Pacific HVDC Oscillation Damping Control Test Plan for the 2016 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. 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.

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.

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 mode which has been shown to be the most wide-spread and troublesome electromechanical mode in the WECC system.

The tests described in this document are very similar to the over 100 PDCI modulation and Chief-Jo brake tests that BPA has executed on a routine bases since 2009. The objectives of these probing tests have included

- understand the inter-area modal properties of the system and how these properties vary over different operating conditions and over a long period of time;
- evaluate the potential impact of modulation control on interconnect system dynamics in the 0 to 5 Hz range;
- evaluate the dynamics of the PDCI system in the 0 to 30 Hz range;
- provide base-lining transfer functions of the system under varying operating conditions and operating years;
- provide comparative information to model-based studies; and
- evaluate control-system robustness, scaling, and gain properties.

The conclusions of these past probing tests have supported the potential benefits of a PDCI damping controller.

The tests in this document are aimed to directly test a prototype feedback damping controller. The tests are very similar to the past probing tests, except the damping controller will be exercised (both in open-loop and closed-loop configurations).

Note that the tests in this document are termed the "**damping controller tests**" while the past tests are termed the "**probing tests**."

Test Monitoring

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

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

<u>Phase 1: Open-loop calibration and open-loop modulation tests</u>

The calibration and open-loop modulation testing are done during the 1st test day to calibrate the system, test system delays, and to verify open-loop transfer functions. The tests are very similar to the calibration tests that have been employed for the 2009-16 probing tests. The tests consist of the following.

- Configuring the controller in open-loop with a controller limit of ±125 MW.
    - Insertion of single-mode modulation signals. The modulation signals shall be the same as used in past probing tests.
    - Insertion of a 20-minute ±20-MW wide-band multi-sine modulation signal.

The multi-sine modulation signal is the same as used for the 2016 probing tests which are a combination of two signals used in the 2014 probing tests.

<u>Phase 2: Closed-loop low-level modulation tests</u>

These tests include the first closed-loop operation of the damping controller. The primary goals are to exercise the controller in closed loop and verify its operation, and to measure open-loop versus closed-loop transfer functions. The tests consist of

- Open-loop tests.

    - Configuring the controller in open-loop with a controller limit of ±125 MW.
        - Insertion of a 20-minute ±20-MW wide-band multi-sine modulation signal.
        - Insertion of PDCI pulses.
- Closed-loop tests.
    - Configuring the controller in closed-loop with a medium gain level and a control limit of ±35 MW.
        - Insertion of a 20-minute ±20-MW wide-band multi-sine modulation signal into the control loop prior to the controller limiter.
        - Insertion of PDCI pulses.

<u>Phase 3: Closed-loop modulation tests and Chief-Jo brake tests under varying control gain</u>

The primary goals are to exercise the controller in closed loop and verify its operation, to measure open-loop versus closed-loop transfer functions, and to measure controller/system performance as a function of controller varying controller parameters. The following test will be repeated with varying gain and controller limit settings.

- Configuring the controller in closed-loop with a specified gain and controller limit.
    - Insertion of a 10-minute ±20-MW wide-band multi-sine modulation signal into the control loop prior to the controller limiter.
    - Insertion of PDCI pulses.
    - Insertion of Chief-Jo brake.
- Configuring the controller open loop.
    - Insertion of PDCI pulses.
    - Insertion of Chief-Jo brake.

2 Test Dates

Phase 1 (open-loop calibration and open-loop modulation tests) will be done on

- **Sep. 13 (Tue.), 2016** with alternative date of Sep. 14 (Wed.)

Phase 2 (closed-loop low-level modulation tests) will be done on

- **Sep. 22 (Thurs.), 2016** with alternative date of Sep. 21 (Wed.)

Phase 3 (closed-loop modulation tests and Chief-Jo brake tests under varying control gain) will be done on:

- **Sep. 29 (Thurs.), 2016** with an alternative date of Sep. 28 (Wed.)

3 Operating Conditions Required For 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

4 Test Precautions and Termination Procedure

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 Coordinator will send out a WECC Net message.

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

- System emergency exists within the WECC
- Interconnections 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.

5 Sequence of Test Events – Phase 1

The list below shows specific test events to be performed. 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 11 (e.g., the definition of MSF-1/30/1/100).

Test Series A: open-loop calibration

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

Step A1 [9:10] Apply +20MW (10 seconds) and -20 MW (10 seconds) via the damping controller. Verify proper function of modulation using Celilo/Sylmar DC metering.

Step A2 [9:15] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of one period (100 seconds) via the damping controller. Adjust scaling if needed.

