Powerlink Queensland

Inverter Based Renewable Plant: GPS Connection Study Process and Expectations

August 2022

Document Purpose

This document is a summary of expectations of the modelling and connection studies needed by Powerlink as part of the connection application process for inverter based resources (solar farm, wind farm or BESS). It also contains Powerlink's preferred approach to the staging of study information / data.

Please note that this is general information based on Powerlink's experiences of connection applications. As a particular connection project develops, the study requirements for that project may develop / change.

The intended audiences of this document are the developers who have made connection enquiries (their likely focus will be the section one), and the consultants for those developers.

This document's focus is on the process and studies expectations prior to agreement of performance standards (5.3.4A letter) and offer to connect. The details of studies expectations section is also relevant for R1 studies.

This document is intended to aid customers in the connection process for inverter based renewable generators. As the power system further develops, and the understanding of plants and relevant limitations / compliance issues are further developed, this document will be updated to capture those learnings in the future. This document is not intended to be used for any commercial contracts.

This document describes a generic set of studies / requirements and project specific requirements may differ based on connection location and plants' technology. More comprehensive studies can be performed by the generator as part of its own assessment of compliance.

Version Control

Version 1.0	March 2022	Initial Version
Version 1.1	March 2022	Minor update to S5.2.5.4
Version 1.2	August 2022	Updates to: PSCAD model version requirements, S5.2.5.4 Pmin Qmin requirements, PSCAD/PSS/e benchmarking. Expanded context for multiple items, including unbalanced fault performance, harmonic assessment,

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1. Connection Application Process

1.1 Context

As part of the NER process for establishing a new connection (NER Chapter 5.3) and following a connection enquiry, a generator is required to submit a connection application. A connection application for generator connection is considered formally complete, if it contains all items as specified in the Rules, and includes all items on AEMO's application checklist[1], which includes (but not limited to) the following:

- GPS document
- Generating system models, demonstration of model adequacy, manuals, OEM documents, RUGs.
- Benchmarking report showing alignment between models
- Power system study report, including sufficient supporting evidence for each clause of the GPS
- Voltage Control Strategy
- Single Line Diagram

There are also guides provided by AEMO in relation to connection application including "Guidelines for Assessment of Generator Proposed Performance Standards" and the "Power System Model Guidelines".

Powerlink's experiences with the assessment of inverter based plant, include:

- Timing of the GPS negotiation process (5.3.4A/B letter) is significantly influenced by the number of iterations of work that are required.
- Completion of the Full Impact Assessment (FIA) is a critical component of the assessment of a proposed inverter based generator.
- FIA progression is assisted by a robust PSCAD model and OEM support.
- Some consultants are time limited to the amount of PSCAD SMIB studies that can be performed.
- While complex interactions can only be assessed in wide area PSCAD models (eg: FIA), many issues can still be identified/resolved in Single Machine Infinite Bus (SMIB) model.

Based on these experiences, to minimise the time for an offer to connect (completion of FIA, completion of GPS due diligence studies, agreement of performance standards - 5.3.4A letter), Powerlink's preferred approach is to segment the delivery of studies for renewable connections into three stages:

1. Preliminary Design
2. FIA Package
3. Full Package

This approach segments a complete connection application into components. Powerlink's input to, and assessment of, key aspects of the generating system occur as early as possible in the process.

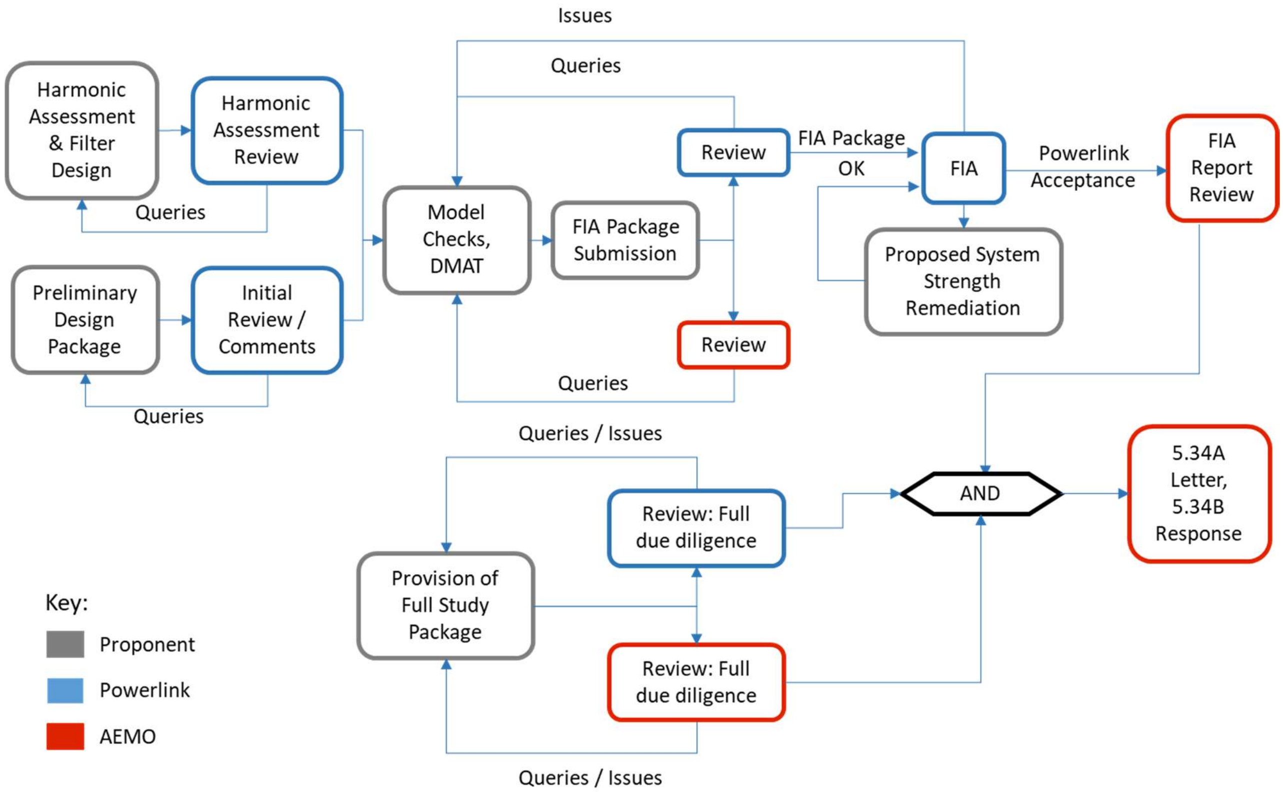
After model aggregation and tuning of the PSCAD model, key generating system performance items are checked in the preliminary design, prior to a proponent performing PSCAD SMIB checks. After in concept agreement with Powerlink, proponent's PSCAD SMIB checks can be performed. If the proponent is confident that the model is robust, then the PSCAD SMIB model can be submitted and checked by Powerlink, and if the model is acceptable, the FIA can be commenced. At any time

1 AEMO - Connection-application-checklist.pdf - https://aemo.com.au/-/media/files/electricity/nem/network_connections/stage-3/connection-application-checklist.pdf

(including during or after FIA), the remainder of the connection studies for a full package can be provided. See below for a process diagram. Agreement on the performance standards, and assessment of system strength impact (5.3.4A letter, and 5.3.4B response), are pre-requisites for an offer to connect. Throughout the review process, the GPS document is negotiated, in accordance with the Rules defined negotiating framework. Prior to the commencement of the generator's studies, it is strongly recommended to have sufficient high level technical discussions with Powerlink. Further details are in sections below.

It remains an option to the generator to provide the Full package as the initial submission. It is also an option that the Preliminary Design and FIA packages are submitted together, if a generator wishes to.

Note that this document is a guide of Powerlink's expectations; the NER applies, and AEMO's requirements may differ. AEMO should be consulted as to when it will start its review.



1.2 Recommended Process

1.2.1 Connection Application

A connection application (possibly non-conforming) needs to be submitted for Powerlink to commence review of partial connection application studies (eg: Preliminary Design). Once this connection application is submitted Powerlink will calculate and then provide harmonic polygons, harmonic allocations, and estimate of future background distortion – requirements for generating system design and S5.2.5.2 assessment. It is expected that detailed harmonic studies are performed prior to preliminary design package: as harmonic studies can have an impact on S5.2.5.1, S5.2.5.4, S5.2.5.5 performance, and VCS, among others.

Note that prior to any studies commencing, it is important to confirm with Powerlink that the transmission network topology that was analysed as part of the connection enquiry response remains valid.

1.2.2 Preliminary Design

It is preferred that before a connection package is submitted for the due diligence and GPS negotiation, technical discussions between the proponent and Powerlink are held to cover the following items relating to the PSCAD model of the generating system and key aspects of the generating system performance. The proponent is to provide technical notes and PSCAD model to cover these items.

In preliminary design discussions, it needs to be demonstrated that the PSCAD model has / is:

1. accessible variables, as per S4.3.5 of the Power System Model Guidelines., and characteristics as per Section 2.2 below
2. been aggregated in a way that is acceptable to Powerlink
3. been demonstrated to have been correctly aggregated
4. been demonstrated to have acceptable performance for both the faulted and the un-faulted phase(s) during unbalanced faults: (ie: dIq/dV configuration)
5. had confirmation that communication delays and meter/plant controller cycle times have been adequately modelled (plant controller to generating unit, and connection point meter to plant controller).
6. a plant controller with reasonable active power / frequency response during a fault ride through event
7. a plant controller with reasonable time to re-regulate post fault clearance (handover / takeover coordination).
8. demonstrated that the reactive power control is sufficient to oppose sub-synchronous oscillations in voltage.
9. consistent with a VCS that has had high level details agreed with Powerlink
10. be consistent with discussions with Powerlink about the connection arrangement, and size of the single largest contingency within the generating system.

