Chapter 5

Assessment requirements by Access Standard

This section outlines the minimum recommended scope of the technical studies you must undertake to assess proposed performance standards and demonstrate compliance.

Note: this is not an exhaustive scope. Transgrid may request additional studies, sensitivities or assessments during the due diligence process.

5.1 Operating scenarios

Your plant assessment must cover a representative range of operating scenarios across the full operating capability of the proposed facility. The sections below describe the minimum sets of operating scenarios for each technology arrangement.

What you need to do

- Provide the SMIB test cases with the relevant operating scenarios setup in both PSS®E and PSCAD.

5.1.1 Active Power Dispatch Scenarios

- Assess active power dispatch scenarios as set out in Table 5-1 to Table 5-4 where:
  - $P_{100\%}$ - maximum active power export at the Connection Point
  - P_{min} - minimum active power export at the Connection Point
  - $P_{-100\%}$ - maximum active power import at the Connection Point

Generating systems

Table 5-1 Generating systems - active power operating scenarios

Scenario	Connection Point active power	
1	$P_{100\%}$	Maximum active power output
2	P_{min}	Minimum active power output

Battery energy storage systems

Table 5-2 BESS - active power operating scenarios

Scenario	Connection Point active power	
1	$P_{100\%}$	Maximum P exporting (discharging) of BESS
2	$P_{0\%}$	P = 0 of BESS, only providing Q support
3	$P_{-100\%}$	Maximum P importing (charging) of BESS

Note: These same scenarios are also for DC-coupled hybrid connections if the DC side resources are **not** independently dispatched.

Hybrid integrated resource systems

- Assess AC coupled hybrid systems against the scenarios in Table 5-3 (full scope of studies) and Table 5-4 (limited set of studies).

Table 5-3 Hybrid active power operating scenarios to be considered for a **full scope of studies**

Scenario	CP Active power	PV/Wind - availability	BESS-availability
Hybrid operation			
1	$P_{100\%}$	Maximum $P_{PV/wind}$ output from PV/wind	P_{BESS} = ($P_{100\%}$-$P_{PV/wind}$) from BESS
2	$P_{0\%}$ (Internal charging)	High $P_{PV/wind}$ (>0.9 p.u.) output of PV/wind. If there are any internal charging limits, use the limit to be the PV/wind generation	High P_{BESS} input (>0.9 p.u.) at machine level (charging) of BESS. If reaching BESS capability, use BESS capability.
BESS only operation			
1	$P_{100\%}$	Disconnected (No P&Q support)	Maximum P exporting (discharging) from BESS
2	$P_{-100\%}$	Disconnected (No P&Q support)	Maximum P importing (charging) from BESS
PV/Wind only (if PV/Wind only is a valid operating scenario)			
1	$P_{100\%}$	Maximum P output from PV/wind	Disconnected (No P&Q Support)
2	P_{min}	Minimum P output from PV/wind	Disconnected (No P&Q Support)

Table 5-4 Hybrid active power operating scenarios to be considered for a **reduced scope of studies**

Scenario	CP Active power	PV/wind - availability	BESS-availability	Recommended minimum scope of NER Assessments
Hybrid operation				
3	$P_{100\%}$	$P_{PV/wind}$ = ($P_{100\%}$-P_{BESS}) from PV/wind, subject to: $P_{PV/wind}$ > minimum active power level of the PV or wind	Maximum P_{BESS} exporting (discharging) from BESS	S5.2.5.4, S5.2.5.5. S5.2.5.11
47	P_{High}	$P_{PV/wind}$ = 0 MW, only provide Q support, Q-at-night	Maximum P_{BESS} exporting (discharging) from BESS	S5.2.5.4, S5.2.5.5, S5.2.5.13

Note: These same scenarios are also for DC-coupled hybrid connections if the DC side resources are independently dispatched.

7 only if Q-at-night operation model is proposed.

5.1.2 SCR and Reactive Power Dispatch Scenarios

- Consider the SCR requirements and reactive power levels in Table 5-5 for each performance standard assessment.

Table 5-5 Summary of SCR and Connection Point reactive power scenarios for each access standard

Clause	Description	SCR (min)	SCR (typical)	Infinite Grid	Q_{MAX} (V_{LOW})	Q_{ZERO} ($V_{NOMINAL}$)	Q_{MIN} (V_{HIGH})
S5.2.5.1	Reactive power capability			Y			
S5.2.5.3	Frequency disturbances	Y			Y		Y
S5.2.5.4	Voltage disturbances			Y	Y	Y	Y
S5.2.5.5 S5.2.5.5A	Fault response	Y	Y		Y	Y	Y
S5.2.5.8	Protection from power system disturbances	Y					
S5.2.5.11	Frequency control	Y			Y		Y
S5.2.5.13	Voltage control	Y	Y		See section 5.15	See section 5.15	See section 5.15
S5.2.5.14	Active power control	Y			Y	Y	Y

5.1.3 Multiple generating system assessment scenarios

Where a Connection Application includes multiple generating systems connected at the same Connection Point or to a common bus, avoid unnecessary duplication by undertaking some GPS compliance studies on a combined-plant basis. Transgrid's Guide on *GPS Assessment Guide for Multi-Generating System Applications* specifies the site-specific model configurations and studies that may be assessed collectively and those that require separate assessment of each generating system.

What you need to do

Take into account that:

- The applicable GPS clause may require assessment with multiple generating systems in service, with each generating system operating individually, or under both scenarios.
- Studies must use the site-specific fault levels and system impedances specified by Transgrid. The fault level at the Connection Point does not change because one or more generating systems are offline.
- Project circumstances may vary. Engage with Transgrid early and provide a clear development plan covering the proposed staging, programme and technical configuration to identify opportunities to minimise duplication and rework.

5.1.4 Q-at-night mode/ operation below cut-in wind speed

- Undertake a reduced assessment scope covering, at a minimum, the assessment requirements specified in Section 5.19.

Note: this applies to PV plants operating in Q-at-night mode and wind farms operating below the cut-in wind speed, including hybrid facilities.

5.2 Reactive power capability – S5.2.5.1

NER Clause S5.2.5.1 requires the plant to have sufficient reactive power capability to support voltage control at its Connection Point. This is necessary to maintain voltage within acceptable limits under the range of expected operating conditions.

What you need to do

- Demonstrate the plant's ability to both supply and absorb reactive power at the Connection Point in accordance with the agreed performance standard.

5.2.1 Expectations and acceptance criteria

- Assess the plant's reactive power capability across the full active power operating range and for Connection Point voltages within ±10% of nominal voltage.
- Test all valid plant operating modes, including all valid dispatch configurations the unconstrained and constrained scenarios defined in Table 5-6.
- Account for temperature derating. If the plant capability derates as temperature increases:
  - provide separate Connection Point reactive power capability curves for different temperatures up to maximum operating temperature (e.g. maximum non-derated temperature and maximum operating temperature) to establish applicable derating at the CP.
  - document the temperature derating characteristics of the production units in the CSR and the RUGs.
- Demonstrate that your proposed S5.2.5.1 reactive power capability is compliant with the S5.2.5.4 CUO requirements across the operating scenarios and temperatures.

Table 5-6 Unconstrained and constrained S5.2.5.1 capability

Unconstrained capability	Constrained capability
• Derived using steady state studies in PSS®E or PowerFactory • Based on plant raw capability • Plant controller limits are removed • Transformer OLTC operation is allowed	• Derived based on dynamic studies in PSCAD or PSS®E • Plant controller operation included with all applicable limits • Transformer OLTC operation is considered

- Present the plant's reactive power capability as a P–Q capability chart showing the maximum reactive power absorption and injection across the plant's active power range. The P–Q capability chart must:

be provided in switching a ficticious capacitor/reactor

  - format using the template included in *Attachment 4 - Transgrid folder structure*
  - show the plant capability and applicable Automatic Access Standard (AAS) based on the project's maximum capacity
  - follow the format of the relevant example in Figure 5-1 or Figure 5-2, depending on the relevant NER version, including the legend
  - clearly number all corner points using a legible font.

- Include the proposed P–Q capability of the plant for voltage levels within ±10% of the nominal voltage.
- If the capability is different beyond ±5% of the mid-point voltage nominated by Transgrid, provide separate P–Q capability curves as per Figure 5-2 to cover:

  - Connection Point voltage within ±5% of mid-point voltage
  - Connection Point voltage between 90% of nominal voltage and 5% of mid-point voltage
  - Connection Point voltage between 5% of mid-point voltage and 110% of nominal voltage

The mid-point voltage is specified in Transgrid's Network Planning Supplementary Report.

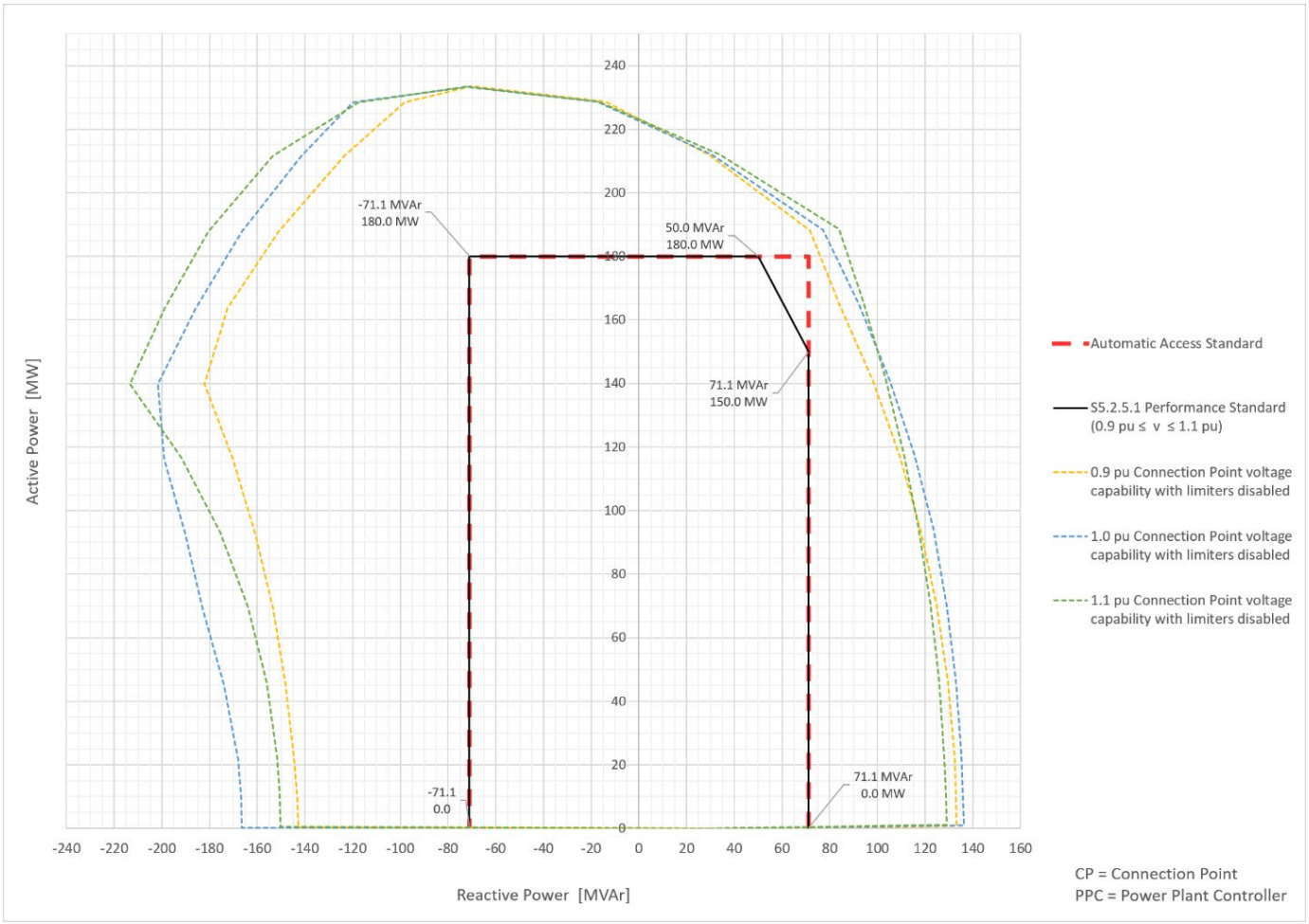


Figure 5-1 Example of a P-Q capability curve format for a 180 MW uni-directional plant with a negotiated performance standard