Step A3 [9:20] Apply ±135 MW MSF-0.1/4x single-frequency signal for four cycles via the damping controller. This will test the saturation limiter on the controller.

Step A4 [9:25] Apply ±125 MW MSF-0.3/4x single-frequency signal for four cycles via the damping controller.

Step A6 [9:35] Apply ±125 MW MSF-1.0/4x for single frequency sine wave for four cycles via the damping controller.

Step A7 [9:40] Disconnect damping controller.

Test Series B: open-loop modulation

Step B0 [11:00] Configuring the controller in **open-loop** with a controller limit of ±125 MW. Connect damping controller.

Step B1 [11:10] Measurement of ambient noise conditions.

Step B2 [11:30] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 12 periods (20 minutes) via the damping controller.

Step B2 [11:55] Disconnect damping controller.

Test Series C: open-loop modulation

Step C0 [15:00] Configuring the controller in **open-loop** with a controller limit of ±125 MW. Connect damping controller.

Step C1 [15:10] Measurement of ambient noise conditions.

Step C2 [15:30] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 12 periods (20 minutes) via the damping controller.

Step C2 [15:55] Disconnect damping controller.

6 Sequence of Test Events – Phase 2

The list below shows specific test events to be performed. 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 11.

The control gain M below shall be selected based upon analysis of phase 1 data. Expected values for M are 3 MW/mHz to 6 MW/mHz. The value **SHALL NEVER EXCEED 18 MW/mHz**.

The amplitude of SQF/2.5/±125/3 is initially set to ±125 MW (see section 11). This may be reduced prior to the tests.

Test Series D: open-loop modulation

Step D0 [9:00] Configuring the controller in **open-loop** with a controller limit of ±125 MW. Connect damping controller.

Step D1 [9:10] Apply ±135 MW MSF-0.1/4x single-frequency signal for four cycles via the damping controller. This will test the saturation limiter on the controller.

Step D2 [9:20] Apply ±125 MW MSF-0.1/4x single-frequency signal for four cycles via the **Probing Signal Generator** outside the damping controller.

Step D3 [9:30] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 6 periods (10 minutes) via the damping controller.

Step D4 [9:45] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller.

Step D5 [9:55] Disconnect damping controller.

Test Series E: closed-loop low control limit

Step E0 [11:00] Configuring the controller in **closed-loop** with a gain of M and a control limit of ±35 MW. Connect damping controller.

Step E1 [11:10] Apply ±125 MW MSF-0.1/4x single-frequency signal for four cycles via the **Probing Signal Generator** outside the damping controller. Observed damping controller output should be on the order of ±30 MW or less. Observed PDCI power swings should not exceed ±160 MW.

Step E2 [11:20] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 12 periods (20 minutes) via the **Probing Signal Generator** outside the damping controller. Observed damping controller output should be on the order of ±15 MW or less and should not reach the limit. Observed PDCI power swings should not exceed ±50 MW.

Step E3 [11:45] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller. Slightly improved or similar damping from the open-loop responses should be observed. The damping controller will likely reach it limits for a few cycles of the oscillation.

Step E4 [11:55] Disconnect damping controller.

Test Series F: open-loop modulation

Step F0 [13:00] Configuring the controller in **open-loop** with a controller limit of ±125 MW. Connect damping controller.

Step F1 [13:10] Apply ±135 MW MSF-0.1/4x single-frequency signal for four cycles via the damping controller. This will test the saturation limiter on the controller.

Step F2 [13:20] Apply ±125 MW MSF-0.1/4x single-frequency signal for four cycles via the **Probing Signal Generator** outside the damping controller.

Step F3 [13:30] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 6 periods (10 minutes) via the damping controller.

Step F4 [13:45] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller.

Step F5 [13:55] Disconnect damping controller.

Test Series G: closed-loop low control limit

Step G0 [15:00] Configuring the controller in **closed-loop** with a gain of M and a control limit of ±50 MW. Connect damping controller.

Step G1 [15:10] Apply ±125 MW MSF-0.1/4x single-frequency signal for four cycles via the **Probing Signal Generator** outside the damping controller. Observed damping controller output should be on the order of ±30 MW or less and the output should not reach the limit. Observed PDCI power swings should not exceed ±160 MW.

Step G2 [15:20] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 12 periods (20 minutes) via the **Probing Signal Generator** outside the damping controller. Observed damping controller output should be on the order of ±15 MW or less and should not reach the limit. Observed PDCI power swings should not exceed ±50 MW.

Step G3 [15:45] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller. Slightly improved or similar damping from the open-loop responses should be observed. The damping controller will likely reach it limits for a few cycles of the oscillation.