Technical details of these items is provided below in Section 2.1.

Because harmonic assessment may be ongoing during the preliminary design work, a notional filter size can be included for the purposes of the preliminary design stage. Harmonic assessment should be completed for the FIA package.

Powerlink will issue Technical Queries in its review of the Preliminary Design (and all subsequent submissions), if any items are not clear or do not adequately demonstrate compliance.

1.2.3 FIA Package

Because the FIA provides a more detailed test of generator performance and is critical in the timeline to receive a connection offer, it is acceptable to provide a partial package to facilitate commencement of the FIA, with other work provided at a later time.

The minimum package for FIA is:

- Draft GPS, in particular S5.2.5.1 , S5.2.5.4
- Demonstration of compliance to an agreeable performance standard for S5.2.5.1 and .4 (using either a disaggregated model [eg: PowerFactory], or PSCAD or PSS/E SMIB model.).
- Completion of S5.2.5.2 assessment / filter sizing is required for S5.2.5.1 assessment.
- Comment confirming that the model has been tuned in SMIB model to have S5.2.5.13 performance consistent with automatic access.
- PSCAD model, RUG, DMAT
- PSS/E model, RUG, DMAT
- PSS/E PSCAD benchmarking (as part of the PSCAD DMAT) should be provided
- PSCAD model must:
    - Have technical characteristics, as per the Preliminary Design section (above, including S5.2.5.5 fault performance)

  - Have demonstrate good model performance, with a DMAT. DMAT is as per AEMO guidelines: either
    - full DMAT of a generic OEM model and an agreed reduced scope (which includes at least Powerlink' minimum tests) DMAT of the site specific model; or
    - full DMAT of the site specific model.
- If a synchronous condenser is proposed, S5.2.5.5 NEM case studies in PSS/E, to check that synchronous condenser size and inertia is appropriate for the network (checking for angular stability)
- Voltage Control Strategy
- Single Line Diagram

It is recommended that the OEM is engaged by the customer to confirm that the settings proposed are reasonable.

In the absence of completed S5.2.5.2 and S5.2.5.4 studies, Powerlink can provide an indication of acceptability of a negotiated S5.2.5.1 access standard. However, it is expected that after completing the studies and design for S5.2.5.2 and S5.2.5.4, any additional reactive power from the plant (up to Automatic Access level) will be provided by the generator and agreed as part of the GPS.

1.2.4 Full Package

Prior to accepting a performance standard (5.3.4A letter) and offer to connect, Powerlink and AEMO must perform due diligence on the full connection application package.

This package can be provided at any time, including alongside the FIA package, or while the FIA is in progress, or after completion of the FIA. Note that any changes made in the PSCAD model, due to changes made in the full package, can necessitate some repeat of FIA studies as needed. Also, changes made to the PSCAD model, due to issues identified in the FIA, can necessitate an updated PSS/e model, which can necessitate repeat of some studies / documentation (eg: PSS/e PSCAD mapping / PSDS).

1.3 Timeframes

Powerlink is commonly queried of various time frames within the connection process. General comments are below:

- Harmonic allocations / impedance polygons.
  - These generally take 4 weeks to calculate from the time a connection application has been notified / fee has been paid, and after request has been made.
  - Confirmation of expected plant size and connection point location is needed for calculation of harmonic data.
- Preliminary Design review, or FIA Package review
  - Typically, a time frame of 3 – 4 weeks for an iteration of review of the Preliminary Design package or FIA package review, assuming that there are no major issues identified.
  - Typically there are multiple iterations of preliminary design / FIA package review needed, prior to acceptability to commence FIA. This process minimizes the scope of rework in each iteration, because key technical issues are identified as early as possible in the process.
- FIA duration
  - Assuming a robust model that Powerlink has had prior experience with, and assuming no issues are identified in the FIA, then a nominal time of 4 - 6 weeks is expected from the time FIA starts. Note that our experience is that there are always some issues that needs to be worked on during the FIA process due to the complexity of the generating systems and interactions seen in FIA studies.
  - FIA duration is mostly determined by:

        - Quality of the PSCAD model prior to FIA commencement
        - Powerlink access to OEM technical experts, and OEM's engagement.
        - OEM's willingness to have open technical discussions.
    - Note that FIA commencement is dependent on (a) successful review of the FIA package, and (b) resources.
    - AEMO typically require 2 – 4 weeks for their review of the FIA report.
    - If the FIA finds an adverse system strength impact, then system strength remediation works may be required, which would necessitate detailed discussions. It is important to have discussions with the OEM's modelling team to swiftly resolve FIA issues, so that all parties can work towards a solution.
- The NER specifies timeframes that the NSP must respond to a connection application. The Preliminary Design package and FIA package do not provide demonstration of compliance to all clauses. So, NER response timeframes are considered to be relevant in relation to the submission of all clauses.
- Prior to the issue of a 5.3.4A letter, other projects can become committed at any time. In this event, some re-work may be required. The scope of that work will be defined by Powerlink / AEMO on a case by case basis, but can include, repetition of FIA, S5.2.5.2, S5.2.5.5, S5.2.5.13
- Note that in general, the quality of the connection study report and documentation is an important factor for getting through to agreement of the performance standard. Plots should clearly show the response being shown (ie: appropriately scaled axes), show the appropriate signals.

2. Preliminary Design Technical and Modelling Expectations

2.1 Technical Characteristics of Preliminary Design / FIA Package

There are technical characteristics of the PSCAD model that can be assessed prior to PSCAD DMAT studies being performed. These are detailed below.

It is expected that:

- a disaggregated model (ie: full reticulation system model) has been first created.
- a PSCAD (or PSS/e) model has been tuned within a SMIB model for S5.2.5.5 and S5.2.5.13, so as to have realistic & reasonable control system settings.
- any required harmonic filtering devices are included in the FIA package: harmonic compliance study can be completed by this time.

Note that it is encouraged to discuss with Powerlink the items in this Preliminary Design phase, prior to the commencement of the PSCAD MAT studies.

2.1.1 Accessible Variables

It is critical for understanding the plant that PSCAD models have accessible variables and relevant flags as per S4.3.5 of the PSMG. The PSMG is a Rules requirement specified document. Note also that the PSMG does not permit different versions of the PSCAD model being supplied to NSP and AEMO.

2.1.2 Model Aggregation

PSCAD models must be aggregated as agreed. There can be phenomena that only exhibit when a 3 winding transformer is modelled as a 3 winding transformer. Therefore, typically, despite the computational burden, 3 winding main transformers should not be aggregated to a 2 winding transformer. Aggregation is typically discussed in early technical meetings.

Typically, PSS/e models have 3 winding transformers explicitly modelled as a 3 winding transformer.

The aggregated PSCAD model must be demonstrated to be correctly aggregated, to check for any error in the aggregation process. This is achieved by:

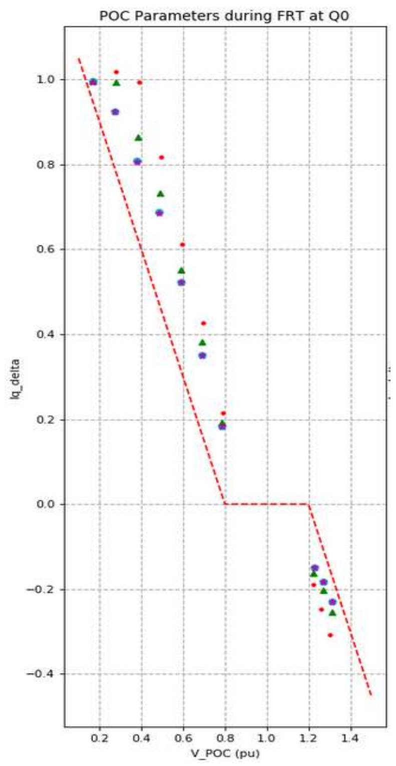
- Turning off all auxiliary dynamic reactive devices (synchronous condenser, STATCOMs)
- Testing, at: Pmax, P50%, P1%, and Qmax and Qmin (6 points), of the unrestricted (no limiters) connection point reactive power capability in both the aggregated PSCAD model and the disaggregated model (eg: PowerFactory model used for harmonic assessment). A BESS should test at Pmax, 0 MW, Pmin. Tests should be carried out at various PoC voltages (eg: 0.9 Vpu, 1.0 Vpu, and 1.1 Vpu)
- Expectation is that for example, a 500 MW plant with 2 equivalent generating units, that an error of < 1 MVA is achieved at the connection point, and that generating unit quantities (active power and reactive power) align between the aggregated model and disaggregated model.
- Quantities at both the connection point and generating unit level should be compared between aggregated and disaggregated models. Additionally, the main transformer tap position should be compared.

Note that aggregation requirements for PSS/E and PSCAD may be different (due to computational limits of PSCAD). If the aggregation method of the PSS/e model is different to the PSCAD model, then the aggregation accuracy of PSS/e model should be checked against the dis-aggregated model as well as (separately to) the PSCAD to dis-aggregated model check.

2.1.3 Performance of Reactive Current in Fault Conditions

Performance of the PSCAD model to unbalanced faults is important to be configured correctly. Depending on the generating unit, positive sequence, negative sequence gains may be available for reactive current injection during fault ride through mode. In most of Powerlink's network, any material contribution to a voltage increase on un-faulted phases (for an unbalanced fault) needs to be avoided if possible. However, no increase on unfaulted phase(s) with a reasonable increase in reactive current on faulted phase(s) can be technically very difficult to achieve in all fault scenarios; and therefore, a reasonable balance must be attempted to be achieved.

