Session 3A Inspecting grid-connected PV systems

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INTRODUCTION

- Solar Photovoltaic (PV) technology makes possible electricity generation from sunlight that is fed into the grid to become an integral part of a utility's generation system.

- PV systems on the grid can be either centralised grid-connected solar farms or decentralised grid-connected systems installed on residential, commercial or industrial buildings.

- Inspecting) grid connected PV systems is undertaken to ensure the systems are safe (electrically and mechanically) and that they have been installed in accordance with the relevant Australia/New Zealand or NEC and International standards.

INTRODUCTION 2

- Figure 1 shows a typical interconnection of a grid connected PV system while Figures 2 / 3 are typical wiring schematics.

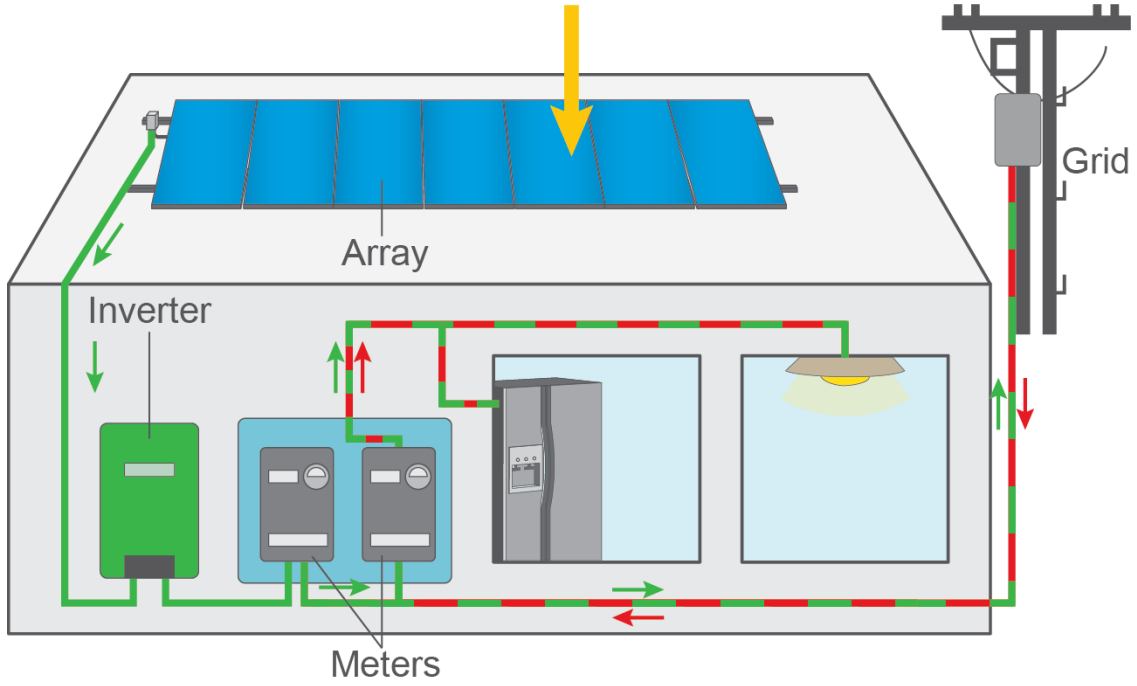


Figure 1: Grid Connected PV Systems

WIRING SCHEMATIC (AS/NZS)

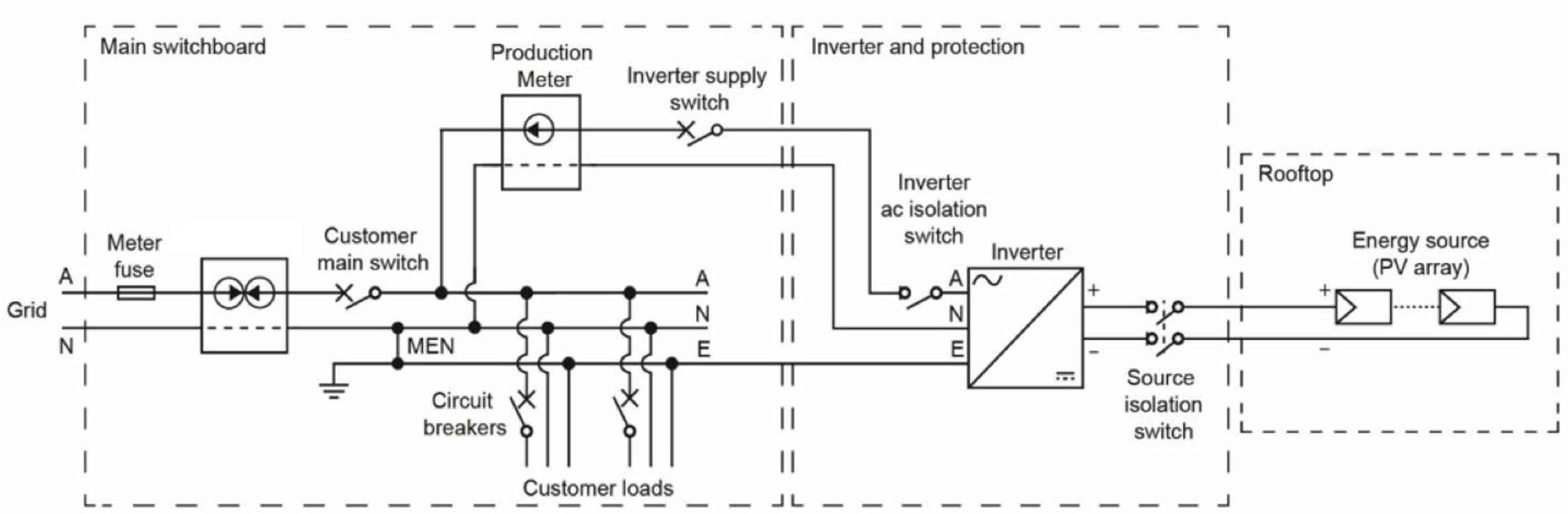


Figure 2: Wiring Schematic

Notes:

1 When inverter is set for ZERO export extra monitoring equipment is mounted near the production meter.

2. Production Meter is a recommendation.

WIRING SCHEMATIC (NEC)

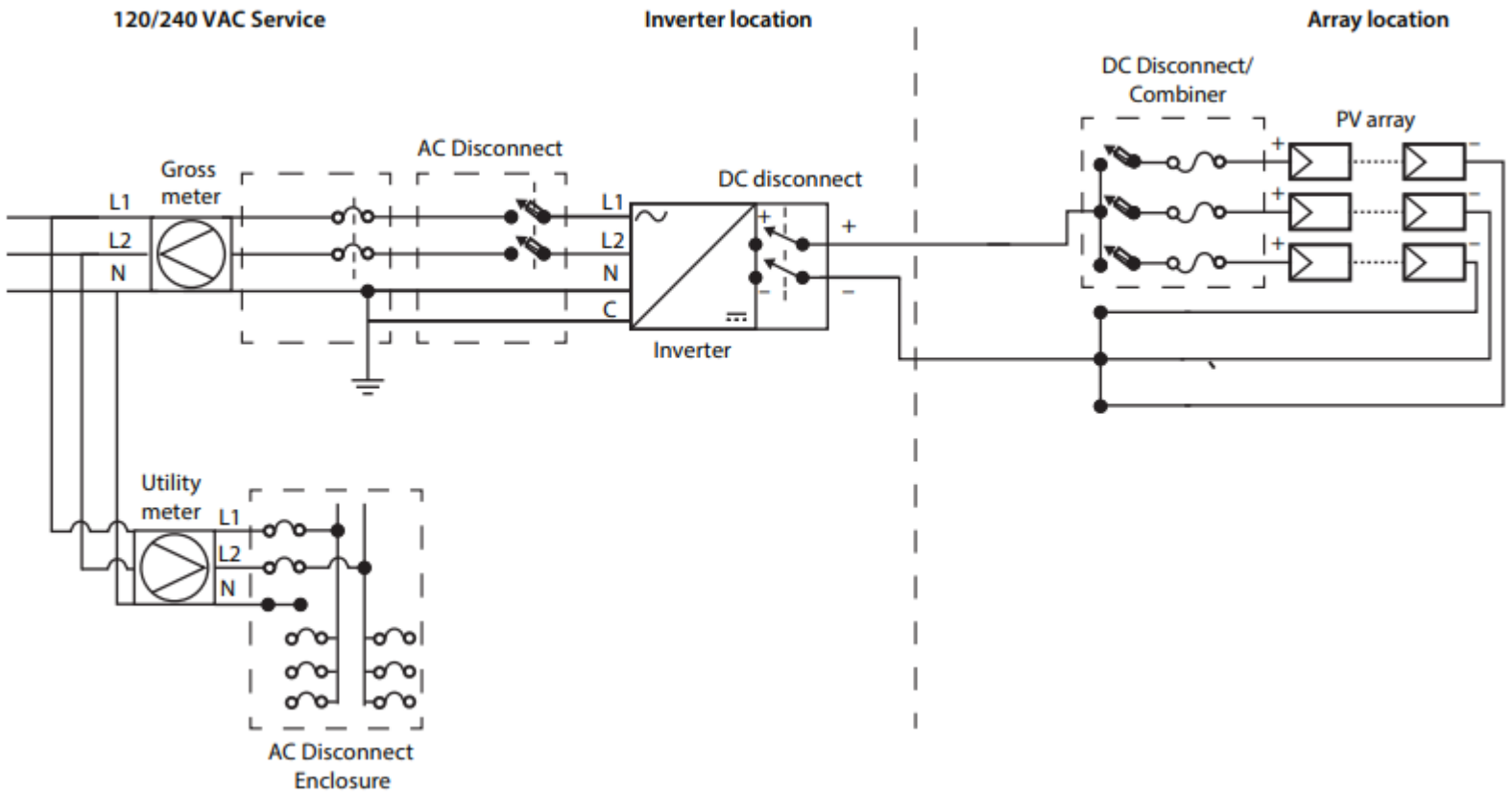


Figure 3: Wiring Schematic

STANDARDS FOR INSTALLATION – AS/NZS

- AS/NZS 3000 Wiring Rules.
- AS/NZS 3008 Electrical Installations-Selection of Cables.
- AS/NZS 3010 Electrical installations - Generating sets.
- AS/NZS 4777 Grid Connection of energy systems by Inverters (series)
- AS/NZS 5033 Installation and Safety Requirements of PV Arrays.
- AS/NZS 1170 Structural design actions
- AS/NZS 1170.2 Structural design actions – Wind actions
- AS 1768 Lightning Protection.

CODES FOR INSTALLATION – NEC/UL

- **NEC Article 690 Solar Photovoltaic (PV) Systems**
- **NEC Article 705 (Interconnected Electric Power Production Sources) for the interconnection to the utility**
- **Article 691 Large-Scale PV**
- UL(IEC)61730 Standard for Photovoltaic (PV) Module Safety Qualification
- UL (IEC)61215 Terrestrial photovoltaic (PV) modules - Design qualification and type approval
- UL (IEC)62109 Safety of power converter for use in photovoltaic power systems.
- UL Standard 1741 Standard for Inverter, converters, Controllers and Interconnection System Equipment for use with Distributed Energy Resources.

STANDARDS FOR INSTALLATION – IEC

- IEC 61215 Crystalline Silicon Terrestrial photovoltaic (PV) modules – Design qualification and type approval
- IEC 61215-1 Part 1: Test requirements
  - IEC 61215-1-1 Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules
  - IEC 61215-1-2 Part 1-2: Special requirements for testing of thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules
  - IEC 61215-1-3 Part 1-3: Special requirements for testing of thin-film amorphous silicon based photovoltaic (PV) modules
  - IEC 61215-1-4 Part 1-4: Special requirements for testing of thin-film Cu(In,GA)$(S,Se)_2$ based photovoltaic (PV) modules
- IEC 61215-2 Part 2: Test Procedures

- IEC 61730 Photovoltaic (PV) module safety qualification.
- IEC 61730-1 Part 1: Requirements for construction.
- IEC 61730-2 Part 2: Requirements for testing.

STANDARDS FOR INSTALLATION – IEC

- IEC 61701 Photovoltaic (PV) modules - Salt mist corrosion testing
- IEC 62804 Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation (PID) - Part 1-1: Crystalline silicon – Delamination
- IEC 62109 Safety of power converter for use in photovoltaic power systems.
- IEC 62109-1 Part 1: General requirements.
- IEC 62109-2 Part 2: Particular requirements for inverters.

- IEC 62930 Electric cables for photovoltaic systems with a voltage rating of 1.5 kV d.c.
  Solar Plugs and Connectors
- AS/NZS 62852 Connectors for d.c. application in photovoltaic systems - Safety requirements and tests.
- AS/NZS 60947.3 Low-voltage switchgear and control gear switches, disconnectors, switch-disconnectors and fuse-combination units. The switch disconnectors shall conform with utilization category d.c. PV2.
- IEC 62446: Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection.

Note: AS/NZS 3000, AS/NZS 5033 and AS/NZS 4777 do reference other balance of systems equipment standards.

VOLTAGE LIMITS AND WORK RESTRICTIONS

Extra Low Voltage Work:

- All extra low voltage wiring should be performed by a ‘competent’ person, which is defined in various standards: “a person who has acquired through training, qualifications, experience or a combination of these, knowledge and skill enabling that person to correctly perform the task required.”

VOLTAGE LIMITS AND WORK RESTRICTIONS 2

Low Voltage Work

- All low voltage work: >120V d.c. or >50V a.c. should be performed by a certified electrician.
- If the system contains ELV wiring installed by a person not by a certified electrician, then a minimum level of inspection by the certified electrician prior to closing the PV array isolators would include:
    - an open circuit voltage test on each PV string and on the total array.
    - A visual inspection of an open PV junction box (randomly selected) and the master array junction box.

VOLTAGE LIMITS AND WORK RESTRICTIONS 3

- These inspections/checks shall confirm as a minimum:
  - the array voltages are as designed and specified.
  - the appropriate cables (Cross Sectional Area and insulation), junction fittings and enclosures have been used.

- Both the non-electrician ELV installer, as well as the electrician, are expected to carry out the checks on the ELV wiring.

- In the NEC standard anything above 60V dc is considered dangerous. Except when module inverters are used, grid connect PV arrays have open circuit voltage typically above 120V dc and hence considered LV.
- LV is dangerous and can kill a person if they come into contact with live terminals.

HOW DOES A GRID CONNECTED PV SYSTEM WORK?

- PV modules convert sunlight into d.c. power. The power produced is supplied into an inverter (PV inverter) that changes the d.c. power output of the PV modules to a.c. power, compatible with the power grid and a.c. appliances.

- The grid-connected system allows for any on-site loads to be powered by the power generated by the PV system or the power drawn from the grid or a combination of the two.

- Excess power generated by the PV system is generally exported to the grid (Some grid operators have export limitations / zero export requirements).

- Demo - https://www.youtube.com/watch?v=VFa3T2Qckx0

HOW DOES A GRID CONNECTED PV SYSTEM WORK? 2

- When there are abnormal grid conditions, the inverter is required to disconnect from the grid and the loads – known as anti-islanding.