Step G4 [15:55] Disconnect damping controller.

7 Sequence of Test Events – Phase 3

The list below shows specific test events to be performed. 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 11.

The control gains M, H, and XH below shall be selected based upon analysis of phase 1 data and phase 2 data. Expected values are 3 MW/mHz to 18 MW/mHz. The value **SHALL NEVER EXCEED 18 MW/mHz**.

The amplitude of SQF/2.5/+125/3 is initially set to +125 MW (see section 11). This may be reduced prior to the tests based upon analysis of prior tests.

Test Series H: closed-loop medium control gain and low control limits

Step H0 [9:00] Configure damping controller in **closed-loop** with a gain of M and a control limit of ±50 MW. (Medium Gain).

Step H1 [9:10] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 6 periods (10 minutes) via the **Probing Signal Generator** outside the damping controller. Observed damping controller output should be on the order of ±15 MW or less and should not reach the limit. Observed PDCI power swings should not exceed ±50 MW.

Step H2 [9:25] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller. Slightly improved or similar damping from the open-loop responses should be observed. The damping controller will likely reach it limits for a few cycles of the oscillation.

Step H3 [9:30] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller. Slightly improved or similar damping from the open-loop responses should be observed. The damping controller will likely reach it limits for a few cycles of the oscillation.

Step H4 [9:35] Configuring the controller in **open-loop** with a controller limit of ±125 MW.

Step H5 [9:40] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller.

Step H6 [9:45] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller.

Test Series I: closed-loop medium control gain and high control limits

Step I0 [10:00] Configure damping controller in closed-loop with a gain of M and a control limit of ±125 MW. (Medium Gain).

Step I1 [10:10] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 6 periods (10 minutes) via the **Probing Signal Generator** outside the damping controller. Observed damping controller output should be on the order of ±15 MW or less and should not reach the limit. Observed PDCI power swings should not exceed ±50 MW.

Step I2 [10:25] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller. Slightly improved or similar damping from the open-loop responses should be observed. The damping controller will likely reach it limits for a few cycles of the oscillation.

Step I3 [10:30] Apply Chief-Jo brake. Slightly improved or similar damping from the open-loop responses should be observed. The damping controller will likely reach it limits for a few cycles of the oscillation.

Step I4 [10:35] Disconnect damping controller.

Step I5 [10:40] Apply Chief-Jo brake.

Step I6 [10:45] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller.

Test Series J: closed-loop high control gain and low control limits

Step J0 [11:00] Configure damping controller in closed-loop with a gain of H and a control limit of ±50 MW. (High Gain).

Step J1 [11:10] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 6 periods (10 minutes) via the **Probing Signal Generator** outside the damping controller. Observed damping controller output should be on the order of ±20 MW or less and should not reach the limit. Observed PDCI power swings should not exceed ±50 MW.

Step J2 [11:25] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller. Slightly improved damping from the open-loop responses should be observed. The damping controller will likely reach it limits for a few cycles of the oscillation.

Step J3 [11:30] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller. Slightly improved damping from the open-loop responses should be observed. The damping controller will likely reach it limits for a few cycles of the oscillation.

Step J4 [11:35] Disconnect damping controller.

Step J5 [11:40] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller.

Step J6 [11:45] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller.

Test Series K: closed-loop high control gain and high control limits

Step K0 [13:00] Configure damping controller in closed-loop with a gain of H and a control limit of ±125 MW. (High Gain).

Step K1 [13:10] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 6 periods (10 minutes) via the **Probing Signal Generator** outside the damping controller. Observed damping controller output should be on the order of ±20 MW or less and should not reach the limit. Observed PDCI power swings should not exceed ±50 MW.

Step K2 [13:25] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller. Improved damping from the open-loop responses should be observed. The damping controller will likely reach it limits for a few cycles of the oscillation.

Step K3 [13:30] Apply Chief-Jo brake. Improved damping from the open-loop responses should be observed. The damping controller will likely reach it limits for a few cycles of the oscillation.

Step K4 [13:35] Disconnect damping controller.

Step K5 [13:40] Apply Chief-Jo brake.

Step K6 [13:45] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller.

Test Series L: closed-loop highest control gain and low control limits

Step L0 [14:00] Configure damping controller in closed-loop with a gain of XH and a control limit of ±50 MW. (Extra high gain).

Step L1 [14:10] Apply ±20 MW MSF-1/30/1/100 multi-frequency signal for a duration of 6 periods (10 minutes) via the **Probing Signal Generator** outside the damping controller. Observed damping controller output should be on the order of ±30 MW or less and should not reach the limit. Observed PDCI power swings should not exceed ±50 MW.