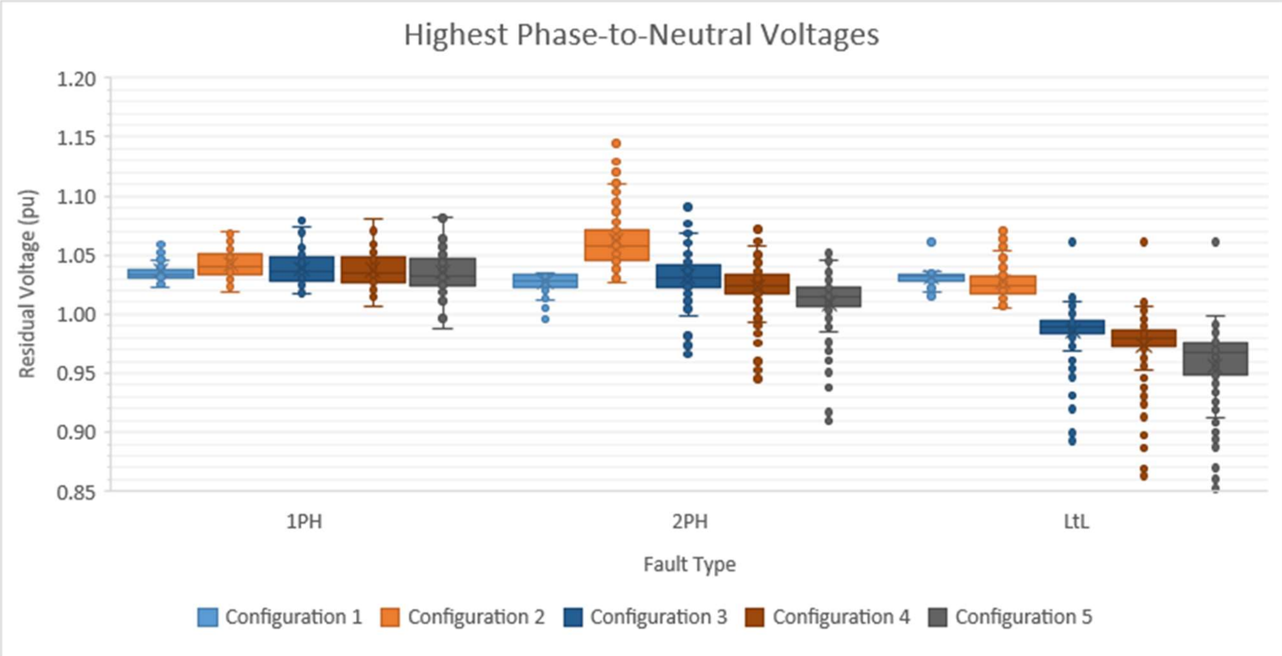
Therefore, as a minimum, a range of positive and negative sequence gains should be studied in SMIB model, for a range of unbalanced faults (ph-ph, ph-g, ph-ph-g), for a range of fault severity (eg: 0.01 Vpu, 0.3 Vpu, 0.6 Vpu, 0.85 Vpu [or other voltage for which fault ride through mode, if present, is activated]), for a range initial reactive power operating points (typically Qmin, Q0, Qmax), assessing both the current contribution (Iq) at the connection point, and the contribution to un-faulted phase voltage. SCR associated with minimum case, and an X/R associated with a minimum case should be used. Faults can be applied for several seconds, to show the settled "in fault" performance. A range of balanced faults should be studied (similar scope to unbalanced faults above), to assess adequacy of Iq contribution for a balanced fault. Ideally, Iq contribution is plotted, similar to the figure below.



For this assessment, plots with appropriate axes are needed of at least: individual phase voltage (PoC), positive and negative sequence voltage (PoC and generating unit), and reactive current (total and sequence components). If there are any issues with Iq rise and settling time, then that should be discussed.

Once the fault response (time domain) have been simulated, the aggregate performance of the configuration can be used, so as to facilitate Powerlink's determination of a plant configuration to achieve reasonable current injected of faulted phase(s), and reasonable voltage increase on non-faulted phase(s).

An example of an aggregated performance assessment of un-faulted phase voltage change is shown below.



Initial studies focus the connection point fault performance; however, both connection point and generating unit level performance needs to be understood, and documented. The GPS and connection study report should report on both PoC and generating unit reactive current quantities.

2.1.4 Communications Delays

If communications delays are not correctly configured, then model performance can be impacted. Communications delays must be shown to be adequately modelled. Note that if communication delays on site are expected to be minimal, there may be a need to model a delay, to represent cycle times of plant controllers / measurement devices.

2.1.5 Plant controller function during / post fault

During / after a fault, expectation is that the plant controller:

- Does not vary the active power, due to the active power / frequency response of the plant controller, during, or immediately after the fault. Ie: it is freezing commands correctly.
- Commences re-regulation of voltage / reactive power promptly after a fault.
- Is appropriately coordinated with generating unit fault ride through thresholds.

The first two items can be easily tested in PSCAD SMIB model, with:

- A single test, with a moderately severe (ie: not shallow) fault for 200 ms, with the active power / frequency function enabled and configured to commence at 50.15 Hz, at 100 ms after fault inception, the swing bus frequency is varied to 50.5 Hz. The plant controller must not send a command to reduce in active power to the generating unit either during the fault, or immediately after the fault (when the frequency measurement has not settled). A general expectation, the plant controller should re-regulate active power of the order of 100 – 200 ms after fault clearance.
- A single test, with a moderately severe (ie: not shallow) fault for 200 ms, with the generating system at a moderately inductive initial operating point, with a reduction in the swing bus

voltage by 5% during the fault. The plant controller has to settle to a reactive power target different to the initial operating condition. Plant controller should be shown to have commenced re-regulating reactive power / voltage of the order of 100 - 200 ms after fault clearance.

The last item, appropriate thresholds, should be considered in the context of the technology used for plant controller and generating units. If both the plant controller and generating unit utilise measurement of the voltage for the purposes of entry / exit of fault ride through mode, then it should be demonstrated that if the plant controller is in fault ride through mode and the generating unit(s) are not in fault ride through mode (or vice-versa), then there is an adequate performance of the generating system.

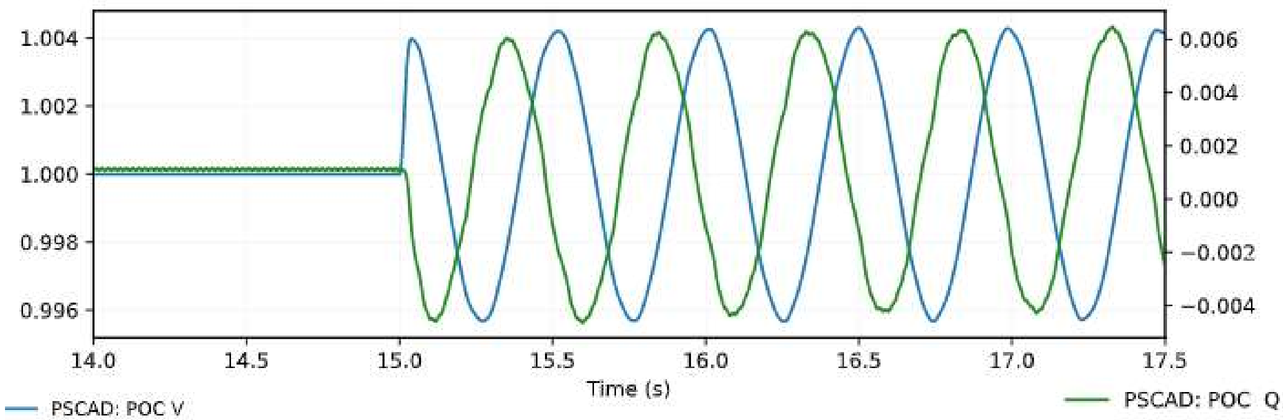
Scenarios where the plant controller is not in fault ride through mode, but the generating units are in fault ride through mode, can result in plant controller windup. Windup should be understood and minimized. Scenarios where the plant controller is in fault ride through mode, but the generating units are not in fault ride through mode, could result in non-controlled connection point voltage.

Performance of these can be understood in SMIB fault studies using different initial reactive powers (to achieve variation in pre-fault generating unit voltage) with fault impedances adjusted to achieve the marginal voltages.

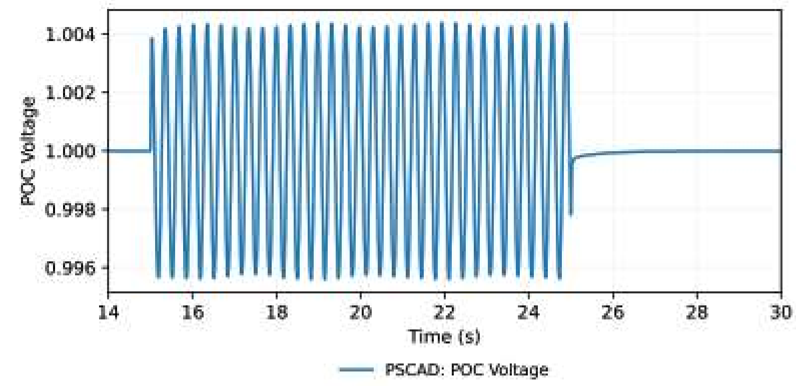
2.1.6 Oscillation Rejection

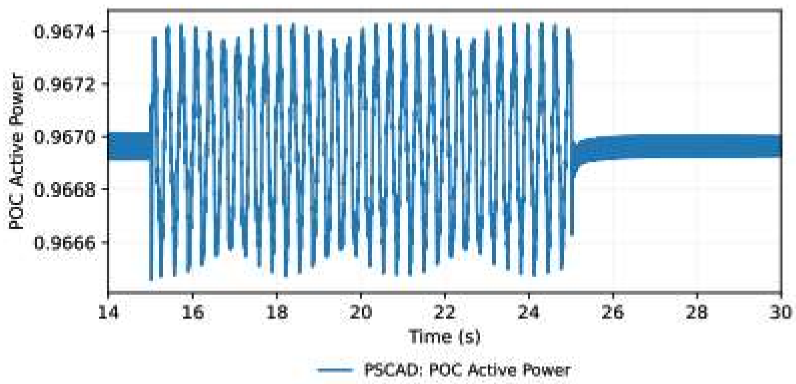
Some plants have difficultly regulating reactive power with sufficient speed to be able to oppose subsynchronous oscillations in voltage. This behaviour can be checked in the oscillation rejection tests that are part of DMAT requirements. In particular, voltage oscillations of 0.1 Hz, 0.5 Hz, 1 Hz, and 10 Hz should be demonstrated. Voltage and reactive power should be shown on the one plot, with different (and appropriate) Y axes for voltage and reactive power; and appropriate X axis time. The angle difference between voltage and reactive power should be reported.

