DOE F 1325.8e Electronic Form Approved by Forms Mgmt. 04/19/2006
(08-89)

United States Government **Department of Energy**

memorandum

Bonneville Power Administration

DATE: February 10, 2014

REPLY TO ATTN OF: TPP/OPP-3

SUBJECT: Pacific HVDC Probing Test Plan for the 2014 Operating Season

TO: Melvin Rodrigues – TPP/OPP3
Margaret Albright – TOT/DITT2
Richard Ellison – TOD/DITT1
T. Snodgrass – TOV/MEAD

1. Summary and Objectives

This is a continuation of probing tests conducted in the period 1999 – 2013. A complete list of test plan figures is available on request. There are several objectives of periodic PDCI probing:

- BPA, California ISO and WECC RC are deploying Mode Meter and Oscillation Detection applications as a part of the synchrophasor investment. PDCI probing is needed to tune up and validate these applications.
- Base-lining inter-area oscillation damping and mode shapes with respect to the system operating conditions so we can better assess the oscillation damping risks and make appropriate capital investments
- Support system and generator model validation with respect to representing inter-area power oscillations (current WECC MVWG activity, deliverable under BPA and WECC WISP)
- Providing a data base for testing tools for measuring power system modal behavior (frequency, damping, energy and mode shape)
- Evaluation of feasibility of inter-area oscillation damping controls (current BPA Technology Innovation project)

The proposed test plan includes three phases:

- Phase 1: calibration and benchmarking of a wide-band probing signal
- Phase 2: periodic probing during the 2014 operating season
- Phase 3: full scale oscillation detection and mode meter tests, and wide-band probing tests

Phase 1: Calibration and benchmarking of a wide-band probing signal

The calibration and benchmarking tests are done at the beginning of the season to ensure that PDCI correctly responds to the probing signal. The tests will include

- Single mode mid level probing
- Insertion of 20-minute pseudo-random noise by modulation of the Pacific HVDC Intertie, similar to one used during 2009 – 2013 summer seasons probing tests
- Insertion of high frequency noiose (1-28 Hz) to evaluate transfer functions of the PDCI system at frequencies above the electromechanical dynamics of the AC system.

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.

Phase 2: scheduled periodic probing during the 2014 operating season

BPA performed probing signal tests since 1999. Original probing tests were mid-level probing included square-wave pulses +/- 125 MW at pre-determined frequencies. Most commonly 0.25 Hz probing was used to excite North-South power oscillations. During 2003 summer operating season, BPA performed about 100 probing tests, often several times daily. Most recently, probing signal included band-limited noise injection as a more effective method to get a picture of the inter-area oscillation modes in the Western Interconnection.

As in recent tests, wide-band probing signal will be used to test the system under a wide variety of operating conditions. The tests have the following purpose:

- determine how frequency, damping and shapes of major WECC modes change with the system conditions
- Determine signal sources providing the best observability of the system modes
- determine transfer functions from DC current order to various AC system signals

The Phase 2 tests will be scheduled as defined below for the hours 9:00 and 15:00 on the following dates, as long as a test procedure does not conflict with a peak in operator workload (every other Wednesday). Additional tests will be done during light load hours by special agreement.

If the system conditions during prior to a test are similar to those already tested the test may be canceled.

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

- 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

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

<u>Phase 3: Full scale oscillation detection and mode meter tests</u>

The objective of this test is to evaluate oscillation signatures (oscillation frequencies, damping and mode shapes) under various generation scenarios in BPA area:

- high wind, high hydro scenario typically observed in early spring
- hydro run-off scenario typically observed in June – July
- end of hydro run-off, thermal base typically observed in August - September

The test will include the following staged events:

- Insertion of 20-minute pseudo-random noise by modulation of the Pacific HVDC Intertie, similar to one used during 2009 – 2013 summer seasons probing tests
- Insertion of the Chief Joseph braking resistor
- Insertion of 1-Hz to 28-Hz wide-band probing at the Celilo Coverter Station

The objective of wide-band probing tests is to evaluate transfer functions of the PDCI system at frequencies above the electromechanical dynamics of the AC system. The probing signal is in the 1-Hz to 28-Hz band and is similar to a test signal used in 2005 and 2008.

