RTO-West Generating Unit Tests

Testing and Model Validation Requirements
(2000-Dec-01; Draft#001)

CONTENTS

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B. ACKNOWLEDGEMENT

This document is based on the document entitled, "General Specification of Generator Testing Deliverables" that was produced for B.C. Hydro's T&D Group by Powertech Labs Incorporated (PLI), a wholly-owned subsidiary of B.C. Hydro.

C. INTRODUCTION

All new generators being connected to the integrated electric system of the Regional Transmission Organization - West at voltages above 35 kV shall be tested by qualified personnel in accordance with the WSCC's 1997-Mar-21 letter, requesting generator testing and model validation of generators in the WSCC, and its attachments [1, 2].

The WSCC's 19997-Mar-21 letter and the associated documents are available from the WSCC's website at:

http://www.wscc.com/gentest.htm

The main objectives of the WSCC's request were:

1. To confirm each generator's over-and under-excited Mvar capabilities.
2. To confirm that each generator is being operated in automatic voltage control mode.
3. To confirm proper governor settings, particularly droop and dead band.
4. To confirm that all controls, limiters and protective relays are properly coordinated to provide adequate protection of the individual generating units and their components while maximizing their contribution to the control of system over- and under-voltages and over- and under-frequencies during major system disturbances.
5. To validate the models used to represent each generating unit in system operating and planning studies.

Any references to the Generation Facility Owner (GFO) in this document are meant to refer to the generator owner or the company performing the generator tests for the GFO.

This document provides a general specification of deliverables for generator testing. Its objective is to ensure that the information and test data provided in generating unit test reports is sufficient for the development and validation of simulation study models in accordance with the WSCC's 1997-Mar-21 request for testing and model validation of all generating units rated 10 MV.A and larger.

This document is a general specification only. Special requirements for individual units may be specified at the time of test plan development during discussions between the RTO-West and the GFO. The GFO and the testing personnel should be guided by applicable standards such as IEEE Std 115-1995 [3], for generator testing, IEEE Std 1110-1991 [4] for generator modeling and other standards including those listed in the Bibliography in Appendix G, of Reference [1].

D. SUMMARY OF TESTS NEEDED FOR MODEL VALIDATION

The following is a summary of the tests needed to develop and properly validate the models used in system simulation studies (powerflow and dynamic simulation studies). The tests preceded by an asterisk (*) are specifically included in the WSCC's February 1997 dynamic test guidelines

[1] or in the WSCC's steady-state test guidelines [2]. Unless otherwise noted, the referenced figures are from the WSCC's dynamic test guidelines [1]

1. Base Value Determination Tests: These tests will provide a correlation between the actual values of the signals in the tests and the “per unit” quantities in modeling studies. This information is especially valuable when determining detailed model parameters of internal blocks in control systems such as the automatic voltage regulator (AVR) of the exciter and the governor control system.

2. *Saturation Test: This test is used to determine the S(1.0) and S(1.2) generator saturation model constants and calculate the appropriate field current level for the D-Axis trip test to avoid the saturated region (refer to Figure D).

3. *Mvar Limit Tests: These tests confirm that the Mvar limits modeled in system powerflow and dynamic simulation studies can be attained and sustained and that limiters and protective relays are properly coordinated. (refer to Figures D and I).

4. *Volts/Hz Limiter (VHL) Test: To verify the performance of the VHL at off-synchronous frequencies and confirm that it is coordinated with protective relays (refer to Figure J).

5. Terminal Voltage Limiter (TVL) Test: To confirm the dynamic performance of the TVL and confirm that it is coordinated with protective relays (this may require a temporary lowering of the TVL setting to avoid FCL action).

6. *D-Axis Trip Test: To calculate D-axis unsaturated impedances and time constants (refer to Figure C).

7. Q-Axis Trip Test: To calculate Q-axis unsaturated impedances and time constants.

8. *Governor Dead Band Test: To determine governor deadband or verify that it is zero (refer to Figure H).

   If this test is not practical, some other means of determining governor deadband shall be proposed by the GFO for consideration by the RTO-West.

9. Load Rejection: These tests will provide an estimation of the machine inertia and governor speed droop and permit an assessment of (a) the ability of the generating unit's speed governing system to control over-speed and return to steady operation near 60 Hz when disconnected from the integrated system and (b) an assessment of the generating unit's voltage control performance during isolated operation.

10. *Power System Stabilizer (PSS) Frequency Response Test: To determine the parameters of the PSS model (refer to Figure E).

11. Frequency Response Tests of Exciter Blocks: The frequency response tests of the components of the exciter will facilitate the development of a detailed exciter model.

12. Step Response Tests of Exciter Blocks: The step response tests of the components of the exciter will facilitate the development of a detailed exciter model and provide a check on the transfer functions derived from the frequency response tests.

13. *Line Drop Compensation (LDC) Test: To determine the LDC setting or verify that it is zero (refer to Figure F).

14. Vref Frequency Response Test (Open Circuit): To check the exciter model parameters.

    14.1. The Efd/Vref plot will provide a check on the exciter model.

    14.2. The Vt/Vref plot will provide a check on the exciter/generator modeling.

15. Vref Frequency Response Test (On-Line): To check the exciter model parameters including the PSS and LDC.

    15.1. The Efd/Vref plot will provide a check on the exciter/LDC model.

    15.2. The Vt/Vref plot will provide a check on the exciter/LDC/generator modeling.

    15.3. The PSS O/P vs P_e plot will provide a check on the PSS modeling.

16. Vref Step Response Test (Open Circuit): Provides a check on the exciter & generator models and verifies the proper performance of the generating unit's voltage control loop.

17. Vref Step Response Test (On-Line): Provide a check on the the exciter, PSS, LDC and generator models.

    17.1. The Efd/Vref plot will provide a check on the exciter and PSS models including the effects of LDC on dynamic performance.