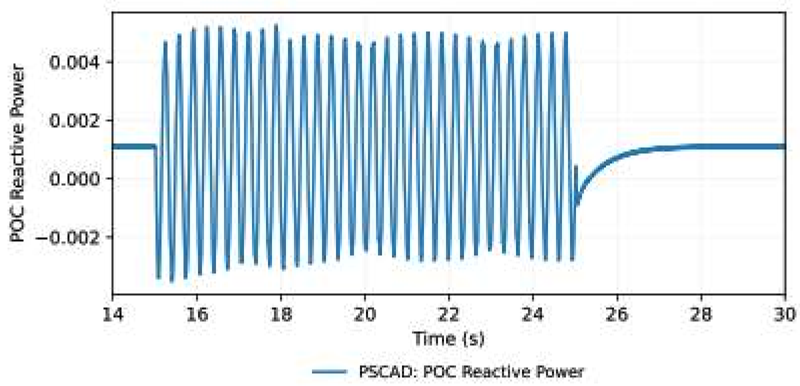
An example of a plot that is helpful for understanding oscillation rejection is as follows:



The following plot is an example of a plot that is NOT helpful for understanding oscillation rejection performance.







Above figures are NOT useful to make any assessment of plant's performance.

2.2 Modelling

Within one of the connection application stages, all of the following must be provided:

- PSS/E model
- PSCAD model
- PowerFactory model suitable for harmonic analysis showing the detailed reticulation system and equivalent Norton harmonic sources(for inclusion in Powerlink's network model for harmonic assessment).
- For synchronous condensors, block diagrams should be provided.
- For grid forming inverters, small signal models and block diagrams will be discussed for each specific project. Typical expectations include:

- The OEM should be submitting an encrypted model in SSAT format, if the submitted block diagram does not represent full dynamics of the plant due to intellectual property (IP) and confidentiality issues.
- The model should include dynamics of both plant controller and inverters.
- Time delays should be included in the model.
- Voltage control and angle/frequency control dynamics including any synthetic inertia at inverter level should be included in the model.

PSS/E and PSCAD model must meet the Rules requirements in the Power System Model Guidelines.

2.2.1 Dynamic Model Acceptance Tests

PSS/E and PSCAD models should be demonstrated to be adequate according to the AEMO published DMAT guidelines. DMAT submission options are as below:

	Option	Full PSS/E DMAT	Partial PSCAD DMAT	Full PSCAD DMAT
1	Complete	Site Specific Model	-	Site Specific Model
2	Partial/OEM	Site Specific Model	Site Specific Model	Generic OEM Model

For a generic OEM model DMAT, the model should be configured with typical gains, typical control modes (eg: generating unit level voltage control), typical size plant (eg: 100 or 200 MW), impedances and configurations. In the Partial/OEM option, both the generic model full DMAT and site specific model partial DMAT are used to inform the robustness of the site specific model.

Note that AEMO published an update to the DMAT in November 2021, which includes a minimum list of items required for the site specific model. In addition to the minimum list in the DMAT appendix, Powerlink requires the following PSCAD / PSS/e DMAT tests to be benchmarked for the site specific model.

DMAT Version 2, Table 22 Reference number	DMAT Test Number Needed	Disturbance Type
58	137, 146	TOV
59	153, 159, 165	Vref Change (only for Vref mode)
60	169	Pref
61	170, 174, 175	Grid Frequency
62	180, 181	Grid Voltage
67	206 – 225	FRT

These tests are benchmarked at the minimum expected SCR. If, at low SCR the PSS/E and PSCAD model responses do not compare well, then this should be discussed with Powerlink further. For BESS models, benchmarking at 0 MW and Pmin is expected.

For a specific project, some further items may also be required for the site specific model.

2.2.2 Model Attributes

Main transformer OLTC must be modelled in PSCAD and PSS/E. PSCAD requires OLTC initialisation logic, ie: fast tapping for the first few seconds of PSCAD simulation time. Models must initialise to any active / reactive power operating point within 3 to 5 seconds.

Some solar plants can operate partial numbers of inverters at night time. The need for modelling this is partially based on the size of the plant. If the night time mode needs to be modelled, then some stability checks are needed in that mode – please discuss with Powerlink; this is not needed as part of the initial / FIA package.

Some wind plants operate in a distinct mode in the absence of wind (eg: some type 3 turbines). If this is the case, then some stability and compliance checks are needed in that mode.

PSCAD models should include appropriate modelling of the saturation of the transformers within the generating system. If the inclusion of saturation is causing alignment issues for PSS/e to PSCAD benchmarking, then saturation could be turned off for those benchmarking studies. R1 model must have saturation included in the PSCAD model.

Models should have be configured with, and have enabled, functionality that is needed to achieve S5.2.5.8 and S5.2.5.11 performance.

Models should include OLTC functionality (distinct to OLTC initialisation), and PSCAD model should include saturation curve characteristics (approximation).

For details of the model used for harmonic studies, please refer to section 3.4 below.

2.2.3 Model Computation / Software Requirements

The PSCAD model must be compatible with PSCAD v5.x. Since July 2022, there is no need to provide a v4.6.x model.. The PSCAD v5.x should be complied with latest Visual studio and Intel OneAPI Fortran Compiler Classic 2021.x (both 32 bit and 64 bit versions to be provided). PSCAD DMAT should be performed in PSCAD version 5.x. PSCAD model time step must be at 10 microseconds or higher.

PSCAD model be compatible with Powerlink's wide area PSCAD model, which includes a requirement that once the generating system PSCAD model is integrated into Powerlink's WAN PSCAD model, the overall execution time of the WAN model is not reduced by the inclusion of the generator. Powerlink's WAN PSCAD main project case is running at 16.6666667 microseconds solution time step and the provided model is integrated using a PNI. If the solution time step of the model is different to 16.6666667 microseconds, a multi-rate PNI will be used. The inverters/turbines should be aggregated accurately at MV side of the transformer as single inverter/turbine instance in PSCAD model to improve simulation speed.

PSS/E model must be compatible with v34.5, or version nominated by AEMO from time to time. PSS/e models must be written in Fortran or acceptable to AEMO. If Fortran is not use, then AEMO is to be notified during preliminary design stage. This can be confirmed in FIA package.

Some PSS/e models include functionality to avoid / minimise spikes that are simulation artefacts. If a model has different spike mitigation options available, then, after the plant has been tuned, the optimal spike mitigation configuration should be implemented. This can be determined by testing the model, with a range of faults (eg: 4 faults of various retained voltages), different source impedances (high / low fault level), with differing spike mitigation options, to determine the optimal configuration. If spike mitigation logic results in an impact on model performance to disturbances, please discuss with Powerlink

2.3 Reporting

The completeness, readability, and usefulness of the connection study report can have a material impact on progression through to 5.3.4A stage. In the connection study report, and all relevant appendicies, it is important that:

- Studies are performed in a way that clearly demonstrates compliance, with all relevant assumptions listed, including all generators that have been included in NEM studies.
- Plots that are included are useful and fit for purposes of conveying information and demonstrating compliance.
- Has been suitably reviewed and quality controlled by the generator prior to submission to Powerlink / AEMO.
- Has plots for fault studies include:
    - Fault ride through flags (plant controller and generating unit)
    - Iq (positive and negative sequence) responses,
    - Per phase voltages

3. GPS Clauses

The following lists expectations of the various GPS clauses. Note that agreement of the GPS is performed in the context of the Rules negotiating framework, that generally requires performance as close to automatic access standards as possible. These are general comments only.

Note that AEMO's may have requirements and guidelines for some clauses that are not listed below, for example S5.2.5.5 multiple fault ride through, S5.2.5.8, S5.2.5.10.