- Note: Anti-islanding is a **safety feature** built into grid connected solar power systems that can shut them off and disconnect them from the grid during a power outage.

SOLAR PV MODULE

- Photovoltaic (PV) modules, also called solar panels, convert sunlight into electricity and form the basis of any solar electric system.

Solar modules shall meet the following IEC standards:

- IEC 61215 Terrestrial photovoltaic (PV) modules - Design qualification and type approval
  - IEC 61215-1 Part 1: Test Requirements
  - One of IEC 61215 Part 1.1, Part 1.2 Part 1.3, part 1.4 which all relate to specific types of modules e.g. crystalline, thin film amorphous etc (See Section 2)
  - IEC 61215-2 Part 2: Test Procedures
- IEC 61730 Photovoltaic (PV) module safety qualification
  - IEC 61730-1 Part 1: Requirements for construction
  - IEC 61730-2 Part 2: Requirements for testing

Useful resource - CEC List – AS/NZS

- The modules could be selected from those on the Australian Clean Energy Council's approved product list **(those following Australian/New Zealand standards)**:

https://www.cleanenergycouncil.org.au/industry/products/modules/approved-modules

INVERTER SELECTION

AS/NZS

An inverter to be used in a Grid Connected PV system the inverter(s) shall comply with:

- AS/NZS4777.2 Grid Connection of energy systems by Inverters – (AS/NZS)
    - Part 2: Inverter Requirements
- IEC62109 Safety of power converters for use in photovoltaic power systems
    - IEC62109-1 Part 1: General requirements
    - IEC62109-2 Part 2: Particular requirements for inverters
- Useful resource - Australian Clean Energy Council's approved product list:

https://www.cleanenergycouncil.org.au/industry/products/inverters/approved-inverters

NEC

- UL Standard 1741 Standard for Inverter, converters, Controllers and Interconnection System Equipment for use with Distributed Energy Resources. (NEC)
- IEC62109 Safety of power converters for use in photovoltaic power systems
    - IEC62109-1 Part 1: General requirements
    - IEC62109-2 Part 2: Particular requirements for inverters

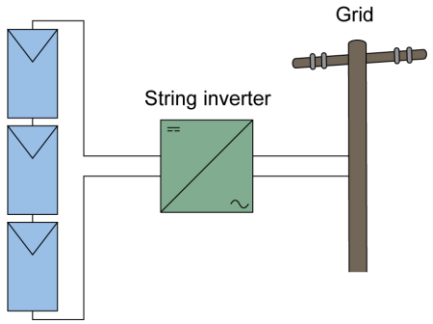
MICRO-INVERTERS (OR MODULE INVERTERS)

- Micro-inverters are small transformerless inverters (some will have an isolating transformer to minimise DC injection currents). They are designed to be mounted either on the back of or adjacent to every solar module, or every second solar module, in an array.

- These are also included under the term PCE (as referenced in AS/NZS 5033) and they need to conform to AS/NZS 4777 and IEC 62109-2 for grid connected PV systems.

SINGLE-TRACKING INVERTERS (STRING INVERTERS)

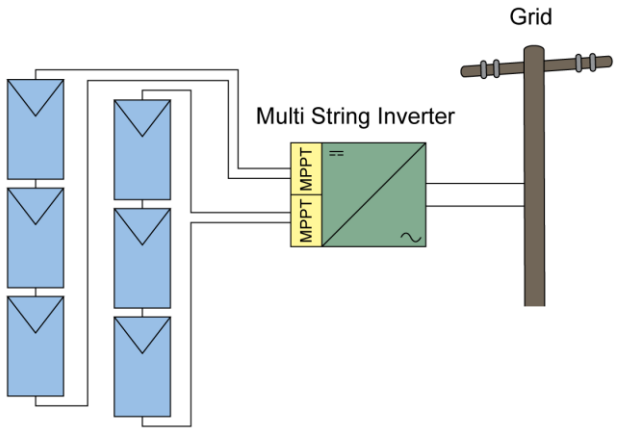
- Single-tracking inverters (also known as string inverters) have one MPPT for the entire array and are used in small grid-connected PV systems.



String Inverter
One String

MULTI-TRACKING INVERTERS

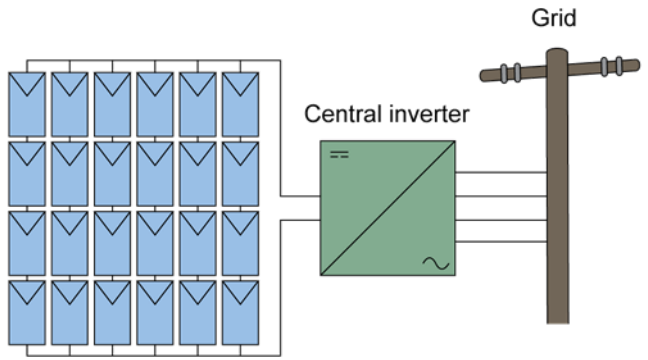
- A multi-tracking inverter (also known as a multi-string inverter) has multiple MPPTs. Each string, or a set of strings, can be connected to an individual MPPT, enabling the MPP of each string, or set of strings, to be achieved.
- For arrays that have strings, or sets of strings, oriented in different directions, multitracking inverters are able to produce a higher energy yield than single-tracking inverters.



Multi-string Inverter

CENTRAL INVERTERS

- Central inverters are used for large grid-connected PV systems and constitute the equivalent to multiple large string inverters.

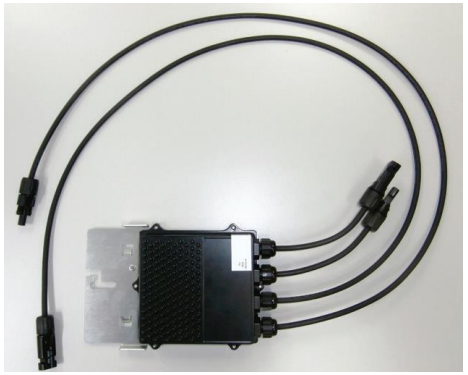


Central Inverters

INVERTERS WITH SOLAR OR POWER OPTIMISERS: MPPTS AT MODULE LEVEL

- Solar optimisers, also known as power optimisers or DCUs (d.c conditioning units), are d.c – d.c converters connected to or embedded in each module and used to operate the module at its maximum power.

- AS/NZS 5033 refers to solar optimisers as d.c. conditioning units



GENERAL SAFETY SUGGESTIONS

Pay special attention, study the site carefully, move slowly before opening or exploring electrical equipment. Learn to recognize indications of a problem.

- Do not assume anything when performing dangerous tasks such as inspecting electrical equipment.
- Do not assume that electrical power is "off" without confirming that using proper test equipment and methods
- Do not assume that system grounding is complete and correct
- Do not assume that all protection devices will work
- Do not assume that bystanders won't move suddenly into the path of danger, or push you into it.
- Do not touch live wires or connections.

PHYSICAL HAZARDS AND PPES

The following lists the physical hazards and the recommended PPE.

- **Sun exposure**: PV arrays are installed with high exposure to the Sun and limited shading. Wearing a hat and keeping the body covered, as well as taking regular breaks in the shade each hour, will reduce exposure to the Sun. Wearing high factor sunscreen on exposed skin is also essential to reduce the risk of burning. Drinking plenty of fluids (preferably water and never alcohol) will help reduce the effects of sun exposure.

- **Cuts**: Many components of a PV system, including metal framing, junction boxes, bolts, nuts, guy wires, anchor bolts, can have sharp edges and cause injury. Also, metal slivers from a drill bit often remain around the edges of a hole and can cause severe cuts. Suitable gloves should be worn when handling metal, particularly when drilling.

PHYSICAL HAZARDS AND PPES 2

- **Bumps**: Working underneath structures, e.g. under the array, could result in bumps to the head. Also any work being performed above another worker poses the risk of objects falling from above and injuring the worker below. A hard hat should be worn at all times in these situations.

- **Trips, sprains and strains**: Worksites can contain rough terrain which can result in trips or sprains, particularly when carrying equipment around. Being aware of site terrain and wearing comfortable shoes can reduce the risk. Lifting heavy equipment can also cause back strains so appropriate lifting methods should be used. This includes lifting with the legs and not the back, and in some cases using equipment to assist with moving heavy equipment.

PHYSICAL HAZARDS AND PPES 3

- **Falls**: Any work on high structures, such as roofs, brings with it the risk of serious falls, from both the structure itself and the access equipment, such as ladders and scaffolding. Ladders should be firmly anchored and supported by a partner. The partner can also assist with moving equipment up to, and down from, the roof. Remember that modules can act like a windsail and knock people over on a windy day, so extra care should be taken in these weather conditions. It is recommended that large modules are carried by 2 people. Edge protection should be used where possible and in some instances is mandatory. Harnesses are sometimes used where edge protection is not possible.

PHYSICAL HAZARDS AND PPES 4

- **Thermal burns**: Metal exposed to the Sun can reach temperatures of 80° C which could result in burns if contact is not broken quickly. Gloves should be worn and any equipment that could become hot should be identified.

- **Animals**: Snakes, insects and other animals often inhabit junction boxes, array framing and other enclosures. Always be prepared when opening enclosures. Knowing the first aid treatment for typical injuries sustained from common local animals (such as snakes and spiders) would be valuable.

ELECTRICAL HAZARDS

Some PV system-specific electrical hazards:

- **PV array**: The PV modules in the array should always be considered live. They generate electricity as light falls on them and just attempting to cover them (e.g. with a blanket) is not a safe practice. Many PV systems have an array voltage of more than 120V DC and it is recommended to isolate these arrays into sections with voltages lower than 120V DC. Where possible, ensure that all PV equipment is isolated before commencing work.

- **Inverter**: The output of an inverter is usually 240V AC, which is a potentially deadly voltage. It is important that all electrical interconnections between the inverter and the switchboard are installed and maintained by a licensed electrician.

- **Wiring**: Connected wiring should always be considered live. Exposed wire ends should be terminated with tape or cable connectors to prevent anyone from coming in contact with them.

SAFE USE OF TEST EQUIPMENT

- All testing equipment should be properly calibrated and appropriately tested before use during an inspection. Any faulty or damaged test equipment shall not be used. Relevant d.c test equipment shall be used on d.c. circuits and a.c. test equipment on a.c. circuits as appropriate.

- In some circumstances inspectors may elect to make current and voltage measurements. For inspectors who elect to use these tools, make sure that the tools themselves do not become a source of damage, or injury.

SAFE INSPECTION PRACTICE

A dangerous situation occurs when the person inspecting the system somehow comes in contact with the positive and negative outputs of the solar array or sub-array when the output voltage is rated greater than DVC-A (that is greater than 60V d.c.)

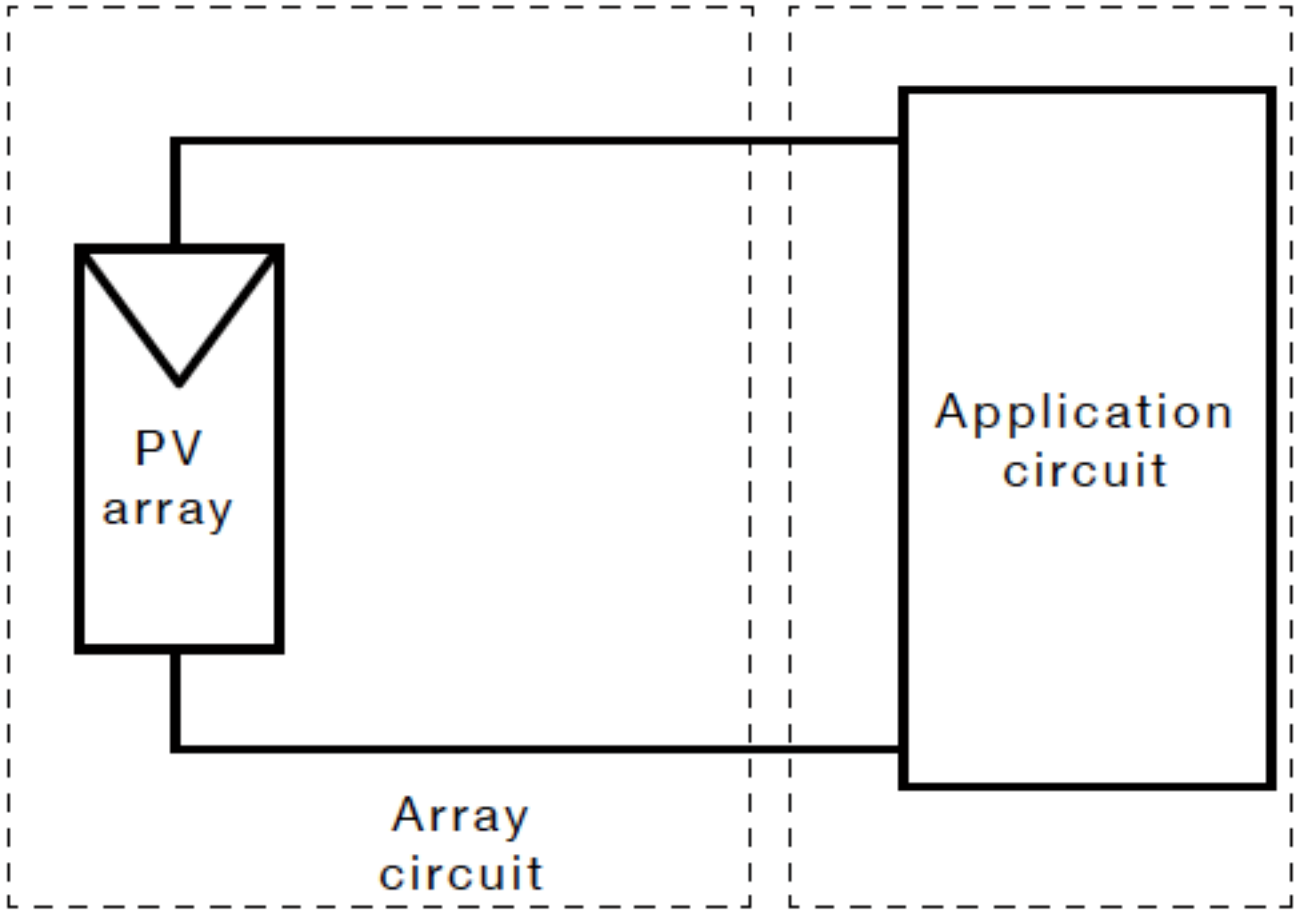
- Most grid-connected systems use solar modules which are connected using double insulated leads with polarised shrouded plug and socket connections.
- Therefore, the dangerous situation is only likely to occur at:
  - the PV Array switch-disconnector (isolator) before the inverter;

  AND
  - the sub-array and array combiner boxes (if used).