The test will include insertion of two 10-minute multi-sine signals by modulation of the Pacific HVDC Intertie

Desired monitored signals include:

- DC voltages, current at both ends of the DC line (PPSM)
- PMU-based AC voltages and currents on both sides of the DC converters.
- PMU voltages and currents on generation units close to the DC ends.

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 WISP Mode Meter are encouraged to participate in this, and to use associated spectral analysis software to observe frequency domain signatures for their service areas.

2. Test Dates

Phase 1 (calibration and bencmarking of wide-area probing signal) will be done on

- **March 13, 2014** with an alternative dates of March 14, 2014 or March 20, 2014

Phase 2 (periodic PDCI probing) will be done on (every other Thursday starting March 20, 2013):

- **March 20, 2014** with an alternative date of March 21, 2014
- **April 3, 2014** with an alternative date of April 4, 2014
- **April 16, 2014** with an alternative date of April 18, 2014
- **April 30, 2014** with an alternative date of May 2, 2014
- **May 14, 2014** with an alternative date of May 16, 2014
- **May 29, 2014** with an alternative date of May 30, 2014
- **June 12, 2014** with an alternative date of June 13, 2014
- **June 26, 2014** with an alternative date of June 27, 2014
- **July 10, 2014** with an alternative date of July 11, 2014
- **July 24, 2014** with an alternative date of July 25, 2014
- **August 7, 2014** with an alternative date of August 8, 2014
- **August 21, 2014** with an alternative date of August 22, 2014
- **September 4, 2014** with an alternative date of September 5, 2014

Phase 3 (full-scale oscillation analysis tests and wide-band probe) will be done on:

- **April 10, 2014** with alternate days of April 11, 15, 18 for early spring season
- **June 19, 2014** with alternate days of June 20, 24, 25 for hydro run-off season
- **September 11, 2014** with alternate days of September 12, 18, 19 for late summer season

If performed on "alternate day", Phase 3 superceeds Phase 2 tests scheduled for same day.

Date	Alternative Date	Test Phase	Brake	PDCI Probe	Wide-band probe*
March 13	March 14, March 20	1		YES	YES
March 20		2		YES	
April 3		2		YES	
April 10	**April 11, 15,18**	**3`**	**YES**	**YES**	**YES**
April 16		2		YES	
April 30		2		YES	
May 14		2		YES	
May 29		2		YES	
June 12		2		YES	
June 19	**June 20, 24, 25**	**3**	**YES**	**YES**	**YES**
June 26		2		YES	
July 10		2		YES	
July 24		2		YES	
August 7		2		YES	
August 21		2		YES	
September 4		2		YES	
September 11	**September 12, 18, 19**	**3**	**YES**	**YES**	**YES**

*** To perform wide-band probe tests the following conditions must be met:**
- the data from Big Eddy 230, Big Eddy 500 and Sylmar PMUs is good and is available to test observers
- real-time spectrum analysis application must be available and running at BPA, calculating and displaying real-time spectrum for the following lines:

- **Big Eddy-Celilo 1, Big Eddy-Celilo 2, Big Eddy-Celilo3, Big Eddy-Celilo 4**
- **Sylmar 1, Sylmar 2**
- **John Day-Grizzly 1 and 2**
- **Slatt – Boardman**
- **Ashe – CGS**
- **John Day – Biglow Canyon**
- **Keeler 230-kV bus voltage**

3. Operating Conditions Required For Tests

Operating Conditions for Ambient and Modulated Test Series

- 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
- 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/PDCI Controller 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 description is given in Section 9.

Test Series A: Calibration Checks on PDCI Probing Signals

Step A0 [9:10] Celilo instrumentation check using +20MW waveform (10 seconds) and -20 MW (10 seconds). Check proper function of PSG using Celilo/Sylmar DC metering.

Step A1 [9:15] Calibration check on MSF-1/5/2/100 for ±10 MW noise probing for a duration of one period (100 seconds). Adjust PSG scaling if needed.