    17.2. The Vt/Vref plot will provide a check on the PSS/exciter/generator modeling with the effects of LDC included.

    17.3. Pe/Vref plot (with and without PSS) would verify the performance of the PSS in damping local mode oscillations. This gives the generator owner confidence that the PSS does not unduly reduce the damping of local oscillations.

18. Unit Synchronization: These tests will provide an overall check on all generating unit models and demonstrate the effect of the PSS on local mode oscillation damping.

19. Governor Frequency Response Tests: These tests will determine the governor model parameters.

20. Pref Step Response (with and without PSS): The Q/Pref plot would check the PSS/exciter/governor/generator modeling and illustrate and assess the magnitude of undesirable changes in reactive output and terminal voltage during directed gate changes.

21. Ramp Rates: These tests will provide an indication of the short-time overload requirements of BCIES equipment should the GFO's generating units be connected to a generation ramp down or ramp-up overload Remedial Action Scheme (RAS). Also they will serve to confirm whether or not the unit can provide spinning reserve and/or supplemental (10 min) reserve.
22. Cold Start Test: This test will determine if the unit can provide supplemental (10 min) reserves and the amount.
23. Hot Start Test: This test will determine the unit's capability to quickly return to service following a trip caused by external system conditions (ie, not resulting from any protective relaying on the unit itself).

E. TEST REPORT REQUIREMENTS

The generator tester shall provide a report (in both paper and electronic format) describing the test procedures and results in sufficient detail to permit replication of each test by others at a later date. The test report shall be signed by the lead test engineer and stamped with his/her seal. The report shall list all members of the test team and indicate their position/job function on the test team.

The electronic version of the test report shall be provided in Microsoft Word format (Office95 or newer version). All test results and documentation (including the test report) shall be provided on a CD-ROM disk. The label on the CD-ROM shall include the name of the plant and the start and end dates of the tests.

An index file (preferably in Excel® format) shall be provided in each CD-ROM folder (subdirectory). This index file shall list all files contained in the folder, identifying the program associated with the file (especially for data files) and a brief description of what the file contains. These index files shall be named, "index_abc.xls", where "abc" is the full or abbreviated name of the folder.

The following information shall be included in the test report:

E.1 General:

1. The name, business address and phone number of the generating unit owner.
2. The name, business address and phone number of the company or individual conducting the tests.
3. A description of the location of the generating plant including the name(s) of the RTO-West substation(s) to which the plant is connected and the names of any intermediate substations.
4. The start and end dates of the tests.
5. The plant name and unit number (include the abbreviated plant name also if applicable).
6. Complete nameplate data and information including the name of the manufacturer and the manufacturer's model number of each major component of the generating unit (ie, generator, exciter, turbine, governor).
7. A listing of the base values for all generator, exciter, governor, etc, parameters expressed in "per unit" form, including, but not necessarily limited to:
   7.1. Generator MVA

7.2. Generator Terminal Voltage
7.3. Generator Field Current: Note that this should be provided in accordance with the definition contained in Appendix B, "Per Unit System" of IEEE Std 421.5-1992, "IEEE Recommended Practice for Excitation System Models for Power System Stability Studies", namely, "…one per unit generator field current is that current required to produce rated synchronous machine terminal voltage on ***THE AIR GAP LINE*** (emphasis added), and one per unit field voltage is the corresponding field voltage…"
7.4. Generator Field Voltage (see above comment).

8. Manufacturer's block diagrams of the machine's controls (especially for the exciter and governor).
9. A complete listing (provided in the report and also in an Excel® file) of all relevant drawings (eg, one-line, control schematic, control block diagram, protection AC schematic, protection DC schematic, wiring diagram, equipment layout diagram, etc) providing:
   9.1. The name, mailing address, phone number, fax number and Email address of the custodian of the drawings from whom full-sized copies of the current versions may be obtained.
   9.2. Drawing number (including revision number).
   9.3. Date of the most recent revision.
   9.4. Drawing Title
   9.5. Drawing type (eg, one-line, control schematic, control block diagram, etc).

E.2 Test Specific

A list of tests, providing the information listed below, shall be provided in an Excel® file and shall also be included in the report:

1. Test Name.
2. Date and time of the test.
3. Graphs of key monitored signals for each test:
   3.1. For example, the graph in the report illustrating the results of the D-axis trip test should show, as a minimum, terminal voltage, speed and field current.
   3.2. For each block in the control system, input and output signals for control blocks illustrating their steady-state gains, polarities and responses to a step change in their input signals.
4. Name of the data file containing the test results.
5. Identification of each recorded signal on each channel (column in the data file)
6. If not provided in the test data file, the following shall be provided in the test report:
   6.1. the exact meaning of each label used in the test file to identify each recorded quantity shall be provided (eg, Et=generator terminal voltage)
   6.2. a diagram showing exactly where each quantity was measured or a listing of all input signals and monitored quantities indicating the specific points on the manufacturer's schematic diagrams where each signal was recorded.

F. TEST DATA REQUIREMENTS

The results of each test shall be provided in digital format as an ASCII file unless another format. Details of the test report requirements are provided in Section E.

The generator tester shall provide complete data files (in electronic format) associated with each test described in the test report.

1. The electronic data shall be supplied on a CD-ROM with files in ASCII or MicroSoft® Excel® format.

2. The date and start time of each test shall be included in the electronic file immediately prior to the test results unless the time-tagging of each sample point contains complete date/time information.

3. The preferred format for date/time-tagging is: yyyy-mm-dd hh:mm:ss.000

4. One data file for each test is preferred. This means that all monitored signals as listed for each test shall be stored in one file. The data shall be continuous (no segmentation) and properly time-tagged.