AS/NZ Standards

This section references requirements from AS/NZS 5033, AS/NZS 4777, AS/NZS 3000, AS/NZS 3008, etc

PV ARRAY SYSTEM CONFIGURATION



Strings- Sub Arrays-Arrays

PV string

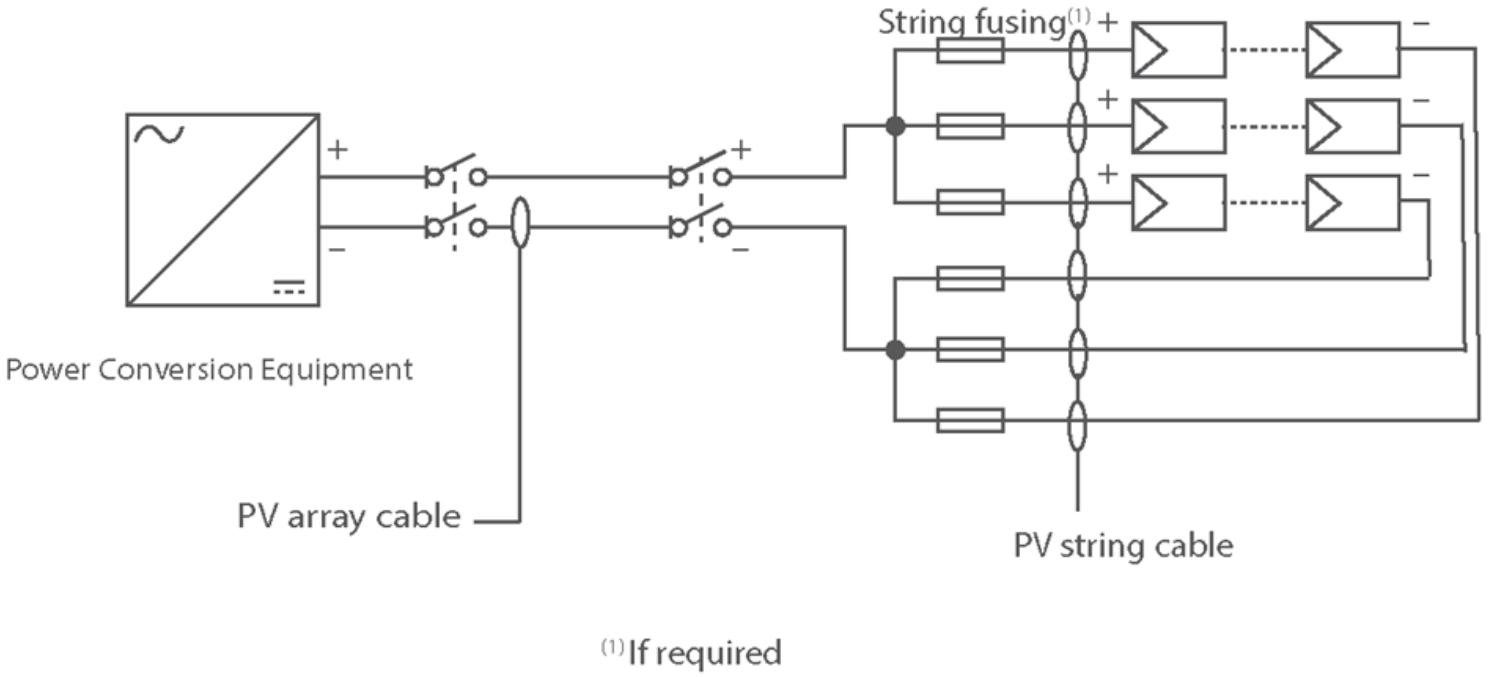
A circuit formed by one or more series connected PV modules.

PV sub-array

An electrical subset of a PV array formed of parallel connected PV strings

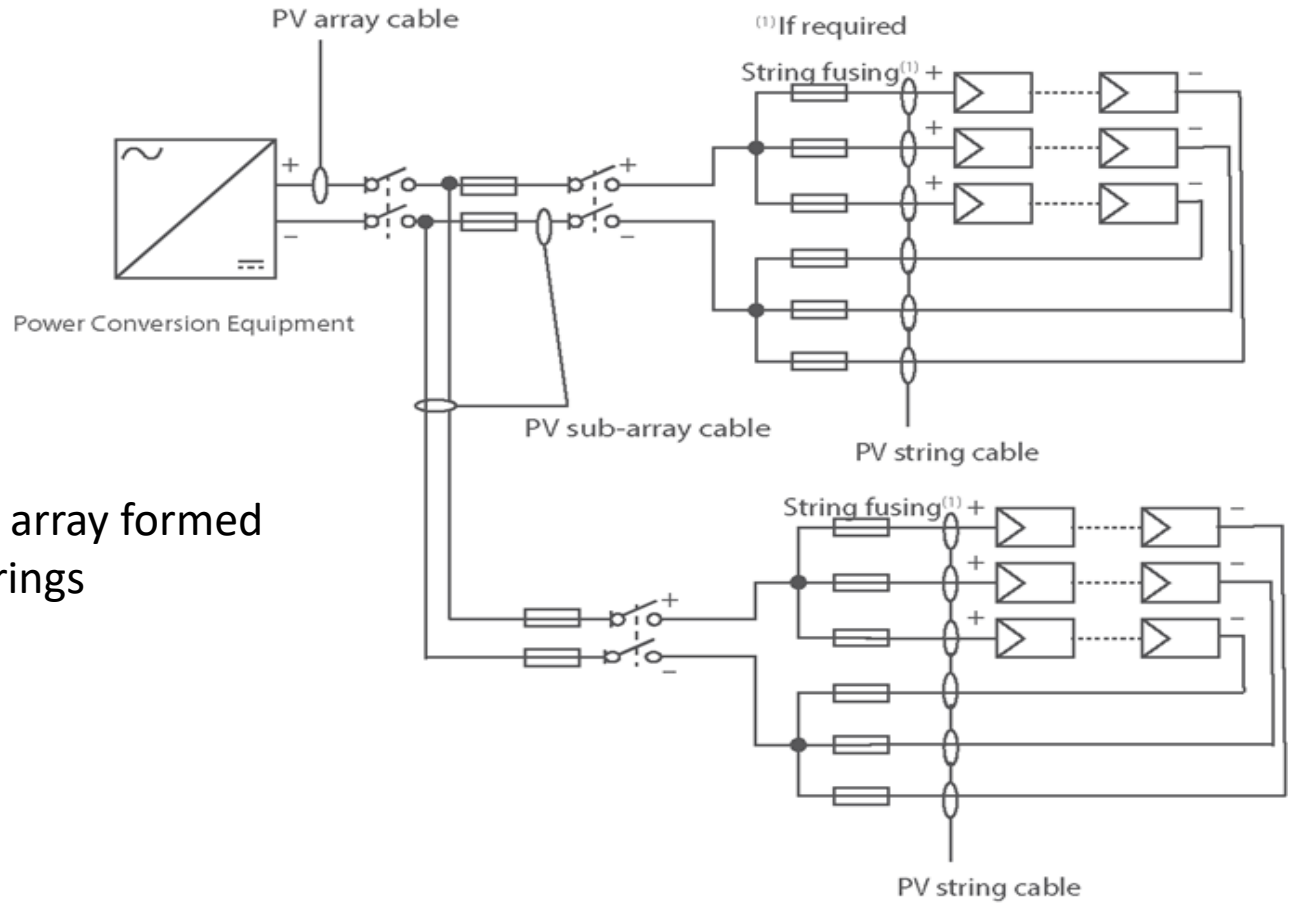
PV array

Assembly of electrically interconnected PV modules, PV strings or PV sub-arrays comprising all components up to the d.c. input terminals of the inverter or other power conversion equipment or d.c. loads.



(1) If required

Strings- Sub Arrays-Arrays



PV sub-array
An electrical subset of a PV array formed of parallel connected PV strings

ASNZS 5033 Installation and safety requirements for photovoltaic (PV) arrays

- 1 Scope and general
- 2 PV array system configuration
- 3 Safety issues
- 4 Selection and installation of electrical equipment
- 5 Marking
- 6 System documentation and commissioning

- Appendix A (informative) Example of signs
- Appendix B (informative) Earthing and d.c. fault conditions
- Appendix C (informative) Non-separated inverter fault current paths
- Appendix D (informative) Maintenance recommendations
- Appendix E (Informative) Testing and commissioning checklists
- Appendix F (informative) Additional commissioning tests
- Appendix G (informative) Lightning protection
- Appendix H (informative) Examples of calculations for determining suitable voltage, thermal current, operational current and making and breaking current for switch disconnectors
- Appendix I (normative) Fire tests, spread of flame and burning brand tests
- Appendix J (normative) Determination of safety factor (SF) multiplier and K_I for $I_{SC\ MOD}$ for Bifacial installations
- Appendix K (normative) Protection against weather and water for dedicated individual enclosures containing switch disconnectors
- Bibliography

AS/NZS 4777.1:2024 Grid connection of energy systems via inverters, Part 1: Installation requirements

- Section 1 Scope and general
- Section 2 General requirements
- Section 3 Connection of the IES to the electrical installation
- Section 4 Connection of energy source to an inverter
- Section 5 Multiple mode IES installation
- Section 6 Signs and labels
- Section 7 System documentation and commissioning
- Section 8 Verification

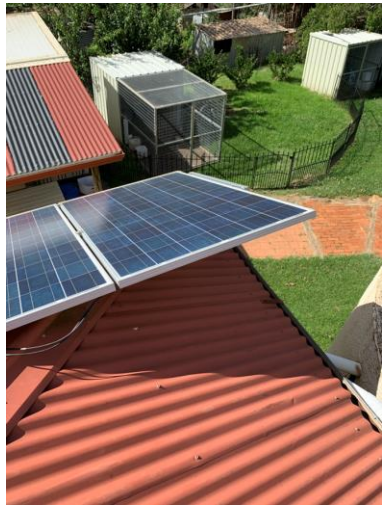
- Appendix A (informative) Example signs
- Appendix B (informative) Voltage rise calculation
- Appendix C (normative) Phase balance
- Appendix D (informative) Information on electricity distributor requirements
- Bibliography

General Wiring and Installation Work

Clause	Description
AS/NZS 3000 1.5.3.1	There are no exposed LV live parts on any installed equipment.
AS/NZS 3000 1.6 & 1.7	All electrical equipment for the system is installed in accordance with AS/NZS3000
AS/NZS 3000 4.1.3	Inverter is of appropriate IP rating for its location.
AS/NZS 3000 3.7.2.3	There are no visible loose connections in LV cables.

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 4.3.2.2	PV mounting structure and attachment to roof visually inspected and appears to be secure.
AS/NZS 5033:2021 4.3.2.2	Any freestanding PV structure was visually inspected and appears to be secure.

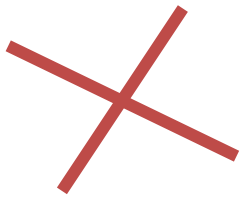


Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 4.3.2.2.8	All array supports, brackets, screws and other metal parts are either: (a) of similar material or stainless steel to minimise corrosion; or (b) where dissimilar metals that can have a galvanic reaction are used, they are galvanically isolated

Array Installation and dc Wiring

Clause	Description
PPA/SEIAPI Grid connected PV System Guidelines	Roof penetrations and/or the roof top components used in the wiring system including secondary shields, isolator shrouds, conduits and conduit glands are suitably installed, sealed and waterproof



Array Installation and dc Wiring

Clause	Description
PPA/SEIAPI Grid connected PV System Guidelines	The PV Array structure allows sufficient clearance to facilitate self-cleaning of the roof to prevent any build-up of leaves and other debris.
PPA/SEIAPI Grid connected PV System Guidelines	Modules have sufficient ventilation space to minimise temperature rise.

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 4.4.2.4	PV Wiring Losses (voltage drop losses) between the most remote PV module in the array to the input of the Inverter are less than 5% of V_{mp} of the array (> 120V).

Example – Voltage drop (Simple resistivity method)

A solar array has been installed and the distance between the output of the array and the inverter is 10 metres. The short circuit current of the array is 13.73A.

- The cable used is of copper and insulation type is XLPE rated for 90°C.
- The cables have a cross sectional area of 4 mm^2
- The cable has a resistivity of 0.0209 ohms/metre/mm^2
- The array has maximum power point voltage of 472V.

$$\mathbf{V_d} = \frac{\mathbf{2} \times \mathbf{L_{CABLE}} \times \mathbf{I} \times \boldsymbol{\rho}}{\mathbf{A_{CABLE}}}$$

= (2 x 10 x 13.73 x 0.0209)/4

= 1.43V

Voltage Drop in percentage) = $\frac{\mathbf{V_d}}{\mathbf{V_{MP}}} \times 100$

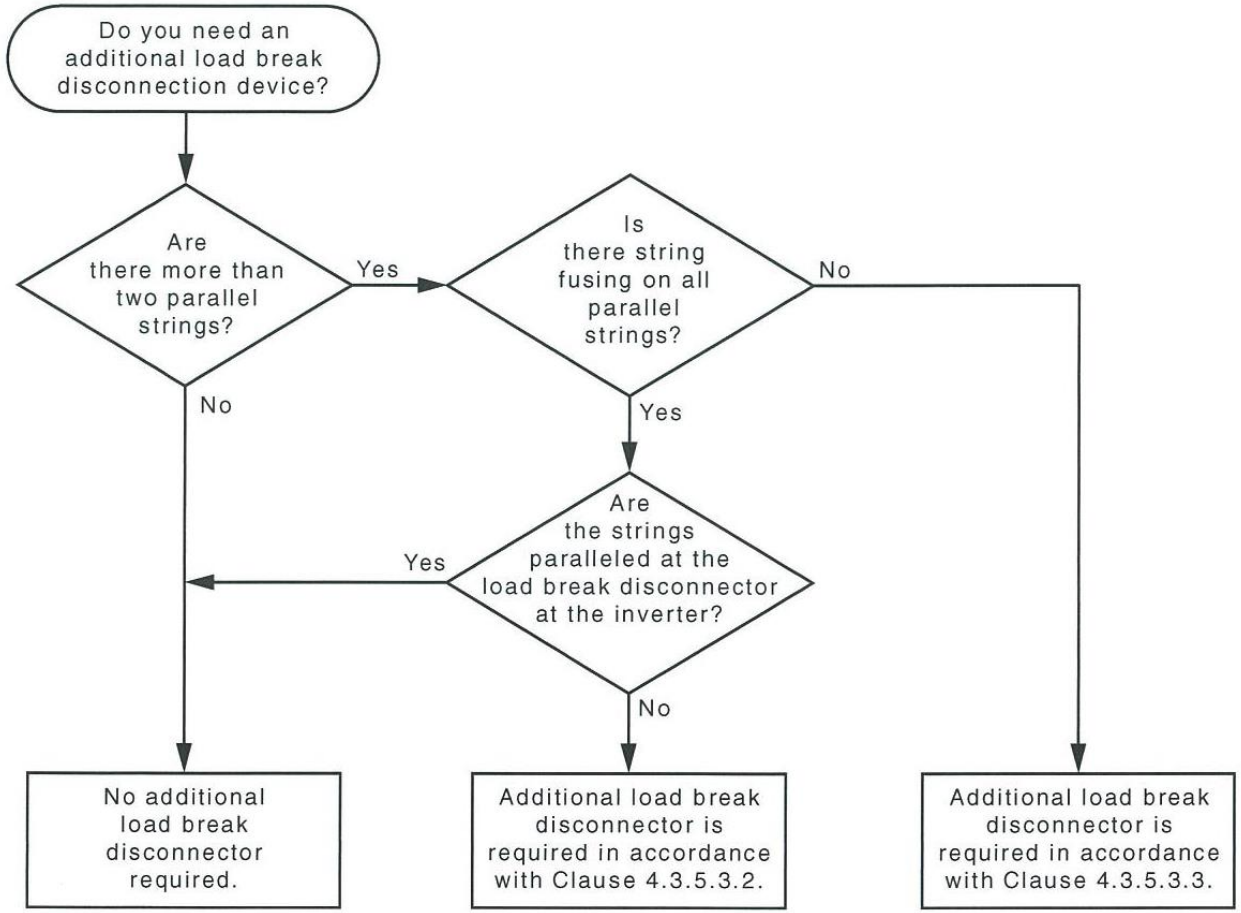
=1.43/472 x 100%

= 0.30%

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 4.3.3.1	Disconnection point has been provided to isolate PV strings (> 120V). *Note: If load breaking disconnection device is installed beside the solar modules at the PV array then each string does not require isolation.*
AS/NZS 5033:2021 4.3.3.1 and Figure 4.2	Where the PV array contains 2 parallel strings or more, a load breaking disconnection device has been installed, if required, in accordance with AS/NZS 5033:2021 Figure 4.2

Figure 4.1


Do you need an additional load break disconnection device?
Are there more than two parallel strings?
Yes
No
Is there string fusing on all parallel strings?
No
Yes
Are the strings paralleled at the load break disconnector at the inverter?
Yes
No
No additional load break disconnector required.
Additional load break disconnector is required in accordance with Clause 4.3.5.3.2.
Additional load break disconnector is required in accordance with Clause 4.3.5.3.3.

