Pacific HVDC Oscillation Damping Control Test Plan for the 2018 Operating Season

1 Summary and Objectives

The following tests are used to evaluate the PDCI damping controller being prototyped under the BPA research and development project TIP-289. Note that these tests take the place of the usual annual probe tests. The objectives of the tests are

- Evaluate the effectiveness of the PDCI damping controller to increase the damping of the NSB mode.
- Evaluate the impact of the PDCI damping controller on all other system modes.
- Exercise the PDCI damping controller's supervisory functions.
- Evaluate the impact of the PDCI damping controller on the PDCI system.

For the past several years, BPA has been developing a PDCI damping controller strategy and hardware. The current state of this development is the BPA TIP-289 research and development project. The goal of TIP-289 is to build and test a prototype PDCI damping controller (DCON). Previous live DCON open-loop and closed-loop tests were conducted in the Fall of 2016 and 2017. The tests in this document extend these previous tests.

The PDCI damping controller uses PMU feedback to modulate the PDCI power with the goal of damping electromechanical oscillations. It is designed to specifically target the NSB (North-South B) mode which has been shown to be the most wide-spread and troublesome electromechanical mode in the WECC system.

Two types of tests are contained in this document:

1. **Active short-term tests**: For these tests, Chief Jo brake pulses, PDCI probing signals are applied to the system while the controller is operated in open-loop and closed-loop configurations. The tests and controller are monitored by human operators similar to the 2016 tests.
2. **Passive long-term tests**: For this test, the system is configured in a closed-loop for an extended period of time (approximately 4 continuous weeks). The controller limits are set to a safe level to avoid any adverse results conditions.

<u>Active Test Monitoring</u>

Specifically, we would like to get several test points with respect to the following system measurements:

- John Day – Malin phase angle
- Big Eddy – Malin phase angle
- Grand Coulee – Malin phase angle
- Grand Coulee – Devers phase angle
- BC – Northwest flows
- BC – Alberta flows (including the tie being out of service)
- California – Oregon Intertie flows
- Midpoint – Summer Lake flows
- Montana Intertie flows (including status of Colstrip generators)

- Path 15 flows
- Path 26 (Midway – Vincent) flows
- East of River flows (in the Desert SW)
- Amount of wind generation in Pacific Northwest

Close examination of system behavior will be made before and throughout the test to confirm that system conditions are suitable for testing, and that the test is proceeding as expected. WECC members having monitoring applications such as the Real Time Dynamic Monitor System (RTDMS) and the DOE Mode Meter are invited to participate in this, and to use associated spectral analysis software to observe frequency domain signatures for their service areas. Results will be shared with Montana Tech and Sandia Labs.

If the system conditions during or prior to an active test are not similar to those already tested in past probing tests, the test may be canceled.

The determination to conduct or cancel a given active test will be made 15 minutes prior to a test by Test Director.

Phase 1: Active Short-Term Open-Loop and Closed-Loop Tests

The goals of these tests include: evaluate all states of the DCON via a diagnostic test, calibrate the DCON, verify open-loop transfer functions, and test the DCON's performance. The tests consist of the following. The closed-loop tests will be repeated with a variety of controller settings. In the following, PSG denotes the Probing Signal Generator, and FO denotes a Forced Oscillation.

- **Diagnostic pre-test**. The DCON is disconnected from the system and connected to a diagnostic tester. The tester checks that all relevant components of the DCON are operating properly.
- **Calibration test**. With the DCON connected in open-loop, a variety of probing signals are placed into the system via the DCON. The goal is to calibrate and verify system scaling factors, limiters, and time delays are within specification.
- **Open-loop wide-band probing test**. The DCON is connected in open loop and a wide-band probing signal is applied to the system via the DCON. This test is used to calculate and check the loop transfer function.
- **Closed-loop wide-band probing test**. The DCON is connected in closed loop and a wide-band probing signal is applied to the system via the PSG. This test is used to verify the controller is safely operating.
- **Closed-loop/open-loop PDCI pulsing test**. A $\pm$125 MW square-wave pulse signal is applied to the system via the PSG with the DCON in open loop and then immediately repeated with the DCON in closed loop. The goal is to evaluate DCON performance.
- **Closed-loop/open-loop Chief Jo pulsing test**. A Chief Jo pulse is applied to the system with the DCON in open loop and then immediately repeated with the DCON in closed loop. The goal is to evaluate DCON performance.
- **Closed-loop/open-loop FO test**. Forced oscillations are induced into the system via the PSG with the DCON in open loop and then immediately repeated with the DCON in

closed loop. A variety of FO frequencies will be considered. The goal is to evaluate DCON performance.

