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Grid-Connected PV Systems Design and Installation

Revisions to the Grid-Connected PV Systems: Design and Installation Australian Edition Version 8.10 Publication

global sustainable energy solutions

Following is the summary of changes to the information within Grid-Connected PV Systems Design and Installation Australian Edition Version 8.10, September 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.*

Chapter 4

1. **Chapter 4 Quiz**

   Replacement:
   Question 4

   Draw a rough I–V curve and power curve for a module with the following characteristics. Calculate and label the PMP and label all three axes.

   - $V_{OC} = 45$ V
   - $V_{MP} = 35$ V
   - $I_{SC} = 8$ A
   - $I_{MP} = 7$ A

Chapter 7

2. **Section 7.2.3**

   Replacement:

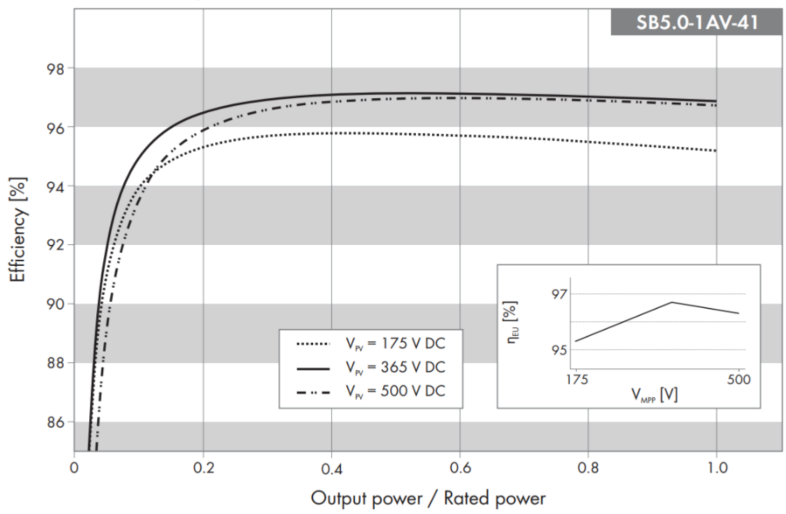

Figure 7.10: Example of an inverter efficiency curve (SMA Sunny Boy 5.0-1AV-41). (Source: SMA Solar Technology AG.)

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

Amendment:

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 falls below f_{LLCO} is used as a reference power level to calculate the required response to the decreasing frequency.

Chapter 12

4. **Chapter 12 Quiz: Question 3 Table**

Amendment:

At 1,000 W/m² (STC)	
Maximum power	315 W
Maximum power voltage (V_{MP})	39.8 V
Maximum power current (I_{MP})	7.92 A
Open circuit voltage (V_{OC})	49.2 V
Short circuit current (I_{SC})	8.50 A
Efficiency	14.3%
Other electrical characteristics	
Power tolerance	+5/–3%
Maximum system voltage	1,000 V
Maximum reverse current	15 A
Series fuse rating	15 A
Temperature coefficient of V_{OC}	–0.36%/°C
Temperature coefficient of I_{SC}	0.061%/°C
Temperature coefficient of P_{MAX}	–0.46%/°C

5. **Chapter 12 Quiz: Question 3**

Amendment:

c. The inverter to be used has an MPPT minimum operating voltage of 150 V. The maximum expected cell temperature is 70°C and the voltage drop can be assumed to be 2% in the cables on the DC side. Use the temperature coefficient for P_{MAX} and calculate:

6. **Chapter 12 Quiz: Question 3**

Amendment:

c. ii The maximum power voltage temperature coefficient

Chapter 14

7. Chapter 14 Quiz: Question 3

Amendment:

An array has four strings of nine modules and the following specifications:

- Module I_{SC} = 10.49 A
- Module V_{MP} = 34.1 V
- The length of the positive string cable is 8 m and the length of the negative string cable is 14 m from the furthest module to the disconnector.
- Array cable length = 22 m
- The cables are XLPE 90°C copper, with a resistivity of 0.0219 Ω/m/mm². Assume the cable has the same specifications as in Table 14.2.

The cables should be sized to have a maximum 1.5% voltage drop on the string cables and a 1.5% voltage drop on the array cables.

a. Calculate the minimum string cable CSA.

b. Calculate the minimum array cable CSA.

