SMA Inverter Australian NER Compliance Report

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2	Added 1.4 Applicability to Grid-following vs and grid-forming Inverters	8
	Changed 2.5 to include information about grid-forming FRT behaviour	13
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	Updated References to latest versions, language improvements	all

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Abbreviations and Definitions

Term	Definition
AAS	Automatic Access Standard (consult NER for definition)
AC	Alternating Current
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AS	Australian Standard
DC	Direct Current
EMT	Refers to Electromagnetic Transient simulation models
FRT	Fault ride through
Generator	A person who engages in the activity of owning, controlling or operating a generating system that is connected to, or who otherwise supplies electricity to, a transmission system or distribution system and who is registered by AEMO as a Generator under NER Chapter 2. For the purposes of NER Chapter 5, the term includes a person who is required or intends to register in that capacity or is a non-registered embedded generator who has made an election under clause 5A.A.2(c). A generator means a plant, it is not a combustion rotor, wind turbine or inverter.
HV	High Voltage
HVRT	High Voltage Ride Through
HyCon	SMA Hybrid Controller
Hz	Hertz
LV	Low voltage
LVRT	Low Voltage Ride Through
MPP	Maximum Power Point Voltage. Refers to the voltage at which the PV array generates its maximum power output.
ms	millisecond
MV	Medium Voltage
MVPS	Medium Voltage Power Station (refers to SMA Medium Voltage Power Station product series)
MW	Megawatt
NEM	National Energy Market
NER	National Electricity Rules
NZS	New Zealand Standard
p.u.	per unit
PFR	Primary Frequency Response
PID	Proportional, Integral, Differential controller algorithm
POC	Point of Connection
PPC	SMA Power Plant Controller (model: PPC-10)
PPM	SMA Power Plant Manager (model: PPM-10)
PQ curve	Active Power (P) and Reactive Power (Q) capability curve

Term	Definition
PSCAD	Refers to PSCAD software for transient power system simulation
PSS®E	Refers to PSS®E software for power system simulation
PV	Photovoltaic. Referring generally to photovoltaic modules that convert light to electricity.
RMS	Root-mean-square
ROCOF	Rate of Change of Frequency
s	second
SC	Sunny Central (refers to SMA Sunny Central product series)
SCADA	Supervisory, Control And Data Acquisition
SCR	Short Circuit Ratio
SCS	Sunny Central Storage (refers to SMA Sunny Central Storage product series)
SMA Controller(s)	Refers to the SMA power plant controllers collectively (i.e. PPC, PPM, HyCon, EDML)
TCP	Transmission Control Protocol
trOVP	Transient Overvoltage Protection

References

SMA References

Document Reference	Document Name	Applicable Inverter Model	File Name
A1.	Operating Manual	SC 2660/2800/2930/3060 UP SC 4000/4200/4400/4600 UP	SC-UP-BE-en-14.pdf
A2.		SC 2200/2475 SC 2500/2750/3000-EV	SC2200-3000-EV-BE-en-26.pdf
A3.		SCS 2300/2400/2530/2630 UP-XT SCS 3450/3600/3800/3950 UP-XT	SCS-UP-BE-en-14.pdf
A4.		SCS 1900/2200/2475/2900	SCS1900-2900-BE-en-19.pdf
A5.	Technical Information	SC 2660/2800/2930/3060 UP	220920_Technical Information SC UP(-US) 2stack_V1.3.1.pdf
A6.		SC 4000/4200/4400/4600 UP	231109_Technical Information SC UP_V3.5.pdf
A7.		SC 2200	Technical Information SC2200_V3.2.pdf
A8.		SC 2475	Technical Information SC2475_V1.0.pdf
A9.		SC 2500-EV	Technical Information_SC2500-EV_V3.2_en.pdf
A10.		SC 2750-EV	Technical Information_ SC2750-EV_V2.4_en_ext.pdf
A11.		SC 3000-EV	Technical Information SC3000-EV_en_ext_V6.1.pdf
A12.		SCS 2300/2400/2530/2630 UP-XT SCS 3450/3600/3800/3950 UP-XT	Technical Information SCS UP(-XT)(-US)_V2.24.pdf
A13.		SCS 2200	161108_Technical Information SCS 2200 (MOW and US)_V3.0.pdf
A14.		SCS 2475	Technical Information SCS 2475_V2.2.pdf
A15.		SCS 2900	Technical Information SCS2900_V1.1.pdf
A16.	Short Circuit Behaviour	SC 2660/2800/2930/3060 UP	210203_Short-circuit current impedance SC2660_2800_2930_3060UP_EN_v1.pdf
A17.		SC 4000/4200/4400/4600 UP	210203_Short-circuit current impedance SC4000_4200_4400_4600UP_EN_v2.pdf
A18.		SC 2200/2475	Short-circuit current impedance SC2200_2475_EN.pdf
A19.		SC 2500/2750/3000-EV	Short-circuit current impedance SC2500_2750_3000-EV_V5.0_EN.pdf

