Pacific HVDC Probing Test Plan for the 2011 Operating Season

Submitted by:
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by: July 1, 2011

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[1] This plan was submitted to the Joint Synchronized Informationr Subcommittee for comment March 4, 2011. No changes are in this version except the test data has been moved to July.

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Pacific HVDC Probing Test Plan for the 2011 Operating Season

1. Summary and Objectives

This is a continuation of probing tests conducted in the period 1999 – 2009. The proposed test plan includes two phases:

- Phase 1: calibration and benchmarking of a wide-band probing signal
- Phase 2: periodic probing during the 2011 operating season

There are several benefits from PDCI probing:

- Base-lining inter-area oscillation damping and mode shapes with respect to the system operating conditions (current activity under North-American Synchro-Phasor Initiative (NASPI) and WECC)
- Model validation with respect to representing inter-area power oscillations (current WECC MVWG activity)
- 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 project)
- Provide data for evaluating Modal Analysis Software under development for the WISP.

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

This test will be performed in coordination with the WECC Joint Synchrophasor Information Subcommittee (JSIS) and the Modeling and Validation Work Group (M&VWG), with the full test scheduled in each of the following periods:

- July 14, 2011 with alternate days of July 19-21, July 26-28.
- September 7, 2011 with alternate days of September 8, 14 or 15.

The alternate days may be used in the event that the test date must be changed or portions of the test must be repeated. Dates may be revised by System Operations to meet system requirements.

The test will include the following staged events:

- Single mode mid level probing
- Insertion of 20-minute pseudo-random noise by modulation of the Pacific HVDC Intertie, similar to one used during August 2008 probing tests
- Insertion of the Chief Joseph braking resistor

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 a PDC StreamReader are invited to participate in this, and to use associated spectral analysis software to observe frequency domain signatures for their service areas. Alternate toolsets for this include Real Time Dynamic Monitor System (RTDMS) and the DOE Mode Meter. Extended data access at the California ISO and at the Pacific Northwest National Laboratory permit almost total backup of BPA monitoring facilities.

Wide Area Monitoring System (WAMS) data from this test 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 will be requested for analysis. Such activities will be coordinated through the WECC Disturbance Monitoring Work Group (DMWG, now reporting to JSIS).

Successful completion of Phase 1 is a pre-requisite for continuation with Phase 2.

Phase 2: scheduled periodic probing during the 2011 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 8:00 and 14:00 bi-weekly on Wednesdays or Thursdays starting June 29, 2011 until September 29, 2011, as long as a test procedure does not conflict with a peak in operator workload. 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.

2. 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[2]

- 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. 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.

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.

[2] As a general rule, a pair of brake insertions (spaced 5 minutes apart) will be performed to start and finish every prolonged session of lower level testing. This interval will not exceed 12 hours, and it may be omitted if the session lasts less that 6 hours without any major change in system topology or operating conditions.

4. 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 A2 [9:20] Chief Joseph brake application for 30 cycles.

Step A3 [9:25] Chief Joseph brake application for 30 cycles.

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.

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 [13:10] Measurement of ambient noise conditions

Step C2 [13:30] Apply a ±20 MW MSF-1/5/2/100 for a duration of 12 periods (20 minutes).

Test Series D[3]: Brake Application

Step D1 [14:10] Chief Joseph brake application for 30 cycles.

Step D2 [14:15] Chief Joseph brake application for 30 cycles.

[3] See footnote 1.

5. 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 [8:10] Measurement of ambient noise conditions

Step A2 [8:30] 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 [14:10] Measurement of ambient noise conditions

Step B2 [14:30] Apply a ±20 MW MSF-1/5/2/100 for a duration of 12 periods (20 minutes).

6. 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.

7. Measurement Requirements

WAMS 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 highly 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

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)

8. 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.

9. 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/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.

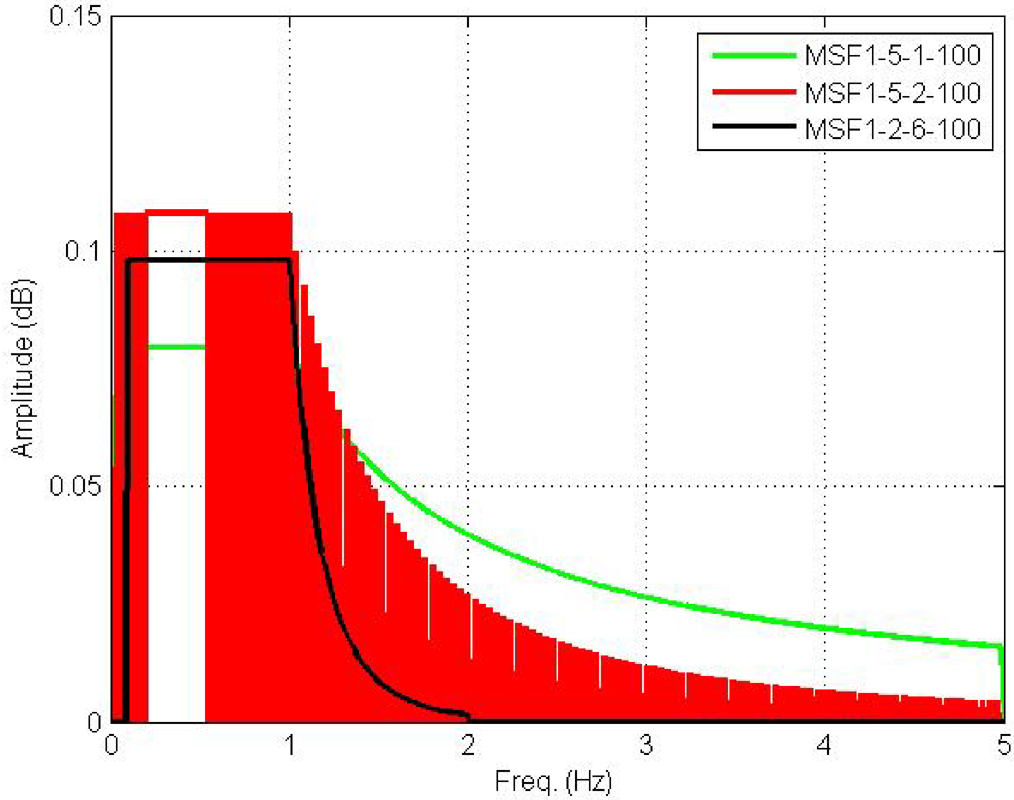

Figure 1: Comparison of signals used in tests B, C and D.

10. 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.

Appendix A: Illustrations of Applied Test Signals

The following figures are illustrative of the system response to signals that will be applied during this test. Additional information on the test signals and system response is provided in [3] and in various other documents cited there.

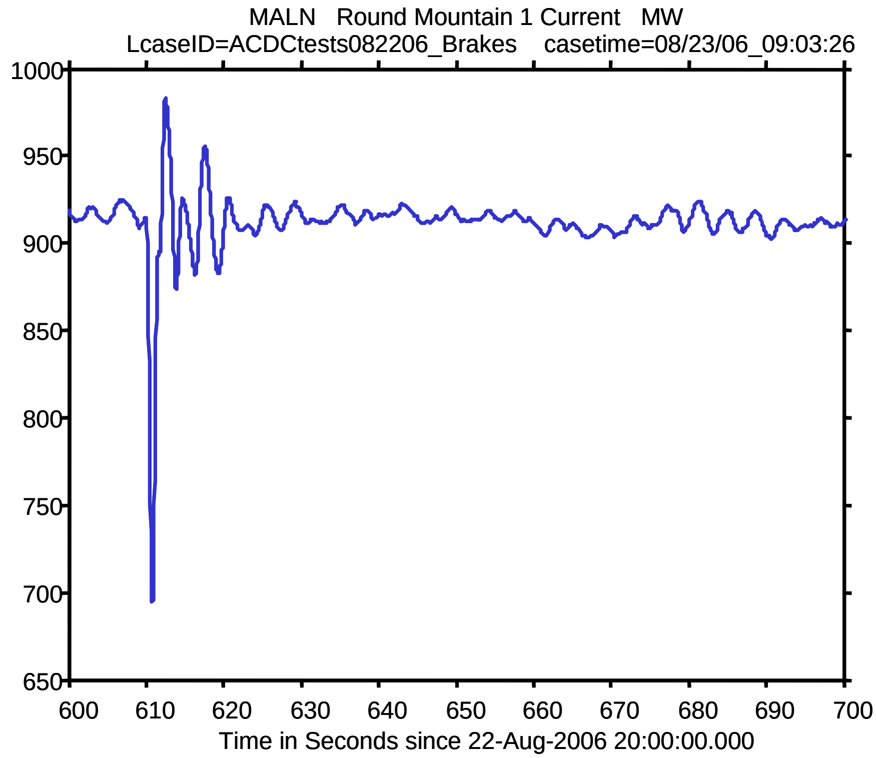

Figure A-1. Malin-Round Mtn MW response to Chief Joseph Brake Application B1, 08/22/06