5. The test results shall appear in columns with the first column being time, for time-domain tests, and frequency, for frequency response tests (Bode plots). The first row of test data shall be the conversion factors required to convert from the recorded values to the physical machine level (primary voltage level) quantities for each of the recorded quantities. The second row of test data shall be the machine level units for each of the recorded values (eg, sec, Hz, kV, Amps, etc). The third row (just above the test results) shall be abbreviated labels for each of the quantities recorded (eg, Et for terminal voltage, Efd for field voltage, etc). The exact meaning of each label shall be provided (either in the test data file or in the test report) along with a description or diagram showing exactly where each quantity was measured and the polarity of the test probes. References should be made to specific points on the manufacturer's schematic diagrams.

6. Preferably, data shall be recorded in machine level quantities. For example, terminal voltage should be recorded in kV (RMS, Line-to-Line), field current in amps, PSS step input in volts or mV, etc. If stored values are different than the machine level values (e.g. A/D converter's integer outputs or mV output of the field shunt, etc), the conversion factor shall be provided in the test data file as discussed in Item 5 above.

7. UEL, OEL and V/Hz limiters shall preferably be tested dynamically and the key parameters (eg, the field voltage for OELs, the MW and Mvar output and terminal voltage for the UEL and the frequency and terminal voltage for the V/Hz limiter) shall be plotted.

8. In addition to the signals specified in Section G (Test Descriptions) additional signals may be required and specified by the RTO-West when detailed test procedures are being developed.

9. In addition to the WSCC tests, some tests such as synchronizing events (or others to be specified by the RTO-West) shall be performed and reported.

10. Any relevant information related to the test procedures used or observations on the performance of equipment shall be included in the report. These shall include deviations from the specified test plan, equipment failures or improper operation, and any test results which are not completely captured by the data recordings.

G. TEST DESCRIPTIONS

The results of each test shall be properly time stamped and recorded in ASCII or Excel® files with the test number and the date and time of each test clearly shown. The Date/Time format shall be YYYY-mm-dd; hh:mm:ss.000.

G.1 Base Value Determination Tests

The report shall include detailed descriptions of steady-state tests conducted to determine the base values of each quantity recorded. For example, a table showing the measured values of each monitored quantity in the excitation control system shall be provided. With the unit running at rated speed but disconnected from the integrated system, the terminal voltage reference setting shall be changed in 7 or more steps through the safe terminal voltage range. That is, signal levels shall be recorded at the following seven points: minimum terminal voltage, 80%, 90%, 95%, 100% and 105% of rated terminal voltage and at the maximum safe short-time (1 minute or however long it takes to take the readings) terminal voltage level. For the excitation system, the quantities recorded shall include, as a minimum:

1. The reference generator terminal voltage (Vref) setting (at the Vref summing junction),
2. All other input signals at the Vref summing junction.
3. The steady-state gain of each input signal at the Vref summing junction.
4. The output (error signal) at the Vref summing junction),
5. The input and output signals of each block in the exciter control scheme including the voltage regulator output signal.
6. The generator field voltage.
7. The generator field current.
8. The generator terminal voltage.
9. Generator speed or terminal voltage frequency.

A similar set of readings shall be made for the governor system with (a) the unit disconnected from the system and the speed/load changer reference signal increased in at least seven steps through the safe operating range and (b) the unit synchronized to the system and the same speed/load changer reference signal similarly increased in at least seven steps from zero to the maximum continuous rating (MCR) of the machine. The governor's "Speed/Load Changer" will be calibrated to obtain position sensor versus Load and position sensor versus speed characteristics.

G.2 *Saturation Test

Field current will be first decreased to its minimum level (preferably to below 0.30 pu terminal voltage) and then increased monotonically (no decrease in field current during the test) in steps until the short term maximum allowable terminal voltage reach is reached (preferably 120% or more of nameplate terminal voltage). To eliminate the effect of the generator open circuit time constant (T'do), the field current should be held constant for a period of approximately one minute before taking each reading. The following quantities shall be recorded: V_a V_b V_c RPM I_{fd} V_{fd}.

G.3 *Mvar Limit Tests

G.3.1 Over- and Under-Excited Steady State Tests

Some aspects of these tests are specified in the WSCC's steady-state testing guidelines [2].

1. The generator output shall be held at the limiting value for at least 15 minutes and preferably for 30 minutes to confirm the steady-state Mvar capability.

2. If the stator heating limit occurs before the field heating limit in the over-excited test conducted at or near the machine's MCR, the generator power output level should be reduced to a value that causes the field heating limits to be the overriding limit to properly verify correct OEL operation.

3. Where system, generating unit or auxiliary bus voltage limits prevent the generator from operating at its over- or under-excited Mvar limits, the unit should be operated as close as possible to those limits and the limiting factor should be stated in the test report. Note that, the TVL (or in some cases the VHL provides this function) should prevent over-voltage at the generator terminals (ie, there should be no need for operator intervention to prevent the generator terminal voltage from exceeding the generator terminal voltage limit). In general the TVL will also prevent excessively high voltage on auxiliary buses. Operator intervention should therefore only be necessary to keep the high voltage bus within safe limits.

4. Over- and under-excited steady-state tests shall be conducted:

   4.1. At or near the machine MCR.

   4.2. At or near 0.0 MW output for all generators incapable of operation in synchronous condenser (S/C) mode.

   4.3. In S/C mode (ie, at 0.0 MW output) for generators capable of operating in this mode.

5. Proper coordination among the machine capability diagram, limiters and protective relays shall be demonstrated by these tests in conjunction with the dynamic tests of Sections G.3.2 and G.3.6.

