Synchrophasor Implementations

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Topics of Discussion

- Description of Manitoba WAMS
- Introduction to Birchtree SVC Project
- Commissioning Results
- Lessons Learned and Future Road Map

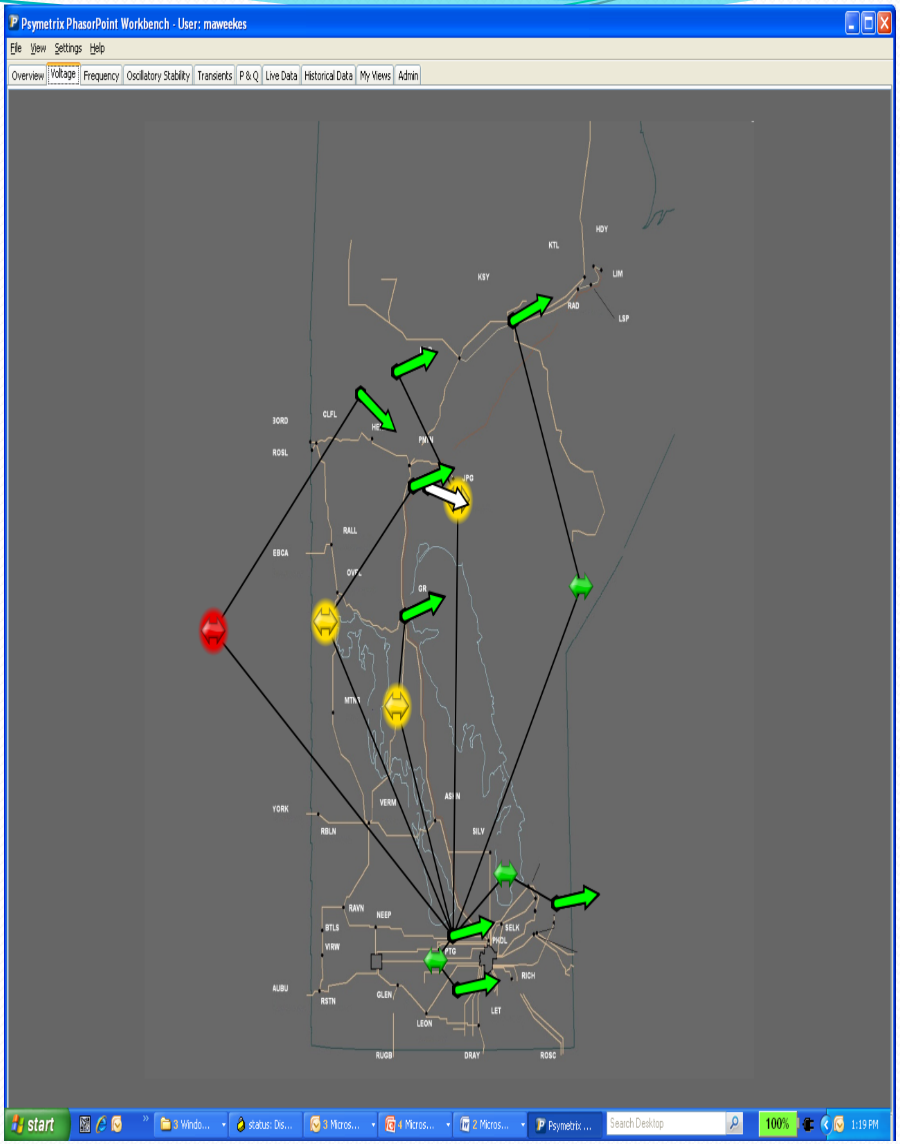
Organization	PDC Contracted	PDC Connected	PMU Confirmed Sites	PMU Connected Devices
Ameren	1	1	21	6
American Trans Co.	N/A	1	N/A	5
Duke Energy	1	1	16	4
Great Rivers Energy	1	1	8	2
Hoosier Energy	1	1	7	9
Indianapolis P&L	1	1	6	7
International Trans Co.	1	1	12	5
Manitoba Hydro	***2***	***1***	***22***	***6***
MidAmerican Energy	1	0	12	0
Minnesota Power	1	1	4	1
Montana Dakota Utilities	0	0	5	0
Northern Indiana Public Service	3	1	8	2
Ottertail Power	2	1	6	3
Vectren	1	0	3	0
WAPA	0	0	4	0
XCEL Energy	0	0	11	0
TOTAL	**16**	**11**	**145**	**50**

Need for wide Area Measurements

- Typical PSS tuning monitors local signals
- Problems can arise with fighting between controllers
- Advantage of monitoring a wide area can be addressed with synchrophasors