8. Chapter 14 Quiz: Question 4

Amendment:

You are supplied with a reel of 4 mm² cable to use as the array cable for a solar PV installation. The array has five strings of ten modules and the following specifications:

- Module I_{SC} = 10.05 A
- Module V_{MP} = 33.24 V
- String cable length = 20 m
- Array cable length = 11 m
- The cables are XLPE 90°C copper, with a resistivity of 0.0219 Ω/m/mm². Assume the cable has the same specifications as in Table 14.2.

a. Calculate the % voltage drop on the array cable.

b. Calculate the maximum allowable % voltage drop on the string cables.

c. Calculate the minimum string cable CSA

9. Chapter 14 Quiz: Question 5

Amendment:

The distance between an inverter and the main switchboard is 26 m. What is the minimum cable CSA that will ensure the voltage drop will be less than 1%?

Assume the following:

- I_{AC} = 12 A
- V = Single-phase 230 V_{RMS}
- The cables are PVC 75°C copper, with a resistivity of 0.0209 Ω/m/mm2.
- Power factor = 1

Assume the cable has the same specifications as in Table 14.2.

Chapter 15

10. Section 15.1.7 - Inverter Efficiency

Extension:

Realistically the value of the inverter efficiency will usually be less than the peak efficiency specified on the inverter manufactuer's datasheet. For example, in Figure 7.10 the maximum efficiency of the Sunny Boy 5.0-1AV-41 is 97% however under most operating conditions, the efficiency will be between 95-97% as shown in the efficiency curve. This value may be more appropriate to use when calculating yield.

Average system losses due to the inverter are in the range of 2–6%, which is equivalent to an efficiency range of 94–98%.

11. Section 15.4 - Greenhouse Gas Savings

Addition:

The desire to help the environment and reduce the household's carbon footprint is also an influencing factor for the installation of a PV system. Each kWh of energy generated by the PV system is one less kWh that is required to be generated by the grid. Given that most of Australia's electricity is generated from coal, this represents an emissions reduction.

To estimate the amount of greenhouse gas savings by installing a PV system, the PV system's estimated electricity generation (kWh) is multiplied by an emission factor. This provides an estimation of the kilograms of Carbon Dioxide equivalent (CO_2-e) that will be offset by the system.

Emissions factors vary depending on the state because each state uses technologies with different emissions intensities to produce their grid electricity. Victoria for example produces most of their power through brown coal power stations with high CO_2 emissions, whereas Tasmania produces most of their power through hydropower with low CO_2 emissions.

> *EXAMPLE*
>
> A system installed in Sydney NSW generates an annual yield of 5295 kWh/year. Assume the GHG emission factor for NSW is 0.87 kg CO_2-e/kWh. Estimate the annual greenhouse gas savings for the system.
>
> *Greenhouse Gas Savings (kg CO_2-e /year)*
> *= Electricity Production (kWh/year) × emission factor (kg CO_2-e/kWh)*
> *= 5295 kWh/year × 0.87 kg CO_2-e/kWh*
> *= 4606.65 kg CO_2-e/year*
>
> Therefore the system will save 4606.65 kg CO_2-e each year. Note that this is independent of whether the solar generation is consumed within the household or not.

Chapter 17

12. Introduction

Addition:

> **IMPORTANT**
>
> The Australian Energy Market Operator operates the distributed energy resource (DER) register. This means that installers need to provide additional information to network service providers (NSPs) or directly to AEMO (depending on the NSP) about the PV systems they are installing. Installers must be across these requirements. Check with your local NSP and refer to the AEMO website (https://www.aemo.com.au/energy-systems/electricity/der-register) for more information.

13. Commissioning & Verification Checklist

Amendment:

A verification checklist may be used as a quality assurance tool to confirm that all qualitative design and installation criteria have been met. A sample system commissioning checklist is included in **Section 17.2.8** in conjunction with a sample testing and commissioning sheet.

