NEM Grid Connection and Generator Compliance

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Presentation Outline

- **NER Compliance for Generators**
- **Validation of Compliance Process following a Plant Change**
- **Compliance & R2 Testing**
- **Q & A**

Section 1
NER Compliance for Generators

NER Compliance for Generators

- The integration of generation into the power system must be coordinated so that levels of quality, reliability of supply and power system security can be maintained

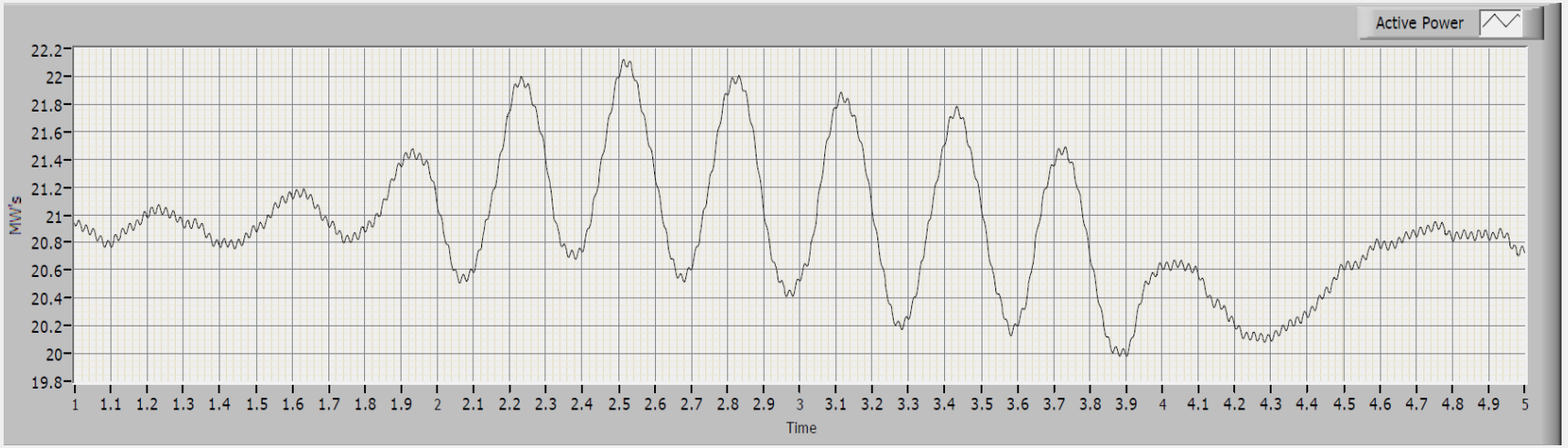
- Reliable and secure operation of a power system is tied to the ability of its mix of generation, transmission, and loads to operate under a variety of conditions

- For this reason, the NER includes processes to coordinate the technical interaction between new and existing generation and the power system

NER Compliance for Generators

- Accurate model data for generators, excitation systems, turbine governors and PSS is required to maintain accurate planning of the power system

- Assists organisations such as AEMO and TNSPs in planning and operation of the network



Commissioning of PSS on 100 MVA GT with settings designed on incorrect data

NER Compliance for Generators – Performance Standards

- Rules specify each generating unit must meet a number of technical requirements and these form part of the technical terms and conditions of the Connection Agreement

- These are met by ensuring generators meet a range of Generator Performance Standards (GPS)

- The Rules allow performance standards to be negotiated between the Proponent, the NSP, and AEMO

- An access standard is a benchmark for determining the appropriate performance standard for each unit:

    - Minimum Access Standard
    - Automatic Access Standard
    - Negotiated Access Standard

NER Compliance for Generators – Performance Standards

- Minimum Access Standard – minimum performance standard specified in Rules. If a generating unit does not meet this standard, plant will be denied access to network

- Automatic Access Standard – The upper bound for an access standard.

- Negotiated Access Standard – Falls somewhere between the automatic and minimum bounds for the standard of performance

- *Note that no generator will have 'minimum' as a standard, instead it will be 'negotiated' at the minimum level.*

Section 2

Validation of Compliance Process following a Plant Change

Validation of Compliance Process following a Plant Change

- Compliance process commences once a Generator proposes to alter plant or install/modifying an existing sub-system (or for new generator connections)

- "Sub-System" means any subcomponents which contribute to a generating system achieving its capability to meet a particular performance standard, such as

  - Excitation systems
  - Turbine governor control system
  - Protection relays
  - Auxiliary power supplies
  - Circuit breakers, etc

Validation of Compliance Process following a Plant Change

- The following actions need to be taken for a plant upgrade (or new connection) *before commissioning:*

  - ✓ Data sheets for the relevant sub-system (incl. generator, exciter, regulator, PSS, limiters, turbine, ramp rates, dead bands etc)
  - ✓ Design Report
  - ✓ Model – functional block diagram and source code
  - ✓ Releasable User Guide
  - ✓ Commissioning Plan

Validation of Compliance Process following a Plant Change – Data sheets

- Prior to the connection, generator must submit registered data related to the new or altered plant

- Registered data falls into two categories:

  (a) *Prior to actual connection and provision of access, data derived from manufacturers' data, detailed design calculations, works or site tests etc (R1)*

  (b) *After connection, data derived from on-system testing (R2)*

- For new connections, all parameters are submitted as R1. Site testing will be required to validate the modified (or new) plant

  - Also valid if the synchronous machine is altered or refurbished

Validation of Compliance Process following a Plant Change – Data sheets

Datasheets can be downloaded
From AEMO website
www.aemo.com.au

10.1	Synchronous Machine Excitation System				
Symbol	Data Description	Units	Data Category	Value	Remarks
	The list of *generating units* to which this information applies.	Text	S, D, R1, R2		
	Manufacturer and manufacturer's type designation or product name.	Text	R1, R2		

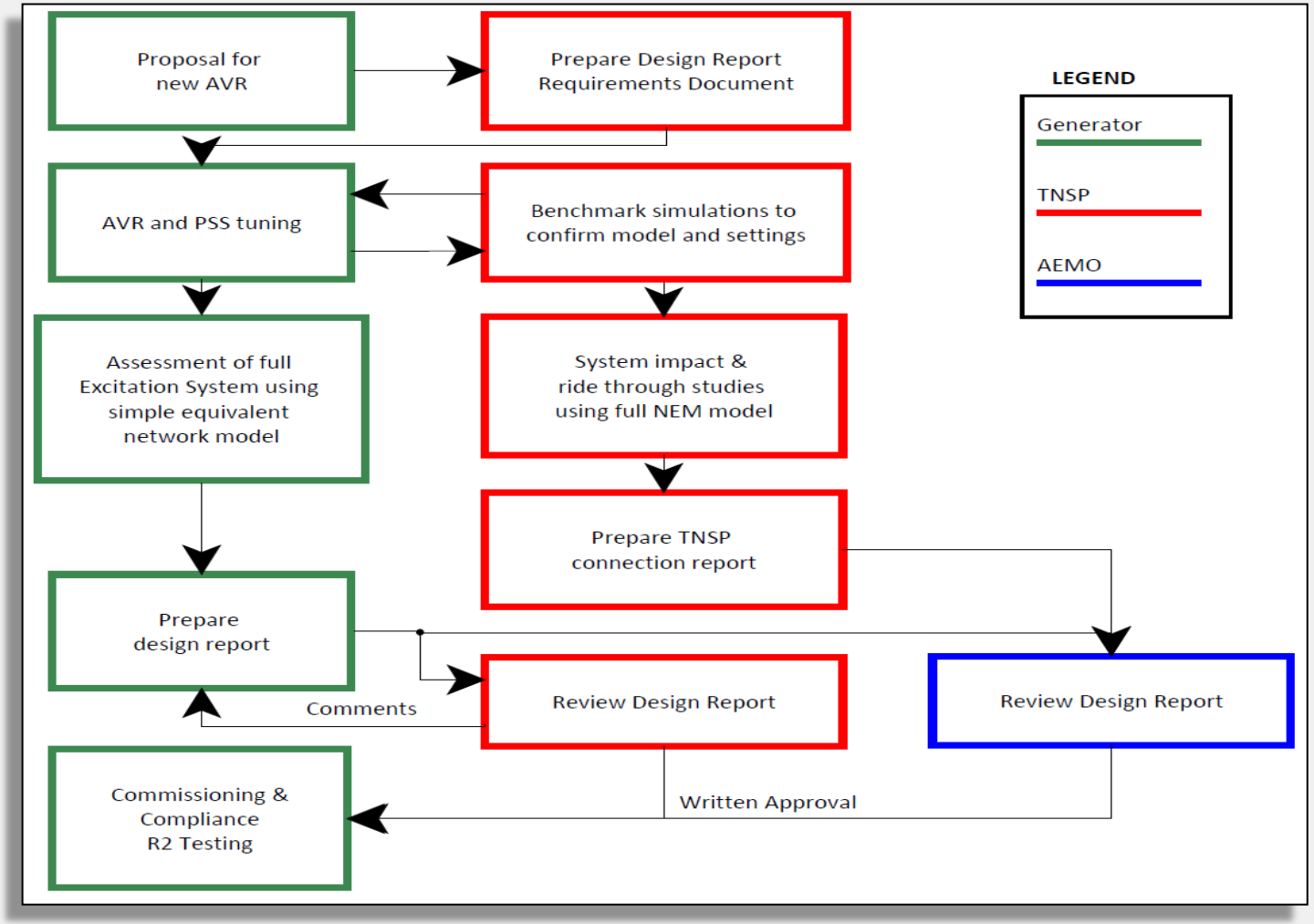
10.1.1	Design Data Sheet				
Symbol	Data Description	Units	Data Category	Value	Remarks
VCEIL	Rotor *voltage* capable of being supplied for 5s at rated *voltage* (VTGEN) and rated speed	V	D, R1		
VFMIN	Minimum field *voltage*	V	D, R1		
	Maximum rate of change of field *voltage*	Rising V/s	D, R1		
	Maximum rate of change of field *voltage*	Falling V/s	D, R1		
	Exciter description including type, ratings, connection schematic, source of any external supplies, etc.	Text	D, R1		
	If applicable, exciter saturation curve over 50%-120% of rated voltage.	Diagram	D, R1		
	Details of the excitation *control* system described in functional block diagram form showing:				
	• *voltage control systems* (*AVR*);				
	• *power system* stabiliser				
	• exciter;				
	• reactive current or *reactive power* compensation (if fitted) (e.g. Load drop compensation/VAr sharing, also referred to as line drop compensation or *reactive power* droop);	Functional block diagram	S, D, R1		

10.1.2	Setting Data Sheet				
Symbol	Data Description	Units	Data Category		
	DC gain of excitation control loop	V/V	D, R1		
	Active power operating range of the *generating unit* when the *PSS* is in operation.		D, R1		
	All functional block diagram parameters, in accordance with Rule s5.2.4 (b), (gains, time constants, mathematical functions, non-linear characteristics, limits, etc.) for:				
	• *voltage control systems* (*AVR*);		D, R2		
	• *power system* stabiliser;		D, R2		
	• exciter;		D, R2		
	• reactive current or *reactive power* compensation;		D, R2		
	• over-excitation limiter;		D, R2		
	• under-excitation limiter;		D, R2		
	• stator current limiter;		D, R2		
	• flux (*V/f*) limiter; and		D, R2		
	• any other limiters that may restrict excitation *control system* operation.		D, R2		

Validation of Compliance Process following a Plant Change – Design Report

- Design report evaluates compliance for Sections of the NER the plant change will affect. As per S5.3.9 (d), these are for an AVR:
  - S5.2.5.5 "Generating system response to disturbances following contingency events"
  - S5.2.5.7 "Partial load rejection"
  - S5.2.5.12 "Impact on network capability"
  - S5.2.5.13 "Voltage and reactive power control"
- For a Governor Control System:
  - S5.2.5.7 "Partial load rejection"
  - S5.2.5.11 "Frequency control"
  - S5.2.5.14 "Active power control"

Validation of Compliance Process following a Plant Change of an AVR



Flow chart of activities and responsibilities associated with preparation and approval of a design report

Validation of Compliance Process following a Plant Change – Design Report

- Design report will present proposed settings and results of simulation studies to demonstrate that with the new sub system the generating unit will comply with the relevant Performance Standards