6. The limiting device shall be identified in each case (eg, VHL, TVL, OEL, FCL, UEL). There should not be any tests in which operator action is the limiting factor. All generators shall be provided with all necessary limiters such that operator intervention is not required to prevent the generator from tripping or being damaged in the event of a system disturbance.

G.3.2 OEL Off-Line Injection Test (FCL-Type)

If the OEL monitors either the AC current out of the exciter transformer or the DC current into the generator field winding, (ie, a Field Current Limiter, FCL), it shall be tested by:

1. With the generator operating off-line at 60 Hz, ramp the field current from its lowest level to the level that produces the maximum permissible short-time generator terminal voltage. Record Ifd, FCL input, FCL output, Efd, Vt and RPM at a sampling rate that would result in test record with between 200 and 500 points.
2. Determine the factor for converting from FCL input to actual field current and plot FCL input vs Ifd to illustrate any non-linearities.
3. Inject a steadily increasing signal into the FCL input and record FCL input and FCL output choosing a sampling time that would result in test record with between 200 and 500 points.
4. Using the conversion factor (or function, if non-linear), plot FCL output vs Ifd to demonstrate FCL setting.

Voltage(s) and current(s) from relay testing apparatus will be applied to the limiter and the angle between voltage and current adjusted to replicate operation at different over-excited power factors.

G.3.3 OEL Off-Line Injection Test (VPQ-Type)

If the OEL uses unit terminal voltage, MW output and Mvar output to limit field current (ie, VPQ-type of limiter), six tests shall be conducted at each of three different voltage levels (90%, 100% and 105% of rated terminal voltage) for a total of 18 tests. The six tests conducted at each voltage level shall be carried out with the angle that the current leads the voltage increasing in 15-degree increments between tests from zero to 90 degrees. At each of the six different power factor angles, the current magnitude will be slowly and steadily increased (at a rate equivalent to approximately 2% of rated MV.A output per second) from zero to 120% of the generator's maximum continuous rating (MCR).

The current magnitude and UEL output shall be recorded (at a sampling rate that produces between 200 and 500 data points) as a function of time. The UEL output signal shall be plotted in the report as a function of current magnitude for each of the six values of power factor angle. The limit points shall also be plotted on a P-Q generator capability diagram, providing four curves, one for each of the four terminal voltage values.

G.3.4 OEL Dynamic Test

If, due to system voltage limitations, this test cannot be conducted with the normal OEL settings, the OEL settings must be lowered to permit this test to demonstrate the dynamic performance of the OEL. Then the OEL settings shall be returned to their normal levels and the test in Section G.3.2 carried out to verify those settings.

For a FCL-type of limiter, this test need only be conducted at one generator MW output level (at the highest level that would not overly stress the unit should protective relay miscoordination cause the unit to trip).

A VPQ-type of limiter shall be tested at two or more MW levels, one at a moderate load that would clearly not overly stress the unit should it trip and the other near the unit MCR.

At each MW output level, the generator's reactive power output shall be increased to 95% of its limit. Then a 10% step increase in V_{ref} will be introduced. V_{ref}, I_{a}, V_{a}, Mvar, I_{fd}, V_{fd}, and the output of the OEL shall be recorded. The unit's MW output shall be recorded also or noted for each test. Refer to Section 10 of the WSCC's dynamic test guidelines [1].

G.3.5 UEL Off-Line Injection Test

Voltage(s) and current(s) from relay testing apparatus will be applied to the limiter and the angle between voltage and current adjusted to replicate operation at different under-excited power factors.

Six tests shall be conducted at each of four different voltage levels (80%, 90%, 100% and 105% of rated terminal voltage) for a total of 24 tests. The six tests conducted at each voltage level shall be carried out with the angle that the current leads the voltage increasing in 15-degree increments between tests from zero to 90 degrees. At each of the six different power factor angles, the current magnitude will be slowly and steadily increased (at a rate equivalent to approximately 2% of rated MV.A output per second) from zero to 120% of the generator's maximum continuous rating (MCR).

The current magnitude and UEL output shall be recorded (at a sampling rate that produces between 200 and 500 data points) as a function of time. The UEL output signal shall be plotted in the report as a function of current magnitude for each of the six values of power factor angle. The limit points shall also be plotted on a P-Q generator capability diagram, providing four curves, one for each of the four terminal voltage values.

G.3.6 UEL Dynamic Tests

If, due to system voltage limitations, this test cannot be conducted with the normal UEL settings, the UEL settings must be temporarily adjusted to permit this test to demonstrate the dynamic performance of the UEL. Then the UEL settings shall be returned to their normal levels and the test in Section G.3.5 carried out to verify those settings.

This test shall be conducted for at least two different generator MW output levels, one at a moderate MW output level (perhaps 20%) that would not overly stress the unit should protection miscoordination cause it to trip, and the other near the generator's MCR.

At each MW output level, the generator's reactive power output shall be decreased to 95% of its var absorption limit. Then a 10% step decrease in V_{ref} will be introduced. V_{ref}, I_a, V_a, Mvar, I_{fd}, V_{fd}, and the output of the OEL shall be recorded. The unit's MW output shall be recorded also or noted for each test. Refer to Section 10 of the WSCC's dynamic test guidelines [1].

*G.4 *Volts/Hz Limiter (VHL) Test*

G.4.1 VHL Off-Line Injection Test

Voltage(s) from relay testing apparatus will be applied to the limiter. The input voltage level will be slowly and steadily increased (at a rate of approximately 2% of rated voltage per second) from zero to 120% of rated terminal voltage. The input voltage and V/Hz limiter output shall be recorded (at a sampling rate that produces between 200 and 500 data points) as a function of time. The V/Hz output signal shall be plotted in the report as a function of input voltage at each frequency level. This test shall be conducted at frequencies of 10 Hz, 30 Hz, 40 Hz, 50 Hz, 55 Hz, 60 Hz, 65 Hz and 70 Hz.