- **NOTE**: The DCON can be de-activated via the "Red Button" under operator discretion.

All PDCI modulation signals used in the above tests were used in the 2016 and 2017 DCON tests.

<u>Phase 2: Active Long-Term Closed-Loop Test</u>

The goal of this test is to evaluate the performance of the DCON for a variety of system conditions and events. The DCON will be connected to the system in closed loop for an extended period with the control limits set to a safe level of +/- 25 MW. All system events will be logged for analysis. The Phase 2 test will only be conducted if analysis of a previous Phase 1 tests shows the system is operating safely. The test consist of the following.

- **Diagnostic pre-test**. The DCON is disconnected from the system and connected to a diagnostic tester. The tester checks that all relevant components of the DCON are operating properly.
- **Calibration test**. With the DCON connected in open-loop, a variety of probing signals are placed into the system via the DCON. The goal is to calibrate and verify system scaling factors, limiters, and time delays are within specification.
- **Open-loop wide-band probing test**. The DCON is connected in open loop and a wide-band probing signal is applied to the system via the DCON. This test is used to calculate and check the loop transfer function.
- **Closed-loop long-term test**. The DCON is configured in closed loop with control limits of X. A wide-band probing signal is applied to the system via the PSG to verify safe operation. A ±125 MW square-wave pulse signal is applied to the system via the PSG to verify safe operation. The system is monitored for two hours to verify safe operation. If safe operation is verified, the system is left on line for four continuous weeks.
- **NOTE**: The DCON can be de-activated via the "Red Button" under operator discretion.

2 Test Dates

Phase 1 will be done on

- **May 9, 2018**

Phase 2 will be

- **Initiated on immediately after the May Phase 1 test.**
- **Stopped approximately 4 weeks later.**
- **Optionally, the unattended test may be extended after a discussion of data collected.**

3 Operating Conditions Required For Tests

3.1 Phase 1 and Tests

Operating Conditions for all PDCI modulation tests

- Power system operation is normal, the system is within System Operating Limits
- Pacific HVDC Intertie (PDCI) in bipolar operation with North to South flow
- PDCI power transfer above 500 MW and less than 3000 MW

Operating Conditions for Brake Insertion Test Series

- Power system operation is normal, the system is within System Operating Limits
- Scheduled brake insertions may be performed even when HVDC conditions do not support ambient and modulated tests

3.2 Phase 2 Test

Operating conditions required to initiate test

- Phase 1 test has been completed
- Power system operation is normal, the system is within System Operating Limits
- Pacific HVDC Intertie (PDCI) in bipolar operation with North to South flow
- PDCI power transfer above 500 MW and less than 3000 MW

4 Test Precautions and Termination Procedure

4.1 Phase 1 3 Tests

If at any time the Test Observers, security coordinators or system operators identify conditions under which the tests should not continue then the Test Director will suspend the test sequence until those conditions are no longer present and the Test Director will send out an RMT message.

Reasons for suspending, modifying, or terminating the test sequence include but are not limited to the following:

- System emergency exists within the Western Interconnect
- Paths operating outside normal limits
- Undamped or unacceptable levels of system oscillations
- Facility operator deems that facility is unsafe for test, or that the test procedure is interfering with proper operation of that facility
- Test procedure is conflicting with a peak in operator workload
- PDCI damping control system not operatioinal
- A disturbance just occurred resulting in system frequency below 59.75 Hz
- **If a disturbance occurs during a probing test, the test must be terminated immediately.**

Additional Notification Procedure

If any AVR/PSS problems are observed notify the Transmission Operator immediately so that information can be communicated to the Generator Operator for their action.