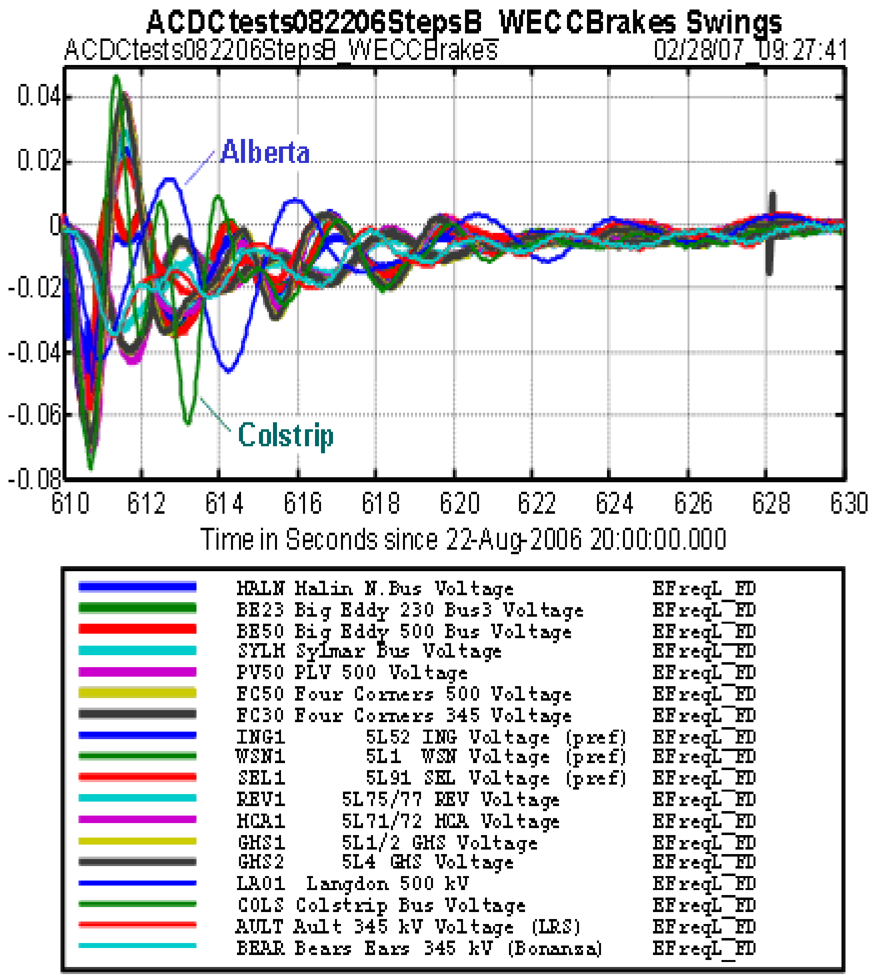

Figure A-2. Frequency swings for Chief Joseph Brake Application B1, 08/22/06

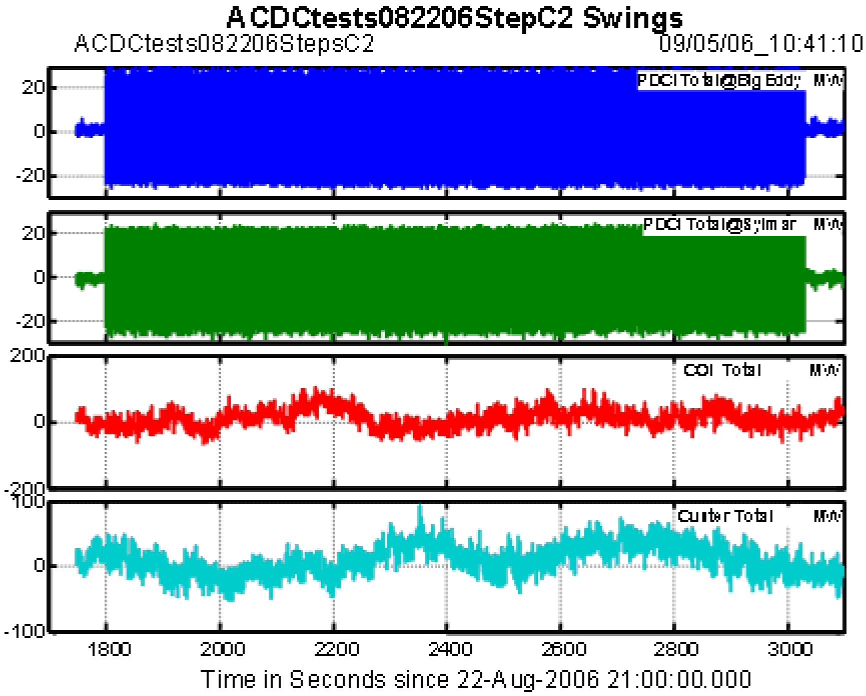

Figure A-3. Response to ±25 MW noise modulation, test step C2 on 08/22/06

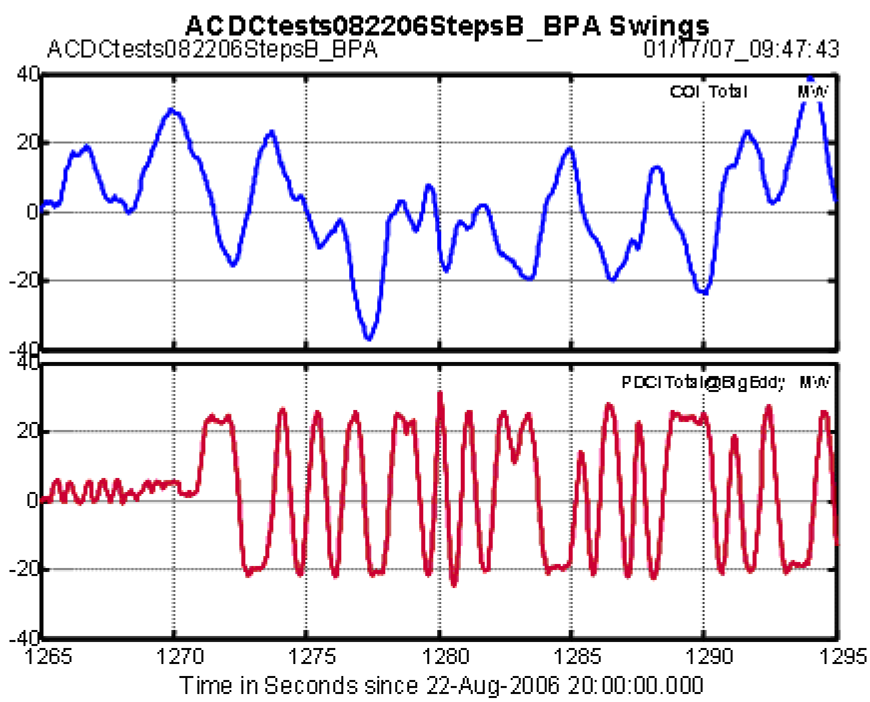

Figure A-5. Startup of ±25 MW noise modulation, test step B3 on 08/22/06

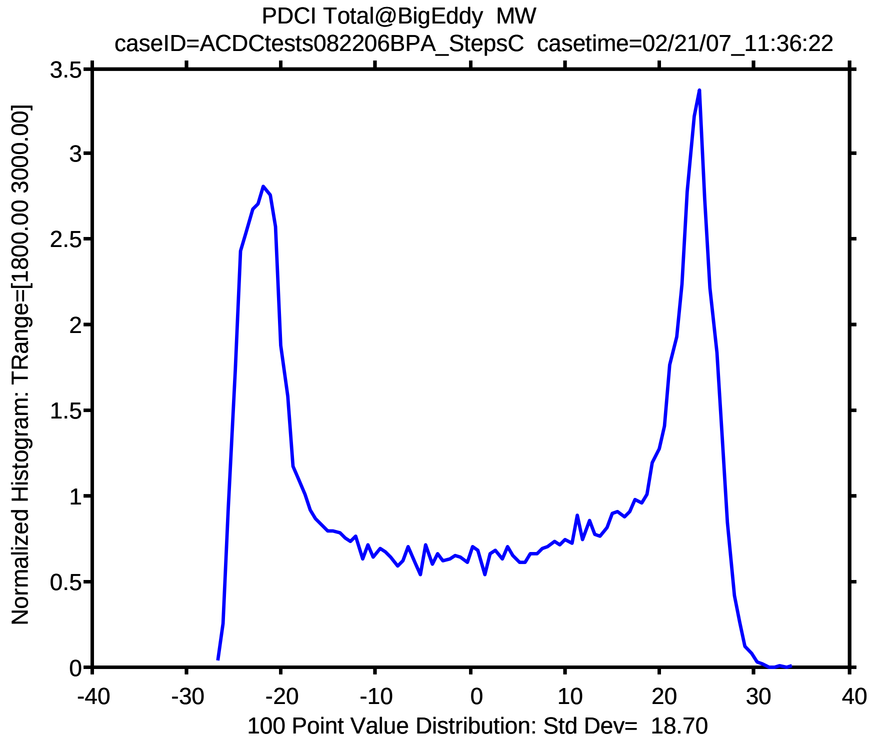

Figure A-6. Histogram for Celilo DC MW response to low level noise probing, test step C2 on 08/22/06

