

Sensitivity Studies and Calibration of Small Signal Models

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Abstract – Inter-connectors are strategically important elements in the power system for their role in bulk power transfer between different areas. The dynamic performance of the interconnector is relatively less certain due to modelling complexity and difficulty in testing, despite its importance to power system security. This paper firstly presents the calibration result of the small signal power system dynamic models of the Australian National Electricity Market (NEM), using the field test measurements of SVC Power Oscillation Dampers in Queensland. Based on the calibrated models, the sensitivities of a number of parameters to system damping are evaluated. The results show that apart from the generator PSS design, the inter-area mode damping is also significantly influenced by the modelling of loads, generator (inertia in particular) and governor.

Index Terms—Power Oscillation Damper, Power System Stabilizer, Oscillatory stability, sensitivity study.

I. INTRODUCTION

Inter-connectors are strategically important elements in the power system for their role in bulk power transfer between different areas. There are, however, limited methods available to comprehensively evaluate the performance of the inter-connector because:

- There is rare opportunity to perform inter-connector test;
- The dynamic performance of the interconnector is influenced by many generators in the network; and
- The power transfer level is typically high and any large-disturbance test will have significant impact to the whole power system.

As a result, the secure operation of the inter-connector is mainly determined through computer simulation (modelling) and operational experience.

The process of gaining understanding of the inter-connector dynamic performance is best illustrated by the Queensland – New South Wales interconnector (QNI) in the Australian Nation Electricity Market (NEM). Since its commission in December 2000, there has been non-stop effort

in studying its dynamic performance and refining the corresponding power system models. Key modelling development stages throughout this period (2000 to 2015) include:

- Stage 1: Development of the real-time Oscillatory Stability Monitoring (OSM) system that monitors the small-signal oscillation among the four mainland states, i.e. Queensland (QLD), New South Wales (NSW), Victoria (VIC) and South Australia (SA)
- Stage 2: Development and calibration of small signal plant models for simulation purpose
- Stage 3: Elevate the small signal stability transfer limits of the inter-connectors (these were limits set by the initial commissioning tests) by detailed modelling the small signal behaviors of these inter-connectors
- Stage 4: Further study of selected generators and refinement of small signal modelling requirements

This paper presents two key tasks performed by the Plant Model Working Group (PMWG) at Stage 2, i.e. small signal model calibration [1] and sensitivity studies [2].

II. BACKGROUND

A. Small Signal Models and Stability

The accuracy of dynamic plant models is critical to the planning and operation of the NEM. Due to the long and linear topology of the NEM grid, various power system stability limits exist and the determination of stability boundaries depends heavily on these models.

Some of the inter-area constraints are of oscillatory (small-signal) stability type. Real-time monitoring systems including the OSM (developed collaborately by Queensland University of Technology and TransGrid [3]) and Psymetrix [4] have been deployed to monitor the damping performances of the inter-area modes of the NEM. The small signal transfer limits of the NEM inter-connectors were set based on inter-network test results prior to 2007. Driven by the need to maximize the utilization of the inter-connector transfer capacities, a priority was given to improve the accuracy of the small signal models

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and to explore the key contributing factors of inter-area mode oscillation damping.

B. Inter-area modes of the NEM

The NEM has three key inter-area modes of oscillation:

- QNI mode: Frequency 1.6 to 2.3 rad/s, machines in QLD swing against those in NSW, VIC and SA;
- I25 mode: frequency 2.3 to 3.0 rad/s, machines in NSW and VIC swing against those in SA;
- I35 mode: frequency 3.0 to 4.0 rad/s, machines in NSW and VIC swing against each other.

Of these, QNI mode and I35 mode are typically the most lightly and heavily damped, respectively. Figure 1 illustrate the relative magnitude and direction of small signal power oscillation of the four Australian states.