Step A4 [9:30] Apply MSF-0.1/4x for ±20 MW single frequency sine wave for four cycles.

Step A5 [9:35] Apply MSF-0.3/4x for ±20 MW single frequency sine wave for four cycles.

Step A6 [9:40] Apply MSF-0.7/4x for ±20 MW single frequency sine wave for four cycles.

Step A7 [9:45] Apply MSF-1.0/4x for ±20 MW single frequency sine wave for four cycles.

Step A8 [10:10] Apply a ±5 MW MSF/27.8/28.1/NA/10B for 1 minute.

Step A9 [10:15] Apply a ±5 MW MSF/27.8/28.1/NA/10C for 1 minute.

Test Series B: Noise Probing

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

Step B2 [11:30] Apply a ±20 MW MSF-1/5/2/100 for a duration of 12 periods (20 minutes).

Test Series C: Noise Probing

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

Step C2 [15:30] Apply a ±20 MW MSF-1/5/2/100 for a duration of 12 periods (20 minutes).

6. Sequence of Test Events – Phase 2

The probing signal for Phase 2 will be a ±20 MW MSF-1/5/2/100 signal for 20 minutes. The list below shows specific test events to be performed. Times for these test events are in Pacific Time.

Test Series A: Noise Probing (Morning)

Step A1 [9:10] Measurement of ambient noise conditions

Step A2 [9:30] Apply a ±20 MW MSF-1/5/2/100 for a duration of 12 periods (20 minutes).

Test Series B: Noise Probing (Afternoon)

Step B1 [15:10] Measurement of ambient noise conditions

Step B2 [15:30] Apply a ±20 MW MSF-1/5/2/100 for a duration of 12 periods (20 minutes).

7. Sequence of Test Events – Phase 3

Phase 3 tests include:

- Chief Joseph brake insertion tests
- The probing signal ±20 MW MSF-1/5/2/100 signal for 20 minutes.
- The probing signal ±5 MW MSF/27.8/28.1/NA/10B and a ±5 MW MSF/27.8/28.1/NA/10C signal for 10 minutes each.

The list below shows specific test events to be performed. Times for these test events are in Pacific Time.

Test Series A: Noise Probing (Morning)

Step A1	[9:14]	Apply Chief Joseph braking resistor
Step A2	[9:20]	Apply a ±20 MW MSF-1/5/2/100 for a duration of 12 periods (20 minutes).
Step A3	[9:44]	Apply Chief Joseph braking resistor
Step A4	[10:15]	Apply a ±5 MW MSF/27.8/28.1/NA/10B for a duration of 60 periods (10 minutes).
Step A5	[10:35]	Apply a ±5 MW MSF/27.8/28.1/NA/10C for a duration of 60 periods (10 minutes).

Test Series B: Noise Probing (Afternoon)

Step B1	[15:14]	Apply Chief Joseph braking resistor
Step B2	[15:20]	Apply a ±20 MW MSF-1/5/2/100 for a duration of 12 periods (20 minutes).
Step B3	[15:44]	Apply Chief Joseph braking resistor
Step B4	[16:15]	Apply a ±5 MW MSF/27.8/28.1/NA/10B for a duration of 60 periods (10 minutes).
Step B5	[16:35]	Apply a ±5 MW MSF/27.8/28.1/NA/10C for a duration of 60 periods (10 minutes).

To perform Steps A4, A5, B4, and B5 the monitoring capabilities outlined in Section 2 must be met.

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 PDC, PMU and PPSM recording is required at BPA locations for the period 0800 through 1800 PDT of the test day.
- Continuous PDC, PMU and PPSM recording is highly desirable at all other WECC locations for the period 0800 through 1800 PDT of the test day where this data is available.
- Continuous recording with the Celilo PPSM is required. It is desired that the recording rate be 960 sps, but 240 sps is acceptable. Data acquisition filters must be set appropriately. To limit file size, it is highly important that the point-on-wave ac signals (signals 16 through 39) not be recorded. It is desirable that a separate recorder be installed for this sometime in the future.