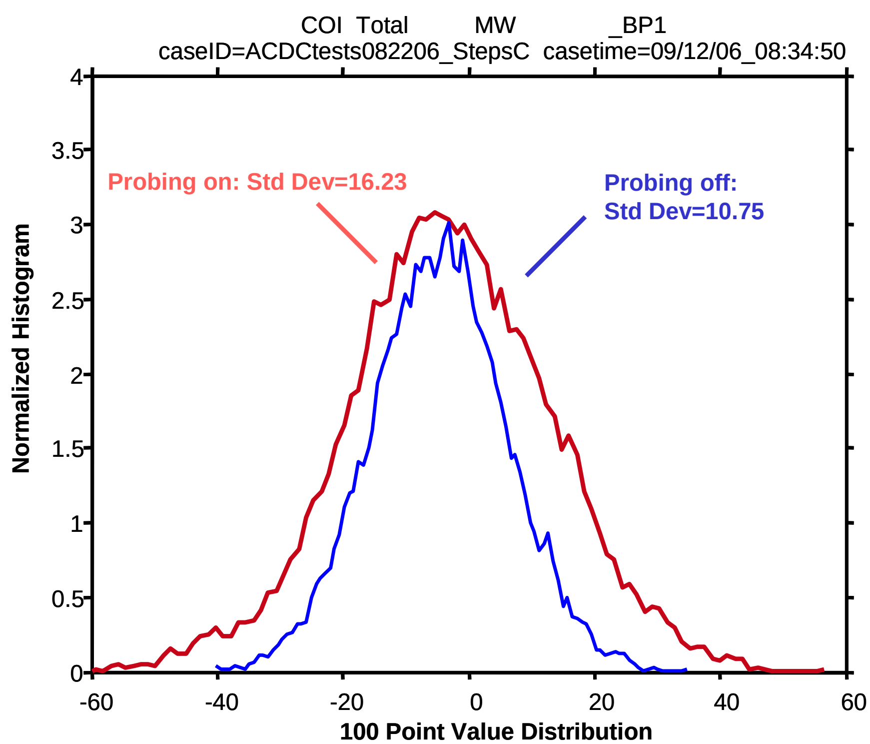

Figure A-7. Histogram for COI MW response to low level noise probing, test steps C on 08/22/06

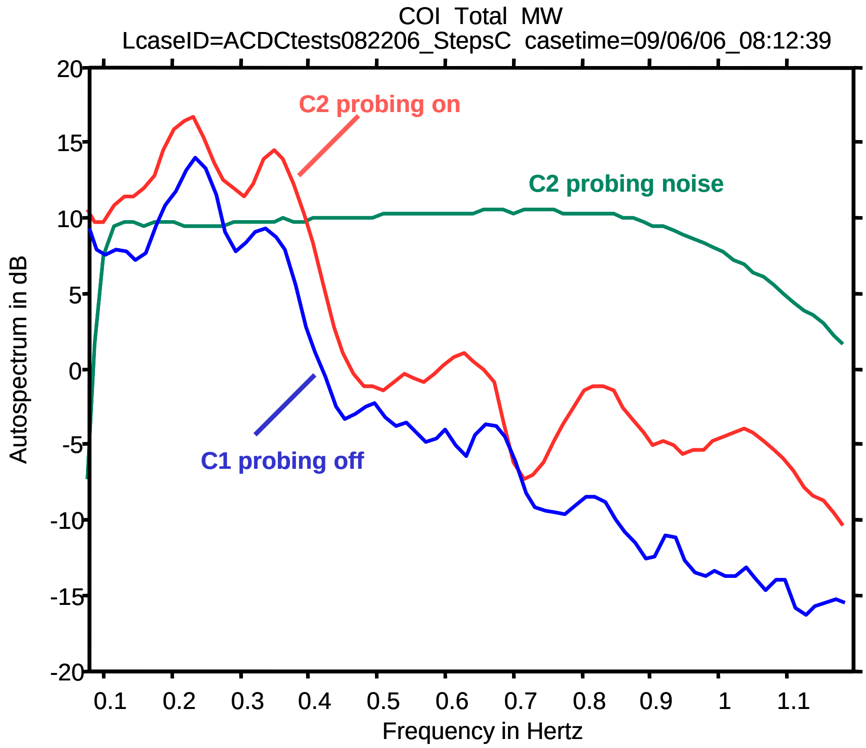

Figure A-8. Key autospectra for level noise probing, test steps C on 08/22/06

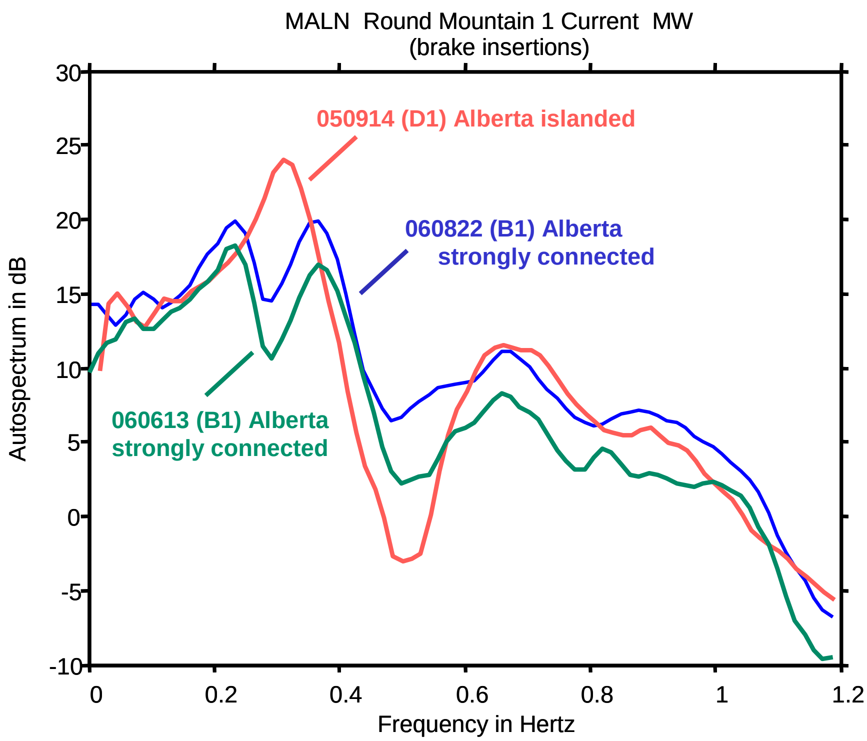

Figure A-9. Effect of Alberta connection on response to insertions of the Chief Joseph dynamic brake

Appendix B: Wide-Band Probing Signal

Figure B-1 shows signal MSF-1/15/1/100 in time and frequency domain. It has 1st-order roll off from 1 Hz to 15 Hz.

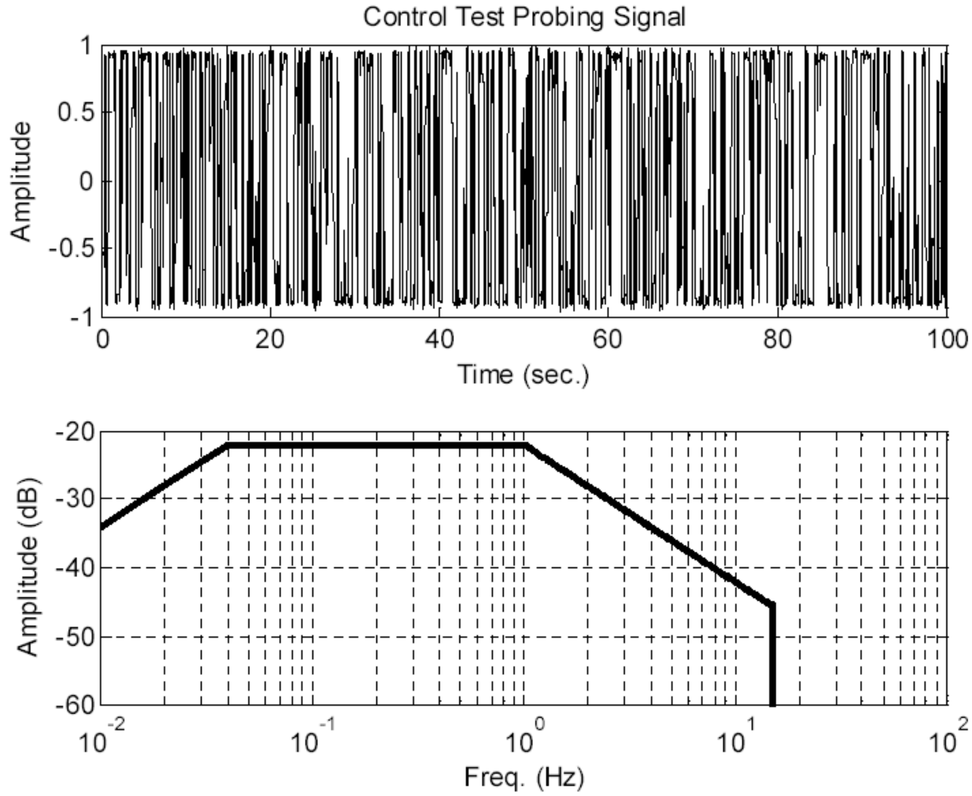

Figure B-1: probing signal MSF-1/15/1/100

Figure B2 compares MSF-1/15/1/100 at +5 MW with the previous wideband probing from 2005 (MSF-20/6/17).