Quick Question

- Which one is a load break switch disconnector and which one is a non-load break disconnector?

A

B

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 4.3.5.2.1	Where a disconnection point is used to isolate the PV array, it is: • readily available. • protected against weather and water, and no more than 150mm from the edge of the PV modules that they are installed under. • Adequately supported so that there is no undue stress on the connection, but able to be disconnected. • Have both the positive and negative disconnection device located together
AS/NZS 5033:2021 5.5.2.2	Where a disconnection point is used, an appropriate sign has been attached to the PV module or structure within 300 mm of the disconnection point to identify the location of the disconnection point: “PV String Disconnection Point”.


WARNING
PV STRING
DISCONNECTION
POINT

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 5.3.3.2.2	If Module Inverters have been installed and the calculated PV d.c. circuit maximum voltage does not exceed 120 V and the PV module(s) are installed within 1.5 m of the inverter, a disconnection device has been installed adjacent to the PV module(s).

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 4.1 (a)	String protection and dc Isolators are rated for dc use
AS/NZS 5033:2021 4.3.4.2	All disconnectors have a voltage rating greater than or equal to PV array maximum voltage

VOLTAGE CORRECTION FACTORS – MONO CRYSTALLINE AND POLYCRYSTALLINE PV

Lowest expected operating temperature (degrees Celsius)	Correction factor
24 to 20	1.02
19 to 15	1.04
14 to 10	1.06
9 to 5	1.08
4 to 0	1.10
-1 to -5	1.12
-6 to -10	1.14
-11 to -15	1.16
-16 to -20	1.18
-21 to -25	1.20
-26 to -30	1.21
-31 to -35	1.23
-36 to -40	1.25

QUIZ

Lowest expected operating temperature (degrees Celsius)	Correction factor
24 to 20	1.02
19 to 15	1.04
14 to 10	1.06
9 to 5	1.08
4 to 0	1.10
-1 to -5	1.12
-6 to -10	1.14
-11 to -15	1.16
-16 to -20	1.18
-21 to -25	1.20
-26 to -30	1.21
-31 to -35	1.23
-36 to -40	1.25

Suppose there is a string of 10 modules with Voc (@STC) of 42.05V. The coldest temperature at the site is 14 deg Celsius. You are on site and have access to the correction factors and want to find out/confirm if the voltage ratings of the cables and disconnectors are higher than the PV array maximum voltage.

Work out the PV array maximum voltage for the string of 10 modules using the correction factors.

QUIZ ANSWER

Lowest expected operating temperature (degrees Celsius)	Correction factor
24 to 20	1.02
19 to 15	1.04
14 to 10	1.06
9 to 5	1.08
4 to 0	1.10
-1 to -5	1.12
-6 to -10	1.14
-11 to -15	1.16
-16 to -20	1.18
-21 to -25	1.20
-26 to -30	1.21
-31 to -35	1.23
-36 to -40	1.25

Answer:
PV array maximum voltage = **1.06** x 10 x 42.05 = **445.73V**

Hence, the cables and disconnectors shall have rating equal to or higher than the PV array maximum voltage

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 4.3.4.2.3 (b)	The dc disconnector meets the current rating specified in Tables 4.3 and 4.4 of AS/NZS 5033.

d.c SWITCH-DISCONNECTOR REQUIREMENTS

To check whether switch-disconnector is suitable for a system, perform the three steps below while referring to the isolator's datasheet. For these calculations, the maximum current is defined as $1.25 \times I_{SC\_ARRAY}$.

Step 1: Thermal effects

- The maximum current must be less than or equal to I_{the} for the installation conditions:
- Indoors at 40°C ambient for isolators installed indoors.
- Outdoors at 40°C ambient for isolators installed outdoors in a location fully shaded all day (e.g. carport, verandah).
- Outdoors at 60°C ambient with solar effects for rooftop isolators or isolators
- Installed externally where the enclosure or shroud will receive direct sunlight.

d.c SWITCH-DISCONNECTOR REQUIREMENTS 2

Step 2: Operational conditions

Consider the isolator configuration when the positive and negative conductors are operating in series. Looking at the first row where U_e is higher than the PV array max voltage, check that I_e is higher than the maximum current.

d.c SWITCH-DISCONNECTOR REQUIREMENTS 3

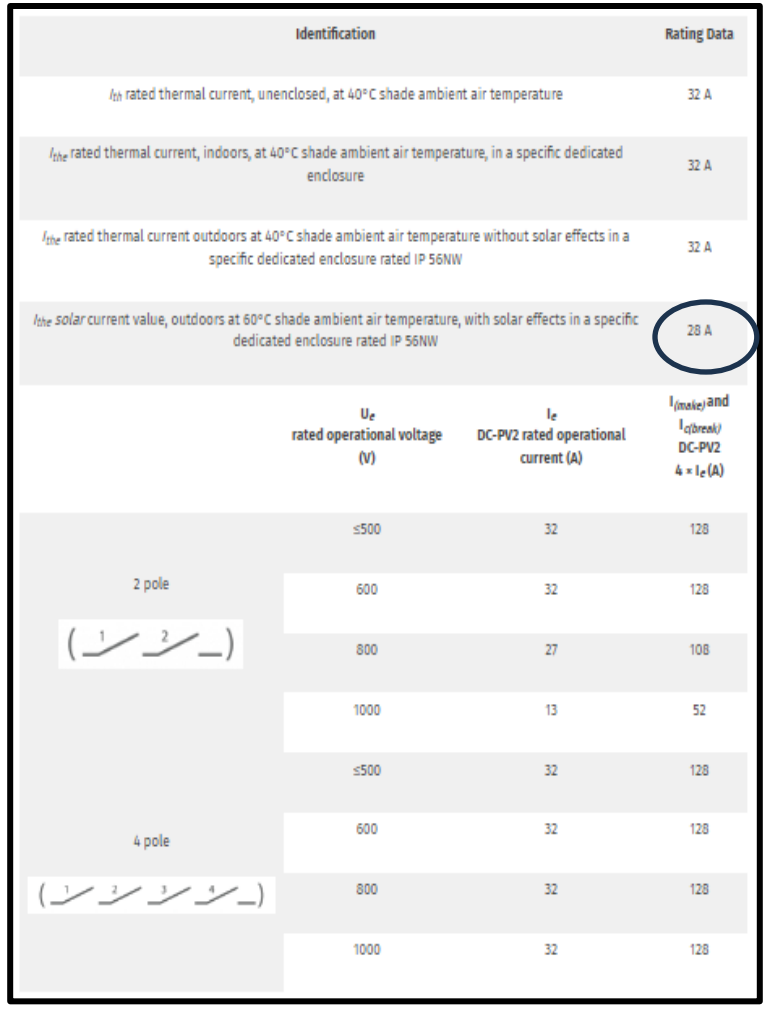
Step 3: Fault conditions

- This step is for non-separated (transformerless) inverters only.
- Considering the isolator configuration when the positive and negative conductors are not working in series (e.g. due to an earth fault on one of the conductors), check that $I_{(make)}$ and $I_{c\ (break)}$ are higher than your maximum current for the maximum voltage U_e.
- When in fault conditions, the isolator must be able to withstand the maximum current using half of the poles (either the negative or the positive side only). The $I_{(make)}$ and *Ic (break)* is the current that one pole can withstand for very short periods of time. The isolator should be replaced after breaking this current.

WORKED EXAMPLE

The switch-disconnector with specifications given in figure below will be used as the rooftop PV array isolator for an array with a **transformerless** inverter. The system has a PV array maximum voltage of 540 V and an array short circuit current of 14 A. The following example checks whether the isolator selected is suitable for this purpose.

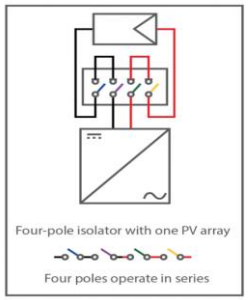
WORKED EXAMPLE 2

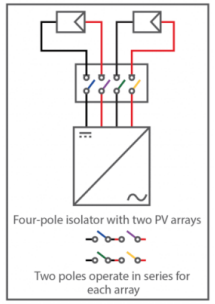


Identification			Rating Data
I_{th} rated thermal current, unenclosed, at 40°C shade ambient air temperature			32 A
I_{the} rated thermal current, indoors, at 40°C shade ambient air temperature, in a specific dedicated enclosure			32 A
I_{the} rated thermal current outdoors at 40°C shade ambient air temperature without solar effects in a specific dedicated enclosure rated IP 56NW			32 A
$I_{the\ solar}$ current value, outdoors at 60°C shade ambient air temperature, with solar effects in a specific dedicated enclosure rated IP 56NW			28 A
	U_e rated operational voltage (V)	I_e DC-PV2 rated operational current (A)	$I_{(make)}$ and $I_{c(break)}$ DC-PV2 $4 \times I_e$ (A)
2 pole	≤500	32	128
	600	32	128
	800	27	108
	1000	13	52
4 pole	≤500	32	128
	600	32	128
	800	32	128
	1000	32	128

- **Step 1.** $1.25 \times I_{SC\_ARRAY} = 1.25 \times 14$ A =17.5 A. This isolator will be installed outdoors in direct sunlight. I_{the} under these conditions (60·C) is 28 A according to data sheet, which is higher than 17.5 A, so the rating is acceptable.

WORKED EXAMPLE 3





Identification			Rating Data
I_{th} rated thermal current, unenclosed, at 40°C shade ambient air temperature			32 A
I_{the} rated thermal current, indoors, at 40°C shade ambient air temperature, in a specific dedicated enclosure			32 A
I_{the} rated thermal current outdoors at 40°C shade ambient air temperature without solar effects in a specific dedicated enclosure rated IP 56NW			32 A
$I_{the\ solar}$ current value, outdoors at 60°C shade ambient air temperature, with solar effects in a specific dedicated enclosure rated IP 56NW			28 A
	U_e rated operational voltage (V)	I_e DC-PV2 rated operational current (A)	$I_{(make)}$ and $I_{c(break)}$ DC-PV2 $4 \times I_e$ (A)
2 pole	≤500	32	128
	600	32	128
	800	27	108
	1000	13	52
4 pole	≤500	32	128
	600	32	128
	800	32	128
	1000	32	128

- **Step 2**. The isolator has four poles and there is only one string to be switched, so the positive and negative conductors will each go through 2 poles. During normal operation, these operate in series, so there are 4 poles total operating in series. Looking at the 4 pole configuration, the next highest U_e above 540 V is 600 V, and the corresponding I_e is 32 A. This is higher than 17.5 A, so the rating is acceptable.

WORKED EXAMPLE 4

Identification			Rating Data
I_{th} rated thermal current, unenclosed, at 40°C shade ambient air temperature			32 A
I_{the} rated thermal current, indoors, at 40°C shade ambient air temperature, in a specific dedicated enclosure			32 A
I_{the} rated thermal current outdoors at 40°C shade ambient air temperature without solar effects in a specific dedicated enclosure rated IP 56NW			32 A
I_{the} *solar* current value, outdoors at 60°C shade ambient air temperature, with solar effects in a specific dedicated enclosure rated IP 56NW			28 A
	U_e rated operational voltage (V)	I_e DC-PV2 rated operational current (A)	$I_{(make)}$ and $I_{c(break)}$ DC-PV2 $4 \times I_e$ (A)
2 pole	≤500	32	128
	600	32	128
	800	27	108
	1000	13	52
4 pole	≤500	32	128
	600	32	128
	800	32	128
	1000	32	128

- **Step 3**. The positive and negative conductors each go through 2 poles. This is a transformerless inverter, so under earth fault conditions, either conductor may switch the full array current and voltage. Therefore, looking at the 2 poles in series configuration, at the 600 V row, the $I_{(make)}$ and $I_{c(break)}$ for the chosen configuration is 128 A. This is higher than 17.5 A, so is acceptable.
- The d.c. isolator meets all three sizing requirements from AS/NZS 5033. Therefore, the chosen isolator and the PV array configuration are compatible.

