 5033:2014*** Clause 4.2, 4.3.5.2 and 4.4.1.3 |
| Array | Array overcurrent protection device (Section 13.2.3) | Fuse or circuit breaker | **Required if:** Another source of current is available that may cause damage to the PV array when under fault conditions. **Sizing:** $1.25 \times I_{SC\ ARRAY} \leq I_{TRIP} \leq 2.4 \times I_{SC\ ARRAY}$ | ***AS/NZS 5033:2014*** Clause 3.3.5.3 |
| Array | Array disconnection device (Section 13.3.3) | Switch-disconnector or circuit breaker | • Load-breaking and lockable in off position<br>• Non-polarised<br>• Voltage and current rating as per ***AS/NZS 5033:2014*** Clause 4.3.5.2 for switch-disconnectors<br>• No live parts may be exposed at any time | ***AS/NZS 5033:2014*** Clause 4.2, **4.3.4, 4.3.5.1, 4.3.5.2,** 4.4.1.3, 4.4.1.4 and 4.4.1.5 |

## 45. Section 13.4 - AC Overcurrent and Disconnection Devices

*Amendment:*

The inverter supply main switch is the primary AC disconnection device for the safe shutdown of a PV system.

The inverter supply main switch is an AC load-breaking, lockable isolating switch installed on the switchboard, or the distribution board if applicable.

The inverter supply main switch is installed at the switchboard or the distribution board, creating a individual circuit for the PV system.

**46. Section 13.7 - Residual Current Device RCD**

*Amendment:*

> ***AUSTRALIAN STANDARDS***
>
> In Australia and New Zealand, ***AS/NZS 4777.2:2020*** outlines the requirements around the use of an RCD with an inverter energy system. In particular see Clauses 2.4.1, 2.10, 7.2.5 and 7.3.5 for details.

## Chapter 14

**47. Section 14.1.2 - Voltage Drop and CSA**

*Replacement:*

Voltage rise increases with higher resistance, so smaller cables (smaller CSA), longer cable runs and higher current flow in the cable increase the voltage rise. Therefore, voltage rise can be reduced by suitable cable design, including reducing the length of the cable or increasing the cable CSA.

There are two commonly used methods that can be used for voltage drop/voltage rise calculations, namely simple resistivity method and the $V_C$ (AS/NZS 3008) method.

### Method 1 - Simple Resistivity Method

This method uses a simple formula to calculate voltage drop/rise present in a cable.

The relationship between voltage drop, cable cross-sectional area (CSA), cable length and current flow is given by:

$$V_d = \frac{2 \times L \times I \times \rho \times \cos\Phi}{A_{CABLE}}$$

**Where:**

- $V_d$ = Voltage drop (in V)
- $L$ = Route length of cable (in m). Multiplying by two adjusts for total circuit cable length.
- $I$ = Current flow (in A). For PV DC cables, the ISC current (at STC) should be used.
- $\rho$ = Resistivity of the conductor (in Ω/m/mm2)
- $\cos\Phi$ = Power factor (include only for AC cables)
- $A_{CABLE}$ = CSA of cable (in mm2)

To find the voltage drop as a loss percentage, simply divide the voltage drop in volts by the system voltage:

$$\%\ Loss = \frac{V_d}{V_{MAX}} \times 100\%$$

**Where:**

- $\%\ Loss$ = Percentage voltage drop in cable
- $V_d$ = Voltage drop (in V)
- $V_{MAX}$ = Maximum system voltage (in V)

If the maximum permissible voltage drop is known, the previous equations can be rearranged to calculate the minimum CSA required:

$$A_{CABLE} = \frac{2 \times L \times I \times \rho}{Loss \times V_{MAX}}$$

The resistivity of conductors varies with temperature. It is recommended that the maximum allowable temperature for the type of cable being used is applied for determining the resistivity of that cable.

The three types of cables that are commonly used within PV systems and their typical maximum temperature ratings include:

- Polyvinyl Chloride (PVC)- maximum temperature 75°C
- Cross Linked Polyethylene (XLPE)- maximum temperature 90°C
- Cross Linked Polyethylene (XLPE)- maximum temperature 110°C

Table 14.1 shows typical resistivities for the different types of cables at their maximum temperature.