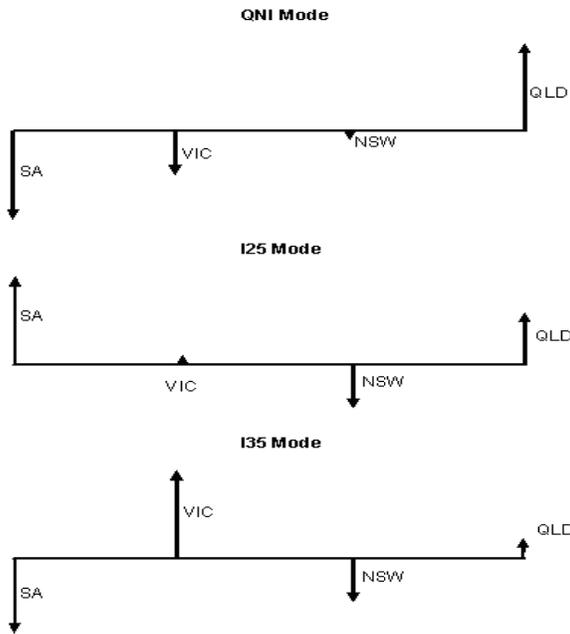


Figure 1. Illustration of the relative magnitude and direction of small signal power oscillation of the four Australian states

III. SMALL SIGNAL MODEL CALIBRATION

A. SVC POD switching tests

The NEM small signal models were calibrated using the measurements taken from the switching tests of the three SVC Power Oscillation Dampers (PODs) from 6th to 9th April 2009 [5]. There are three phases for the on/off switching tests:

- Phase 1 – Greenbank POD was turned on and off, while Blackwall and South Pine PODs were off;
- Phase 2 – South Pine POD was turned on and off, while Blackwall and Greenbank PODs were off; and
- Phase 3 – Blackwall and Greenbank PODs were turned on and off, while the South Pine POD was off.

The status of each SVC POD is shown in the time plot in Figure 3 with green dashes indicating “in service” periods.

B. Calibration methodology

Figure 2 illustrates the methodology adopted in calibrating the small signal models. Key steps taken are:

- Obtain the derived-from-measurement variations of the QNI mode damping and frequency during the SVC POD on/off testing period from the OSM system;
- Obtain the derived-from-model variations of the QNI Mode damping and frequency by MUDPACK [6] simulation based on the system snapshots created for the testing period; and
- Assess the relationship between the derived-from-measurement and derived-from-model contributions to the parameters of the QNI Mode that are made by the different SVC PODs.

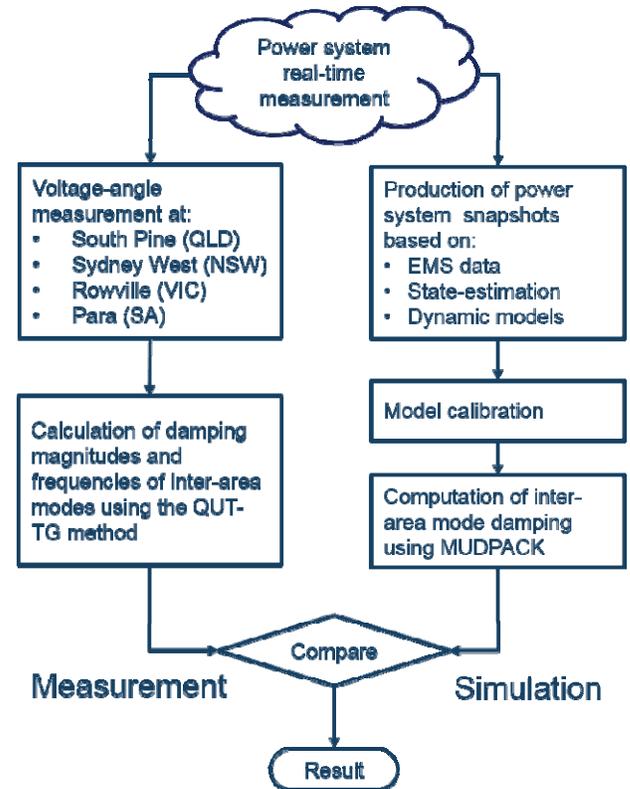


Figure 2. Methodology for comparing OSM measurement and MUDPACK simulation results