4.2 Phase 2 Test

Phase 2 is a multi-week tests and can be terminated by system operators for any PDCI malfunctioning condition.

5 Sequence of Test Events – Phase 1

The list below shows specific test events to be performed over one day. Times for these test events are in Pacific Daylight (Advanced) Time (PDT).

The time and the duration of specific test events can be adjusted, during the test itself, to minimize interference with smooth operation of the power system. Signal descriptions are given in Section 10 (e.g., the definition of MSF-1/30/1/100). **PSG** denotes the Probing Signal Generator; **DCON** denotes the damping controller. The **Calibration Signal** consists of the following sequence:

- a +20MW 10-sec. pulse followed immediately by a -20 MW 10-sec. pulse;
- four cycles of a ±135-MW 0.1-Hz sine wave (SF/0.1/4x);
- four cycles of a ±125-MW 1.0-Hz sine wave (SF/1.0/4x).

The control gains **M**, **H**, and **XH** below shall be selected based upon analysis and progress of the test. Expected values are 3 MW/mHz to 18 MW/mHz. The value **SHALL NEVER EXCEED 18 MW/mHz**.

Test Series 0: diagnostic check

Prior to the below tests, the **DCON** is disconnected from the system and a diagnostic check is completed on the system. If the diagnostic check verifies safe operation, the DCON is re-connected to the PDCI system.

Test Series A: open-loop calibration and modulation

Step A0 [9:00] Configuring the DCON in open loop with a controller limit of ±125 MW.

Step A1 [9:10] Apply Calibration Signal via the DCON. Verify proper operation.

Step A2 [9:15] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 12 periods (20 minutes) via the DCON.

Test Series B: closed-loop vs open-loop performance, medium gain

Step B0 [10:00] Configure DCON in closed loop with a gain of **M** and a limit of ±125 MW.

Step B1 [10:10] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 3 periods (5 minutes) via the PSG. Observed DCON output should be on the order of ±20 MW or less. **Observed PDCI power swings should not exceed ±50 MW**.

Step B2 [10:20] Apply SQF/2.5/±125/3 with an amplitude of ±125 MW via the PSG. Slightly improved damping from the open-loop responses should be observed. **Observed PDCI power swings should not exceed ±125 MW**.

Step B3 [10:25] Apply Chief-Jo brake. Slightly improved damping from the open-loop responses should be observed. The damping controller will likely reach it limits for the first full cycle of the response.

Step B4 [10:30] Configure DCON in open loop.

Step B5 [10:35] Apply Chief-Jo brake.

Step B6 [10:40] Apply SQF/2.5/±125/3 with an amplitude of ±125 MW via the PSG.

Test Series C: closed-loop vs open-loop performance, high gain

Step C0 [11:00] Configure DCON in closed loop with a gain of **H** and a limit of ±125 MW.

Step C1 [11:10] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 3 periods (5 minutes) via the PSG. Observed DCON output should be on the order of ±20 MW or less. **Observed PDCI power swings should not exceed ±50 MW**.

Step C2 [11:20] Apply SQF/2.5/±125/3 with an amplitude of ±125 MW via the PSG. Slightly improved damping from the open-loop responses should be observed. **Observed PDCI power swings should not exceed ±125 MW**.

Step C3 [11:25] Apply Chief-Jo brake. Slightly improved damping from the open-loop responses should be observed. The damping controller will likely reach it limits for the first full cycle of the response.

Step C4 [11:30] Configure DCON in open loop.

Step C5 [11:35] Apply Chief-Jo brake.

Step C6 [11:40] Apply SQF/2.5/±125/3 with an amplitude of ±125 MW via the PSG.

Test Series D: open-loop calibration and modulation

Step D0 [13:00] Configuring the DCON in open loop with a controller limit of ±125 MW.

Step D1 [13:10] Apply Calibration Signal via the DCON. Verify proper operation.

Step D2 [13:15] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 12 periods (20 minutes) via the DCON.

Test Series E: closed-loop vs open-loop performance, extra high gain

Step E0 [14:00] Configure DCON in closed loop with a gain of **XH** and a limit of ±125 MW.

