Bonneville
POWER ADMINISTRATION

Required Voltage and Frequency Control Performance Commissioning Tests STD-N-000001 Number 01 REVISION 01

Standard/Technical Content Owner: TPP

DISTRIBUTION STATEMENT: Approved for public release

DESCRIPTION:

This document is a supporting document to the BPA STD-N-000001, Technical Requirements for Interconnection to the BPA Transmission Grid. It details the commission tests of electrical performance that are required for generators to be given clearance for commercial operation. This document is not a comprehensive list of technical requirements, nor a comprehensive list of required commissioning tests. See BPA STD-N-000001 and the following supporting documents:

STD-N-000001-02, "Generation Commissioning Milestones Required for Commercial operations"

STD-N-000001-03, "Generation Commissioning Task Checklist Required for Commercial Operations"

STD-N-1-000001-04, "Generation Commissioning Process Flow for Commercial Operations"

This document's content does not address contractual topics or requirements.

Questions should be directed to the applicable BPA Customer Service Engineer or Transmission Account Executive.

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REVISION HISTORY

- Revision 01 (Current Revision) 04/03/2025. Updates were made to all four sections. Removed references to STD-N-000002 which was archived and added references to supporting documents STD-N-000001-02, STD-N-000001-03, and STD-N-000001-04. Calculations, figures and data tables were updated. Content was edited to align with STD-N-000001-00 Revision 9 and IEEE 2800.
- Revision 00, 2/18/2021

1. TEST MEASUREMENTS AND SUBMISSION TO BPA

The commissioning tests below require measurements to be taken in accordance with Figure 11, which assumes interconnection to transmission facilities at a 230 kV bus.

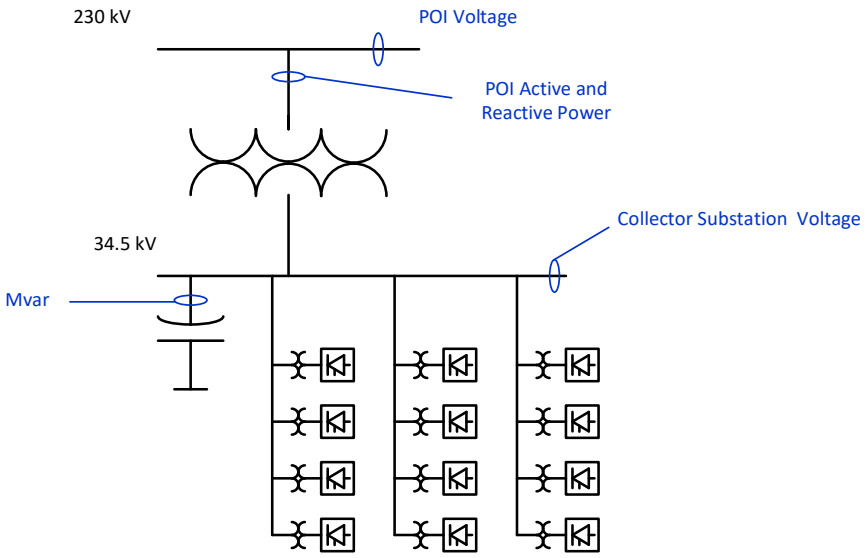


Figure 11.---Test measurement points

Output of solar and wind power plants may vary during the test period due to wind and cloud cover variability respectively. Therefore, BPA recommends the tests be performed several times to attain measurement consistency.

The generator operator shall provide the following test recordings (refer to Figure 11,

Figure 22, Figure 33, Figure 44, Figure 55, Figure 66) for each test:

- Time (unit is second, sub-second sample resolution)
- Point of Interconnection (POI) voltage in per unit (provide per unit base used)
- Collector substation voltage in per unit (provide per unit base used)
- POI active and reactive power (MW and Mvar)

- Mvar of collector system capacitor and reactor banks, one recording per device

With the test recordings, the following meta-data shall be provided:

- The name of the generating facility
- The POI
- The MW capability of each of the types of generation in the plant (e.g. solar, battery)
- The total requested interconnection service (in MW, not including surplus).
- POI target voltage from the BPA voltage schedule
- Nominal kV of the Collector Substation Voltage (e.g. 34.5 kV in Figure 1)
- The programmed droop setting of the voltage control system
- The programmed droop and deadband settings of the frequency control system (supply both over- and under-frequency parameters if distinct)