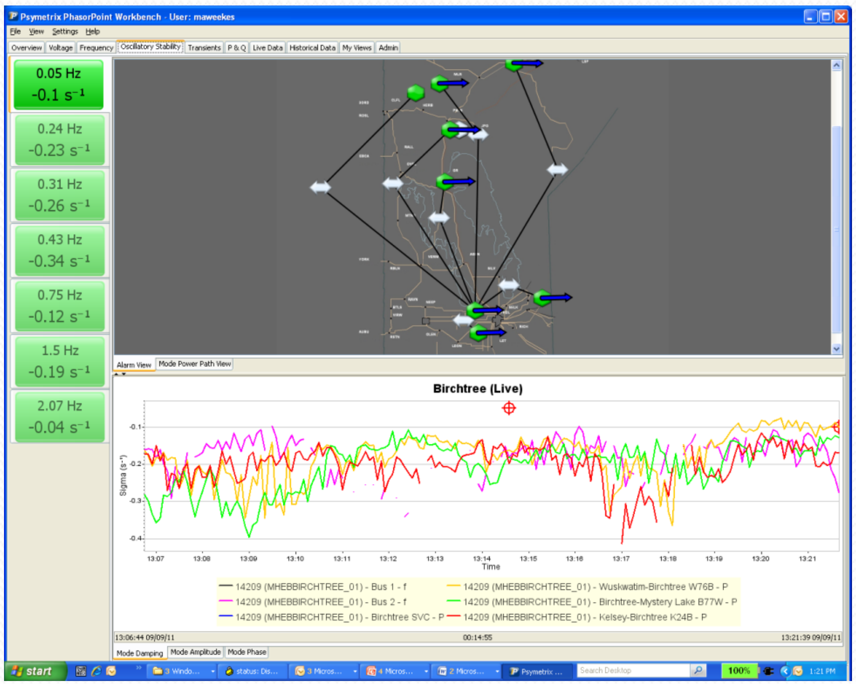
WAMS

- Phasorpoint tool used primarily to see the modes on the system



Phasor Point

Mode Charting



Mode Power Path

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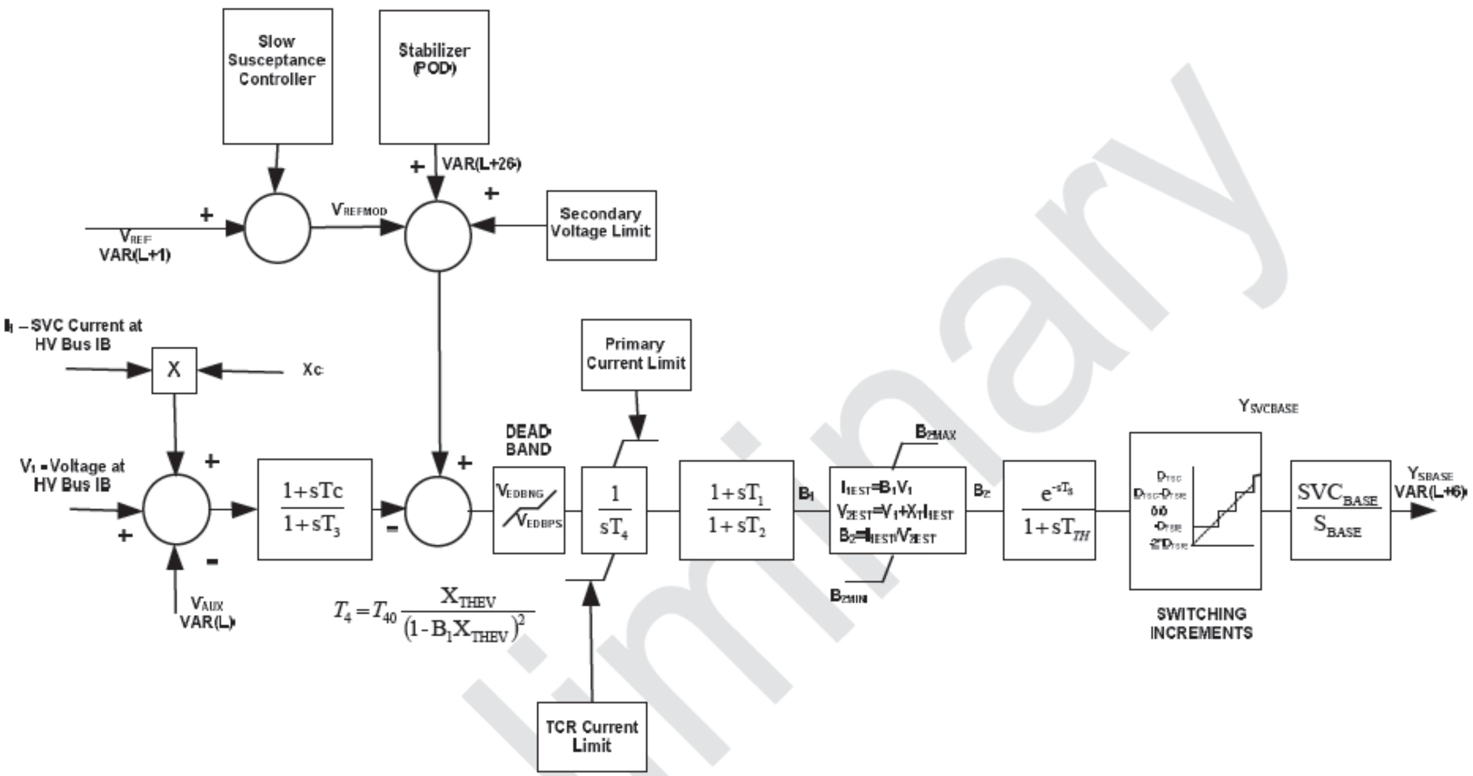
Sites Chosen

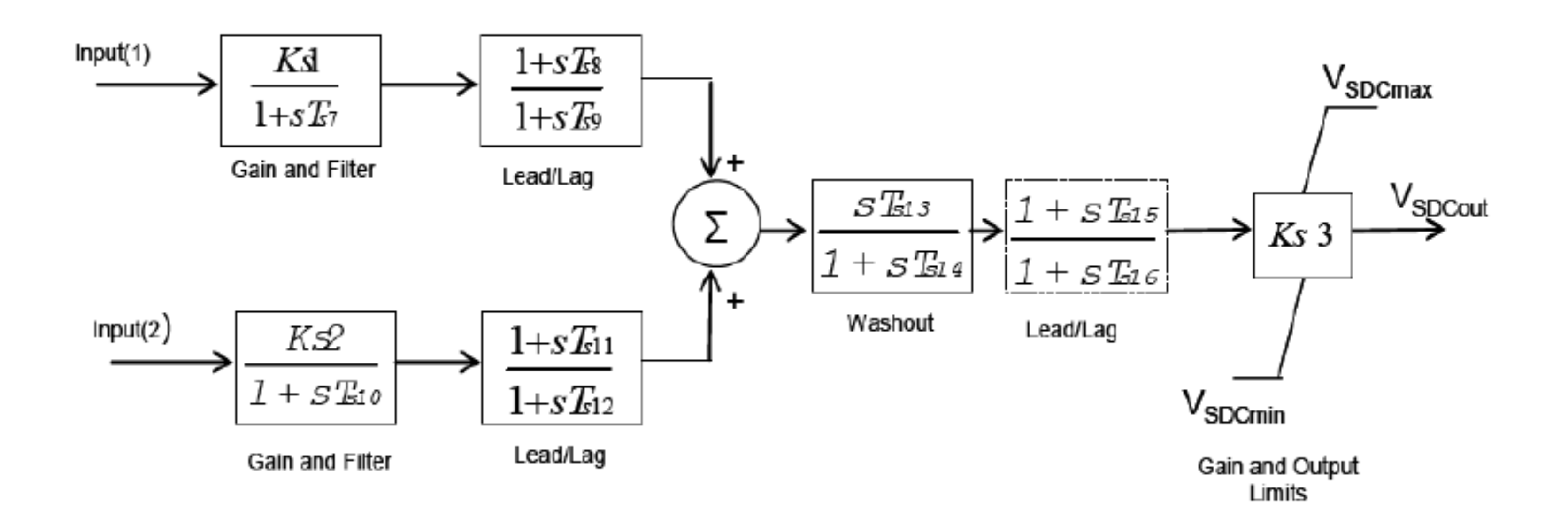
- known inter-area modes in our Northern ac.
- sensitivities of modes to various power flow conditions
- Upcoming projects in Northern ac
- Future sites will increase from 6 to 30 PMU locations
- Using existing TFR devices

Birchtree SVC Controller



BTSVC – Voltage Controller

Power Oscillation Damper (POD)



Commissioning Objectives

- **Transfer function verification** of the SVC voltage and POD controllers
- **Tuning the POD** to provide good damping performance for the modes within the frequency range of interest 0.5 to 0.9 Hz
- **Minimize the interaction** between the Ponton SVC and Birchtree SVC
- **Optimize the Birchtree SVC POD and Ponton SVC SDC settings** for most northern ac system generation patterns and operating conditions

Risks and Mitigations

- Output is correctly controlled from input, as expected
- Check the degree of movement in the rest of the system in response to a step change
- Confirm consistency with time-domain measurements
- Decide criteria for "unacceptable" oscillations.
- Switch controllers off one-by-one or plant-by-plant, separated by a period of time.

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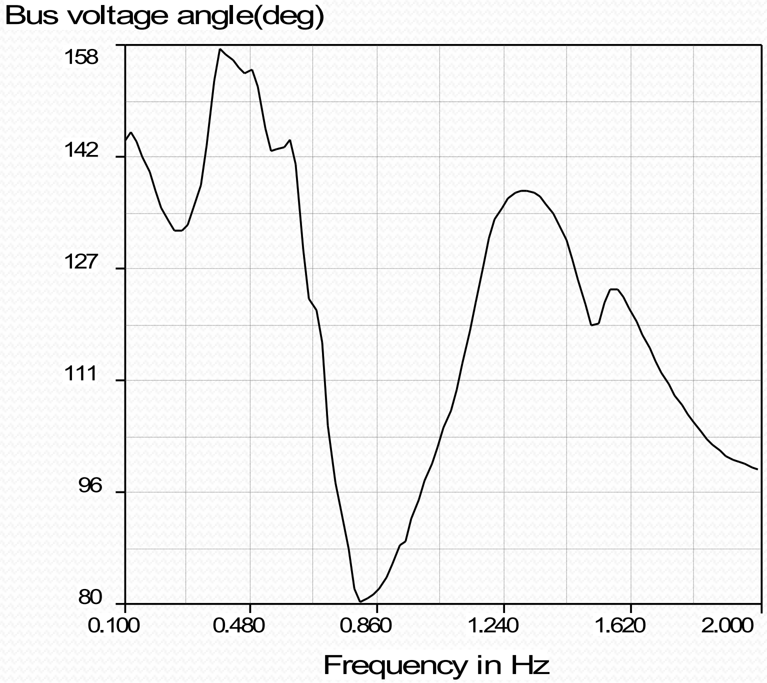
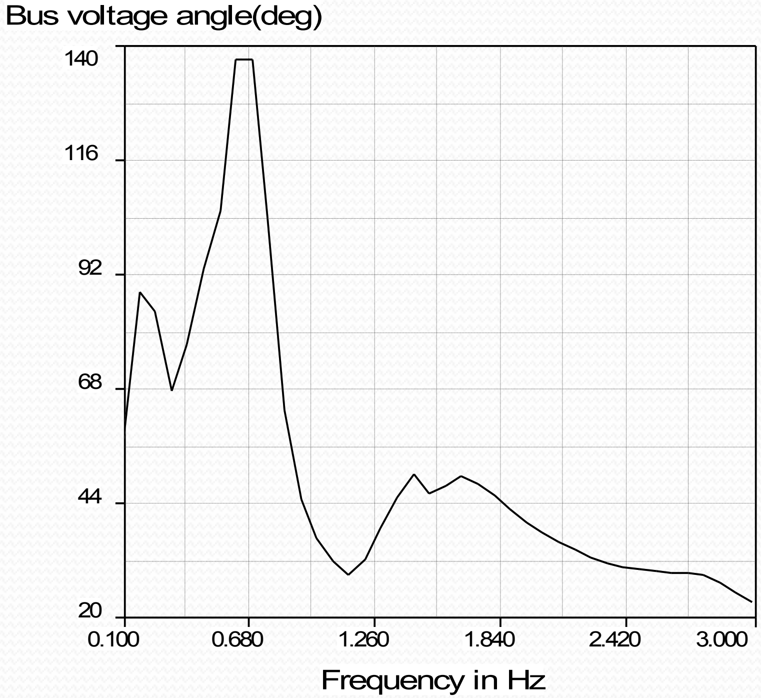
System Frequency Response