Document Reference	Document Name	Applicable Inverter Model	File Name
A20.		SCS 2300/2400/2530/2630 UP-XT	210203_Short-circuit current & impedance SCS2300_2400_2530_2630UP-XT_EN_v1.pdf
A21.		SCS 3450/3600/3800/3950 UP-XT	210203_Short-circuit current & impedance SCS3450_3600_3800_3950UP-XT_EN_v2.pdf
A22.		SCS 1900/2200/2475/2900	180914_Short-circuit current & Impedance SCS1900_2200_2475_2900_EN.pdf
A23.	Grid Forming Manual	SCS UP, SCS UP-XT	SMA SCS R10 Grid Forming Manual.pdf

External References

Document Reference	Document Name	Reference Location
B1.	National Electricity Rules—Version 196	https://energy-rules.aemc.gov.au/ner/452
B2.	Clarification of Generator Technical Performance Requirements (S5.2.5.5)	https://www.aemo.com.au/-/media/Files/Electricity/NEM/Network_Connections/Transmission-and-Distribution/Clarification-of-S525-Technical-requirements.pdf
B3.	Interim Primary Frequency Response Requirements	https://aemo.com.au/-/media/files/initiatives/primary-frequency-response/2020/interim-pfrr.pdf?la=en

1 Introduction

1.1 Purpose

This document collates general information and declarations that support the compliance of SMA products to the Australian National Electricity Rules (NER). The supporting information provided has been organised in accordance with the relevant technical requirements from Schedule S5.2.5.1 to S5.2.5.16 of the NER.

1.2 Scope of Rules Covered

This document references clauses from the NER, Ref B1.

Although the declarations are organised by NER clause number, these declarations may not demonstrate complete compliance to all parts of the clause. NER requirements are usually assessed at the POC; achieving compliance may be beyond the scope of SMA's equipment.

1.3 Applicability of NER Chapter 5

The technical requirements in Chapter 5 of the NER apply to any system classified as a Generator that is registered in the NEM. This includes large-scale solar and storage plants utilising the SMA MVPS and SC/SCS products.

At the time of writing, exemption from registration as a Generator and the technical requirements in Chapter 5 of the NER is only possible for systems with an active power output less than 5 MW. For more information, please see clause 2.2.1(c) of the NER (Ref B1) and publications from AEMO relating to generator exemptions.

1.4 Applicability to Grid-Following and Grid-Forming Inverters

SCS inverters can operate in one of two fundamentally different control modes:

- Grid-following: inverter operates as a current source. Requires a grid voltage established by other generators.
- Grid-forming: inverter operates as a voltage source and directly controls its voltage amplitude and phase angle. Operates in parallel with other generators or as a standalone generator.

Although the dynamic response and capabilities of these inverter types is different, the contents of this document are generally applicable to both grid-connected grid-forming and grid-following inverters unless otherwise stated.

2 National Electric Rules Chapter 5

2.1 S5.2.5.1 Reactive Power Capability

SMA can only provide general information on achieving the AAS in S5.2.5.1 since it depends on the overall plant design. The AAS of S5.2.5.1 requires that the plant can provide reactive power, Q, in the range:

$$-0.395\,P_{max} \leq Q \leq 0.395\,P_{max}$$

where P_{max} is the maximum active power output of the plant. AAS also requires that the full range in reactive power is available at any level of active power output. This is equivalent to being capable of achieving P_{max} at a power factor of 0.93.

To achieve AAS, the PQ capability curve of the inverter needs to be considered. In the example PQ curve shown in Figure 2-1, note that the inverter cannot provide reactive power whilst at its maximum active power output due to the limitation in the inverter's apparent power rating. Therefore, the total apparent power rating of the plant needs to be increased by a factor of $\frac{1}{0.93}$ times higher than the required active power rating to allow AAS. Section 2.4 of this document outlines additional criteria that requires further increases in the plant's apparent power rating.

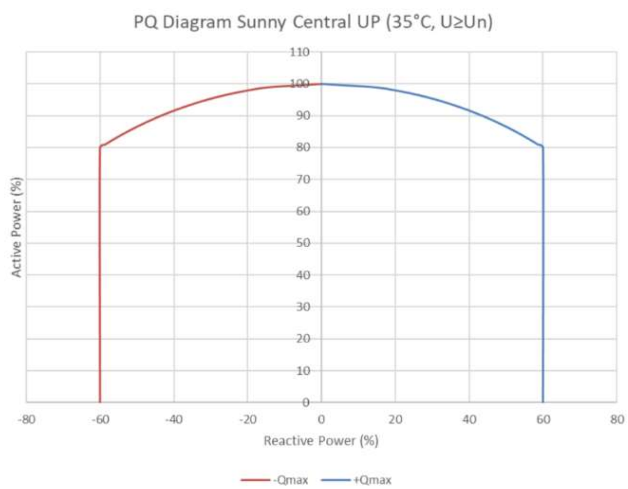

Figure 2-1: Example PQ curve for Sunny Central UP inverter

2.2 S5.2.5.2 Quality of Electricity Generated

The requirements in S5.2.5.2 AAS are applied at the POC, and compliance must consider the overall plant design including 3rd party equipment. Therefore, SMA inverters on their own do not ensure compliance with S5.2.5.2 AAS.