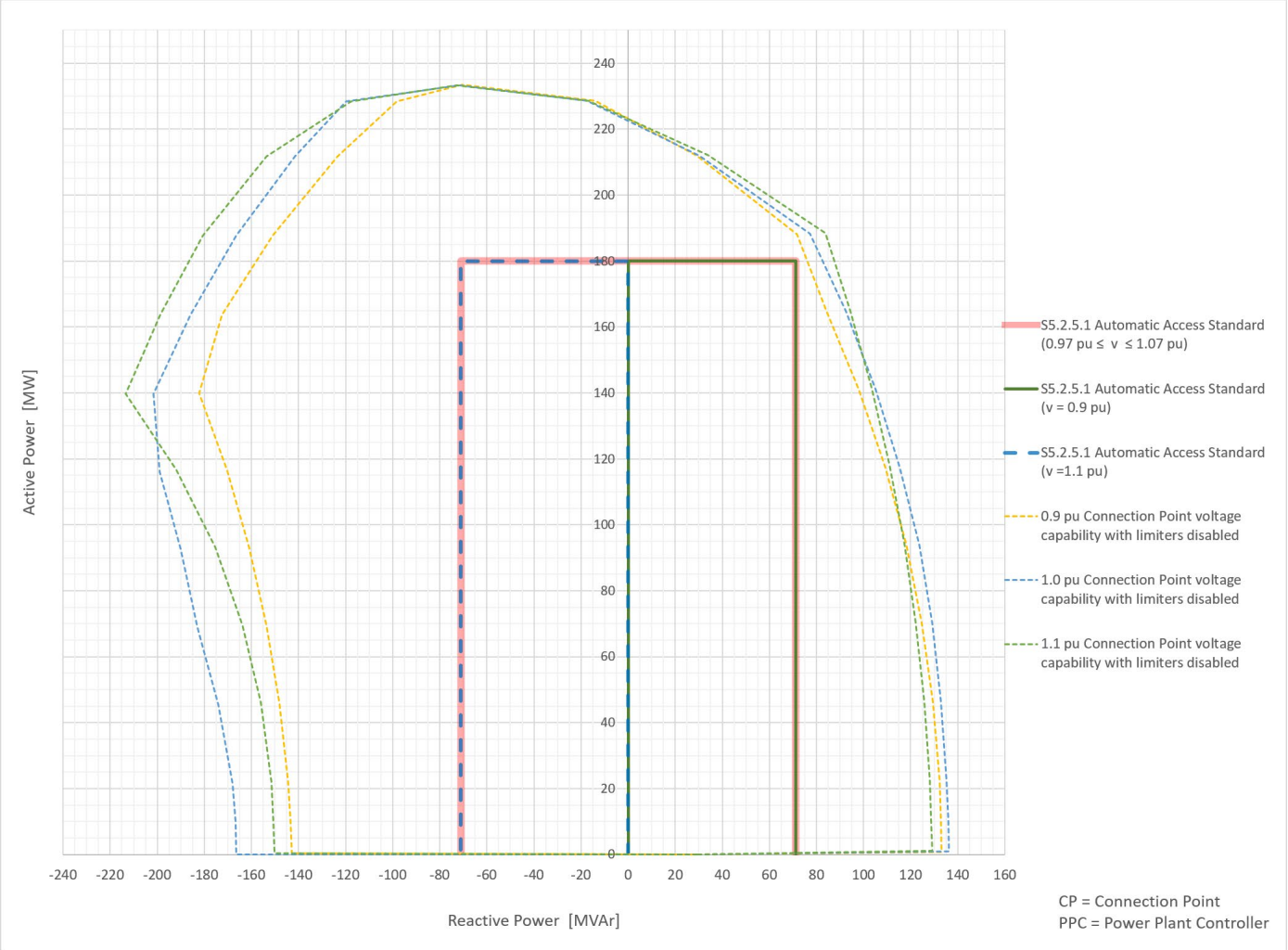


Figure 5-2 Example of a P-Q capability curve format for a 180 MW uni-directional plant with a mid-point voltage of 1.02pu

Note: The example assumes a midpoint voltage of 1.02 p.u. and illustrates the AAS applicable under NER version 234 or later. Include the proposed performance in addition to the curves shown.

The proposed performance standard for S5.2.5.1 in the GPS must include:

- The proposed reactive power capability at the normal operating temperature
- The proposed capability at higher temperatures, including the applicable derating methodology
- The maximum operating temperature and the operational arrangements that apply above this temperature
- Any reactive power compensation required when the plant is not generating.

You do not need to include the unconstrained PQ capability curves in the proposed GPS. However, the VCS and the RUGs require the full capability charts, including unconstrainted capability (see Figure 5-1 or Figure 5-2). See the VCS guide for more details.

5.2.2 Methodology

Unconstrained capability

- Assess the unconstrained reactive power capability of the plant using either PSS®E (aggregated model) or PowerFactory(detailed model without aggregation) steady state load flow analysis.
- When modelling the plant in detail without aggregation, wind plants must use PowerFactory.
- Determine the maximum reactive power capability at the Connection Point for each specified Connection Point voltage. Base the assessment on the maximum capability of the production units, without applying PPC limits. OLTC operation may be considered.
- Check the following equipment limits are met when determining the maximum reactive power capability:
  - MV and HV bus voltages remain within the normal operating range of 0.9 p.u. to 1.1 p.u.
  - Transformers are not thermally overloaded
  - Production unit terminal voltages remain outside the FRT and protection activation ranges
  - Production unit-level current and power limits are observed.
- Document all limits and assumptions used to determine reactive power capability in the CSR.

Constrained capability

- Determine the constrained reactive power capability of the plant using PSS®E or PSCAD dynamic studies with an infinite bus SMIB configuration, based on all plant components and associated limiters in-service.
- Where the main transformer is equipped with an OLTC, represent the OLTC using a dynamic model. To reduce the overall simulation time, use a sufficiently shorter OLTC time constant.
- Perform the dynamic simulations as follows:

Operate the PPC in voltage droop control mode8.

Using the infinite bus voltage source, ramp up the Connection Point voltage to the desired voltage (0.9 p.u.,1.0 p.u, 1.1 p.u., and ±5% of mid-point voltage).

Wait for the PPC to achieve the desired active power level – or set up the load-flow solution with the active power output at the desired level.9

Apply to the PPC a voltage setpoint sufficiently large enough to force the reactive power flow at the Connection Point into the capability limits.

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8 Note that some models apply setpoint limits at the PPC level which could prohibit the true capability of the plant being achieved. In this case, switch the plant to reactive power control mode instead and note it in the report.

9 Some PPCs have relatively slow active power ramp rates, so this can help reduce the simulation time required to achieve the desired active power level.

Once steady state has been reached in the simulation, take RMS measurements of P\Q\V at the Connection Point and production unit terminals.

Repeat Steps 1 to 5 for a range of active power levels (e.g., -100%,10 -50%, 0%, 50% and 100%) to create a P–Q chart.

If a Negotiated Access Standard is proposed, consider all the corner points of the P–Q curve.

10 Or minimum possible power output.

Common issues, considerations and recommendations

Reactive power compensation when not generating active power

When the plant is electrically connected to the network without generating active power, it must limit the resulting voltage change at the Connection Point. Relevant operating conditions include:

- Night-time operation of solar farms
- Operation of wind farms below cut-in wind speed
- Operation of battery storage systems at minimum state of charge
- Operation of the plant when production units are disconnected

Under these conditions, the balance of plant equipment such as collector network, transformers, capacitor banks, harmonic filters, etc., will supply or absorb reactive power and affect the voltage at the Connection Point.

The applicable Access Standards for the allowable change in the voltage at the Connection Point are:

- AAS (NER S5.2.5.1(a2)) – requires the voltage to not change when the plant connects
- MAS (NER S5.2.5.1(b2) – requires the magnitude of the voltage change to be less than 1% when the plant connects.

Note: NER S5.2.5.1 requires that the magnitude of the voltage change at the Connection Point to be calculated using steady state conditions and for the highest system impedance nominated under clause S5.2.5.13(m). The assessment should also consider an initial Connection Point voltage of 1.1 p.u. to account for the maximum reactive power associated with collector cables and harmonic filters.

The requirements under S5.2.5.1 (a2) and (b2) can be met by:

- Using the reactive power capability from the production units. Where this approach is proposed, indicate in the GPS how many production units would be required to provide the necessary reactive power compensation and the plant operation under S5.2.5.13.
- Operational arrangements to disconnect balance of plant equipment such as switching out collector network and/or the harmonic filters when the production units are not connected.
- Installing additional reactive compensation equipment to offset balance of plant reactive power.

As part of your Connection Application, you must propose and describe how the plant will meet this requirement for Transgrid's assessment.

Common issues, considerations and recommendations

Operational capability at higher temperatures

For compliance with NER version 234 or higher, the GPS should clearly specify the active power capability, the maximum temperature for operation and expected plant operation beyond that temperature (for example, linear reduction of power at the production unit terminals to zero above the maximum operating temperature). Where applicable, the GPS must specify the temperature-derating relationship for ambient temperatures below the maximum operating temperature, including whether the capability is derated linearly or in accordance with another defined function, curve or methodology.

Where the plant cannot meet the AAS reactive power capability of 39.5% of maximum active power at higher temperatures, the proposed negotiated reactive power capability should aim to provide at least 39.5% of the linearly derated active power.