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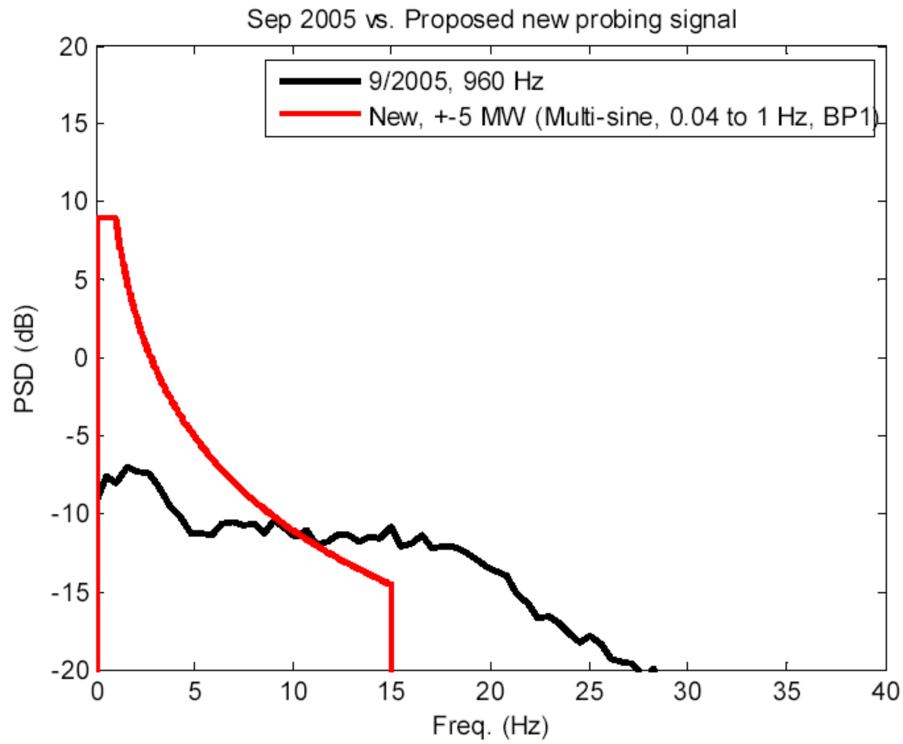


Figure B-2: comparing probing signal MSF-1/15/1/100 with MSF-20/6/17

Appendix C: Probing Test Simulations

A wide-band probing signal MSF/1/15/4/100 was simulated in GE PSLF program. System frequency, bus voltages and key flows were recorded and further analyzed.

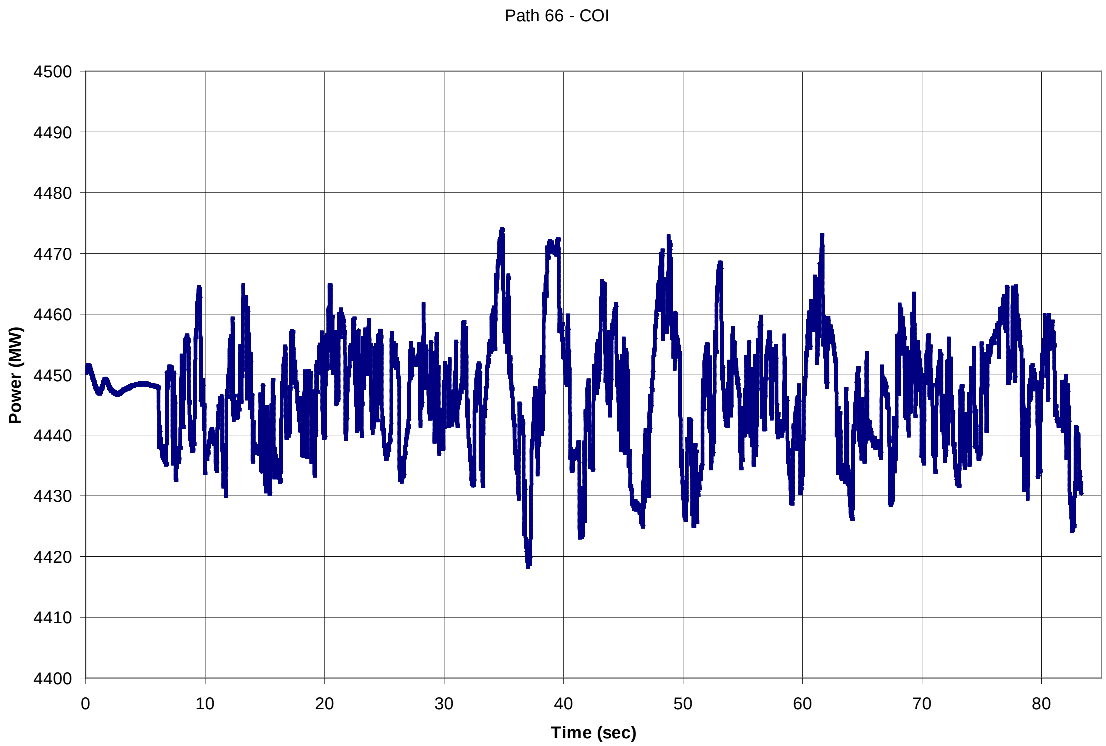


Figure C-1: COI power during +/- 25 Amp DC current wide-band probe

The 2008 Heavy Summer operating case was used in the following simulations. Various disturbances were simulated during a probing test. Figure C-2 compares simulations of 2 Palo Verde outage during the probing test with a 2 Palo Verde outage without a probe. It is evident that probing test can degrade system damping performance if a disturbance to occur during the test. Therefore, probing tests must be supervised and, if a disturbance is detected, promptly terminated.

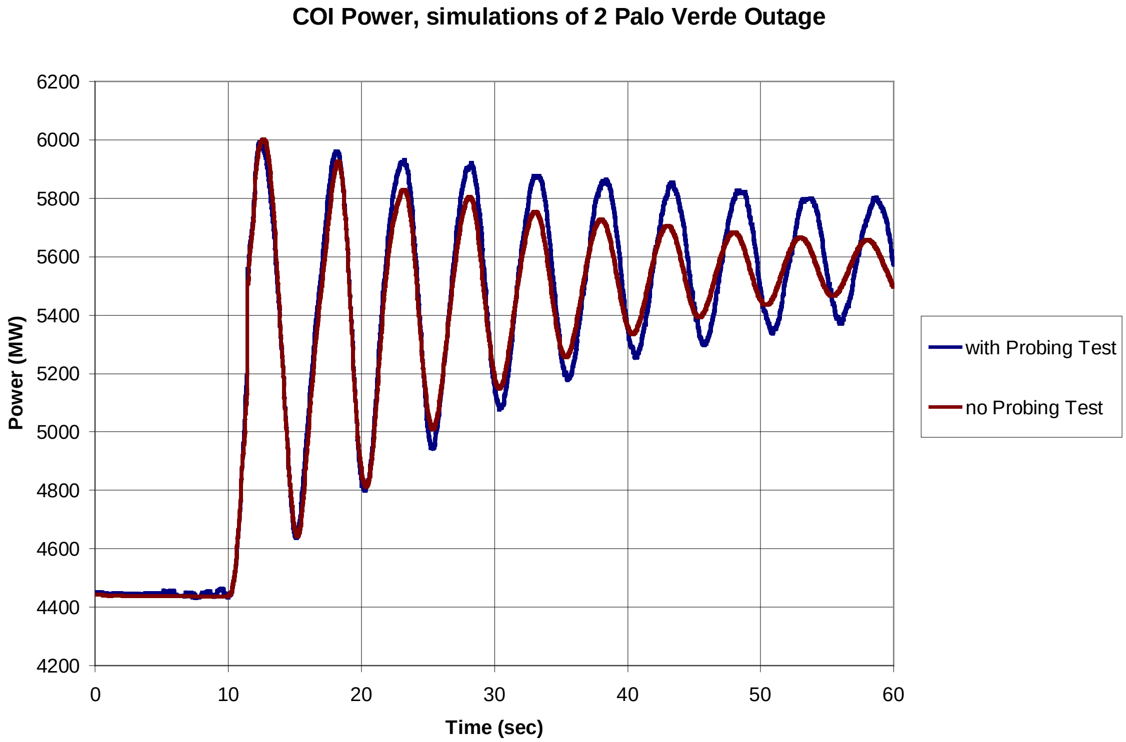


Figure C-2: simulations of 2 Palo Verde outage with and without a probe, 2008 heavy summer case.