Step E1 [14:10] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 6 periods (10 minutes) via the PSG. Observed DCON output should be on the order of ±20 MW or less. **Observed PDCI power swings should not exceed ±50 MW**.

Step E2 [14:25] Apply SQF/2.5/±125/3 with an amplitude of ±125 MW via the PSG. Slightly improved damping from the open-loop responses should be observed. **Observed PDCI power swings should not exceed ±125 MW**.

Step E3 [14:30] Configure damping controller in open loop.

Step E4 [14:35] Apply SQF/2.5/±125/3 with an amplitude of ±125 MW via the PSG.

Test Series F: closed-loop vs open-loop performance, forced oscillation, medium gain

Step F0 [15:00] Configure damping controller in open loop.

Step F1 [15:10] Apply FO:

Apply ±20 MW SF/0.4/32x via the PSG (80-sec. 0.4-Hz sine wave).
Observed PDCI power swings should not exceed ±60 MW.

Step F2 [15:13] Configure DCON in closed loop with a gain of **M** and a limit of ±125 MW. Apply FO:

Apply ±20 MW SF/0.4/32x via the PSG (80-sec. 0.4-Hz sine wave).
Observed PDCI power swings should not exceed ±100 MW.

Step F3 [15:20] Configure damping controller in open loop. Apply FO:

Apply ±30 MW SF/1.0/60x via the PSG (60-sec. 1.0-Hz sine wave).
Observed PDCI power swings should not exceed ±60 MW.

Step F4 [15:23] Configure DCON in closed loop with a gain of **M** and a limit of ±125 MW. Apply FO:

Apply ±30 MW SF/1.0/60x via the PSG (60-sec. 1.0-Hz sine wave).
Observed PDCI power swings should not exceed ±100 MW.

Step F5 [15:30] Configure damping controller in open loop. Apply FO:

Apply ±20 MW SF/3.0/180x via the PSG (60-sec. 3.0-Hz sine wave).
Observed PDCI power swings should not exceed ±60 MW.

Step F6 [15:33] Configure DCON in closed loop with a gain of **M** and a limit of ±125 MW. Apply FO:

Apply ±20 MW SF/3.0/180x via the PSG (60-sec. 3.0-Hz sine wave).
Observed PDCI power swings should not exceed ±100 MW.

Step F7 [15:40] Configure damping controller in open loop. Apply FO:

Apply ±20 MW SF/5.0/3000x via the PSG (60-sec. 5.0-Hz sine wave). **Observed PDCI power swings should not exceed ±60 MW**.

Step F8 [15:43] Configure DCON in closed loop with a gain of **M** and a limit of ±125 MW. Apply FO:

Apply ±20 MW SF/5.0/300x via the PSG (60-sec. 5.0-Hz sine wave). **Observed PDCI power swings should not exceed ±100 MW**.

Test Series G: closed-loop vs open-loop performance, high gain, alternative signal

Step G0 [16:00] Configure DCON in closed loop with a gain of **H,** a limit of ±125 MW, and a primary feedback of BigEddy/Malin.

Step G1 [16:10] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 6 periods (10 minutes) via the PSG. Observed DCON output should be on the order of ±20 MW or less. **Observed PDCI power swings should not exceed ±50 MW**.

Step G2 [16:25] Apply SQF/2.5/±125/3 with an amplitude of ±125 MW via the PSG. Slightly improved damping from the open-loop responses should be observed. **Observed PDCI power swings should not exceed ±125 MW**.

Step G3 [16:30] Configure damping controller in open loop.

Step G6 [16:35] Apply SQF/2.5/±125/3 with an amplitude of ±125 MW via the PSG.

6 Sequence of Test Events – Phase 2

The list below shows specific test events to be performed over approximately four weeks. Times for these test events are in Pacific Daylight (Advanced) Time (PDT).

The time and the duration of specific test events can be adjusted, during the test itself, to minimize interference with smooth operation of the power system. Signal descriptions are given in Section 10.