5.3 Quality of electricity generated – S5.2.5.2

5.3.1 Expectations and acceptance criteria

NER clause S5.2.5.2 is intended to ensure that the connecting plant does not cause power quality levels to exceed the applicable standards. This includes voltage fluctuations (flicker), harmonic voltage distortion and voltage unbalance.

What you need to do

- Undertake the harmonic assessment in accordance with Transgrid's *Attachment 2 - Harmonic Assessment Requirements* in the Data Response.
- Design the plant to meet the project-specific AAS power quality emission limits specified in the CPTSR.
- Where necessary, incorporate appropriate harmonic filters into the plant design to achieve the allocated AAS harmonic emission limits.
- If you cannot meet the AAS for one or more harmonic orders and propose a Negotiated Access Standard, consult Transgrid with appropriate assessment evidence and justification.
- Repeat the harmonic assessment as part of the R1 capability assessment using the final plant design. This assessment must incorporate the final balance-of-plant configuration, reticulation system, transformer impedances, harmonic filters and any other equipment or design parameters that may materially affect harmonic performance.

5.4 Response to frequency disturbances – S5.2.5.3

5.4.1 Expectations and acceptance criteria

NER clause S5.2.5.3 requires the plant to remain in continuous uninterrupted operation for a range of frequency disturbances. After a disturbance is cleared and the frequency is returned to pre-disturbance level, the plant response must also return to the pre-disturbance level.

What you need to do

- Provide a frequency vs protection time threshold graph comparing the production unit frequency ride-through capability against the applicable NER AAS requirement.

5.4.2 Methodology

- Assess the plant's frequency ride-through capability using a PSS®E dynamic model.
- Conduct tests at the minimum fault level for the combinations of operating scenarios listed in Section 5.1.1
- Provide plant response for the frequency disturbances listed in Table 5-7. The disturbances can be simulated in a sequence or individually. In each case, the frequency must return to 50 Hz after the disturbance. Consider the following rate of change of frequencies (RoCoF) when applying the frequency disturbances:
  - ±4 Hz/s for the first 0.25 s
  - ±3 Hz/s for the remaining duration

Table 5-7 Frequency disturbance ride-through tests

Disturbance	Frequency [Hz]	Duration [s]
1	52	120
2	51	600
3	49	600
4	47	120

Common issues, considerations and recommendations

Unstable frequency response under very low SCR scenarios

Unstable plant responses may in some cases be observed in SMIB studies for extreme frequency disturbances such as 52 Hz and 47 Hz. Where this occurs, investigate available plant tuning options to improve this behaviour. However, where the instability is due to power transfer limitations at low SCR in a SMIB environment, you may provide supporting evidence to confirm this limitation in the CSR (e.g. by including PV or QV curve analysis under site-specific conditions). However, do not compromise other aspects of plant performance to solely address this behaviour.

Where significant instability occurs under less extreme frequency disturbances, try using parameter tuning to improve the plant response. If further tuning is not feasible, discuss alternative solutions with Transgrid and AEMO. Generally, limiting the maximum active power change (dP) for a frequency response is not the preferred approach. If this is the only viable option, provide evidence and seek formal approval from Transgrid and AEMO.

At low fault levels, during large active power changes, the plant may enter FRT mode during a frequency disturbance. This behaviour may be more pronounced in SMIB studies, which do not incorporate voltage support from nearby dynamic plant present in the network. In such cases, consider undertaking further assessment using a wider network representation (for example, using the PSS®E NEM Model) to demonstrate whether the observed behaviour is specific to the SMIB representation.

5.5 Response to voltage disturbances – S5.2.5.4

5.5.1 Expectations and acceptance criteria

NER clause S5.2.5.4 requires the plant to remain in continuous uninterrupted operation during a range of voltage disturbances, without disconnecting or becoming unstable.

What you need to do

- Demonstrate ride-through capability for specified under-voltage and over-voltage events using both the PSS®E and PSCAD dynamic models.
- For longer-duration voltage disturbances, including the 1.15 p.u. over-voltage disturbance, demonstrate:
  - the exact duration using the PSS®E dynamic model
  - at least 20 seconds using the PSCAD dynamic model.
- Demonstrate that, after the disturbance is cleared and the Connection Point voltage returns to the pre-disturbance level, plant response also returns to the pre-disturbance level. The response should demonstrate that no unintended limiters remain active and that the plant does not remain latched in fault ride-through mode.

- Complete a production unit CUO capability assessment in PSCAD to demonstrate that the plant is appropriately sized to maintain both the active and reactive power at the Connection Point for voltage variations of up to ±10% within the normal operating voltage range.
- If production units are derated within the proposed operating temperature range, conduct the production unit CUO capability assessment at both the normal operating temperature and the proposed maximum operating temperature.
- Where the Voltage Control Point of the plant is not at the Connection Point, demonstrate the ride through capability at the Connection Point.

5.5.2 Methodology

- Use the historical voltage range in the Network Planning Supplementary Report for the S5.2.5.4 assessments.

5.5.2.1 Voltage ride-through assessment

- Use a SMIB model with an infinite source to represent the network.
- Assess the voltage and duration of the voltage disturbances in Table 5-8, using the applicable operating scenarios in Section 5.1.
- For hybrid integrated resource systems, the operating scenarios in Table 5-3 must be assessed as a minimum. These represent the more onerous or boundary operating conditions.
  - Include, as a minimum, the tests in Table 5-8, conducted either:
    - Individually for each voltage level for the required duration (preferred approach). In this case, return the Connection Point voltage to the pre-disturbance level after the specified duration or
    - As a continuous voltage profile containing multiple steps for each voltage level for the required duration. In this case, return the Connection Point voltage to the pre-disturbance level after all the steps in the voltage profile is completed.
    - Perform the voltage profile tests with unbalanced voltages (only one or two phases reaches the expected voltage levels given in Table 5-8 while the healthy phase/s remains at pre-disturbance level). Plot individual phase voltages at the Connection Point for these tests.
- For all simulations:
  - Lock the transformer taps11.
  - Create the disturbances using the standard library PLBVFU1 model or AEMO's ZINGEN model in PSS®E.

Table 5-8: Voltage disturbances for S5.2.5.4

11 OLTC operation can be considered for disturbances longer than the OLTC delay time, if required.

Connection Point voltage [p.u.]	Disturbance duration12 [s] (from the start of the disturbance)
>1.3	0.02
1.3	0.2
1.25	2
1.2	20
1.15	1200
1.1	1200
0.9	1200
0.8	10
0.7	2

Your CSR must include:

- An assessment of the plant's ride-through capability
- Plots showing the PPC active and reactive power commands issued to the production units, together with the FRT flags and other relevant control signals.

5.5.2.2 Production unit CUO capability assessment

Use this assessment to confirm that the total installed capacity of the production units is sufficient to deliver the required active and reactive power at the Connection Point while maintaining CUO across the normal operating voltage range.

What you need to do

- Perform the CUO assessments for the following scenarios in primary voltage control mode, initialising the cases to the operating scenarios in Section 5.1:
  - Initial Connection Point voltage set at 1.0 p.u.
    - Apply voltage disturbance to 0.9 p.u. and 1.1 p.u.
    - Maintain each disturbance for 20 seconds.
  - Initial Connection Point voltage set at historical voltage

12 The disturbance duration for each voltage step is measured from the commencement of the disturbance.

- Apply Voltage disturbance of ±0.1 p.u. while ensuring that Connection Point voltage remains within 0.9 p.u. to 1.1 p.u.13
- Maintain each disturbance for 20 seconds.

- Measure the values of P/Q/V at the Connection Point and terminals once the plant has reached steady state operation during the disturbance (for example, at 15 s).

Common issues, considerations and recommendations

Considering the operation of OLTC

For voltage variations of **10% or less** within 90-110% of nominal voltage:

- Maintain CUO without sole reliance on OLTC operation.
- Use a co-ordinated strategy using production units' short-term overload capability, plant switching and OLTC operation to meet the CUO requirement at the Connection Point.
- Provide sufficient OEM documentation to demonstrate the applicable short-term overload capability.

Only rely on the OLTC when assessing the plant's voltage ride-through capability where the disturbance duration exceeds the OLTC operating time delay. Tap-changing actions can take minutes to respond. If plant relies solely on a tap-changing transformer to respond to a voltage disturbance, without any other voltage control measures, it will not meet the CUO requirements because active power and reactive power output will reduce until the tap change is completed.

For voltage disturbances within 90-110% of nominal voltage, where the voltage variation is **greater than 10%**, you can correct active power reduction at the Connection Point by OLTC operation, as long as the disturbance duration exceeds the OLTC operating time delay.

FRT re-triggering

Transgrid expects the fault ride-through (FRT) to activate during a sufficiently high over-voltage or low under-voltage disturbance. However, consider tuning the FRT if it retriggers as the voltage returns to the normal range (0.9 p.u. – 1.1 p.u.) following the disturbance. When voltage returns to the normal operating range, the plant's active power should return to its pre-disturbance value, or to a value consistent with the control requirements under NER clause S5.2.5.13.

Plant at Connection Point voltage of less than 66 kV

If the plant is connecting to a MV network where the Connection Point voltage is less than 66 kV with no automatic tap changing transformer, the location of the S5.2.5.4 compliance assessment can be negotiated to the nearest location at or above 66 kV as agreed with AEMO and Transgrid.

13 For example, from V_{High} to the minimum of 1.1 p.u., and V_{High}+0.1 p.u.

5.6 Disturbance ride-through capability – S5.2.5.5

5.6.1 Expectations and acceptance criteria

NER Clause S5.2.5.5 requires the plant to remain in continuous uninterrupted operation during and following specified power system disturbances. This includes demonstrating the plant's ability to ride through credible contingency events and multiple disturbances without disconnection.

What you need to do

- Undertake a range of SMIB and wide-area NEM studies, using the SMIB scope indicated in Section 5.1, to demonstrate that the connecting plant:
  - remains in CUO during and following the disturbances specified in NER clause S5.2.5.5
  - maintains stable and adequately controlled operation throughout each disturbance and the subsequent recovery period.
- Provide studies that demonstrate effective coordination between the PPC and production unit controls, including that the:
  - PPC and production units enter FRT mode in a coordinated manner for disturbances that exceed the applicable LVRT or HVRT initiation thresholds
  - PPC does not exhibit control windup when the production units are in FRT mode but the PPC is not
  - production unit controls do not exhibit control windup when the PPC is in FRT mode but the production units are not.

Note: The appropriate coordination arrangement will depend on the OEM's control design. However, to prevent control windup, conflicting control responses or poorly controlled plant behaviour, coordinate the FRT thresholds, hysteresis, delays and associated control settings of the PPC and production units. Provide sufficient studies to demonstrate this coordination across the applicable disturbance range.

5.6.2 Methodology

5.6.2.1 Scope of the PSS®E NEM studies – credible contingencies

See Section 4.10 for how to set up the base cases for the PSS®E NEM studies.