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2022 3.1,	**FOR DOMESTIC DWELLINGS** The maximum voltage of the array does not exceed 1000 VDC. (Note: Max 1500V for other electrical installations)

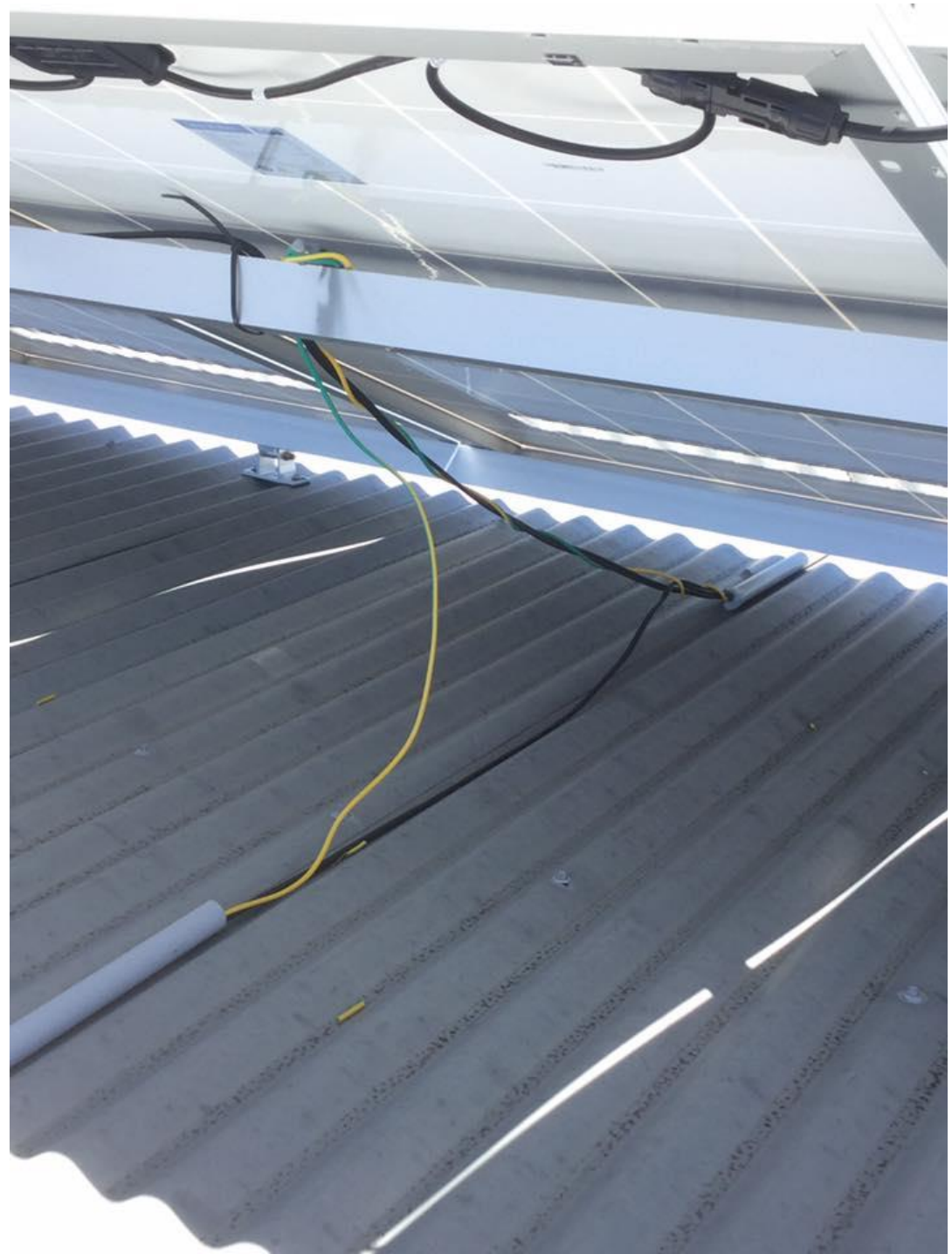
Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 2.1.6	Modules in the same string are installed in the same orientation within +/- 5 degrees

A minimum tilt of 10° is recommended to take advantage of self-cleaning during rain events. Horizontally mounted arrays will require additional maintenance [cleaning] and this should be included in the recommended maintenance schedule.

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 5.3.1	The PV array cabling is distinctively marked SOLAR in permanent, legible and indelible English, or where the cable is not distinctively marked, distinctive coloured labels marked 'SOLAR' attached at intervals not exceeding 2 metres



Is this permitted, yes or no?

Array Installation and dc Wiring

Clause	Description
AS/NZS 3000:2018 3.9.4.1; AS/NZS 5033:2021 4.4.3, 4.4.5.	Array wiring and wiring to the inverter is protected from mechanical damage.
AS/NZS 5033:2021 4.4.3,1	• do not lie on roofs or floors without an enclosure or conduit • are protected against abrasion, tension, compression and cutting forces that may arise from thermal cycles, wind and other forces during installation and throughout the life of the installation; and • are supported so they do not suffer fatigue due to wind affects.

Array Installation and dc Wiring

Clause	Description
AS/NZS 3000 1.5.14; AS/NZS 5033:2021 4.1 (d)	Array wiring and wiring to the inverter is protected from UV.
AS/NZS 5033:2021 4.4.3.3, AS/NZS 5033:2021 4.4.6.2	Double insulation has been maintained between any live conductor and any earthed or exposed conductive part

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 4.4.5.2.2	PV d.c. cables installed within ceilings in buildings are enclosed in metal or heavy-duty insulating conduit
AS/NZS 5033:2021 4.4.5.2.2	PV d.c. cables installed within buildings (not in ceilings) are enclose installed in medium duty insulating wiring enclosure *NOTE: Where the wiring system is installed near building sur faces (such as those concealed within 50 mm from a surface), extra protection methods beyond the requirements of this Clause may be required to meet AS/NZS 3000.*

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 4.4.5.2.2	PV d.c. cables installed external to the building, and not in a restricted access location, are installed in a wiring enclosure to ensure restricted access of the PV d.c cables

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 4.3.9.1	All dc connectors are of the same type/model from the same manufacturer where they are married at a connection point

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 4.4.2.2	Array cables meets the current rating i.e. If overcurrent protection is not provided, then the current rating of dc cable is 1.25 x I_{array} (or 1.25 x I_{bf}) If overcurrent protection is provided, then the current rating for dc cable is equal to the rating of overcurrent device

Array Installation and dc Wiring

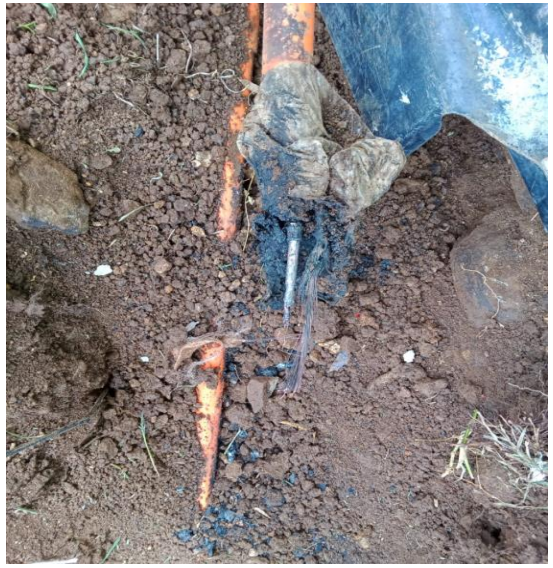
Clause	Description
AS/NZS 3000:2018 3.9.3 & 3.3.2.8; AS/NZS 5033:2021 4.4.3.1	All cables/wiring in the installation are securely fixed in place to minimise any movement of the cable.
AS/NZS 5033:2021 4.4.4.1	Any conduit is installed such that they are protected from UV or the conduit is UV stabilised

Array Installation and dc Wiring

Clause	Description
AS/NZS 3000:2018 1.5.14, 3.3.2.10	Array wiring and inverter wiring is protected from fauna where deemed necessary.

Array Installation and dc Wiring

Clause	Description
AS/NZS 3000:2018 3.1.2; AS/NZS 5033:2021 4.4.21	Array wiring is rated for the expected voltage (i.e. PV array maximum voltage)
AS/NZS 3000:2018 3.7.3, AS/NZS 5033:2021 4.4.6.1	All joints in cables are enclosed e.g. in junction boxes and/or comply with the exceptions of AS/NZS3000 Clause 3.7.3



Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 4.4.3.3	Double insulation has been maintained between the positive and negative conductors/terminations within all enclosures
AS/NZS 3000:2018 3.3.2.6	There is no evidence of mechanical damage to LV cables.

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 4.4.2.1	Wiring from array to isolator/inverter is single conductor cable both insulated and sheathed.

Array Installation and Wiring

Clause	Description
AS/NZS 5033:2021 4.4.2.1	All array cables are (a) temperature rated to the application; (b) UV resistant if exposed to the environment; (c) flexible (multi-stranded) to allow for thermal/wind movement of arrays/modules
AS/NZS 3000:2018 3.9.4	LV array and inverter cables are not directly installed near building surfaces as per AS/NZS 3000 requirements
AS/NZS 3000:2018 3.9.8	Any dc wiring located in the ac switchboard complies with the segregation, insulation and labelling requirements of AS/NZS 3000

Array Installation and dc Wiring

Clause	Description
AS/NZS 3000:2018 4.1.2 & 4.1.3; **AS/NZS 5033:2021 4.4.6.1, 4.4.7.2**	dc enclosure/s at the array have a minimum IP 55 rating and have been correctly installed to maintain IP rating. Any disconnector in a dedicated individual enclosure must not have top entry conduit or glands. If the number of cable entries to the enclosure is two or less, the entries are on the lower entry face of the enclosure. Where conduit systems have a section in an outdoor environment and terminates into an enclosure with a d.c. isolator, the conduit has a drain device fitted at the lowest point.

Array Installation and dc Wiring

Clause	Description
AS 3000:2018 4.1.2 & 4.1.3 . AS/NZS 5033:2021 4.4..	PV cable junction boxes mounted outdoors have a minimum IP 55 rating, and have been correctly installed to prevent water ingress

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 4.3.6	Where there is a number of PV array strings, and could result in a potential fault current in any one string greater than reverse current of an individual module - appropriate string protection is provided. [e.g. Fuses or non-polarised circuit breakers]
AS/NZS 5033:2021 3.3.4	Has string overcurrent protection been installed? It will be required if: I_{SC} x (number of strings at the array) > or equal to Module reverse current rating

Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 3.3.5	The string and sub-array protection current rating is according to AS/NZS 5033 Table 3.5 String protection (if required): $1.2 \times I_{STRING\ MAX} < I_n \leq I_{MOD\ MAX\ OCPR}$ Which becomes: $1.2 \times 1.25 \times K_I \times I_{SC\ MOD} < I_n \leq I_{MOD\ MAX\ OCPR}$ Sub-array protection (if required): $\mathbf{I_n \geq S_{SA} \times I_{STRING\ MAX}}$ Where: 1. S_{SA} = strings in parallel in the sub-array. 2. $I_{STRING\ MAX}$ (if no DCUs) = $1.25 \times K_I \times I_{SC\ MOD}$

STRING FUSE SIZING EXAMPLE

A PV system has 3 strings of PV modules, and no DCUs. The modules have a I_{SC} of 9.8 A and an $I_{MAX\ OCPR}$ of 20 A. The K_I factor has been determined to be 1 (mono-facial), and the inverter has a potential backfeed current of 3 A.

According to AS/NZS 5033:2021, **string overcurrent protection is required if**:

$$\mathbf{I_{F\ STRING} + I_{BF\ TOTAL} > I_{MOD\ MAX\ OCPR}}$$

Which when simplified becomes: $(S_A - 1) \times I_{STRING\ MAX} + I_{BF\ TOTAL} > I_{MOD\ MAX\ OCPR}$

$$(S_A - 1) \times 1.25 \times K_I \times I_{SC\ MOD} + I_{BF\ TOTAL} > I_{MOD\ MAX\ OCPR}$$

$$((3 - 1) \times 1.25 \times 1 \times 9.8\ A) + 3\ A > 20\ A$$

$24.5\ A + 3\ A > 20\ A \rightarrow$ **TRUE**, so string overcurrent protection is required.

STRING FUSE SIZING EXAMPLE 2

According to AS/NZS 5033:2021, string overcurrent protection sizing I_n must comply with:

$$\mathbf{1.2 \times I_{STRING\ MAX} < I_n \leq I_{MOD\ MAX\ OCPR}}$$

Which becomes: $1.2 \times 1.25 \times K_I \times I_{SC\ MOD} < I_n \leq I_{MOD\ MAX\ OCPR}$

$$1.5 \times 1 \times 9.8\ A = 14.7A$$

Therefore, I_n must be more than 14.7 A and less than or equal to 20 A. We would probably choose a 20 A fuse.

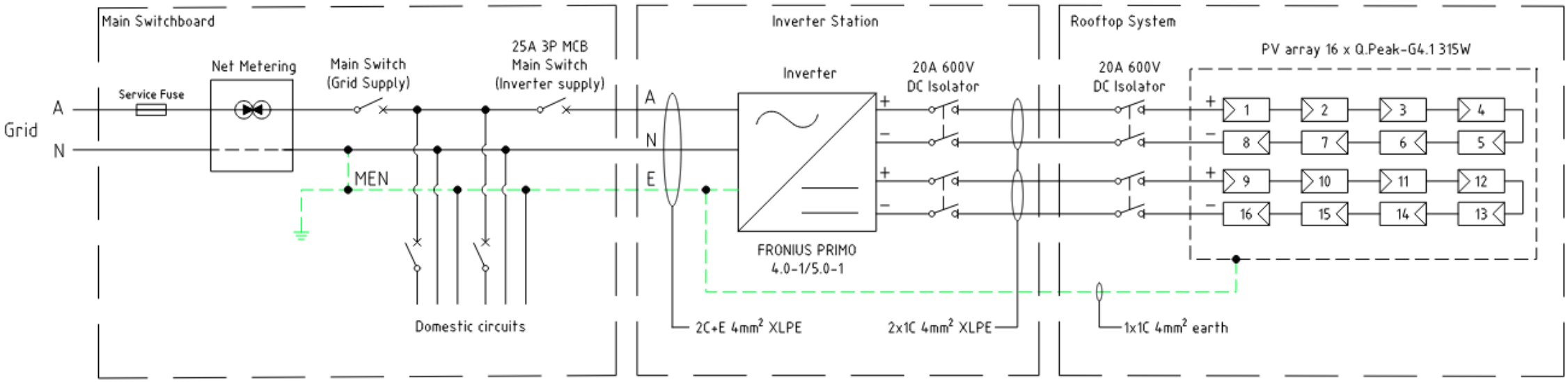
Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 3.3.5	The current rating (I_n) of the PV array overcurrent device (if required) is as per the following: (No DCU's) $I_n \geq S_A \times I_{STRING\ MAX}$ Where: 1. S_A = strings in parallel. 2. $I_{STRING\ MAX}$ (if no DCUs) = $1.25 \times K_I \times I_{SC\ MOD}$
AS/NZS 5033:2021 4.3.6.4	If string protection is installed, the fuse holders have a current rating equal to or greater than the corresponding fuse

Array Installation and dc Wiring

Clause	Description
AS/NZS 3000:2018 5.1.2; AS/NZS 5033:2021 4.6	The PV array mounting frames and modules have an equipotential bond connected to the earthing terminal on the switchboard/distribution board to which the inverter is connected, either directly or via the inverter main earth conductor. (Refer figure 4.13 of AS/NZS 5033)
AS/NZS 5033:2021 4.6.3	The PV array frame and/ module earthing connections and methods comply with standards requirements

Example Diagram – Equipotential earth connection



Array Installation and dc Wiring

Clause	Description
AS/NZS 5033:2021 5.3.2	PV cable junction boxes are labelled 'WARNING: HAZARDOUS DC VOLTAGE'
AS/NZS 5033:2021 Cl 4.6.7	If a transformer-less inverter (non-galvanically isolated) is installed, a functional earth is not connected to the dc positive or negative.
AS/NZS 5033:2021 Cl 4.6.7	If the PV array is functionally earthed an Earth Fault Interrupter is installed

Array Installation and dc Wiring

Clause	Description
PPA/SEIAPI Grid connected PV System Guidelines	The dc cables connecting to the inverter are mechanically secured in such a manner that they cannot be inadvertently unplugged from the inverter.