C. Test results and model calibration

Figure 3 shows the variation of QNI mode damping at different phases of the SVC POD tests. Key findings are:

- The damping performance of the QNI mode has been improved when the three SVC PODs (Blackwall, Greenbank and South Pine) are all in service;
- The averaged QNI mode frequency and damping values are 1.83 rad/s and -0.44 Np/s respectively. It is estimated that the QNI mode damping has been improved by an order of 0.08 Np/s, which is contributed by the two new SVC PODs; and

- When the effective gains of the a QLD generator's PSS and Blackwall POD are reduced, the simulated results appear to align better with the OSM measurements.

the MUDPACK model for simulation purpose. New investigation was commenced afterward to determine the possible contribution factors for the mismatch between simulation and measurement.

As a result, the "effective gains" of the a QLD generator's PSS and Blackwall POD derived from the test results in

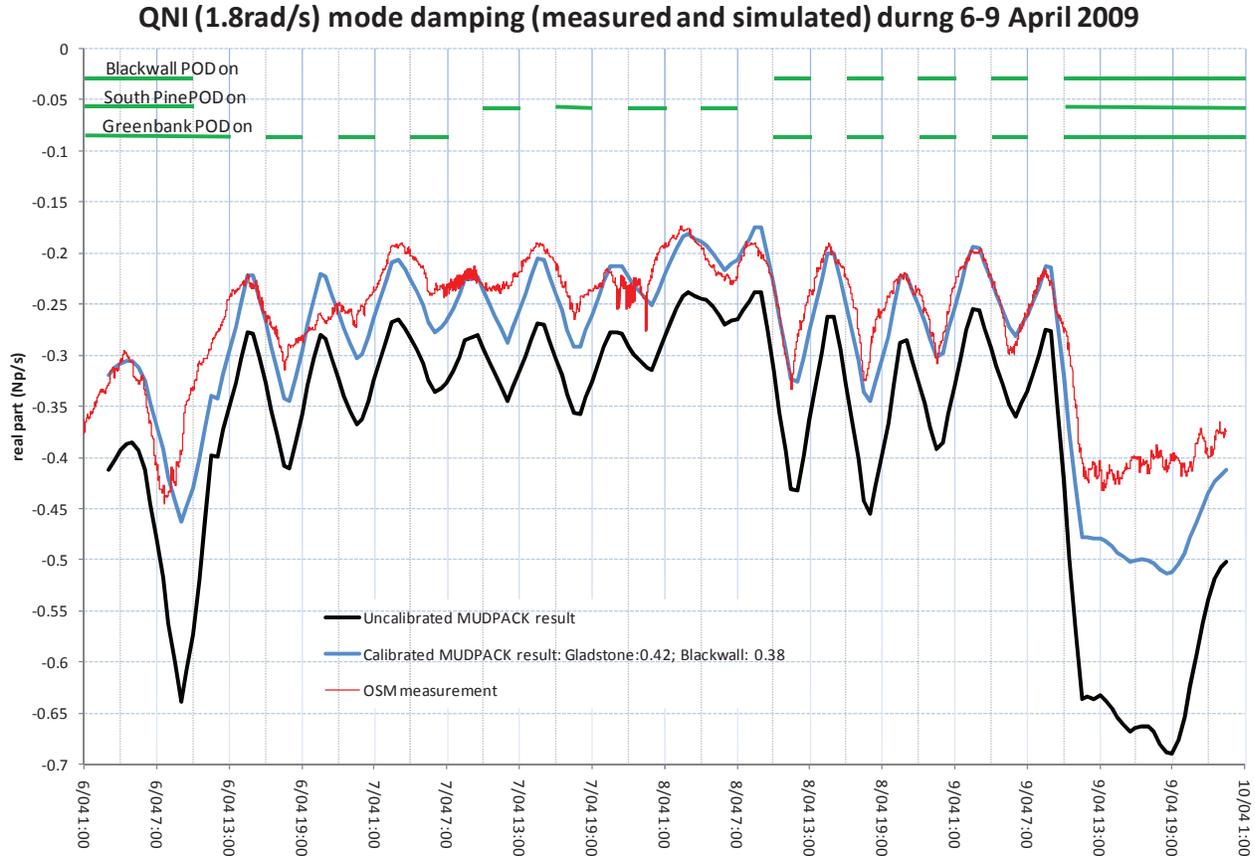


Figure 3. Summary of Measured (OSM) and MUPACK simulation results for the QNI Mode damping performances