The 2011 Light Spring case was used in the following simulations. Various disturbances were simulated during a probing test. Figure C-2 compares simulations of 2 Palo Verde outage during the probing test with a 2 Palo Verde outage without a probe. The effects of probing are not as pronounced as they were in the heavy summer case.

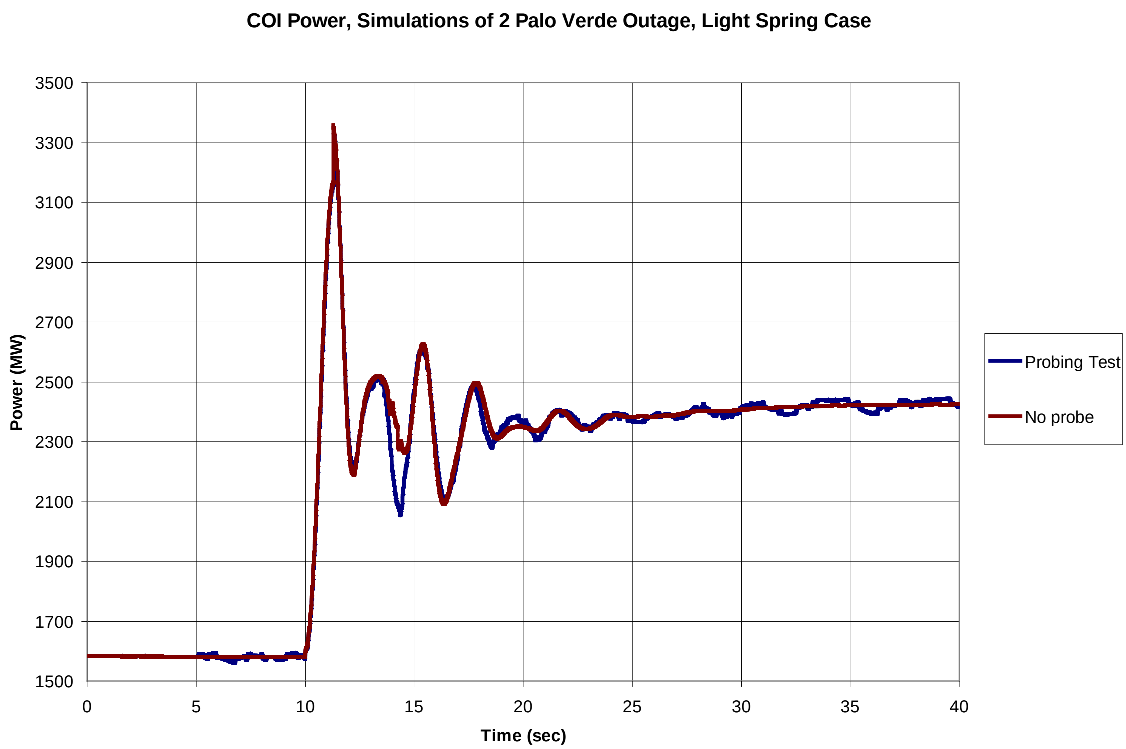


Figure C-2: simulations of 2 Palo Verde outage with and without a probe, 2011 light spring case

Appendix D: Results 08hs01pr_prb Simulations - Working Note

Dan Trudnowski
Feb. 2009

This case applies a wide-band multi-sine PDCI probing signal to the PSLF simulation 08hs01. Figure D-1 shows the probing signal and the spectrum. The remaining figures show the response of each generator. Note that the spectrum above 1 Hz rolls off very sharply. This indicates that PDCI modulation has low gain to the higher turbine modes.

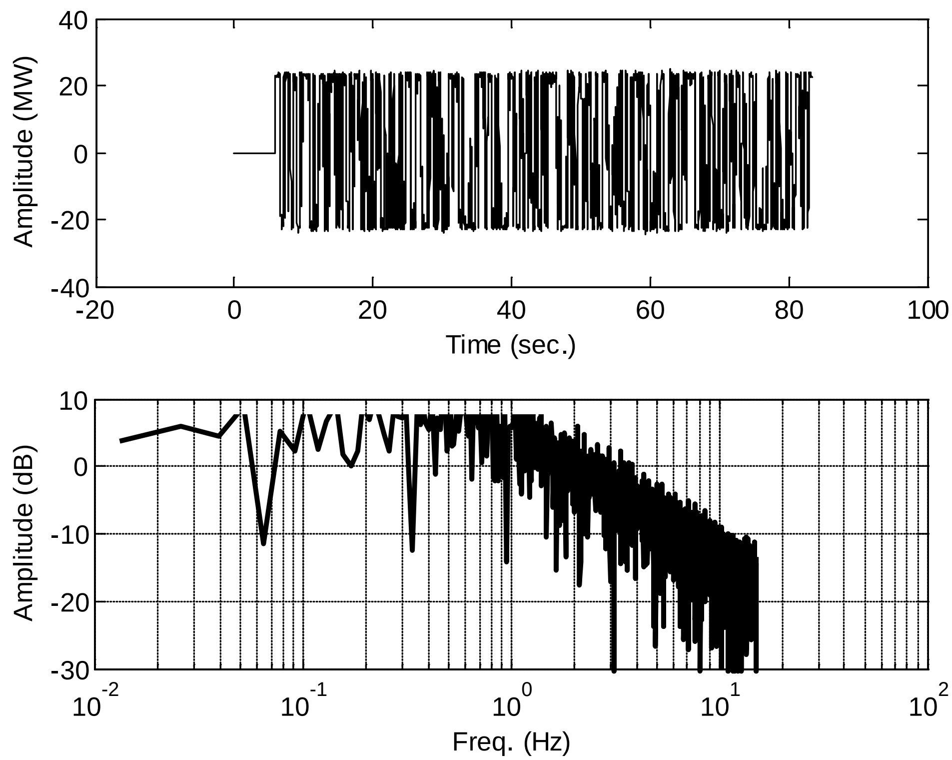
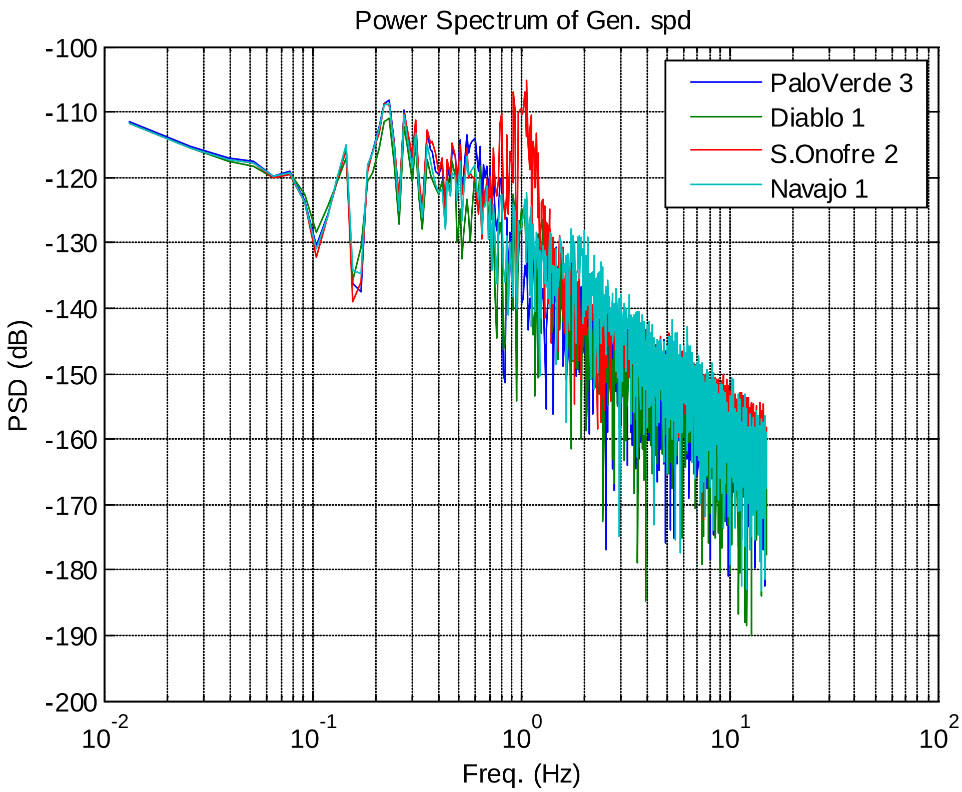
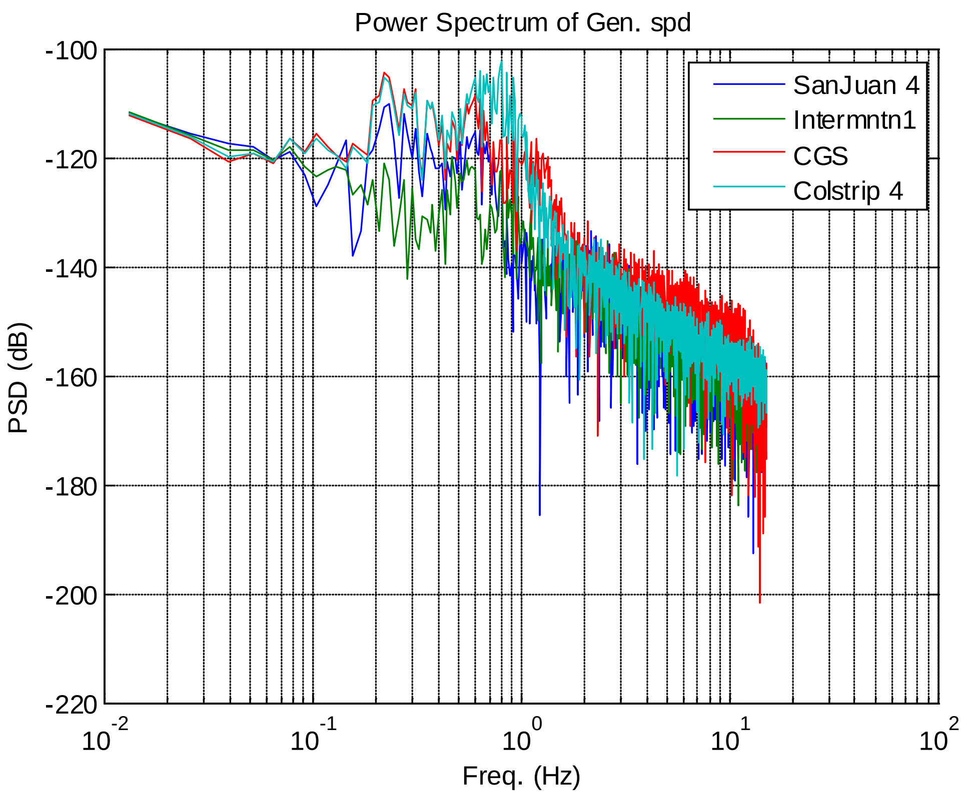
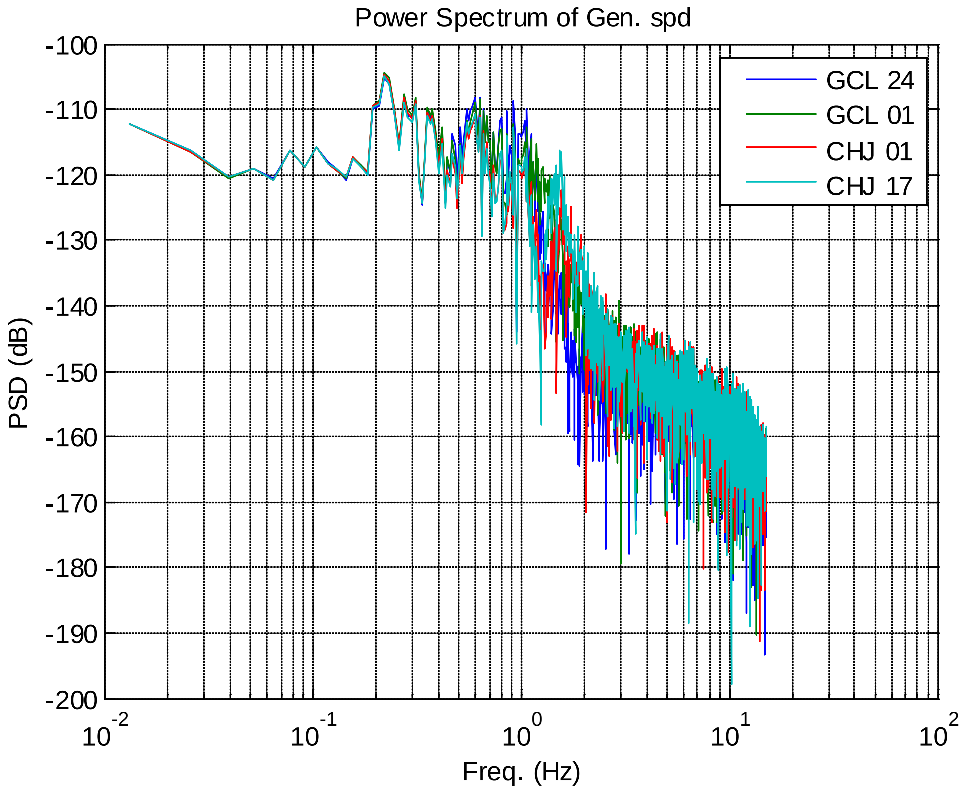