14. Commissioning & Verification Checklist

Removal:

Installer name:	
Installer accreditation number (if applicable):	
Installer signature:	
Commissioning date:	
Installation address: Client name: Client contact details:	
PV module manufacturer:	PV module model number:
PV module installation meets relevant building codes: YES ☐ NO ☐	
All PV modules connected to the same MPPT are of the same make and model or have similar rated electrical characteristics: YES ☐ NO ☐	
All PV modules connected to the same string have the same angle of tilt and azimuth: YES ☐ NO ☐	
Number of modules in series: String 1: String 2: String 3: String n: (add more as required)	Number of strings in parallel: Sub-array 1: Sub-array 2: Sub-array 3: Sub-array n: (add more as required)
Array mounting system manufacturer:	
Array mounting system model:	
Array mounting system certified for installation site parameters: YES ☐ NO ☐	
Array mounting system does not use or contact any galvanically dissimilar metals: YES ☐ NO ☐	
All penetrations and fixings are suitably sealed and weatherproofed: YES ☐ NO ☐	
PV array voltage complies with site regulations: YES ☐ NO ☐	
PV system wiring is suitably protected from mechanical action: YES ☐ NO ☐	
PV array uses single-core double-insulated cabling compliant to relevant standards: YES ☐ NO ☐	
Overcurrent protection is provided where required: YES ☐ NO ☐ NOT REQUIRED ☐	

All DC components are rated correctly for DC usage and have voltage ratings greater than or equal to the PV array maximum voltage: YES ☐ NO ☐ All AC components are rated correctly for AC usage. YES ☐ NO ☐
All components are suitable for their environment and have the appropriate IP and UV ratings: YES ☐ NO ☐
Disconnection devices and protection devices (where installed) are readily available in the case of maintenance or emergency: YES ☐ NO ☐
Disconnecting devices comply with frequency-of-use requirements and are rated for the temperature-adjusted operational circuit current: YES ☐ NO ☐
Disconnectors are rated to switch full-load currents (where required) and are not polarity–sensitive (in the case of DC circuit breakers): YES ☐ NO ☐
PV array disconnectors interrupt all live conductors: YES ☐ NO ☐
PV conductor current-carrying capacity is equal to or greater than the potential system fault current or the overcurrent protection (where installed): YES ☐ NO ☐
PV cabling, where exposed to the elements, is UV-resistant or installed in UV-resistant enclosures: YES ☐ NO ☐
A method of securing cabling has been used that will last the lifetime of the system: YES ☐ NO ☐
DC cabling within buildings is enclosed in heavy-duty-rated protection: YES ☐ NO ☐ NOT REQUIRED ☐
Combiner boxes are installed according to manufacturer recommendations: YES ☐ NO ☐
Combiner boxes are suitably protected from the environment using appropriate bottom-entry cable glands: YES ☐ NO ☐
Double insulation between all conductors is maintained throughout the system: YES ☐ NO ☐
PV plugs, sockets and connectors comply with relevant standards, are rated for the installation environment and connect only with the same make and model: YES ☐ NO ☐
Blocking and bypass diodes, where installed external to the PV module are suitably protected and grade according to relevant standards and system parameters: YES ☐ NO ☐
Overcurrent protection (where required) is installed at the end of the conductor that is most electrically remote from the PV modules: YES ☐ NO ☐ NOT REQUIRED ☐

A DC disconnector is located adjacent to the inverter if the array is not in line of sight from the inverter: YES ☐ NO ☐
Where multiple DC disconnection devices are installed, they are ganged together or grouped and labelled such that it is clear that all must be operated to isolate the system: YES ☐ NO ☐ NOT REQUIRED ☐
All exposed metal module frames and mounting equipment are earthed and equipotentially bonded in accordance with the relevant standards: YES ☐ NO ☐
Equipment used for PV module and mounting frame earth connections is fit for purpose: YES ☐ NO ☐
Earthing has been arranged so that the removal of a single module earth connection will not disrupt the continuity of the bonding connections for the rest of the array: YES ☐ NO ☐
Earthing conductor type and size comply with the relevant standards: YES ☐ NO ☐
PV array functional earthing is done close to or within the inverter and is done according to the relevant standards: YES ☐ NO ☐ NOT REQUIRED ☐
The inverter complies with the relevant country standards: YES ☐ NO ☐
The inverter installation complies with the manufacturer's instructions, the distribution network service provider's rules and regulations and relevant legislation: YES ☐ NO ☐
Inverters connected to LV PV arrays have an internal or external earth fault alarm system: YES ☐ NO ☐
Inverters connected to arrays with direct functional earthing have an earth fault interrupter, which will shut the PV system down and provide a fault alarm when an earth fault occurs: YES ☐ NO ☐ NOT REQUIRED ☐
Signage and labelling conforms to the relevant standards and guidelines: YES ☐ NO ☐

15. Section 17.2.8 - Test Records

Addition:

Example test records

The following pages contain a sample commissioning checklist as well as a sample testing and commissioning sheet which could be used as part of the system commissioning.