Step L2 [14:25] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller. Improved damping from the open-loop responses should be observed. The damping controller will likely reach it limits for a few cycles of the oscillation.

Step L3 [14:30] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller. Improved damping from the open-loop responses should be observed. The damping controller will likely reach it limits for a few cycles of the oscillation.

Step L4 [14:35] Disconnect damping controller.

Step L5 [14:40] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller.

Step L6 [14:45] Apply SQF/2.5/+125/3 with an amplitude of ±125 MW via the **Probing Signal Generator** outside the damping controller.

8 Test Coordinator and 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 Web page.
3. The day before each test, BPA will send a message on the WECC Net 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:
1-360-418-8001, passcode **2338#**

9 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
- San Onofre
- Navajo (16.06 Hz)
- Palo Verde (8.3 Hz)
- Four Corners (10.49 Hz)

10 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.

11 Test Signals

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

File Name	Test	Type	Band Width or Frequency
MSF/1/30/1/100	A-M	Multi-sine fitted	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.
MSF/0.1/4x	A	Single Freq Sine	Four sine wave cycles
MSF/0.3/4x	A	Single Freq Sine	Four sine wave cycles
MSF/0.7/4x	A	Single Freq Sine	Four sine wave cycles
MSF/1.0/4x	A	Single Freq Sine	Four sine wave cycles
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.

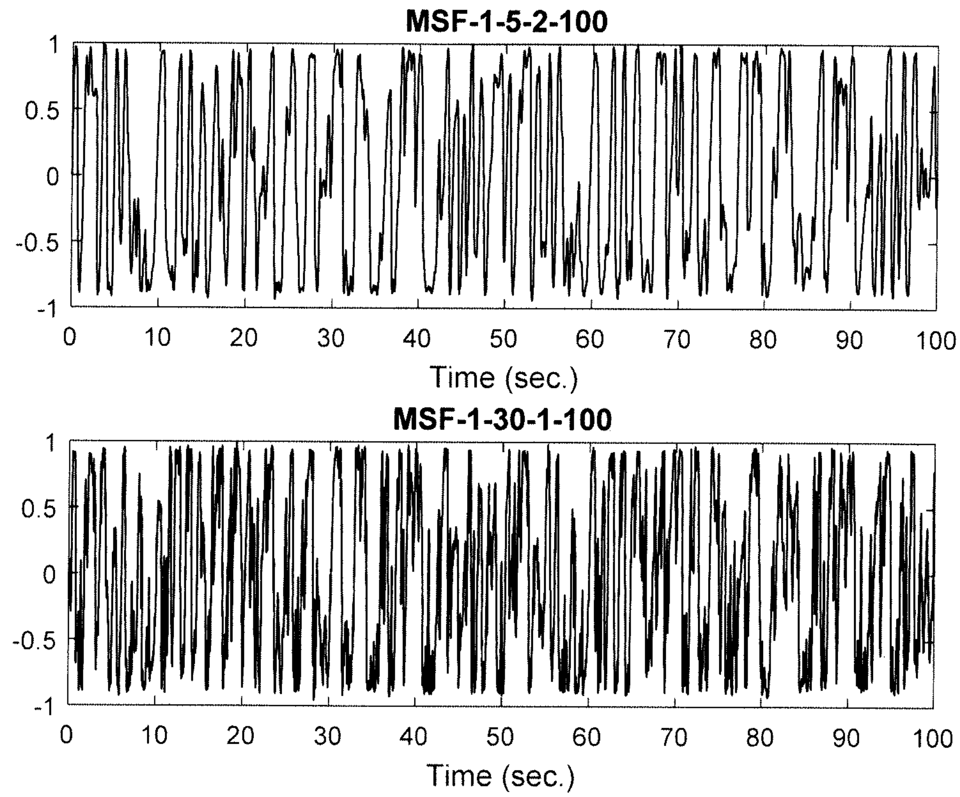

Figure 1: Comparison of MSF signals used in 2014 and 2016.