Figure D-1: PDCI probing applied to 08hs01.


Power Spectrum of Gen. spd
PSD (dB)
Freq. (Hz)
PaloVerde 3
Diablo 1
S.Onofre 2
Navajo 1


Power Spectrum of Gen. spd
PSD (dB)
Freq. (Hz)
SanJuan 4
Intermntn1
CGS
Colstrip 4


Power Spectrum of Gen. spd
PSD (dB)
Freq. (Hz)
GCL 24
GCL 01
CHJ 01
CHJ 17
-100
-110
-120
-130
-140
-150
-160
-170
-180
-190
-200
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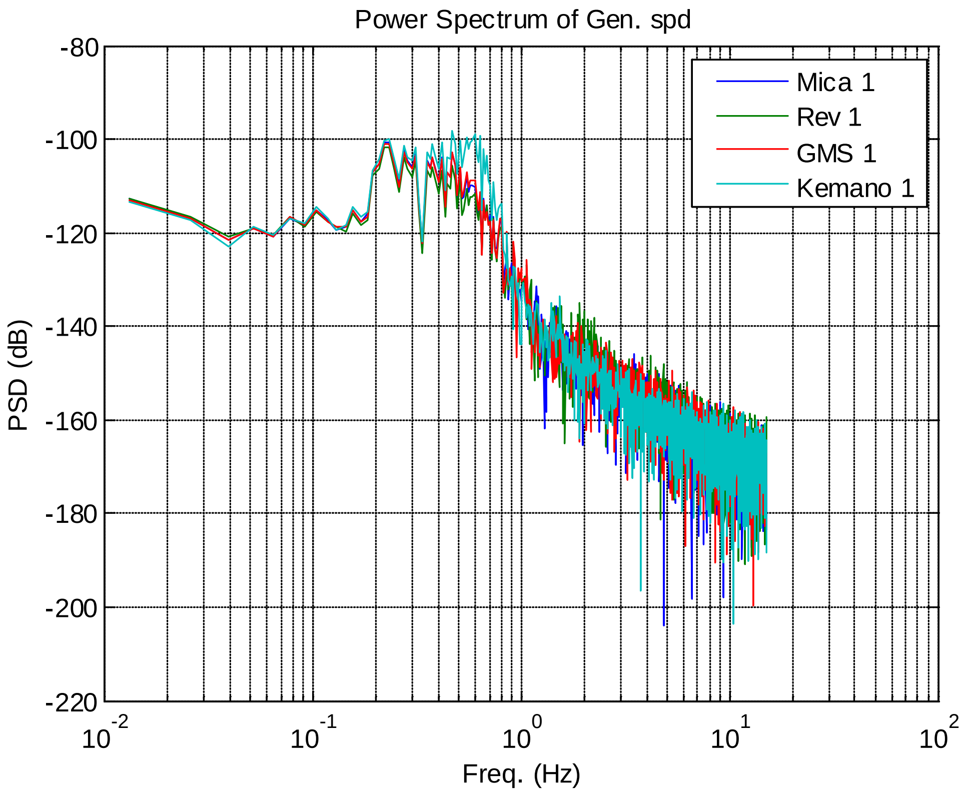
10^{-1}
10^{0}
10^{1}
10^{2}


Power Spectrum of Gen. spd
PSD (dB)
Freq. (Hz)
Mica 1
Rev 1
GMS 1
Kemano 1
-80
-100
-120
-140
-160
-180
-200
-220
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

Appendix E: Transfer Function Results from the 2009 Probing Tests

(Condensed from full report, Reference [4]. Please request full report for complete content)

Summary

During the summer of 2009, BPA executed 14 PDCI probing tests. These tests are meant to serve several objectives. One specific objective includes the feasibility evaluation of inter-area oscillation damping controls. Results from the tests are promising and support many of the findings in the model-based studies conducted to date. They indicate good control scaling and robustness properties when using frequency signals as an output signal.

