VICTORIA – SOUTH AUSTRALIA (HEYWOOD) INTERCONNECTOR UPGRADE

TEST PROGRAM FOR INTER-NETWORK TESTS

AUSTRALIAN ENERGY MARKET OPERATOR

Version Release History

VERSION	DATE	BY	REVIEWED	CHANGES
1.0	22/5/2015	Michael Redpath	Christian Schaefer	Initial draft
2.0	24/8/2015	Gratian Punchiwedikkarage Michael Redpath	Christian Schaefer	Added Monitoring and recording section, stage 1 constraint information and process charts. Restructured and extended for compliance with Rules clause 5.7.7.
3.0	8/9/2015	Michael Redpath	ElectraNet	ElectraNet's comments incorporated. Constraint information revised. For issue as draft test program to jurisdictional planning representatives under Rules clause 5.7.7(n)
4.0	7/10/2015	Michael Redpath	Natalie O'Connor Cathy Sage	Incorporates feedback from Powerlink, TasNetworks and TransGrid
5.0	6/11/2015	Michael Redpath	Christian Schaefer Natalie O'Connor	For publication as final under Rules clause 5.7.7(q)

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Important Notice

Purpose

This document has been prepared by AEMO as required by rule 5.7.7(q) of the National Electricity Rules (Rules), and has effect only for the purposes set out in the Rules. The Rules and the National Electricity Law (Law) prevail over this document to the extent of any inconsistency.

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1. SCOPE

This inter-network test program for the Victoria – South Australia (Heywood) interconnector upgrade is published in accordance with the requirements of Clause 5.7.7(q) of the National Electricity Rules (Rules), which deals with inter-network tests. It only covers the inter-network tests required under clause 5.7.7 for the Heywood interconnector upgrade. It does not cover plant commissioning tests and other network tests that may be required.

The Heywood interconnector upgrade project will increase the transfer capability between Victoria and South Australia via the Heywood Terminal Station (HYTS) from a maximum of 460 MW to approximately 650 MW in both directions. By increasing power transfer capability by more than 3%, the interconnector upgrade is anticipated to have a material inter-network impact. On this basis, and in accordance with Clause 5.7.7 and the Inter-network Test Initiation Guidelines, AEMO has determined that inter-network tests are required.

2. INTERCONNECTOR UPGRADE BACKGROUND

The Heywood interconnector connects South Australia to south-west Victoria. Interconnector transfer is presently limited to a maximum of 460 MW in both directions by the rating of the two existing 500/275 kV transformers at the Heywood Terminal Station.

AEMO (as network service provider) and ElectraNet are joint proponents of the Heywood interconnector upgrade to increase power transfer capability.

AEMO and ElectraNet are responsible for upgrade works in Victoria and South Australia respectively. The upgrade consists of:

- Installation of a third 500/275 kV transformer at HYTS to remove the 460 MW thermal transfer limit. AEMO has identified that this transformer is scheduled for initial service in December 2015.
- Series compensation on the South East – Tailem Bend 275 kV (SESS – TBTS) lines - this alleviates stability limits. ElectraNet has identified that the series compensation is scheduled for initial service in July 2016.

To meet its responsibility for the upgrade works in Victoria, AEMO has engaged AusNet Transmission Group Pty Ltd. in its capacity as transmission network service provider to install, own and operate the third 500/275 kV transformer at HYTS.

AEMO and ElectraNet aim to achieve full commercial service of the Victoria – South Australia (Heywood) interconnector upgrade by March 2017.

3. REQUIREMENTS OF THE RULES ADDRESSED IN THIS TEST PROGRAM

AEMO in its capacity as system operator of the National Electricity Market, notified the Proponent that it believed an inter-network test was required in accordance with cluse 5.7.7(g).

AEMO issued an initial draft of the test program to each *jurisdictional planning representative* in accordance with Clause 5.7.7(m) and received their feedback under Clause 5.7.7(o). AEMO responded individually to each *jurisdictional planning representative* who provided feedback on the draft test program. Where required, the representatives' feedback was included in the text, and relevant sections have were reworded and expanded as a result.

AEMO subsequently published a revised draft of test program in accordance with Clause 5.7.7(p)(1) and invited *Registered Participants* to make written submissions. AEMO received no submissions from *Registered Participants* on the draft test program.

As noted in section 1 of this document, AEMO is now publishing this finalised test program in accordance with Clause 5.7.7(q).

4. NEED FOR INTER-NETWORK TESTS

Inter-network tests for the Heywood interconnector upgrade are intended to measure the impact on system damping. They are required to:

- Quantify the impact of the Heywood interconnector upgrade on damping of modes of oscillation within and between all NEM regional networks for the full range of power transfer on the upgraded interconnector.
- Verify that the damping of all modes of oscillation meets specified Rule requirements.
- Validate the system model at the increased interconnector transfer between Victoria and South Australia in both directions as afforded by the upgrade.

Inter-network tests are required following commissioning of each major upgrade component. Tests will therefore be conducted in two stages as outlined below.

Stage 1

Stage 1 Inter-network Tests shall be carried out following installation and commissioning of the third HYTS transformer.

Stage 2

Stage 2 Inter-network Tests shall be carried out following installation and commissioning of the SESS – TBTS series compensation.

5. COMPLIANCE WITH CLAUSE 5.7.7 OF THE RULES

Clause 5.7.7 (r) states that in determining the test program, AEMO must so far as practicable have regard to the following four principles:

1. Power system security must be maintained in accordance with Chapter 4 of the Rules.
2. The variation from the central dispatch outcomes that would otherwise occur if there was no inter-network test should be minimised.
3. The duration of the tests should be as short as possible consistently with test requirements and power system security. and
4. The test facilitation costs to be borne by the Proponent should be minimised.

Principle 1

At all times, AEMO will have sole management of power system security, and no variation to the requirements of Chapter 4 are required by these tests.

Principle 2

System conditions for conduct of the tests will be achieved through normal market dispatch and, therefore, does not represent a distortion of market outcomes. The tests may be scheduled to coincide with particular loading and interconnector transfer conditions that appear in predispatch. However no action, other than waiting for more favourable opportunities, is intended to secure particular test conditions.

Principle 3

The main determinant of the time required for a test is the duration of data acquisition needed to characterise the frequency and damping of oscillation modes. Experience from previous tests has established minimum testing times that will give satisfactory results and are relatively immune to the influence of market variations. There is no trade-off required between the test period and system security, because the latter is continuously managed by AEMO to the same standard, whether or not there is a test in progress.

Principle 4

This Test Program does not envisage it will be necessary AEMO to acquire Test Facilitation Services (as contemplated by the Clause 5.7.7(ac)) to establish conditions necessary for the Inter-network Tests (refer section 9 of this document).

6. TEST METHODOLOGY

6.1 Test Conditions

Tests will involve continuous monitoring of system damping over a nominated range of system conditions. Test conditions are to be defined in terms of the following key system variables known or predicted to affect system damping:

- Power transfer between Victoria and South Australia via Heywood and Murraylink over the full range afforded by the upgrade.
- South Australian demand over a range of ≤ 900 MW to at least 2800 MW
- South Australian wind generation over a range of ≤100 MW to at least 1000 MW
- Southerly QNI flow to at least 1000 MW

Test facilitation services may be utilised if the required conditions are not obtained within a reasonable time (refer section 9).