Refer to the harmonics data provided in **A5–A15** for assessing the quality of electricity generated. The following documents are also available upon request from SMA Application Engineering:

- Norton and Thevenin impedance models for the SMA MVPS
- Flicker Coefficients

2.3 S5.2.5.3 Generating System Response to Frequency Disturbances

The SMA inverters listed in Table 2-2 have tripping functions as detailed below in Table 2-1. Under- and over-frequency ride through capability curves for SMA inverters can be found in **A5–A15**.

Table 2-1: S5.2.5.3 Tripping Functions

Scenario	Tripping function in SMA inverters
Tripping on voltage / current / phase angle asymmetries	There is no tripping on asymmetrical phase currents/voltages/angles.
Tripping on high harmonics or high voltage fluctuation/flicker levels	No tripping apart from standard voltage trip limits.
Tripping on high ROCOF	ROCOF is the trigger in the PID function which is deactivated per default. Inverter withstands ROCOF of up to 4.5 Hz/s.
Tripping on high voltage on a single phase	This is part of the HVRT functionality and can be adjusted as needed. Each single phase is monitored separately.

Table 2-2: SMA Inverters referenced for S5.2.5.3 compliance

Inverter Type	Sunny Central	Sunny Central Storage
2 Stacks 1500 Vdc	SC 2660 UP	SCS 2300 UP-XT
	SC 2800 UP	SCS 2400 UP-XT
	SC 2930 UP	SCS 2530 UP-XT
	SC 3060 UP	SCS 2630 UP-XT
3 Stacks 1500 Vdc	SC 4000 UP	SCS 3450 UP(-XT)
	SC 4200 UP	SCS 3600 UP(-XT)
	SC 4400 UP	SCS 3800 UP(-XT)
	SC 4600 UP	SCS 3950 UP(-XT)
Legacy 1000 Vdc	-	SCS 1900
	SC 2200	SCS 2200
	SC 2475	SCS 2475
	-	SCS 2900
Legacy 1500 Vdc	SC 2500-EV	-
	SC 2750-EV	-
	SC 3000-EV	-

2.4 S5.2.5.4 Generating System Response to Voltage Disturbances

The SMA inverters listed in Table 2-3 have the capability to ride through short-term overvoltage events of up to 1.4 p.u. for 20 ms without damage to inverter components. Inverters supplied with the trOVP option have an increased capability to ride-through short-term overvoltage events of up to 2 p.u. for 1.66 ms and 1.7 p.u. for 3 ms without damage to inverter components. The trOVP feature is only available as an option for inverters from the "*A4 release*" or later.

For the Sunny Central-EV series inverters and the SC/SCS inverters with maximum 1000/1100 Vdc input, please see **A7–A11** and **A13–A15** respectively for the withstand duration at 1.4 p.u. voltage.

For compliance to NER S5.2.5.4(a)(2) to (8), see **A7–A15**. These *Technical Information* documents show the LVRT and HVRT capability of the inverter over a longer time period.

Inverter models within a particular inverter series have different HVRT capabilities, which may impact the overall plant's ability to achieve the AAS for S5.2.5.4. In addition, the voltage levels declared by SMA are at the inverter's AC terminals, which is different to the voltage at the POC where this clause is assessed. For the SC/SCS UP series of inverters, SMA Australia recommends the SC 4200 UP as the maximum inverter size for solar and the SCS 3600 UP(-XT) for storage to ensure compliance with AAS S5.2.5.4.

For compliance to NER S5.2.5.4(a)(6), the plant must be capable of "continuous uninterrupted operation" for "90% to 110% of normal voltage continuously". In accordance with guidance from AEMO in **B2**, the plant must be capable of operating at the maximum active power rating (P_{max}) and simultaneously the maximum reactive power (as defined in S5.2.5.1) for any connection point voltage between 90% and 110%. As grid connected inverters are current-limited devices, the inverter cannot increase its current output above its rated value in order to maintain the rated apparent power output when the AC output voltage drops below 1.0 p.u. Therefore, additional inverters are required to achieve the plant's full active and reactive power rating down to a connection voltage of 90%.

The previously mentioned power capabilities are also required up to the maximum temperature specified in the site's performance standard, which is generally 50°C.