- Model verification (frequency response) of SVC POD design



Phase



Magnitude

The frequency response characteristic (magnitude and phase) of the transfer function between Birchtree SVC input and voltage angle (frequency

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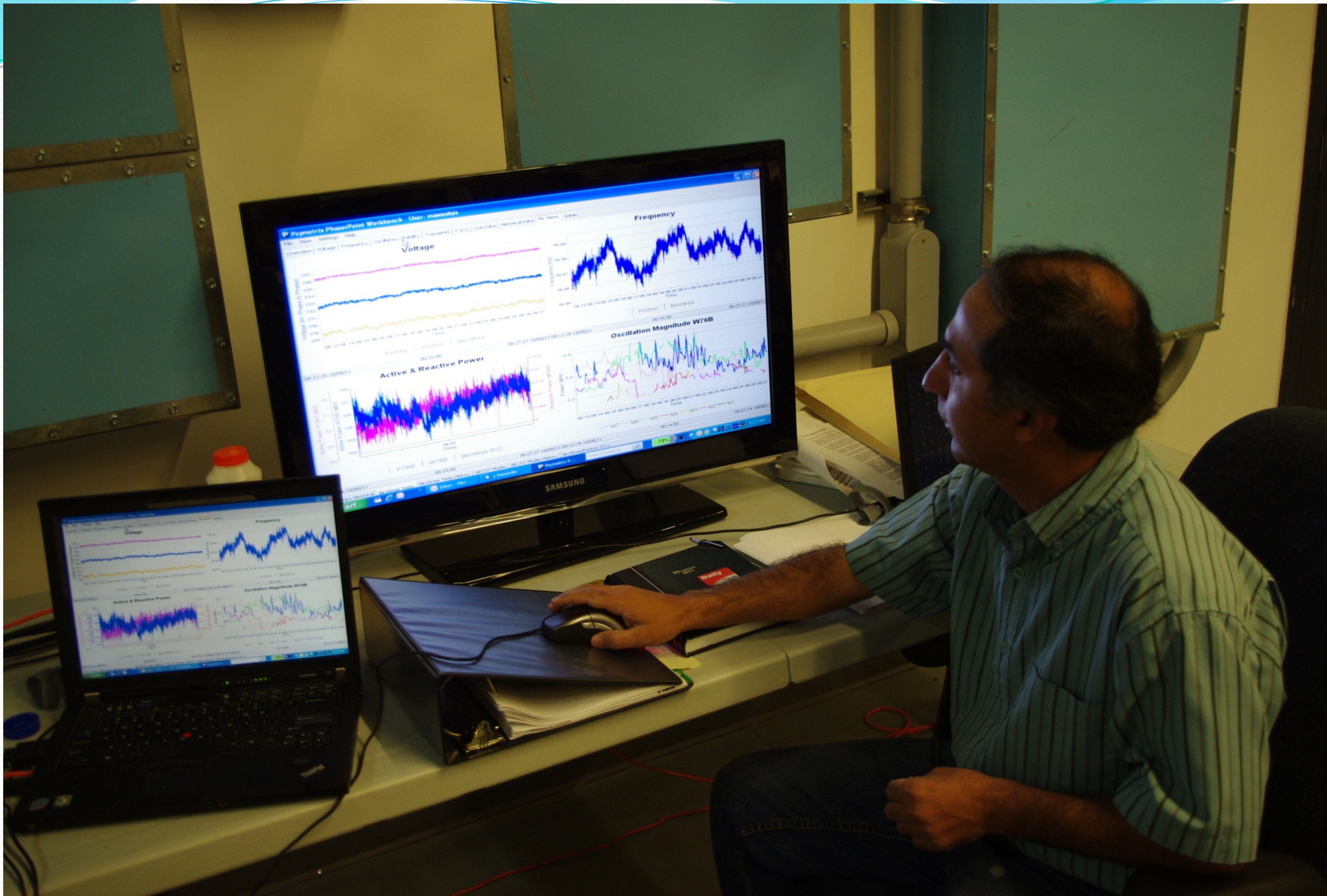
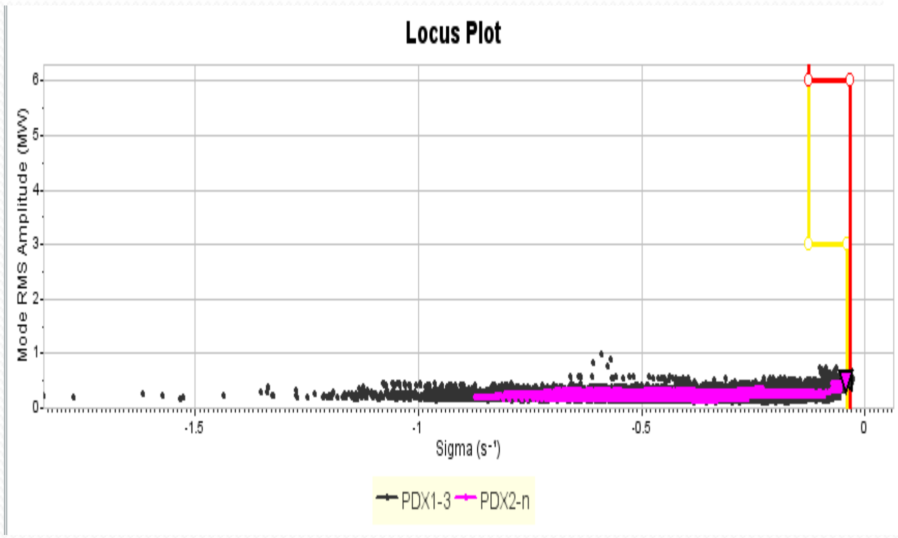

Psymetrix PhaserPoint Workbench
Voltage
Frequency
Active & Reactive Power
Oscillation Magnitude W76B
SAMSUNG