The control gain **M** and limit **L** below shall be selected based upon analysis of phase 1 data. Simulation studies and results from 2016 suggest values for **M** are 3 MW/mHz to 12 MW/mHz. The value **SHALL NEVER EXCEED 18 MW/mHz**. Simulation studies suggest a value for **L** is 25MW.

Test Series 0: diagnostic check
Prior to the below tests, the **DCON** is disconnected from the system and a diagnostic check is completed on the system. If the diagnostic check verifies safe operation, the DCON is re-connected to the PDCI system.

Test Series H: open-loop calibration and modulation

Step H0 [9:00] Configuring the DCON in open loop with a controller limit of ±125 MW.

Step H1 [9:10] Apply Calibration Signal via the **DCON**. Verify proper operation.

Step H2 [9:15] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 12 periods (20 minutes) via the **DCON**.

Test Series I: closed-loop vs open-loop performance, medium gain

Step I0 [10:10] Apply SQF/2.5/±125/3 with an amplitude of ±125 MW via the **PSG**.

Step I1 [10:15] Configure DCON in closed loop with a gain of **M** and a limit of ±**L** MW.

Step I2 [10:20] Apply SQF/2.5/±125/3 with an amplitude of ±125 MW via the **PSG**. Slightly improved damping from the open loop responses should be observed. **Observed PDCI power swings should not exceed ±125 MW**.

Step I3 [10:25] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 6 periods (10 minutes) via the **PSG**. Observed DCON output should be on the order of ±20 MW or less. **Observed PDCI power swings should not exceed ±50 MW**.

Step I4 [10:35] Set response limits in Celilo bipole controls to +/-25MW. Verify settings:

Channel A__________ Channel B___________

Apply SQF/2.5/+125/3 with an amplitude of +125 MW via the PSG.

Verify in DFR that Celilo response is limited to +/-25MW

Step I5 [11:00] Observe the operation for the next 2 hours to verify proper operation under ambient conditions. If all systems verify to be operating correctly, leave system operating for an extended time (approximately 4 weeks).

After 4 weeks the project team will meet to discuss if unattended operation should be extended.

7 Test Director and other Role Responsibilities

Test coordination will be as follows:

1. Test Director will schedule the tests through the BPA outage dispatcher.
2. Test Director (BPA technical staff) will post proposed test dates on the BPA External Web page at https://transmission.bpa.gov/Business/Operations/SystemNews/default.aspx
3. The day before each test, BPA will send a message on the RMT notifying of the tests.
4. If there are concerns about abnormal system conditions, BPA dispatcher should be contacted as early as possible to cancel a test. The test will be resumed the next hour after the system returns to normal.
5. The probing signal will be injected by an operator of Celilo converter station. The operator will clear with the BPA dispatcher before the signal injection.

A listing of contact persons and test observers with phone numbers and e-mail addresses will be provided 10 days in advance of the test.

A phone bridge will be available on the day of the test:
1-360-418-8224, passcode **2338#**

8 Measurement Requirements

WISP and BPA synchro-phasor data from these tests will be recorded automatically. However, it is necessary that the operators of the measurement facilities assure that the recording systems are ready for this, and that the owners of the data be aware that copies of the records may be requested for analysis.

Required measurements for Test Series

- Continuous PMU recording is required at BPA locations for the period 0800 through 1800 PDT of each test day.
- Damping controller logging is required for each test case.
- Celilo PDC is required for the period 0800 through 1800 PDT of each test day.
- SWREC at the Bipole control (BCP) level every 60 seconds during the full hour of each test is required during each test.
- Continuous PMU recording is highly desirable at all other WECC locations for the period 0800 through 1800 PDT of each test day where this data is available.

Key real-time resources for this are PDC StreamReaders, located at key locations, plus the spectral analysis tool provided as an add-on for the PDC StreamReader. Other documents refer to this tool as Dynamic Signal Analyzer (**DSA**), and that terminology is used here. Equivalent functionalities can also be obtained from alternate toolsets such as RTDMS and the DOE Mode Meter.

It is essential that DSA analysis be immediately available to the Test Director throughout the test. StreamReaders with DSA are essential at Dittmer and highly desirable at Celilo.