General Test Conditions:

- Unless otherwise specified, the upper limit of the plant's active power output during testing is the lesser of 25% of the MW rating or 40 MW total. Headroom (between power production and prevailing maximum power) is required to observe response during some tests (e.g. under-frequency step test). These requirements must be met throughout the duration of the testing period. The intent is to ensure that control performance test results are not ambiguous due to limitations on the primary energy source.
- Before initiating a test, notify BPA Transmission Customer Service Engineer and/or Transmission Account Executive.
- A ramp rate limit of 20 MW per minute shall be observed during test preparation and post-test (of each test). The ramp rate limit shall not be used during the frequency response test itself.

Test Recording Submission requirements

- Test recordings shall be provided by email to Commissioningtestdata@bpa.gov mailbox and directly to your BPA Customer Service Engineer (CSE).
- Please provide an .xlsx file with the plant name and this standard's name in the filename (e.g. “MyPlantName_std-n-1-01.xlsx”).
- Please contact the Commissioningtestdata@bpa.gov mailbox regarding how to format the test recordings within the .xlsx file for the plant. The BPA team will reply to your email or will set up a brief meeting to review the expected format of the test recordings.

2. REQUIRED TESTS FOR POWER PLANT VOLTAGE CONTROLS

2.1 Requirement R1:

BPA requires:

- The power plant shall operate in continuous voltage control mode.
- The voltage control shall have no dead-band.
- The power plant shall demonstrate effective reactive power droop of 1.5% to 2.5% (effective droop could be different from the actual controller droop or slope settings, example of effective droop calculation is shown below).
- Required reactive power response time is less than 5 seconds (see explanation below). The definition of “response time” is that in IEEE 2800.
- The overshoot in the POI voltage shall be less than 10%
- The power plant voltage controller shall coordinate control of all plant level shunt capacitors and reactors where they are required by interconnection requirements.
- The requirement on reactive droop applies at the Point of Interconnection (POI).
- The generator operator shall report the bus selected as voltage reference for voltage control. The generator operator shall report the line compensation settings.

2.1.1 *Required Inspection of Voltage Controller Settings:*

The generator operator shall:

- Prioritize the safety of personnel and equipment.
- Confirm that the plant-level voltage control mode is enabled.
- Confirm that the plant-level voltage controller has no dead-band.
- Confirm that the plant level voltage controller has module enabled that coordinates switching of plant-level shunt capacitors and reactors were applicable.
- Record reactive droop or slope setting in the voltage controller.
    - Note that the droop / slope software setting may not be the same as the effective reactive droop described above. A 2% droop means a 2% change up or down from the target voltage results in moving the reactive output to 33% of the plant aggregate MW capability (bucking or boosting voltage depending on the direction of the 2% voltage change).
- Notify BPA Transmission Customer Service Engineer and/or Account Executive prior to initiating the test.
- Check that system voltages are normal and determine the direction of the voltage step. Typically, the BPA transmission system is operated at voltages higher than 1.0 per unit, meaning the reference voltage step needs to be in the downward direction to avoid reaching collector system voltage limits.

- Check the plant reactive capability in the control software. Ensure that the plant response is not limited by the stated reactive capability.

2.2 Required Test T1:

The generator operator shall perform a 2% voltage reference step for at least 60 seconds to demonstrate that the plant meets the voltage control requirement. Ensure that the plant does not reach its full reactive capabilities during the step test.

Reactive Droop Calculation and Response Time Confirmation:

1. Confirm reactive power droop value by tabulating your test data like Table 1.

Table 11.— Reactive Power Droop Calculation Example

Description / Variable Name	Initial	@ 5[s]	@ 60[s]	Delta (Δ)
Input Voltage Step (PU) / $V_{step,\ pu}$	N/A	N/A	N/A	-0.03
POI Voltage V (PU of 240 kV) / V_{pu}	1.0		0.988	-0.012
Plant POI Reactive Power Q (Mvar) / Q_{MVAR}	-5	-28	-30	-25
Min voltage observed per unit $V_{min,pu}$				0.987
MW Base / MW_{base}	125	125	125	125
Droop				**0.09**
Change in Q within Response Time as a % of total change	0	-23	-25	**92%**

$$Reactive\ Droop\ =\ (\Delta V_{pu}\ )\ /\ \left(\frac{\Delta Q_{MVAR}}{0.33 * MW_{base}}\right)$$

Example: 125 MW wind power plant

A 2% voltage step down test resulted in a 1.2% voltage decrease and -25 Mvar reactive power change (export decreased) at the POI.