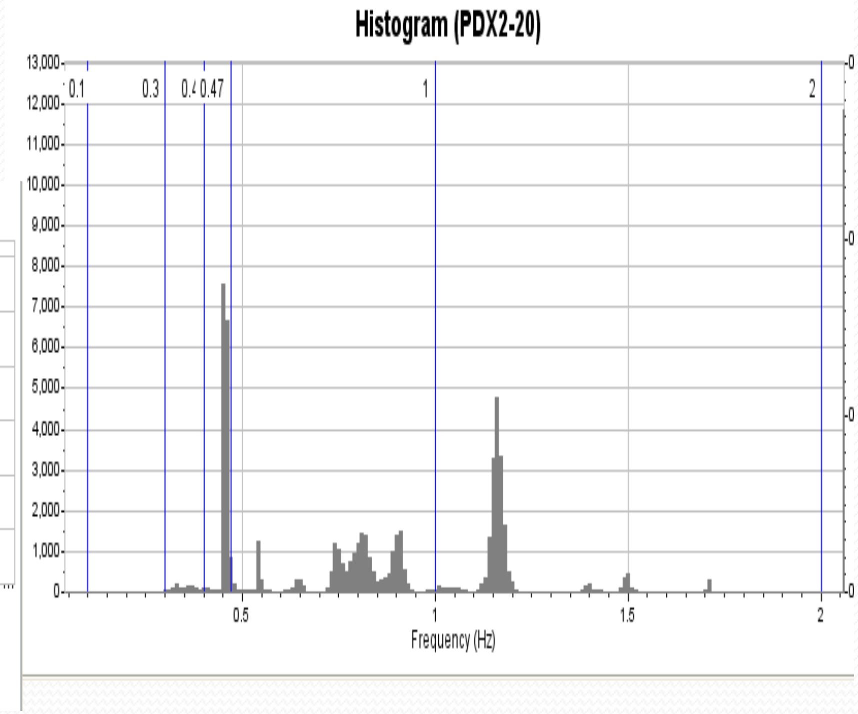
Mode Trending

Root locus of mode

- Trending and verification of damping controller performance



Observability of the mode over time



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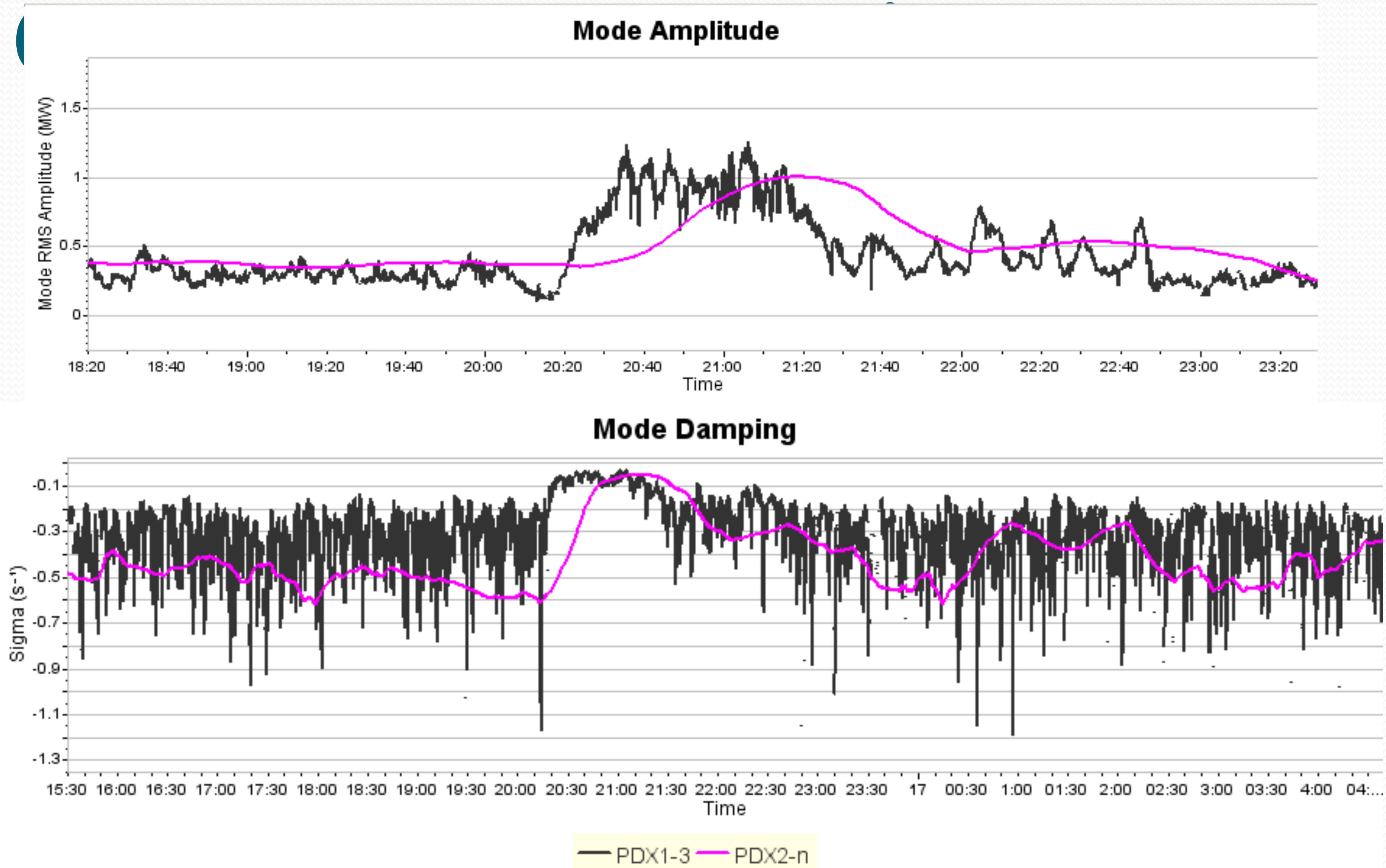
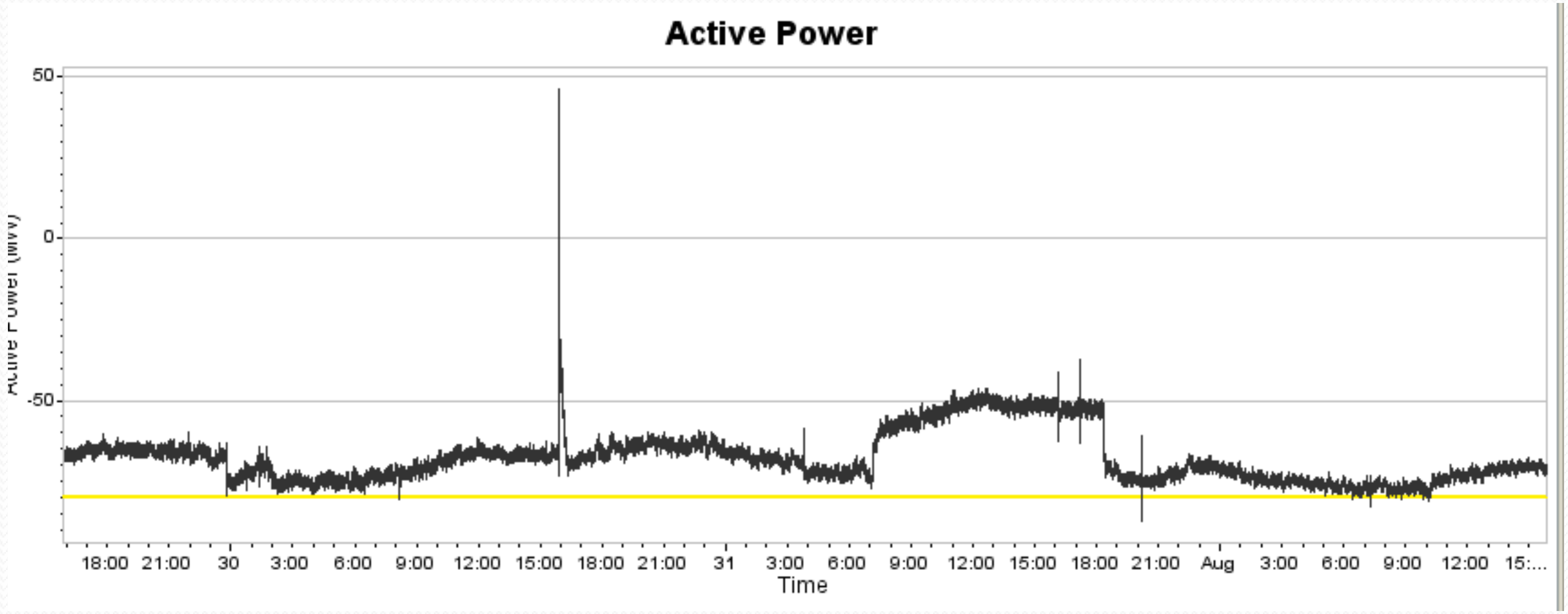
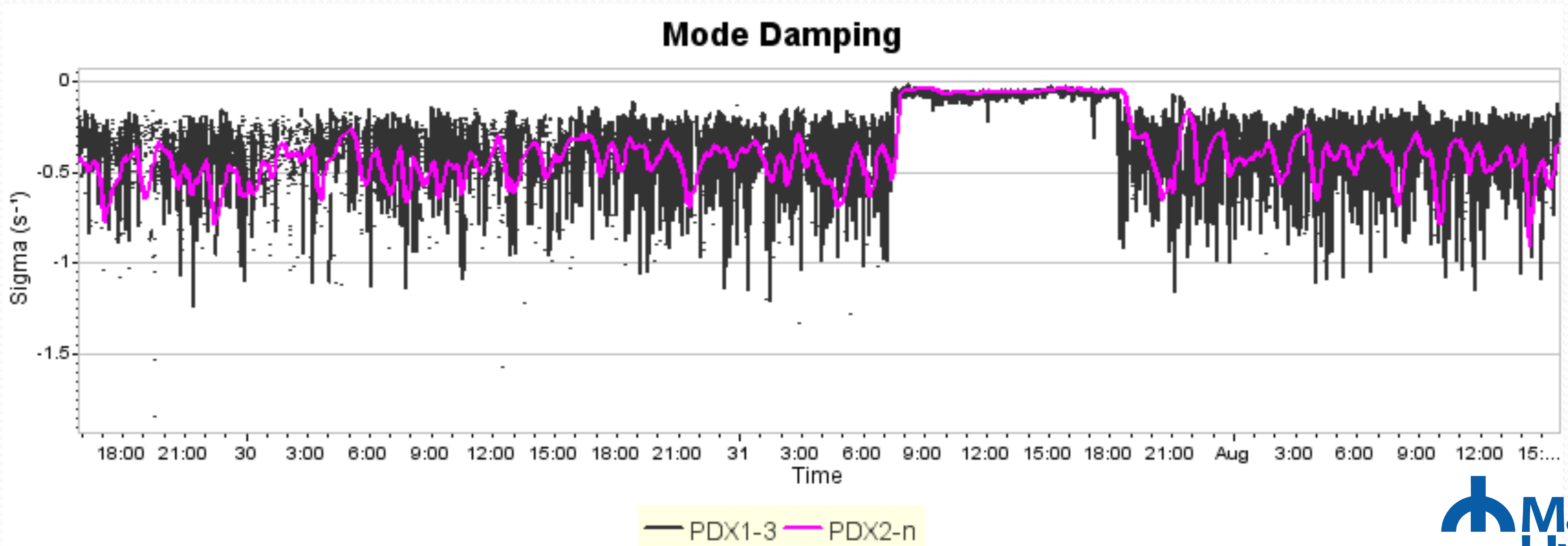