The following paths should be monitored during the tests:

- Ingledow – Custer
- Montana Intertie
- California – Oregon Intertie
- Pacific HVDC Intertie
- Midway – Vincent
- Palo Verde - Devers

Power spectrum should be monitored at the following generators for any torsional activities:

- Colstrip (9.45 Hz)
- Columbia Generating Station (around 5.2 Hz)
- Boardman (around 10 Hz)
- Diablo Canyon
- Navajo (16.06 Hz)
- Palo Verde (8.3 Hz)
- Four Corners (10.49 Hz)

9 Test Preparations

The Celilo Probing Signal Generator (PSG) will be furnished with a suitable menu of playback files. These playback files will be verified on site for MW scaling and other characteristics before their use in long term probing.

10 Test Signals

The following table describes various types of noise signal definitions, some of which will be used in the test.

File Name	Type	Band Width or Frequency
MSF/1/30/1/100	Optimized multi-sine function	Content from 0.02 to 30 Hz; rolls off from 0.1 to 0.02 Hz as a 1st-order; rolls off as a 1st-order after 1 Hz; 100 seconds long.
SF/x/N	single Freq Sine	N sine wave cycles at frequency x Hz.
SQF/2.5/±125/3	Square wave function	±125-MW 2.5-sec period repeated for 3 cycles.

MSF/N1/N2/N3/N4:
N1 – highest frequency at which the signal amplitude is 1
N2 – frequency at which the signal amplitude is 0
N3 – signal roll-off rate
N4 – duration in seconds
Some frequency components removed (see Figures 1 and 2, showing selected components removed above 1 Hz).

SQF/N1/N2/N3:
N1 – square wave period (sec.)
N2 – amplitude (MW)
N3 – number of cycles
See Figure 3 for an example.

Figures 1 and 2 illustrates the difference between the signals used in 2014 (MSF-1-5-2-100) and the one proposed for 2016 (MSF-1-30-1-100). The new signal (red curve) shifts some of the energy to the higher frequencies necessary to excite the full control band of the PDCI.

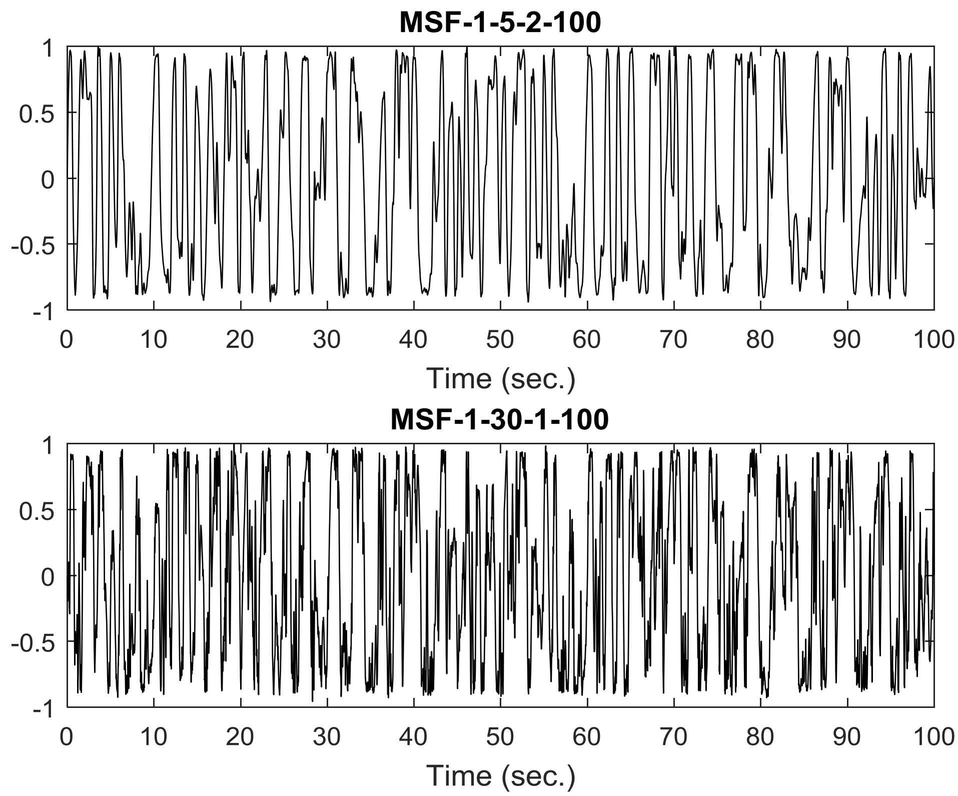

Figure 1: Comparison of MSF signals used in 2014 and 2016.