Clean Energy Council Limited (ABN 84 127 102 443) owns the copyright in this material and grants use of this material to GSES for the purpose of inclusion in its training manual (May 2021). Disclaimer: This template checklist has been prepared by the CEC for use by accredited installers. The CEC is not responsible for and does not guarantee or accept any liability whatsoever for the accuracy or completeness of the information contained in the checklist.

GRID-CONNECTED SOLAR PV POWER SYSTEM COMMISSIONING CHECKLIST

VERSION 1.1, NOVEMBER 2020

System address	
Systems owner's name	
System owner's email address	
System owner's phone number	
My Jobs reference number (optional)	
Date of installation	
Please tick and/or insert a value for each relevant field to confirm compliance for this job. Mark any unrequired fields as NA (not applicable).	
Building type	☐ Domestic ☐ Non-domestic
National meter identifier (NMI)	
Meter number	
Number of phases (supply)	
Distribution network service provider (DNSP)	
Energy retailer at the time of commissioning	
Network preapproval reference	
Export limiting requirements	
PV MODULE (SOLAR PANEL) CHECKLIST	
Panel manufacturer	
Panel model	
Panel DC connector manufacturer	
Panel DC connector type/model *e.g. MC-4 or MC-4EVO2*	
STRING 1: Number of panels / orientation (azimuth/tilt) / MPPT # *e.g. 12 / 270º / 30º / MPPT 1*	/ / /
STRING 2: Number of panels / orientation (azimuth/tilt) / MPPT #	/ / /
STRING 3: Number of panels / orientation (azimuth/tilt) / MPPT #	/ / /
STRING 4: Number of panels / orientation (azimuth/tilt) / MPPT #	/ / /
STRING 5: Number of panels / orientation (azimuth/tilt) / MPPT #	/ / /
STRING 6: Number of panels / orientation (azimuth/tilt) / MPPT #	/ / /
String fuse current and voltage rating if installed *e.g. 15A / 1000V*	/
PV array short circuit current – calculated as the sum of all the array currents at STC	A
PV array maximum voltage – calculated for lowest operating temperature	V
DC LOAD BREAKING DISCONNECTOR (DC ISOLATOR) CHECKLIST	
DC isolators	
DC isolator manufacturer/s	
DC isolator model/s	
Number of DC isolators	
All DC isolators are correctly rated and configured for the PV arrays they isolate	☐

Inverter integrated DC isolators	
The inverter has an integrated DC isolator	☐
The inverter integrated DC isolator meets all the requirements in the Australian standards	☐
A manufacture's specification (spec) sheet and declaration has been provided and included with system documentation	☐ Spec sheet ☐ Declaration
Does the local state or territory regulator require a physically separate adjacent DC isolator to be installed at the inverter (PCE)?	
Installation and testing of DC isolators	
DC isolators enclosures IP maintained *e.g. orientation approved, pips installed if supplied*	☐
DC isolators installed to all relevant standards, guidelines, and manufacturer's instructions.	☐
All DC isolators have been tested (turned off) under load	☐
CONDUIT AND CABLING CHECKLIST	
Conduit compliantly installed and adequately supported *e.g. glued, secured and labelled*	☐
Roof penetrations for cabling system adequately sealed *e.g. appropriate collard flashing for roof material*	☐
Cable is mechanically protected and supported as per AS/NZS 3000 and AS/NZS 5033	☐
DC cable volt drop (Vd) is less than 3%	☐ Voltage drop %
INVERTER (PCE) CHECKLIST	
Inverter manufacturer	
Inverter model	
Number of inverters	
Number of maximum power point trackers (MPPT)	
Maximum inverter DC input power	W
Maximum inverter DC input current per MPPT	A
Maximum inverter DC input short circuit current per MPPT	A
The inverter is installed to all relevant standards, guidelines, and manufacturer's instructions	☐
The AC isolator (if required) is mounted adjacent to the inverter and is correctly rated and lockable	☐
The AC circuit breaker is mounted in the switchboard and is correctly rated and lockable	☐
The AC cable voltage rise from inverter terminals to the point of supply is less than 2%	☐ Voltage rise %
AC voltage at inverter terminals under load and no-load	V / V
MOUNTING STRUCTURE (MOUNTING SYSTEM) CHECKLIST	
Mounting system manufacturer	
Mounting system model	
The mounting system is installed to all relevant standards, guidelines, and manufacturer's instructions	☐