- Consider contingencies involving a representative range of network elements near the proposed connection, including:
  - Transmission lines and transformers
  - Shunt reactive plant
  - Large loads
  - Large synchronous generating units, including relevant units in other regions, such as Loy Yang or Kogan Creek.

- For projects located near the NSW border, include relevant contingencies in the adjoining region, such as Victoria or Queensland.
- Assess a range of fault types, including balanced and unbalanced faults and contingencies involving automatic reclosing. Use primary and circuit-breaker-fail protection clearance times in accordance with the NER requirements.

Note: The applicable network elements and protection clearance times are specified in the relevant Regional Network Data Documents. For contingencies in other NEM regions, use the standard NER protection clearance times in Table S5.1a.2 unless otherwise directed by Transgrid or AEMO. Where applicable, incorporate relevant special protection schemes in the Data Response.

5.6.2.2 Multiple fault ride through (MFRT) requirements

- Complete the multiple contingency assessments required by AEMO in the DMAT. Transgrid does not expect additional extensive assessment of multiple contingencies.
- Provide a written report or letter from the OEM to confirm the capability of the plant to ride through multiple contingencies, as required in S5.2.5.5. The OEM must provide evidence such as a PSCAD study or a FAT report to justify its ability to comply. This evidence should include:
  - The minimum SCR at the production unit terminals that the units can remain connected and perform as close as is reasonably practicable to CUO. Transgrid expects that the units will remain in stable operation but does not require strict CUO compliance.
  - Details of any plant limitations that impede the plant's ability to remain in CUO, such as fault counters that trip the plant, temperature thresholds in the chopper circuit, total cumulative current in a certain time interval. These plant limitations must not reduce plant's capability to meet the proposed access standard for MFRT.
  - Confirmation that these plant limitations are captured in the OEM's PSS®E and PSCAD models.
- Include the minimum SCR at the production unit terminals and the OEM-identified plant limitations in your proposed GPS.

Note: the selection of plant settings and tuning must not prohibit the MFRT capability of the plant. This includes coordinating relevant PPC and production unit settings, such as FRT mode exit delays.

5.6.2.3 Scope of the PSCAD SMIB studies – single balanced and unbalanced faults

Assess the plant's response to balanced and unbalanced faults using the PSCAD SMIB model for the operating scenarios specified in Section 5.1.

Table 5-9 Fault response operating scenarios

Parameter	Values
Connection Point Voltage	V_{HIGH} for Q_{MIN}, V_{NOM} for Q_{ZERO} V_{LOW} for Q_{MAX}
Connection Point active power	• Operating scenarios as per Section 5.1
Connection Point reactive power	Q_{MAX}, Q_{ZERO}, Q_{MIN}
Fault level	Minimum and typical

- Apply faults at the Connection Point using the following methodology:
  - adjust the fault impedance to achieve a range of Connection Point voltage depths (maintain the fault X/R ratio at the same value as the Thevenin impedance)
  - assess a representative range of fault types, including three-phase-to-ground (3PHG), two-phase-to-ground (2PHG), single-phase-to-ground (1PHG) and phase-to-phase faults
  - assess retained voltage over the ranges of 0.0-0.7 pu and 1.25-1.35 pu, using increments of no more than 0.1 pu.
  - for shallow disturbances with retained fault voltages between 0.7-0.9 pu and between 1.1-1.25 pu, the voltage increment between disturbances should be reduced (e.g. to 0.02 pu) to provide additional data points around the commencement threshold.
- Apply the longer of:
  - the applicable fault clearance time specified in NER clause S5.1a.8, corresponding to column 4 of Table S5.1a.2
  - at transmission voltage levels:
    - for unbalanced faults, the longest specific circuit-breaker-fail protection clearance time in the nearby network
    - for 3PHG faults, the longest specific primary protection clearance time in the nearby network.

See the Regional Data document for specific clearance times.

5.6.2.4 Scope of the PSS®E SMIB studies – single balanced faults

- To ensure performance of the PSS®E model is consistent with the proposed performance standards, carry out fault tests in PSS®E following a similar approach to that specified for PSCAD.
- Conduct tests according to the operating scenarios listed in Table 5-10.

Table 5-10 Fault response operating scenarios

Parameter	Values
Connection Point Voltage	V_{HIGH} for Q_{MIN}, V_{LOW} for Q_{MAX}
Connection Point active power	Operating scenarios as per Section 5.1
Connection Point reactive power	Q_{MAX}, Q_{MIN}
Fault level	Minimum

Note: pending the performance of the PSS®E model, Transgrid and AEMO may request additional studies. The subset of PSS®E testing can only be reduced if sufficient studies are provided in DMAT, benchmarking and NEM studies.

Common issues, considerations and recommendations

Unstable responses in NEM studies

Where the plant and/or network response is unstable following a tested contingency, replace the plant model with an equivalent negative load and repeat the study. This comparison should be used to determine whether the instability is caused by the plant's dynamic response or is pre-existing under the modelled network conditions.

Where the instability is pre-existing, investigate its cause and confirm that the network initial conditions are appropriate, including:

- No excessive thermal overloading under N-1 conditions
- Appropriate network voltage profiles
- Interconnector flows within the applicable stability limits.

Where the network has been configured under excessively onerous conditions (for example, with QNI flow above the applicable transient stability limit) the base case should be corrected and the study repeated to confirm stable operation of the network and connecting plant.

Where the instability is attributable to the connecting plant, investigate and address the issue through control retuning or other appropriate measures.

Overvoltages observed in the responses

Assess transient and retained overvoltages for each type of unbalanced fault. To avoid undesirable phase voltages above 1.1 p.u., investigate model and control tuning to minimise overvoltages where practical. Your CSR must clearly document this assessment and demonstrate that the relevant model parameters and control settings have been optimally tuned to minimise overvoltages.

5.7 Responses to disturbances following contingency events – S5.2.5.5A

5.7.1 Expectations and acceptance criteria

NER Clause S5.2.5.5A requires connecting plant to respond appropriately to disturbances during and following contingency events to support voltage recovery and stable power system operation. This includes demonstrating appropriate active and reactive current responses during and following disturbances, while maintaining stable plant operation.

What you need to do

- Use studies to demonstrate that the plant can remain in CUO while providing fast, stable and adequately controlled voltage support during undervoltage and overvoltage events. The same studies can be used to demonstrate compliance with both NER clauses S5.2.5.5 and S5.2.5.5A, provided the required assessment criteria and results are included for each clause.
- Assess the plant's response against the applicable AAS criteria, including:
  - Additional positive-sequence capacitive reactive current injection of at least 4% of maximum continuous current for each 1% reduction in positive-sequence voltage at the Connection Point below 85% of nominal voltage
  - Additional positive-sequence inductive reactive current injection of at least 6% of maximum continuous current for each 1% increase in positive-sequence voltage at the Connection Point above 115% of nominal voltage
  - Recovery of active power to at least 95% of its pre-disturbance level within 100 ms
  - A reactive current rise time of no more than 40 ms
  - A reactive current commencement time of no more than 10 ms
  - An adequately controlled reactive current response.
- Where the plant cannot meet the AAS, provide a detailed explanation supported by response plots and sufficient investigation to demonstrate the plant has been optimally tuned for the connecting location (see: CSR requirements under Section 6 for expectations on performance negotiation).

Reactive current response

- Demonstrate reactive current injection during undervoltage events and reactive current absorption during overvoltage events at the Connection Point, consistent with Figure 5-3. The assessment should:
  - Cover a representative range of balanced and unbalanced faults
  - Include all applicable active and reactive power operating scenarios
  - Identify the point at which the response saturates due to production unit reactive current limits, whether these limits apply during normal operation or FRT mode.
- Demonstrate reactive current capability using both PSS®E and PSCAD studies. Present reactive current commencement time and rise time using PSCAD studies for balanced and unbalanced faults.

The next section outlines the scope of studies required in each simulation platform.

Un-faulted phase voltage during unbalanced faults

- Demonstrate the level of voltage increase in the unfaulted phases during unbalanced faults using PSCAD studies.
- Tune the plant controls (e.g. negative-sequence current) to maintain unfaulted-phase voltages below 1.1 p.u.

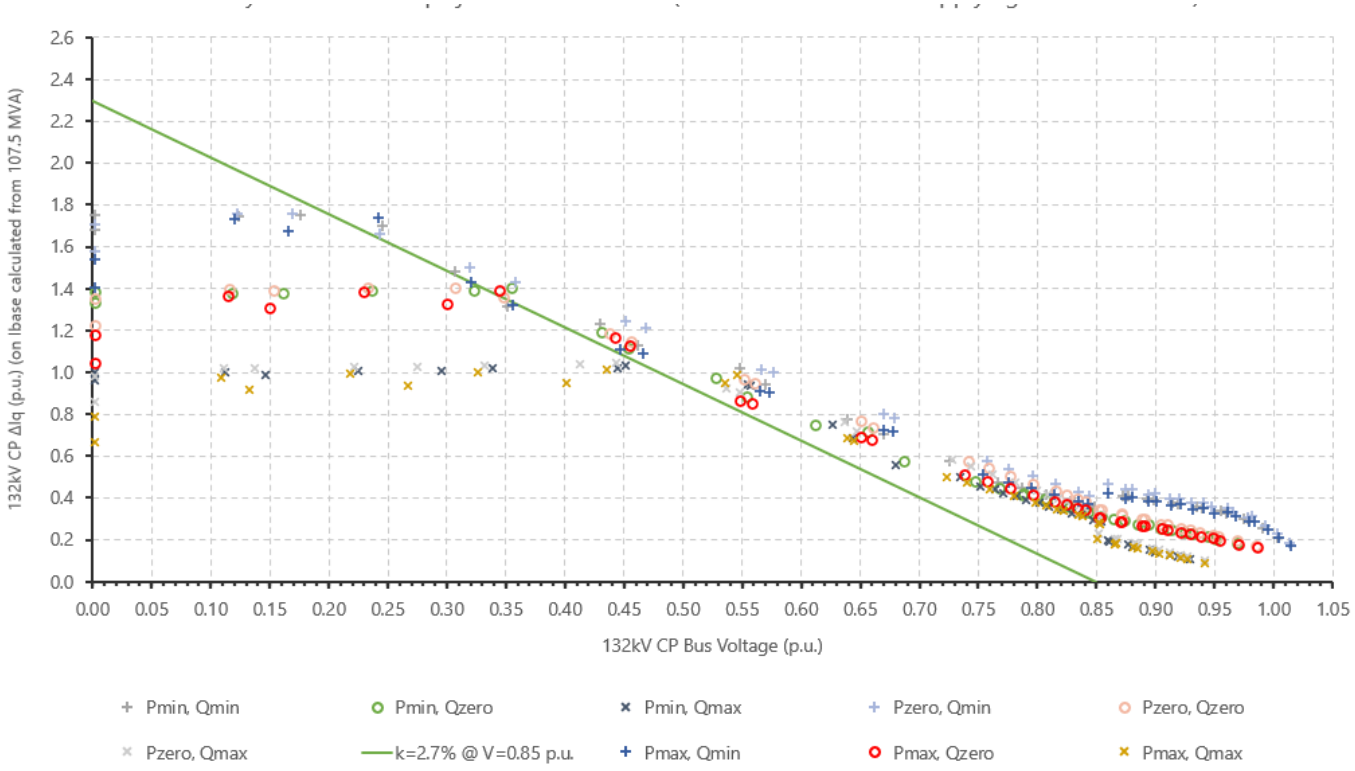


Figure 5-3 Example graph showing the magnitude of reactive current injection at the Connection Point

Post fault response

- Demonstrate the active power recovery time following fault clearance,14 using the SMIB and NEM studies.