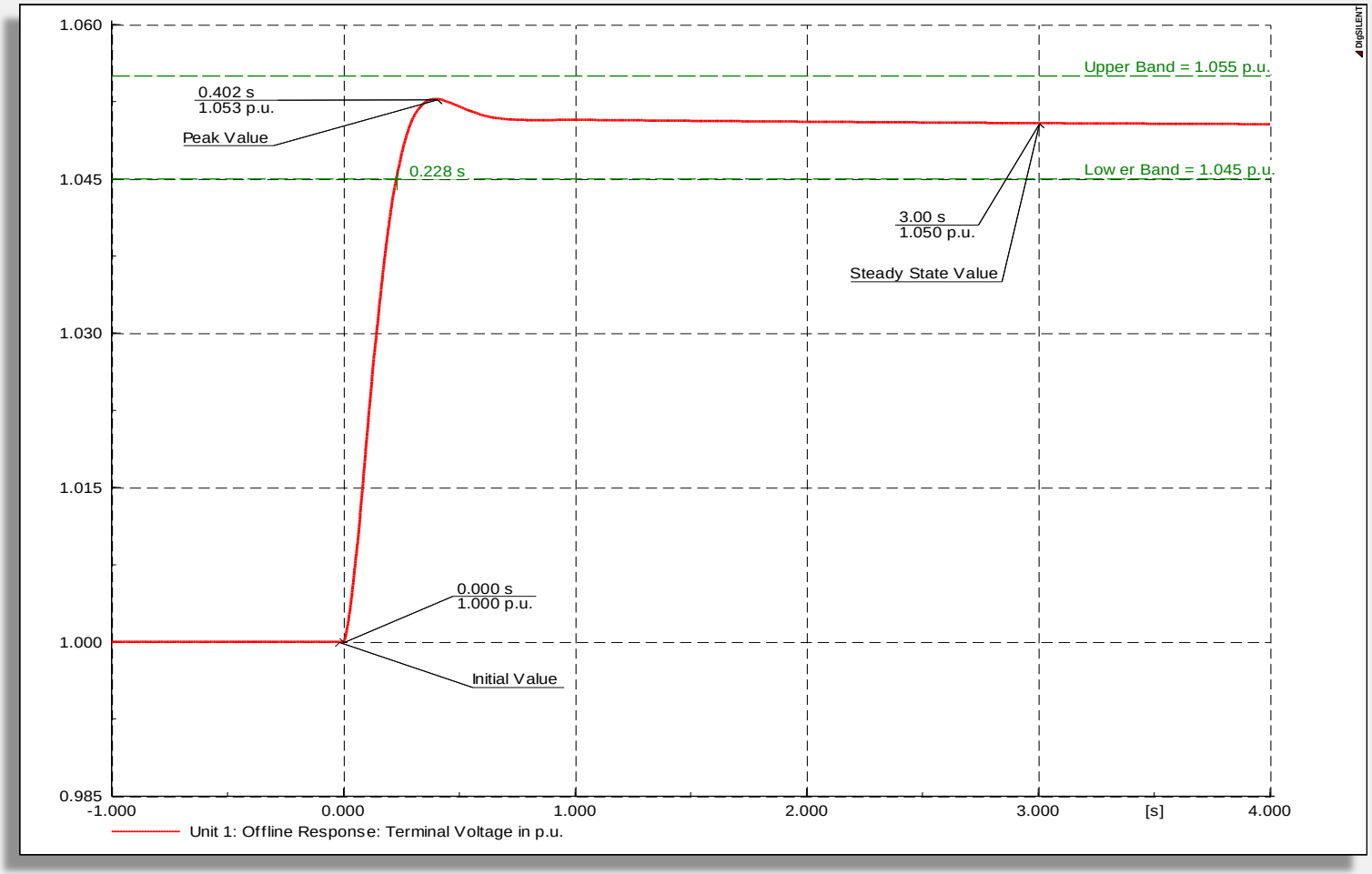
- The document will contain:

  - ✓ AVR and/or Governor design and assessment of performance offline and online
  - ✓ PSS design
  - ✓ Small signal stability analysis
  - ✓ Excitation limiter design and assessment of online performance
  - ✓ Co-ordination with generator protection
  - ✓ Recommend/propose settings

- AEMO will then consider the proposed settings as those values that will be used during commissioning. Any large deviations will need to be explained

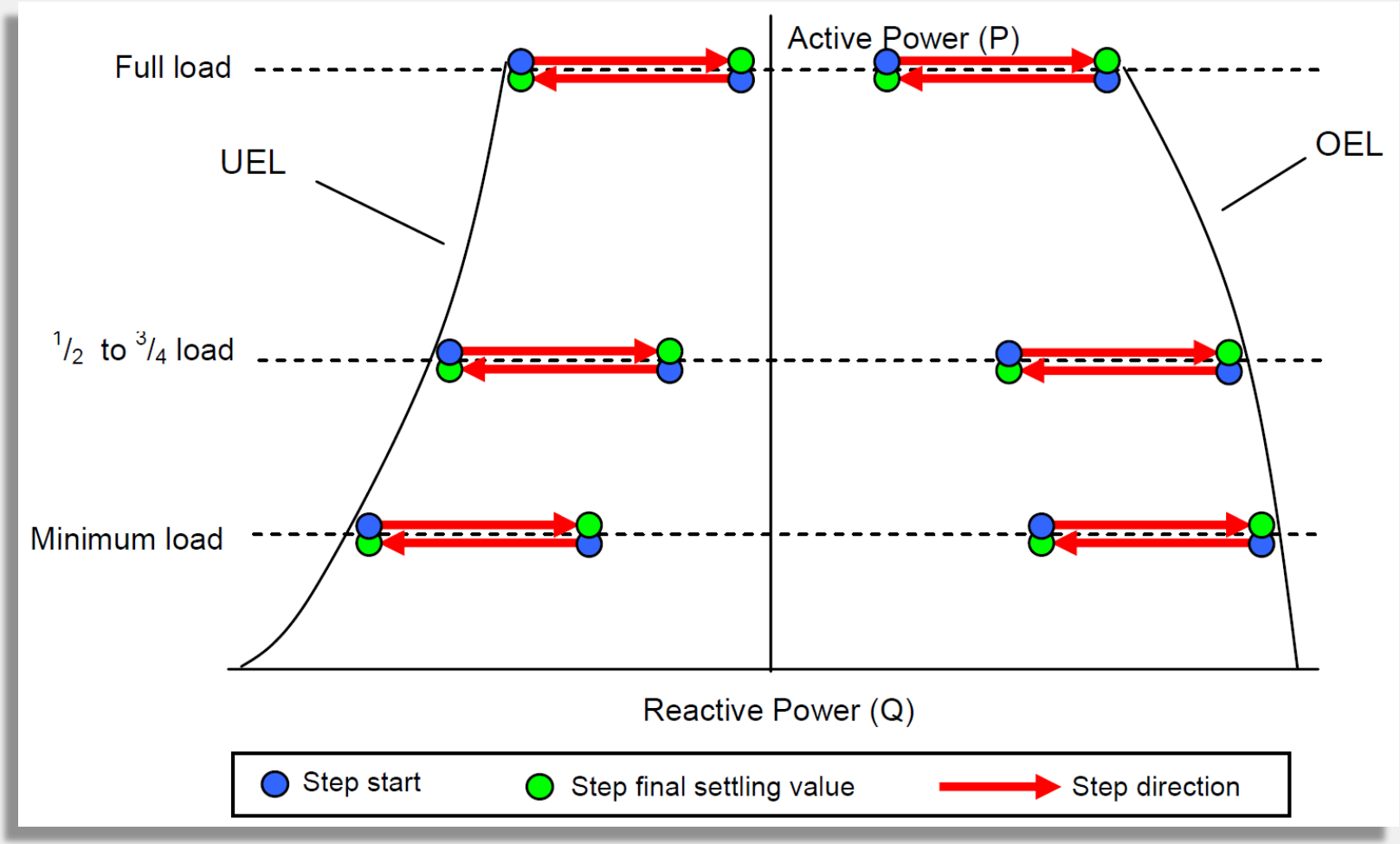
Validation of Compliance Process following a Plant Change – S5.2.5.13

- Unsynchronised Settling Time < 2.5 seconds for 5% change



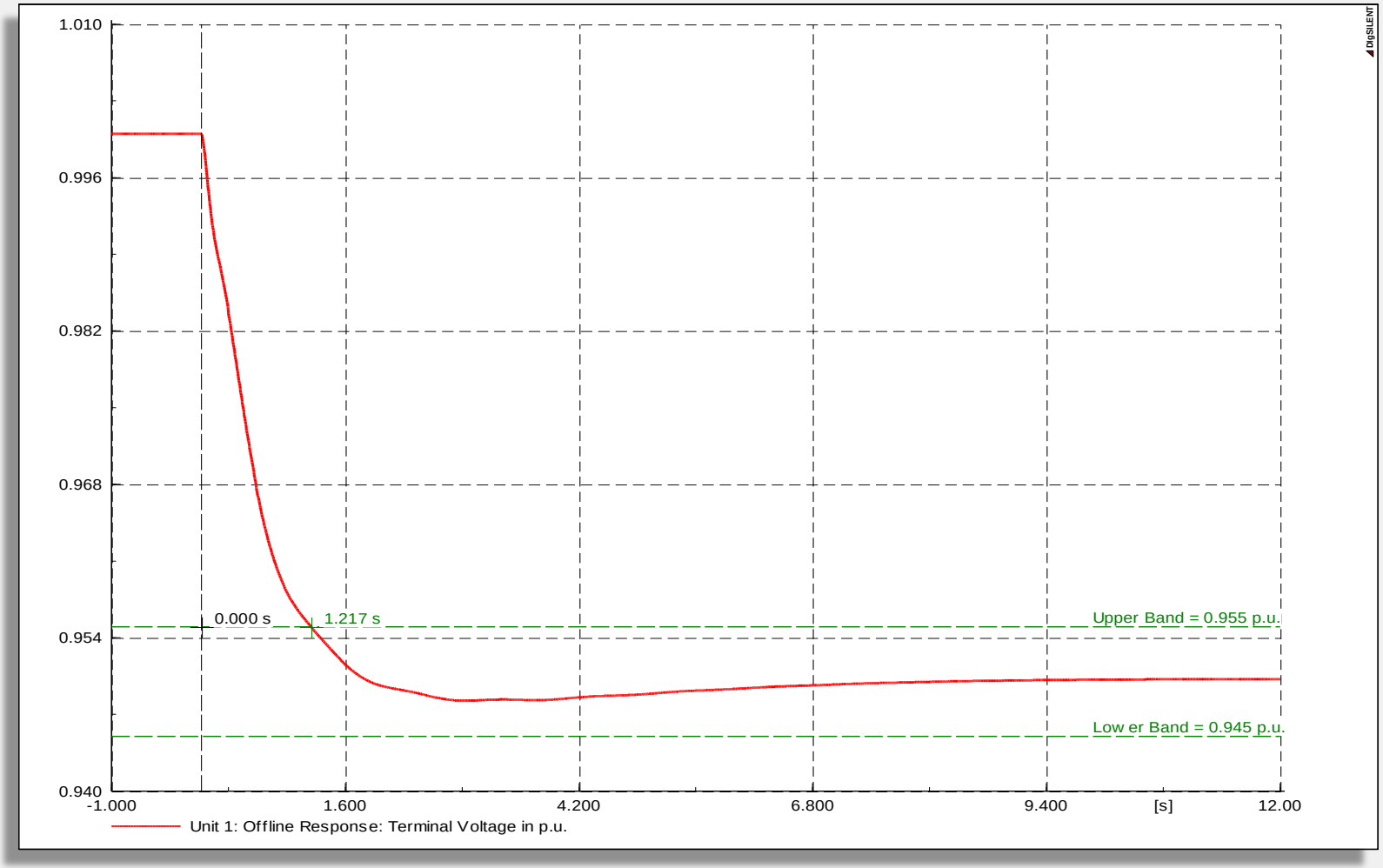
Validation of Compliance Process following a Plant Change – S5.2.5.13