Mode Amplitude
Mode RMS Amplitude (MW)
1.5
1
0.5
0
18:20 18:40 19:00 19:20 19:40 20:00 20:20 20:40 21:00 21:20 21:40 22:00 22:20 22:40 23:00 23:20
Time
Mode Damping
Sigma (s⁻¹)
-0.1
-0.3
-0.5
-0.7
-0.9
-1.1
-1.3
15:30 16:00 16:30 17:00 17:30 18:00 18:30 19:00 19:30 20:00 20:30 21:00 21:30 22:00 22:30 23:00 23:30 17 00:30 1:00 01:30 2:00 02:30 3:00 03:30 4:00 04:...
Time
PDX1-3
PDX2-n

Unexpected Results Captured

- Mode increases with lower power
- Initial response of POD with other settings
- Clock error

Cont….System Baselining





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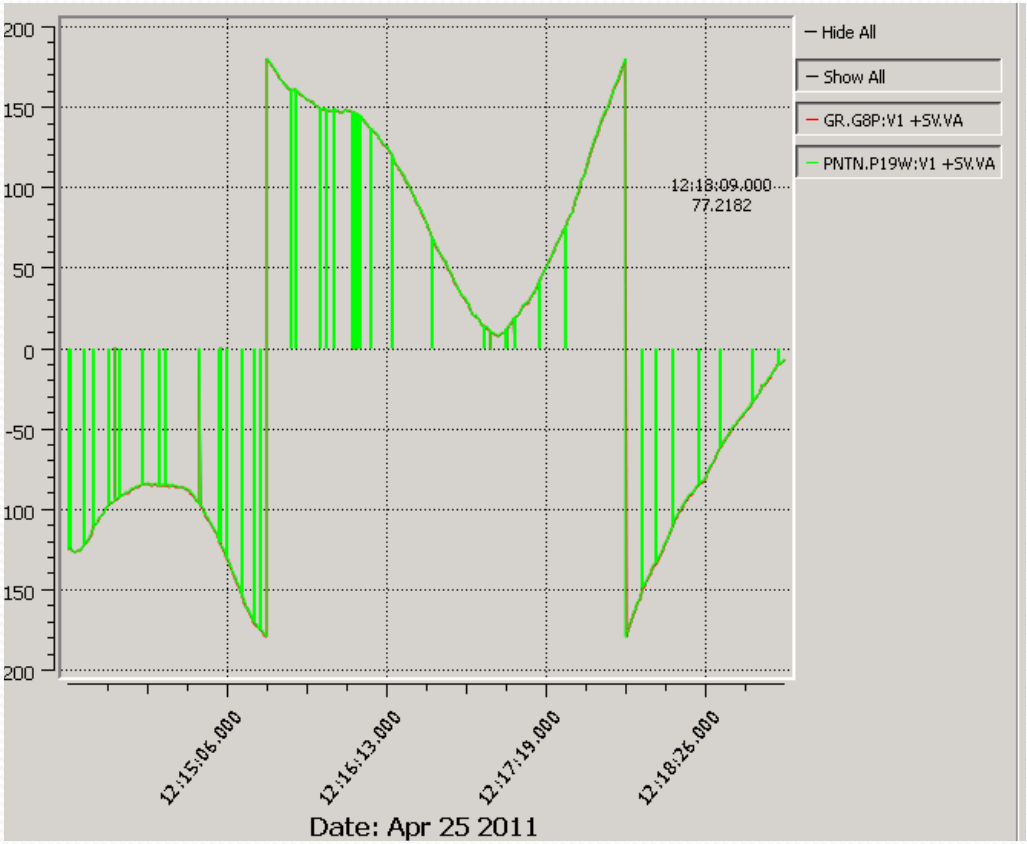
Cont…..System Baselining