Although results are very promising, some issues are of concern. First, use of a parallel AC flow as a feedback signal is a poor choice due to the non-minimum phase transfer-function zero detected during 2 of the 14 tests. This phenomena was observed in the 1970s during PDCI modulation control and in recent minniWECC studies. The non-minimum phase zero is also seen in some other frequency signals. Second, use of a frequency signal near the DC terminal results in large high-frequency gain. This issue may be rectified using a direct frequency sensor approach as opposed to a numerical derivative of the phase angle. This is likely further rectified if the frequency is measured near a generator at each end of the DC line. Third, relative frequency signals from the north end of the DC line to Malin were also explored with less than promising results. This signal has very large high-frequency content making it less attractive as a feedback signal. Also, its phase properties are not close enough to the idealistic 180º.

Future work should focus on continuing the tests and analysis. One item that merits investigation is to compare the transfer-function gain properties of the probing tests with the properties from the model studies recently conducted. This will provide information on the scaling properties of the PDCI modulation control. That is, the expected improved damping per size of modulation control. Also, wider PMU coverage is needed. Specifically, allowing evaluation of relative north to south signals for many probing cases. Lastly, methods and sensors to limit the high-frequency gain of a frequency measurement are needed.

Selected Figures

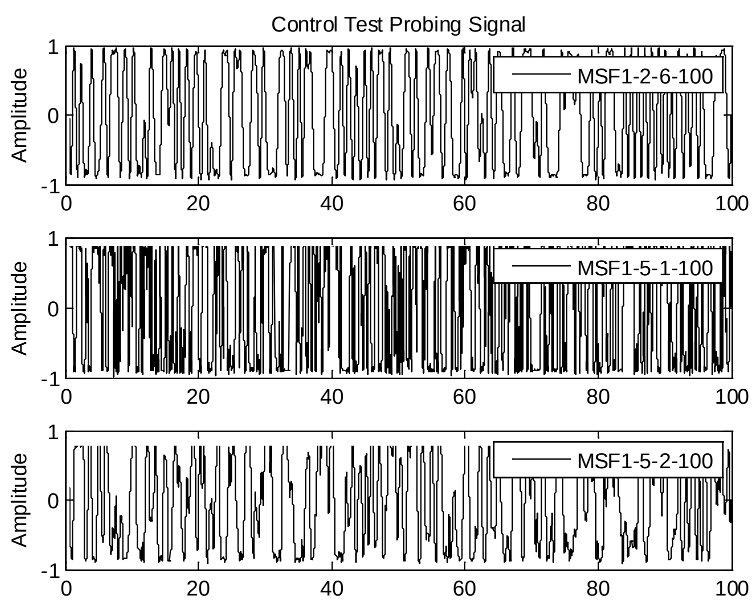


Figure E-2: Three probing signals.

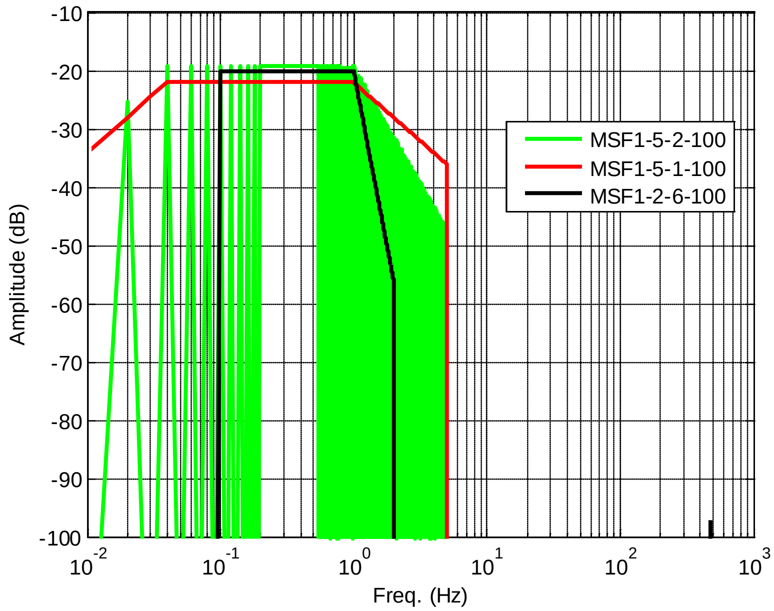


Figure E-3: Frequency content of probing signals, semi-log plot.

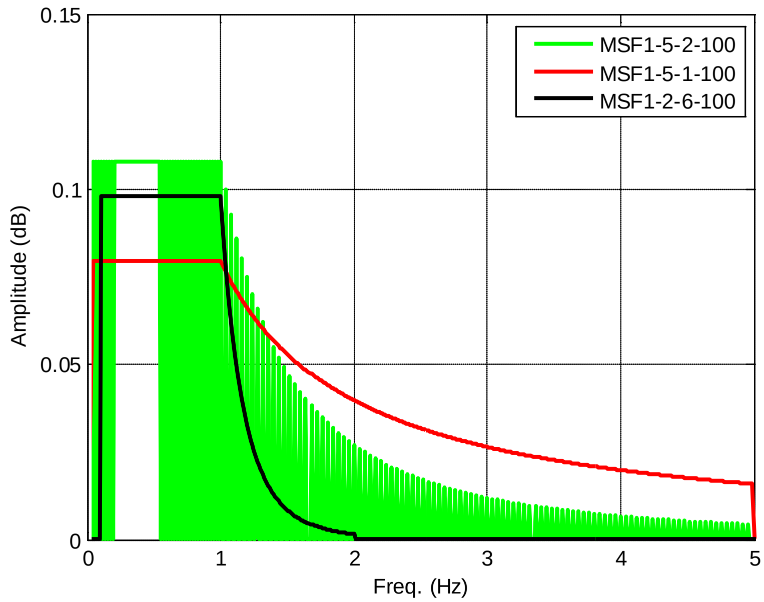


Figure E-4: Frequency content of probing signals, linear plot.

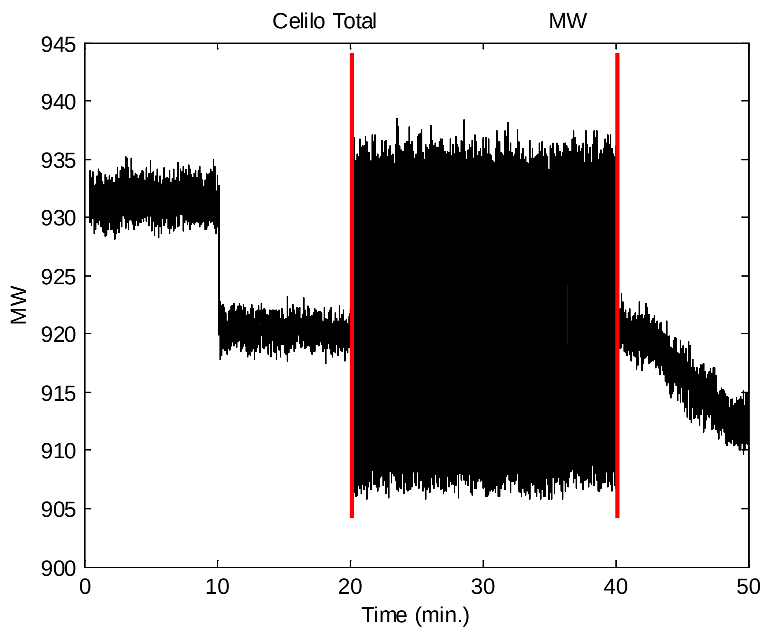


Figure E-5: Typical probing signal measured at Celilo AC MW.

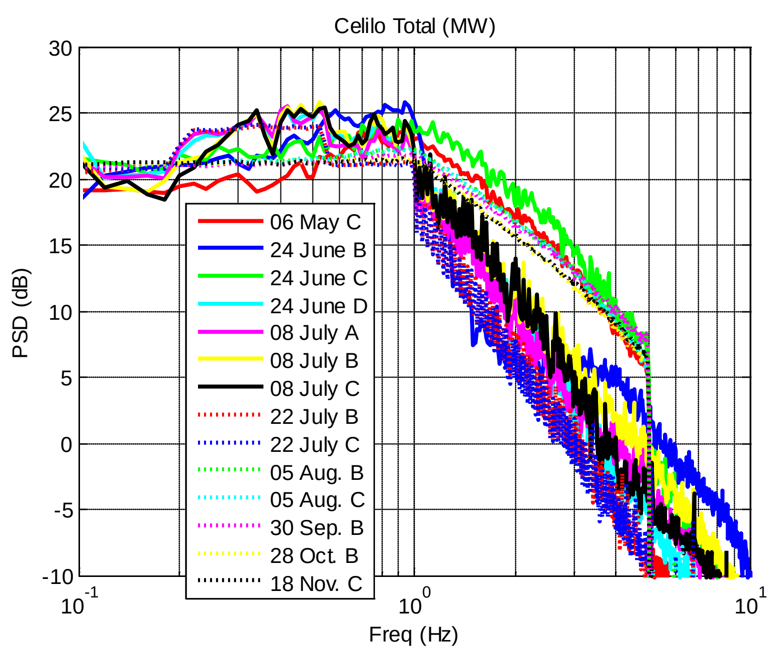


Figure E-6: Frequency content of probing signals at Celilo AC MW.