- Step response simulations without limiter operation



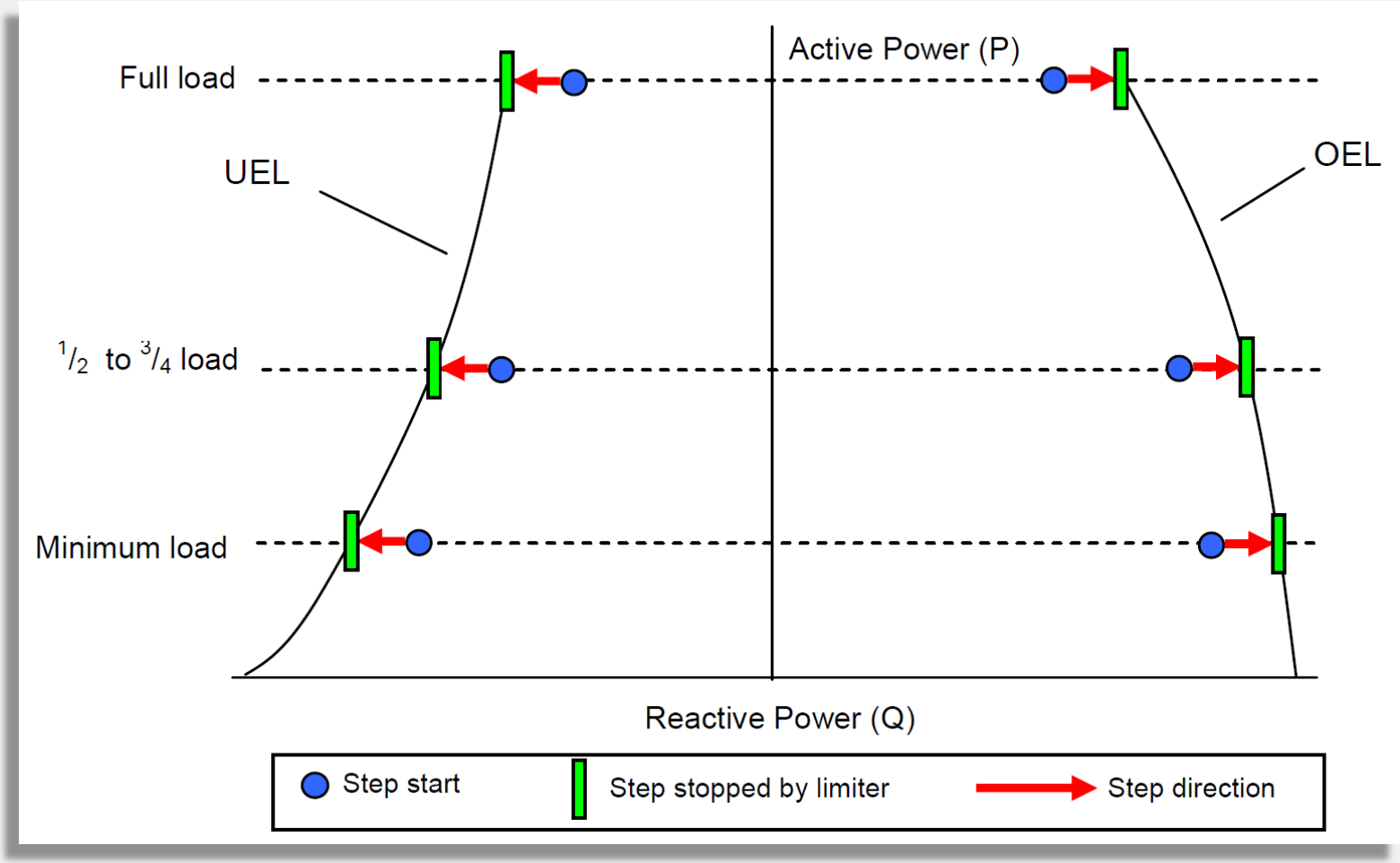
Validation of Compliance Process following a Plant Change – S5.2.5.13

- Synchronised Settling Time < 5 seconds for 5% change



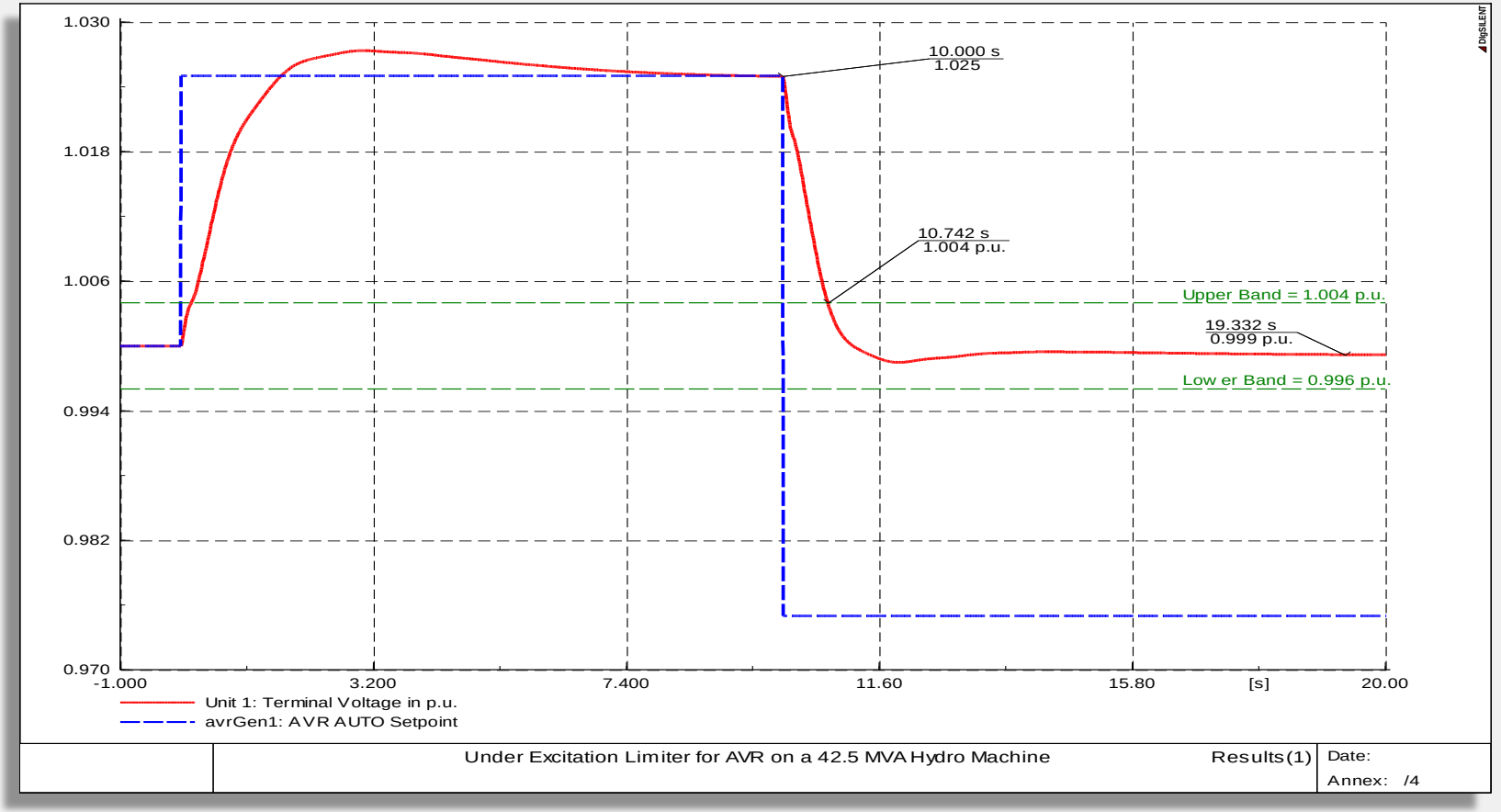
Validation of Compliance Process following a Plant Change – S5.2.5.13

- Step response simulations into excitation limiters



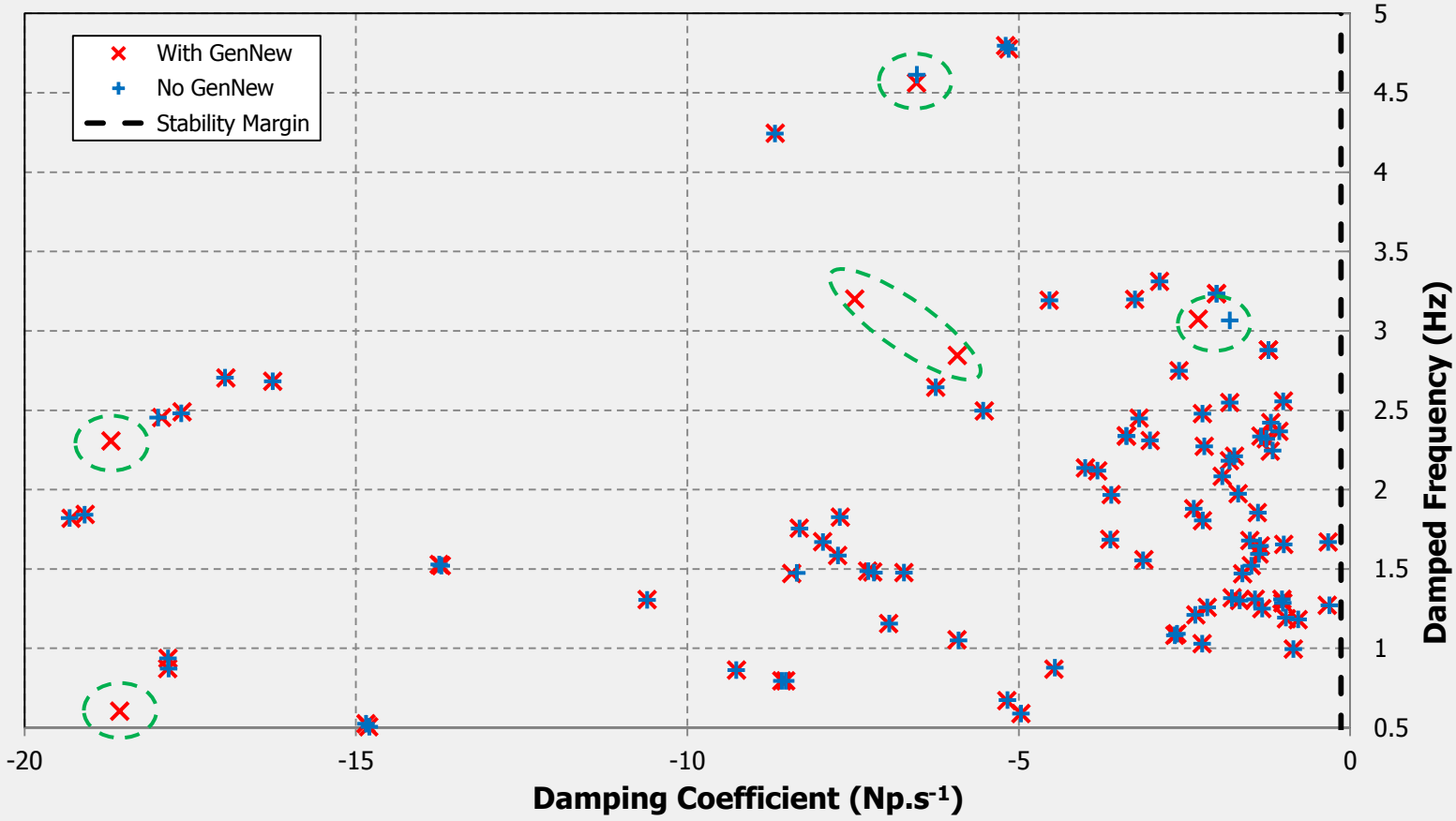
Validation of Compliance Process following a Plant Change – S5.2.5.13

- Excitation Limiter Settling Time < 7.5 seconds for 5% disturbance when operating into a limiter from a point where a disturbance of 2.5% would just cause the limiter to operate



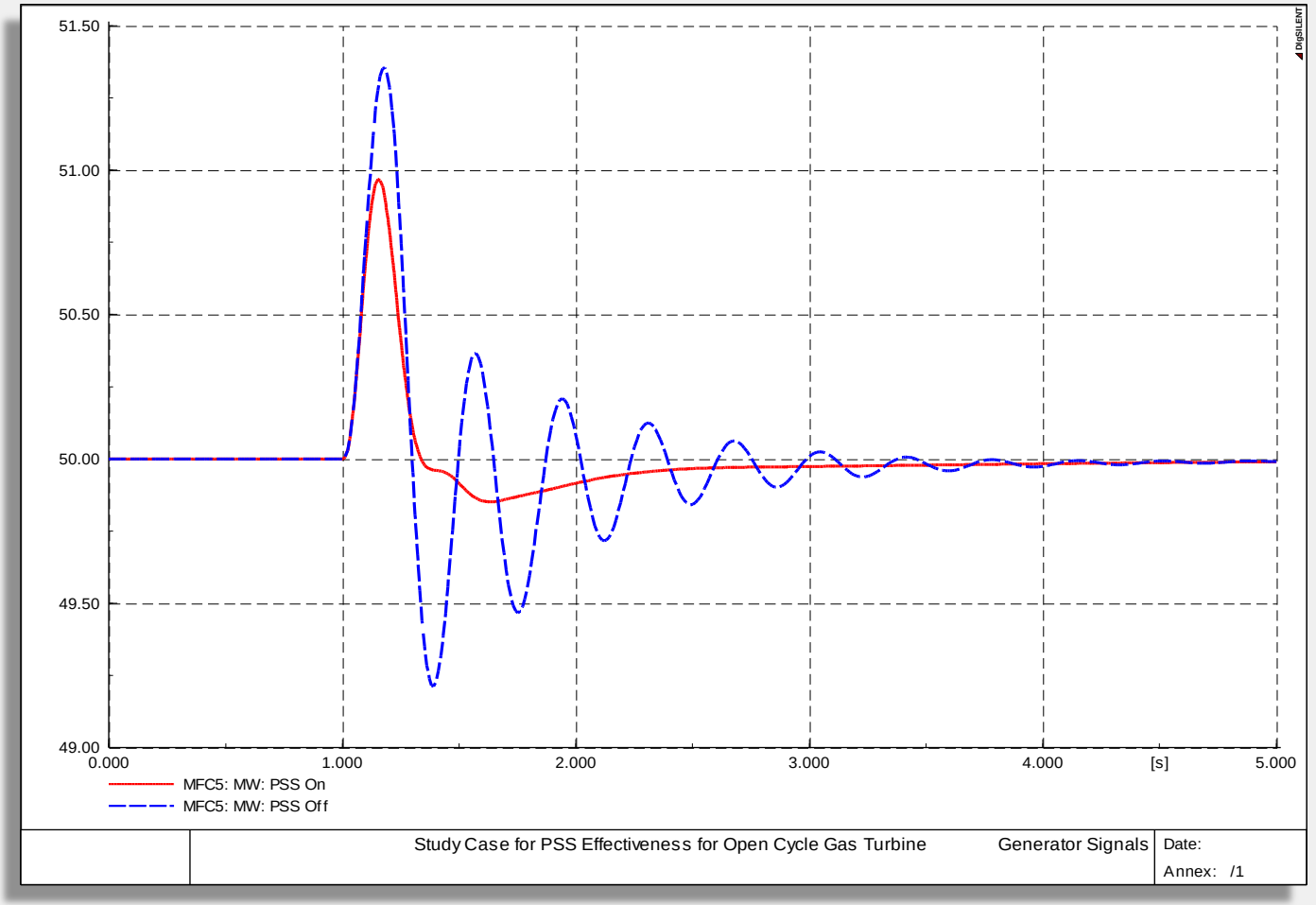
Validation of Compliance Process following a Plant Change – S5.2.5.13