Tests are to be carried out at a series of hold points defined by fixed limits to power transfer over the Heywood and Murraylink interconnectors. The full constraint set for the applicable stage of the upgrade is to be applied in addition to the fixed transfer limits at all times during the tests. It is anticipated that the full constraint set will at times undercut the fixed limits, subject to system generation and loading conditions.

The majority of inter-network tests will be carried out under transmission system normal conditions. Tests may be conducted during planned outages of major transmission plant where system damping is considered to be affected. This may include outages of SVCs and major transmission lines. AEMO and ElectraNet will identify any planned outages for which tests are to be conducted. It is not intended to arrange transmission plant outages for the purpose of conducting inter-network tests where this would reduce transfer capability or otherwise impact adversely on the market.

6.2 Generic System Damping Tests

The majority of system damping tests will utilise the continuous system perturbations caused by small, natural variations in system load and generation. No deliberate switching of transmission lines or other plant will be required for these tests. The cost of performing the tests and the impact on system security and the market is therefore minimised.

A generic system damping test at a nominated hold point will involve the following steps:

- Pre-test simulations of expected damping performance for the proposed test conditions using the University of Adelaide's Mudpack program.
- Raising of the constraint on maximum Vic-SA interconnector transfer within the National Electricity Market Dispatch Engine (NEMDE) to the hold point level required for the test
- Continuous security monitoring by AEMO
- Allowing the market to deliver the required transfer over the Heywood interconnector and other interconnectors to be specified in the detailed test procedures
- Observation and monitoring of system damping until the required range of system conditions is obtained - a period of at least 24 hours is anticipated for each test
- Cessation of test operation at the fixed transfer level required for the test and market operation within secure constraints
- Offline test analysis by identification of changes in damping that occurred during the test period, compared with changes indicated by simulation of the actual test conditions

At the conclusion of each test and based on results of the offline test analysis, the Test Co-ordinator (refer section 8) shall advise whether:

- Adequate data are available to identify the level of damping at the test level;
- Damping observed during the test was within the expected range; and
- A test at a higher transfer level may be scheduled, subject to AEMO's management of system security.

Flowcharts illustrating the process for conducting the tests, reviewing the test results and progressing between test hold points are included in appendix A.

6.3 Series Capacitor Switching Tests

Manual switching of the SESS – TBTS series compensation may be included in stage 2 tests to supplement the generic system damping tests. These tests would involve insertion and bypass of both series capacitors simultaneously. As both SESS-TBTS lines will remain in service, the risks associated with these tests are lower than for line switching and are considered acceptable. Long and short duration switching tests are proposed.

Long duration tests will involve switching the series capacitors on both SESS-TBTS lines in and out together for consecutive 2~3 hour periods. The process to perform these tests would be similar to a generic system damping test as described in section 6.2. The system will be operated to constraints applicable without the series capacitors in service during these tests.

Short duration tests will involve simultaneous switching of both series capacitors. The capacitors will be bypassed (switched out) and reinserted (switched in) within about two minutes. Time domain measurements will be obtained during the tests to enable assessment of system performance. The series capacitors will be in service before and after these tests. This will enable the system to be operated at higher levels of power transfer and yield more useful test results, while meeting system security requirements.

Results of similar short duration switching tests conducted on the QNI interconnector were obscured by randomly occurring background oscillations. The series capacitor short duration switching tests may be curtailed if similar issues with background oscillations are encountered.

ElectraNet and AEMO will determine appropriate times for long and short duration series capacitor switching tests, taking into consideration the availability of the series capacitors and security of the NEM.

6.4 Monitoring of Naturally Occurring Disturbances

Existing monitoring equipment records naturally occurring disturbances on the power system. Records of such disturbances can be useful in identifying system damping as well as non-linear or "large signal" system responses. Records of any natural system disturbances occurring during the inter-network test program will be reviewed and if considered valuable, included as test evidence to verify system dynamic performance and to validate the simulation model.

7. PROPOSED TIMING OF THE TESTS

Before stage 1 Inter-network Tests, the Heywood transformer will be commissioned by AusNet Transmission Group Pty Ltd. Before stage 2 Inter-network Tests, the series capacitors will be commissioned by ElectraNet. Commissioning under the relevant agreements for those works will include functional checks of all associated protection systems including the series capacitor bypass scheme.

AEMO will monitor the switching operations performed as part of the plant commissioning tests. Recordings will be analysed where considered to provide useful information about system damping.

Stage 1 Inter-network Tests will start when the Heywood transformer commissioning tests are complete, and the transformer is cleared for normal service. Stage 1 tests are expected to begin in December 2015 and be complete by July 2016.

Stage 2 Inter-network Tests will start when the SESS-TBTS series capacitor commissioning tests are complete, and the series capacitors are cleared for normal service. Stage 2 tests are expected to begin in July 2016 and be complete within about eight months. High demand and peak interconnector flows are most likely to be delivered by the market during the 2016-17 summer.

8. MANAGEMENT OF POWER SYSTEM SECURITY DURING THE TESTS

AEMO will exercise its normal responsibility for power system security throughout the test program and must be satisfied that the power system meets the security requirements specified in Chapter 4 of the Rules at all times. AEMO will manage security mainly by observing constraints that are included in the dispatch engine NEMDE.

The security risks, already small, are further mitigated by the following:

- Each test will be supported by simulations that will cover worst-case outcomes. Tests will not proceed if the predicted performance is outside of specified Rules requirements.
- AEMO and ElectraNet will certify that they are satisfied on the basis of simulations that the proposed test conditions lie within the secure technical envelope.
- AEMO will monitor system damping continuously throughout the system damping tests using on-line monitoring equipment as described in appendix C. If measured damping is outside of Rules requirements, the on-line monitoring equipment will raise an alarm immediately, the test will be cancelled and AEMO will reduce interconnector transfer to a secure level.
- AEMO will monitor system responses in real time during the short duration series capacitor switching tests. If measured responses are outside of Rules stability requirements or not as anticipated, the test will be cancelled and AEMO will reduce interconnector transfer to a secure level.
- At all times during the tests, the proponents' and major plant contractors' technical staff will be available to provide remedial action if required.

Under Clause 5.7.7(ad) an Inter-network Test must be coordinated by an AEMO-nominated officer (Test Co-ordinator) with authority to stop the test or any part of it, or vary the procedure within pre-approved guidelines determined by AEMO if that officer considers them necessary. The guidelines determined by AEMO for taking these actions are outlined in section 10.

There is no need for special contingency arrangements as all tests will be carried out under secure system conditions applicable to future commercial operation of the upgraded Heywood interconnector. The normal security-constrained dispatch provided by NEMDE will ensure sufficient reserve to cater for reduced flow between Victoria and South Australia to within constraints applying before the upgrade.

9. REQUIRED POWER SYSTEM CONDITIONS FOR CONDUCTING A TEST

System damping tests will require relatively constant system conditions over several hours, and hence will avoid the morning run-up and peak, the evening peak, and the nightly hot water peak. Indicative test periods are 9 am to 5 pm, and midnight to 7 am on most days.