IV. I25 MODE SENSITIVITY STUDIES

Following the alignment of measured and simulated damping of the QNI mode of oscillation, the focus was shifted to calibrating the I25 mode where the simulated response showed better damping than the measurement. Table 1 compares the damping magnitudes and frequencies between simulated and measured responses. The results show that while the characteristic oscillating frequencies are similar, the simulated response is at least 0.2 Np/s better damped than the measured one.

TABLE 1. I25 MODE DAMPING PERFORMANCE

	Simulated result		OSM measurement	
	mean	σ	mean	σ
Damping (Np/s)	-0.5326	0.0335	-0.2920	0.0355
Frequency (rad/s)	2.7700	0.0953	2.7008	0.0648

Figures 4 and 5 show the damping and frequency plots of

the original I25 mode performance. The x-axis represents the measured (OSM) result and the y-axis represents the simulated (MUDPACK) result. While the measured and simulated frequencies are similar (i.e. the majority of results concentrates along the diagonal) in Figure 5, the results in Figure 4 show that the simulated results are better damped.

Based on simulation, the work investigated the sensitivities of the plant model parameters and the power system parameters to the I25 oscillatory mode. Key parameters for testing include:

- Active and reactive load indices;
- Generator governor model status;
- Generator inertias in SA; and
- Gains of some power system stabilisers (PSS) and SVC power oscillation dampers (POD).

A. Sensitivity of load indices

Voltage dependent exponential load models of the form in (1) and (2) are used in the simulation.

$$P = P_0 \cdot \left(\frac{V}{V_0}\right)^{N_p} \quad (1)$$

$$Q = Q_0 \cdot \left(\frac{V}{V_0}\right)^{N_q} \quad (2)$$

Typical load indices of $N_p = 1$ and $N_q = 3$ are used for generic load unless otherwise specified. Where load indices have been defined for specific industrial loads (smelters, etc.), they would have remained unchanged.

Sensitivity studies were carried out by varying N_p and N_q . The results show that:

- The progressive reduction of N_p brings the simulated damping closer to the OSM measurements (see Figure 6) but turns the simulated frequency further away from the OSM measurement values (see Figure 7);
- N_q has negligible influence on damping and frequency.

B. Effect of SA Governor models

The effect of including and excluding SA governor models are studied. The results (see Figures 8 and 9) show that simulated damping increases further (and deviates more from the measured values) when governor models are removed.

C. Sensitivities of generator inertias

Sensitivity studies were carried out by varying the inertias of SA generators by 20%. The results (see Figures 10 and 11) show that increasing the SA generator inertias reduce the damping of the I25 oscillatory mode.

D. Sensitivities of PSS gains

The sensitivity of each generator PSS in the NEM to the I25 mode was studied by varying the PSS gain. As expected, the simulation showed that PSS gain is the most effective model parameter for damping the I25 mode. While most of the PSS's in the NEM has positive contribution in dampening the I25 oscillatory mode, the presence of some PSS's in NSW and QLD may lead to some level of reduction in the I25 mode damping.