- Impact of Connecting a Generating Unit with PSS



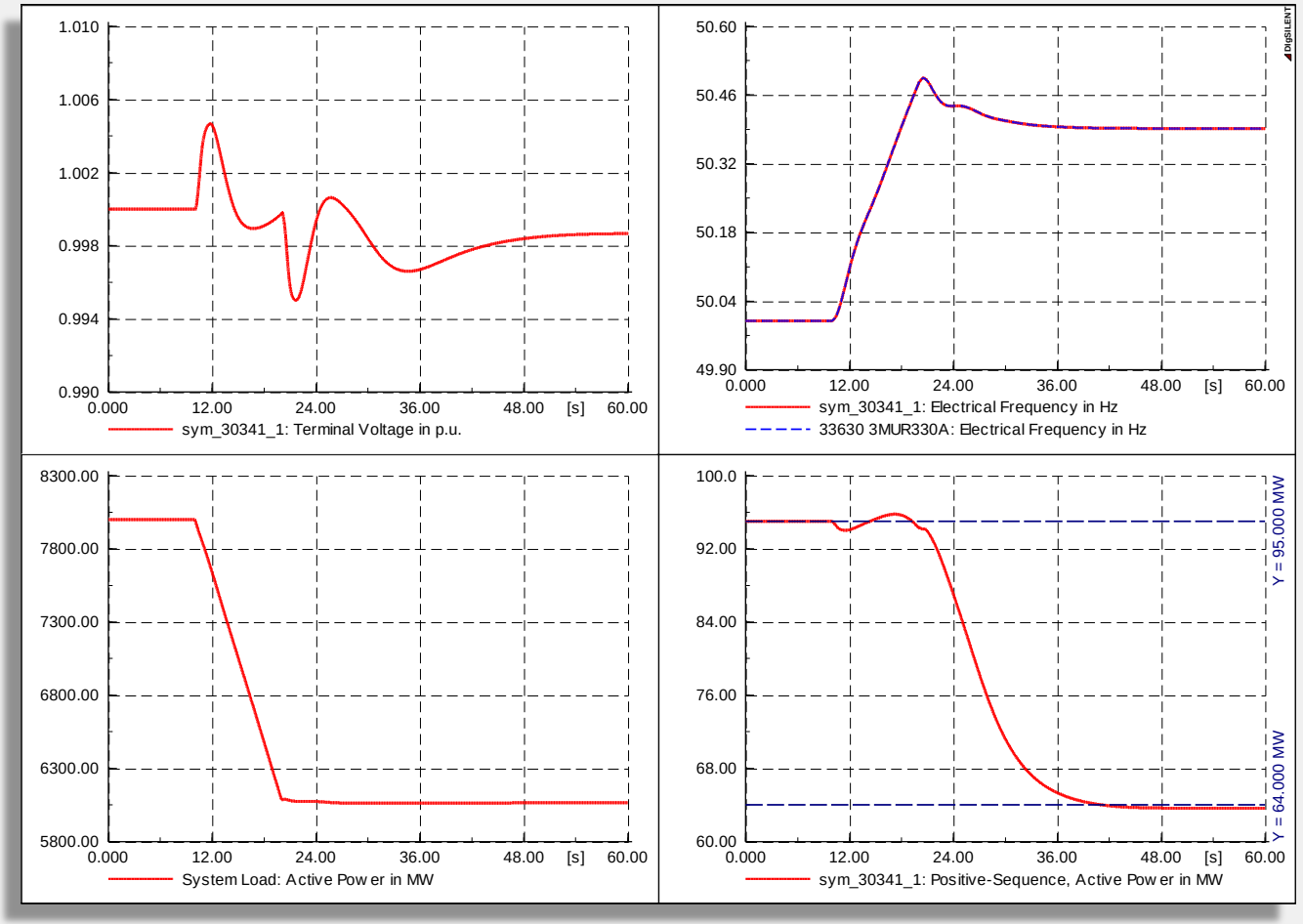
Validation of Compliance Process following a Plant Change – S5.2.5.13

- Effectiveness of the PSS in Time Domain



Validation of Compliance Process following a Plant Change – S5.2.5.7

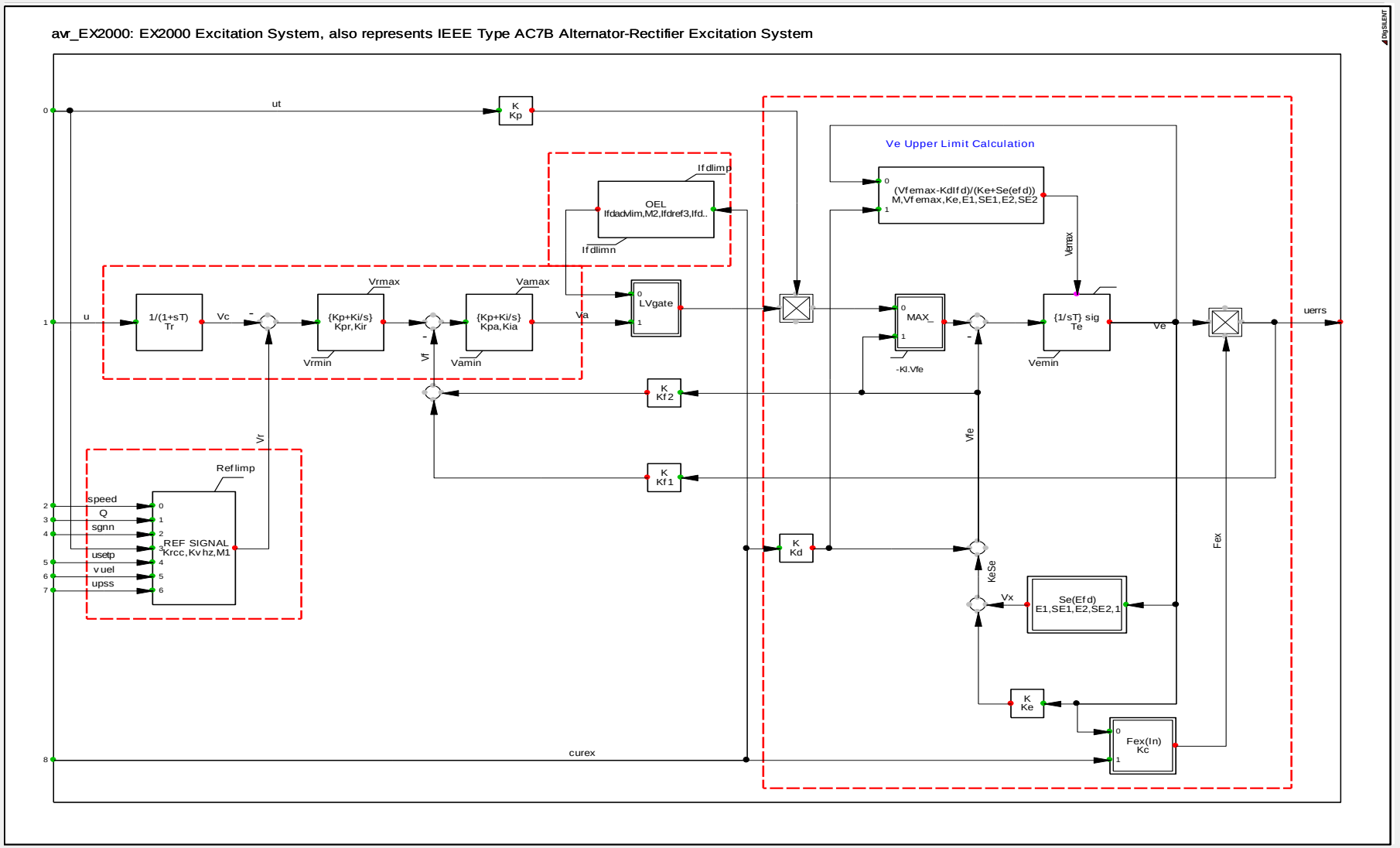
- Partial Load Rejection



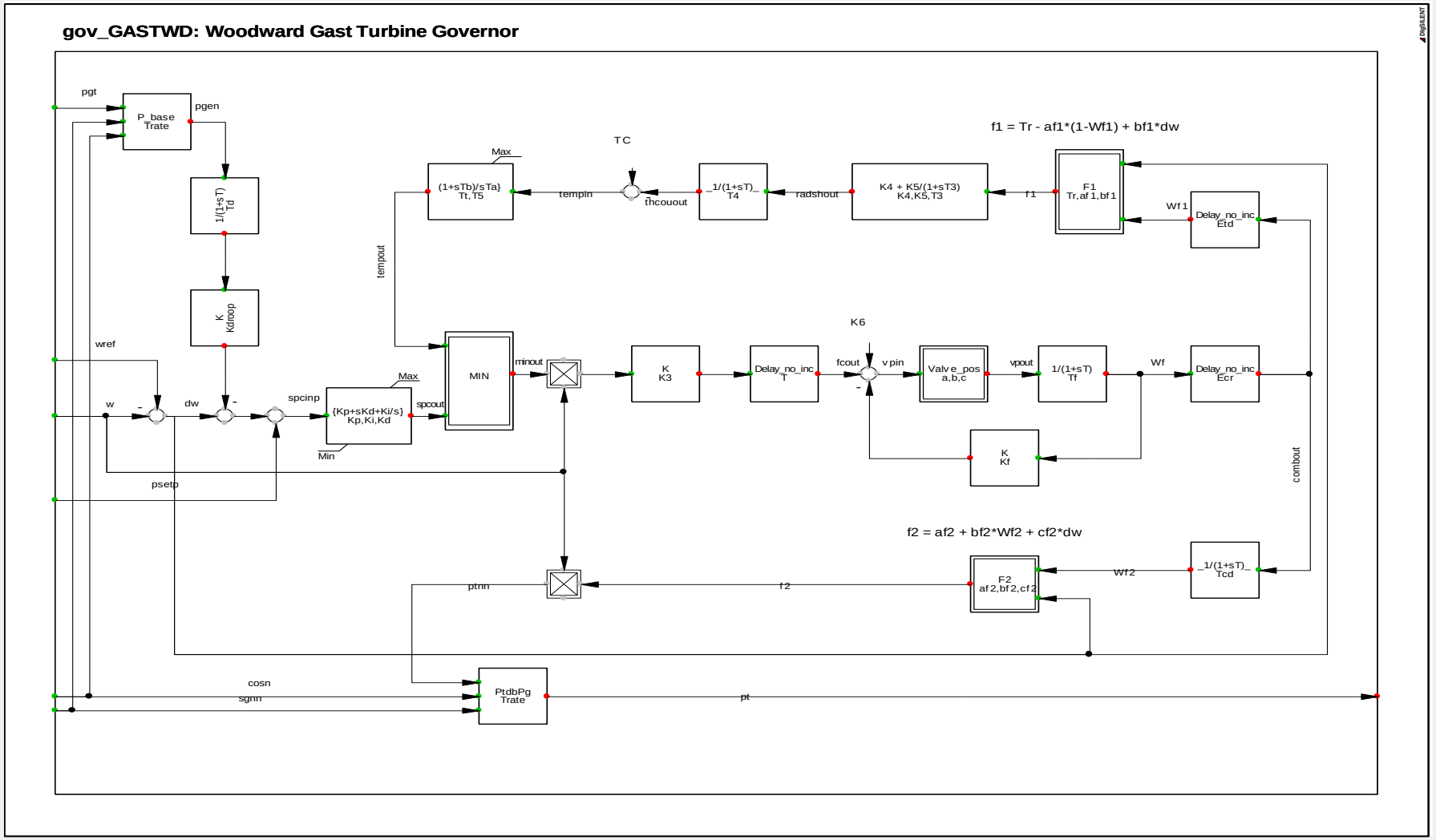
Validation of Compliance Process following a Plant Change – Functional Block Diagram

- The functional block diagram is required by TNSP and AEMO. It should include as a minimum when studying new connections or planed alterations/upgrades:
  - Generator parameters;
  - Exciter and AVR;
  - Reactive power/current compensation;
  - PSS;
  - Excitation Limiters (UEL/OEL);
  - Governor control system and turbine;

Validation of Compliance Process following a Plant Change – Functional Block Diagram (cont.)