Switching out or in of critical interconnecting lines for substantial periods during the test may invalidate results and cause a need to repeat or extend the test interval. Critical lines are those that have an impact on system damping, and will be identified to AEMO by Transmission Network Service Providers (TNSPs). Having a line switched out for the full duration of a test has no impact, provided the test conditions can be obtained in a secure manner.

System conditions for conducting a system damping test will generally require total power transfer in a specified direction between Victoria and South Australia. This will be achieved through normal market dispatch. The tests may be scheduled to coincide with particular loading and interconnector transfer conditions that appear in predispatch. No action, other than waiting for more favourable opportunities, is intended to obtain these conditions.

This test program does not identify any requirement for engaging Test Facilitation Services. However, Clause 5.7.7(u) of the Rules provides that:

> u The Proponent in respect of an inter-network test must seek to enter into agreements with other Registered Participants to provide the test facilitation services identified in the test program in order to ensure that the power system conditions required by the test program are achieved.

AEMO and ElectraNet expect that the range of system conditions required to complete the tests will be delivered by the Market. However, should the full range of required conditions not be obtained within a reasonable period of time, AEMO and ElectraNet may seek to obtain test facilitation services in order to complete the tests.

Test facilitation services would only be sought for completion of stage 2 tests at least 12 months after the SESS-TBTS series compensation is commissioned.

If Test facilitation services are required, AEMO will amend the test program accordingly at that time.

10. GUIDELINES AND DECISION MAKING FOR CONTINUING OR CONCLUDING A TEST

A test will be scheduled on the basis of:

- NEMDE predispatch indicating:
  - Ability to achieve required Victoria – South Australia transfer in the specified direction within security constraints.
  - Regional demands and transfers on other interconnectors consistent with the test scope.
  - No planned switching of critical interconnecting lines during the period.
- Availability for service of all apparatus necessary for monitoring test outcomes being confirmed.

The guidelines given by AEMO to the Test Co-ordinator are summarised below.

Under clause 5.7.7(ad), the Test Co-ordinator may stop, suspend, reschedule or abandon the test or any part of it or vary the procedure in the event that:

- There is a predicted inability to maintain secure dispatch at the test transfer level.
- The on-line damping monitoring systems become unavailable.
- There is a problem with any installation of damping monitoring equipment or damping analysis software that could prevent analysis of results or invalidate the test.
- On-line damping monitor shows low damping, and AEMO has the reasonable opinion that this can be best corrected by reducing transfer between Victoria and South Australia.
- There is a necessity to vary test procedures or redesign the test to ensure that relevant conclusions and recommendations may be drawn from the test results.
- Extra analysis or review (in consultation with the relevant TNSPs or AEMO) is required,
- A contingency disturbs the expected constancy of system conditions or any other changes in system conditions occur that may invalidate test data.
- An unplanned outage of a critical line or SVC occurs that is not restored to normal within 10 minutes.
- There is a problem with any transmission plant. or
- AEMO identifies any other reasonable grounds to stop the test consistent with its obligations under the Rules.

Except in urgent circumstances, the Test Co-ordinator will consult with relevant test team members who could inform the decision (including AEMO and ElectraNet).

AEMO will implement any constraint required to maintain security when a decision is made in accordance with the above guidelines.

11. TEST ANALYSIS

11.1 Measuring the Power System Response

Power system response will be monitored using existing, permanently-installed measuring equipment at a number of locations. This equipment will record all system data required for the Inter-network tests. It includes the following:

- **Oscillatory System Monitor (OSM)** – The OSM consists of phasor measurement units (PMUs) located near load centres in the four mainland regions. The PMUs record voltage magnitude and relative angle in each region referred to a common GPS time signal. The OSM includes two software tools for calculating and recording the damping and frequency of major system oscillatory modes derived from PMU measurements.

    - Psymetrix PhasorPoint real-time oscillatory stability tool – continuously displays an historic record of measured damping in AEMO's control centres. This on-line tool calculates damping of dominant system oscillation modes from voltage phasor measurements averaged over several minutes. It will be used for system security assessment during test periods.

    - Modal identification algorithm developed by Queensland University of Technology (QUT) and TransGrid – calculates system modal damping from PMU measurements over a longer period. This off-line tool has been benchmarked for accuracy and nominated by AEMO to assess damping in accordance with Schedule S5.1.8 of the Rules including, if required, applying constraints to ensure that the criterion for "adequate damping" in the Rules is satisfied.

- **High Speed Monitors (HSMs)** – The HSMs record continuous RMS data at 50 samples per second plus triggered waveform data. HSM data will be used to assess time domain system responses to series capacitor switching and naturally occurring disturbances. Triggered waveform data will be used to check for evidence of sub-synchronous resonance (SSR) or sub-synchronous control interaction (SSCI) following service of the SESS – TBTS series capacitors.

Further details of monitoring equipment are included in appendix C.

11.2 Analysis of Test Results

At each testing stage, the measured levels of damping will be compared with computer-based damping analysis applied to system loadflow “snapshots” captured by AEMO’s systems during the tests. These comparisons will be used to:

- Determine whether system damping performance is consistent with that predicted by the system model, and hence whether analytical results can be extrapolated to less favourable system conditions that are not tested (including post-contingency damping).
- Where necessary, develop or refine procedures to adjust simulation parameters or simulation output to improve representation of actual system damping.

Any significant differences between the simulated and measured responses should be explainable. Inexplicable results may lead to a need to repeat tests, vary the test procedure or necessitate a delay to the test program while the discrepancy is investigated.

12. IMPACT ON PARTICIPANTS' PLANT

12.1 Generic System Damping Tests

The equipment used to measure power system damping measures the inherent damping of the power system without need for specific disturbances to be applied. Hence, most of the inter-network tests will have no visible or material impact on Participants' plant connected to the Grid.

12.2 Series Capacitor Switching Tests

The disturbance caused by insertion and bypass of the SESS – TBTS series capacitors as seen by Participants will be no greater than routine switching of local transmission lines.

13. COMMUNICATION WITH PARTICIPANTS

This test program has been placed on the AEMO website in accordance with clause 3.13.13. Tests described in this program may only start after 20 business days from publication.

Market Notices will be issued giving notice of the following:

- Intended commissioning of the third Heywood transformer and the intended start of stage 1 inter-network tests.
- Intended commissioning of the SESS – TBTS series compensation and the intended start of stage 2 inter-network tests.

During active testing, a Market Notice and/or Communication will be issued to advise when a series of tests will be conducted. This will be done weekly, with daily updates if the test schedule changes. As dispatch for testing will be achieved through the market systems, the market impact of the scheduled test will be evident to market participants through predispatch and dispatch schedules.

If it is necessary to vary a test procedure, in a manner that AEMO reasonably considers does not differ materially from that stated in this Program, AEMO will advise the market of the change reason through established communications.

At the end of testing at each test hold point, a final Market Notice will be issued to advise when the increased capability of the Heywood interconnector (as defined by the hold point) ceases to be subject to Inter-network test conditions and is released to the Market. This step is at AEMO's discretion, and will follow consideration by AEMO of a report on the results of all damping tests for that hold point.