Reactive Droop = $(\ 0.988 - 1.0\ )\ /\ (\frac{-25}{41.25})\ =\ 0.0198, or\ 2\%$

2. Confirm Sufficient Response During Response Time

The power plant reactive power decreases by 23 Mvar within 5[s] after the voltage step and 25 Mvar within 60[s].
Percent change $=\ 23/25\ *100\%\ =\ 92\%$ *exceeds the 90% definitional to response time. Thus, the plant passes the test.*

3. Confirm Acceptable Overshoot

$$Overshoot\ \% = \frac{V_{pu\ final} - V_{min,pu}}{V_{pu,initial} - V_{pu,final}} * 100\%$$

The power plant POI voltage started at 1.0 per unit on a 240 kV base and settled at 0.988 per unit. The minimum voltage observed during the transition was 0.987 per unit. The start and the end are 0.012 per unit different. The minimum value was 0.001 per

unit below the final value. The overshoot is therefore $\frac{0.988-0.987}{1.0-0.988} = \frac{.001}{.012} = 8.3\% < 10\%$. The overshoot is approximately 8.3 %, which is less than 10 % and therefore passes the test.

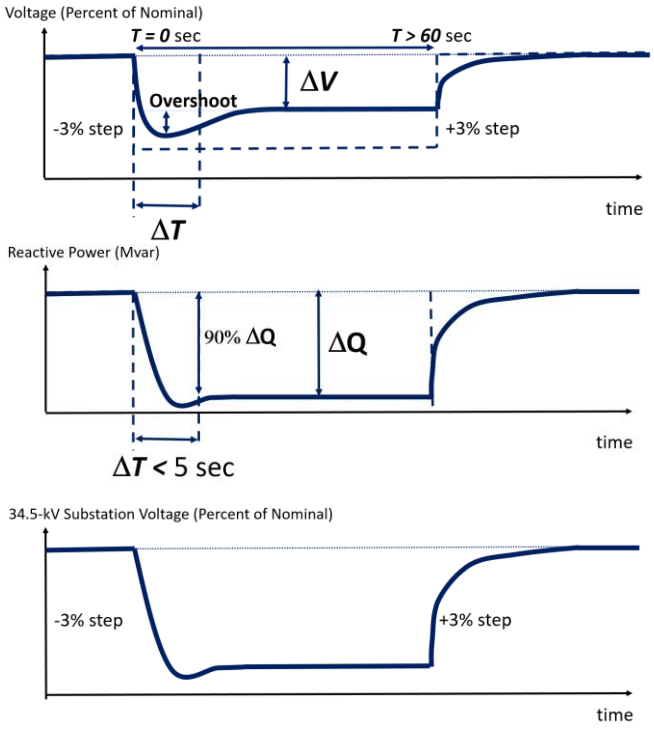


Figure 22.--- Generic Test Recordings for the Voltage Step Test

3. REQUIRED TESTS FOR POWER PLANT VOLTAGE CONTROL AT LOW ACTIVE POWER

3.1 Requirement R2:

BPA requires:

- The plant must be able to absorb (at the POI) Mvars greater than or equal to 33% of the maximum active power rating of the plant or other amount as required by BPA interconnection studies. See required tests T2a and T2b.
- Generation must be able to maintain their Minimum Reactive Capability for POI voltages inside a defined voltage band around the scheduled voltage at the POI at all times including when transitioning between control modes (e.g., NightVAR mode, WindFree mode, day mode, etc.) and shall not violate POI voltage swing requirements as listed in STD-N-000001-00 section 6.4.3.1 or as required by the interconnection study. These requirements must also be met during times of no and low real power output, such as times of low solar irradiance or low wind. See required test T2c.

- From STD-N-000001-00 section 6.4.3.1: For switched equipment supporting generation reactive power requirements (including shunt reactive devices and primary energy conversion devices like solar panels and wind turbines), voltages at the POI shall not vary more than 0.5% per switching operation

3.1.1 *Required inspection of voltage controller settings:*

- See requirement R1 of this document.