For an approximate estimation of the quantity of inverters required to meet S5.2.5.1 and S5.2.5.4(a)(6), the following equation can be used:

$$Quantity\ of\ inverters \cong \frac{P_{POC}}{\cos\varphi_{rated} \times \left(1 - P_{AC\ loss,P.U.}\right) \times S_{rated,50\,°\mathrm{C}} \times \left(1 - \Delta V_{drop,P.U.}\right)}$$

where

- P_{POC} is the required active power output of the plant at the POC in MW
- $\cos\varphi_{rated}$ is the power factor required at the POC, which is 0.93 according to S5.2.5.1
- $P_{AC\ loss,P.U.}$ are the losses in p.u. on the AC side between the MVPS and POC

- $S_{rated,50\,°C}$ is the inverter's apparent power rating at an ambient temperature of 50 °C
- $\Delta V_{drop,P.U.}$ is the per unit voltage drop for which the plant must remain in continuous uninterrupted operation. A default value of 0.15 is suggested to account for a voltage dip down to 0.9 p.u. at the connection point and nominal transformer voltage of 1.05 p.u.

The final quantity of inverters required for compliance to S5.2.5.4 requires more detailed engineering design and/or simulation to confirm. The equation above is for estimation purposes only.

Voltage disturbances may also impact the minimum DC voltage of the inverter. A minimum ratio of DC voltage to AC voltage must be maintained for the inverter to operate in grid feed-in. The minimum DC voltage as a function of the reactive power setpoint and AC voltage is provided in A5 - A11. If the minimum DC voltage of the inverter rises above the PV array MPP voltage during a high AC voltage disturbance, a reduction in Active Power may be experienced. During design of the PV array, care should be taken to ensure the PV array MPP voltage does not fall below the expected minimum DC voltage.

Table 2-3: SMA SC and SCS UP series inverters with HVRT capability of 1.4 p.u. for 20 ms

Inverter type	Sunny Central	Sunny Central Storage
2 Stacks 1500 Vdc	SC 2660 UP	SCS 2300 UP-XT
	SC 2800 UP	SCS 2400 UP-XT
	SC 2930 UP	SCS 2530 UP-XT
3 Stacks 1500 Vdc	SC 4000 UP	SCS 3450 UP(-XT)
	SC 4200 UP	SCS 3600 UP(-XT)
	SC 4400 UP	SCS 3800 UP(-XT)

2.5 S5.2.5.5 Generating System Response to Disturbances Following Contingency Events

The SMA inverters listed in Table 2-5 comply with the S5.2.5.5(c) AAS as they can:

- Remain operating in the event of 15 voltage disturbances in any 5-minute period which causes the connection point voltage to drop below normal voltage for a total duration of 1,800 milliseconds, provided that the voltage transients remain within the capability curves, as specified in documents **A5–A15**;
- Ride through an unlimited number of LVRT faults, provided the sum of fault-duration does not exceed the LVRT capability charts, or there is at least 60 seconds of separation where the power system faults exceed the LVRT capability curve; and
- Ride through a "number of consecutive faults" with 0 millisecond delay between faults according to Table 2-4, where once the number of consecutive faults is reached, there is a minimum of 60 seconds delay to allow the buffer module to sufficiently recharge, before the commencement of any additional faults.

Table 2-4: Multiple consecutive fault scenarios supported in this declaration

Fault Duration [ms]	Number of consecutive faults	
	Retained Voltage (0.8–0.4 pu)	Retained Voltage (0.4–0 pu)
80–120	15	15
175	15	10
220	15	8
430	10	4

S5.2.5.5(f) to (i) requires asynchronous generating units to absorb or supply reactive current to support the grid voltage during a fault. Information on the reactive fault current capabilities of SMA inverters, is detailed in **A16–A22** for the relevant inverter model.. Full dynamic grid support with reactive current feed-in during short circuit events is not possible while the inverter is in Q on Demand (Q at night) operation.

Table 2-5: SMA Inverters referenced for S5.2.5.5 compliance

Inverter type	Sunny Central	Sunny Central Storage
2 Stacks 1500 Vdc	SC 2660 UP	SCS 2300 UP-XT
	SC 2800 UP	SCS 2400 UP-XT
	SC 2930 UP	SCS 2530 UP-XT
	SC 3060 UP	SCS 2630 UP-XT
3 Stacks 1500 Vdc	SC 4000 UP	SCS 3450 UP(-XT)
	SC 4200 UP	SCS 3600 UP(-XT)
	SC 4400 UP	SCS 3800 UP(-XT)
	SC 4600 UP	SCS 3950 UP(-XT)
Legacy 1000 Vdc	-	SCS 1900
	SC 2200	SCS 2200
	SC 2475	SCS 2475
	-	SCS 2900
Legacy 1500 Vdc	SC 2500-EV	-
	SC 2750-EV	-
	SC 3000-EV	-

FRT behaviour in grid-following mode

Functional descriptions for grid-following inverters, including key parameters are included in the "Dynamic Grid Support (FRT)" section of **A1–A4** for the relevant inverter

FRT behaviour in grid-forming mode

In grid-forming mode of the SCS inverter the fault behavior is slightly different compared to standard operating mode. The configuration of FRT in grid forming mode is described in document **A23**. The recommended configuration is “k-factor advanced” with a default k-factor of 6. A virtual impedance is applied to allow inherent fault current.