3.1 General Requirements – Plant Tuning / Configuration.

In general:

- If generating units can be configured to regulate the generating unit (inverter/turbine) level voltage, then this is strongly recommended (and this is regardless of location within Queensland): as it can provide for a more robust generating system for future system strength challenges. If there are site wide control limitations with generating units regulating the generating unit's voltage (eg: site power factor or Q control can not be implemented with generating unit fast voltage control), then please discuss with Powerlink. Typically, plants are in voltage droop control for the significant majority of the time: and plant performance in this generating system operating mode is of higher importance than other control modes.
- To account for future system strength changes, and to ensure that the generating system has a level of resilience, expectation is that all inverter based plants have stable and reasonable operation post fault clearance, or for voltage disturbances, with an SCR = 3. This is the case even if the minimum fault level exceeds SCR of 3. In the case where the minimum SCR exceeds 3, GPS compliance is not assessed at SCR 3 (only stability [eg: not re-triggering of fault ride through mode, non-oscillatory response, etc] is assessed). Typically, the DMAT (site specific model and generic model) results are used for this assessment. If the site the minimum SCR significantly exceeds 3, and if it is difficult to tune the plant such that SCR = 3 stable performance and compliant performance at expected SCRs is achieved, then please talk with Powerlink. In this scenario, at minimum Powerlink would need to understand that plant has the capability of stable operation at SCR =3 with an alternate set of settings, and Powerlink would need to understand the minimum SCR for which the plant is stable.
- In general, if the SCR (based on the minimum synchronous fault level, and plant MVA base), is less than 3, then the plant should be tuned for stable and compliant operation at the minimum fault level the inverters can operate at. Alternatively, if the SCR in the minimum fault level scenario exceeds 3, then the plant should be tuned and compliant for the minimum fault level. Plant should be compliant for the maximum fault level, however if this is challenging to achieve (if there is a wide range in minimum / maximum fault level), then please discuss with Powerlink Note that in North Queensland, despite the synchronous fault level, there have been system strength challenges, so generating units, and the plant controller, should be tuned for SCR of 3.
- Note that an SCR of 3, the stability requirements above are not considered to be significant / relevant for grid forming inverters.
- The following should ensure that the right fault levels are used:
  - Maximum and minimum fault level scenarios are consistent with the maximum and minimum fault levels as specified in Powerlink's TAPR (Appendix E). X/R ratio should be obtained from NEM case that has been configured to achieve the fault level scenario.
  - Typical configuration of synchronous units for one of the minimum fault level scenario is listed below.
  - Note that the AEMO snapshots are tuned for specific user conditions so, they should be modified in order to achieve the required minimum and maximum fault levels and appropriate intra-regional and inter-regional power flows.
  - Available Fault Level (AFL) quantities are not useful for tuning of the plant and making any primary plant decision.

  - The latest version model from the OEM should be used for performance tests / generator assessment. Please discuss with Powerlink if this is not appropriate.

3.2 General Requirements – NEM Model Tuning

For S5.2.5.5 and S5.2.5.13, assessment is expected to be performed within NEM models.

- NEM files should be based off latest AEMO snapshots.
- NEM files should normally consider:
  - high and low fault level scenarios; A typical synchronous generator dispatch for a low fault level case could be 4 x Tarong units, 2 x Stanwell units, 1 x Callide unit, 4 x Gladstone units and 2 x Kareeya units.
  - high and low transfers on nearby transmission corridors (inter-regional or intra-regional connectors).
  - Wind farms and BESS plants should consider dispatches at day and night time (ie: with / without solar farms).
  - Different operating points should be considered (eg: charging, discharging, neutral active power for BESSs).
  - Depending on the specific project, the range of system NEM files is needed for either all S5.2.5.5 and S5.2.5.13 studies, or a subset of these studies for sensitivity studies.
- NEM files should consider, to some level, generators that are committed or existing. The list of committed generators may change at any point in time in the connection process. In general:
  - Plants that are near to the generator being studied should be explicitly modelled with their dynamic model.
  - Very large (> 200 MW) generators moderately remote from the connection point should be explicitly modelled.
  - Other generators (ie: large or small generators remote from the connection point), should be considered, and modelled as a negative load if appropriate, for the purposes of reducing the nearby online synchronous sources, or affecting a change to the power flow on a nearby transmission corridor.
  - Generators connecting to south west Queensland will need to explicitly model generators in northern NSW.
- Powerlink will advise as to the committed plant Powerlink considers should be included. Note that it is strongly suggested to re-check with Powerlink just prior to commencement of NEM S5.2.5.5 / S5.2.5.13 studies.
- When including generators, care should be taken to ensure that inter-regional and intra-regional transfers are within technical and stability limits (eg: non excessive power transfers, reasonable voltage profile).
- In Far North Queensland, Powerlink is constructing a 3rd 275kV circuit. Powerlink can provide a Python script for this network change.

3.3 S5.2.5.1

In general:

- Within the GPS, the agreed capability (potentially limited by connection point limiters), should be shown, with a data table defining the capability.
- Capability should be calculated using the best available data of the generating system, without any margin kept in reserve.
- Within the connection study report, capability curves should be provided. These figures are illustrative, and should: (a) show the full unrestrained capability of the generating system, and (b) show the region of agreed capability (possibly restrained / limited capability) for which the plant is compliant with all other GPS clauses (including S5.2.5.4 and S5.2.5.13).

- If switched shunt reactive devices are included within the generating system, then capability diagrams should include the effect of any switching logic.
- For BESSs, the capability should be defined for both charging and discharging modes.
- In the context of large generating systems that have large 33kV reticulation systems, the electrically farthest generating unit needs to be shown to stay online. This can be achieved by determining, within a dis-aggregated model, the maximum voltage change between the 33kV bus and the electrically farthest generating unit, and using that voltage difference in conjunction with generating unit voltage protection settings and 33kV bus voltage to assess the ability of the farthest generating unit to stay online.
- S5.2.5.1 capability is shown with all generating units and all auxiliary plant in service. S5.2.5.1 does not, by itself, permit generating units / reactive equipment to come offline, unless specifically indicated. S5.2.5.1 capability curves are generally calculated from dis-aggregated models, but can be calculated from aggregated models, assuming the dis-aggregated and aggregated models have been benchmarked to each other [ie: aggregation check].
- The agreed capability is applicable for both (a) active power limited by energy source input limitation; and (b) reference active power limitations. If this is a limitation for generating systems for which the generating unit has an inherent minimum active power limitation, then this should be explicit in the GPS.
- Local limit and temperature derating information should be explicit in the GPS, and detailed, if required, in the VCS.
- Solar farm night time reactive power injection should be studied and performance agreed in the GPS. Expectation is that a connection point reactive power of at least 0 MVAr +/- 1 MVAr at night time can be achieved.
- If, within the scope of the negotiating framework, a performance standard less than automatic access is proposed, then evidence of all generating units operating at their maximum capability must be provided.
- Confirmation that the DC side design is sufficient to support maximum active power and maximum capacitive reactive power.
- The loading on the main transformer (both HV and LV windings) should be checked, and sized to meet S5.2.5.1 and S5.2.5.4 requirements. Headroom for harmonics should be considered.
- Generating unit voltage limitation(s) should be checked.
- For Type 3 (DFIG) wind farms, the zero wind capability should be included in the capability diagram.
- For solar farms, the night time reactive power capability should be listed.
- The rating of any 33kV incomer cables should be understood and modelled if there is the potential to impact generating system active / reactive power capability.

3.4 S5.2.5.2

In general:

- After a connection application fee has been paid, Powerlink provides:
  - harmonic allocations,
  - network harmonic impedance polygons, and
  - estimate of future harmonic background levels.
- Harmonic performance is assessed in the context of AS 61000.3.6:2001, and TR 61000.3.6:2012.
- Acceptance of the S5.2.5.2 performance standard requires a study using the initial reticulation system model. Expectations of the harmonic studies include:
  - Clear, explicit and detailed description of the method used in the analysis.
  - Use of Norton equivalent models.
    - OEM derivation / justification of the Norton equivalent model should be provided.

        - In general, the harmonic current of the worst case active power level should be considered.
        - The Norton equivalent impedance may vary with active power levels – this variation of impedance should be considered.
        - The Norton equivalent impedance should be a complex impedance.
        - Solar farm night time mode is likely to not have similar harmonic Norton equivalent model as day time, and so should be modelled separately.

    - Use of a disaggregated reticulation system model.
    - Transformer saturation characteristics (of both the main transformer and the generating unit transformers) to be included in model. Highest reasonably expected voltage should be considered. Transformer saturation of the MV / LV generating unit transformer may need to be modelled separately to the generating unit Norton equivalent model.
    - Traversal of the vertices of the network harmonic impedance polygons. If polygon vertices are far apart, then impedance points along the polygon edge should be included. Impedance points internal to the polygon can also be considered.
    - Compliance assessment with and without the presence of background distortion. Both of these assessments are performed against the allocation of the plant. This means that the total effect of distortion caused by the generating units, and amplification of background due to the reticulation system, must be assessed against the allocation.
    - Summation within the generating system: linear summation is typical conservative assumption, unless more specific detailed information is available.
    - Summation of generating system distortion and background should be as per the General Summation Law (ie: default alpha exponents).
    - Calculation of amplification factors of the generating system –with and without filters.
    - Compliance assessment without filter (to show extent of harmonic problem if that filter is out of service).
    - Sensitivity studies to changes in reticulation system impedances should be performed.
    - Sensitivity studies to internal outages (eg: outage of collector group) should be performed.
    - If a wind farm is using type 3 turbines (DFIG), then the turbine operation when the turbine generator is disconnected (converter connected) – ie: under no wind conditions – should be assessed separately to normal operation.
    - No particular consideration should be made for triplen harmonics when there is a delta winding in the generating system: they should be assessed in the same manner as other harmonic orders.
    - If assessment in the presence of background distortion utilises the 95% percentile of the area (distinct to vertices / polygon boundary) of the harmonic polygon [as a proxy for 95% percentile of time], then it is important to understand the harmonic performance in the remaining 5% of polygon area: including the network configuration that it aligns to. This because 95% of polygon area does not reflect 95% of time.
    - In general, if harmonic studies indicated a need for HV connected harmonic filters, then detailed discussion with Powerlink should occur prior to finalizing the design.
    - If there is a need for harmonic filter (as indicated by harmonic studies using future background harmonic levels), but with no need for a filter with existing background levels, then a discussion with Powerlink should occur to explore option to install a harmonic filter if the need arises during the lifetime of the plant (distinct to initial commissioning of the plant). This is particularly the case for harmonic orders for which compliance cannot be readily maintained using 33 kV filtering (ie: higher order harmonics).
    - Background levels for which the plant must remain in compliance for may be specified in the GPS S5.2.5.2.
    - If a separate project becomes committed, then harmonic allocations may have to be revised.
    - To facilitate harmonic analysis in the operation of the plant, connection point (or HV) harmonic current from a suitable CT core should be recorded.