14. TEST PROCEDURE

14.1 Stage 1 – Service of Third HYTS Transformer

Prerequisites for Stage 1 tests.

- HYTS M3 transformer in service and commissioned.
- Network constraints for service of the M3 transformer implemented in market systems (NEMDE).

Stage 1 test hold points.

The full constraint set for service of the M3 transformer is to be applied in addition to the fixed hold point transfer limits at all times during stage 1 tests.

Hold Point	Applicable constraints
1	± 500 MW via HYTS, ± 650 MW via HYTS and Murraylink
final	System normal constraints for service of the M3 transformer apply (test methodology as for hold point 1 - refer Section 6.2)

Table 1: Stage 1 Test Hold Points

For the stage 1 hold point tests, Vic-SA flows will be driven by the market within the defined constraints. System damping will be continuously monitored during the hold point testing period. Larger system disturbances, exceeding pre-defined HSM trigger thresholds shall be recorded if they occur. Most of the nominated market driven test scenarios are required to be covered at each hold point before proceeding to the next hold point. The test scenarios are similar for each hold point.

System damping performance will be reviewed to determine whether damping is satisfactory and what correction factor (offset) needs to be applied to the level of damping obtained from Mudpack simulations. Simulation results, using system snapshots taken at the time of tests, will then be used to show that system damping following the worst case contingency for each oscillatory mode would not fall below the level required by the Rules.

Appendix B outlines revised and new constraints expected to determine the maximum level of HYTS transfer during stage 1 inter-network testing. These constraints are under review and subject to change before or around the time of the tests.

Damping tests

- SA to Vic flow as driven by market within the defined constraints.
- Continuous monitoring of system damping.
- Continuous monitoring of system disturbances.

Review Test Results

- Compare damping measurements with Mudpack simulation results from system snapshots.
- Review Mudpack results for next hold point with worst case contingency.
- Compare records of any naturally occurring disturbances with simulations using Power Technologies International's PSS/E program with relevant system snapshots.

Assessment Criteria

The following criteria must be satisfied before proceeding to the next hold point.

- System damping meets Rules requirements at all times.
- Responses to any disturbances meet system stability guidelines.
- Measured damping and responses to any disturbances compare with simulations.

Simulation model calibration and/or offset to the simulated damping will be adjusted, if required, to improve agreement with measurements.

14.2 Stage 2 - Service of SESS – TBTS Series Capacitors

Stage 1 inter-network tests are assumed to have been completed before the start of stage 2 tests. Stage 2 tests are to include series capacitor short duration switching tests as well as generic system damping tests.

Prerequisites for Stage 2 tests

- SESS – TBTS series capacitor off-line commissioning is completed.
- Series capacitor automatic bypass scheme is in service.
- Series capacitors are available for service.
- Network constraints for service of series capacitors are available for implementation in market systems (NEMDE).

AEMO proposes that initial series capacitor testing involves a short-duration insertion followed by analysis of the recorded current waveforms to demonstrate absence of sub-synchronous oscillations. To make any oscillations easier to observe, AEMO proposes to conduct this test when the Heywood interconnector power transfer is low (i.e. 50 Hz phase currents are low). Current waveforms recorded during subsequent testing and naturally occurring events will be analysed to confirm the absence of sub-synchronous oscillations.

At the first stage 2 test hold point, the constraint set applicable without the series capacitors will remain in effect. Hold points are to be set such that the Vic-SA transfer limit is not less than that applicable at the conclusion of the stage 1 tests (without the series capacitors).

Stage 2 test hold points

Hold Point	Applicable Constraints
1	• Constraint set applicable without the HYTS – SESS series capacitors in service
2	• ± 600 MW via HYTS, ± 800 MW via HYTS + Murraylink • Constraint set applicable with one of the two HYTS – SESS series capacitors in service (to apply with both series capacitors in service – shall revert to hold point 1 constraints if one or both series capacitors are out of service)
3	• ± 650 MW via HYTS, ± 850 MW via HYTS + Murraylink • Constraint set applicable with the HYTS – SESS series capacitors in service
4	• ± 700 MW via HYTS, ± 850 MW via HYTS + Murraylink • Constraint set applicable with the HYTS – SESS series capacitors in service
Final	• Constraint set applicable with the HYTS – SESS series capacitors in service (test methodology as for previous hold points - refer Section 6.2)

Table 2: Stage 2 Test Hold Points

14.2.1 Hold Point 1

Vic – SA flow as driven by market and limited by constraints applicable without SESS-TBTS series capacitors in service.

Series capacitor short duration switching tests

Vic to SA ≥ 500 MW - wait for flow to be driven by market:

- Insert and bypass the No 1 or No 2 line series capacitor.
- Insert and bypass the No 1 and No 2 line series capacitors simultaneously.

SA to Vic flow ≥ 500 MW - wait for flow to be driven by market:

- Insert and bypass the No 1 or No 2 line series capacitor.
- Insert and bypass the No 1 and No 2 line series capacitors simultaneously.

Damping tests

- SA to Vic flow as driven by market within pre-existing constraints.
- Continuous monitoring of system damping.
- Continuous monitoring of system disturbances.
- Both series capacitors switched in and out for consecutive 2~3 hour periods.

Review test results

- Compare damping measurements with Mudpack results from system snapshots.
- Compare records of any naturally occurring disturbances with PSS/E simulations using relevant system snapshots.
- Adjust simulation model or model calibration if required.
- Review any available waveform data from the HSMs for evidence of sub-synchronous resonance (SSR) or sub-synchronous control interaction (SSCI).

If assessment criteria met then proceed to hold point 2.

14.2.2 Hold Point 2

Vic – SA flow as driven by market and limited as shown in Table 2.

Series capacitor short duration switching tests

Vic to SA flow ≥ 550 MW - wait for flow to be driven by market:

- Insert and bypass the No 1 or No 2 line series capacitor.
- Insert and bypass the No 1 and No 2 line series capacitors simultaneously.

SA to Vic flow ≥ 550 MW - wait for flow to be driven by market:

- Insert and bypass the No 1 or No 2 line series capacitor.
- Insert and bypass the No 1 and No 2 line series capacitors simultaneously.

Damping tests

- SA to Vic flow as driven by market within applicable constraints.
- Continuous monitoring of system damping.

Review test results as for hold point 1.

If assessment criteria met then proceed to hold point 3.

14.2.3 Hold Point 3

Vic – SA flow as driven by market and limited as shown in Table 2.

Series capacitor short duration switching tests

Vic to SA flow ≥ 600 MW - wait for flow to be driven by market:

- Insert and bypass the No 1 or No 2 line series capacitor.
- Insert and bypass the No 1 and No 2 line series capacitors simultaneously.

SA to Vic flow ≥ 600 MW - wait for flow to be driven by market.

- Insert and bypass the No 1 or No 2 line series capacitor.
- Insert and bypass the No 1 and No 2 line series capacitors simultaneously.

Damping tests as for hold point 2.

Review test results as for hold point 1.

If assessment criteria met then proceed to final hold point.