Negative sequence reactive current injection

Because negative-sequence control strategies may vary between OEMs, your CSR must clearly describe the strategy implemented in the plant.

What you need to do

- Use PSCAD studies to demonstrate the negative-sequence reactive current response during unbalanced faults.
- Demonstrate that the strategy contributes to reducing overvoltages in the unfaulted phases while maintaining a stable and adequately controlled response at the Connection Point.

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14 NER defines the end of the disturbance as 20 ms after the last time the Connection Point voltage is outside the range 0.9 p.u. to 1.1 p.u.

5.7.2 Methodology

5.7.2.1 Scope of the PSCAD SMIB studies – single balanced and unbalanced faults

The setup and operating conditions to be used for the PSCAD SMIB studies are as per the criteria outlined in the previous section for clause S5.2.5.5 assessment.

Test requirements

- For capacitive reactive current injection assessment, apply faults with a residual voltage at the Connection Point in the range between 0.0 p.u. and 0.9 p.u. in sufficiently incremental steps to determine the reactive current injection performance.
- Similarly, for inductive reactive current injection, apply disturbances with a residual voltage at the Connection Point in the range between 1.1 p.u. and 1.3 p.u. in sufficiently incremental steps.

Measurements

At a minimum, measure and plot the following signals (in addition to the Connection Point and production unit terminal P/Q/V/frequency):

- Positive and negative sequence reactive current injection at the Connection Point and production unit terminals.
- Positive and negative sequence voltage at the Connection Point and production unit terminals.
- Individual phase rms voltages (to check for over-voltages on the un-faulted phases).
- PPC and production unit FRT/freeze flags.
- Production unit current limit activation flag (if applicable)
- Individual rms phase currents at production unit terminal (to demonstrate the current saturation of the production unit).
- Other relevant signals related to the control strategy, e.g. GFM related signals.

Active power recovery

- Calculate and record the active power recovery time at the Connection Point for each applicable disturbance.
- Present a scatter plot of active power recovery time against positive-sequence retained voltage at the Connection Point.

Reactive current injection magnitude

- Measure the positive- and negative-sequence voltages and reactive currents at the Connection Point and production unit terminals immediately before fault clearance, or at another time agreed with Transgrid.
- For grid-forming plants where reactive current (Iq) decays during a fault, consult Transgrid to agree on a project-specific measurement point for recording the Iq K-factor performance in the GPS. Regardless of the agreed measurement point, the K-factor must meet the 0% MAS requirement when measured immediately before fault clearance, using the longest CBF clearance time applicable to the surrounding network.
- Tabulate and present the results in the graphical format shown in Figure 5-3 (ΔIq as a function of the positive sequence voltage curve). Clearly identify the points where the production unit current levels are saturated. (All the unsaturated points in the graph are expected to be above the curve for the proposed access standard.)

Reactive current rise time

- Calculate the positive-sequence reactive current rise time at both the Connection Point and production unit terminals.
- Use a time scale that clearly demonstrates the calculated rise time. See Figure 5-4 for further guidance on rise time calculation.

Reactive current commencement time

- Measure the commencement time from the instance where the proposed initiating condition is satisfied to the point where the reactive current reaches 10% of mean sustained value (where the 10% threshold is based on the rise time calculation).
- Calculate and plot the commencement time for positive sequence reactive current injection at both Connection Point and the production unit terminals to a scale that is sufficient to clearly demonstrate the commencement time. See Figure 5-5 for further guidance on commencement time calculation.

How to present your results

- Use scatter plots to present performance against retained fault voltage depth.
- Use box-and-whisker plots to present the un-faulted phase voltages for unbalanced faults, to assess any over-voltages on the un-faulted phases.
- Tabulate the results in MS Excel (or similar), so the level of reactive current injection can be filtered and assessed.
- Only consider cases where the reactive current response initiating condition is satisfied.
- Note that active power recovery calculation has separate requirements according to the NER.

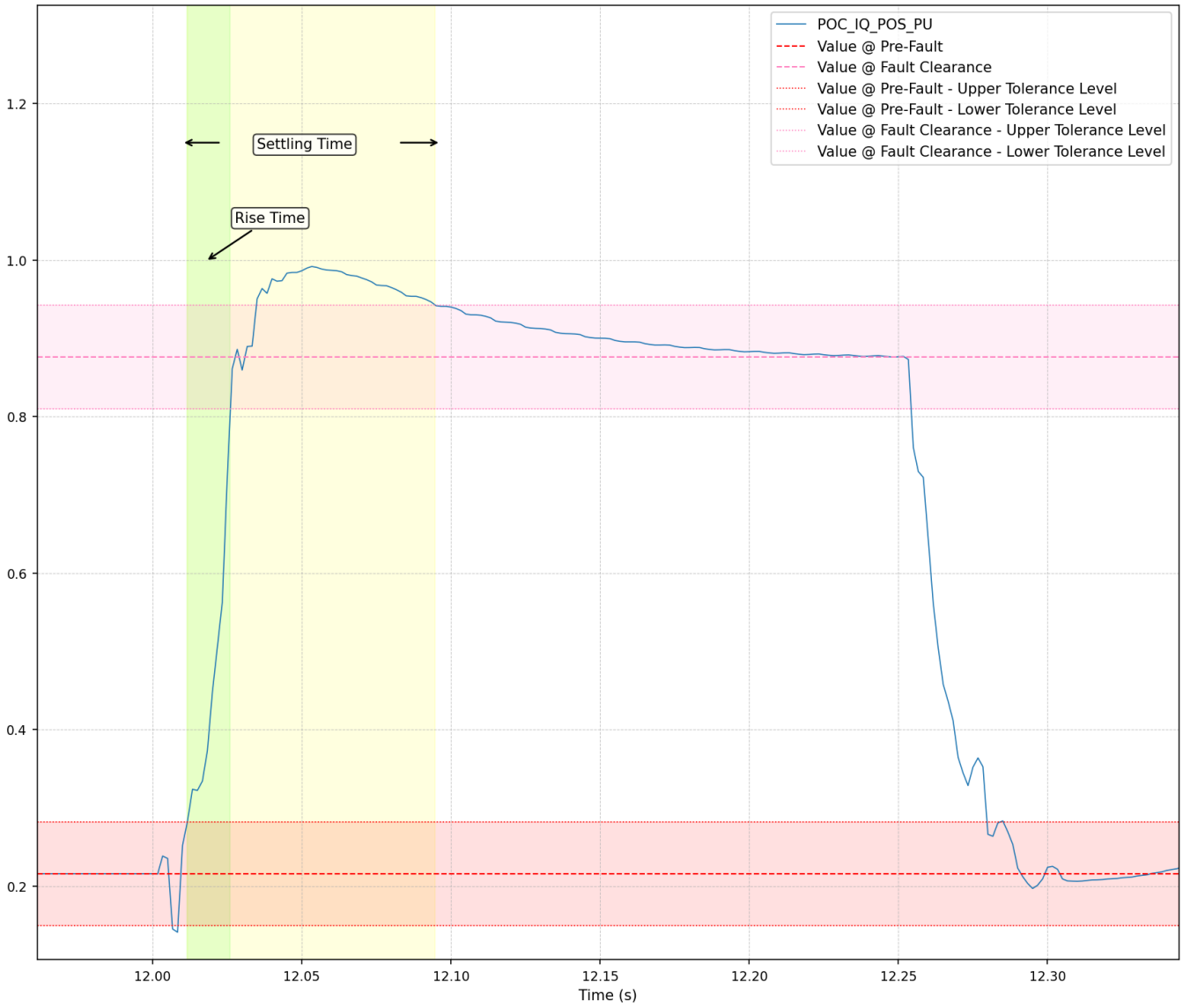


Figure 5-4: Rise time demonstration

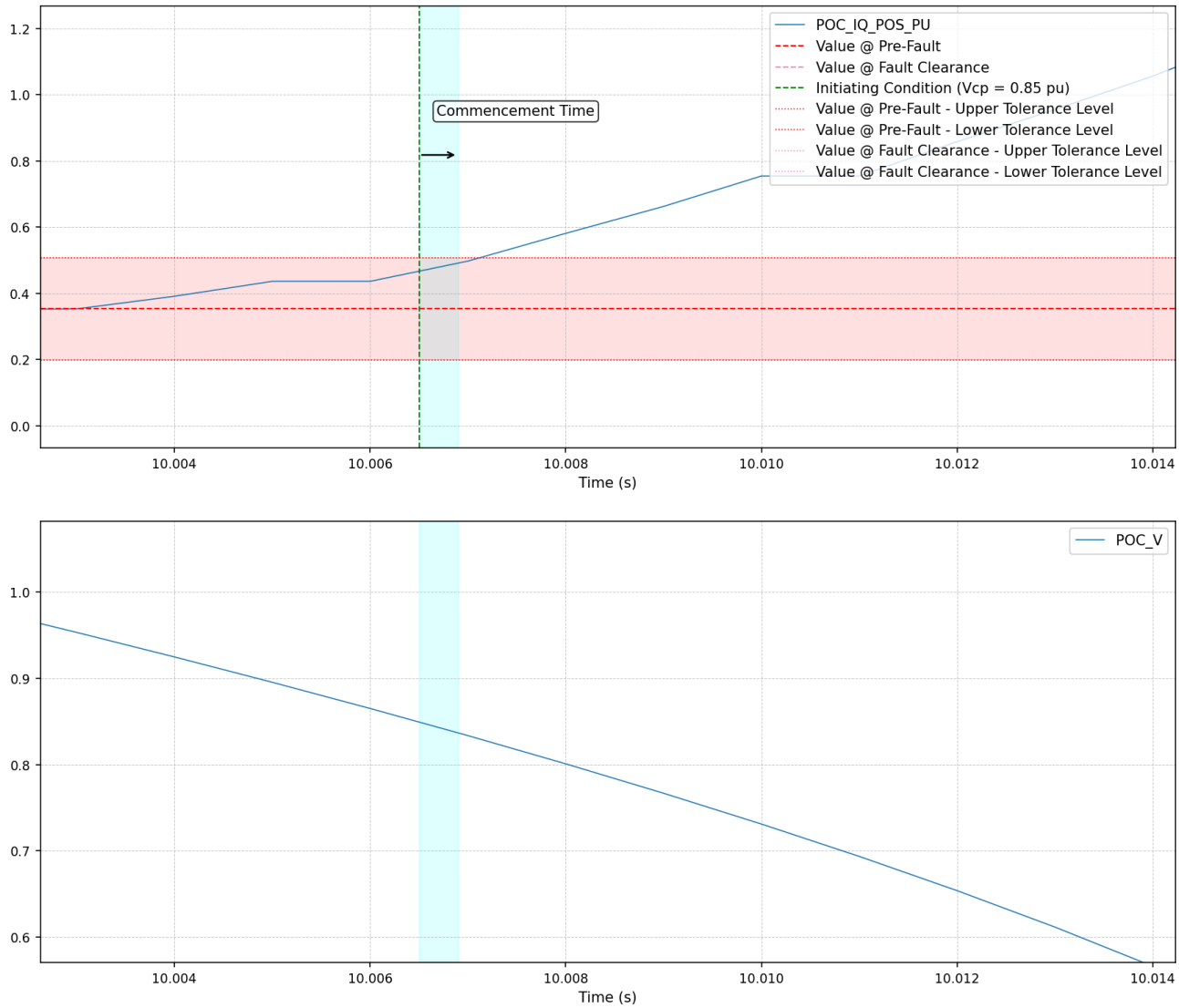


Figure 5-5: Commencement time demonstration

5.7.2.2 Scope of the PSS®E SMIB studies – single balanced faults

- Use PSS®E SMIB simulations for balanced faults to demonstrate the performance of the PSS®E model, using an approach consistent with the PSCAD assessment.