*Table 14.1: Resistivity for different cables (Ω/m/mm²).*

| Cable Type | Copper | Aluminium |
|---|---|---|
| PVC-75°C | 0.0209 | 0.0328 |
| XLPE 90°C | 0.0219 | 0.0345 |
| XLPE 110°C | 0.0233 | 0.0367 |

*EXAMPLE*

A solar array that has 8 modules in series has been installed and the distance between the output of the array and the PV inverter is 8 metres. The short circuit current of the array is 10.45 A.

- The cable used is of copper and insulation type is XLPE rated for 90°C.
- The cable has a cross sectional area of 4 mm2
- The copper cable has a resistivity of 0.0219 Ω/metres/mm2
- The maximum power point voltage of the array is 269.6 V

Using,

$$V_d = \frac{2 \times L \times I \times \rho}{A_{CABLE}}$$

$$= \frac{2 \times 8 \times 10.45 \times 0.0219}{4}$$

$$= 0.9154\ V$$

$$\text{Voltage drop in percentage} = \frac{V_d}{V_{MAX}} \times 100\%$$

$$= \frac{0.9154}{269.6} \times 100\%$$

$$= 0.34\%$$

## Method 2 - Calculating $V_c$ using *AS/NZS 3008.1.1:2017* Tables

As previously mentioned, resistivity depends on the material of the conductor (e.g. copper, tinned copper, aluminium) as well as temperature.

$$V_C = \frac{1{,}000 \times Loss \times V_{MAX}}{L \times I}$$

**Where:**

- $V_c$ = Millivolt drop per amp-metre route length (in mV/Am)
- ***Loss*** = Maximum permissible voltage drop in the cable (dimensionless, i.e. 5% = 0.05)
- $V_{MAX}$ = System voltage (in V)
- ***L*** = Route length (in m).
- ***I*** = Current flow through the cable (in A). For PV DC cables, the ISC current (at STC) should be used.

 

## 48. Section 14.2.1 - String Cables

*Replacement:*

### String Cables: Calculating the Minimum CSA

To keep the voltage drop below the maximum threshold, the minimum CSA of the string cables should be calculated. It is calculated using either of the methods outlined in Section 14.1.2.

As discussed in Section 14.1.2, the modules in a string should be connected such that the area of inductive loops is minimised. This means that the positive string cable and the negative string cable may be different lengths. If this is the case, the expression "2 × L" in *Method 1 – Simple Resistivity Method* will need to be replaced by the length of the positive string cable plus the length of the negative string cable:

$$A_{CABLE} = \frac{(L_{+CABLE} + L_{-CABLE}) \times I \times \rho}{Loss \times V_{MAX}}$$

Because *Method 2 – Calculating $V_C$ using AS/NZS 3008.1.1:2017 Tables* only uses the one-way route length, it is recommended to use the longer of the positive and negative string cable lengths to calculate $V_C$, if the two are of different lengths.

According to the standards, the maximum permissible DC voltage drop is 3%: this number is a combined limit across all cabling on the DC side, including the string cabling and the array cabling.

*EXAMPLE:*

The MPP voltage of a string at STC is 216 V, and the short circuit current is 10 A. The length of the positive cable is 18 m and the length of the negative cable is 18 m from the furthest module to the inverter. The cables are XLPE 90°C copper, with a resistivity of 0.0219 Ω/m/mm².

As per the applicable standards, the maximum permissible voltage drop between the furthest module and the inverter is 3%. This figure also needs to include the array cable voltage drop, so the string cable should have a maximum permissible voltage drop of 1.5%.