April 25, 2011 – 11:14:00 to 11:19:00 – Approx. 2 hours before event

Clock Errors



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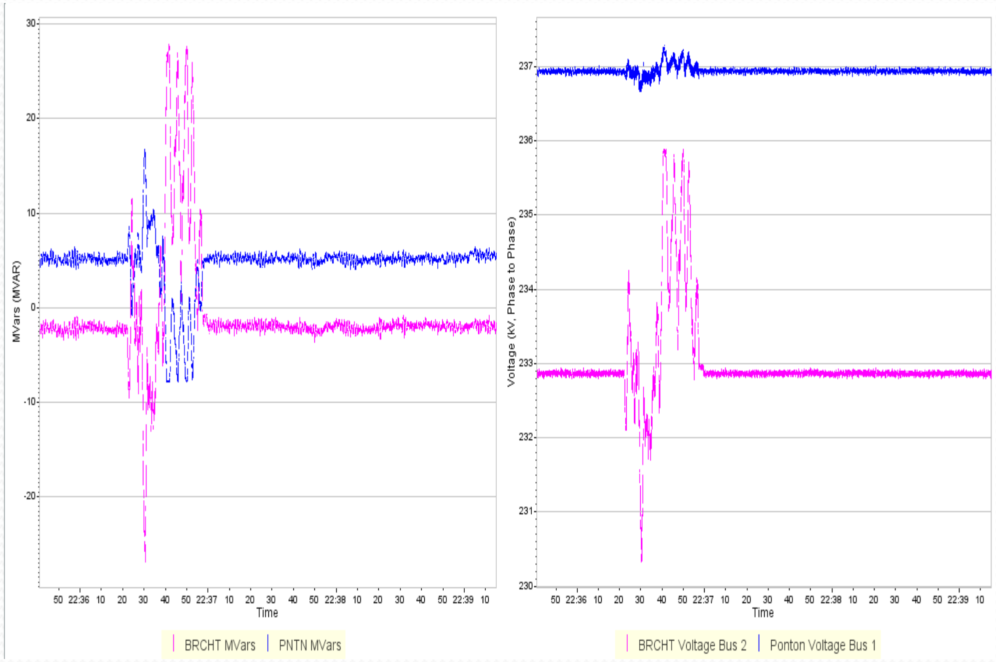
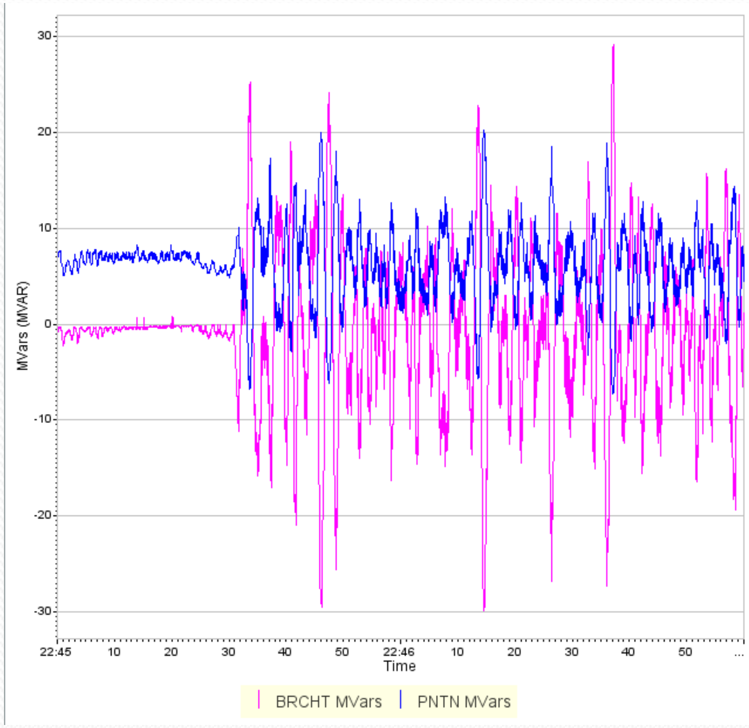
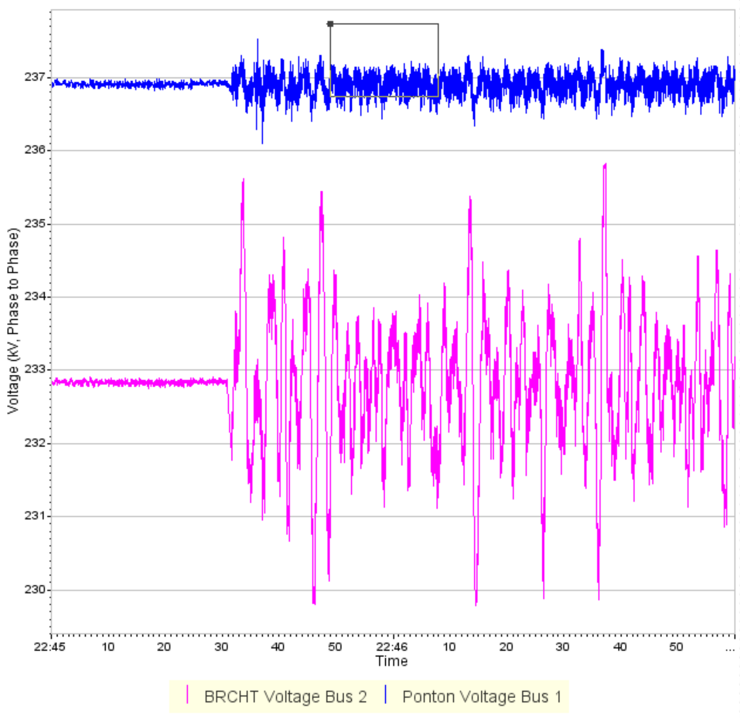
POD First Settings