Note: Where sufficient evidence is provided through the DMAT and model benchmarking, the reduced operating scenarios specified in Table 5-10 may be used. Studies undertaken under Section 5.6.2.4 may also be used for this assessment, provided the required signals and performance metrics are included.

5.7.2.3 Scope of the PSS®E NEM studies – single balanced contingencies

Section 5.6.2.1 describes the setup of the PSS®E NEM base cases and the applicable contingency studies.

- For each PSS®E NEM simulation, calculate and present the active power recovery time at the Connection Point.

Common issues, considerations and recommendations

Active power recovery time of NEM results

In the PSS®E NEM studies, transient variations can appear in the network frequency after the faults are cleared. This can impact the plant's active power recovery, especially for grid forming inverters. If the NEM studies show significantly higher active power recovery times compared to SMIB studies, investigate the root cause(s) and report the issue and the results in the CSR. This must include whether the active power recovery time is exacerbated by concurrent network frequency events or similar phenomena for the relevant contingencies.

Active power recovery – BESS charging versus discharging

Present the active power recovery results for charging and discharging cases separately as significant differences are observed in certain scenarios. Additional breakdowns of operating scenarios and test conditions can be presented, where relevant.

Outlier cases for reactive current response/ active power recovery time

Present the rise times, commencement times or active power recovery times as percentile/scatter plots if a few outliers are significantly longer. This can demonstrate whether the majority of cases are compliant if the studies cover the full range of Connection Point voltages for the variation of fault depths considered.

5.8 Response to abnormal voltage quality – S5.2.5.6

The NER clause S5.2.5.6 requires the plant to not disconnect from the power system as a result of voltage fluctuation, harmonic voltage distortion and voltage unbalance conditions at the Connection Point within the limits specified in S5.1a. The CPTSR specifies these requirements as they apply to the connecting plant.

What you need to do

- Obtain an OEM statement of compliance confirming that the plant meets the requirements of S5.2.5.6. If the OEM cannot provide this statement, additional evidence, such as Factory Acceptance Test (FAT) results may be required.
- Update the proposed performance standard in the GPS for S5.2.5.6 to incorporate the applicable limits specified in the CPTSR.

Note: Transgrid applies a margin to the planning levels for voltage fluctuations and harmonic voltage distortion when setting these quality of supply limits. The margin provides operational headroom and reduces the likelihood of plant disconnection during infrequent events where power quality levels can exceed the applicable planning levels.

5.9 Partial load rejection for synchronous production units – S5.2.5.7

The partial-load rejection requirements in NER S5.2.5.7 only apply to synchronous generation. As the scope of this Guide is limited to the requirements for asynchronous plant, partial-load rejection requirements are not addressed.

5.10 Protection from power system disturbances – S5.2.5.8

5.10.1 Expectations and acceptance criteria

NER Clause S5.2.5.8 requires protection and control systems to be coordinated with the agreed performance standards so the plant is not unnecessarily disconnected during power system disturbances. This includes demonstrating that protection systems operate only for conditions where disconnection is required and remain stable for disturbances that the plant is required to withstand.

What you need to do

- Ensure that the GPS records:
  - conditions where the plant must not trip, where otherwise it would be allowed under the performance standards to disconnect
  - conditions where it must disconnect, where otherwise it must remain in CUO
  - anti-islanding trip schemes, special protection schemes (SPS) and emergency control schemes.
- Demonstrate plant performance under extreme frequency excursions using a SMIB model to show that the:
  - plant reduces its active power by 50% of its pre disturbance level for over frequency events which exceeds the threshold of 0.5 Hz below the upper limit of the extreme frequency excursion tolerance limit15 within 3 seconds;
  - voltage and frequency protection activate in both the PSCAD and PSS®E models for each protection range
  - plant does not trip for a sudden voltage phase angle shift of 20 degrees at the Connection Point.

5.10.2 Methodology

5.10.2.1 Response to frequency disturbance

- Perform a frequency disturbance test at or slightly above 51.5 Hz at the maximum active power.
- Report the time taken for the active power to drop by 50%, which should be less than 3 seconds.

15 This corresponds to 51.5 Hz based on the current frequency operating standards effective from 9th October 2023.

5.10.2.2 Protection System

- Perform voltage and frequency disturbance tests to drive the voltage or frequency at the production unit terminals to the respective voltage and frequency protection thresholds.
- Repeat these tests using both the PSS®E and PSCAD SMIB models with each test simulated sufficiently long to demonstrate that the plant trips at the appropriate protection setting.
- Include plots of each test showing the corresponding trip flags of the production unit, if they are available.

5.10.3 Voltage phase shift test

- Include any vector shift or similar protections used in the plant in both the PSCAD and PSS®E models.
- Perform the voltage phase shift test at the minimum SCR with a step change of 20 degrees to the phase angle of the SMIB voltage. (The plant should ride through the disturbance and return to the pre disturbance voltage, active power and reactive power levels.)
- Repeat the tests using both the PSS®E and PSCAD SMIB models.

5.11 Protection systems that impact on power system security – S5.2.5.9

NER Clause S5.2.5.9 requires the plant to be equipped with protection systems that detect and clear faults within the required timeframes while minimising impacts on power system security. This includes demonstrating that protection systems are appropriately coordinated, reliable, and incorporate suitable redundancy where required.

What you need to do

- Propose the applicable fault clearance times for primary protection, back-up protection, and breaker failure protection systems across the entire generating system as part of the proposed GPS.
- Ensure fault clearance times for high and medium voltage protection systems comply with the system standards specified in clause S5.1a.8.
- Specify fault clearance times for low voltage protection systems based on the proposed plant design and included in the GPS.

Note: given that more accurate protection clearance time information may only become available during the detailed design phase, fault clearance times recorded in the GPS at the R1 stage can be updated.

5.12 Detection and response to unstable operation – S5.2.5.10

Connecting plant must meet the requirements specified under NER clause S5.2.5.10. This includes being able to:

- Detect connecting plant's voltage, reactive power and active power instability at the Connection Point
- Disconnect units for unstable behaviour, with configurable enablement conditions and settings agreed with Transgrid and AEMO
- Upon detecting a plant instability, promptly execute a hierarchy of actions based on configurable trigger conditions, thresholds, and time frames agreed with Transgrid and AEMO.
- Communicate information from its detection system to Transgrid and AEMO control centre(s)
- Receive a remote tripping signal from Transgrid.

Further information on Transgrid's specific requirements applicable for any instability detection scheme is available in the *Instability Monitoring System Guide for Asynchronous Generators* – see the Commissioning Package provided with your Data Response.

For production systems with an active power capability of 100 MW or greater, the plant must:

- Have access to a phasor measurement unit (PMU) capable of providing system data to both AEMO and Transgrid
- Be capable of receiving information from AEMO regarding the system's contribution to instability, where such information is available and provided in a format nominated by AEMO.

5.13 Frequency control – S5.2.5.11

5.13.1 Expectations and acceptance criteria

Under NER S5.2.5.11, a connecting plant must demonstrate that its frequency control system can automatically and appropriately vary active power output in response to power system frequency disturbances, to support power system frequency stability. The plant must provide its frequency response in accordance with the specified droop and deadband settings.

What you need to do

- Provide assessments demonstrating that the plant's active power response:
  - Follows the specified droop and deadband for both under-frequency and over-frequency disturbances. Is stable and remains unchanged for disturbances where the frequency remains within the frequency deadbandRemains within the active power limits for both under-frequency and over-frequency disturbances.
- Provide a:
  - Table of droop calculations for a range of frequency steps
  - Graph comparing theoretically calculated active power response at the Connection Point with the simulated active power response
- Where an integrated resource system is proposing to participate in the FCAS market, demonstrate the operation of the plant with a droop setting of 1.7%, or the alternative droop setting proposed for operation.16

5.13.2 Methodology

- Assess the frequency control of the plant using both PSS®E and PSCAD SMIB models.
- Conduct tests for all the applicable combinations of operating scenarios in Section 5.1.

16 At present, AEMO will accept a droop setting as low as 1.7% for an integrated resource system that is proposing to participate in the FCAS market.

- For the frequency droop assessment, simulate the frequency disturbances in Table 5-11 with a frequency ramp rate of 1 Hz/s considering the dispatch scenarios specified in Section 5.1.
- Perform at least disturbances of 52Hz, 51Hz, 49Hz and 47Hz considering Q_{max} and Q_{min} dispatch scenarios in PSCAD17. (Perform the rest of the PSCAD and all PSS®E studies considering the Q_{zero} dispatch condition.)

Note: The disturbances may be performed sequentially or individually, with the ramp rate applied until the target frequency is reached. If the droop implemented has more than one gradient (two or more staged droop response), select frequency steps to assess each stage of the droop response.

Table 5-11 Frequency control disturbances

Disturbance	Frequency [Hz]
1	52.0
2	51.5
3	51.0
4	50.5
5	50.1
6	50.02
7	50.01
8	49.99
9	49.98
10	49.9
11	49.5
12	49.0
13	48.5
14	48.0
15	47.0

17 If S5.2.5.3 studies were not conducted in PSCAD considering Q_{max} and Q_{min} dispatches. Otherwise, all the tests can be performed considering Q_{zero} dispatch

Note: The duration of each frequency disturbance must be sufficiently long to allow the active power response to settle. The steady state measurements of frequency and active power must be recorded and compared against the expected response based on the specified droop. Measurements must be provided as an Excel attachment.