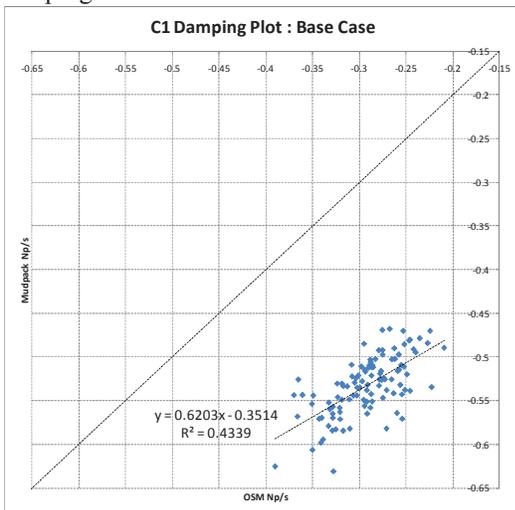


Figure 4. Damping Plot: I25 mode base case

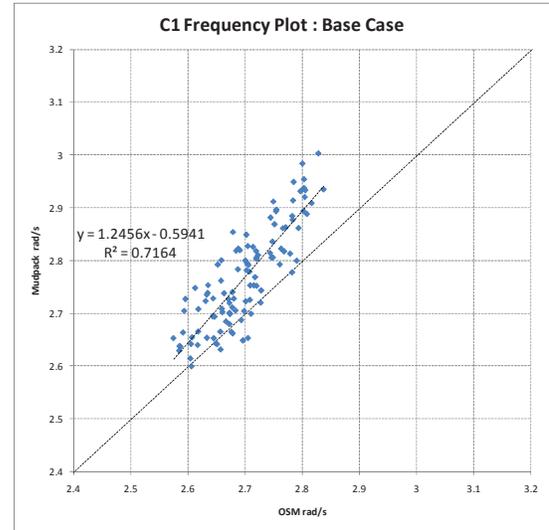


Figure 5. Frequency Plot: I25 mode base case

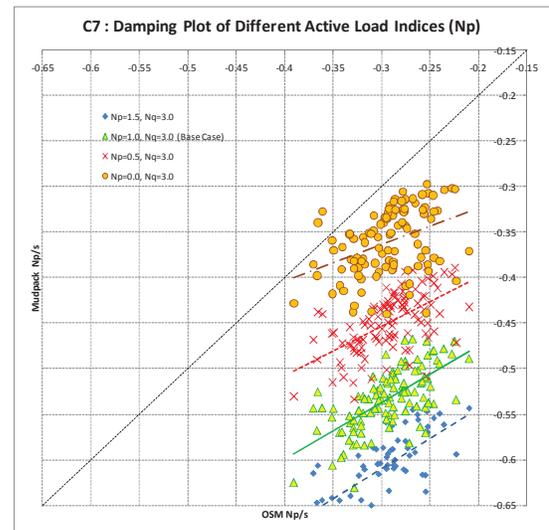


Figure 6. Damping Plot: Influences of different active load indices (N_p)

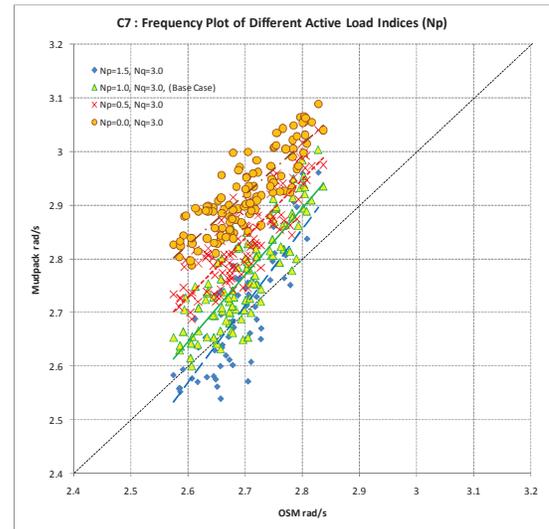


Figure 7. Frequency Plot: Influences of different active load indices (N_p)