14.2.4 Hold Point 4

Vic – SA flow as driven by market and limited as shown in Table 2.

Series capacitor short duration switching tests

Vic to SA flow ≥ 650 MW - wait for flow to be driven by market:

- Insert and bypass the No 1 or No 2 line series capacitor.
- Insert and bypass the No 1 and No 2 line series capacitors simultaneously.

SA to Vic flow ≥ 650 MW - wait for flow to be driven by market:

- Insert and bypass the No 1 or No 2 line series capacitor.
- Insert and bypass the No 1 and No 2 line series capacitors simultaneously.

Damping tests as for hold point 2.

Review test results as for hold point 1.

If assessment criteria met then proceed to final hold point.

14.2.5 Final Hold Point

Vic – SA flow as driven by market and limited by constraints applicable with the HYTS – SESS series capacitors in service (refer Table 2).

Series capacitor short duration switching tests

Vic to SA flow ≥ 700 MW - wait for flow to be driven by market:

- Insert and bypass the No 1 or No 2 line series capacitor.

SA to Vic flow ≥ 700 MW - wait for flow to be driven by market:

- Insert and bypass the No 1 or No 2 line series capacitor.

Damping tests as for hold point 2.

Review test results as for hold point 1.

If assessment criteria met then release full interconnector capacity to the market.

APPENDIX A – TEST PROCESS CHARTS

Heywood inter-network testing process chart is as follows

Figure 1: Testing process

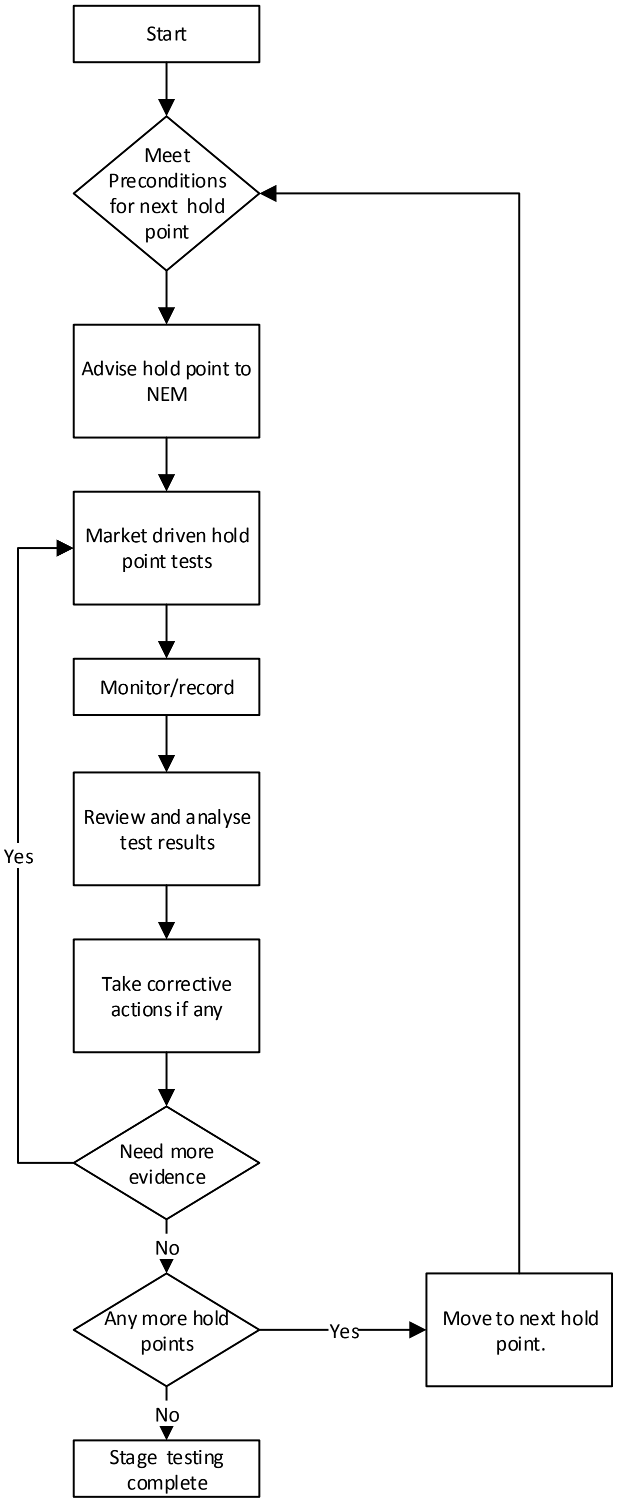
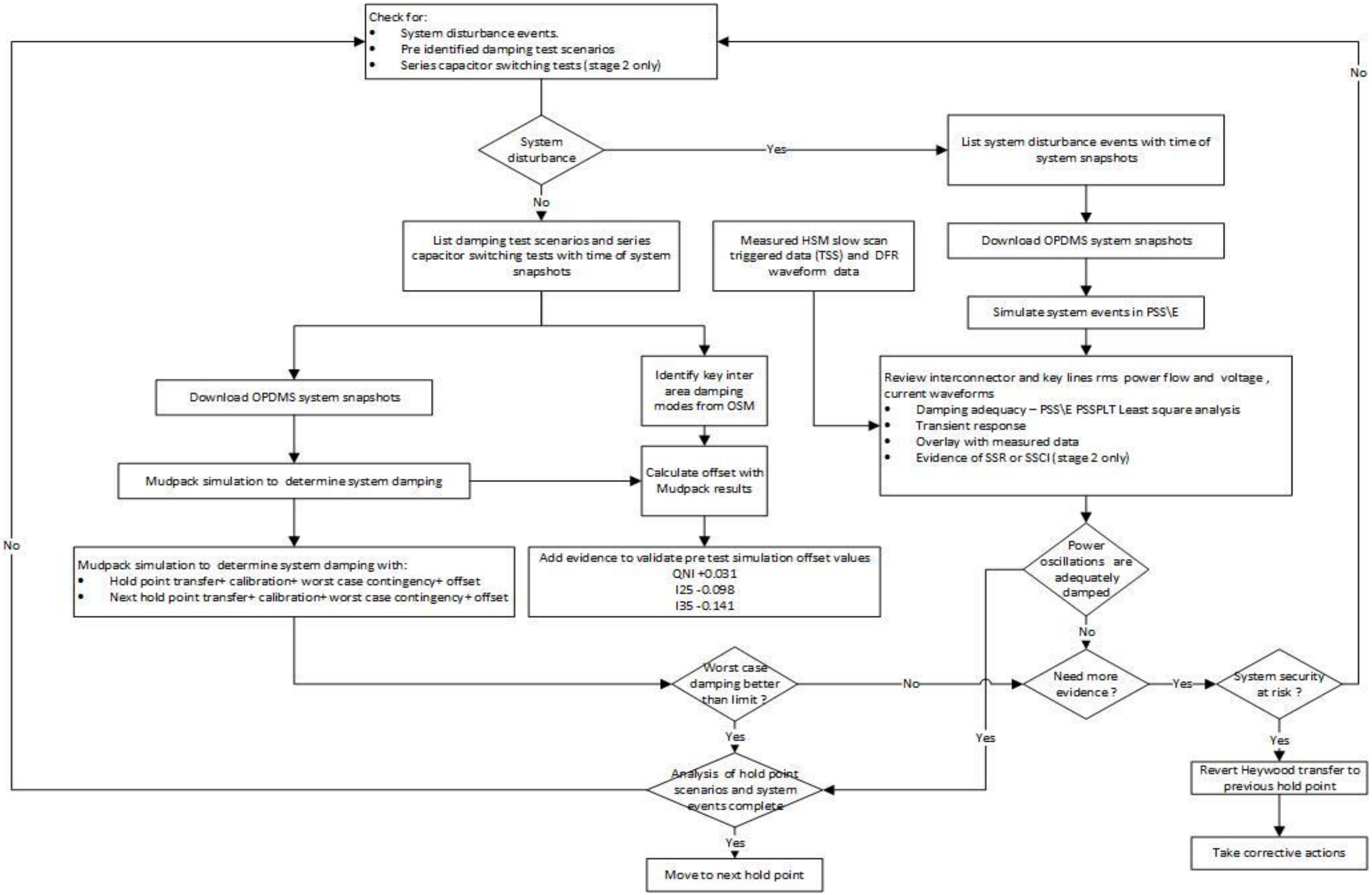