Common issues, considerations and recommendations

Unstable frequency response during very low SCR scenarios

If unstable plant responses are observed in SMIB studies for extreme frequency disturbances, such as 48 Hz or 52 Hz, further investigations must be undertaken and presented in the CSR. See "Common issues, considerations and recommendations" in Section 5.4 for further guidance.

5.14 Impact on network capability – S5.2.5.12

5.14.1 Expectations and acceptance criteria

NER Clause S5.2.5.12 requires the plant to be designed and operated so that it does not adversely impact network capability or power transfer capability. This includes demonstrating that the plant's capabilities, control systems and operational arrangements minimise constraints on the existing network while maintaining power system security.

What you need to do

- Perform both steady state and dynamic studies using the PSS®E NEM model to demonstrate that the plant connection will not adversely impact capabilities of the transmission network – and that the connection will not reduce intra-regional or inter-regional power transfer capability.
- For the applicable network contingencies, assess impacts on:
  - Thermal loading of transmission lines and transformers
  - Network voltages and voltage step changes
  - Power system stability.

5.14.2 Methodology

- Ensure the PSS®E NEM model base case is stable before assessing the impact of connecting the proposed new plant (see Section 4.10).
- Use the list of contingencies and the fault clearance times in the Regional Network Data document(s). Consider:
  - All contingencies up to at least three buses away in the main system for potential Connection Points in the 330 kV or 500 kV transmission system.
  - Additional contingencies in the nearby network for Connection Points in the sub-transmission network.

- For plant connecting close to the Queensland or Victoria networks
  - Consider a range of contingencies in the nearby region. Assume the standard clearance times in NER S5.1a.8 unless otherwise specified by Transgrid or AEMO.
- For plant connecting to the main system
  - Consider tripping the largest generator and the largest load in NSW or Queensland.
- For plant connecting close to a bulk supply point
  - Consider contingencies in the distribution network. Request information from Transgrid using the RFI process.
- Take into account any special protection schemes (SPS) associated with the committed and in-service generators. SPS details are included in the Regional Network Data document.

5.14.3 Steady State Assessment

- Set up the steady state PSS®E NEM study cases so the connecting plant is at its maximum output, including maximum charging and discharging for a connecting BESS.
- Dispatch the nearby generators and BESS so nearby transformer and transmission line loadings under system normal conditions are less than or equal to the continuous rating.
- To assess the network performance under N-1 conditions, disconnect a single network element (a transmission line or transformer), the largest generator and the largest load and solve the load flow with both OLTCs and switch shunts locked and the loading of the network elements in the region.
- Record all nearby bus voltages and bus voltage changes.
- Assess and record a wide range of different network N-1 conditions for all nearby major elements.
- Study each contingency with and without the connecting plant in service.
- Analyse each element below to assess the impact of addition of the plant on the network.

Thermal capacity

- Ensure the transmission line and transformer loadings under N-1 conditions are less than or equal to the contingency rating using the ratings listed in the relevant Data Response.
- Provide a comparison of line and transformer loadings with and without the plant in service.
- Identify any thermal capacity issues caused by the plant.

Bus voltage

- Ensure all the bus voltages in the relevant region are in the range 0.9 p.u. to 1.1 p.u. under system normal conditions and N-1 condition[18] or otherwise stated in the relevant Regional Network Data document.

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18 If the voltage droop response of nearby plants were not properly considered in PSS®E load flow this may not be achievable in N-1 condition (i.e., post contingency). In such cases, provide an explanation in the CSR and consider the dynamic performance obtained under clause S5.2.5.5/S5.2.5.5A.

Step change in voltage

- Assess the step change to the voltages at the nearby buses in the region for each N-1 contingency, with and without the plant in service.
- The voltage changes should be less than or equal to:[18]
  - 10% for contingencies of transmission line or transformer
  - 5% for large generator trip.

Step change in voltage for tripping the proposed connection

- Assess the size of the step voltage change for the tripping the proposed connecting generator. (The size of the voltage step should be less than 5%.[18])

5.14.4 Dynamic assessment

Contingency assessment

- In addition to the steady-state assessment, perform dynamic studies for each scenario and contingency discussed above.
- Results can be reused from studies already been completed for the NER clause S5.2.5.5 assessment, provided they include the signals specified under 'Results and Plotting' below.

Impact on power transfer capability

- Use dynamic studies to assess the impact of the connecting plant on relevant inter-regional or intra-regional power transfer limits.
- Perform the following assessment both with and without the connecting plant in service:
  - Adjust the generation dispatch so that the interconnector flow is close to the relevant stability limit (i.e., marginally stable conditions).
  - Simulate the critical credible contingency event/s associated with the power transfer limit. See AEMO's *interconnector capability document* and Transgrid OMs in the Data Response for the relevant limit and the associated critical contingency event/s.
  - Where the critical contingency involves large generator or load trip events, conduct studies both with and without a fault applied prior to the trip event.
  - Adjust the generation dispatch to increase the interconnector flow in steps of approximately 20 MW and repeat the simulation of the critical contingency event. Repeat until the system is unstable.
  - Present the plots of the dynamic studies including both marginally stable and unstable scenarios.
- Perform the stability-limit assessment for both directions of power flow:
  - AAS: the power transfer limit with the connecting plant in service must be equal to or greater than the corresponding limit without the plant in service in each direction.
  - MAS: the reduction in the power transfer limit with the connecting plant in service must not exceed the combined sent-out generation of the plant's production units.

How to present your results

- For all dynamic assessments for this clause, include plots of the:
  - voltage of nearby busbars
  - power flow in the nearby network
  - rotor angle for nearby large synchronous generating units, large NSW synchronous generating units and one or two large generators on the other region (i.e. QLD or VIC depending on the interconnector under study).

Common issues, considerations and recommendations

Impact on inter- or intra-regional power transfer limits

The connecting plant will not comply with the AAS for NER clause S5.2.5.12 if it reduces any relevant power transfer limit. If a reduction is identified, consult AEMO and Transgrid to determine whether a negotiated performance standard may be acceptable.

Note: negotiating the performance standard for NER clause S5.2.5.12 may require additional dynamic studies to:

- Further assess the likely impact of the reduction in power transfer capability
- Demonstrate whether the plant can meet the MAS.

5.15 Voltage and reactive power control – S5.2.5.13

5.15.1 Expectation and acceptance criteria

Under NER S5.2.5.13, a connecting plant must demonstrate that its control system can regulate voltage, reactive power and/or power factor, and respond appropriately to network disturbances, setpoint changes and changing power system conditions within the required response time and accuracy requirements, to support voltage stability and secure network operation.

What you need to do

- Demonstrate stable and adequately damped control system performance across the expected operating range, such that it:
  - Does not degrade the damping of any critical mode of oscillation of the power system
  - Does not cause instability in voltage, reactive power or active power within the power system.

Primary and secondary control models

The assessment methodologies and acceptance criteria in this Guide are based on using voltage droop control as the primary voltage control mode and reactive power control as the secondary mode. If you propose using an alternative primary or secondary control mode, consult Transgrid and AEMO before submitting your Connection Application.

What you need to do

- Configure your plant's control system to operate in voltage droop control mode and regulate voltage in accordance with the following requirements:
  - Voltage setpoint must be continuously controllable over a range of at least ±5% of nominal voltage above and below the target voltage determined by Transgrid19.
  - Voltage droop must be 12.7% on a rated MW base (expressed in MVA).
  - Where the plant is operating with a reduced number of production units in-service (for example, if some of the inverters or wind turbine generators are out-of-service), scale the droop base (in MW measured at the Connection Point) in proportion to the number of in-service production units while maintaining the 12.7% droop setting.
- Demonstrate an adequately damped20 response for setpoint changes and voltage disturbances in both primary and secondary control modes.
  - Check the Supplementary Report for additional project-specific requirements for voltage and reactive power control, including any remote voltage control point requirements.
- Document all assessment results described in Section 5.15.2 in the CSR, which must include:
  - A summary of the results
  - Detailed results in a tabular format or in an Excel file as an attachment (or equivalent).

Partial operation

- To verify plant operation with reduced number of production units in-service, perform a limited assessment of the voltage droop control with 50% of the production units in-service. The assessment must demonstrate that:
  - voltage droop is maintained at 12.7% with the droop base scaled to 50% of plant's rated MW capacity
  - the reactive power limits are scaled proportionally to reflect the reduced number of production units in service.
- Capture the modelling instructions for partial operation in the RUGs as outlined in Section 4.4.3.

5.15.2 Methodology

- Assess the plant's voltage and reactive power control performance under typical and maximum impedance across a range of operating scenarios, as specified in Section 5.1.

Scope of the PSS®E and PSCAD SMIB studies

19 NER S5.2.5.13 requires that the target voltage be determined by the Network Service Provider in accordance with clause S5.1.4(c).

20 Please see the applicable "adequately damped" criteria in NER Chapter 10 – Glossary.

- Complete the full scope of assessments in PSS®E, including SMIB studies and wide-area NEM studies based on OPDMS snapshots
- Undertake a limited set of SMIB assessments in PSCAD. At a minimum, include limiter tests for voltage setpoint changes and voltage disturbances in voltage droop control mode.

Voltage droop assessment

- Validate the plant's voltage droop settings through voltage setpoint or voltage disturbance response. This can be demonstrated by:
  - applying a series of incremental voltage disturbances at the voltage source across the normal operating range of the PPC or
  - directly applying a series of voltage setpoints to the PPC.
- At each test level, record the steady-state voltage and reactive power measurements and assess them against the expected voltage droop response.
- Tabulate voltage and reactive power measurements in Excel (or other equivalent format).

Voltage setpoint changes

Non-limiter tests and limiter tests are required, depending on the initial reactive power conditions.

- For non-limiter tests apply, ±5% voltage setpoint changes, including the return step, through the PPC model. At a minimum, test:
  - ±5% voltage setpoint changes for Q_{ZERO} cases
  - -5% for Q_{MAX} cases
  - +5% for Q_{MIN} cases.
- For limiter tests, apply ±2.5% voltage setpoint changes through the PPC to step away from the reactive power limit, followed by a further ± 5% voltage setpoint step change into the reactive power limit.
- Include detailed plots for each test in the CSR.
- Calculate the settling times for voltage, reactive power and active power at the Connection Point using the applicable NER definitions.
- Present the results in the CSR to demonstrate the accuracy (present the voltage control error in the form of the equations below) of the PPC in achieving the target setpoint.
- $Voltage\ control\ error = \left|\frac{V_{expected\ at\ CP} - V_{measured\ at\ CP}}{V_{expected\ at\ CP}}\right| \times 100\%$
- $V_{expected\ at\ CP} = V_{setpoint} - \frac{droop \times Q_{measured\ at\ CP}}{droop\ base}$

Voltage disturbances (voltage droop control mode)

- Apply voltage disturbances of ±5% to the SMIB voltage source via a voltage playback, with the plant operating in voltage droop mode.
- Adjust the disturbance applied at the SMIB voltage source as needed to achieve a voltage change of between ±2% and ±5% at the Connection Point. Alternatively, apply a shunt at the Connection Point to produce the required disturbance magnitude.
- For non-limiter tests, apply the following grid voltage disturbances, including the return step:
  - ±5% and return steps for Q_{ZERO} cases
  - +5% for Q_{MAX} cases
  - -5% for Q_{MIN} cases.