G.4.2 VHL Dynamic Test

With the generator operating off-line at between 50 Hz and 55 Hz (or at the lowest safe operating speed if operation in this range is not advisable), the terminal voltage of the generator shall be raised to 95% of the VHL setting. A 10% increase in Vref shall be introduced in the terminal voltage to force the VHL to act to control the terminal voltage to a safe level. The terminal voltage and the output of the Volts/Hz limiter will be recorded.

G.5 Terminal Voltage Limiter (TVL) Test

With the unit operating at synchronous speed but disconnected from the rest of the system, the terminal voltage shall be raised to 95% of the TVL setting. Then a 10% step change in Vref shall be injected into the Vref summing junction. Vref, Vt, Efd, Ifd and TVL output shall be recorded.

*G.6 *D-Axis Trip Test*

With the generator operating in fixed field voltage mode at zero MW output and moderately underexcited (absorbing reactive power), the generator unit breaker shall be tripped. I_a V_a RPM, MW, Mvar, I_{fd} V_{fd} shall be recorded.

G.7 Q-Axis Trip Test

This test is described in Reference [5].It may not be necessary to repeat this test until perfect alignment along the Q-Axis is achieved if simulation studies using parameters estimated from the tests closely match the test results.

Ideally, the field voltage should be kept constant. However, even if this cannot be achieved, this test can lead to good estimates of Q-Axis parameters by trial and error (adjusting the generator parameters and simulating the test including field voltage deviation and speed changes until the simulation matches the test). I_a V_a RPM, MW, Mvar, I_{fd} V_{fd} shall be recorded.

*G.8 *Governor Dead Band Test*

G.8.1 Governor Dead Band – Speed Test

With the unit operating at rated speed (60 Hz) but disconnected from the integrated system (main breaker open), introduce a small, steadily increasing signal at the governor speed reference summing junction for a period just long enough to observe a ramping up of the generator speed. Then keep the speed reference signal constant for a short period followed by a ramping down of the speed reference signal, again at a slow steady rate. Calculate the governor deadband as illustrated in Figure H of the WSCC's dynamic test guidelines [1].

The speed reference (input) signal, speed reference summing junction output, governor output, gate position and speed or terminal voltage frequency should be recorded at a sampling rate that would produce between 200 and 1000 data points.

If this test is not practical, some other means of determining governor deadband shall be proposed by the GFO for consideration by the RTO-West.

G.8.2 Governor Dead Band – Power Test

With the unit operating at about 80% of its MCR, introduce a small, steadily increasing signal at the governor power reference summing junction for a period just long enough to observe a ramping up of the generator MW output. Then keep the P_{ref} signal constant for a short period followed by a ramping down of P_{ref}, again at a slow steady rate. Calculate the governor deadband as illustrated in Figure H of the WSCC's dynamic test guidelines [1].

The P_{ref} (input) signal, the P_{ref} summing junction output, governor output, gate position, active power and speed should be recorded at a sampling rate that would produce between 200 and 1000 data points.

If this test is not practical, some other means of determining governor deadband shall be proposed by the GFO for consideration by the RTO-West.

G.9 Load Rejection

At least one load rejection test, conducted at an output level slightly less that the MW output level that would result in an over-speed shutdown of the generator. If tripping of the unit breaker is used for this test and that would normally shutdown the unit, this shall be disabled. Any over-frequency or over-speed protection should not be disabled. If higher level load rejection tests are to be done as part of the normal commissioning tests for the unit, these tests should be recorded.

The test parameters should be recorded for at least two minutes or until the terminal voltage oscillations damp out to less than 0.10% of its steady-state value and until oscillations in all other parameters (eg, speed) damp out to less than 1.00% of their steady-state values. Record real generator MW output (to provide the precise time of the trip), speed (or terminal voltage frequency), terminal voltage(s), field voltage and field current as well as the outputs of the power system stabilizer (PSS), terminal voltage limiter (TVL) and the Volts/Hertz Limiter (VHL) and any protective relays that might be expected to operate (for the higher load rejection tests). These parameters shall be recorded at a sampling rate that would provide a test record of between 200 and 500 samples.

G.9.1 <u>Governor Droop</u>

Operate the unit at a moderate power output level that is just low enough such that the over-speed following the tripping of the unit is within safe limits for the machine (ie, lower than any over-speed protection). Note the generator MW output level if it is not being recorded. Calculate the governor permanent droop as shown in Figure G of the WSCC's dynamic test guidelines [1].

G.9.2 <u>Machine Inertia Constant</u>

From the highest load rejection test, calculate the machine inertia constant as shown in the 1997-Apr-28 version of Figure A of the WSCC's dynamic test guidelines [1].

*G.10 *Power System Stabilizer (PSS) Frequency Response Test*

A low amplitude square wave shall be injected into each PSS input with the other inputs held at their nominal levels. The amplitude and frequency of the square wave signal shall be such that the PSS doesn't reach its output limits. Fast-Fourier Transform (FFT) techniques shall be used to derive the PSS transfer function.

As an alternative to the square-wave test described above, low voltage random noise could be injected into each PSS input with the other inputs held at their nominal levels. This test will provide the frequency response (magnitude and phase) of the PSS, enabling time constants and gains to be determined. The results will be recorded in Bode Plot fashion (ie, magnitude (in dB) of PSS gain vs frequency and phase lag of the output signal compared to the input signal versus frequency) using semi-log plots (logarithmic frequency axis).

G.11 Frequency Response Tests of Exciter Blocks

A low amplitude square wave shall be applied at the input of each exciter control block with the other inputs held at their nominal levels. The amplitude and frequency of the square wave signal shall be such that the blocks do not reach their output limits. Fast-Fourier Transform (FFT) techniques shall be used to derive the transfer function of each block.