The roof penetrations for the mounting system are adequately sealed *e.g. tiles maintain their original ingress protection*	☐
The mounting system manufacturer's exclusion zones are adhered to and meet the minimum requirement of AS/NZS 1170.2	☐
The array frame is certified to AS/NZS 1170.2	☐
Galvanically dissimilar metals are **not** in contact with each other *e.g. separated by nylon or rubber spacers*	☐
The panels are installed to the panel manufacturer's instructions	☐
The panels are installed within the manufacturer's clamping zones	☐
All bolts and terminations are correctly torqued	☐
Mounting system and panels are correctly earthed	☐
Earth connections are UV and mechanically protected *e.g. gal sprayed*	☐
Earth fault alarm type *e.g. visual, audible, electronic, etc.*	
OTHER	
System is labelled as per requirements in AS/NZS 3000, AS/NZS 5033, AS/NZS 4777.1 and CEC guidelines	☐ AS/NZS 3000 ☐ AS/NZS 5033 ☐ AS/NZS 4777.1 ☐ CEC Guidelines
LV wiring system installed by a licensed electrical worker	☐
LV wiring system tested and certified by a licensed electrical worker	☐
System is compliant as per AS/NZS 5033 *Section 5 - Marking & Documentation, and Appendix A*	☐
Distributed energy resource (DER) documented as per NSP requirements	☐
Inverter settings	
Inverter is installed as per network service provider (NSP) Connection Agreement	☐
Country code settings are set to Australia	☐
Volt Var - setting *e.g. 250V / 40%*	V / %
Volt Var - setting – V2	V / %
Volt Var - setting – V3	V / %
Volt Var - setting – V4	V / %
Volt **Watt** – setting *e.g. 250V / 30%*	V / %
Volt **Watt** – setting – V2	V / %
Volt **Watt** – setting – V3	V / %
Volt **Watt** – setting – V4	V / %
Export limit - setting	W
Inverter shuts down within 2 seconds of isolation	☐
Inverter takes at least 60 seconds to start after re-connection to supply	☐
Inverter then takes 6 minutes to ramp up to 100%	☐

TESTING AND COMMISSIONING SHEET													
	Commissioning Information Details Using the panel nameplate information		Calculated Information Details Refer to AS/NZS 5033:2014 Cl 4.2 a, b, c and Cl 5.4.1	Commissioning Test Details Refer to AS/NZS 5033 Appendix D for correct testing procedures.						Commissioning Information Details Measured at, or obtained from PCE			
	Voc (V)	Isc (A)	PV Array Maximum Voltage PVAMV (V)	Continuity of strings and correct polarity (Y or N)	Earth continuity (Ω)	Insulation resistance (M Ω) +ve to E / -ve to E	Non-Operational condition at time of testing (No load condition)			Operational condition at time of commissioning. (Under Load condition)			
Array							Open circuit voltage - Voc (V)	*Short circuit current – Isc (A)	*Irrad (W/M²)	Operational Voltage (V)	Operational Current (A)	Power (W)	*Irrad (W/M²)
String 1													
String 2													
String 3													
String 4													
String 5													
String 6													
MPPT 1													
MPPT 2													
MPPT 3													

Greyed out cells may not be required depending on specific system design but can assist an installer in confirming correct system operation.

*Note: *non-mandatory*

DECLARATION OF RESPONSIBLE PERSONS	
I hereby sign and verify that this system has been designed, installed and commissioned to all relevant Australian standards, state and territory regulations, and CEC guidelines.	
CEC-accredited designer's name	
CEC accreditation no.	
Date:	Sign:
CEC-accredited installer's name	
CEC accreditation no.	
Date:	Sign:
Licensed electrician's name	
Licensed electrician no.	
Date:	Sign:

SYSTEM OWNER'S DECLARATION	
I confirm that I have received an operating manual and have been instructed on the safe operation of the system.	☐
I confirm that the CEC-accredited installer named above: a. Is the installer that physically undertook the installation, or; b. Supervised the installation by physically attending the site at three stages of the installation, at job set-up (beginning), mid-installation check-up (during), and testing and commissioning (end).	a. ☐ or b. ☐
System owner's name:	
Date:	Sign::