Required facilities for real-time analysis

A key objective in the proposed tests is to "Refine and validate methods that identify power system dynamics with minimal or no use of probing signals." 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 desirable at Celilo and PNNL Richland. It is also suggested that California ISO and other organizations that have PDC StreamReaders or alternate toolsets use them to observe test results in their service areas.

The following paths should be monitored during the tests:

- Ingledow – Custer
- Montana Intertie
- California – Oregon Intertie
- Pacific HVDC Intertie
- Midway – Vincent
- Palo Verde – Devers
- Big Eddy – Celilo 3 and 4 MW and MVAR flow and frequency spectrum
- John Day – Grizzly 1 and 2 MW and MVAR flow and frequency spectrum

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)
- Biglow Canyon (14 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/1/5/2/100	A-C	Multi-sine fitted	Content from 0.02 to 5 Hz; rolls off from 0.1 to 0.02 Hz as a 1st-order; rolls off as a 1st-order after 1 Hz; every other bin outside 0.2 Hz to 0.5 Hz is removed; 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
MSF/27.8/28.1/NA/10B	A,B Phase 3	Multi-sine	Content from 1-Hz to 28 Hz.
MSF/27.8/28.1/NA/10C	A,B, Phase 3	Multi-sine	Content from 1-Hz to 28 Hz.

MSF/N1/N2/N3/N4

MSF:
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 Figure 1, showing selected components removed above 1 Hz)

Figure 1 illustrates the difference between an existing narrow band (2 Hz) probing signal and two different 5 Hz probing signals. The red curve used in this test plan (MSF 1-5-2-100) shifts energy at selected frequencies from the 1-5 Hz range to the range less than 1 Hz to improve identification of modes in this range. Additional background material is provided in Appendices A-E.

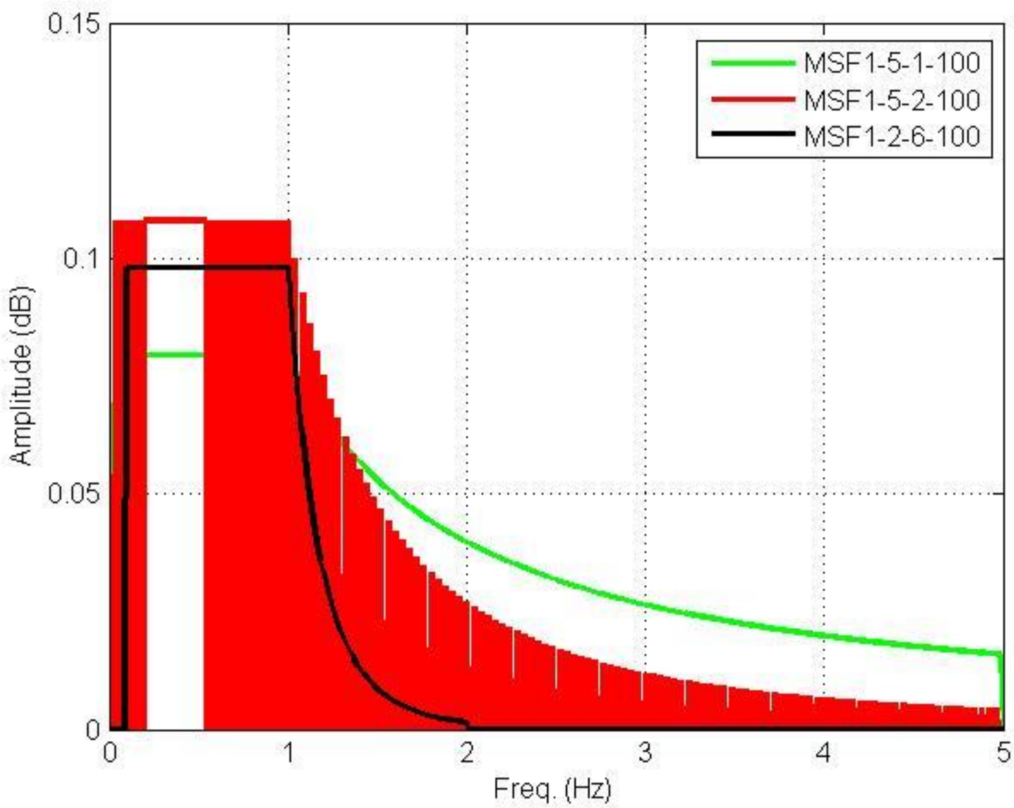

Figure 1: Comparison of signals used in Phases 1 thru 3.