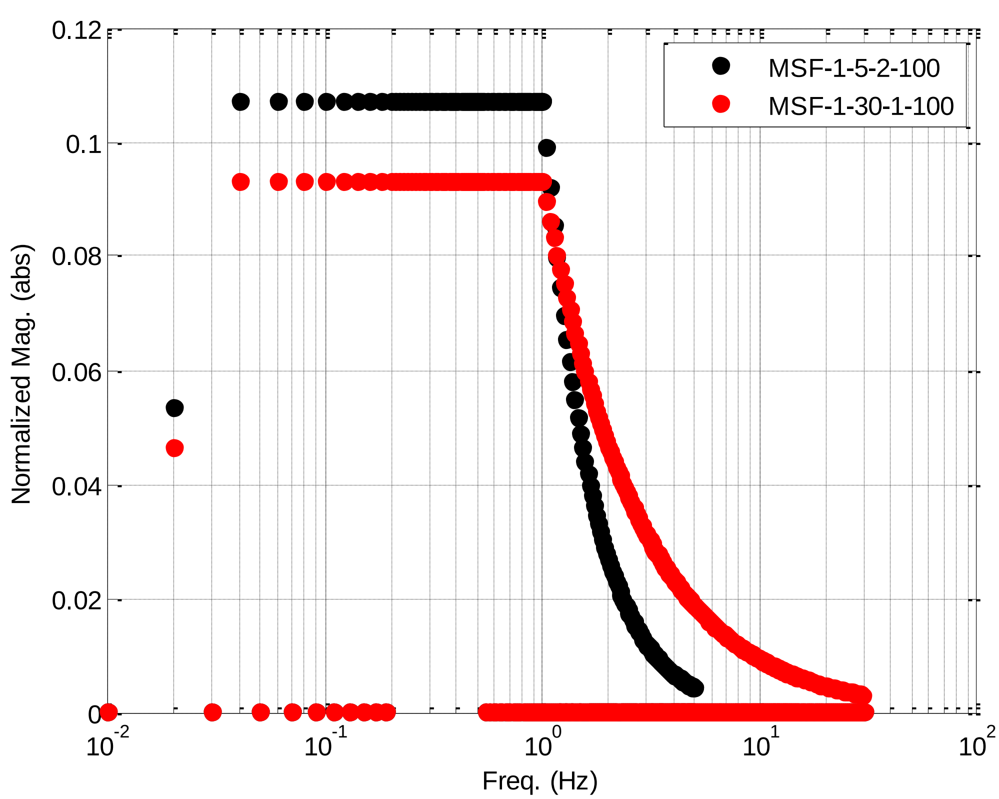

Figure 2: Spectrum of signals in Figure 1.

Figure 3 illustrates the Square Wave Function SQF/2.5/±125/3 with an amplitude of ±125 MW. The pulses are low-passed filtered.