Appendix 5: Quiz Answers

16. Chapter 12: Question 3 - (c) ii

Amendment:

$$\gamma_{VMP}\left(\frac{V}{°C}\right) = \frac{\gamma_{PMP}\left(\frac{\%}{°C}\right)}{100} \times V_{MP}$$
$$= \frac{-0.46}{100} \times 39.8\ \text{V}$$
$$= -0.183\left(\frac{V}{°C}\right)$$

17. Chapter 12: Question 3 - (c) iii

Amendment:

$$V_{MP\ at\ 70°C} = [V_{MP\ at\ STC} + (\gamma_{VMP} \times (T_{X°C} - T_{STC}))]$$
$$= [39.8\ V + (-0.183\ \text{V/°C} \times 45\text{°C})]$$
$$= 31.57\ \text{V}$$

18. Chapter 12: Question 3 - (d) iii

Replacement:

$$V_{OC\ at\ 0°C} = V_{OC\ at\ STC} + (\gamma_{VOC} \times \text{cell temperature difference})$$
$$= 49.2\ V + (-0.177\ \text{V/°C} \times -25\text{°C})$$
$$= 53.63\ \text{V}$$

19. Chapter 12: Question 3 - (d) iv

Removal:

$$V_{MP\ at\ 0°C} = V_{MP\ at\ STC} - (\gamma_{VOC} \times \text{cell temperature difference})$$
$$= 39.8\ V - (0.177\ \text{V/°C} \times -25\text{°C})$$
$$= 44.23\ \text{V}$$

20. Chapter 12: Question 3 - (d) v

Removal:

$$\textit{Maximum number of modules } (V_{MP}) = \frac{\textit{maximum MPPT voltage} \times \textit{safety margin}}{V_{MP\ at\ 0°C}}$$
$$= \frac{500 \times 0.95}{44.23}$$
$$= 10.74\ \text{modules}$$

21. Chapter 14: Question 3

Replacement:

a. String cable:

Using the Simple Resistivity Method:

$$
\begin{aligned}
A_{CABLE} &= \frac{(L_{+CABLE} + L_{-CABLE}) \times I \times \rho}{Loss \times V_{MAX}} \\
&= \frac{(8\text{ m} + 14\text{ m}) \times 10.49\text{ A} \times 0.0219\ \Omega/\text{m}/\text{mm}^2}{0.015 \times (9 \times 34.1)\text{ V}} \\
&= 1.098\text{ mm}^2
\end{aligned}
$$

Using Table 14.2 and the V_C AS/NZS 3008.1.1:2017 Method:

$$
\begin{aligned}
Maximum\ V_C &= \frac{1{,}000 \times Loss \times V_{MAX}}{L \times I} \\
&= \frac{1{,}000 \times 0.015 \times (9 \times 34.1)\text{ V}}{14\text{ m} \times 10.49\text{ A}} \\
&= 31.35\text{ mV/Am } (DC)
\end{aligned}
$$

Converting to three-phase:

$$
\frac{31.35\text{ mV/Am}}{1.155} = 27.14\text{ mV/Am } (\textit{three-phase AC})
$$

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 mm² cable.

b. Array cable:

Using the Simple Resistivity Method:

$$
\begin{aligned}
A_{CABLE} &= \frac{2 \times L \times I \times \rho}{Loss \times V_{MAX}} \\
&= \frac{2 \times 22\text{ m} \times (4 \times 10.49)\text{ A} \times 0.0219\ \Omega/\text{m}/\text{mm}^2}{0.015 \times (9 \times 34.1)\text{ V}} \\
&= 8.78\text{ mm}^2
\end{aligned}
$$

Using Table 14.2 and the V_C AS/NZS 3008.1.1:2017 Method:

$$
\begin{aligned}
Maximum\ V_C &= \frac{1{,}000 \times Loss \times V_{MAX}}{L \times I} \\
&= \frac{1{,}000 \times 0.015 \times (9 \times 34.1)\text{ V}}{22\text{ m} \times (4 \times 10.49\text{ A})} \\
&= 4.99\text{ mV/Am } (DC)
\end{aligned}
$$

Converting to three-phase:

$$
\frac{4.99\text{ mV/Am}}{1.155} = 4.32\text{ mV/Am } (\textit{three-phase AC})
$$

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 10 mm² cable.