3.2 Required Test T2a:

The generator operator shall:

- Prioritize safety of personnel and equipment.
- Perform applicable parts of this test in the absence of primary energy. For example, a solar and battery generation facility shall perform the test when there is no solar irradiance (at night). If that operation typically involves plant reconfiguration, such as disconnecting devices for protection or entering a different software control loop, the plant should reconfigure. The intent is to capture the plant's typical operation in the absence of primary energy (examples are "NightVAR" mode and "WindFree" mode).
- The generator operator shall perform steps in the voltage reference in the downward direction.
- The steps shall stop when any plant equipment applicable rating exceedance is imminent or the reactive capability of the plant does not change with an additional step, whichever comes first.
- Notify BPA Transmission Customer Service Engineer and/or Account Executive prior to initiating the test.

Reactive Capability Calculation:

1. Calculate reactive capability at low active power output by tabulating test data like Table 2.

Table 22.— Reactive Capability Calculation Example for tests T2a, T2b

Description / Variable Name	Final
Cumulative Input Voltage Reference Step (PU) / $V_{step,\ pu}$	4%
MW Base / MW_{base}	125
Reactive Power Absorbed at POI (Mvar) / Q_{min}	47
POI Voltage at the time of recording Q_{min} / V_{pu}	1.034
Plant POI Reactive Power Q (%) / Q_pu	**37.6%**

$$\textit{Reactive Capability at Low Power Output} = Q_{min}/MW_{base} * 100$$

Example: 125 MW wind power plant
The plant is producing 0 MW and 0 Mvar. Then a 2% voltage step down, and 4 additional 0.5% steps test resulted in the plant absorbing (bucking) 47 Mvar at the POI.
Reactive Capability at Low Power Output$= 47/125 * 100 = 37.6\%$. *This passes the test.*

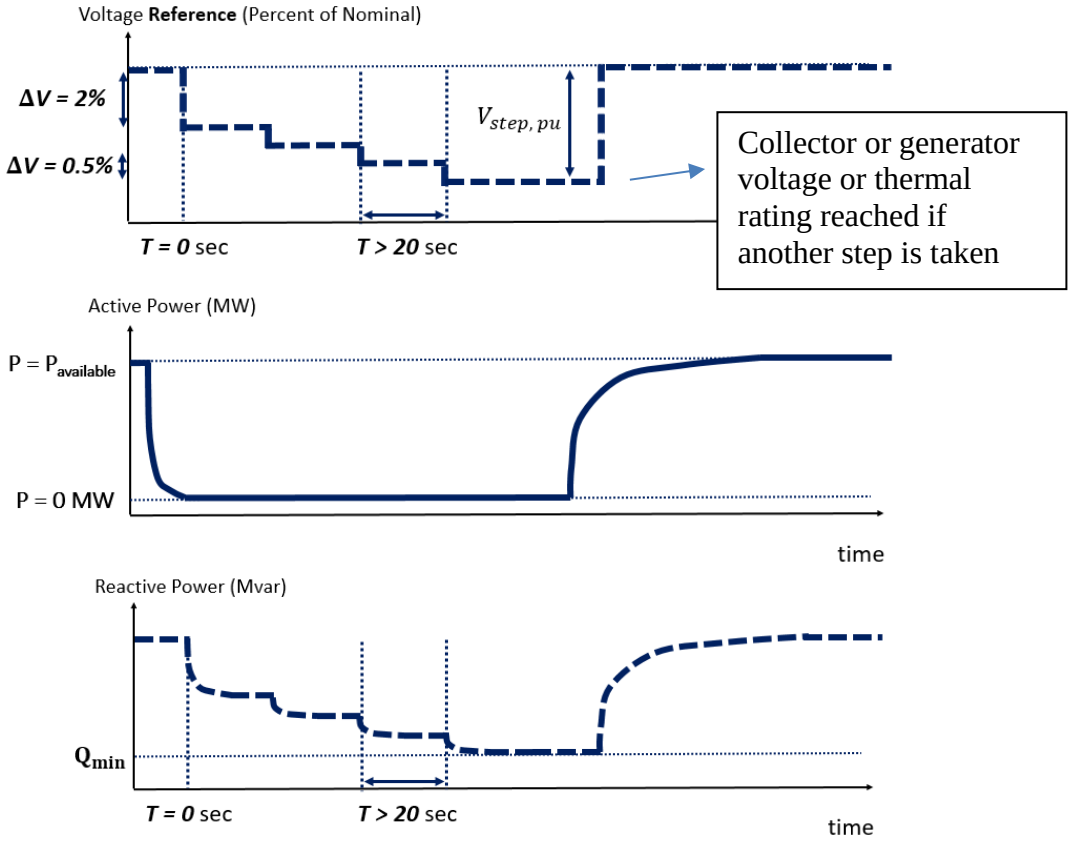


Figure 33.--- Generic Test Recordings for the Lower Active Power Reactive Capability Test