Validation of Compliance Process following a Plant Change – Functional Block Diagram (cont.)



Validation of Compliance Process following a Plant Change – Model Source Code

- As per AEMO Model Guidelines and Clause S5.2.4(b)(6), model source code must be provided in an unencrypted form suitable for at least one of the software simulation products nominated by AEMO
  - PSS/E
  - PowerFactory
  - TSAT
- The model source code is expected to contain the model of the plant being altered/upgraded, and any other plant that might have an impact on the unit or system performance

Source: AEMO (http://www.aemo.com.au/registration/118-0001.html)

Validation of Compliance Process following a Plant Change – Releasable User Guide

- As per AEMO Model Guidelines and Clause S5.2.4(b)(6), the generator must also provide a Releasable User Guide (RUG)
- The RUG is a document associated with the functional block diagram and model source code and explains how to include the plant in the system model
- It must contain sufficient information so that a Registered Participant can use the encrypted model source code to carry out studies
- It should contain (but not limited to)
  - ✓ Model parameters and values
  - ✓ Instructions on how to use the encrypted model source code
  - ✓ Connection point details
  - ✓ Commissioning dates

Validation of Compliance Process following a Plant Change – Commissioning Plan

- The generator must supply detailed commissioning program 3 months in advance (for transmission connected generator) as per **S5.2.4** of the NER

- The TNSP and AEMO must agree with the program and have the right to witness commissioning tests

Section 3
Compliance & R2 Testing

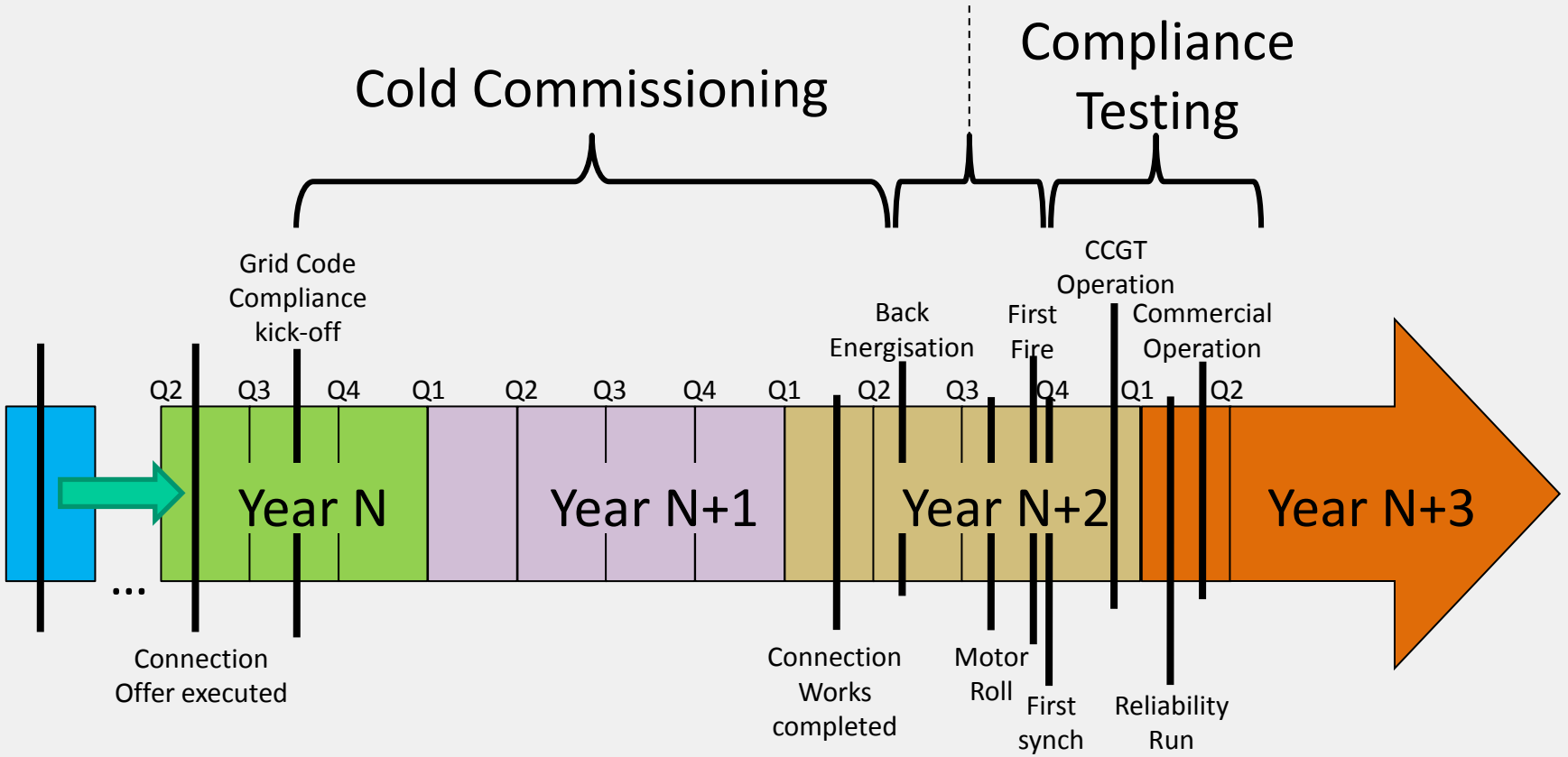
Compliance & R2 Testing

- Compliance Testing is the process of performing on-site tests to evaluate compliance with the relevant Performance Standards affected by the upgrade
- R2 testing is the process of performing on-site tests to validate R1 data
- "Type-testing" of plant is permissible, but excludes plant that has settings that can be applied on-site
  - R2 and Compliance testing is required on all AVR's and turbine governors of each unit
  - Type testing is possible on machinery, i.e. Synchronous Generators, Rotating Exciters

Compliance & R2 Testing – Compliance Program

- The onus is on the generator and their consultants to develop a "Compliance Program"
- A Reliability Panel, put together by the AEMC, have developed a template that Generators can follow to develop a "Compliance Program"
  - ***www.aemc.gov.au/Market-Reviews/Completed/Template-for-Generator-Compliance-Programs.html***
- A compliance program will consider all clauses within the Generators Performance Standard and be valid for the life of the plant
- It is the framework to assist generators in evaluating and maintaining compliance

Compliance & R2 Testing – Compliance Program



Compliance & R2 Testing – Compliance Program

- Compliance testing of an AVR and/or Governor for the Performance Standards they affect would occur every 4 years as recommended in the template

- R2 testing of the analysed sub-system must occur following any plant change, i.e. installation, modification, change in firmware or software version, etc.

- Test methodology includes:

  - Unsynchronised and synchronised AVR step response tests
  - Frequency response testing (droop testing)
  - Partial and full load rejections
  - AVR step response test of excitation limiters
  - AVR and PSS transfer function measurements over required frequency range

Compliance & R2 Testing – cont.

- As the control system is the system being tested, the recording system is required to be independent of the control system

- Therefore, an independent data logger, or Data Acquisition (DAQ) is required to measure the quantities during each test

Compliance & R2 Testing – Data Acquisition

- Typical signals measured during tests and the AEMO required resolution:
  - Terminal voltage (5 V)
  - Active power (0.01 MW)
  - Reactive power (0.05 MVAr)
  - Rotor voltage (2 V)
  - Rotor current (1 A)
  - Stator frequency (0.01 Hz)
- Overall measurement time constants for each of the quantities must not exceed 20 msec (50 Hz)
- Results to be made available in electronic format to allow for assessment by AEMO and/or TNSP

Refer to AEMO's "Commissioning requirements for generating systems" for full details (www.aemo.com.au)

Compliance & R2 Testing – Process

- When commissioning a proposed plant alteration:

1. Perform R2 testing, such as frequency response (transfer function) testing (as appropriate to the technology of the relevant sub system);
2. Carry out time domain measurements and recordings during commissioning of new or modified sub-system;
3. Prepare comparisons between measured and modelled responses in frequency and time domain to meet requirements specified by AEMO;
4. Produce a Compliance & R2 Test Report;
5. Provide data and reports to TNSP and AEMO within 3 months after commissioning as per S5.2.4 of the NER;

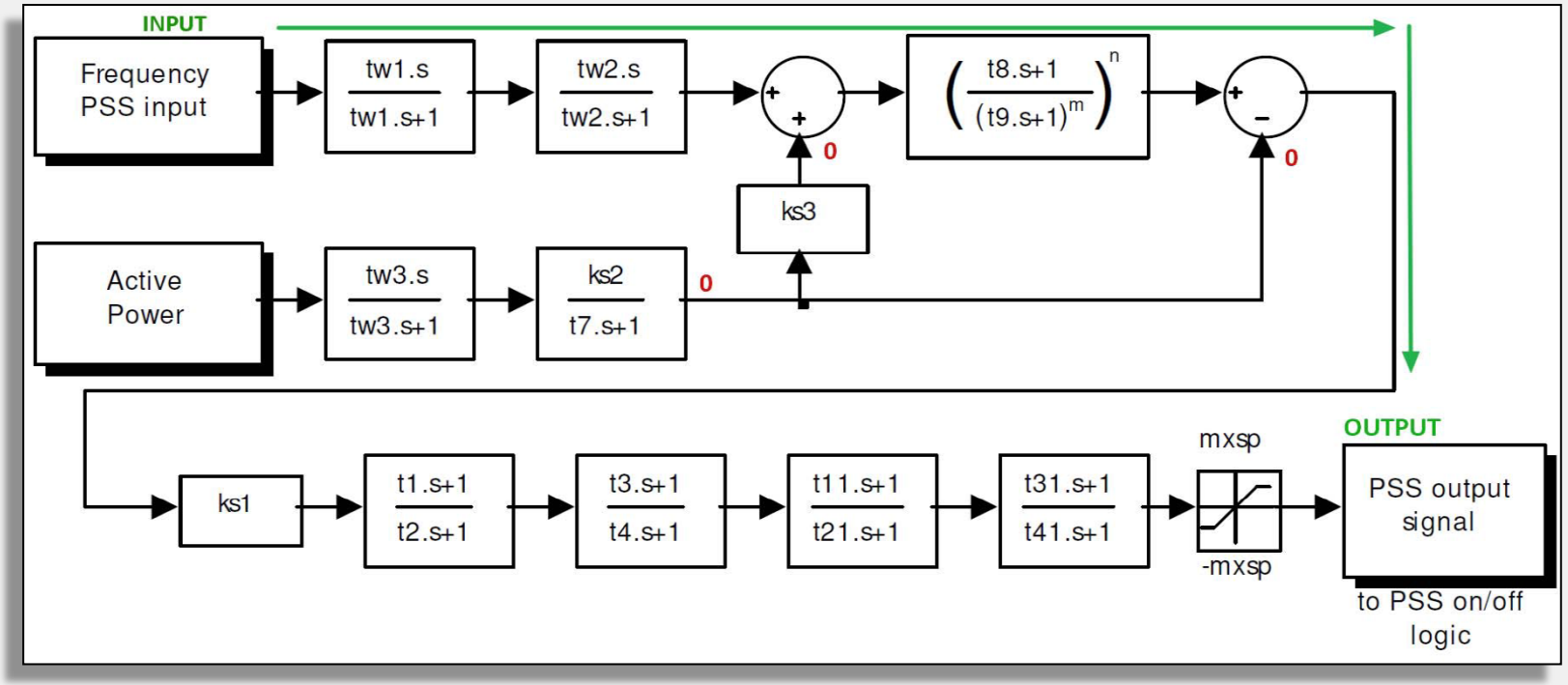
Compliance & R2 Testing – Accuracy Requirements

- For control system models, overall linear response over 0.1 – 5 Hz must be within:
  - Magnitude within 10% of actual control system magnitude
  - Phase must be within 5 degrees of the actual control system phase

- For time domain response
  - Rapid slopes in simulated response compared to actual plant response must be within
    - 10%; and
    - From start to finish of the slope, 20 msec