Figure 2: Review and assessment process chart



APPENDIX B – CONSTRAINTS AFFECTING HYTS TRANSFER

Stage 1 Tests

Oscillatory stability limits

System normal oscillatory stability limits applicable for stage 1 inter-network testing are summarised below.

	Without operational margin			With 25 MW operational margin		
	HYTS	**HYTS + Murraylink**	**HYTS if QNI southward transfer $1200 \geq P_{QNI} \geq 800MW$**	**HYTS**	**HYTS + Murraylink**	**HYTS if QNI southward transfer $1200 \geq P_{QNI} \geq 800MW$**
SA to Vic	$\sum Ti * Ci - 1.65 * 47.58$ (refer Figure 3 for Ti and Ci)	HYTS limit + 150	QNI offset to be advised	$\sum Ti * Ci - 1.65 * 47.58 - 25$ (refer Figure 3 for Ti and Ci)	HYTS limit + 150-25	QNI offset to be advised
Vic to SA	570	790	N/A	545	765	N/A

Table 3 : Stage 1 oscillatory stability limits

Figure 3 : SA to Vic oscillatory stability limit via HYTS - equation terms and coefficients (without operation margin).

Description of Term (T_i)	Coefficient (C_i)
Constant (1 always)	8.3277
No. of SA PSS in Service	21.0656
SA Wind Generation [MW]	0.2474
SA Synchronous Generation [MW]	0.2829
VIC Wind Generation [MW]	0.0847
VIC Synchronous Generation [MW]	-0.0291
NSW Inertia [on 100 MVA base]	0.3418
SA Inertia [on 100 MVA base]	-2.7741
NSW to VIC Power Flow [MW]	-0.0394

Voltage and transient stability limits

The following system normal voltage and transient stability equations have been updated to incorporate the third HYTS transformer. These limits may at times undercut the test hold point limits, subject to system generation and loading conditions.

	Voltage stability		**Transient stability**	
	Constraint ID	**Description**	**Constraint ID**	**Description**
Vic to SA	V^^S_NIL_TBSE	for trip of SE-TB line	V::S_NIL_TBSE	for trip of SE-TB line
	V^^S_NIL_MAXG_AUTO	for trip of largest generator	V::S_NIL_MAXG_AUTO	for trip of largest generator
	V^S_HYCP	for trip of HYTS-MLTS		
SA to Vic	No SA to Vic voltage stability limits		New limit	for trip of SE-TB line

Table 4 : Stage 1 transient and voltage stability limits

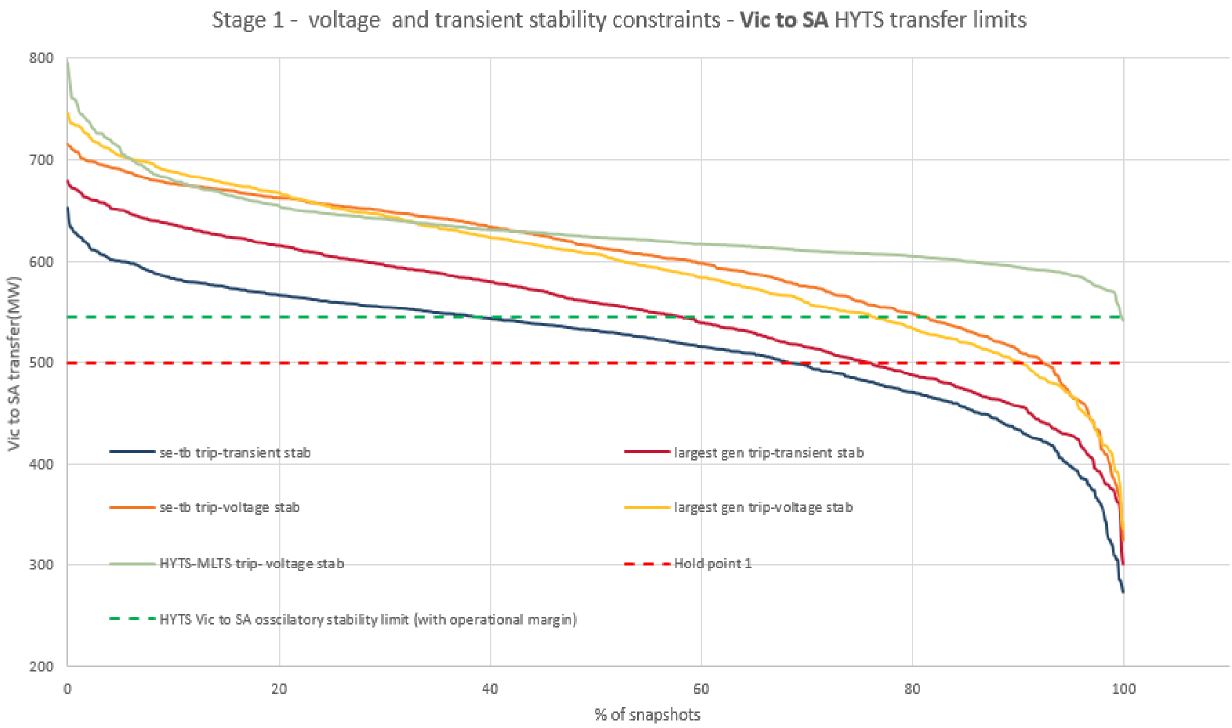
Thermal limits

The following line thermal limits may constrain HYTS interconnector below planned stage 1 hold points.

- Thermal rating of the HYTS-SESS 275 kV lines. AEMO will apply dynamic ratings for the HYTS – SESS lines calculated as a continuous function of ambient temperature at HYTS.
- Thermal rating of Tailem Bend and Tungkillo 275 kV line and Tailem Bend – Mobilong 132 kV line. ElectraNet has initiated two projects to upgrade these lines with a target completion date of June 2016.

The following graphs show new and revised constraints on HYTS power transfer calculated from a representative set of 2014-2015 OPDMS snapshots.