Using the *Simple Resistivity Method*, the minimum cable size for the string cables is calculated as follows:

$$A_{CABLE} = \frac{2 \times L \times I \times \rho}{Loss \times V_{MAX}}$$

$$= \frac{2 \times 18\text{ m} \times 10\text{ A} \times 0.0219\ \Omega/\text{m}/\text{mm}^2}{0.015 \times 216\text{ V}}$$

$$= 2.43\text{ mm}^2$$

Using Table 14.1 and the *$V_C$ AS/NZS 3008.1.1:2017 Method*, the minimum cable size for the string cables is calculated as follows:

$$Maximum\ V_C = \frac{1{,}000 \times Loss \times V_{MAX}}{L \times I}$$

$$= \frac{1{,}000 \times 0.015 \times 216\text{ V}}{18\text{ m} \times 10\text{ A}}$$

$$= 18\text{ mV/Am } (DC)$$

Converting to three-phase:

$$\frac{18\text{ mV/Am}}{1.155} = 15.58\text{ mV/Am } (\textit{three-phase AC})$$

Assuming the selected cable may operate up to its rated insulation temperature of 90°C, the minimum conductor CSA that meets the calculated $V_C$ requirement is a 4 mm² cable. This is because the $V_C$ method is typically more conservative than the resistivity method.

### Section 14.2.2 - Sub-array Cables

*Replacement:*

**Sub-array Cables: Calculating the Minimum CSA**

To keep the voltage drop below the maximum threshold, the minimum CSA of the sub-array cables should be calculated. It is calculated using either of the methods outlined in Section 14.1.2:

According to the standards, the maximum permissible DC voltage drop is 3%. This includes the string cable voltage drop, the sub-array voltage drop and the array cable voltage drop. For systems that have sub-arrays, it is reasonable to divide the voltage drop threshold by three for each type of cable: array, sub-array and string. This means the permissible voltage drop is 1% for each of these cables.

*EXAMPLE*

An array has two sub-arrays, each one comprised of two strings. The $V_{MPP}$ at STC of each string is 216 V and the short circuit current in the string is 10 A. The VMPP of the sub-array cable remains at 216 V, but the current is multiplied by 2 (two parallel strings) to give 20 A.

The sub-array cables will be 5 m long and the permissible voltage drop is set at 1%, as per the principles outlined in this section. The cables are XLPE 90°C copper, with a resistivity of 0.0219 $\Omega/m/mm^2$.

Using the *Simple Resistivity Method*, the minimum cable size for the sub-array cables is calculated as follows:

$$A_{CABLE} = \frac{2 \times L \times I \times \rho}{Loss \times V_{MAX}}$$

$$= \frac{2 \times 5\text{ m} \times 20\text{ A} \times 0.0219\ \Omega/\text{m/mm}^2}{0.015 \times 216\text{ V}}$$

$$= 1.35\text{ mm}^2$$

Using this method, a 1.5 $mm^2$ cable would be sufficient.

Using Table 14.1 and the $V_C$ *AS/NZS 3008.1.1:2017 Method*, the minimum cable size for the sub-array cables is calculated as follows:

$$Maximum\ V_C = \frac{1{,}000 \times Loss \times V_{MAX}}{L \times I}$$

$$= \frac{1{,}000 \times 0.01 \times 216\text{ V}}{5\text{ m} \times 20\text{ A}}$$

$$= 21.6\text{ mV/Am } (DC)$$

Converting to three-phase:

$$\frac{21.6\text{ mV/Am}}{1.155} = 18.7\text{ mV/Am } (\textit{three-phase AC})$$

Assuming the selected cable may operate up to its rated insulation temperature of 90°C, the minimum conductor CSA that meets the calculated $V_C$ requirement is a 2.5 $mm^2$ cable.

## 49. Section 14.2.3 - Array Cables

*Replacement:*

**Array Cables: Calculating the Minimum CSA**

To keep the voltage drop below the maximum threshold, the minimum CSA of the array cables should be calculated. This figure is calculated using either of the methods outlined in Section 14.1.2:

> *EXAMPLE*
>
> An array comprises two strings. The $V_{MPP}$ at STC of each string is 216 V and the string short circuit current is 10 A. The $V_{MPP}$ of the array cable remains at 216 V; the array current is 20 A: 2 parallel strings at 10 A.
>
> The array cables will be 10m long and the permissible voltage drop is set at 1.5% as per the principles outlined in this section. The cables are XLPE 90°C copper, with a resistivity of 0.0219 Ω/m/mm².
>
> Using the *Simple Resistivity Method*, the minimum cable size for the array cable is calculated as follows:
>
> $$A_{CABLE} = \frac{2 \times L \times I \times \rho}{Loss \times V_{MAX}}$$
>
> $$= \frac{2 \times 10\text{ m} \times 20\text{ A} \times 0.0219\ \Omega/\text{m}/\text{mm}^2}{0.015 \times 216\text{ V}}$$
>
> $$= 2.70\text{ mm}^2$$
>
> Using this method, a 4 mm² cable would be sufficient.
>
> Using Table 14.1 and the *$V_C$ AS/NZS 3008.1.1:2017 Method*, the minimum cable size for the array cable is calculated as follows:
>
> $$Maximum\ V_C = \frac{1{,}000 \times Loss \times V_{MAX}}{L \times I}$$
>
> $$= \frac{1{,}000 \times 0.015 \times 216\text{ V}}{10\text{ m} \times 20\text{ A}}$$
>
> $$= 16.2\text{ mV/Am } (DC)$$
>
> Converting to three-phase:
>
> $$\frac{16.2\text{ mV/Am}}{1.155} = 14.03\text{ mV/Am } (three\text{-}phase\ AC)$$
>
> Assuming the selected cable may operate up to its rated insulation temperature of 90°C, the minimum conductor CSA that meets the calculated $V_C$ requirement is a 4 mm² cable.

## 50. Section 14.3.1 - AC Inverter Cable

*Replacement:*

**AC Inverter Cable: Calculating the Minimum CSA**

To keep the voltage rise below the maximum permitted, the minimum CSA should be calculated for the AC inverter cable. As mentioned in Section 14.1.2, the AC inverter cable is usually as short as possible, which will reduce the size of the CSA required.

The minimum CSA of a single phase AC cable is calculated by either of the methods outlined in Section 14.1.2. Many AC cable manufacturers provide tables specifying the voltage drop/rise per metre of AC cable for various currents.

*EXAMPLE:*

The inverter for use with a 2 kWp PV array is to be installed so that the AC cabling route will be 30 m between the inverter and the main switchboard. The cables are XLPE 90°C copper, with a resistivity of 0.0219 Ω/m/mm². What is the minimum CSA required for the AC cabling to ensure that the voltage rise will be less than 1%?

Assume the following:

Maximum inverter output current = 11 A

Single phase supply: AC voltage = 230 $V_{RMS}$

Power factor = 1

Using the Simple Resistivity Method, the minimum cable size for the AC cable is calculated as follows:

$$A_{CABLE} = \frac{2 \times L \times I \times \rho \times cos\Phi}{Loss \times V_{MAX}}$$

$$= \frac{2 \times 30 \text{ m} \times 11 \text{ A} \times 0.0219\ \Omega/\text{m}/\text{mm}^2 \times 1}{0.015 \times 230 \text{ V}}$$

$$= 4.19 \text{ mm}^2$$

Using this method, a 6 mm² cable would be sufficient.

Using Table 14.1 and the $V_C$ *AS/NZS 3008.1.1:2017* Method, the minimum cable size for the AC cable is calculated as follows:

$$Maximum\ V_C = \frac{1{,}000 \times Loss \times V_{AC}}{L \times I}$$

$$= \frac{1{,}000 \times 0.01 \times 230 \text{ V}}{30 \text{ m} \times 11 \text{ A}}$$

$$= 6.97 \text{ mV/Am } (\textit{single-phase AC})$$

Converting to three-phase:

$$\frac{6.97 \text{ mV/Am}}{1.155} = 6.03 \text{ mV/Am } (\textit{three-phase AC})$$

Assuming the selected cable may operate up to its rated insulation temperature of 90°C, the minimum conductor CSA that meets the calculated $V_C$ requirement is a 10mm² cable.