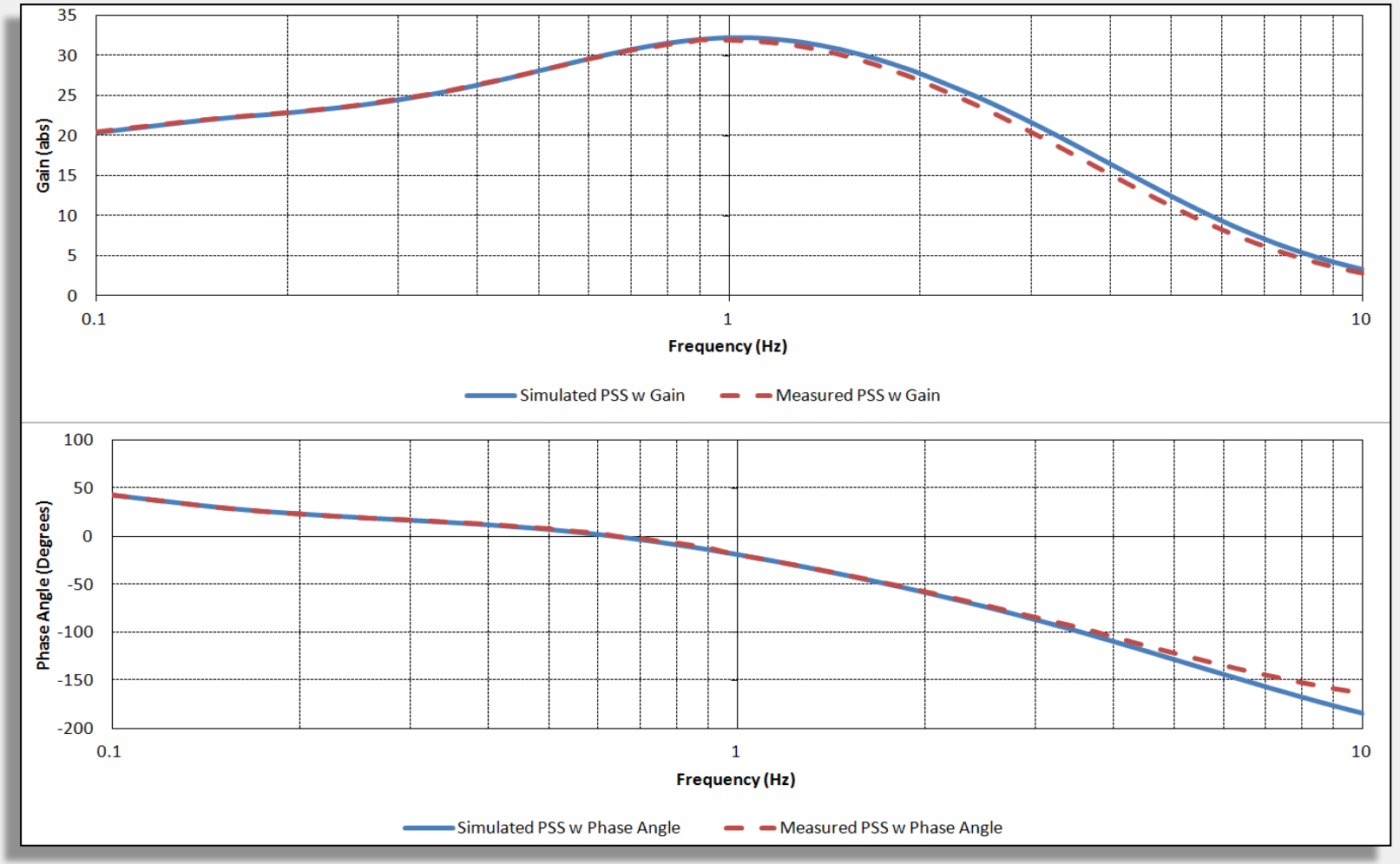
Refer to AEMO's "Generating System Model Guidelines" for full details (www.aemo.com.au)

- Set up for a Transfer Function test of the PSS frequency channel



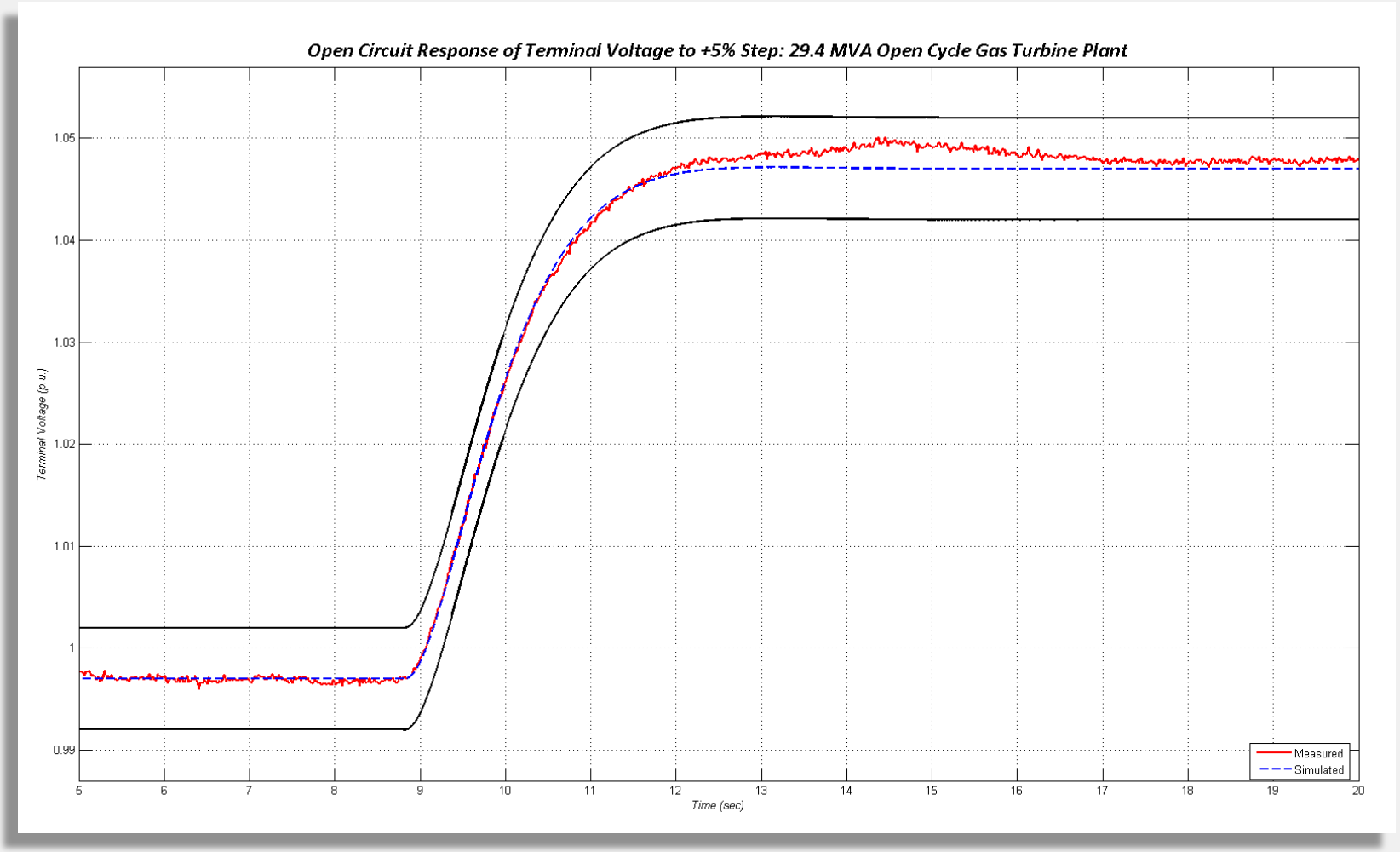
Compliance & R2 Testing – R2 Testing

- Transfer function testing of the PSS Frequency Channel



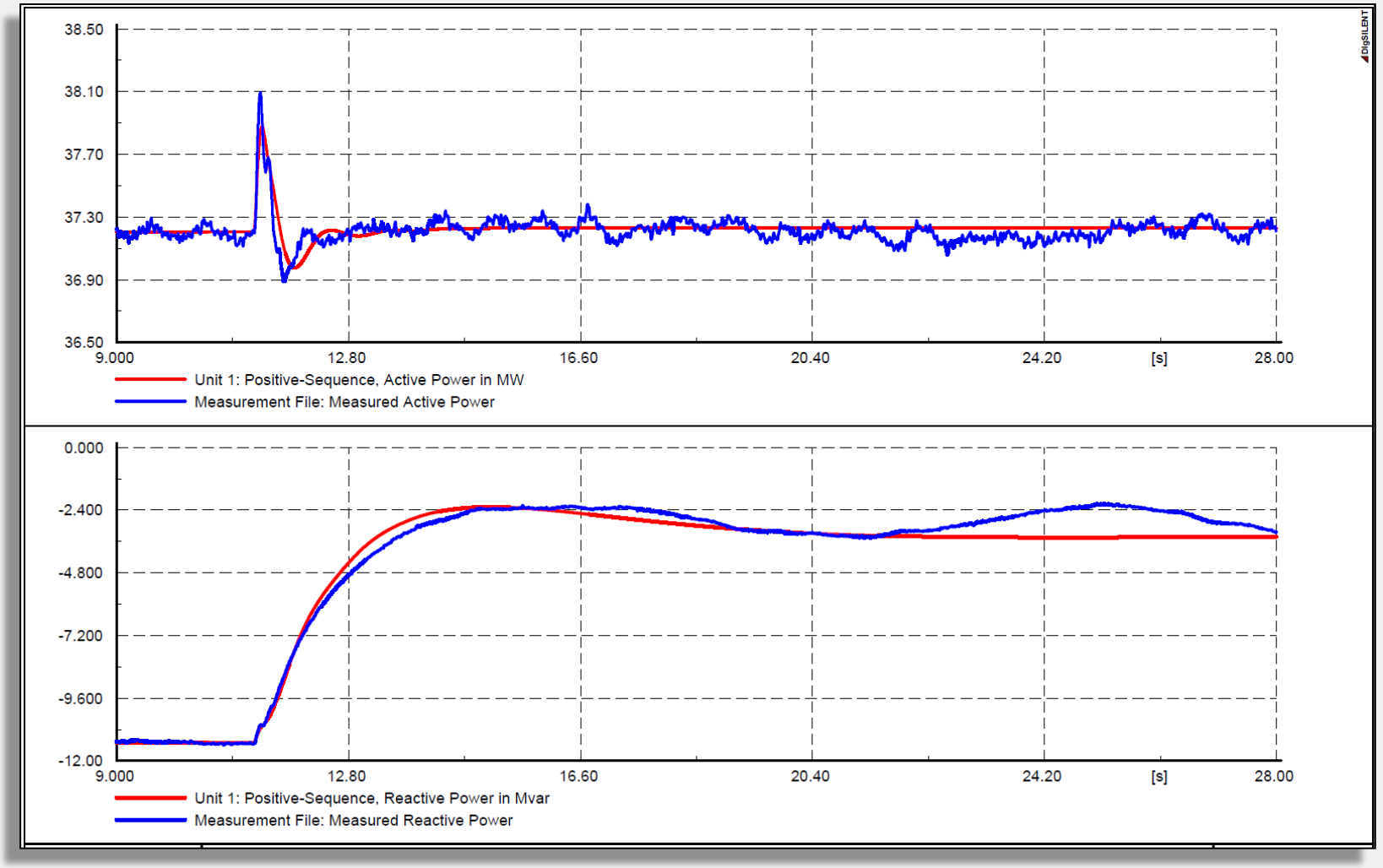
Compliance & R2 Testing – Example of Accuracy Requirements