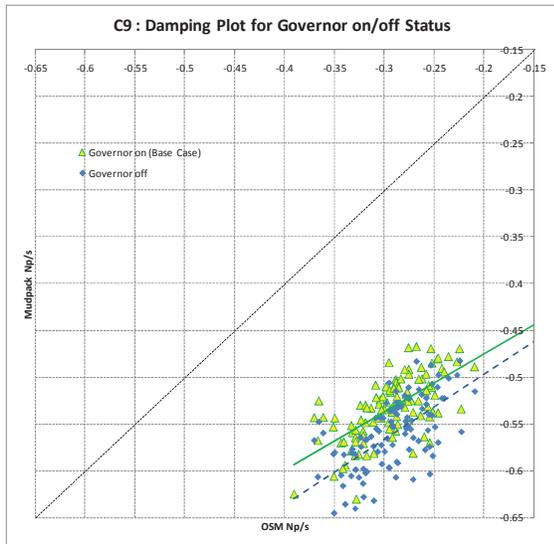


Figure 8. Damping Plot: Influence of Governor Model

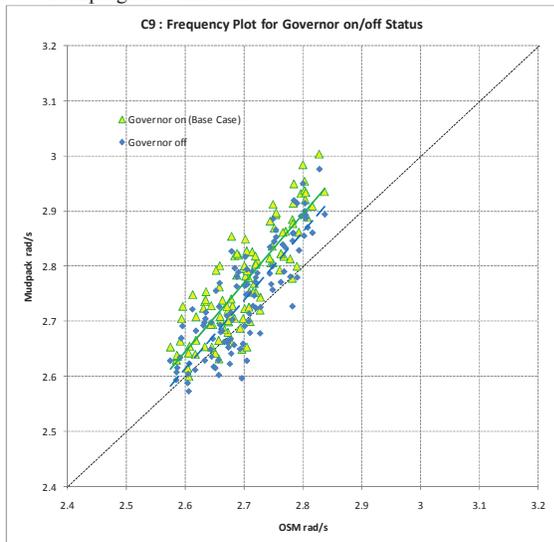


Figure 9. Frequency Plot: Influence of Governor Model

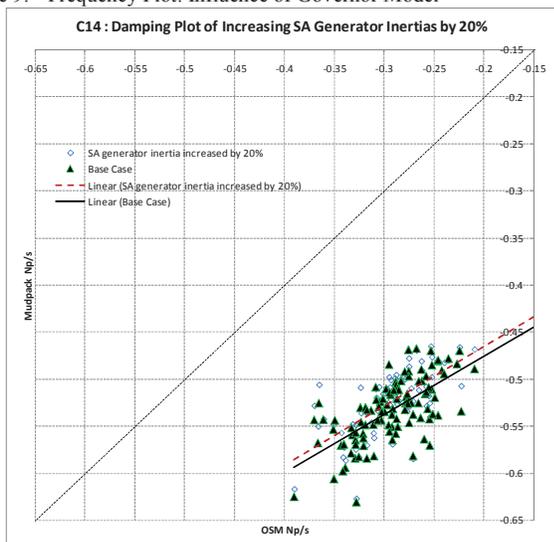


Figure 10. Damping Plot: Influence of increasing SA generator inertias

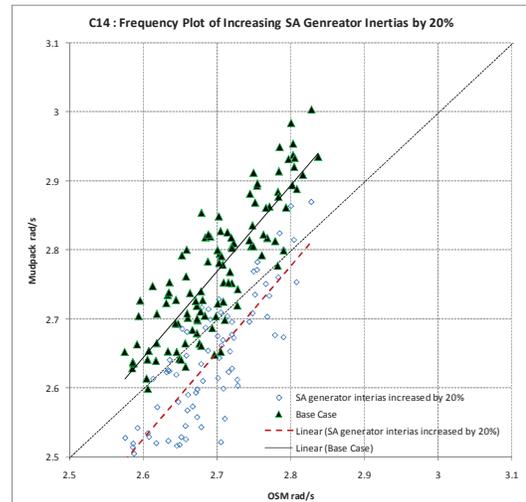


Figure 11. Frequency Plot: Influence of increasing SA generator inertias

I. CONCLUSION

This paper summarizes the major modelling work for the NEM small signal models from 2007 to 2009. The results of the model calibration and sensitivity studies lead to a series of refinements of the small signal models. The calibrated models have been used subsequently for determining the small signal transfer limits of the SA-VIC and QNI inter-connectors. The small signal transfer limit of SA-VIC ac-interconnector has been raised from 420 MW to 560 MW in December 2011 and that unconditional QNI limit, based on Psymetrix availability, be raised from 950 MW to 1078 MW in 2013.

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