## Chapter 16

### 51. Section 16.1 - Standards and Best Practice

*Amendment:*

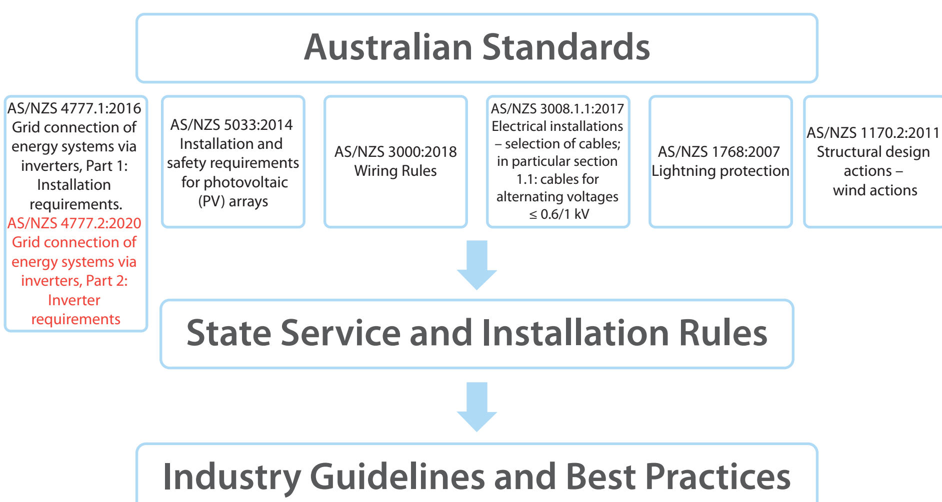


*Figure 16.2: Relevant standards for PV designers and installers.*

 