The current capacity is restricted to the inverter’s nominal current rating, unless the optional feature “Current Boost” is applied. With this optional feature, the fault current magnitude can be increased for short-term. The increased fault current magnitude can only be guaranteed for the first fault in case of multiple consecutive faults. The ride through of multiple consecutive faults is not restricted otherwise.

2.6 S5.2.5.6 Quality of Electricity and Continuous Uninterrupted Operation

The SMA inverters listed in Table 2-6 will maintain uninterrupted operation during the following disturbances at the inverter’s AC terminals:

1. Voltage fluctuation according to Table 1 AS/NZS61000-3-7:2001
2. Voltage fluctuation according to Table 1 AS/NZS61000-3-7:2001
3. Harmonic voltage distortion according to Table 1 AS/NZS61000-3-6:2001
4. A negative sequence voltage of up to 1.4% averaged over 30 minutes
5. A negative sequence voltage of up to 2.0% averaged over 10 minutes
6. A negative sequence voltage of up to 4.0% averaged over 1 minute for once in one hour

Table 2-6: SMA SC(S)-UP Inverters referenced for S5.2.5.6 compliance

Inverter type	Sunny Central	Sunny Central Storage
2 Stacks 1500 Vdc	SC 2660 UP	SCS 2300 UP-XT
	SC 2800 UP	SCS 2400 UP-XT
	SC 2930 UP	SCS 2530 UP-XT
	SC 3060 UP	SCS 2630 UP-XT
3 Stacks 1500 Vdc	SC 4000 UP	SCS 3450 UP(-XT)
	SC 4200 UP	SCS 3600 UP(-XT)
	SC 4400 UP	SCS 3800 UP(-XT)
	SC 4600 UP	SCS 3950 UP(-XT)

The SMA inverters listed in Table 2-7 will maintain uninterrupted operation during the following disturbances at the inverter’s AC terminals:

1. Voltage fluctuation according to Table 1 AS/NZS61000-3-7:2001
2. Harmonic voltage distortion according to Table 1 AS/NZS61000-3-6:2001
3. A negative sequence voltage of up to 1.3% averaged over 30 minutes
4. A negative sequence voltage of up to 2.0% averaged over 10 minutes
5. A negative sequence voltage of up to 2.5% averaged over 1 minute

Table 2-7: SMA SC(S) Inverters referenced for S5.2.5.6 compliance

Inverter type	Sunny Central	Sunny Central Storage
Legacy 1000 Vdc	-	SCS 1900
	SC 2200	SCS 2200
	SC 2475	SCS 2475
	-	SCS 2900
Legacy 1500 Vdc	SC 2500-EV	-
	SC 2750-EV	-
	SC 3000-EV	-

2.7 S5.2.5.7 Partial Load Rejection

This schedule of the NER is not directly applicable to SMA equipment. Further information can be provided upon request.

2.8 S5.2.5.8 Protection of Generating Systems from Power System Disturbances

SMA inverters continuously monitor the grid frequency, which enables the inverter to disconnect from the utility grid in the case of over-frequency or under-frequency. Multiple over-frequency and under-frequency tripping thresholds and trip delay times can be configured. Refer to "Automatic Shutdown Functions - Monitoring the Power Frequency" in **A1–A4** for the relevant inverter for more information.

2.9 S5.2.5.9 Protection Systems that Impact on Power System Security

This schedule of the NER is not directly applicable to SMA equipment. Further information can be provided upon request.

2.10 S5.2.5.10 Protection to Trip Plant for Unstable Operation

The SMA inverters listed in Table 2-8 can meet the requirements of S5.2.5.10 using the functionalities listed in 2.10.1 through 2.10.5. Compliance with S5.2.10 does not specifically require an SMA controller.

2.10.1 Imbalanced Operation

Inverters operate with a negative sequence system regulation to avoid unsymmetrical currents. A detailed description is provided in 3.1.

2.10.2 Protection functions based on Passive Detection Methods

SMA inverters and controllers utilise passive detection methods for voltage and frequency, such as ROCOF, over-/under-voltage, and over-/under-frequency. If measurements of these quantities exceed the preconfigured limits, the inverters will disconnect from the grid. This detection method operates based on measurements at the POC or at the AC terminals of the inverter.

2.10.3 Failure of inverter control systems

If the inverter's internal control systems fail, the output from that inverter will cease. Operation is ceased to protect the inverter hardware and the electrical installation the inverter is connected to from damage which may result from uncontrolled operation.