  - For solar farms, both day time and night time harmonic performance is to be assessed (so that the need or lack of need of filter switching can be determined, due to harmonic resonance). Solar farm inverter night time harmonic distortion can be different (ie: different Norton equivalent) to day time mode.
  - Notch filters can result in harmonic amplification challenges. Instead, a C type damp filter should be considered in design.

Note that, in general, due to the uncertainties of the harmonic modelling, Powerlink may be able to accept a performance standard, even if, a conservative harmonic study shows some minor / infrequent non-compliant operation.

3.5 S5.2.5.3

Accurate modelling of frequency protection systems is expected (including generating unit level frequency protections). S5.2.5.3 can be assessed in either PSS/e or PSCAD.

3.6 S5.2.5.4

General expectation / comments:

- Powerlink will define for each project
  - V_Qmax – a typical voltage consistent with historical data and expected operation at the maximum capacitive reactive power expected of the plant (Qmax)
  - V_Qmin – a typical voltage consistent with historical data and expected operation at the maximum inductive reactive power expected of the plant (Qmin).
- The following conditions should be assessed, with the given assessment criteria.
- Note the following table assume that both V_Qmin and V_Qmax are either 1pu or greater than 1pu. If V_Qmax or V_Qmin is less than 1.0pu, please discuss the below assessment with Powerlink.
- If there are more onerous operating point(s) than that at Pmax (Pmax and Qmax/Qmin) please discuss this with Powerlink in relation to S5.2.5.4 and other GPS assessments. For some technologies / plant configurations, some Pmin Qmin / Pmin Qmax tests are not required. Additionally, some generating units have capabilities that impose irregular connection point active / reactive power capabilities: testing at corner points is generally required.

ID	Technology	Initial Operating Conditions			Connection Point Voltage Change	Assessment Criteria
		Active Power	**Reactive Power**	**Voltage (Vpu)**		
1	SF, WF, BESS	Pmax	Qmax	1.0	To 0.9 Vpu, and separately 1.1 Vpu	Plant stays connected, P and Q are not reduced
2	SF, WF, BESS	Pmax	Qmin	1.0		
3	BESS	Pmin	Qmax	1.0		
4	SF, WF, BESS	Pmin	Qmin	1.0		
5	SF, WF, BESS	Pmax	Qmax	V_Qmax	To (V_Qmax – 0.1) Vpu	Plant stays connected, P and Q are not reduced
6	SF, WF, BESS	Pmax	Qmin	V_Qmin	To (V_Qmin – 0.1) Vpu	Plant stays connected, P and Q are not reduced
7	SF, WF, BESS	Pmax	Qmax	V_Qmax	To 1.1 Vpu	Plant stays connected, P and Q are not reduced
8	SF, WF, BESS	Pmax	Qmin	V_Qmin		
9	SF, WF, BESS	Pmax	Qmax	V_Qmax	To 0.9 Vpu,	Plant stays connected; and voltage is regulated at either the plant level of generating unit level during transient period; and the total plant level reactive power response during transient period is at, or exceeds the response of the plant controller alone. (ie: generating units can not remain stuck in FRT mode)
10	SF, WF, BESS	Pmax	Qmin	V_Qmin		
11	BESS	Pmin	Qmax	V_Qmax		
12	SF, WF, BESS	Pmin	Qmin	V_Qmin		
13	SF, WF, BESS	Pmax	Qmax	V_Qmax	To 0.7, 0.8, 1.15, 1.2, 1.25, 1.3, 1.35 Vpu curves	Plant stays connected.
14	SF, WF, BESS	Pmax	Qmin	V_Qmin		
15	BESS	Pmin	Qmax	V_Qmax		
16	SF, WF, BESS	Pmin	Qmin	V_Qmin		

Further comments:

- S5.2.5.4 is assessed with no impedance between the swing bus and the connection point bus.
- A test for the voltage going down to 0.7 or 0.8, and then going up to 0.9 Vpu should be performed, to ensure that the plant exits LVFRT mode if the connection point voltage is 0.9 Vpu. Similarly, a test for the voltage going up to 1.15 or 1.2 Vpu, and then going down to 1.1 Vpu should be performed, to ensure that the plant exits HVFRT mode if the connection point voltage is 1.1 Vpu.
- Assessment of 0.7, 0.8, 0.9 and 1.1, 1.15, 1.2 Vpu criteria can be conducted in PSS/e or PSCAD. Short duration high voltage criteria (voltages > 1.2 Vpu) should be conducted in PSCAD.
- In the table above: Pmin refers to, for the purposes of S5.2.5.4 assessment:
  - For a wind farm, 1% Pmax

  - For a solar farm, 1% Pmax
  - For a BESS, both maximum charging mode load, and also P = 0 MW.

- If the connection equipment, between the connection point and the generator's local HV bus is either an underground cable or an overhead line that is more than 1 km away, then a discussion will be required between Powerlink / AEMO / Generator as to S5.2.5.4 compliance assessment, and management of the differences between the local bus and connection point bus in voltage / active power / reactive power.
- The generator's normal voltage will be equal to the nominal voltage (eg: 275kV or 132kV).
- Statement from generator that plant will not trip for voltages above 1.35 Vpu at the PoC for 20 ms, including that there are no overvoltage protection elements with trip times less than 20 ms.
- Local limit (as listed in S5.2.5.1), must be dynamically calculated, to include any dependency of active power on the PoC voltage.
- Depending on the generating system configuration and generating unit OEM, there may be a requirement to assess S5.2.5.4 with a voltage drop on 1 phase or 2 phases to 0.7 Vpu for 2 seconds, or 0.8 Vpu for 10 seconds.
- During a voltage drop to 0.9 Vpu, changes to the reactive power consumption / charging of passive devices (cables, shunt capacitors) may occur. Reactive power is to be maintained at the connection point, to account for any changes in reactive power from passive equipment.
- If a generating system includes generating unit that have short term overload capability that is commensurate with main transformer tap changer delays, then please discuss S5.2.5.4 assessment with Powerlink.
- Note that when the active and reactive power "are not reduced", then this is a reference to an active power and reactive power response that does adversely affect as disturbance. Examples:
  - If the plant is initially operating inductively, and the connection point voltage drops to 0.9 Vpu, it is acceptable (and required) that the reactive power of the generating system moves to its capacitive limit.
  - If a plant is initially operating at its capacitive limit, if the voltage increases to 1.1 Vpu, then the plant should reduce reactive power until the inductive limit is reached.
  - If a plant is initially operating at its inductive limit, and if the the voltage increases to 1.1 Vpu, then the reactive power must remain at its inductive limit, ie: must not operate more capacitively.

3.7 S5.2.5.5

In general:

- The 275kV network CB failure clearance time is 325 ms, all other 132 / 275 / 330 kV times are as per the NER requirements. In general, autoreclose can be considered to be enabled on all feeder faults, with, in general, a 5 second deadtime.
- Powerlink will advise as to the clearance times of distribution network faults in the area.
- A range of contingencies should be studied, including:
  - Nearby and remote faults.
  - Remote faults: on the transmission system, and slower remote faults on the nearby distribution system. These should cover scenarios where the generating systems is marginally within its fault ride through mode, marginally outside its fault ride through mode, and show performance when only one of plant controller and generating unit is in fault ride through mode.
  - Faults that change the power transfer on nearby power transmission corridors, or loss of generation of nearby generators

- Reactive current injection performance requirements should be defined at the connection point. Generating unit level performance contribution can be additionally listed.

- Plant controller should not be regulating (either voltage / reactive power or frequency / active power) during a disturbance for which the plant controller considers a fault (ie: plant controller has entered FRT mode).
- Generating system should have the capability to recover active power within 100 ms after fault clearance (assuming voltage recovers to 0.9 pu and frequency does not exceed frequency regulation threshold). Active power recovery may need to be configured to be slower if needed for network requirements.
- Generating system should be re-regulating active power / frequency and reactive power / voltage within ~200ms after clearance of a fault.
- When the plant controller considered that there is a fault on the power system, then the plant controller should not use frequency / voltage measurements, for the purposes of post fault regulation of active / reactive power once the plant controller's FRT mode has been cleared.
- The reactive current injection should be configured to achieve an outcome that a reasonable amount of reactive current is contributed on the faulted phase, and any increase to current on unfaulted phase(s) is minimised (to avoid exacerbating the disturbance and avoid causing a disturbance to the unfaulted phase).).
- Performance of the current injection algorithm should be assessed (in PSCAD). In particular, any contribution to the increase in voltage on unfaulted phases (for an unbalanced fault) should be carefully considered. This is particularly the case for generating units for which the positive sequence and negative sequence current injections can be independently configured. Generally, this is assessed in PSCAD with a fault applied for an extended duration. Refer to sections 2.1.3 and 2.1.5 above. Note also AEMO may have further requirements for Iq compliance assessment.
- If Powerlink has been involved in discussions regarding the level of reactive current response (ie: dIq/dV gradient), then if there are any issues identified with the 40 ms rise and 70 ms settling time requirements, please discuss further. Generally, rise and settling times commence when the generating unit voltage has dropped below its FRT threshold. Iq rise and settling times should be listed in a table of all cases that have been studied.
- Reactive current rise and settling times should be assessed in PSCAD SMIB model, and should consider balanced and unbalanced faults.
- Temporary overvoltage events should be studied in PSCAD.
- Multiple fault ride through:
    - Evidence of model MFRT is supplied as part of the DMAT.
    - Confirmation from OEM should be provided to confirm compliance of the plant, on aspects that may not be modelled, including: any chopper resistor / auxiliary supplies.
- There is no need to assess tower failure faults (causing double circuit trip), but there may be a need to study double circuit contingencies, for double circuit contingencies that have a history of double circuit outages, as per AEMO's Vulnerable Transmission Lines[2] list.
- Different OEM / generating units have different algorithms for entering (or not having) fault ride through mode (eg: positive sequence voltage below a threshold; any phase voltage below a threshold, etc). The voltage quantity that is used in the GPS for the purposes of dIq/dV specification (threshold and magnitude of contribution) should be based on the voltage quantity used in the generating unit to enter fault ride through mode. The negative sequence contribution must be explicitly listed in the GPS.