As an alternative to the square-wave test described above, low voltage random signals could be injected to various test points and the frequency response at specified test points recorded. This test will provide time constants and gains of the different blocks of the exciter. A Bode plot showing the gain and phase lag of each block as a function of frequency shall be provided.

G.12 Step Response Tests of Exciter Blocks

A small step change will be injected to various test points and response at specified test points will be recorded. This test will provide a check on the time constants and gains determined in Test G.11. The input and output signals for each block shall be recorded.

G.13 *Line Drop Compensation (LDC) Test

With the unit operating at zero MW and moderately under-excited, open the unit circuit breaker to disconnect the unit from the system. Terminal voltage(s), Mvar output, field voltage and current should be recorded along with the outputs of the TVL and VHL.

G.14 Vref Frequency Response Test (Open Circuit)

With the unit running at rated speed (60 Hz) and rated terminal voltage, a low amplitude square wave shall be injected into the Vref summing junction with the other inputs held at their nominal levels. The amplitude and frequency of the square wave signal shall be such that neither any of the control block nor the exciter output shall hit any limits. The following quantities shall be recorded: V_{ref}, AVR output, V_a V_b V_c RPM, I_{fd}, V_{fd}, OEL output, VHL output, TVL output. Fast-Fourier Transform (FFT) techniques shall be used to verify the machine transfer functions (Efd vs Vref and Vt vs Vref).

As an alternative to the square-wave test described above, low voltage random signals, with the unit running at rated speed (60 Hz) and rated terminal voltage, a white noise signal could be injected at the Vref summing junction to produce Bode plots for (a) Efd vs Vref and (b) Vt vs Vref

G.15 Vref Frequency Response Test (On-Line)

With the unit running at approximately 80% of its MCR and rated terminal voltage, a low amplitude square wave shall be injected into the Vref summing junction with the other inputs held at their nominal levels. The amplitude and frequency of the square wave signal shall be such that neither any of the control blocks nor the exciter output shall hit any limits. The following quantities shall be recorded: V_{ref}, AVR output, I_a V_a V_b V_c, P_e, Q, RPM, I_{fd}, V_{fd}, OEL output, VHL output, TVL output. Fast-Fourier Transform (FFT) techniques shall be used to verify the machine transfer functions (Efd vs Vref, Vt vs Vref, PSS O/P vs Pe and Pe vs Vref).

As an alternative to the square-wave test described above, with the unit running at approximately 80% of its MCR and rated terminal voltage, low voltage random signals could be injected at the Vref summing junction and Bode plots produced for (a) Efd vs Vref and (b) Vt vs Vref, (c) PSS O/P vs Pe and (d) Pe vs Vref.

G.16 Vref Step Response Test (Open Circuit)

With the unit operating at 60 Hz and 0.90 pu terminal voltage and isolated from the rest of the system (ie, open circuit, speed-no-load, operation) A step change will be introduced in the terminal voltage reference setting, V_{ref}. The size of the step change in, V_{ref}., shall be greater than 5% but less than the value that would cause the excitation system to hit any limits. If a 5% step change cannot be made without limiter action, the initial terminal voltage should be lowered. The following quantities shall be recorded: V_{ref}, AVR output, I_a V_a V_b V_c RPM, I_{fd}, V_{fd}, OEL output, VHL output, TVL output.

The test values for td, tr, tp, ts and overshoot (refer to Fig 3 of Reference [7]) shall be calculated and tabulated in the test report.

G.17 Vref Step Response Test (On-Line)

With the unit on-line and operating at approximately 70% of MCR and the PSS in service, reduce the terminal voltage until the generator is operating at approximately 70% of its var absorption limit (or, if system conditions do not permit such a high var absorption level, set the terminal voltage to be near the low end of the normal operating range). Introduce a step increase in the terminal voltage reference setting, V_{ref}.

The size of the step change in, V_{ref}., shall be greater than 5% but less than the value that would cause the excitation system to hit any limits. If a 5% step change cannot be made without limiter action, the initial terminal voltage should be lowered. If this still results in limiter action, the step size can be reduced. The following quantities shall be recorded: V_{ref}, AVR output, I_a V_a V_b V_c, P_e, Q, RPM, I_{fd}, V_{fd}, OEL output, VHL output, TVL output.

Repeat this test with the PSS disabled.

G.18 Unit Synchronization

If the phase angle difference between the system and generator voltages (the angle across the synchronizing breaker) is not readily available, use auxiliary transformers to obtain the instantaneous difference voltage between the incoming (generator) and running (system) voltages to estimate the phase angle and slip frequency at the instant that the synchronizing breaker closes. The difference voltage waveform should look like an AM signal with a 60 Hz carrier frequency. The slip frequency and phase angle across the synchronizing breaker at the instant of closure can be estimated from the envelope of the waveform.

Conduct two unit synchronization events (with and without the PSS). Record:

1. Phase angle across the synchronizing breaker or the difference voltage (instantaneous value) between the generator and the system.
2. Generator and System Frequencies (not necessary if the instantaneous voltage angle across the synchronizing breaker is recorded).
3. Generator real (MW) and reactive (Mvar) power output.
4. Generator terminal voltage
5. Generator field voltage
6. PSS input(s) and output.

G.19 Governor Frequency Response Tests

G.19.1 Governor Off-Line Frequency Response Test

With the unit running off-line at 60 Hz and rated terminal voltage, a low amplitude square wave shall be injected into the speed/load changer summing junction with the other inputs held at their nominal levels. The amplitude and frequency of the square wave signal shall be such that neither any of the control blocks nor the governor output shall hit any limits. Fast-Fourier Transform (FFT) techniques shall be used to verify the machine transfer functions and provide Bode plots for each block in the governor control scheme and for the output of the governor, the gate position (hydro units) or valve position (thermal units).