2.10.4 Communication Failure

For plants which utilise an SMA Controller, inverters are continually communicating with the SMA Controller whether receiving direct commands or not. This continual communication is used to ensure that the plant can always operate as required, so that where either the SMA Controller or inverter fails to communicate with the required regularity, the inverters power output will go to a preconfigured fallback value.

2.10.5 Other functions

The *Troubleshooting* section in **A1–A4**, contains a list of error codes that indicate the protection functions available in the inverter. These demonstrate some of the events that will trigger the inverter to disconnect from the grid based on environmental sensors, grid measurements and the status of internal circuits. Any failures will cause the inverter to disconnect to protect both itself and the grid.

Table 2-8: SMA Inverters referenced for S5.2.5.10 compliance

Inverter type	Sunny Central	Sunny Central Storage
2 Stacks 1500 Vdc	SC 2660 UP	SCS 2300 UP-XT
	SC 2800 UP	SCS 2400 UP-XT
	SC 2930 UP	SCS 2530 UP-XT
	SC 3060 UP	SCS 2630 UP-XT
3 Stacks 1500 Vdc	SC 4000 UP	SCS 3450 UP(-XT)
	SC 4200 UP	SCS 3600 UP(-XT)
	SC 4400 UP	SCS 3800 UP(-XT)
	SC 4600 UP	SCS 3950 UP(-XT)
Legacy 1000 Vdc	-	SCS 1900
	SC 2200	SCS 2200
	SC 2475	SCS 2475
	-	SCS 2900

Inverter type	Sunny Central	Sunny Central Storage
Legacy 1500 Vdc	SC 2500-EV	-
	SC 2750-EV	-
	SC 3000-EV	-

2.11 S5.2.5.11 Frequency Control

SMA controllers can provide a P(f) function or “frequency droop”. Further information on the required products and software functions related to frequency control is available upon request.

2.12 S5.2.5.12 Impact on Network Capability

This NER schedule is not directly influenced by SMA equipment. Further information can be provided upon request.

2.13 S5.2.5.13 Voltage and reactive power control

SMA Controllers have been developed to allow compliance with this clause. SMA Controllers feature a voltage control mode which regulates the voltage at the POC by adjusting the reactive power setpoint of the connected inverters. Alternatively “Voltage-droop” or Q(V) functions are commonly used for voltage control. Information on the voltage control mode, Q(V) function, and power factor control modes can be provided for the specific SMA Controller upon request.

2.14 S5.2.5.14 Active Power Control

Active power control of the overall plant and whether it meets the requirements of this clause depends on the plant controller used (e.g. an SMA Controller or 3rd party device) and how active power setpoints are defined in the SCADA or overall control system.

SMA equipment can facilitate the required active power control through existing interfaces at either the inverter or plant controller level. Sections 2.14.1–2.14.2 provide an overview of key control interfaces for design consideration.

2.14.1 SMA Sunny Central Modbus Interface

A Modbus TCP interface provides monitoring and control of inverter operating parameters including active and reactive power setpoints. For documentation of the Modbus interface, contact SMA Australia for a watermarked copy of the Sunny Central Modbus interface.

The section named “Principles of Active Power Limitation” in **A1–A4**, provides a description of how the inverter processes active power setpoints from different signal sources, the minimum time delay between Modbus commands, and the “WGra” parameter for control of the linear ramp rate between power setpoints.

2.14.2 SMA Power Plant Manager

The PPM has a Modbus TCP interface for specification of power setpoints, which are applied to the overall PV/storage system, typically at the POC. The PPM also has parameters for adjustment of its control dynamics including the ramp rates. The PPM in conjunction with solar-only plants or plants incorporating AC-coupled storage with Sunny Central Storage can achieve reaction times < 200 ms in an adequately designed communications network to support compliance with S5.2.5.14.

2.15 S5.2.5.15 Short circuit ratio

The SMA inverters listed in Table 2-9 whilst operating in grid-following or grid-forming mode are designed to function properly in weak grids. During lab testing and exemplary EMT simulation results, SMA have successfully demonstrated stable operation of the inverter in grid-following operation at a Short-circuit ratio as low as 1.0 at the inverter LV terminals for PV (Sunny Central) and BESS (Sunny Central Storage).

However, with lower SCR there is an increasing risk of fundamental power system operation limits which must be considered carefully and accordingly a proper project specific parameter tuning is mandatory.

It is not appropriate to use phasor/RMS models (e.g., PSS®E or Power-Factory) to simulate inverter behaviour at low SCR as this model does not reflect instabilities of the inverter, so that it behaves equal also at lower SCR's. In reality the inverter might behave differently. Therefore, only instantaneous value (EMT) models can be used for that purpose. SMA provides an appropriate generic EMT model on request.

Table 2-9: SMA inverter operation at low SCR.