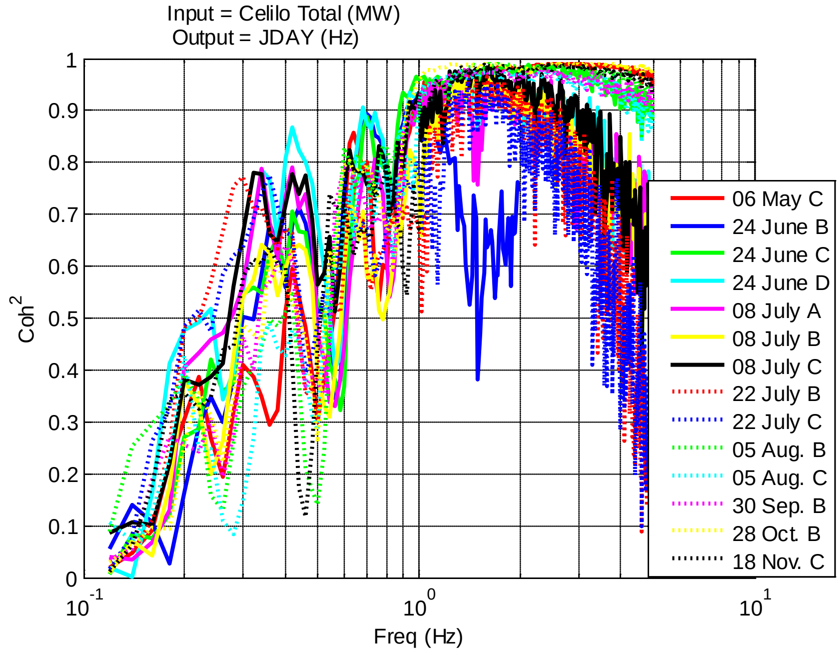


Figure E-6 [7]: Coherency at JDAY frequency

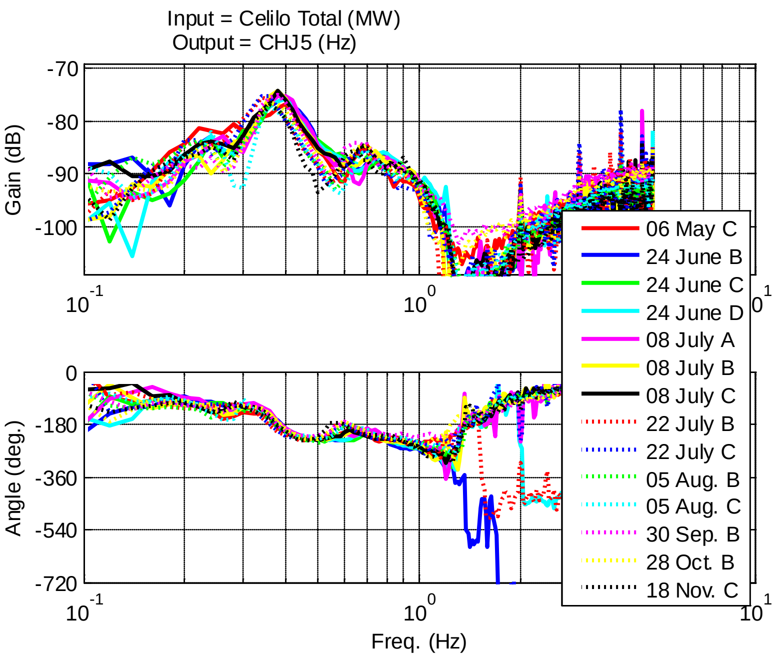


Figure E-8 [8]: Transfer function from Celilo MW to CHJ5 Hz; plot 1.

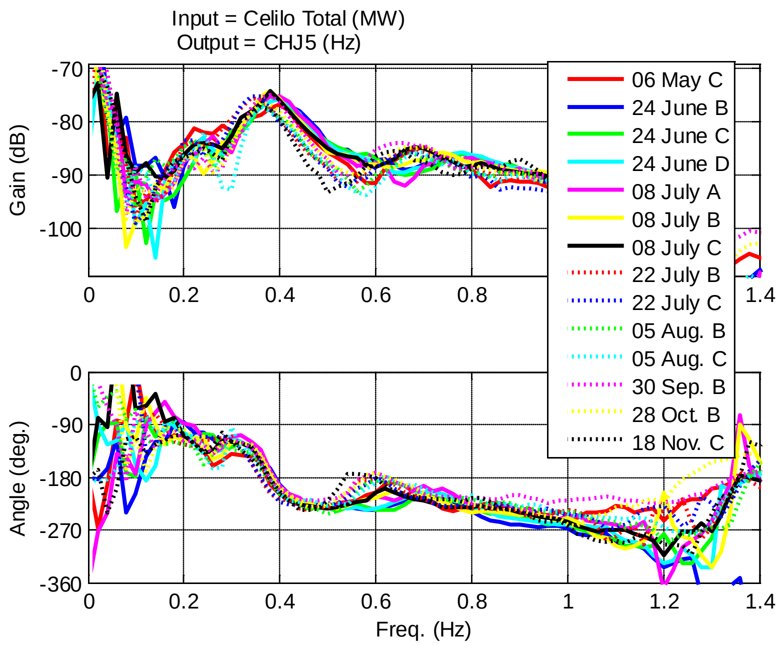


Figure E-9 [9]: Transfer function from Celilo MW to CHJ5 Hz; plot 2.

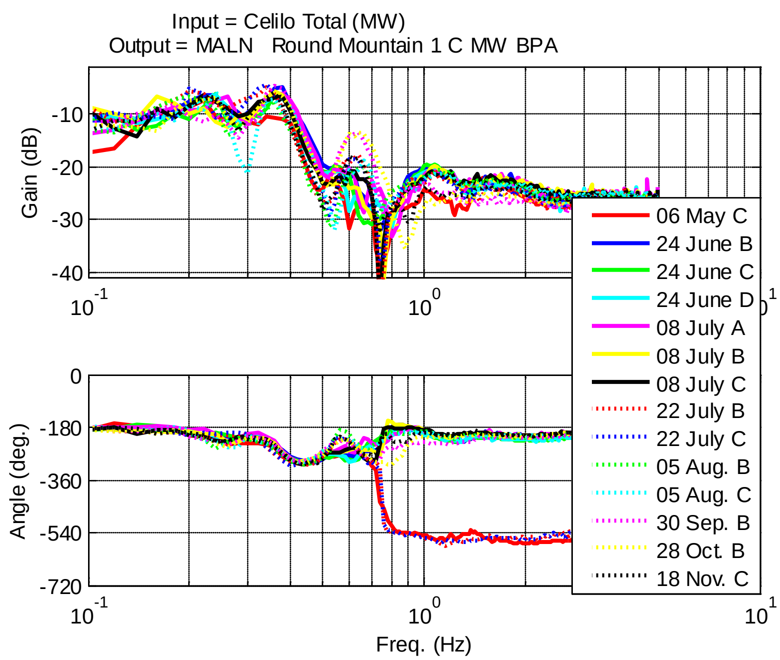


Figure E-10 [10]: Transfer function from Celilo MW to Malin-Rnd. M. MW; plot 1.

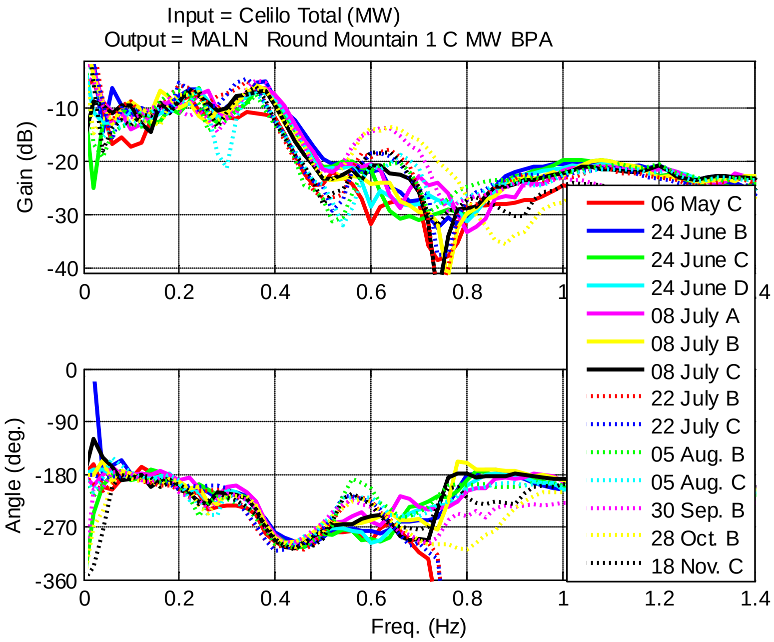


Figure E-11[11]: Transfer function from Celilo MW to Malin-Rnd. M. MW; plot 2.