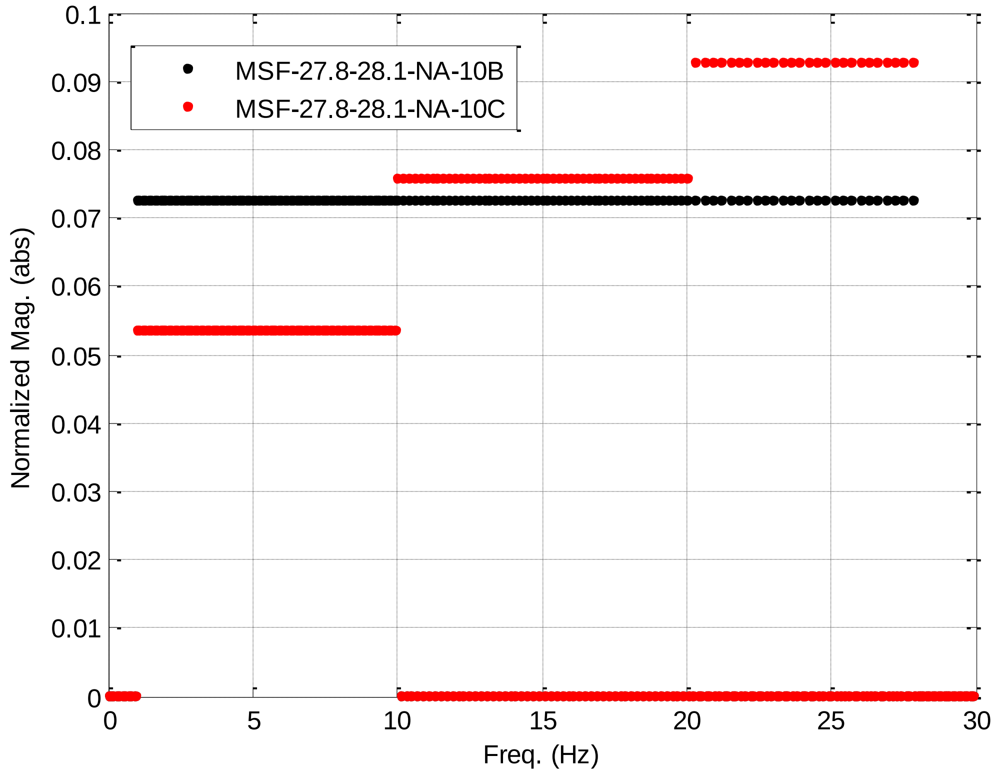

Figure 2: Spectrum of high-frequency probing signals. Signals are normalized to unity.

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

[4] **Transfer Function Results from the 2009 PDCI Probing Tests,** Dan Trudnowski, September 2010.

TEST APPROVALS

This test plan submitted by:

Dmitry Kosterev – TPP
William A. Mittelstadt TPP/MBO
Dan Goodrich – TOT
Jim Burns – TOT

Approved: ____ Date:__________________
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Approved: ____ Date:__________________
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Approved: ____ Date:__________________
Manager – Richard Ellison, Dittmer Dispatch TOD

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Manager – T. Snodgrass, Munro Dispatch TOV

Table 2. Coordination and Contact Person List (updated 2/11/14)

Contact	Utility	Function	Phone	Email
Chief Dispachers		All WECC dispachers		chiefdis@wecc.biz
Jim Burns	**BPAT**	**Test Director**	**360- 418-2331**	**jwburns@bpa.gov**
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Telephone Bridge		System Test Bridge (20 ports) 360-418-8224	360-418-8224	Passcode 2338#

If you experience telephone bridge difficulties please call the Ross Telephone Office at extension 8888 (360-418-8888).

For other questions call the test director or Bill Mittelstadt at 503-891-2246