Inverter type	Sunny Central	Sunny Central Storage
2 Stacks 1500 Vdc	SC 2660 UP	SCS 2300 UP-XT
	SC 2800 UP	SCS 2400 UP-XT
	SC 2930 UP	SCS 2530 UP-XT
	SC 3060 UP	SCS 2630 UP-XT
3 Stacks 1500 Vdc	SC 4000 UP	SCS 3450 UP (-XT)
	SC 4200 UP	SCS 3600 UP (-XT)
	SC 4400 UP	SCS 3800 UP (-XT)
	SC 4600 UP	SCS 3950 UP (-XT)
Legacy 1000 Vdc	-	SCS 1900
	SC 2200	SCS 2200
	SC 2475	SCS 2475
	-	SCS 2900
Legacy 1500 Vdc	SC 2500-EV	-
	SC 2750-EV	-

Inverter type	Sunny Central	Sunny Central Storage
	SC 3000-EV	-

Grid-forming SCR

As grid-forming inverters do not rely on an external grid and PLL for reference, any SCR is theoretically possible, particularly in islanded operation where other generating sources are not required. However, grid-forming inverter operation in parallel with the public electricity network still requires a proper project specific parameter tuning to ensure the requirements of NER can be met. In general, plants specified with Sunny Central Storage in grid-forming mode are expected to perform better at low SCR than plants with inverters in grid-following mode only.

SCR Calculation Method at inverter terminals:

The effective impedance seen at the inverter terminals must be calculated. With this value the synchronous short-circuit power at the inverter terminals can be determined. The synchronous short-circuit power divided by the inverter nominal apparent power rating gives the SCR at the inverter terminals.

When calculating the effective impedance, it must be considered that the effective impedance which is seen by *N* parallel inverter units must be multiplied by *N* (see Figure 2). In this simplified example, the effective impedance of the HV transformer and the grid impedance must be multiplied by *N*.

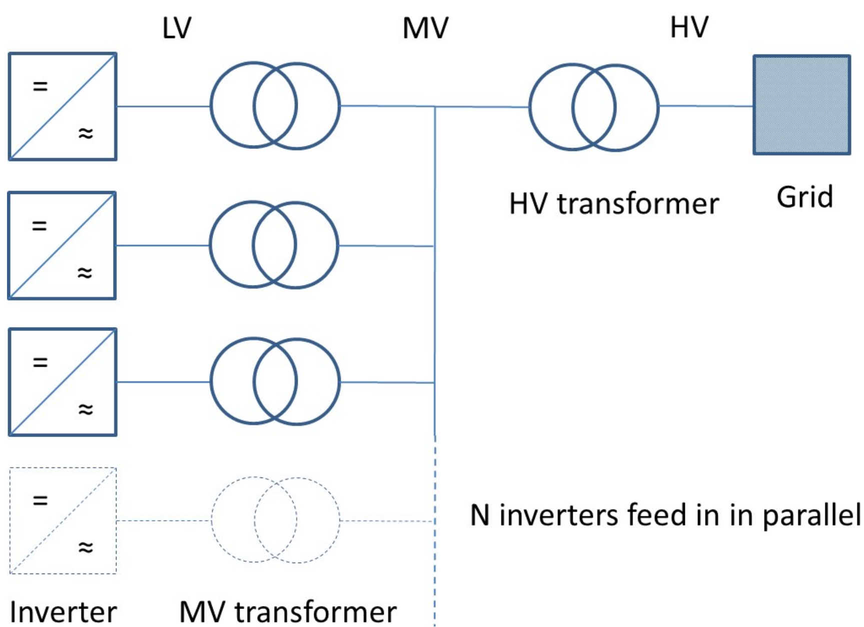

Figure 2: Simplified schematic of "N" inverters in parallel with a common HV transformer

2.16 S5.2.5.16 Voltage phase angle shift

The SMA inverters listed in Table 2-10 do not have a protection or monitoring feature that will act upon a voltage phase angle shift.

Furthermore, the SMA inverters listed in Table 2-10 can maintain connected and operational in the event of a phase angle jump of 30 degrees. This statement does not cover phase angle jumps with simultaneous voltage dips in weak grids. Please contact SMA to discuss multiple parallel events in detail.

Table 2-10: SMA inverter operation with voltage phase angle shift

Inverter type	Sunny Central	Sunny Central Storage
2 Stacks 1500 Vdc	SC 2660 UP	SCS 2300 UP-XT
	SC 2800 UP	SCS 2400 UP-XT
	SC 2930 UP	SCS 2530 UP-XT
	SC 3060 UP	SCS 2630 UP-XT
3 Stacks 1500 Vdc	SC 4000 UP	SCS 3450 UP (-XT)
	SC 4200 UP	SCS 3600 UP (-XT)
	SC 4400 UP	SCS 3800 UP (-XT)
	SC 4600 UP	SCS 3950 UP (-XT)
Legacy 1000 Vdc	-	SCS 1900
	SC 2200	SCS 2200
	SC 2475	SCS 2475
	-	SCS 2900
Legacy 1500 Vdc	SC 2500-EV	-
	SC 2750-EV	-
	SC 3000-EV	-

3 Additional Information for Grid Studies

3.1 Operation During Grid Imbalance

The SMA inverters listed in

Table 3-1 operate with a negative sequence regulation system to avoid asymmetrical currents. In case of asymmetrical grid voltage, the negative sequence system regulation adjusts the currents after approximately 1s back to symmetry in steady-state operation.