As an alternative to the square-wave test described above, with the unit operating off line and at 60 Hz, introduce a white noise signal at the speed reference summing junction and provide Bode plots for each block in the governor control scheme and for the output of the governor, the gate position (hydro units) or valve position (thermal units).

G.19.2 Governor On-Line Frequency Response Test

With the unit running at approximately 80% of its MCR and rated terminal voltage, a low amplitude square wave shall be injected into the speed/load changer summing junction with the other inputs held at their nominal levels. The amplitude and frequency of the square wave signal shall be such that neither any of the control blocks nor the governor output shall hit any limits. Record the inputs and outputs of each block in the governor control scheme and the PSS inputs and output. Also record the output of the governor, the gate position (hydro units) or valve position (thermal units) and the electrical power output of the generator. Fast-Fourier Transform (FFT) techniques shall be used to determine the transfer function for each block.

As an alternative to the square-wave test described above, with the unit operating on line near 70% of MCR, introduce a white noise signal at the power output reference summing junction and provide Bode plots for each block in the governor control scheme and for the PSS. Also provide Bode plots for the output of the governor, the gate position (hydro units) or valve position (thermal units) and the electrical power output of the generator.

G.20 Pref Step Response Test

With the unit operating on line near 70% of MCR, introduce a 10% step increase in Pref at the power output reference summing junction and record the inputs and outputs of each block in the governor control scheme and the PSS. Also record the output of the governor, the gate position (hydro units) or valve position (thermal units) and the electrical power output of the generator.

Repeat the test with the PSS disabled.

G.21 Ramp Rates

1. While operating at less than 10% of maximum MW output, the reference power output setting, Pref, shall be increased instantaneously (within 100 ms) to its maximum value. The following parameters shall be recorded at a sampling rate that would provide a test record of between 200 and 500 samples:
   - 1.1. Generator real power output.
   - 1.2. Generator reactive power output.
   - 1.3. Generator terminal voltage.
   - 1.4. PSS output
2. While operating at greater than 90% of maximum MW output, the reference power output setting, Pref, shall be decreased instantaneously (within 100 ms) to its minimum value. The following parameters shall be recorded at a sampling rate that would provide a test record of between 200 and 500 samples:
   - 2.1. Generator real power output.
   - 2.2. Generator reactive power output.
   - 2.3. Generator terminal voltage.
   - 2.4. PSS output

G.22 Cold Start Test

After sitting idle for at least 16 hours since it was last shutdown, the unit shall be started, synchronized to the system and loaded to its maximum output level. This test shall be conducted at least once and preferably three times, with at least a 16 hour shutdown between starts. Complete records of all tests shall be kept and made available on request. The time from the start of the test (a) to the instant of synchronizing and (b) to each output power level (increments of 20% of rated output) shall be recorded using a stop watch. The following parameters shall be recorded at a sampling rate that would provide a test record of between 200 and 500 samples:

1. Generator speed.
2. Generator real power output.
3. Generator reactive power output.
4. Generator terminal voltage.
5. PSS output

G.23 Hot Start Test

Immediately following a non-lockout shutdown at an output power level above 20% of rated output, the unit shall be started, synchronized to the system and loaded to its maximum output level. This test shall be conducted at least three times. Complete records of all tests shall be kept and made available on request. The time from the start of the test to (a) the instant of synchronizing and (b) to each output power level (increments of 20% of rated output) shall be recorded using a stop watch. In addition, the following parameters shall be recorded at a sampling rate that would provide a test record of between 200 and 500 samples:

1. Generator speed.
2. Generator real power output.
3. Generator reactive power output.
6. Generator terminal voltage.
7. PSS output

H. MODEL VALIDATION

The GFO shall provide validated models for each major component (ie, generator, exciter, turbine/governor) in block diagram format showing the transfer function contained in each block in LaPlace Transform format [6, 7, 8].:

If the models developed by the GFO are not suitable for direct use by the RTO-West in its system simulation studies, the RTO-West will convert the models into a suitable format for use in system operating and planning studies. In addition, the RTO-West may conduct simulation studies of pertinent commissioning tests to validate the converted models in accordance with the WSCC's 1997-Mar-21 request for generator tests and model validation[9].

The requirements of the models that the GFO must develop are:

1. The models shall be suitable for use in dynamic simulation programs (positive sequence network representation valid for studying phenomenon in the 0 to 10 Hz range) such as:

   1.1. PTI's PSS/E (Version 24 or later) program, PSSDS.

   1.2. GE's dynamic simulation study program, PSDS (Version 11.0 or later).

   1.3. Matlab's Simulink (Version 5.2 or later) program (from "The Math Works, Inc)

2. Data for the generator models described in Reference [5] shall be derived from the field tests.

3. Model data:

   3.1. The model data shall be provided in both electronic format (as input data files for the program used for the GFO's model validation simulation studies) and included in the test report (electronic and paper format).

3.2. A block diagram for the excitation control system, including the PSS and LDC shall be provided showing the inputs and outputs of each block and showing the transfer function (in LaPlace format) of each block.

3.3. A block diagram for the governor shall be provided showing the inputs and outputs of each block and showing the transfer function (in LaPlace format) of each block.

3.4. The model data shall include the settings used for each model parameter.

3.5. The simulation software for which input data files correspond shall be clearly indicated (preferably as "comment" entries in the data files themselves) including the version number of the software.

3.6. If the input data files have both ASCII and binary formats, both forms shall be provided.

3.7. The data files shall be saved in a separate folder (sub-directory) on the test CD-ROM.

4. The models shall be valid for dynamic simulation studies using a positive sequence representation of the power system and should permit accurate simulation of power system oscillations in the frequency range from 0 Hz to 10 Hz.