## 52. Section 16.1.1 - Service and Installation Rules

*Amendment:*

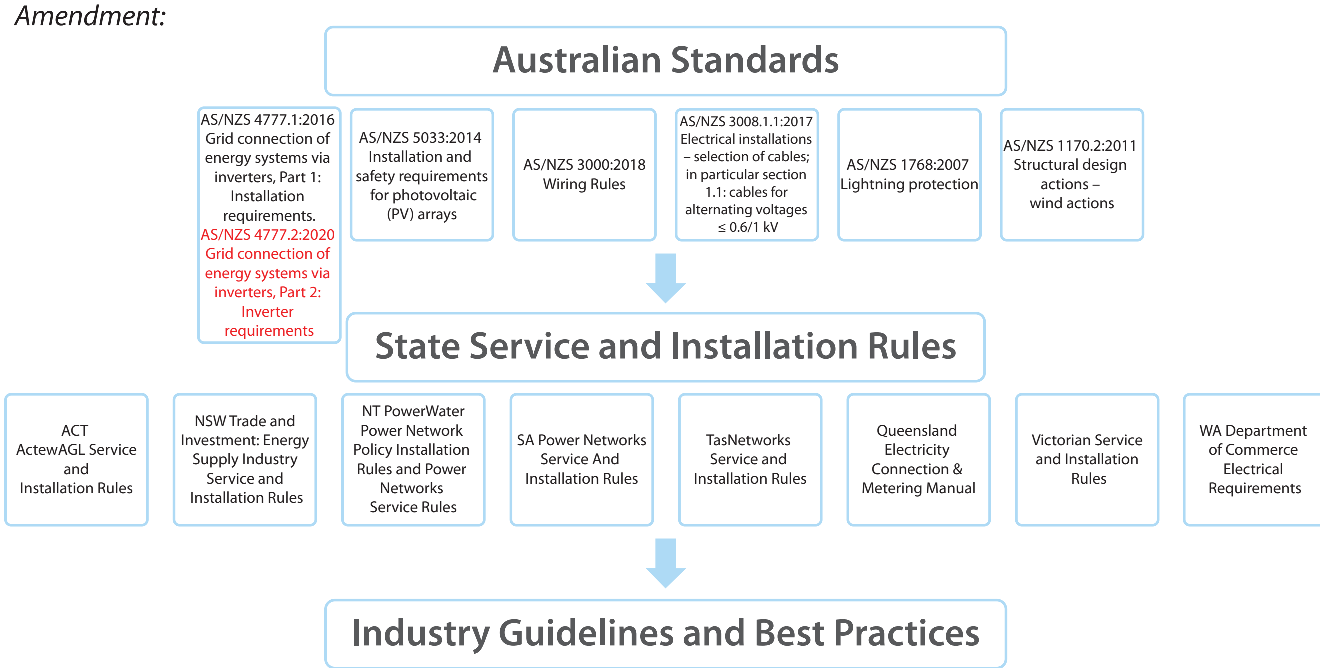


*Figure 16.3: Local service and installation rules vary across locations.*

## 53. Section 16.1.1 - Service and Installation Rules

*Amendment:*

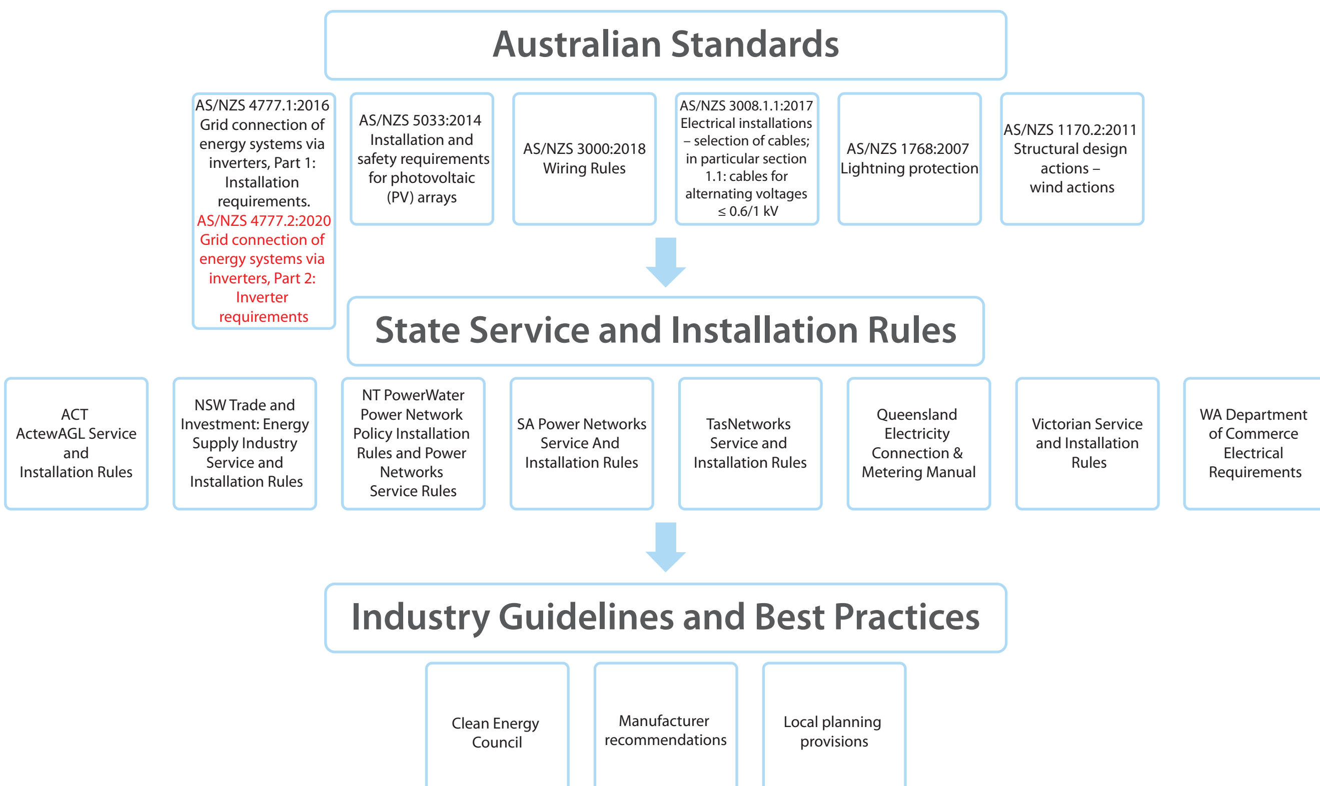


*Figure 16.5: Industry guidelines and best practices are vital for keeping PV installation standards high.*

## Chapter 17

**54. Section 17.2.4 - Inverter to Inverter AC Disconnector and Grid Connection**

*Amendment:*

1. ***Confirm continuity between the inverter and the inverter supply main switch:*** Measure the continuity between the inverter and the inverter supply main switch and the neutrals from the inverter to the grid connection board (main switchboard or distribution). If there is a separate inverter AC disconnector, measure the continuity between the inverter and the inverter AC disconnector and then the inverter AC disconnector and the inverter supply main switch.
2. ***Measure the grid voltage at the inverter and inverter supply main switch:*** Ensure that the DC disconnectors are open (switched off) and then reconnect the inverter supply main switch. Measure the grid voltage on the grid side of the inverter, on the grid side of the inverter AC disconnector (if present) and at the inverter supply main switch.