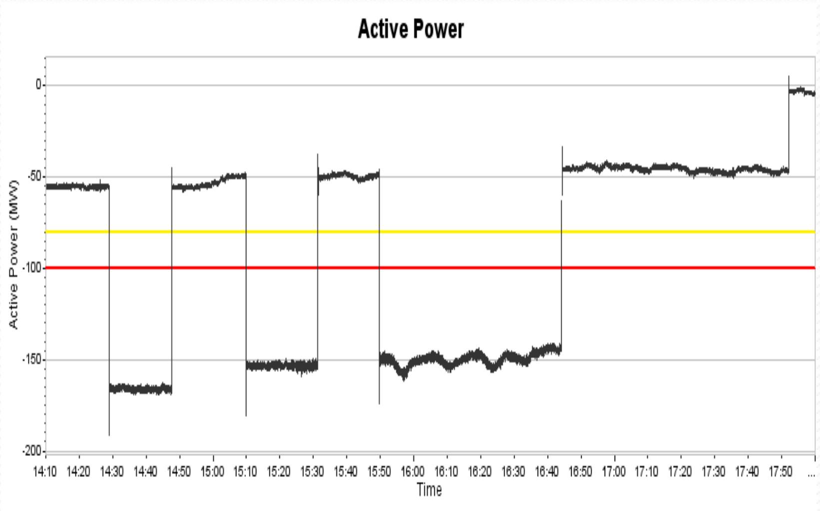


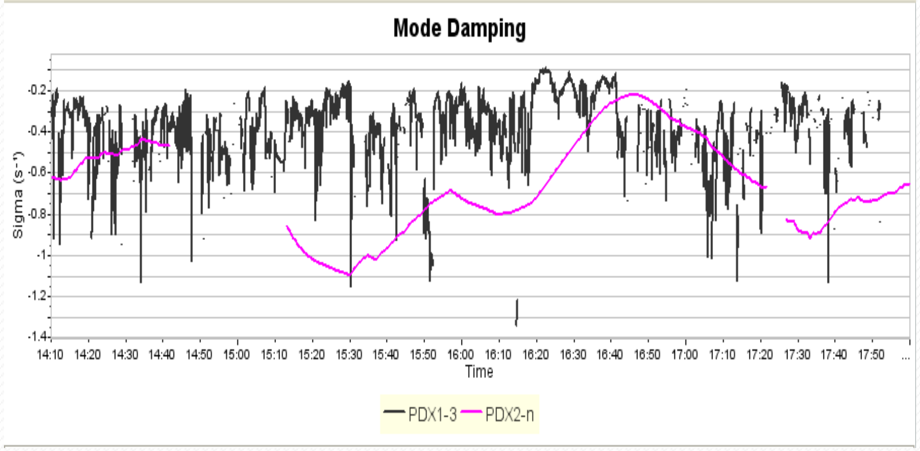
POD Second Settings

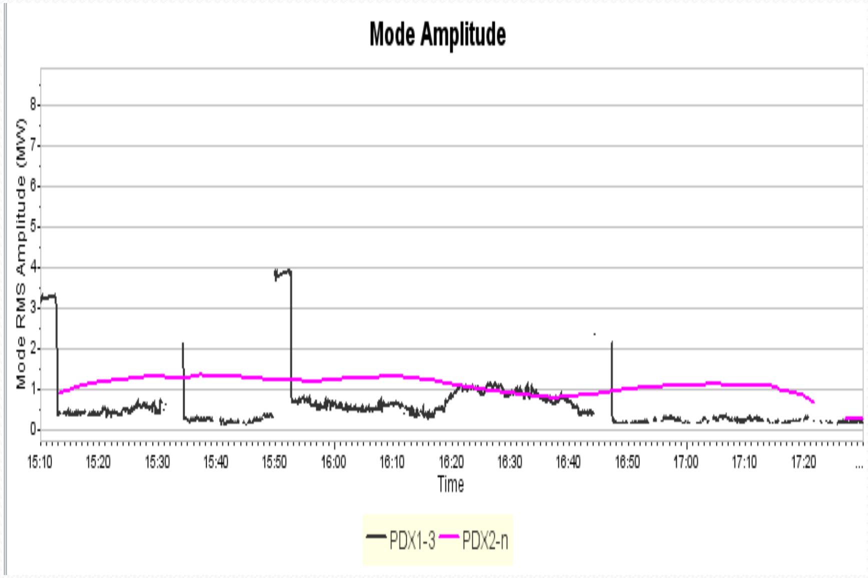




Open/Close line test







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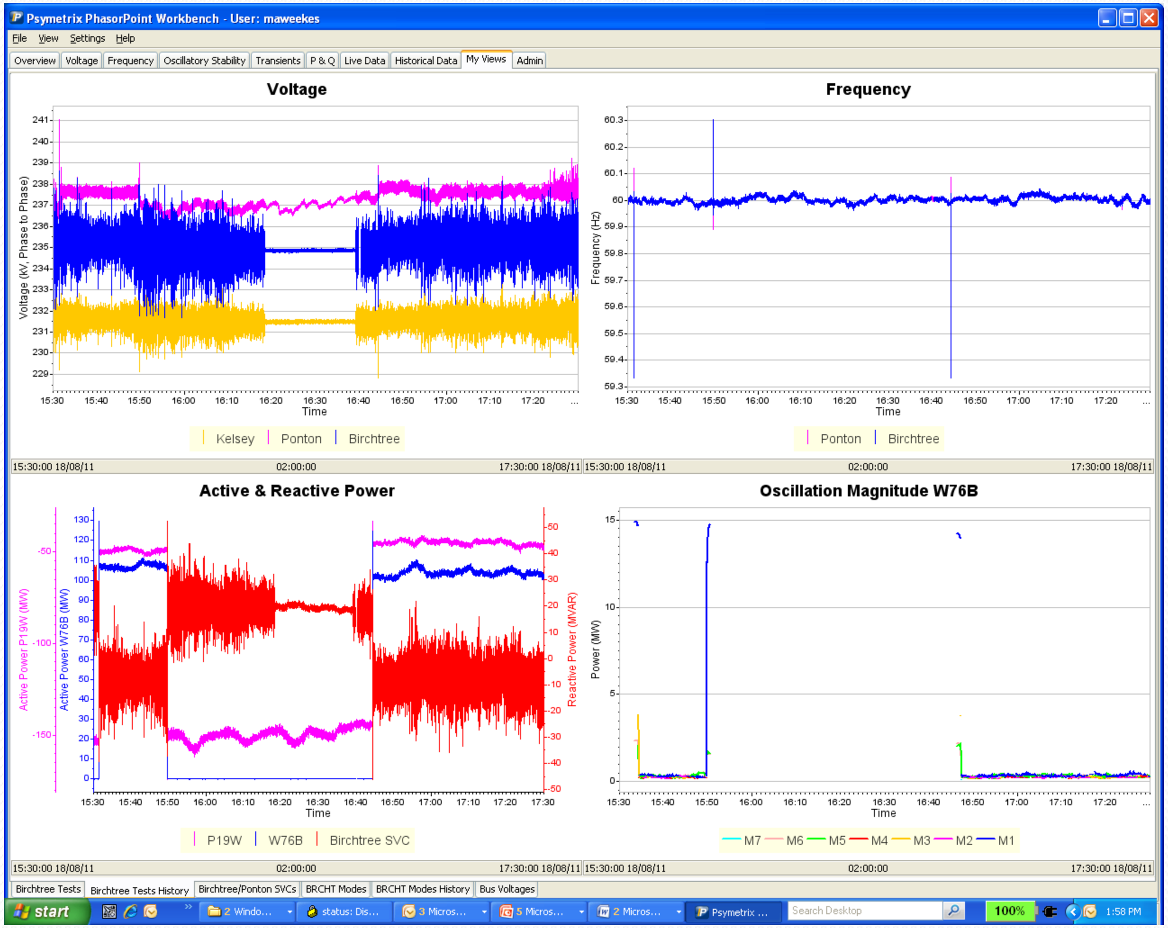
Open/Close Line Test