3.3 Required Test T2b:

The generator operator shall:

- Prioritize safety of personnel and equipment.
- Curtail the active power output of the power plant to the lesser of 5% of the MW rating of the plant and 40 MW.
- Follow remaining procedures from Required Test T2a.

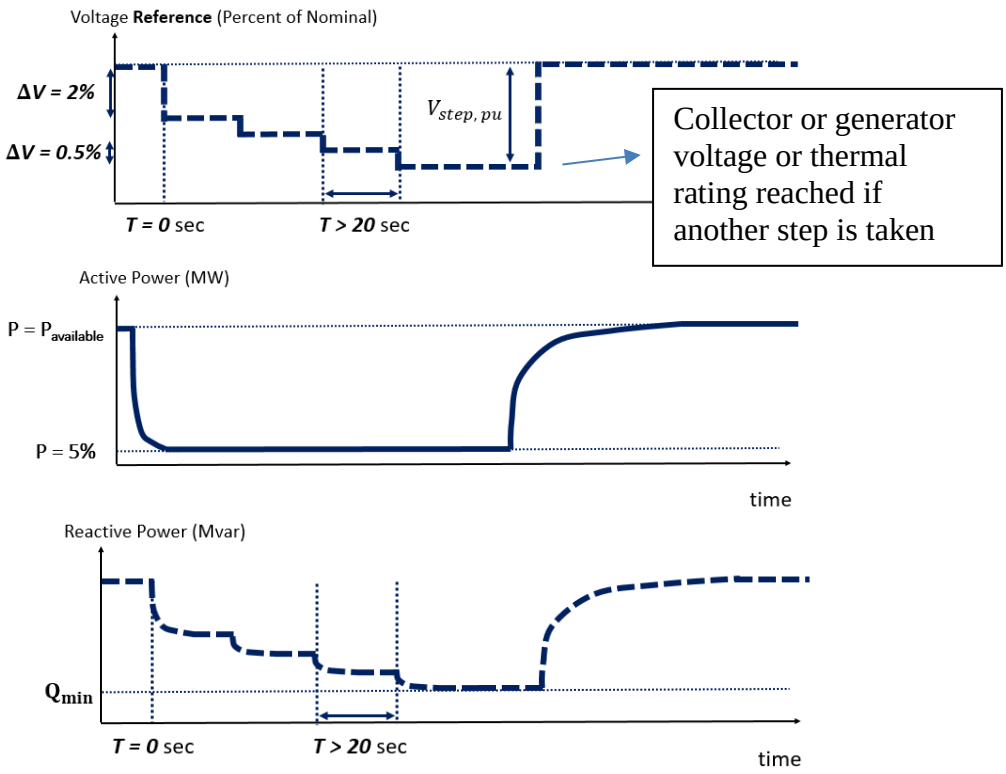


Figure 44.--- Generic Test Recordings for the Lower Active Power Reactive Capability Test

3.4 Required Test T2c:

The intent of this test is to confirm continuous reactive capability throughout transition to different operating modes associated with presence/absence of the primary energy source (e.g. solar, wind).

Some plants may choose to implement this by staggering the equipment performing the transition between modes over time.

The generator operator shall:

- Prioritize safety of personnel and equipment.
- Operate with active power output of the power plant less than the lessor of 5% of the MW rating of the plant and 40 MW.
- Perform the test when there is no primary energy (e.g. at sundown for solar facilities). Ensure the plant is bucking such that it meets the requirement for reactive capability as a pre-test condition (see test T2b).
- Observe a transition from positive MW output operating mode to 0 MW output operating mode (e.g. day mode to night mode for solar facilities) for all equipment under test. Perform the transition following typical operating practice.
- Wait until response has settled.