Inverter and dc Switchgear

Clause	Description
AS/NZS 3000:2018 4.1.3 and PPA/SEIAPI Guidelines	Inverter is of appropriate IP rating for its location.
AS/NZS 3000:2018 1.7.1 & 1.7.2	Inverter (or any heavy part of system) is installed/mounted safely and there appears no imminent risk of the item falling.
AS/NZS 3000:2018 1.7.1 & 1.7.2	Inverter has been installed in a location that has safe access and adequate working space

Quick Question

Does the following inverter have suitable IP rating to be installed outdoor?

TECHNICAL DATA FRONIUS PRIMO (3.0-1, 3.5-1, 3.6-1, 4.0-1, 4.6-1)

GENERAL DATA	PRIMO 3.0-1	PRIMO 3.5-1	PRIMO 3.6-1	PRIMO 4.0-1	PRIMO 4.6-1
Dimensions (height x width x depth)	645 x 431 x 204 mm				
Weight	21.5 kg				
Degree of protection	IP 65				
Protection class	1				
Overvoltage category (DC / AC) [1]	2 / 3				
Night time consumption	< 1 W				
Inverter design	Transformerless				
Cooling	Regulated air cooling				
Installation	Indoor and outdoor installation				
Ambient temperature range	-40 - +55 °C				
Permitted humidity	0 - 100 %				
Max. altitude	4,000 m				
DC connection technology	4x DC+ and 4x DC- screw terminals 2.5 - 16 mm²				
AC connection technology	3-pole AC screw terminals 2.5 - 16 mm²				
Certificates and compliance with standards	DIN V VDE 0126-1-1/A1, IEC 62109-1/-2, IEC 62116, IEC 61727, AS 4777-2, AS 4777-3, G83/2, G59/3, CEI 0-21, VDE AR N 4105				
Country of manufacture	Austria				

Inverter and dc Switchgear

Clause	Description
AS/NZS 3000:2018 1.7.1	There is adequate clearance around the inverter in accordance with inverter manufacturer's recommendation with adequate space and ventilation.
AS/NZS 5033 3.5.3	Where the calculated PV d.c. circuit maximum voltage is above 120 V or the PV array is connected to a non-separated inverter conforming to IEC 62109-2, an earth fault alarm system has been installed.

Inverter dc Switchgear

Clause	Description
AS/NZS 5033:2021 4.5.3.1	A load breaking disconnection means has been provided at the inverter to break the PV dc currents. **Either** an adjacent and physically separate load break disconnection device in accordance with Clause 4.3.4.2; **OR** A load break disconnection device that is part of and within the PCE, where the device and the PCE conform to AS/NZS 4777.2 . *NOTE 2 The internal load break disconnection device does not provide isolation of the PCE. Separate safe work methods should be employed to isolate the PCE before performing any work on the PCE (refer to PCE manufacturer instructions).*

Inverter dc Switchgear

Clause	Description
AS/NZS 4777.2 :2020 2.12.1	Where any load break switching device is part of and within the inverter and does not meet the requirements of this Clause (2.12.1) a warning label shall be used to indicate that an additional external load break switching device is required. Documentation for an inverter that requires an external load break switching device shall include the requirement of an additional external load break switching device that conforms to the requirements AS/NZS 4777.1.

Inverter dc Switchgear

Clause	Description
AS/NZS 3000:2018 2.2.4.2; AS/NZS 4777.1:2016 3.4.3; AS/NZS 5033:2021 4.1	If there is a separate disconnection device at the inverter, connected to the array, it is dc rated.
AS/NZS 3000:2018 2.4.2; AS/NZS 4777.1:2016 3.4.3; AS/NZS 5033:2014 4.3.1	If there is a separate dc disconnection device located adjacent to the inverter it is correctly rated for actual required dc voltage and current in accordance with AS/NZS:5033

Quiz

Does the following inverter SMA sunny Boy 5.0 have an in-built dc disconnection device that meets the requirement of AS/NZS5033 and AS/NZS4777.2?

Technical data	Sunny Boy 3.0	Sunny Boy 3.6	Sunny Boy 4.0	Sunny Boy 5.0	Sunny Boy 6.0
Input (DC)					
Max. generator power	5500 Wp	5500 Wp	7500 Wp	7500 Wp	9000 Wp
Max. input voltage	600 V				
MPP voltage range	110 V to 500 V	130 V to 500 V	140 V to 500 V	175 V to 500 V	210 V to 500 V
Rated input voltage	365 V				
Min. input voltage / initial input voltage	100 V / 125 V				
Max. usable input current input A / input B	15 A / 15 A				
Max. DC short-circuit current input A / input B	20 A / 20 A				
Number of independent MPP inputs / strings per MPP input	2 / A:2; B:2				
Output (AC)					
Rated power (at 230 V, 50 Hz)	3000 W	3680 W	4000 W	5000 W[1)]	6000 W
Rated / Max. apparent power	3000 VA / 3000 VA	3680 VA / 3680 VA	4000 VA / 4000 VA	5000 VA[1)]/5000 VA[1)]	6000 VA / 6000 VA
Rated voltage / range	220 V, 230 V, 240 V / 180 V to 280 V				
Power frequency / range	50 Hz, 60 Hz / −5 Hz to +5 Hz				
Rated power frequency / rated grid voltage	50 Hz / 230 V				
Rated / Max. output current	13.1 A / 13.7 A	16 A / 16 A	17.4 A / 18.2 A	22 A / 22.8 A	26.1 A / 26.1 A
Power factor at rated power	1				
Adjustable displacement power factor	0.8 overexcited to 0.8 underexcited				
Feed-in phases / connection phases	1 / 1				
Efficiency					
Max. efficiency / European Efficiency	97.0% / 96.4%	97.0% / 96.5%	97.0% / 96.5%	97.0% / 96.5%	97.0 % / 96.6 %
Protective devices					
Input-side disconnection point	●				
Ground fault monitoring / grid monitoring	● / ●				
DC reverse polarity protection / AC short circuit current capability / galvanically isolated	● / ● / –				
All-pole-sensitive residual-current monitoring unit	●				
Protection class (as per IEC 61140) / overvoltage category (according to IEC 60664-1)	I / III				
Arc-fault circuit interrupter (AFCI) / I-V and P-V diagnostic function	● / ●				

Quiz Answer

Does the following inverter - SMA sunny Boy 5.0 has an in-built dc disconnection device?

Technical data	Sunny Boy 3.0	Sunny Boy 3.6	Sunny Boy 4.0	Sunny Boy 5.0	Sunny Boy 6.0
Input (DC)					
Max. generator power	5500 Wp	5500 Wp	7500 Wp	7500 Wp	9000 Wp
Max. input voltage	600 V				
MPP voltage range	110 V to 500 V	130 V to 500 V	140 V to 500 V	175 V to 500 V	210 V to 500 V
Rated input voltage	365 V				
Min. input voltage / initial input voltage	100 V / 125 V				
Max. usable input current input A / input B	15 A / 15 A				
Max. DC short-circuit current input A / input B	20 A / 20 A				
Number of independent MPP inputs / strings per MPP input	2 / A:2; B:2				
Output (AC)					
Rated power (at 230 V, 50 Hz)	3000 W	3680 W	4000 W	5000 W[1)]	6000 W
Rated / Max. apparent power	3000 VA / 3000 VA	3680 VA / 3680 VA	4000 VA / 4000 VA	5000 VA[1)]/5000 VA[1)]	6000 VA / 6000 VA
Rated voltage / range	220 V, 230 V, 240 V / 180 V to 280 V				
Power frequency / range	50 Hz, 60 Hz / −5 Hz to +5 Hz				
Rated power frequency / rated grid voltage	50 Hz / 230 V				
Rated / Max. output current	13.1 A / 13.7 A	16 A / 16 A	17.4 A / 18.2 A	22 A / 22.8 A	26.1 A / 26.1 A
Power factor at rated power	1				
Adjustable displacement power factor	0.8 overexcited to 0.8 underexcited				
Feed-in phases / connection phases	1 / 1				
Efficiency					
Max. efficiency / European Efficiency	97.0% / 96.4%	97.0% / 96.5%	97.0% / 96.5%	97.0% / 96.5%	97.0 % / 96.6 %
Protective devices					
Input-side disconnection point	●				
Ground fault monitoring / grid monitoring	● / ●				
DC reverse polarity protection / AC short circuit current capability / galvanically isolated	● / ● / –				
All-pole-sensitive residual-current monitoring unit	●				
Protection class (as per IEC 61140) / overvoltage category (according to IEC 60664-1)	I / III				
Arc-fault circuit interrupter (AFCI) / I-V and P-V diagnostic function	● / ●				

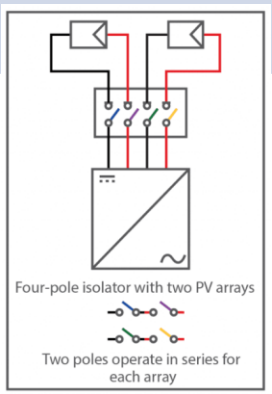
SMA Australia Pty Ltd

Grid Connect PV Inverter

MODEL NUMBER	RATED AC OUTPUT (VA)	INTEGRATED PV ISOLATOR	INTEGRATED PV ISOLATOR EESS REGISTERED*	INVE SETT MET
STP10.0-3AV-40 (AS4777-2 2020)	10000	Inbuilt	Yes	Monitoring A
STP8.0-3AV-40 (AS4777-2 2020)	8000	Inbuilt	Yes	Monitoring A
STP5.0-3AV-40 (AS4777-2 2020)	5000	Inbuilt	Yes	Monitoring A
STP 50-41 (AS4777-2 2020)	50000	Inbuilt	No	Monitoring A
STP3.0-3AV-40 (AS4777-2 2020)	3000	Inbuilt	Yes	Monitoring A
STP6.0-3AV-40 (AS4777-2 2020)	6000	Inbuilt	Yes	Monitoring A
STP4.0-3AV-40 (AS4777-2 2020)	4000	Inbuilt	Yes	Monitoring A
SB6.0-1AV-41 (AS4777-2 2020)	6000	Inbuilt	Yes	Monitoring A
SB5.0-1AV-41 (AS4777-2 2020)	5000	Inbuilt	Yes	Monitoring A

Inverter and dc Switchgear

Clause	Description
AS/NZS 5033:2021 4.5.4	If there is a dc disconnection device mounted adjacent to the inverter input it has been installed to prevent the spread of fire.
AS/NZS 3000:2018 2.3.2.2.1; AS/NZS 5033:2021 4.3.4.2.2 (e)	The dc disconnection device at the inverter is able to be secured in the off (open) position.
AS/NZS 3000:2018 2.1.2 (f), 4.1.2 & 4.1.3	The dc disconnection device at the inverter is correctly wired.



Inverter and dc Switchgear

Clause	Description
AS/NZS 5033:2021 4.3.4.2.2 (d)	The dc disconnection device at the inverter is not polarised and activates in all active conductors
AS/NZS5033:2021 4.3.5.3.1 (b)	The dc disconnection at the inverter is readily available

Inverter and dc Switchgear

Clause	Description
AS/NZS 5033:2021 4.5.4.2	If multiple dc disconnection devices are installed at the inverter, they are grouped and ganged so they operate simultaneously or grouped in a common location
AS/NZS 5033:2021 5.5.2.1	If multiple dc disconnection devices are installed at the inverter the correct warning sign indicating the need to operate all dc isolators to isolate the equipment is present

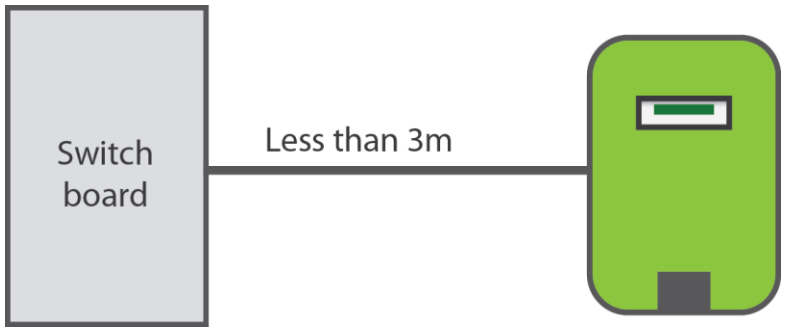
ac Switchgear and ac cabling

Clause	Description
AS/NZS 4777.1:2016 3.2.2	The inverter(s) ac output is connected to the main switchboard or distribution board.
AS/NZS 3000:2018 7.3.4.1 (a) AS/NZS4777.1 2016 3.4.3	If the inverter is not adjacent (within three meters, with each item fully visible from both locations) to the switchboard to which it is connected, there is a labelled readily available isolating switch adjacent to the inverter

AC SWITCH-DISCONNECTOR NEAR INVERTER

The a.c. switch disconnector (isolator) shall be compliant to AS/NZS 4777.1 requirements, in particular, Clauses 3.4.3 and 1.3.2 (or equivalent updates). Mainly, the following shall apply.

- Where the inverter is not within 3 metres and in the line of sight of the switchboard to which it is connected, an isolator shall be provided at the inverter so that a person operating the switch has a clear view of any person working on the inverter.