[2] AEMO | List of Vulnerable Transmission Lines - https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/power_system_ops/procedures/op-supporting-docs/vulnerable-lines.pdf

3.8 S5.2.5.7

3.8.1 Assessment Method

- With a low fault level, with the generator exporting maximum active power, perform SMIB studies as follows:
- Perform two PSCAD SMIB studies, determining plant stability / operation:

1. With a load of 30% of the proposed generator's Pmax at the PoC (unity power factor) modelled, and a source impedance consistent with a low fault level scenario, trip the load to determine plant response.
2. With the voltage / frequency / angle response to a system event (based on PSS/e study, as per below), play back this voltage / frequency / angle response [as measured at the point of connection] to the PSCAD generator model.

- Perform one PSS/e SMIB study, determining plant stability / operation:

3. With the voltage / frequency / angle response to a system event (based on PSS/e study, as per below), play back this voltage / frequency / angle response [as measured at the point of connection] to the PSS/e generator model.

- Additional to the studies, confirmation is needed that the generating units do not have a maximum power angle change protection function, and if they do, then what the setting is.

3.8.2 Method for determining response (from system model) for PSCAD and PSS/e SMIB study

Using a low fault level PSS/e full NEM OPDMS system file:

- Ensure that all recently committed renewable generators in the area are in service at appropriate level (ie: near Pmax). [ie: the same generators required as per S5.2.5.5 studies].
- For proposed generators in South Queensland, ensure that QNI is 1000 MW south (or more). Assuming the swing bus is in NSW / Vic (not Queensland), if additional Queensland generation is needed to be added (to increase QNI southerly transfer), then this should be done by either (a) reducing Queensland system load; or (b) increasing Queensland generation. If (b), then do not add any generation within South Queensland (ie: add generation to Central or North Queensland).
- For proposed generators in Central or North Queensland, ensure that Boyne Island load is at maximum load of study cases available.
- Do not model the proposed generator.
- Governors disabled (short term response is of interest).
- For South Queensland:
  - Trip QNI (both Bulli Creek – Dumaresq branches), to observe response.
  - If system is not stable, reduce QNI southerly transfers, so that a stable Queensland system is obtained post separation.
- For Central and North Queensland:
  - Trip Boyne Island load.
  - If system is not stable, trip the maximum portion of the Boyne Island load that results in a stable system.
- With the proposed generator <u>not</u> modelled, for the given event, monitor, at the proposed PoC the voltage magnitude, frequency, and phase.
- Ensure that the system conditions used are documented in the connection studies report.
- Use this recorded response to play back the voltage magnitude, frequency and angle response to determine plant stability within PSCAD SMIB and either PSS/e SMIB or PSS/e NEM model. For the angle response, only the immediate change of angle (after trip of QNI / Boyne Island), is of relevance.

3.9 S5.2.5.8

Plants should have the capability to reduce active power by 50% within a short time frame in the presence of very high frequency. If a generating system is unable to quickly reduce active power, then supporting evidence should be provided, and alternate scheme proposed. Discussion are required with AEMO as to timeframes required to reduce active power (typically of the order of 3 seconds).

Typical words for parts of S5.2.5.8 are in Section 4 below.

Note that previously Powerlink expected duplicated relays to detect sub-synchronous oscillations. This requirement is being reviewed as part of a review of S5.2.5.10 standard expectations.

3.10 S5.2.5.9

Expectation is that there are duplicated protection systems, each capable of fault clearance within times that are consistent with the NER times for connection point voltage. Each of the duplicated protection systems would clear a given fault with the same circuit breaker/s at the same time. Ie: cascading tripping can not occur – a fault on one 33 kV feeder should not result in the loss of supply to another 33 kV feeder.

Energisation of the main transformer should not substantially vary the voltage at the connection point, to below 0.9 Vpu or above 1.1 Vpu. Either point on wave switching is needed, or a transformer energisation study is needed.

Note that 275 kV clearance times can necessitate particular circuit breaker arrangement (eg: a circuit breaker at the generator end of a transformer ended line).

Note that it is acceptable that a collector circuit is tripped out for a fault in a generating unit, if that is necessary to achieve required fault clearance times. In general the speed of protection system clearance is of greater criticality to the network than whether a single collector group has a higher likelihood of tripping (due to mal-grading with generating unit protection). The 33kV bus protection and 33kV collector group protection must be coordinated. Ie: the bus should only be cleared if there is a genuine bus fault, or a trip of the collector group CB with that CB failing.

Typical words for parts of S5.2.5.9 are in Section 4 below.

3.11 S5.2.5.10

In general, Powerlink's expectation is that a generating system does not trip and does not ramp down if it detects unstable power system operation. An alarm is required, and possible operating protocol may be needed.

Note that Powerlink is currently reviewing standard expectations for the GPS and VCS.

3.12 S5.2.5.11

S5.2.5.11 assessment can be conducted in SMIB. Note that AEMO may require compliance demonstrated in NEM model.

3.13 S5.2.5.12

Note that almost always, assuming a generator does not connect directly to a inter or intra regional corridor, an automatic access standard is unlikely to be achieved. For example, every generator in South Queensland will reduce the Central Queensland – South Queensland transient stability limit, but by less than the output of the generator (ie: maximum supportable load increases).

Thermal overloading on nearby 132kV or distribution networks should be assessed: to determine the need for a thermal runback scheme.

Voltage step change limits are not required to be assessed in this clause. Expectation is of a dynamic study where an inter-regional connector is set to its stability limit and its angle and voltage are observed with the plant explicitly modelled, and compared to the same fault but with the plant modelled as a negative load.

Typical words for S5.2.5.12 are in Section 4 below.

3.14 S5.2.5.13

In general,

- S5.2.5.13 should have compliance demonstrated in NEM studies (not SMIB). SMIB could be used for initial tuning (prior to FIA), but compliance demonstration is required in NEM files.
- In general, S5.2.5.13 should demonstrate compliance for 5% voltage disturbances that are external to the generating system (eg: switching of a large, potential fictitious shunt reactive device at the connection point).
- S5.2.5.13 should also demonstrate compliance for voltage reference step changes. These should include: +/-5% changes, from different reactive power operating points (eg: OER, UER, UPF), and should include a 5% Vref step when the plant is approximately 2.5% Vref step away from any limit.
- The results of each study should be summarised with a data table showing all cases studied and the rise and settling time of each quantity.
- In general, plants should have the capability to operating in Qref or PFref mode, one or two checks of stability should be performed to demonstrate stability, but the scope of studies should be minimal.
- Voltage step coming out of the limiter should be tested: the response needs to meet GPS times.
- Depending on the configuration of the network, sensitivity studies with the next nearest largest voltage control device out of service may be needed.
- If a plant is connecting in South East Queensland (where there are power oscillation damping [POD] devices on Powerlink SVCs), then the plant may need a capability to coordinate with SVC control so that it doesn't have adverse impact on existing POD performance.
- It is expected that BESSs have the capability for power system stabilisation functionality.

3.15 S5.2.8

The generating system's equipment should have equipment able to withstand a connection point fault as specified as per Powerlink's standard equipment specifications[3].

Note that this implies demonstration that the both the HV and 33kV switchboard equipment is suitably rated.

3.16 Voltage Control Strategy

3.16.1 Measurement Points

Care must be taken that the measurement points are carefully chosen, and agreement is reached if appropriate. For example, whether the plant controller measurements are being taken from the connection point, or the local high voltage bus. If measurements are being taken from the local high voltage bus (ie: distinct to the connection point), then discussion is needed.

[3] Substation Ratings Specification (powerlink.com.au)

3.16.2 Generating System Configuration

Some generating units prioritise either active power or reactive power. For some OEMs, there are technical challenges with active power prioritisation.

Care must be taken if considering a voltage higher than nominal on the 33kV system. There can be effects of generating unit saturation, or generating unit transformer saturation that could be impacted.

In general, generating systems are to be configured to control the voltage of the high voltage side of the transformer (or the connection point), operate in voltage droop control, with 4% droop on MVA base (slower outer control loop). Additionally, if available, the generating units should regulate the generating unit's voltage in fast voltage control.

The voltage control strategy should not list a particular value as the voltage reference target. In plant testing and operation, the voltage target will be set as per Powerlink / AEMO operational requirements.

3.16.3 Failure / Alternate Modes

The voltage control strategy includes details of plant operation. It needs to include high level information as to what will occur in various failure modes / conditions, including:

- Failure of communications between plant controller and generating units
- Failure of communications between plant controller and plant controller meter.
- Failure of connection point VT
- Failure of main transformer OLTC (ie: inability to regulate 33kV voltage)
- Outage of a subset of generating units (expect: that connection point reactive power limits scale proportionally, to minimise the S5.2.5.4 non-compliance), while maintaining S5.2.5.13 compliance.
- Switching schemes of any auxiliary devices.
- Algorithm / method of handling partial clouding (for solar farms)
- Solar farm – night time design and voltage during transition from daytime to nighttime mode and vice-versa
- Wind farm – high wind speed performance
- Wind farm – minimum active powers needed.
- Wind farm – no wind performance.