- Initiate a transition back from 0 MW output operating mode to positive MW output operating mode (e.g. night mode to day mode) for all equipment under test. Perform the transition following planned typical operating practice.
- Each test recording must be sufficient in duration to demonstrate an acceptable transition. It should be clear that a transition occurred.

Performance Calculation:

Table 33 Reactive Capability Calculation for test T2c

Description / Variable Name	Final
Reactive Power Absorbed at POI (Mvar) at start of test / Q_0	38.0
POI Voltage at the start of test / $V_{0,pu}$	1.030
MW Base / MW_{base}	100
Smallest Magnitude Reactive Power Absorbed at POI (Mvar) / Q_{min}	36.5
POI Voltage at the time of Q_{min} / $V_{min,pu}$	1.026
Reactive Power Absorbed at POI (Mvar) after test / Q_f	37.0
POI Voltage after test / $V_{f,pu}$	1.028
Minimum POI Reactive Power Q (%) / $Q_{min,pu}$	**34.0%**
Maximum voltage deviation from $V_{0,pu}$ as a result of transition / $V_{\%}$	**0.39%**

Example: 100 MW solar power plant
A 100 MW solar power plant was absorbing 38 Mvar right before the first equipment started the transition from > 0 MW output to ≤ 0 MW output. Pre-transition, $\frac{38\ Mvar}{100\ MW\ base} = 38\%$ *meets the > 33% requirement. During the transition, a 1.5 Mvar reduction of Mvar capability was observed resulting in the plant absorbing 36.5 Mvar. During the transition,* $\frac{36.5\ Mvar}{100\ MW\ base} = 36.5\%$ *meets the > 33% requirement. After the final equipment transitions, the reactive power output of the solar facility was 37 Mvar, which still meets the > 33% requirement.*

4. REQUIRED TESTS FOR POWER PLANT FREQUENCY CONTROLS

4.1 Requirement R3:

BPA requires:

- The plant shall be capable of providing autonomous primary frequency response.
- The plant shall have plant-level frequency controller module installed and enabled.
- The frequency controller shall provide frequency response in accordance with droop between 3% and 5% (inclusive).
- The requirements on active droop apply at the POI.
- The frequency controller may have a frequency dead-band. The frequency dead-band shall be less than or equal to +/- 0.06% (of 60 Hz, i.e. 36 mHz).
- The frequency control shall have an active power step response time, time to reach 90% of the total final response, of less than 5 seconds. When the step response time is not achievable due to physical limitations of the interconnecting plant, this requirement can be modified. The fastest response achievable by generating plant technology is required. It is expected that fast acting technologies, such as IBRs, should operate in less than 5 seconds and generation plants limited by slower prime movers, such as hydropower, may require a longer step response time. Reminder, the pretest MW set point shall not exceed 40MW. If you believe this is not possible for your preferred technology, consult your BPA Transmission Customer Service Engineer and/or Account Executive.
- The plant response shall be sustained for the duration of frequency events.

4.1.1 *Required Inspection of Frequency Control Settings:*

The generator operator shall:

- Prioritize safety of personnel and equipment.
- Confirm that within the frequency controller software the droop setting does not exceed the range of allowable droop settings.
- Confirm that the frequency dead-band is less or equal to +/-0.06% (+/-36 mHz) in the frequency controller software.
- Provide droop and dead-band settings in the frequency controller software to BPA Transmission Customer Service Engineer and/or Account Executive. BPA recommends submission of a screenshot or photo if possible.
- Notify BPA Transmission Customer Service Engineer and/or Account Executive prior to initiating the test.

4.2 Required Test T3a:

The generator operator shall:

- Conduct a 1% (600 mHz) step to the measured frequency in upward direction for at least 60 seconds simulating an over-frequency event (see Figure 55**Error! Reference source not found.**).