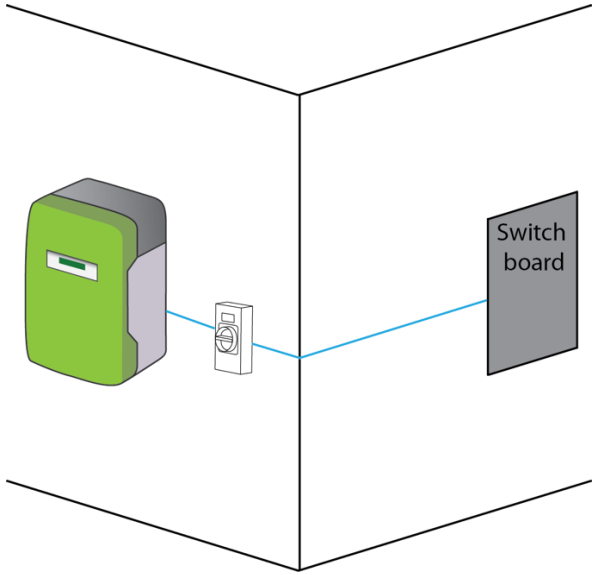


An a.c. switch-disconnector is not required when the distance between the switchboard and the inverter is less than 3m and the inverter is visible from the switchboard

SWITCH-DISCONNECTOR NEAR INVERTER 2

a.c. switch-disconnector is required when distance is greater than 3m or the switchboard is not visible from the inverter

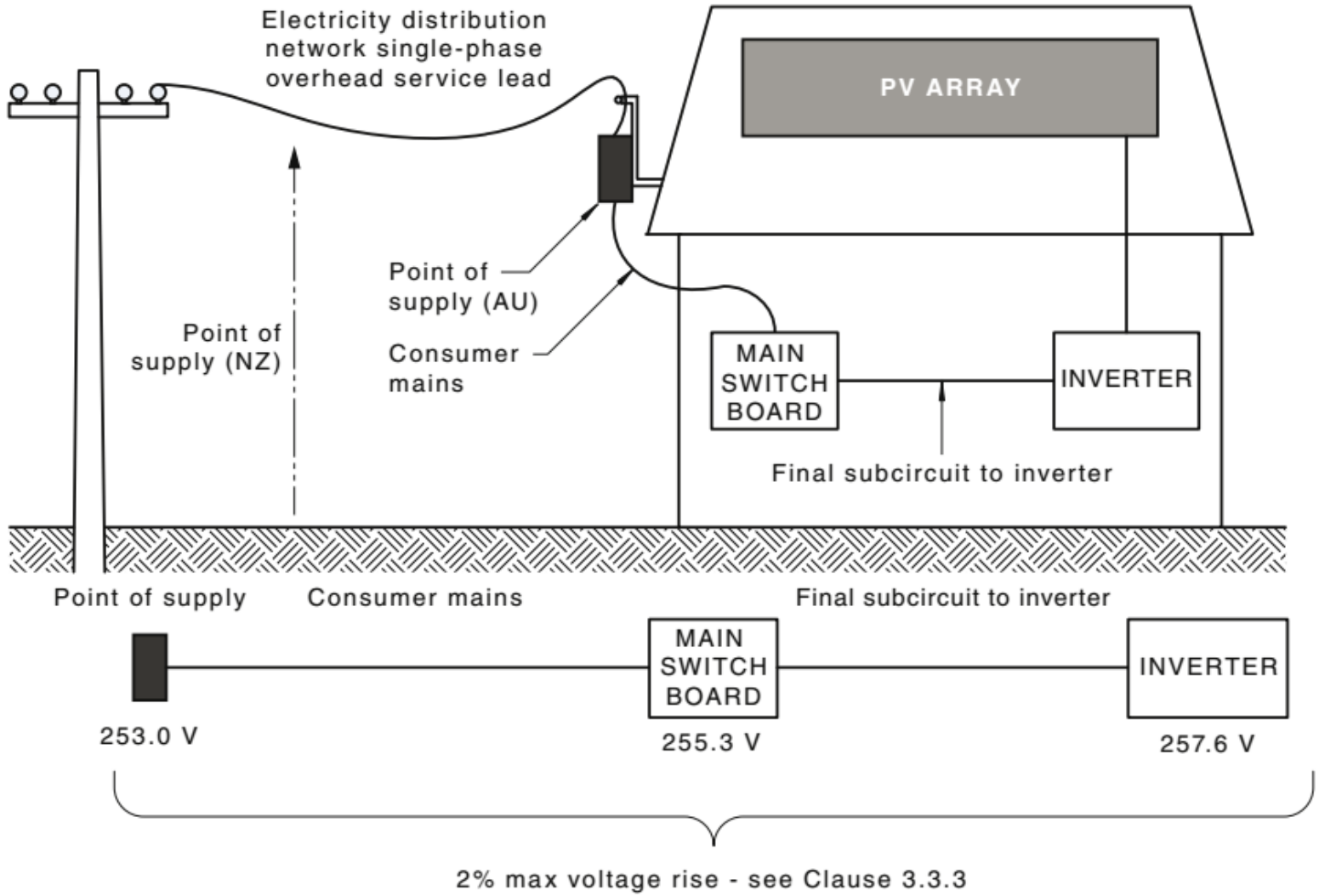
SWITCH-DISCONNECTOR NEAR INVERTER 3



a.c. switch-disconnector required when the switchboard is away from the line of sight

ac cabling

Clause	Description
AS/NZS 4777.1:2016 3.3.3	Voltage rise is less than 2% between the inverter and the point of connection to the grid


Electricity distribution network single-phase overhead service lead
PV ARRAY
Point of supply (AU)
Consumer mains
Point of supply (NZ)
MAIN SWITCH BOARD
INVERTER
Final subcircuit to inverter
Point of supply
Consumer mains
Final subcircuit to inverter
MAIN SWITCH BOARD
INVERTER
253.0 V
255.3 V
257.6 V
2% max voltage rise - see Clause 3.3.3

Worked Example

TABLE 41

THREE-PHASE VOLTAGE DROP (V_c) AT 50 Hz

CABLE TYPES: CABLE TYPES: SINGLE-CORE INSULATED AND SHEATHED COPPER CONDUCTORS, LAID FLAT TOUCHING OR TOUCHING INSIDE A COMMON WIRING ENCLOSURE

1	2	3	4	5	6	7	8	9	10	11
Conductor size	Three-phase voltage drop (V_c) at 50 Hz, mV/A.m									
	Conductor temperature, °C									
	45		60		75		90		110	
mm²	Max.	0.8 p.f.	Max.	0.8 p.f.	Max.	0.8 p.f.	Max.	0.8 p.f.	Max.	0.8 p.f.
1	40.3	40.3	42.5	42.5	44.7	44.7	46.8	46.8	49.7	49.7
1.5	25.9	25.9	27.3	27.3	28.6	28.6	30.0	30.0	31.9	31.9
2.5	14.1	14.1	14.9	14.9	15.6	15.6	16.4	16.4	17.4	17.4
4	8.77	8.77	9.24	9.24	9.71	9.71	10.2	10.2	10.8	10.8
6	5.86	5.86	6.18	6.18	6.49	6.49	6.81	6.81	7.23	7.23
10	3.49	3.49	3.68	3.68	3.86	3.86	4.05	4.05	4.30	4.30
16	2.20	2.20	2.32	2.32	2.43	2.43	2.55	2.55	2.71	2.71
25	1.40	1.40	1.47	1.47	1.55	1.55	1.62	1.62	1.72	1.72
35	1.02	1.02	1.07	1.07	1.12	1.12	1.18	1.18	1.25	1.25

Source: Table 41 AS3008

Using Table 41, determine the voltage rise and percentage voltage rise for the inverter ac cable where:

- Selected cable size is PVC V75 single core 10mm^2. (From Table 41, the three-phase V_c value is 3.86 mV/Am)
- Route length = 20 m,
- Maximum ac current = 35.7 A,
- 240V ac voltage

Answer:

$$V_r = \frac{(V_c \times L \times I)}{1000}$$

Converting three-phase values to single-phase from Table 5:

3.86 x 1.155 = 4.46 mV/Am (single phase)

V_r = (20 m × 35.7 A x 4.46 mV/Am) / 1000 = 3.18V

$\%V_r$ = (3.18/240) x 100% = 1.33%

You will then consider V_{rise} in consumer mains cable and sub-mains etc (if applicable) and the combined Vrise shall not exceed 2%. If required, you will upsize to 16mm sq.

ac Switchgear

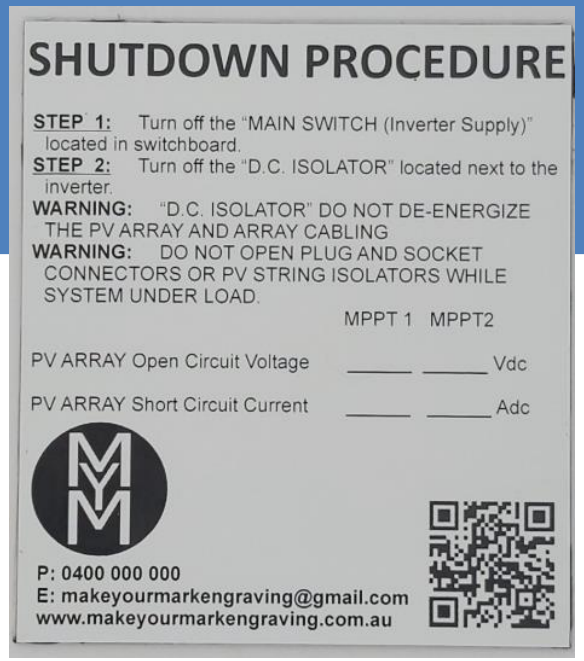
Clause	Description
AS/NZS 3000:2018 7.3.5.2 & 7.3.8.2.2 AS/NZS 4777.1:2016 3.4.3	An ac circuit breaker is mounted within the switchboard to act as a main switch for the inverter system and to protect the cable from the switchboard to the inverter
AS/NZS 4777.1:2016 3.4.3	The inverter ac circuit breaker on switchboard can be secured in the open position
AS/NZS 4777.1:2016 3.4.2	The inverter ac circuit breaker is correctly rated to protect the ac cable installed between the inverter and switchboard to which it is connected

ac cabling

Clause	Description
AS/NZS 4777.1:2016 3.4.3	The ac cables installed between the inverter and the switchboard to which it is connected are rated at a minimum of the inverter's maximum output current
AS/NZS 3000:2018 3.9.4	Inverter cables are not directly installed near building surfaces as per AS/NZS 3000 requirements
AS/NZS 5033:2021 4.4.3.2	Connection of ac and dc components in same enclosure are segregated i.e. there must be physical separation between ac and dc in an enclosure where wiring from both components are terminated.

signage

Clause	Description
AS/NZS 5033:2021 5.7	Shutdown procedure is correct and is permanently fixed at inverter and/or on main switchboard.
AS/NZS 4777.1:2016 6.3	If the solar system is connected to a distribution board, the following sign is located on main switchboard & all immediate distribution boards. ‘WARNING’, ‘MULTIPLE SUPPLIES’ ‘ISOLATE INVERTER SUPPLY AT DISTRIBUTION SWITCHBOARD’ and ‘MAIN SWITCHBOARD’



signage

Clause	Description
AS/NZS 4777.1:2016 6.2 (b)	The ac circuit breaker in the switchboard is labelled: ‘MAIN SWITCH (INVERTER SUPPLY)’ or similar.
AS/NZS 4777.1:2016 6.2 (a)	Sign – ‘WARNING’, MULTIPLE SUPPLIES’, ‘ISOLATE ALL SUPPLIES BEFORE WORKING ON SWITCHBOARD’ located on the switchboard

signage

Clause	Description
AS/NZS 4777.1:2016 6.2	Where the inverter is not adjacent to the main switchboard, inverter location information shall be displayed on the switchboard to which the inverter system is directly connected.
AS/NZS5033:2021 5.6 AS/NZS 5033:2021 5.44	a green ‘PV’ sticker is permanently fixed within the buildings main switchboard and site plan is located at the switchboard and/or meter panel. The words ‘’DP” or ‘’SW” or ‘’AC” are stated below ‘’PV” to denote the type of disconnection for emergency workers.

Quiz

- In the green ‘PV’ sticker, what does the words ‘’DP’’ or ‘’SW’’ or ‘’AC’’ depict?

Refer to the clause number of AS/NZS5033.

Quiz Answer

Clause 5.4 of AS/NZS5033, page 75

(a) "AC " - For inverters where the calculated PV d.c. circuit maximum voltage is less than 120 V d.c. at the inverter PV input, and the PV modules are within 1.5m of the inverter are installed.

(b) "DP" – Where a disconnection point is used as the isolation method.

(c) "SW" – Where a load break disconnection device is used as the isolation method.

signage

Clause	Description
AS/NZS 5033:2021 5.5.1	Disconnection devices near inverter is appropriately labelled.
AS/NZS 4777.1:2016 6.2	Grid supply main switch is labelled ‘MAIN SWITCH (GRID SUPPLY)’ or similar.

VOLTAGE RISE

- All existing and new cabling shall be checked for the maximum voltage rise between the point of supply and the inverter a.c. terminals (grid-interactive port) in accordance with the following requirements. The overall voltage rise from the point of supply to the inverter a.c. terminals (grid-interactive port) shall not exceed 2% of the nominal voltage at the point of supply.

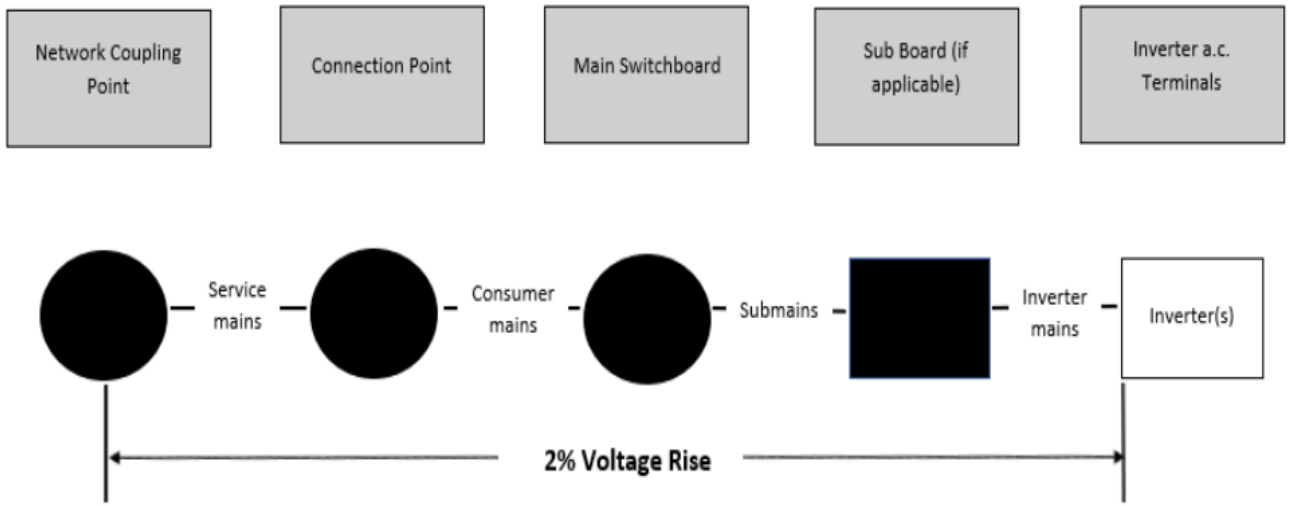


Figure 15 Depiction of the allowable 2% voltage rise

Source: Extracted from ‘’Standard for Small IES Connections’’ by ENERGEX and Ergon Energy

VOLTAGE RISE 2

- Refer to Appendix C of AS/NZS 4777.1 for guidance and examples on the voltage rise calculations.
- The AS/NZS 3008.1 formula and method shall be used:

$$V_d = \frac{(V_c \times L \times I)}{1000}$$

SIGNAGE

- The signage requirements recommended in AS/NZS5033 (Clause 5.3) and AS/NZS 4777.1 (Section 6) shall be complied with in the installation of the grid connected PV system. Essentially, the table below states the common signage required and their locations.