- Unsynchronised +5% step response on 29.4MVA open cycle GT



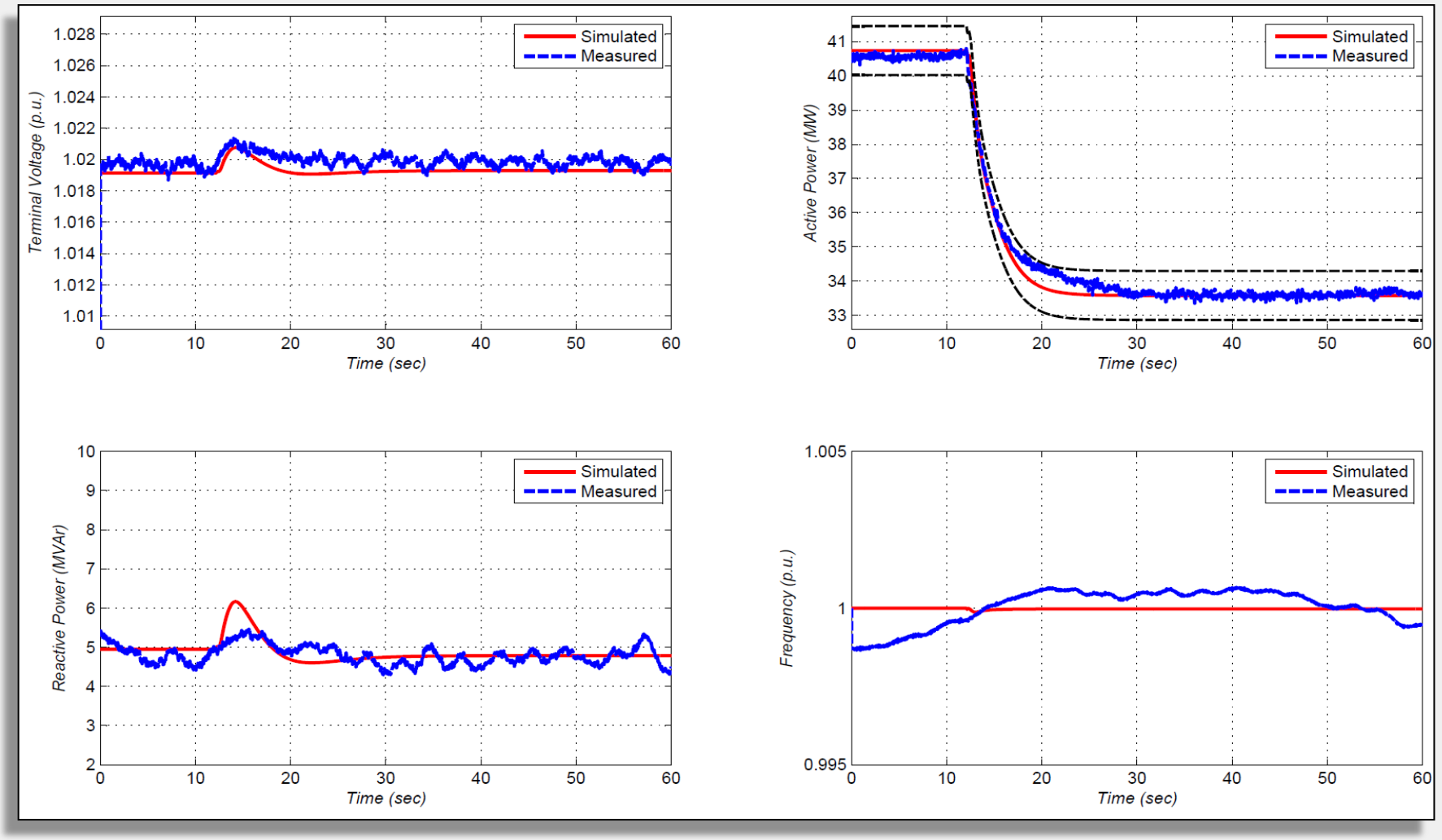
Compliance & R2 Testing – Example of Accuracy Requirements

- Synchronised +2.5% step response on a 42.5MVA hydro machine



Compliance & R2 Testing – Turbine Governor Testing

- Frequency response (droop) testing on a 79.4MVA aero derivative GT



Compliance & R2 Testing – Turbine Governor Testing

- Generator droop can be verified based on pre and post disturbance loading of the generator and the "observed" change in generator speed

  Droop = $(\Delta\omega/\omega_n) \times (P_n/\Delta P) \times 100\%$

- Where
  - $\Delta\omega$ is the change in generator speed (or frequency)
  - ω is system frequency
  - P_n is the generator rating
  - ΔP is the change in power output (P1-P0)

Compliance & R2 Testing – Turbine Governor Testing

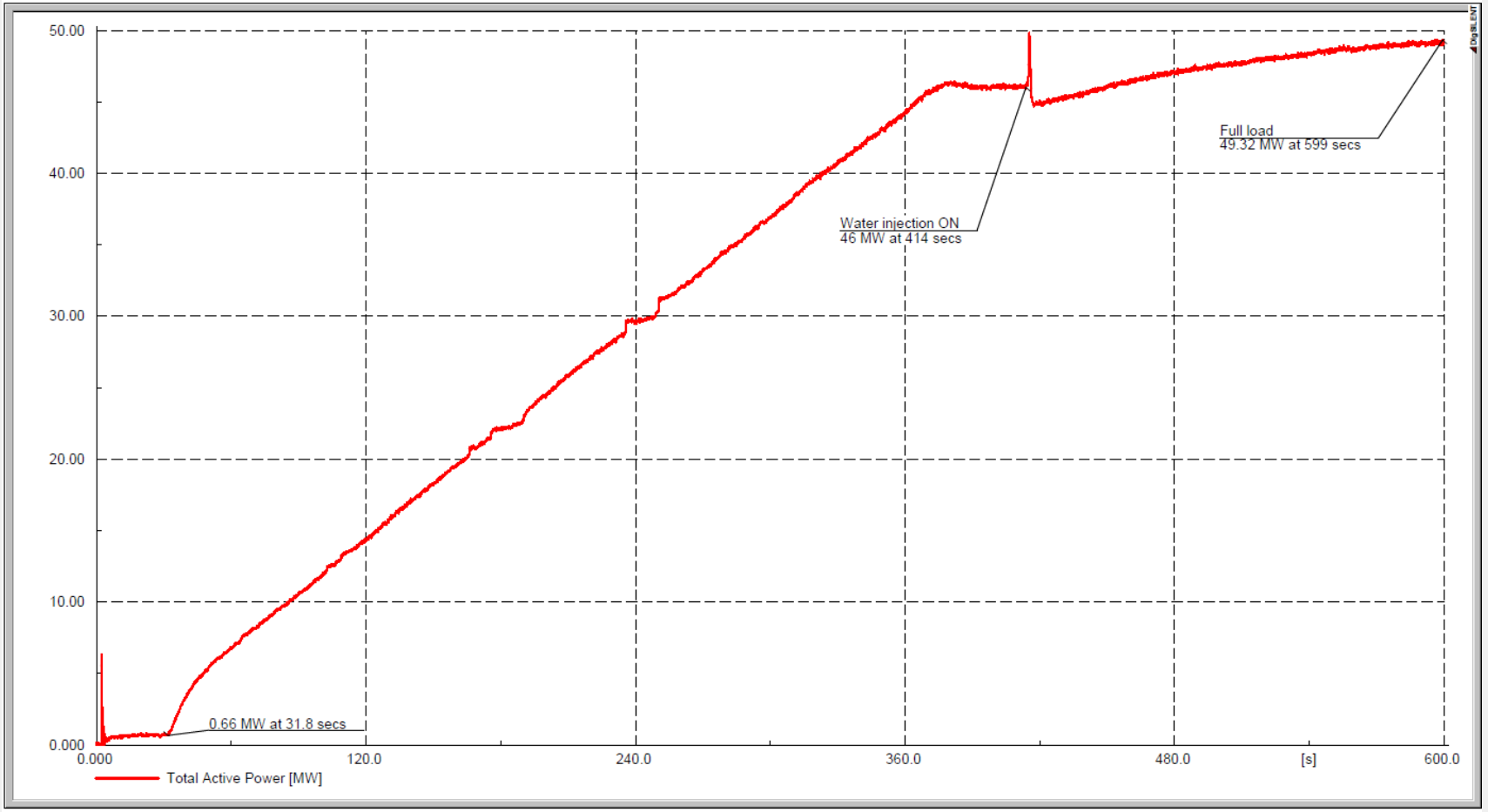
- Other turbine governor tests would be defined by the type of turbine (i.e. hydro, gas, steam) but would produce a similar outcome

- Other testing would include verification of:

  - Ramp rates
  - Dead bands
  - Load Limiters (such as Exhaust Gas Temperature limiter)
  - Fuel valve or guide vane characteristics
  - Steam flow demand
  - Stability

Compliance & R2 Testing – Turbine Governor Testing

- Verification of Ramp Rates and Active Power Control

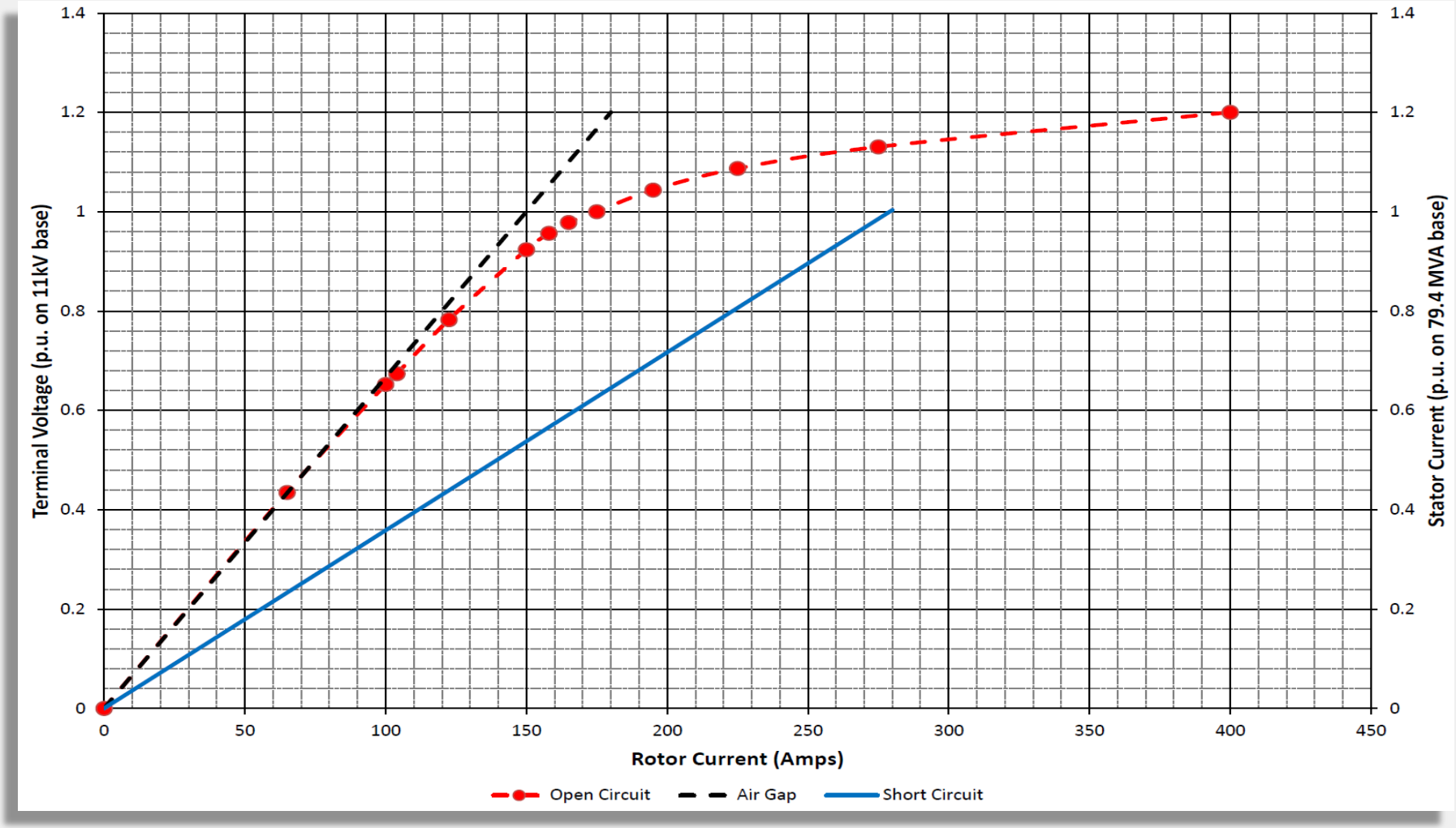


Compliance & R2 Testing – Synchronous Machine

- For new connections, the R1 data for the synchronous machine parameters will also need to be verified as R2 via on site testing.
  - This will also occur if there are plant modifications to the synchronous machine (re-winding, new rotor, etc);
- The following tests will assist in the validation of the synchronous machine parameters:
  - Open- and short-circuit characteristic
  - Partial load rejections with AVR in constant current mode
    - Assists with calculation of d- and q-axis parameters
  - Partial load rejection with AVR in AUTO
    - Assists with calculation of generator inertia
  - Steady state vee curve measurements
  - Standstill Frequency Response (SSFR) as per IEEE Standard 115-1995