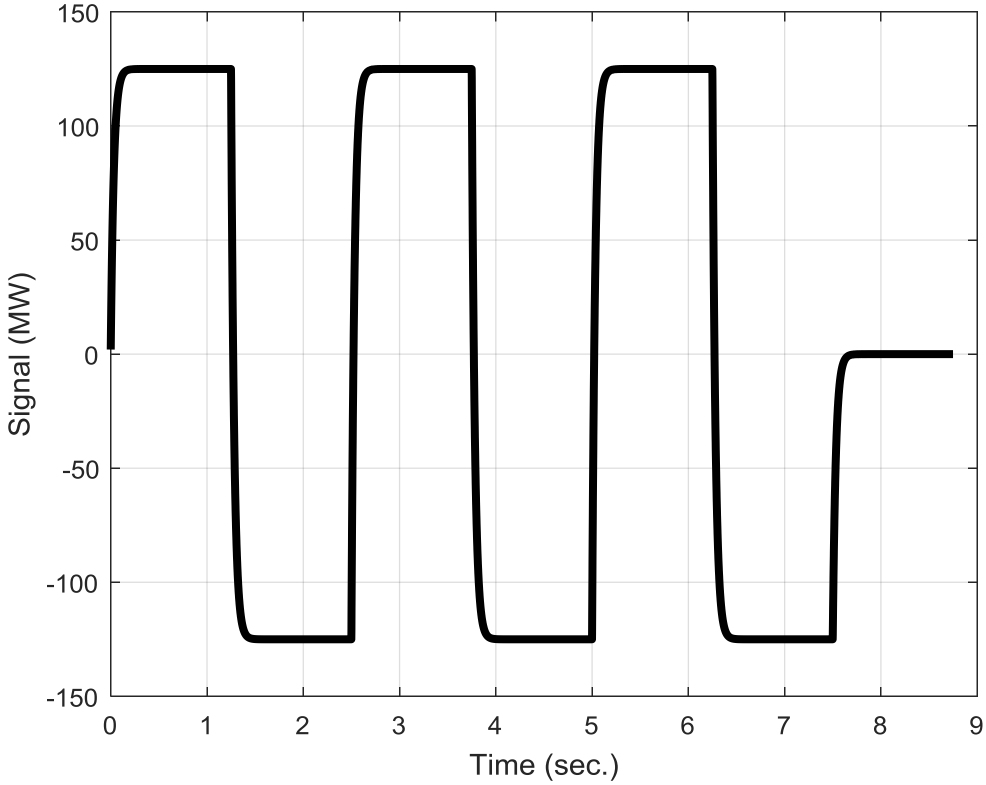

Figure 3: Example SQF/2.5/±125/3 signal.

11 References

[1] **Interim Report on the Model Validation Tests of June 7, 2000 -- Part 1: Oscillatory Dynamics**, principal investigator J. F. Hauer. WSCC Performance Validation Task Force (PVTF) of the Modeling and Validation Work Group, October 26, 2000.

[2] **Integrated Monitor Facilities for the Western Power System: WAMS Analysis in 2005**, J. F. Hauer, W. A. Mittelstadt, K. E. Martin, J. W. Burns, and Harry Lee. Interim report of the WECC Disturbance Monitoring Work Group, December 2005.

[3] **Use of the WECC WAMS in Staged System Tests for Validation of System Performance and Modeling: Summary Report for September 2005–August 2006,** J. F. Hauer, W. A. Mittelstadt, J W. Burns, K. E. Martin, Harry Lee, and D. J. Trudnowski**.** Interim report of the WECC Disturbance Monitoring Work Group, April 25, 2007. (Available at ftp://ftp.bpa.gov/pub/WAMS_Information/). Included as Chapter 14 in the **Power System Stability and Control** v2olume of **The Electric Power Engineering Handbook**, edition 2, L. L. Grigsby ed., CRC Press, Boca Raton, FL, 2007.

[5] **Modes of Inter-Area Power Oscillations in Western Interconnection,** WECC Joint Synchronized Information Subcommittee report, 2014.

[6] **Transfer Function Results from the 2009 and 2011 PDCI Probing Tests,** Dan Trudnowski, Oct. 2011.

[7] **2012 PDCI Probing Tests,** Dan Trudnowski, Oct. 2012.

[8] **2013 PDCI Probing Tests,** Dan Trudnowski, May 2014.

[9] **2014 PDCI Probing Tests,** Dan Trudnowski, Jan. 2014.

Test Approvals

This test plan submitted by:

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Approved: MELVIN RODRIGUES Digitally signed by MELVIN RODRIGUES Date: 2018.04.05 15:46:56 -07'00' Date:_________________

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Approved: ____ Date:_________________

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Table 2. Coordination and Contact Person List (please update attached file)