The reactive current contribution is calculated by each generating unit using the sequence components of voltage and is determined for each sequence component separately when the positive sequence component falls outside the lower or upper voltage level for commencing the reactive current contribution, according to the following formula:

$$I_{qVRT} = (V_{meas} - db) \times K \times I_{nominal} + I_{q\ prefault}$$

where,

- I_{qVRT} = sequence component of reactive current contribution during disturbance
- V_{meas} = sequence component of voltage measured at the generating unit terminals
- db = lower or upper boundary of voltage at which the reactive current contribution commences
- K = rate at which reactive current is applied (% $I_{nominal}$) and is equal for both positive and negative sequence components
- $I_{nominal}$ = maximum continuous current of each generating unit
- $I_{q\ prefault}$ = sequence component of reactive current before the disturbance

If I_{qVRT} + $I_{total\ prefault}$ > $I_{nominal}$, then I_{qVRT} is prioritized.

In the event of an asymmetrical grid fault, the generating system has facilities capable of keeping voltage increase below 10% of the nominal voltage in the phases unaffected by the fault.

With a symmetrical grid voltage and symmetrical impedances (transformer, cables etc.) the negative sequence current of the generating system does not lead to negative sequence voltages higher than 0.1% at the connection point for the symmetrical disturbances listed in S5.2.5.5 of the NER.

Table 3-1: SMA Inverter Operation During Grid Imbalance

Inverter type	Sunny Central	Sunny Central Storage
2 Stacks 1500 Vdc	SC 2660 UP	SCS 2300 UP-XT
	SC 2800 UP	SCS 2400 UP-XT
	SC 2930 UP	SCS 2530 UP-XT
	SC 3060 UP	SCS 2630 UP-XT

Inverter type	Sunny Central	Sunny Central Storage
3 Stacks 1500 Vdc	SC 4000 UP	SCS 3450 UP (-XT)
	SC 4200 UP	SCS 3600 UP (-XT)
	SC 4400 UP	SCS 3800 UP (-XT)
	SC 4600 UP	SCS 3950 UP (-XT)
Legacy 1000 Vdc	-	SCS 1900
	SC 2200	SCS 2200
	SC 2475	SCS 2475
	-	SCS 2900
Legacy 1500 Vdc	SC 2500-EVV	-
	SC 2750-EV	-
	SC 3000-EV	-

Grid-forming behaviour

Inverters in grid forming operation produce a balanced voltage at the output terminals. In case of voltage unbalance, the inverter will supply an unbalanced current, which acts to improve voltage symmetry (and supply asymmetric loads that cause the imbalance in the first place). By adjusting the negative sequence droop parameter DrpVolNs the negative sequence response can be adjusted. The prioritization of reactive current during the fault is by default not active in grid forming mode. Please see the A23 for parametrization options.

3.2 Mandatory Primary Frequency Response 4.4.2A(a) and 11.112.2

According to clause 11.112.2 and 4.4.2A(a) of the NER, AEMO separately publishes technical requirements for a mandatory PFR. Based on **B2**, all new and existing generators are required to provide an active power change in response to frequency changes, with the following requirements:

1. Plants that already have PFR functionality implemented may be required to change the deadband of the response.
2. The PFR implemented at the POC is defined by the following droop equation, which shall be no more than 5%:

$$Droop\ (\%) = 100 \times \frac{\Delta F/_{50}}{\Delta P/_{P_{max}}}$$

   where ΔF is the frequency deviation beyond the limit of the deadband in Hz, ΔP is active power change in MW, and P_{max} is the maximum operating level in MW.
3. Plant must be able to achieve 5% change in active power output within no more than 10s.
4. There is no requirement to maintain stored energy in their system for the purpose of providing the PFR.

To implement the PFR at the POC, a P(f) function can be configured in the SMA Controller or the customer SCADA system.

It is recommended that AEMO is consulted and simulations are undertaken to determine the parameters of the P(f) function. These P(f) parameters must be provided to SMA no less than 4 weeks prior to scheduled commissioning for new plants, and no less than 4 weeks prior to the date of implementation on-site for existing plants.

P(f) functionality for power decrease/increase is available in PSS®E and PSCAD models with functionality described in the modelling documentation.

Once the settings are established, SMA Service should be contacted via the SMA Online Service Centre https://my.sma-service.com to schedule implementation in the device on site.

Instructions for configuring a PFR or P(f) function in the PPM are currently under development, contact SMA Australia Application Engineering department for further information.