5. Generator models shall properly account for magnetic saturation effects.

6. The models shall be used in simulation studies and the results shall be compared with the corresponding commissioning test results by plotting simulation study and test results on the same graph (model validation graphs). Both the graphical and tabulated data for these plots shall be provided in ASCII file or Excel® format on the test CD-ROM disk.

The following model validation graphs shall be included as a minimum [1] (the Figures referenced are those found in Reference [1]):

1. Figure A (similar to WSCC's Figure G): Derivation of Machine Inertia Constant, H, and governor droop, R, from trip of P_0 MW.

2. Figure B: Estimation of Maximum and Minimum field voltages from response to setp changes in voltage regulator reference setting.

3. Figure C: Estimation of generator reactances and time constants (D-Axis) from trip test at zero power factor under-excited.

4. Figure D: Estimation of Field Current Base Value and generator saturation parameters from open circuit magnetization curve.

5. Figure E (PSS): Estimation of Power System Stabilizer (PSS) Linear Transfer Function Parameters from Frequency Response Test (include a similar plot showing the transfer function angle). For PSSs with multiple inputs, these plots (magnitude and angle) shall be

repeated for each input signal while keeping the other input signals constant at their normal quiescent levels.

6. Figure E (Exciter): Provide magnitude and angle plots for each block in the excitation control system (refer to Item 5 above).

7. Figure E (Governor): Provide magnitude and angle plots for each block in the governor control system (refer to Item 5 above).

8. Figure F: Estimation of Voltage Requlator Series Current Compensating Reactance (Load Drop Compensation, LDC, setting) from Response to Tripping Zero Power Factor Under-Excited Current.

9. Figure H: Estimation of Intentional Dead Band from response to Ramp change of Governor Speed Reference.

10. Figure I: Estimate of (Long Term) Over-Excitation Limiter (OEL) Characteristics from response to large step increase in voltage regulator reference signal.

11. Figure J: Response of shaft speed and voltages following trip from moderate real power output level to reveal V/Hz limiter characteristics.

12. Vref Step Response (No Limiter Action): Refer to Fig 3 of Reference [7]. The test and simulation values for td, tr, tp, ts and overshoot (refer to Fig 3 of Reference [7]) shall be calculated and tabulated in the model validation report along with the percentage difference between the simulation value and the test value (ie, express the simulation value as a percentage change from the test value). The simulation study values for each these five parameters shall not differ from the corresponding test values by more than 10% of the test value.

I. GLOSSARY & DEFINITIONS

Term	Definition
ACC	Area Control Center
AGC	Automatic Generation Control: This is the equipment that automatically adjusts generator MW output in response to changing system conditions such as frequency, time error, scheduled interchange level, etc.
AVR	Automatic Voltage Regulator: The component of a synchronous generator's excitation control system that serves to control the generator terminal voltage.
CE	Connecting Entity: Any entity connecting to the RTO-West.
Efd, Vfd	Field voltage: The voltage at the terminals of the field winding.
Et, Vt	Generator terminal voltage: Positive sequence voltage at the generator terminals.
FCL	Field Current Limiter

Term	Definition
GFO	Generation Facility Owner: The owner of the generating unit that is or will be connected to the TRTO-West.
Ifd	Field winding current
LDC	Load Drop Compensation: The component of the AVR of a generator's excitation control system that compensates for part of the voltage drop through the generator's unit transformer.
Q	Reactive Power Output measured at the generator terminals (LV bus).
Pe	Electrical Power Output at the generator terminals.
RAS	Remedial Action Scheme
TFO	Transmission Facility Owner: The owner of the transmission facilities to which the CE is connecting.
Vref	Reference voltage: the desired output voltage of the generator compensated by any LDC.
Pref	Power Reference: the desired electrical power output from the generator.

1 "Test Guidelines for Synchronous Unit Dynamic Testing and Model Validation", WSCC Control Work Group and Modeling & Validation Work Group, February 1997.

2 "Synchronous Machine Reactive Limits Verification" (1997-Mar-21 version of the document of the same name attached to the 1996-Nov-25 letter from Joseph W. Comish, WSCC to Operations Committee and Power Plant Contacts).

3 IEEE Std 115-1995, "IEEE Guide: Test Procedures for Synchronous Machines", IEEE Power Engineering Society, Electric Machinery Committee.

4 IEEE Std 1110-1991, "IEEE Guide for Synchronous Generator Modeling Practices in Stability Analyses", IEEE Power Engineering Society, Power System Engineering and Electric Machinery Committees.

5 "Derivation of Synchronous Machine Parameters from Tests", F.P. de Mello and J.R. Ribeiro, IEEE Transactions on Power Apparatus and Systems, July/August 1977, pp 1211-1218.

6 IEEE Std 421.1-1986 (R1996), "IEEE Standard Definitions for Excitation System for Synchronous Machines"

7 IEEE Std 421.2-1990, "Guide for Identification, Testing and Evaluation of the Dynamic Performance of Excitation Control Systems".

8 IEEE Std 421.5-1992, "IEEE Recommended Practice for Excitation System Models for Power System Stability Studies".

9 1997-Mar-21 letter from Dennis E. Eyre, WSCC Executive Director, to Planning Coordination Committee, Operations Committee and Non-WSCC Member Generation Owners to which was attached, (1) The WSCC's February, 1997 document entitled, "Test Guidelines for Synchronous Unit Dynamic Testing and Model Validation"

and (2) The 1996-Nov-25 letter from Joseph W. Comish, WSCC, to Operations Committee and Power Plant Contacts and (3) an updated version of the attachment to item 2 which was entitled, “Synchronous Machine Reactive Limits Verification”.