In the connection application stage (prior to 5.3.4A), high level comment on these items is needed. In R1 stage, separate detailed documents may be required (eg: communications design report). Note that in general, the failure of a piece of equipment within the generating system is not necessarily a reason to trip the plant: ramping down in agreed timeframes is preferred, if a shutdown of the plant is required.

3.16.4 Solar Farm Behaviour at Night Time

In general, expectations for solar farm behaviour at night time include:

- Connection point reactive power capability of at least 0 MVAr
- Voltage control at PoC
- Compliant harmonic performance (S5.2.5.2)

Compliant harmonic performance may necessitate harmonic filters to stay in service (to avoid resonance/amplification issues). Inverters may need to stay online providing reactive power. General preference is that plant should be configured to be in voltage control mode (with a reactive power capability range that includes 0 MVAr at the connection point). A prior discussion with Powerlink is required If plant can only operate in reactive power control mode (that achieves a reactive power of 0 MVAr at the connection point).

. Alternatively, solar farms can be disconnected at the point of connection at night time. A description of the night time configuration is required in the VCS, including any transitions, and this can be done prior to 5.3.4A letter. Depending on the proposed configuration, there may be modelling requirements. Modelling (PSS/e and PSCAD models and RUGs) for night time mode should be provided prior to 5.3.4A letter.

If inverters are staying online (in reactive power mode), then a dynamic model of the plant at night time is to be provided. Some checks on the model stability in the night time configuration is needed (ie: subset of DMAT), and some checks of plant performance are needed.

In general, performance expectations include:

- Provision of reactive power as per the proposed S5.2.5.1 nighttime capability, including 0 MVAr for all voltages between 0.9 Vpu and 1.1 Vpu. Note that this does not imply that all inverters need to stay online at nighttime, just that a sufficient number of inverters need to be online to achieve 0 MVAr at the connection point.
- Inverters that stay connected for all voltage profiles of S5.2.5.4, with the inverters responding within its capability for S5.2.5.4 over-voltage profiles.
- Inverters that stay connected for a range of fault types (studied on a low SCR scenario)
- Stable S5.2.5.13 response

Detailed scope is to be discussed with Powerlink and AEMO.

3.16.5 Other

If (in plant operation) some proportion of generating units are unavailable / out of service, then the requirement is that a proportional amount (to S5.2.5.1 capability) of reactive power is provided. This has potential implications on the AVR design of three winding connection point transformers. Additionally, for three winding connection point transformers, there should be careful consideration of 33kV bus regulation noted in the VCS. For example: regulating just one of the two buses at a time (in which case, what are the condition(s) to regulate the other bus), taking an average of the two bus voltages, or regulating one bus based on a current / Q algorithm.

The general expectation is that compliance is maintained as far as possible when a generating system is in a degraded state. Therefore, reactive power limits should scale with proportion of online generating units that are online.

If a switchable capacitor bank is included within the generating system, then it should not be too large: in general, the switching of the capacitor should not result in an instantaneous (ie: before inverter / plant controller action) change of connection point voltage of more than 3%.

If a HV cable is proposed as part of the connection arrangement, then careful consideration of the harmonic performance (including potential amplification of background harmonics) prior to commitment of a cable (compared to an overhead line), should be performed.

There is currently no differentiation between operation constraints that are related to system strength, and operational constraints that are related to economic dispatch / thermal constraints. Therefore, if a generator receives an active power command of 0 MW, then all inverters should be disconnected. This may then necessitate disconnection of shunt capacitors / harmonic performance. The proposed actions for an active power command of 0 MW should be documented in the VCS.

To facilitate harmonic analysis in the operation of the plant, connection point (or HV) harmonic current from a suitable CT core should be recorded. This should be included in the VCS.

4. Typical GPS Wordings

4.1 S5.2.5.8

Standard inclusions:

The *generating system* must be automatically disconnected within 120 [or 220] milliseconds by a remote control scheme whenever the part of the network to which it is connected has been disconnected from the national grid and has formed an island. The *Generator* will co-ordinate with the Network Service Provider to ensure that remote signals are provided to the *Generator* to facilitate implementation of the anti-islanding protection scheme. The remote signals will be derived from either the status of network elements or comparison of phase angle measurements.

4.2 S5.2.5.9

Note: [HV Voltage] is either 330 kV, 275 kV, 132 kV or 110 kV, as appropriate.

Times are either: (100, 120, 250), or (120, 220, 430) ms for the (“[HV primary clearance time]”, “[MV primary clearance time]”, “[CB Fail time]”).

Assumed that medium voltage bus has a nominal voltage of 33 kV.

Auxiliary equipment (eg: harmonic filters) protection clearance time should be explicitly listed.

1. *Generating system* Fault Clearance Times

   Fault location: [HV Voltage] kV bus and [HV Voltage]/33 kV transformer

      'A’ protection ≤ [HV primary clearance time] ms

      'A' protection CB fail ≤ [CB Fail time] ms

      'B’ protection ≤ [HV primary clearance time] ms

      'B' protection CB fail ≤ [CB Fail time] ms

   Fault Location: 33 kV Bus

      ‘A’ Protection: ≤ [MV primary clearance time] ms

      ‘A’ Protection CB fail: ≤ [CB Fail time] ms

      ‘B’ Protection: ≤ [MV primary clearance time] ms

      ‘B’ Protection CB fail: ≤ [CB Fail time] ms

   Fault Location: 33 kV Feeders

      ‘A’ Protection: ≤ [MV primary clearance time] ms

      ‘A’ Protection CB fail: ≤ [CB Fail time] ms

      ‘B’ Protection: ≤ [MV primary clearance time] ms

      ‘B’ Protection CB fail: ≤ [CB Fail time] ms

The setting of all primary and backup *protection systems* must satisfy the following criteria:

i. Protection operating characteristics must not result in Network User failing to comply with the Generator Performance Standards.

ii. Protection operating characteristics must be such that cascading tripping of equipment within the *generating system* does not occur, except that protection on the 33kV collector group feeders may trip for faults on downstream equipment where required to meet maximum fault clearing times.

2. The *generating system* has primary *protection systems* to disconnect from the *power system* any faulted element within the protection zones that include the Connection Point within the fault clearance times listed above.
3. Each primary *protection system* has sufficient redundancy to ensure that a faulted element within its protection zone is disconnected from the *power system* within the applicable fault clearance time with any single protection element (including any communications facility upon which that *protection system* depends) out of service.
4. Breaker fail *protection systems* are provided to clear faults that are not cleared by the circuit breakers controlled by the primary *protection system*, within the breaker failure fault clearance times, listed above.
5. The *protection system* design is coordinated with other *protection systems*, avoids consequential disconnection of other Network Users' facilities and takes into account the Network Service Provider's existing obligations under their connection agreements with other Network Users.
6. The Network Service Provider and the *Generator* will cooperate in the design and implementation of *protection systems* to comply with this clause S5.2.5.9, including cooperation on:
    1. the use of current transformer and *transformer* and *voltage transformer* secondary circuits (or equivalent) of one party by the *protection system* of the other;
    2. tripping of one party's circuit breakers by a *protection system* of the other party; and
    3. co-ordination of *protection system* settings to ensure inter-operation.
7. Energisation of [any of] the *Generator's* [HV Voltage]/33 kV transformer will not result in the *voltage* at the Connection Point varying outside the range 0.9 pu to 1.1 pu of Normal Voltage.
8. Faults within [any of the HV or] the 33 kV blindspot(s) are cleared from the network side within a primary clearance time of [MV primary clearance time] ms.

4.3 S5.2.5.12

The *generating system* has *plant* capabilities and *control systems* that are sufficient so that when *connected* to the *power system* it does not reduce any *inter-regional power transfer capability* below the level that would apply if the *generating system* were not *connected*.

For intra-regional limits, the *generating system* has plant capabilities, *control systems* and operational arrangements sufficient to ensure there is no reduction in:

- the ability to supply Customer load as a result of a reduction in *power transfer capability*; and
- power transfer capabilities into a region by more than the combined sent out generation of the *generating system's* operating *generating units*.

The operational arrangements may include:

i. Application of real time ratings
ii. Implementation of a fast run-back scheme following plant outages (subject to renegotiation of S5.2.5.8 with AEMO and the Network Service Provider)
iii. Pre-contingent constraints on generator output.

Pursuant to ii. above, the *generating system* must preserve the ability within the *control systems* to receive a remote signal from the Network Service Provider and/or AEMO and automatically run-back or trip to a specified or agreed capacity following the outage of a critical transmission element.

5. R1 GPS Compliance Package Expectations

After agreement of performance standards (5.3.4A letter), and after a project has become committed, the generator will enter R1 phase. Ie: prior to plant registration. In general, expectations of the R1 package include:

- That minimal changes (related to detailed design / factory data) are made to the data / configuration / models of the (pre-5.3.4A) connection package. If proposed changes are significant, then those changes would be managed as part of a 5.3.9 process.

- Expected refinements include:
  - Modelling of saturation in PSCAD model.
  - Detailing of failure and alternate modes in the VCS.

- Powerlink expects a report detailing any and all changes between the data / impedances / configuration / models / settings of the data in the (pre-5.3.4A) connection package and the R1 data as part of the R1 package submission. Due diligence on R1 package is inefficient and very lengthy without such report.
- It is expected that the model impedances have been updated with design / factory data prior to the submission of the R1 package. If studies have to be repeated, then they should be performed with the design / factory data.
- If there are significant changes in design, then please discuss with Powerlink and AEMO prior to submitting an R1 package, and this would be managed as part of a 5.3.9 process. In this scenario, it is important that all changes are listed. If changes have been made that are not listed in the technical note, then Powerlink's review process will be delayed.

Note that there are multiple requirements as part of R1 studies that are not detailed in this document (eg: protection detailed designs, communications failure mechanisms, etc).