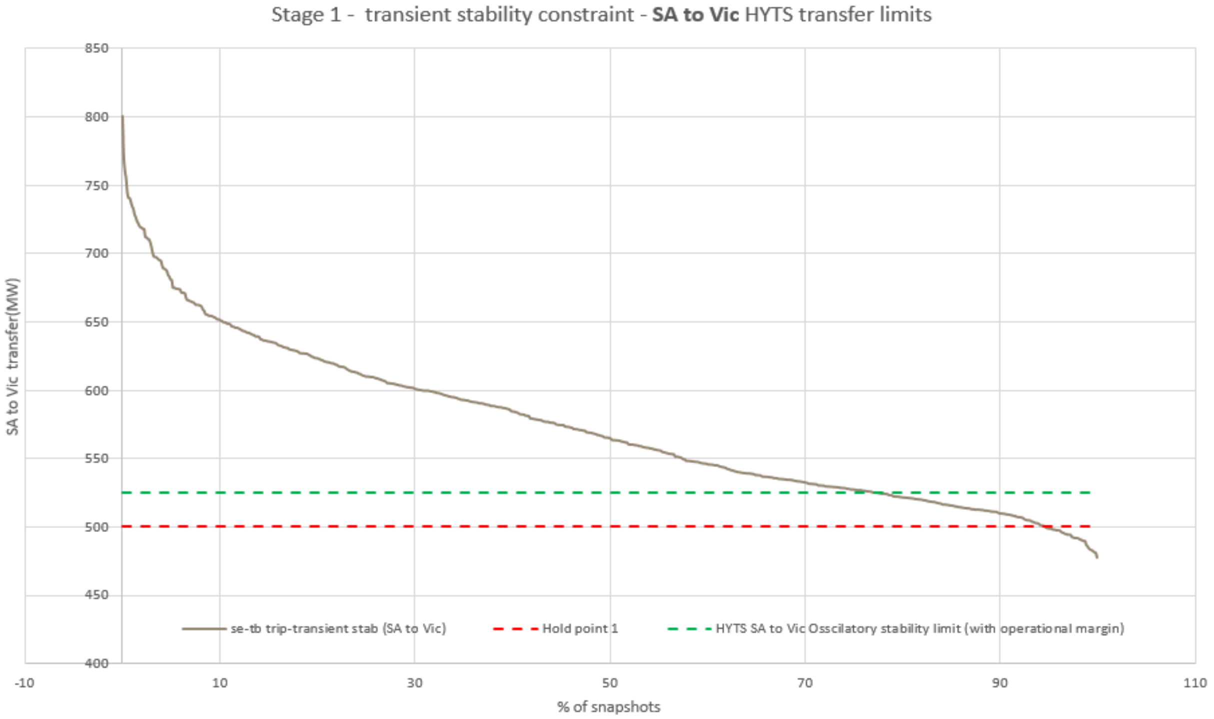
Figure 4 : Vic to SA HYTS transfer – Voltage and transient stability constraints



The system normal Vic to SA transient limit via HYTS for trip of a SESS-TBTS 275 kV line is the most restrictive limit over other voltage and transient limits (Figure 4). During the first stage 1 hold point test, the Vic to SA transfer limit via HYTS may be above 500 MW 70% of the time. During the final stage 1 test hold point, the transient stability limit via HYTS for trip of SESS-TBTS 275 kV line may be below the 545 MW oscillatory stability limit 60% of the time.

Figure 5 shows the SA to Vic HYTS transient transfer limit plotted for a representative set of OPDMS snapshots. 95 % of the time, the new system normal SA to Vic transient HYTS transfer limit for trip of SESS-TBSS 275 kV line may be above stage 1- hold point 1 (500 MW). 75% of the time HYTS limit may be above the SA to Vic oscillatory stability limit (525 MW). The hold point limit itself or oscillatory stability limits are therefore expected to be the limiting factors for SA to Vic transfer during stage 1 inter-network testing.

Figure 5 : SA to Vic HYTS transfer – Transient stability constraint



Stage 2 Tests

Constraints with service of the SESS – TBTS line series capacitors to be advised.

APPENDIX C- MONITORING AND RECORDING

High Speed Monitors (HSM)

The existing HSMs located at Heywood terminal station (HYTS), Dederang terminal station (DDTS), South Morang terminal station (SMTS), Murray Switching Station (MSS), South East substation (SESS), Tailem Bend terminal station (TBTS), Para, Davenport and Robertstown will be used to monitor and record inter-network test results.

Victorian HSM and South Australian HSM data are to be accessed through AEMO's OPDMS system and used to view and tag events for long term storage and to download information for analysis (access to SA HSM data to be conformed). Generally, the HSM systems directly measure 3 phase to ground voltage, 3 phase current and calculate 3 phase real power, 3 phase reactive power, positive sequence voltage magnitude, angle and frequency.

Continuous slow scan 50 Hz data are stored for two weeks. A number of the Victorian HSMs are configured to trigger a slow scan data recording automatically for network disturbances. The triggered data are polled periodically and downloaded by the OPDMS system to CSV files on a file share. User tagged events are transferred to long-term storage and continue to be available through the OPDMS system.

The Victorian HSMs include a Digital fault Recorder (DFR) function. Victorian and South Australian DFRs are currently capable of recording in excess of 128 samples per cycle. DFR waveform data will be used in searching for evidence of sub synchronous resonance (SSR) or sub synchronous control interactions (SSCI). **One month prior** to start of stage 1 testing, HYTS and SESS DFR pre fault length and post fault length are required to set to 1 s and 4 s respectively. The sampling rate should be in excess of 64 samples per cycle.

Table 5 and Table 6 show the Victorian and South Australian HSM monitors and measured quantities available for the recording the inter-network tests.

Oscillatory Stability Monitoring (OSM)

OSM uses phasor measurement unit (PMU) measurements to produce real-time parameter estimates of the three global oscillatory modes (QNI, I25 and I35) in the NEM based on a modal-identification algorithm developed by Queensland University of Technology (QUT) and TransGrid. The OSM also includes the Psymetrix PhasorPoint real-time oscillatory stability tool, which uses the same PMU measurements.

OSM (Oscillatory Stability Monitor) data can be accessed using a PI datalink in Excel. The PI Tags start with OSM. (e.g. OSM.PARA.DEG). Quantities such as angles, kV, kA and modes are stored. The parameters of the three Mainland modes are shown in the screenshot below. Modes 1, 2 and 3 correspond to QNI, I25 and I35 respectively. NPS is the calculated damping in neper per second (Np/s), whereas RPS is the frequency of oscillation in radians per second (rad/s).