## Chapter 18

**55. Section 18.1.4 - Maintenance Schedule**

*Amendment:*

| | |
|---|---|
| Check the operation of the disconnectors and circuit breakers (rooftop disconnector, array DC disconnector, inverter AC disconnector and inverter supply main switch) | Annually |

**56. Section 18.2.2 - Determine the Cause**

*Amendment::*

Depending on the indicators, the following steps could be used (Figure 18.5):

a. ***Investigate whether there is a blackout:*** Check the whole property for signs of a blackout.

b. ***Inspect the AC disconnectors and/or circuit breakers:*** The AC disconnectors should be inspected to see whether any have been switched off or have any external signs of damage. This includes the inverter supply main switch located in the switchboard and, if present, the inverter AC disconnector located adjacent to the inverter.

c. ***Measure the voltage at the inverter AC disconnector and at the inverter supply main switch:*** The line voltages should be measured between the active conductors and the neutral, and the active conductors and the earth. The voltage between the neutral and the earth could also be measured. The voltage should be measured on both sides of the disconnectors, working from the inverter towards the switchboard. This can be used to identify the location of the fault.

 

**57. Appendix 3 - Formulae Summary**

*Replacement:*

## Chapter 14

### Calculating Voltage Drop

$$V_d = \frac{2 \times L \times I \times \rho \times cos\Phi}{A_{CABLE}}$$

**Where:**

- $V_d$ = voltage drop in volts.
- $L$ = route length of cable in metres (multiplying by two adjusts for total circuit wire length).
- $I$ = current flow in amperes (for DC calculations, the $I_{SC}$ at STC current should be used).
- $\rho$ = resistivity of the wire in $\Omega/m/mm^2$.
- $cos\Phi$ = power factor (include only for AC cables).
- $A_{CABLE}$ = CSA of cable in $mm^2$.

**58. Appendix 3 - Formulae Summary**

*Replacement:*

**Calculating Voltage Drop as Percentage**

$$Loss = \frac{V_d}{V_{MAX}}$$

- $Loss$ = voltage drop in the conductor expressed as a decimal, e.g. 3% = 0.03.
- $V_d$ = voltage drop in volts.
- $V_{MAX}$ = system voltage in volts.

**Calculating the Maximum Permitted $V_C$**

$$V_C = \frac{1{,}000 \times Loss \times V_{MAX}}{L \times I}$$

**Where:**

- $V_C$ = millivolt drop per amp-metre route length in millivolts per amp-metre.
- $Loss$ = maximum permissible voltage loss in the conductor, expressed as a decimal, e.g. 3% = 0.03.
- $V_{MAX}$ = system voltage in volts.
- $L$ = route length of cable in metres.
- $I$ = current flow in amperes.

## 59. Appendix 5 - Quiz 13 Answers

*Replacement:*

### Question 5

**Voltage**

As there are seven modules in each string, the total system voltage is:

$$V_{MAX\_OC\_ARRAY} = V_{OC\_ARRAY} + \gamma_{OC} \times (T_{MIN} - T_{STC}) \times N_S$$
$$= (44.3\text{ V} \times 7) + (-0.003/°\text{C} \times 44.3\text{ V})$$
$$\times (2°\text{C} - 25°\text{C}) \times 7$$
$$= 310.1\text{ V} + -0.1329\text{V}/°\text{C} \times -23°\text{C} \times 7$$
$$= 331.49\text{ V}$$

A maximum array voltage of 331.49 V will be used to check the suitability of the PV array DC isolator.

**Current**

The maximum array current is:

***1.25 × ISC_ARRAY = 1.25 × 3 × 8.1 A = 30.375 A***

From these calculations, the protection device current rating must be greater than 30.375 A.
A maximum array current of 30.38 A will be used to check the suitability of the PV array DC isolator.

 