Compliance & R2 Testing – Synchronous Machine

- Generator Open and Short Circuit Characteristic



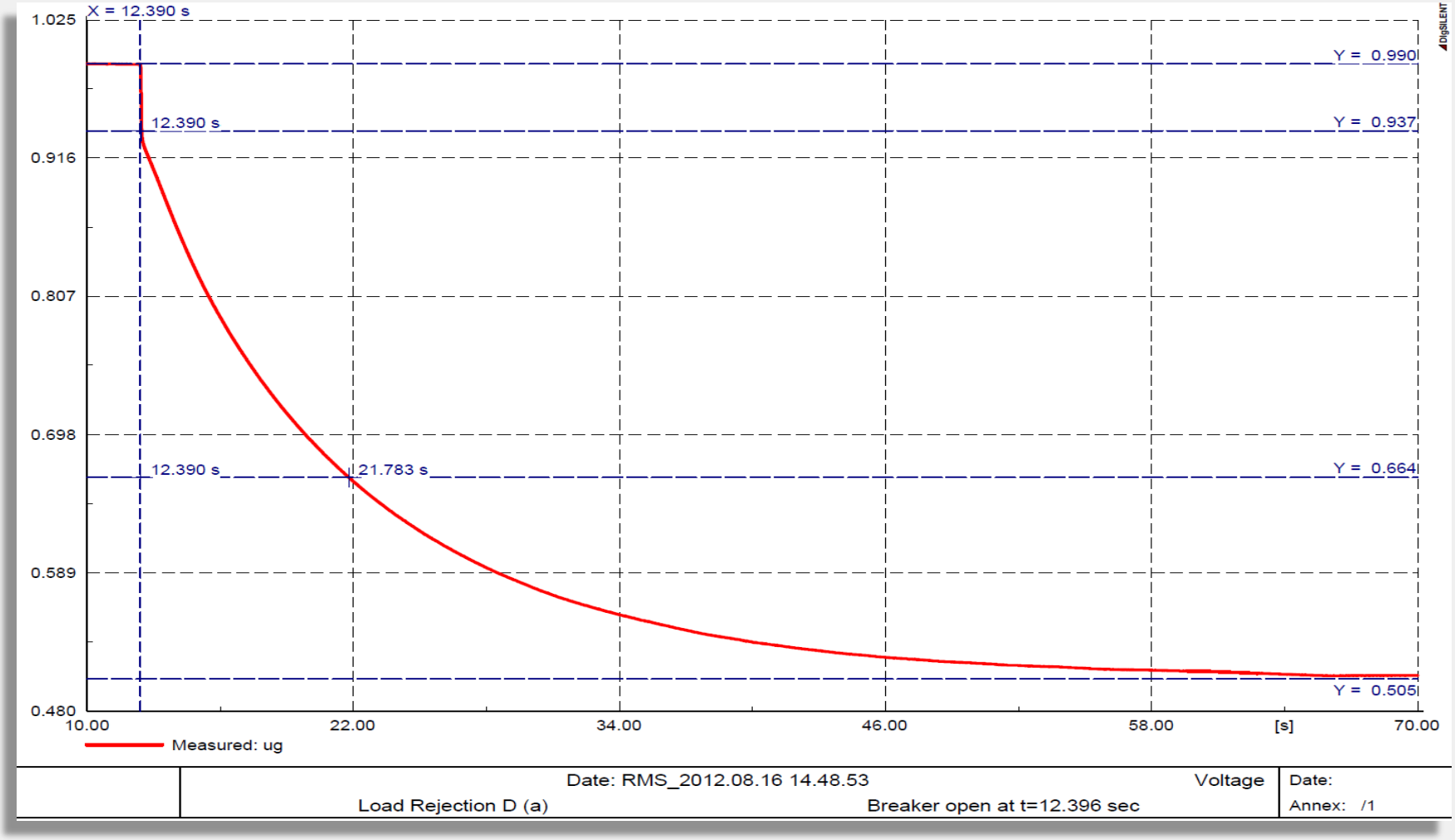
- Calculation of Xd from Open and Short Circuit Data
  - Ratio of Short Circuit Current (If_{sc}) and No Load Field Current at 1 per unit terminal voltage (If_{base}) on air gap (from Open Circuit Curve)

    $Xd_{unsat} = If_{sc}/If_{base}$

  - Gives unsaturated value of Xd
  - To obtain the saturated value, use the measured No Load Field Current at 1 per unit terminal voltage

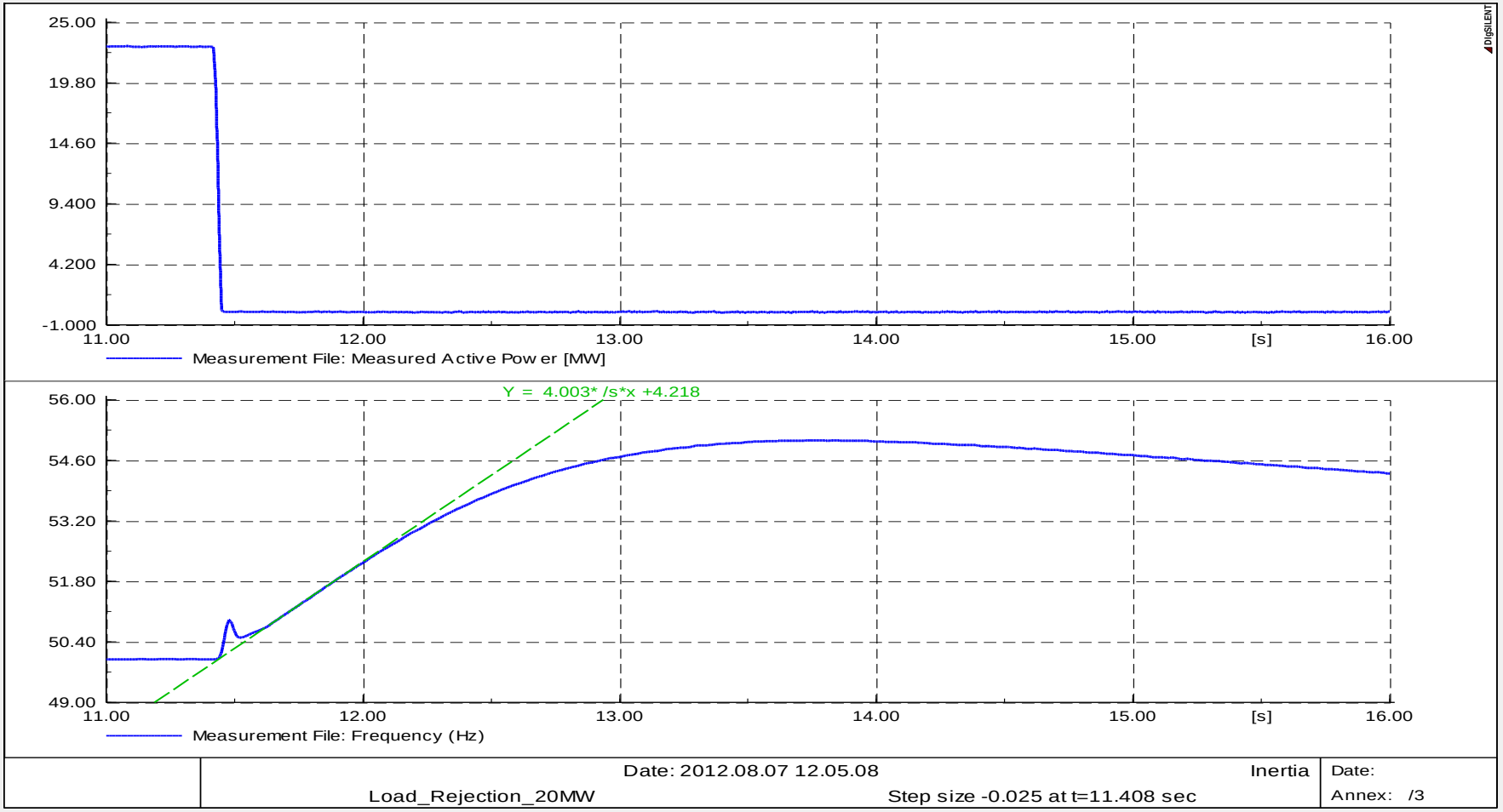
Compliance & R2 Testing – Synchronous Machine

- Generator Parameters from Load Rejections in Constant Current Mode



Compliance & R2 Testing – Synchronous Machine

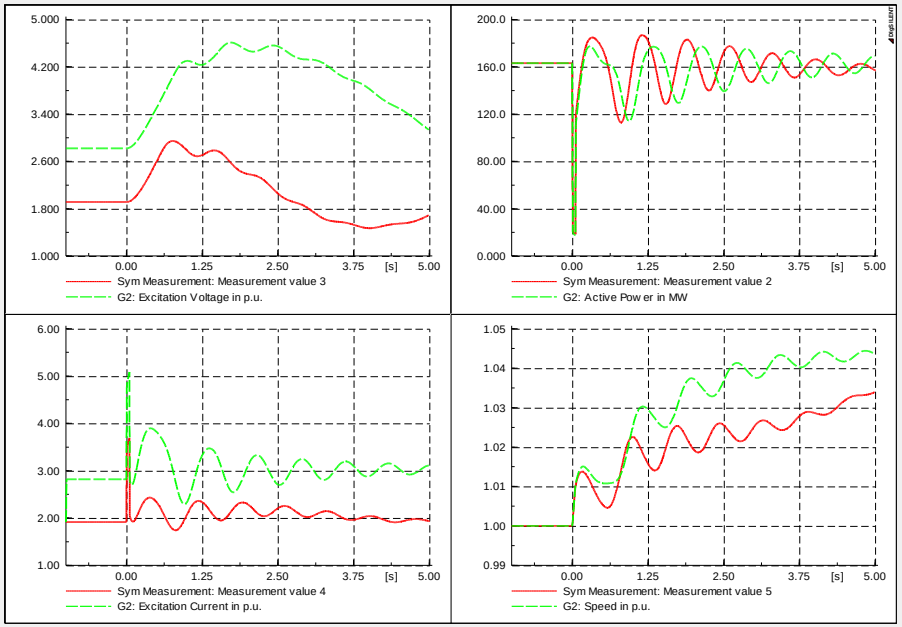
- Partial Load Rejection for Generator Inertia



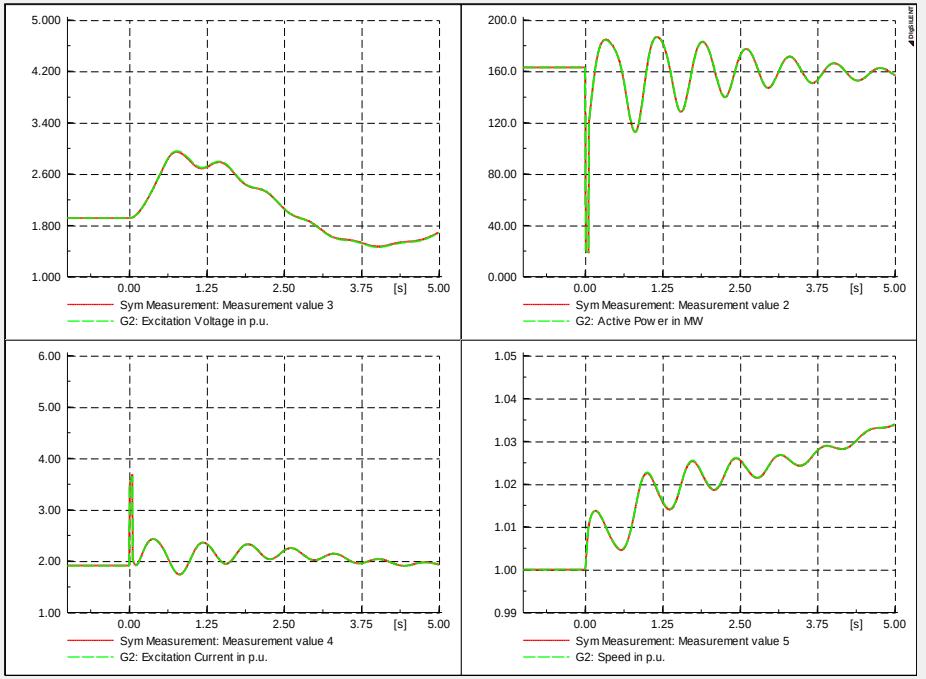
Compliance & R2 Testing – Synchronous Machine

- Issues with R2 Testing of Synchronous Machine
  - For brushless excitation systems, it is often not possible to measure generator field current or voltage due to rotating diodes
  - Need to disable feedback of terminal voltage during partial load rejections, i.e. "Constant Current Mode" (not MANUAL)
  - Difficulties in deriving q-axis data from load rejections
  - Need to achieve near 0 MW on thermal units (base load)
  - Possible overspeed condition during load rejection event
  - SSFR testing provides theoretically more accurate results, but requires downtime of generator and injection on to stator and recording rotor deviations
- Possible to perform "Parameter Identification" simulations
  - Non linear optimization tool, capable of multi parameter identification for one or more dynamic models, given a set of measured input and output signals
  - Example of Parameter Identification simulation...

Compliance & R2 Testing – Parameter Identification



- Optimisation of Xd, Xq, and Tdo' using PowerFactory Parameter Identification Tool



Thank You!