\\PIProd\OSM.MAINLAND.MODE1.NPS	OSM - MAINLAND.MODE1 NPS
\\PIProd\OSM.MAINLAND.MODE1.RPS	OSM - MAINLAND.MODE1 RPS
\\PIProd\OSM.MAINLAND.MODE2.NPS	OSM - MAINLAND.MODE2 NPS
\\PIProd\OSM.MAINLAND.MODE2.RPS	OSM - MAINLAND.MODE2 RPS
\\PIProd\OSM.MAINLAND.MODE3.NPS	OSM - MAINLAND.MODE3 NPS
\\PIProd\OSM.MAINLAND.MODE3.RPS	OSM - MAINLAND.MODE3 RPS
\\PIProd\OSM.MAINLAND.MODE4.NPS	OSM - MAINLAND.MODE4 NPS
\\PIProd\OSM.MAINLAND.MODE4.RPS	OSM - MAINLAND.MODE4 RPS
\\PIProd\OSM.MAINLAND.MONITOR.STATUS	OSM Mainland Monitor Status

The Psymetrix PhasorPoint system is a phasor-based Wide Area Monitoring System (WAMS) that analyses and monitors power networks using modern phasor measurement appliances. A phasor-based WAMS is a network of fast synchronised measurements of voltage and current phasors (synchrophasors) that enables users to monitor the angular stability and dynamics of a power system. The PhasorPoint application is currently used by AEMO to monitor the small signal stability of some known oscillation modes.

Monitoring of System Disturbances

System Market Incident Reporting Kiosk (SMIRK) reports, NEM RTO Daily reports and EPSOC logs can be used to identify system disturbance events and details of the disturbance. SMIRK reports include time of the incident, its description and invoked constraint details etc. NEM RTO Daily Reports include a high level summary of the last 24 hours of NEM operations including frequency events, unplanned outages, lack of reserve conditions (LOR) and line reclassifications etc. EPSOC logs include high-level event descriptions which can be sorted by region and time.

Identifying Damping Test Scenarios

NEO is a data analysis, viewing and accessing tool from the AEMO WARE database. NEO is useful to view regional demand, interconnector flows, wind forecast and reserve data etc.

NEO and Pi ProcessBook (or datalink) can identify system scenarios suitable for analysis for inter-network testing purposes.

The Pi system is capable of collecting, storing and presenting historical and near real time data. Pi Processbook is an application with built in displays to visualise trends, dynamic bars, current values, time based summary data, etc. that can update in near real time. Pi datalink is an Excel add-in that allows data to be retrieved into a spreadsheet and then processed with normal spreadsheet operations.

Substation	Monitor	Monitored line	Current recorded all 3 phases	Voltage recorded all 3 phases	Active power recorded in all 3 phases	Reactive power recorded in all 3 phases	Positive seq voltage and angle	Frequency
Dederang(DDTS)	DDTS_1-1	Murray 1	Y	Y	calculated	calculated	calculated	calculated
		South Morang (SMTS) 1	Y	Y	calculated	calculated	calculated	calculated
	DDTS_1-2	Murray 2	Y	Y	calculated	calculated	calculated	calculated
		South Morang (SMTS) 2	Y	Y	calculated	calculated	calculated	calculated
	DDTS_2_1	Wodonga (WOTS) 1	Y	Y	calculated	calculated	calculated	calculated
Heywood (HYTS)	HYTS_1-1	ADP 1	Y	Y	calculated	calculated	calculated	calculated
		ADP 2	Y	Y	calculated	calculated	calculated	calculated
	HYTS_1-2	SESS 1	Y	Y	calculated	calculated	calculated	calculated
		SESS 2	Y	Y	calculated	calculated	calculated	calculated
South Morang (SMTS)	SMTS_1-1	KTS 1	Y	Y	calculated	calculated	calculated	calculated
		SYTS 1	Y	Y	calculated	calculated	calculated	calculated
		SYTS 2	Y	Y	calculated	calculated	calculated	calculated
	SMTS_2-1	F2 transformer	Y	Y	calculated	calculated	calculated	calculated
		H1 transformer	Y	Y	calculated	calculated	calculated	calculated
		H2 transformer	Y	Y	calculated	calculated	calculated	calculated
Murray	MUR30B_67_68_M1	Dederang 1	Y	Y	calculated	calculated	calculated	calculated
		Dederang 2	Y	Y	calculated	calculated	calculated	calculated
		Murray gen 1&2 (M1)	Y	Y	calculated	calculated	calculated	calculated

Substation	Monitor	Monitored line	Current recorded all 3 phases	Voltage recorded all 3 phases	Active power recorded in all 3 phases	Reactive power recorded in all 3 phases	Positive seq voltage and angle	Frequency
	MUR30C_M3_M5_M7	Murray gen 3&4 (M3)	Y	Y	calculated	calculated	calculated	calculated
		Murray gen 5&6 (M5)	Y	Y	calculated	calculated	calculated	calculated
		Murray gen 6&7 (M7)	Y	Y	calculated	calculated	calculated	calculated
	MUR30D_M9_M11_M13	Murray gen 8&9 (M9)	Y	Y	calculated	calculated	calculated	calculated
		Murray gen 10&11(M11)	Y	Y	calculated	calculated	calculated	calculated
		Murray gen 13&14(M13)	Y	Y	calculated	calculated	calculated	calculated

Table 5: Victorian HSMs and measured quantities

Substation	Monitored line	Current recorded all 3 phases	Voltage recorded all 3 phases	Active power recorded in all 3 phases	Reactive power recorded in all 3 phases	Frequency
Davenport	NPS 1	Y	Y	Y	Y	Y
	NPS 1	Y	Y	Y	Y	Y
	Playford	Y	N	Y	Y	N
	Brinkworth	Y	Y	Y	Y	Y
	Bungama	Y	Y	Y	Y	Y
	Canowie	Y	Y	Y	Y	Y
	Cultana	Y	Y	Y	Y	Y
	Belalie	Y	Y	Y	Y	Y
	Olympic Dam	Y	Y	Y	Y	Y
Robertstown	Tungkillo	Y	Y	calculated	calculated	Y
	Para	Y	N	N	N	N
	Mokota	Y	Y	calculated	calculated	N
	North West Bend 1	Y	N	N	N	N
	North West Bend 2	Y	Y	calculated	calculated	N
	Waterloo	Y	Y	calculated	calculated	N
Tailem Bend	South East 1	Y	Y	calculated	calculated	Y
	South East 2	Y	Y	calculated	calculated	Y
	Cherry Gardens	Y	Y	calculated	calculated	N
	Tungkillo	Y	Y	calculated	calculated	N
Para	Magill	Y	Y	Y	Y	Y

	Templers West	Y	Y	Y	Y	N
	Transformer 1	Y	N	N	N	N
	Torrens Island 4	Y	Y	Y	Y	Y
	West Bus	N	Y	N	N	N
	Transformer 2	Y	N	N	N	N
	Parafield Gardens West	Y	Y	Y	Y	Y
	Tungkillo	Y	Y	Y	Y	N
	SVC 1	Y	N	Y	Y	N
	Blyth West	Y	Y	Y	Y	Y
	Robertstown	Y	Y	Y	Y	N
	SVC2	Y	N	Y	Y	N
South East	Heywood 1	Y	Y	Y	Y	Y
	Heywood 2	Y	Y	Y	Y	N
	Tailem Bend 1	Y	Y	N	N	Y
	Tailem Bend 2	Y	Y	N	N	N
	SVC2	Y	N	Y	Y	N
	SVC1	Y	N	Y	Y	N

Table 6: South Australian HSMs and measured quantities