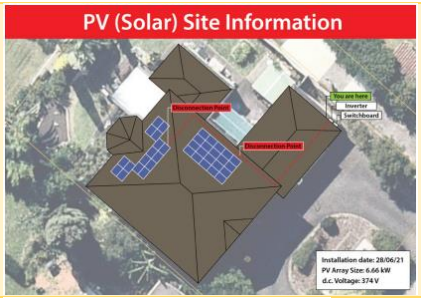
SIGNAGE 2

Signage	Example
PV d.c. cables Permanently and legibly marked with **'SOLAR'** every 2m	
When wiring system is installed in an accessible ceiling space or within an accessible floor space, a warning label shall be installed / Combiner boxes WARNING: HAZARDOUS d.c. VOLTAGE	
On or immediately adjacent to the main metering panel and main switchboard (See notations: AC, SW or DP in AS/NZS5033)	

SIGNAGE 3

PV array DC disconnecting devices Sign located in a prominent location on the disconnector with: “PV array D.C. isolator”	
Where there are multiple DC disconnection devices that are not ganged	
Disconnection point - A sign shall be attached to the PV module or structure within 300 mm of the disconnection point to identify the location of the disconnection point:	

SIGNAGE 4

Solar system layout shall be shown on a plan (map or drawing) located at the main switchboard and/or meter box	
"Multiple Supplies" – Isolate All Supplies before working on the switchboard. In a prominent position on the switchboard the inverter is connected to. Refer to Clause AS/NZS 4777.1:2016 Clause 6.2 a)	
Shutdown procedure The procedure shall be placed adjacent to and visible from the equipment to be operated in the event of a shutdown.	Refer to example in AS/NZS5033 

SIGNAGE 5

Inside Main Switchboard: A sign adjacent to inverter main switch with: 'Main Switch (Inverter Supply)' 'Main Switch (Grid Supply)' 'Inverter Located at' Refer to AS/NZS 4777.1 for more details.	**MAIN SWITCH (INVERTER SUPPLY)** **MAIN SWITCH (GRID SUPPLY)** **INVERTER LOCATED ON _____**
On the inverter-adjacent AC isolator (if present). Refer to AS/NZS 4777.1:2016 Clause 6.8	INVERTER A.C. ISOLATOR

SIGNAGE 6

Generally, the following mandatory signage shall be applied:

- A sign should be included in the switchboard stating:
- ‘WARNING’, ‘MULTIPLE SUPPLIES’ and ‘ISOLATE ALL SUPPLIES BEFORE WORKING ON THIS SWITCHBOARD’.
- A sign with text ‘MAIN SWITCH (Inverter SUPPLY)’ shall be permanently fixed adjacent to the main switch for the inverter.
- Where the inverter is connected to the main switchboard, a sign with text ‘MAIN SWITCH (GRID SUPPLY)’ shall be permanently fixed adjacent to the main switch for the grid supply.
- Where the inverter is connected to the distribution switchboard, a sign with text ‘MAIN ISOLATOR (NORMAL SUPPLY)’ shall be permanently fixed adjacent to the isolator for the normal supply to the distribution switchboard.
- NOTE: The terms ‘grid supply’, ‘normal supply’ and ‘mains supply’ can be used alternatively

If the inverter is not mounted near the switchboard, then there should be a sign in the switchboard stating where the inverter is located.

SIGNAGE 7

- There should be a sign on the switchboard stating the location of the PV array, the maximum d.c. array short circuit current and array open circuit voltage from the system.
- PV d.c cables shall be permanently and legibly marked with ‘SOLAR’ every 2m.
- Any junction boxes used between the array and the inverter should have a sign ’WARNING: HAZARDOUS d.c. VOLTAGE’ on the cover.
- A sign with text ‘PV ARRAY d.c. ISOLATOR’ shall be fixed permanently adjacent to the PV array d.c. switch disconnector.
- Where there are multiple disconnection devices, a sign with texts ‘WARNING: MULTIPLE d.c. SOURCES’ and ‘TURN OFF ALL d.c. ISOLATORS TO ISOLATE EQUIPMENT’ shall be fixed near the inverter.

SIGNAGE 8

- A green PV label indicating that there is a PV system at the site using the notations – (See notations: AC, SW or DP in AS/NZS5033).

- Solar system layout shall be shown on a plan (map or drawing) located at the main switchboard and/or meter box.

- Where a disconnection point is used, an appropriate sign shall be attached to the PV module or structure within 300 mm of the disconnection point to identify the location of the disconnection point: “PV String Disconnection Point”.

- A sign with steps to safely shut down the system shall be fixed adjacent to and visible from the equipment to be operated in the event of shutdown. This sign may also include detailed steps of the start-up procedure.

TESTING AND COMMISSIONING

The verification and testing of the system shall be compliant to AS/NZS 5033, in particular clauses 4.7.2 and 4.7.3. The following mandatory tests shall be applied in addition to the recommendations specified in AS/NZS 3000:

- Continuity of the earthing system
- Insulation Resistance test
- Polarity test
- Open circuit voltage (V_{0c})

TESTING AND COMMISSIONING 2

- After visual inspection and testing are completed, the system shall be commissioned, in the appropriate sequence according to the shutdown and reconnection instructions.

TESTING AND COMMISSIONING 3

- In some systems (e.g. utility scale, large commercial systems) testing and commissioning shall be in accordance with **IEC62446: Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection**.

DOCUMENTATION

The system inspection shall be properly documented and retained for any future reference. The Utility procedures on inspection documentation retention shall be applied for grid connected PV system.

NEC 2023

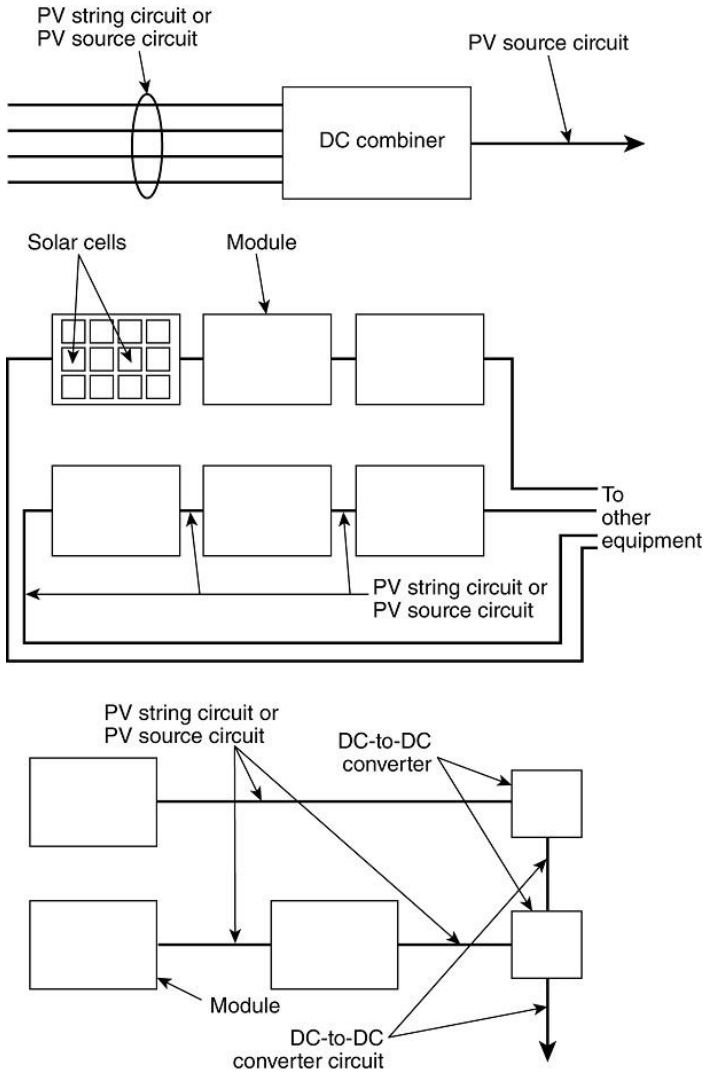
This section references mainly NEC Article 690.

Note: Not everything has been repeated, only important points have been emphasized.

NEC 2023 Article 690

- Part I General (Scope, Definitions)
- Part II Circuit Requirements
- Part III Disconnecting Means
- Part IV Wiring Methods and Materials
- Part V Grounding and Bonding
- Part VI Source connections

Common Terminologies



Array Installation and dc Wiring

Article/Section	Description
NEC 2023 Article 690.7	PV system dc circuits does not exceed 1000 volts within or originating from arrays located on or attached to buildings and PV system dc circuits inside buildings.
NEC 2023 Article 690.7	PV system dc circuits on or in one- and two-family dwellings have a maximum voltage of 600 volts or less

PV Disconnector

Article/Section	Description
NEC 2023 Article 690.13	Each PV system Disconnector indicates whether it is in the off or on position and is permanently marked “PV SYSTEM DISCONNECT”
NEC 2023 Article 690.13 (C)	Each PV system disconnection means consist of not more than six switches or six sets of circuit breakers or a combination mounted in a single enclosure or in a group of separate enclosures.

Conductor Ampacity

Article/Section	Description
NEC 2023 Article 690.8 (B)	The ampacity of PV circuits conductors is the greater of the following: equal to or greater than a) **1.25 x maximum current** (Note: maximum current is 1.25 x sum of Isc currents of modules connected in parallel) Eventually, 1.56 x sum of Isc currents of modules connected in parallel ***(This applies to systems without adjustment and correction factors)*** Or b) **Conductor ampacity is maximum current in 690.8(A)** calculated with adjustment and correction factors

Overcurrent Protection

Article/Section	Description
NEC 2023 Article 690.9	PV system dc circuit and inverter output conductors and equipment are protected against overcurrent. (in accordance with 690.9(A)(1), (A)(2), or (A)(3)) Overcurrent protection in PV dc circuit is not required where both conditions are met: *1. The conductors have sufficient ampacity for the maximum current* *2. The currents from all sources do not exceed the maximum overcurrent protection device rating for the PV modules or inverter*

PV arc-fault circuit interrupter

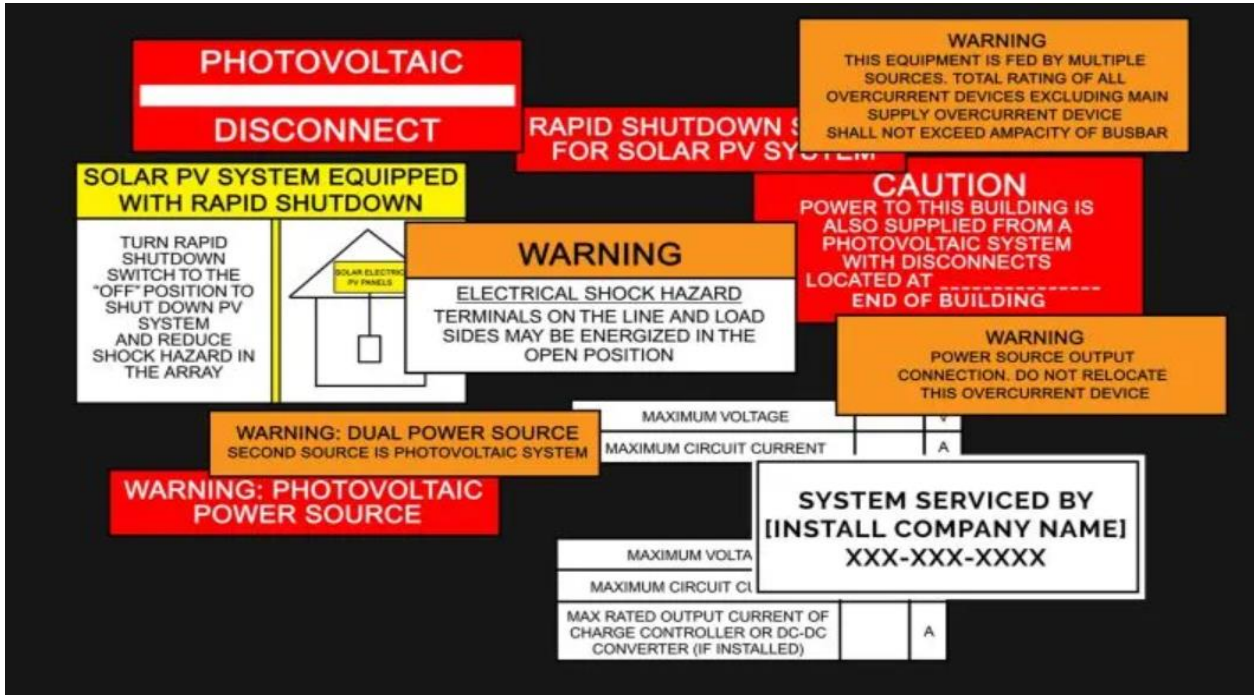
Article/Section	Description
NEC 2023 Article 690.11	Photovoltaic systems with PV system dc circuits operating at 80 volts dc or greater between any two conductors are protected by a listed PV arc-fault circuit interrupter or equivalent *(Exception: PV dc circuits that utilise metal clad cables in metal raceways or metal enclosed metal cable trays and where installation complies with one of the following (1) Where the PV system dc circuits are not installed in or on buildings. (2) The PV system dc circuits are located in or on detached structures*

Wiring/Enclosure

Article/Section	Description
NEC 2023 Article 690.31 (D)(2)	The following wiring methods and enclosures that contain PV system dc circuit conductors have been marked with the wording **WARNING: PHOTOVOLTAIC POWER SOURCE or SOLAR PV DC CIRCUIT**: (1) Exposed raceways, cable trays, and other wiring methods (2) Covers or enclosures of pull boxes and junction boxes (3) unused conduit openings

Labels

Article/Section	Description
NEC 2023 Article 690.31	The labels or markings are visible after installation. The labels are reflective, and all letters are capitalized and are of minimum height of 9.5 mm (3⁄8 in.) in white on a red background.



DC circuits inside Buildings

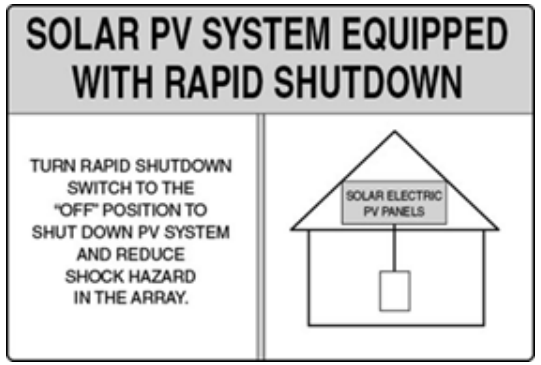
Article/Section	Description
NEC 2023 Article 690.31 (D) (1)	Where inside buildings, PV system dc circuits that exceed 30 volts or 8 amperes are contained in metal raceways, in Type MC metal-clad cable or in metal enclosure. *Exception: With PVHCS installed its permitted with non-metallic enclosure/raceway/cables at the point of penetration of the surface of the building.*

Ground Fault Protection

Article/Section	Description
NEC 2023 Article 690.41(B)	The requirements for ground fault protection have been met as per NEC 2023. PV system dc circuits that exceed **30 volts or 8 amperes** are provided with GFDI protection meeting the requirements of 690.41(B)(1) and (B)(2).

Rapid Shut-down Function

Article/Section	Description
NEC 2023 Article 690.12	PV system circuits installed on or in buildings include a rapid shutdown function (initiation device could be a disconnection device) to reduce shock hazard for firefighters ***(Exception: (1) Ground-mounted PV system circuits that enter buildings that only house PV equipment (2) PV equipment and circuits installed on non-enclosed detached structures (carports or similar structures)***



Inverter Disconnecting Means

Article/Section	Description
NEC 2023 Article 690.15	Disconnecting means has been provided to disconnect inverters from all conductors that are not solidly grounded. The disconnecting means is one of the following: *(1) An equipment disconnecting means in accordance with 690.15(C)* *(2) An isolating device as part of listed equipment where an interlock or similar means prevents the opening of the isolating device under load* *(3) For circuits with a maximum circuit current of 30 amperes or less, an isolating device in accordance with 690.15(B) (e.g. mating connector, finger-safe fuse holder etc)*

The End

THANK YOU