Active Power Droop Calculation and Response Time Calculation:

1. Confirm active power droop value by populating a similar table with your test data.

Table 44.— Active Power Droop Calculation Example

Description / Variable Name	Initial $t=t_0=0$[s]	t = 5[s]	t = 52[s]	Delta
Frequency Step (per unit) / $-F_{step,pu}$	N/A	N/A	N/A	0.01
Plant POI Active Power (MW) / P_{MW}	15	5	4	-11
MW Base / MW_{base}	50	50	50	50
Deadband (per unit) / db_{pu}	0.0006			
Droop				**0.043**
MW Change within Response Time as a % of total change	0	10 MW	-11 MW	**90.9%**

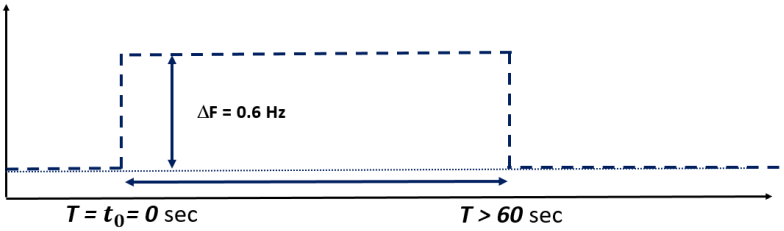
$$Active\ Droop\ = -(\ F_{step,pu} - db_{pu}) \ / \left(\frac{[P_{t=52[s],MW}] - [P_{t=0[s],MW}]}{MW_{base}}\right)$$

Example: 50 MW wind power plant
A 50 MW wind power plant was operating at 15 MW on average prior to the step in frequency setpoint. Following the 1% step in frequency setpoint, the plant MW output reduced to 4 MW on average (at $t_0 + 52[s]$). The deadband is 36 mHz or 0.0006 per unit. $Active\ Droop\ = -(\ 0.01 - 0.0006) \ / \left(\frac{4-15}{50}\right) =$ *4.3%, which is within the acceptable range of active droops.*

2. Confirm sufficient step response time

The plant had achieved 10 MW change within the first 5[s] of the frequency step and 11 MW in 52[s].
Change during allowable Response Time window: 10/11 = 90.9%, which exceeds the 90% definitional to response time, and thus the plant passes the test.

Frequency Setpoint (Hz):



Active Power (MW):

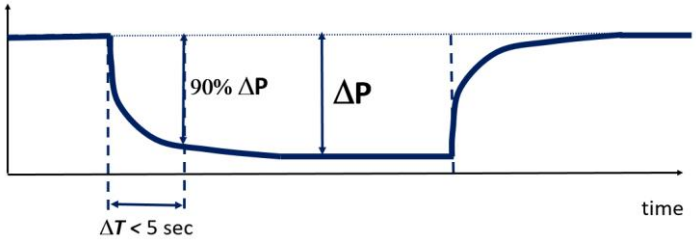


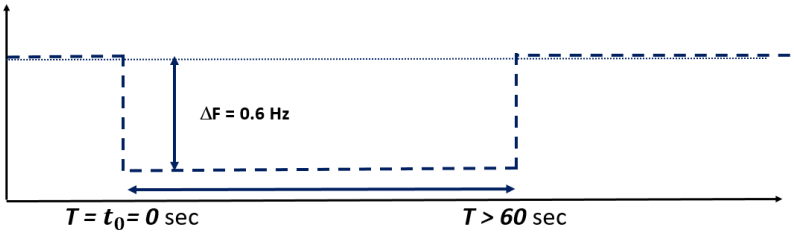
Figure 55. Generic Test Recordings for the Over-frequency Step Test

4.3 Required Test T3b:

The generator operator shall conduct a 1% (600 mHz) step to the measured frequency in the downward direction for at least 60 seconds simulating an under-frequency event (see Figure 66).

Example: 50 MW wind power plant (see Required Test T3a:)

Frequency Setpoint (Hz):



Active Power (MW):

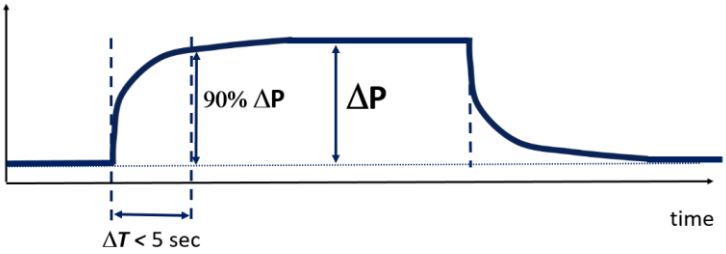


Figure 66. Generic Test Recordings for the Under-Frequency Step Test

5. REFERENCES

Bonneville Power Administration (BPA), U.S. Dept. of Energy. STD-N-000001, Technical Requirements for Interconnection to the BPA Transmission Grid, Portland, Oregon.

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