22. Chapter 14: Question 4

Replacement:

a. Array cable:

Using the Simple Resistivity Method:

$$V_d = \frac{2 \times L \times I \times \rho}{A_{CABLE}}$$
$$= \frac{2 \times 11 \text{ m} \times (5 \times 10.05) \text{ A} \times 0.0219 \ \Omega/\text{m}/\text{mm}^2}{4 \text{ mm}^2}$$
$$= 6.05 \text{ mm}^2$$
$$Loss = \frac{V_d}{V_{MAX}}$$
$$= \frac{6.05 \text{ V}}{(10 \times 33.24) \text{ V}}$$
$$= 0.018$$
$$= 1.8 \ \%$$

Using the V_C AS/NZS 3008.1.1:2017 Method:

$$V_d = \frac{L \times I \times V_C}{1{,}000}$$
$$= \frac{11 \text{ m} \times (5 \times 10.05) \text{ A} \times (10.9 \times 1.155) \text{ mV/Am}}{1{,}000}$$
$$= 6.96 \text{ V}$$
$$Loss = \frac{V_d}{V_{MAX}}$$
$$= \frac{6.96 \text{ V}}{(10 \times 33.24) \text{ V}}$$
$$= 0.022$$
$$= 2.2 \ \%$$

b. String cable:

Using the Simple Resistivity Method result:

$$V_{DROP\ ALLOWABLE\ STRING\ CABLE} = V_{DROP\ MAX} - V_{DROP\ ARRAY\ CABLE}$$
$$= 3.0 \ \% - 1.8 \ \%$$
$$= 1.2 \ \%$$

Using the V_C AS/NZS 3008.1.1:2017 Method result:

$$V_{DROP\ ALLOWABLE\ STRING\ CABLE} = V_{DROP\ MAX} - V_{DROP\ ARRAY\ CABLE}$$
$$= 3.0 \ \% - 2.2 \ \%$$
$$= 0.8 \ \%$$

c. String cable CSA:

Using the Simple Resistivity Method result:

$$A_{CABLE} = \frac{2 \times L \times I \times \rho}{Loss \times V_{MAX}}$$
$$= \frac{2 \times 20 \text{ m} \times 10.05 \text{ A} \times 0.0219 \ \Omega/\text{m}/\text{mm}^2}{0.012 \times (10 \times 33.24) \text{ V}}$$
$$= 2.21 \text{ mm}^2$$

Using Table 14.2 and the V_C AS/NZS 3008.1.1:2017 Method:

$$Maximum\ V_C = \frac{1{,}000 \times Loss \times V_{MAX}}{L \times I}$$
$$= \frac{1{,}000 \times 0.008 \times (10 \times 33.24) \text{ V}}{20 \text{ m} \times 10.05 \text{ A}}$$
$$= 13.23 \text{ mV/Am } (DC)$$

Converting to three-phase:

$$\frac{13.23 \text{ mV/Am}}{1.155} = 11.45 \text{ mV/Am } (three\text{-}phase\ AC)$$

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

23. Chapter 14: Question 5

Replacement:

AC cable:

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

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

$$= \frac{2 \times 26\ \text{m} \times 12\ \text{A} \times 0.0209\ \Omega/\text{m/mm}^2 \rangle}{0.01 \times 230\ \text{V}}$$

$$= 5.67\ \text{mm}^2$$

Using Table 14.2 and the V_C AS/NZS 3008.1.1:2017 Method:

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

$$= \frac{1{,}000 \times 0.01 \times 230\ \text{V}}{26\ \text{m} \times 12\ \text{A}}$$

$$= 7.37\ \text{mV/Am}\ (DC)$$

Converting to three-phase:

$$\frac{7.37\ \text{mV/Am}}{1.155} = 6.38\ \text{mV/Am}\ (three\text{-}phase\ AC)$$

Assuming the selected cable may operate up to its rated insulation temperature of 75°C, the minimum conductor CSA that meets the calculated V_C requirement is a 10 mm² cable.

24. Chapter 15: Question 4 - (b)

Amendment:

$$Energy\ yield = Array\ rated\ power \times Irradiation \times System\ efficiency$$

$$Array\ rated\ power = \frac{Energy\ yield}{Irradiation \times System\ efficiency}$$

$$Array\ rated\ power = \frac{13{,}000\ kWh}{1{,}352.33\ \text{kWh/m}^2\text{/year} \times 0.789} = 12.18\ \text{kW}$$

$$Number\ of\ modules = \frac{12.18\ \text{kW}}{0.24\ \text{kW}} = 50.75 = 51\ \text{modules}$$