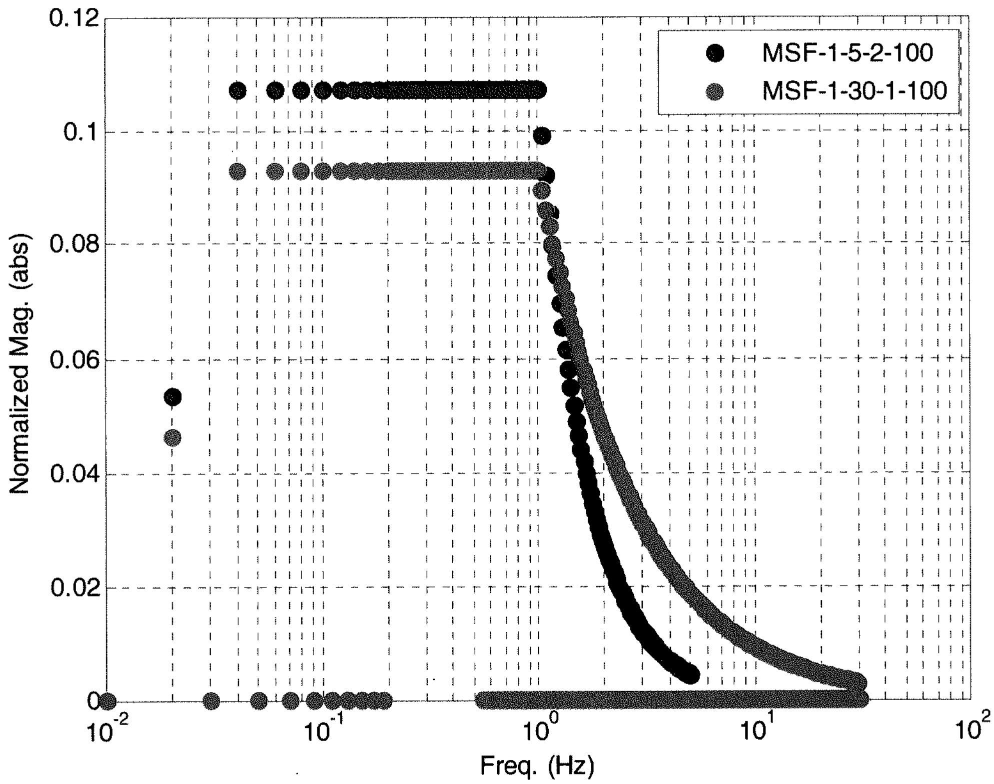

Figure 2: Spectrum of signals in Figure 1.

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

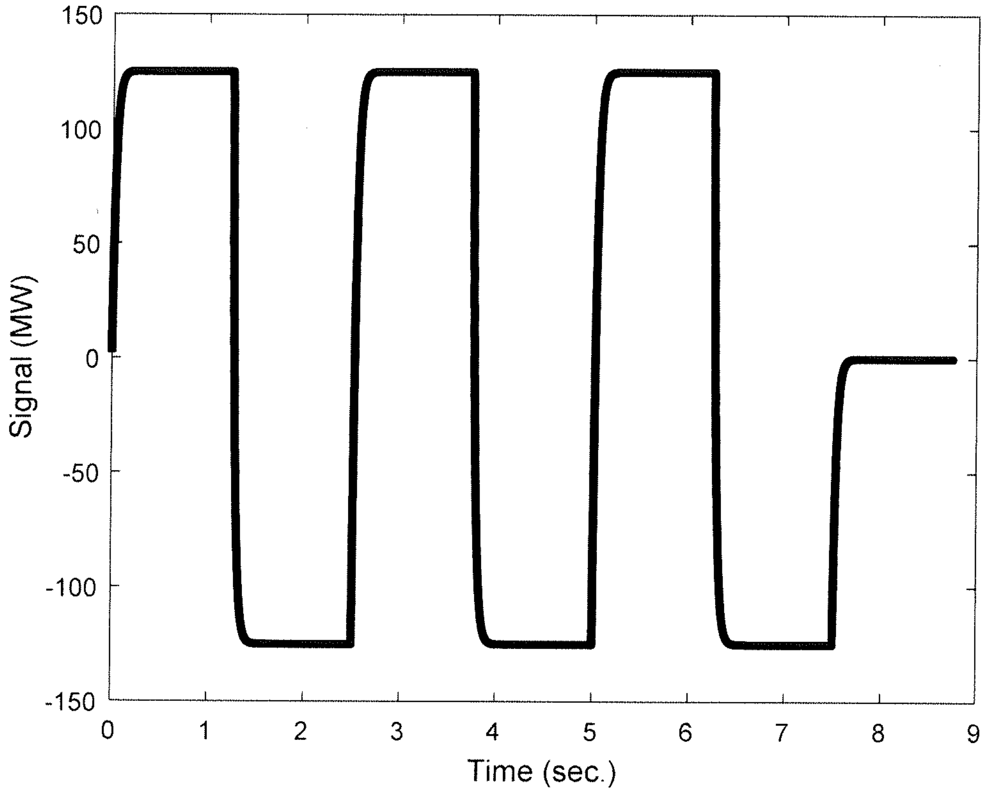

Figure 3: Example SQF/2.5/±125/3 signal.

12 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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