- For the limiter tests:
  - Initialise the plant at the applicable reactive power limit at the Connection Point.
  - Apply a ±2.5% grid voltage change to step away from the limit
  - Follow this with a further 5% grid voltage step change into that same limit.
- Calculate the rise time21 of reactive power and settling times for Connection Point voltage, reactive power and active power using the applicable NER definitions under both typical and the highest system impedance scenarios.

Reactive power setpoint changes

Both non-limiter tests and limiter tests are required, depending on the initial reactive power conditions.

- Perform these tests using the typical system impedance conditions.
- Switch the PPC to reactive power control mode and ±0.5 p.u. of the reactive power range established under clause S5.2.5.1 of the performance standards (i.e., apply a reactive power setpoint step size of 100% of Q_{MAX} or Q_{MIN} via the PPC model).
- Calculate reactive power settling times using the applicable NER definition.
- Present the results in the CSR to demonstrate the accuracy of the plant reactive power response in achieving the target setpoint.

Voltage disturbances (reactive power control mode)

- Apply voltage disturbances of ±5% to the SMIB voltage source under typical system impedance conditions, with the plant operating in reactive power control mode.
- Calculate the settling times for reactive power using the applicable NER definition.

NEM wide PSS®E studies

- Set up the PSS®E base cases so that the Connection Point voltage and reactive power conditions are suitable for assessing both non-limiter and limiter operation.
- For each of the PSS®E NEM base cases described in Section 4.10, perform the following tests in both the primary control mode (voltage droop control) and the secondary control mode:
  - ±5% voltage setpoint changes
  - voltage disturbances in the range of ±2% to ±5%, applied by switching a ficticious capacitor or reactor at the Connection Point
- Assess the response of the plant to switching of nearby reactive plant
- Report the corresponding rise time and settling time in the CSR.

21 Rise time assessment is only applicable for voltage disturbances where the limiter is not activated.

Limiter testing

Alternative methodologies can be used to assess limiter operation. For example, Transgrid uses the following methodology to assess reactive power limiter performance:

- Apply a 2.5% voltage step to step away from the limiter operating point and allow the plant to reach steady-state operation. This may require at least 10 seconds or longer.
- Configure the system so that steady state solution is achieved before applying the step into the limiter, taking into account any OLTC operation that may occur.
- Apply a further 5% voltage step towards the limiter operating point (i.e., a net step of 2.5% into the limiter).
- Assess the plant response, including limiter activation, voltage control performance, and recovery to steady-state operation.

Common issues, considerations and recommendations

Voltage instabilities at low SCR and X/R

Using the voltage playback method to simulate voltage disturbances can introduce voltage instabilities due to modelling artefact, under low SCR and X/R conditions. When such issues are observed, simulate voltage disturbances by switching shunt devices at the Connection Point to produce the required voltage change.

Interaction with nearby plant in wide-area NEM studies

When undertaking assessments for NER clause S5.2.5.13 using NEM network cases, the interactions between the connecting plant and nearby dynamic plant may contribute to prolonged response characteristics, including increased rise times and settling times. Where such interactions affect the assessment outcome, undertake suitable sensitivity studies to quantify and demonstrate the impact of the nearby plant(s). Discuss the results with Transgrid and agree on an appropriate assessment approach before finalising the study conclusions.

Performance of secondary control modes

Some OEMs employ control system architectures in which the primary and secondary control modes share a common set of control gains. In such cases, ensure that tuning changes made to improve the performance of the secondary control mode do not adversely affect or compromise the performance of the primary control mode.

Voltage drops and instability issues during low SCR conditions

5.16 Active power control – S5.2.5.14

5.16.1 Expectation and acceptance criteria

Under NER S5.2.5.14, a connecting plant must demonstrate that it can automatically increase, decrease, maintain and control active power transfer in response to dispatch instructions.

What you need to do

- Demonstrate that the plant can ramp its active power linearly between setpoints without exceeding Connection Point active power limits, based on plant's rated MW capacity.
  - this applies to all relevant operating configurations, including BESS-only, PV-only or Wind-only (as applicable) and the hybrid system as a whole, including demonstrating active power sharing between the individual parts of plant.
- Use sufficient sensitivity studies to demonstrate the:
  - general stability of the active power response
  - smooth transitions between modes, where applicable
  - operation of individual PPCs where the plant includes more than one;
  - coordination of the PPCs for each individual DUID
  - operation of the plant as a whole.
- Perform a limited assessment of active power reference step changes with the PPC active power ramp-rate limits disabled.
  - This allows the underlying dynamic response and damping characteristics of the generating system's active power controller response to be assessed independently of artificial ramp-rate constraints.

5.16.2 Methodology

- Assess the active power control of the plant using both PSCAD and PSS®E SMIB models under minimum fault level conditions.
- Test the following sequence of active power setpoints transitions as a percentage of the rated capacity of the plant:
  - 100% → 50% (discharging or generating)
  - 50%→ 0% (discharging or generating)
  - 0% → -50% (charging for BESS)
  - -50% → -100% (charging for BESS)
  - -100% → 100%, (charging to discharging/generating)

Common issues, considerations and recommendations

Voltage drops and instability issues during low SCR conditions

If the fault level and SCR at the Connection Point are low, active power step change tests using a SMIB model may lead to very large voltage variations at the Connection Point. This behaviour may result in instability and potentially trigger FRT mode. Where this occurs, undertake equivalent testing using a PSS®E NEM model with a comparable SCR maintained at the Connection Point.

Present the resulting plant response in your CSR and discuss the outcomes with Transgrid and AEMO.

5.17 Short circuit ratio – S5.2.5.15

5.17.1 Expectation and acceptance criteria

NER clause S5.2.5.15 requires inverter-based generating systems to operate stably and remain connected at the agreed short circuit ratio (SCR) at the Connection Point.

What you need to do

- Perform withstand SCR assessments using PSCAD in accordance with AEMO requirements in *Technical Note – System Strength Withstand SCR Methodology Review V2.1*.
  - Consider the requirements of Table 2 and Table 3 of AEMO's Technical Note and refer to the latest version of the SSIAGError! Bookmark not defined..
- Perform the withstand SCR under the following operating conditions, as applicable:
  - at maximum generation (for generating systems)
  - at maximum discharging and charging for BESS (taking into account AEMO's guidance on active power absorption limits for the charging scenario as per the Technical note above)
  - all applicable hybrid system scenarios specified in Section 5.1, including:
    - Hybrid operation, with the BESS charging at 100% and PV / Wind @ 100%
    - Hybrid operation at maximum active power output at the Connection Point, with PV / Wind generation output prioritised.
    - If you use different parameter settings for the Clause S5.2.5.15 assessment than those in the site-specific PSCAD model for other GPS clause assessments, document all such variations in both the Connection Study Report and the PSCAD RUG.

Common issues, considerations and recommendations

Performing studies when control point is different from Connection Point

Where voltage control is implemented at a remote location rather than at the Connection Point, you must still demonstrate compliance with the minimum SCR requirements specified in clause 5.2.5.15 at the Connection Point. If the current plant configuration makes it difficult to represent or assess the required minimum SCR at the Connection Point, discuss the proposed modelling approach with Transgrid (through an RFI) before undertaking the assessment.

5.18 Fault current – S5.2.8

5.18.1 Expectation and acceptance criteria

NER clause S5.2.8 requires the plant to be designed so that:

- Its fault current contribution is within the limits specified by the Network Service Provider
- All plant and switching equipment can safely withstand and interrupt fault current levels at the Connection Point

Transgrid's assessment of fault current contributions is based on the PowerFactory model as described in Section 4.7.2. Fault levels are calculated based on the ANSI 'momentary' fault currents method.

What you need to do

- Use the same model and calculation method to undertake the fault level assessment and propose the performance standard for NER clause S5.2.8.
- Check that the production units' fault current response is accurately represented in the PowerFactory model so that it closely reflects the expected response of the actual equipment.

The plant fault current contribution

- Calculate the fault current contributions from its plant for the following fault types:
  - Three phase fault current
  - Single phase to ground fault current
  - Phase to phase to ground fault current
- Record these fault level contributions in the GPS (the levels should be less than the limits specified in the CPTSR).

The plant equipment fault withstand capability

As specified in the CPTSR, the fault current level that the plant must be capable of withstanding through the Connection Point.

- Check that the plant equipment withstand capability specified in the GPS considers the withstand capability of the entire generating system, including the earthing grid.

The plant's circuit breaker fault current breaking capability

- Demonstrate that each circuit breaker used to isolate the plant from the network can interrupt, without damage or restrike, the maximum fault current that could reasonably flow through it for faults within the plant and faults on the transmission network.
- Consult Transgrid if the plant's circuit breaker is not capable of meeting the AAS specified in the CPTSR.

5.19 Instructions for Q-at-Night operation of solar farms and operation of wind farms below cut-in wind speed

Transgrid expects generating systems to operate in primary voltage control mode during Q-at-Night operation and when wind farms are operating below cut-in wind speed. For projects where voltage droop control is the primary control mode, the plant must operate in voltage droop control mode using the same reactive power–voltage droop settings applied during normal operation.

5.19.1 NER Clause Assessment Requirements

S5.2.5.1

These operating modes must be considered when establishing the reactive power capability of the generating system. The applicable reactive power capability under each operating mode must be specified in the GPS

S5.2.5.2

To comply with Clause S5.2.5.2, when conducting the harmonic assessments of the plant you must consider Q-at-Night operation of solar farms and operation of wind farms below cut-in wind speed (see Transgrid's *Attachment 2 - Harmonic Assessment Requirements*).

S5.2.5.5

The following limited studies must be conducted at the minimum fault level at the Connection Point in both Qmax and Qmin:[22]

- A three-phase fault at the PoC, cleared within primary protection clearing times.
- A line-to-line-to-ground fault at the PoC, cleared within circuit-breaker failure protection clearing times.

22Qmax and Qmin is the Qmax and Qmin applicable under Q-at-night operation/operation below cut-in wind speed as established in Clause S5.2.5.1 assessments

S5.2.5.13

Assessments must be conducted to demonstrate compliance with Clause S5.2.5.13, as required by NER clause S5.1.5.1(h)(1), demonstrating the compliance with the applicable settling-time requirements.

Other Clause Assessments

As required by the NER Clause S5.2.5.1(h)(2), these operating modes must also be considered when establishing performance standards for the following clauses:

- S5.2.5.9, S5.2.5.10, S5.2.5.15, S5.2.6.1 and S5.2.6.2
- S5.2.5.8, in relation to the applicable protection requirements