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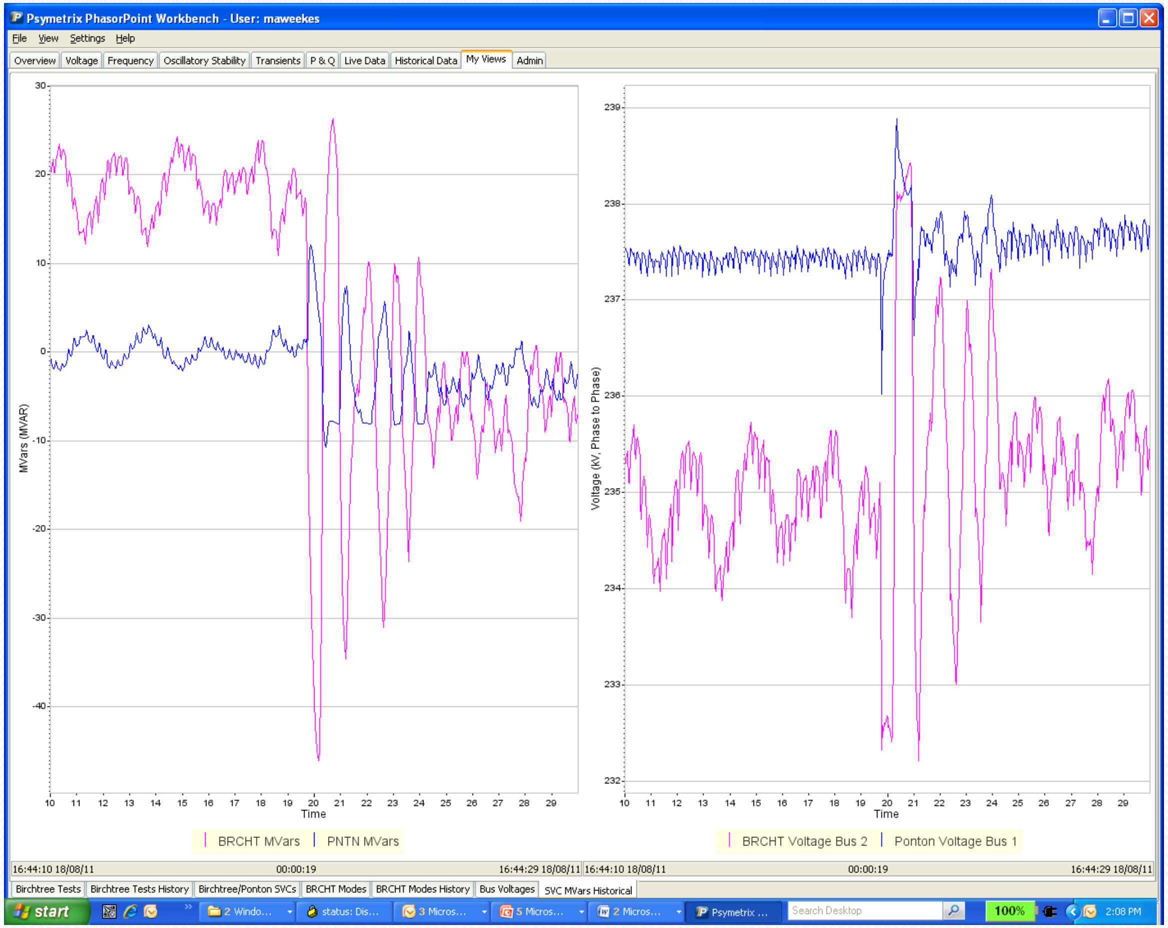
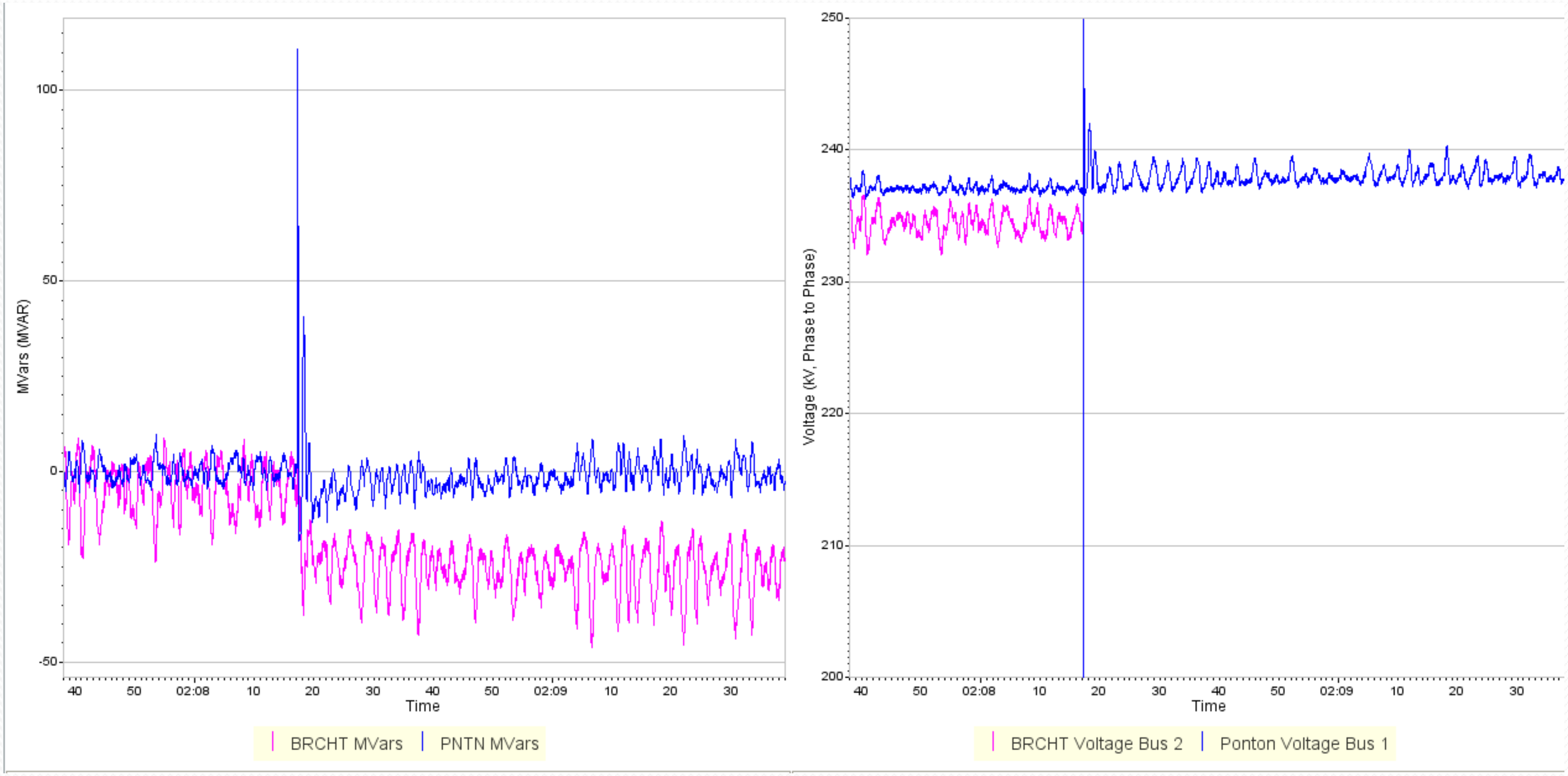
Open/Close Line Test



SLG Fault



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Lessons Learned

- **Channel Selection** (problem with power calculation if switching occurs)
- Importance of doing a **frequency response** intially to confirm models
- **Real time feedback** to see if and how multiple power system controllers may fight with each other.
- **Clock errors can be significant** and need mitigation measures both in real time and regular maintenance
- **Integration of analog signals** in the future to PMU data (also significance of proper channel selection and sites)
- **Unusual Modes were identified** as consistently observed on the system but low in magnitude

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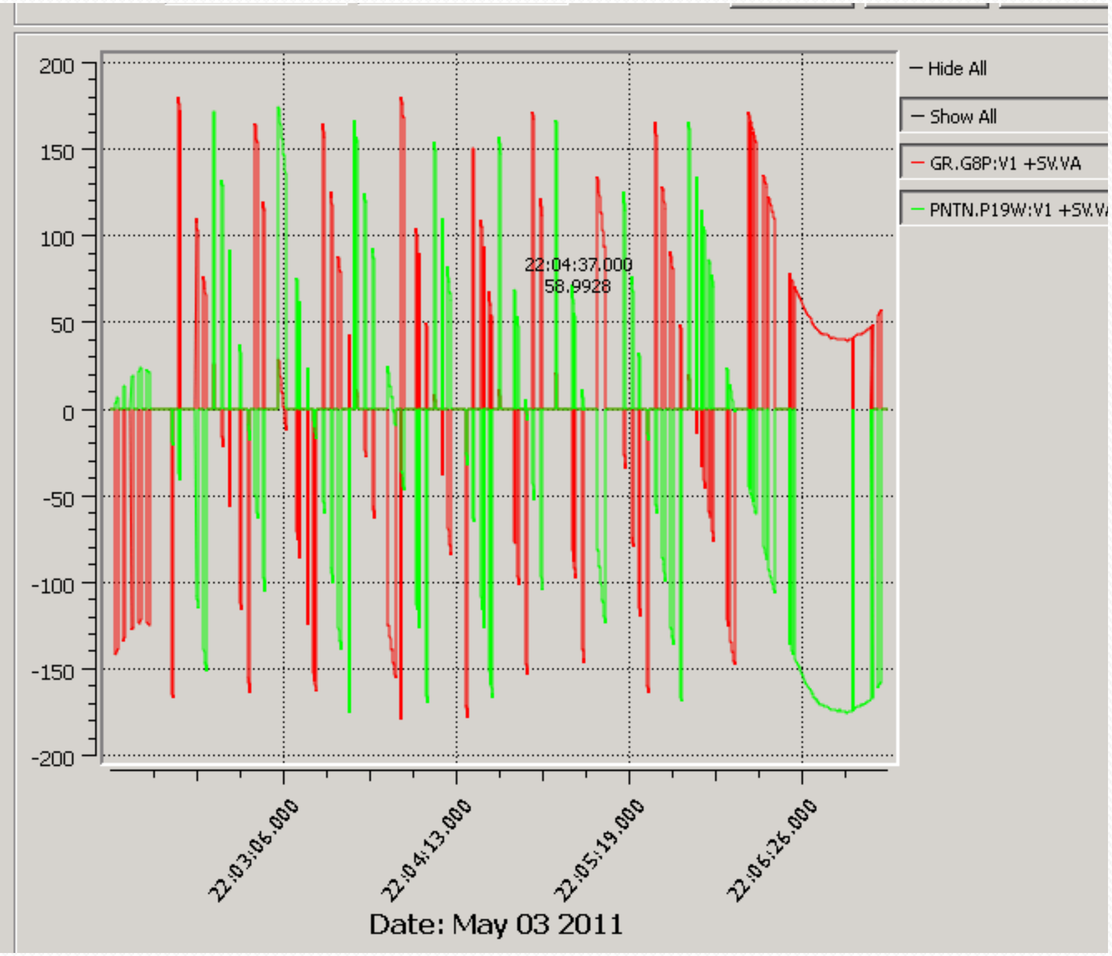
Future Road Map

- Model verification (complement NERC testing)
- Investigations to increase transfer limits through compound event analysis
- Investigation of islanding and coherency of generators
- Integration with real time tools that use power models (benchmarking)
- EMS state estimator improvement especially after the full complement of PMUs are on the system

Questions ??

Cont…..System Baselining

May 3, 2011



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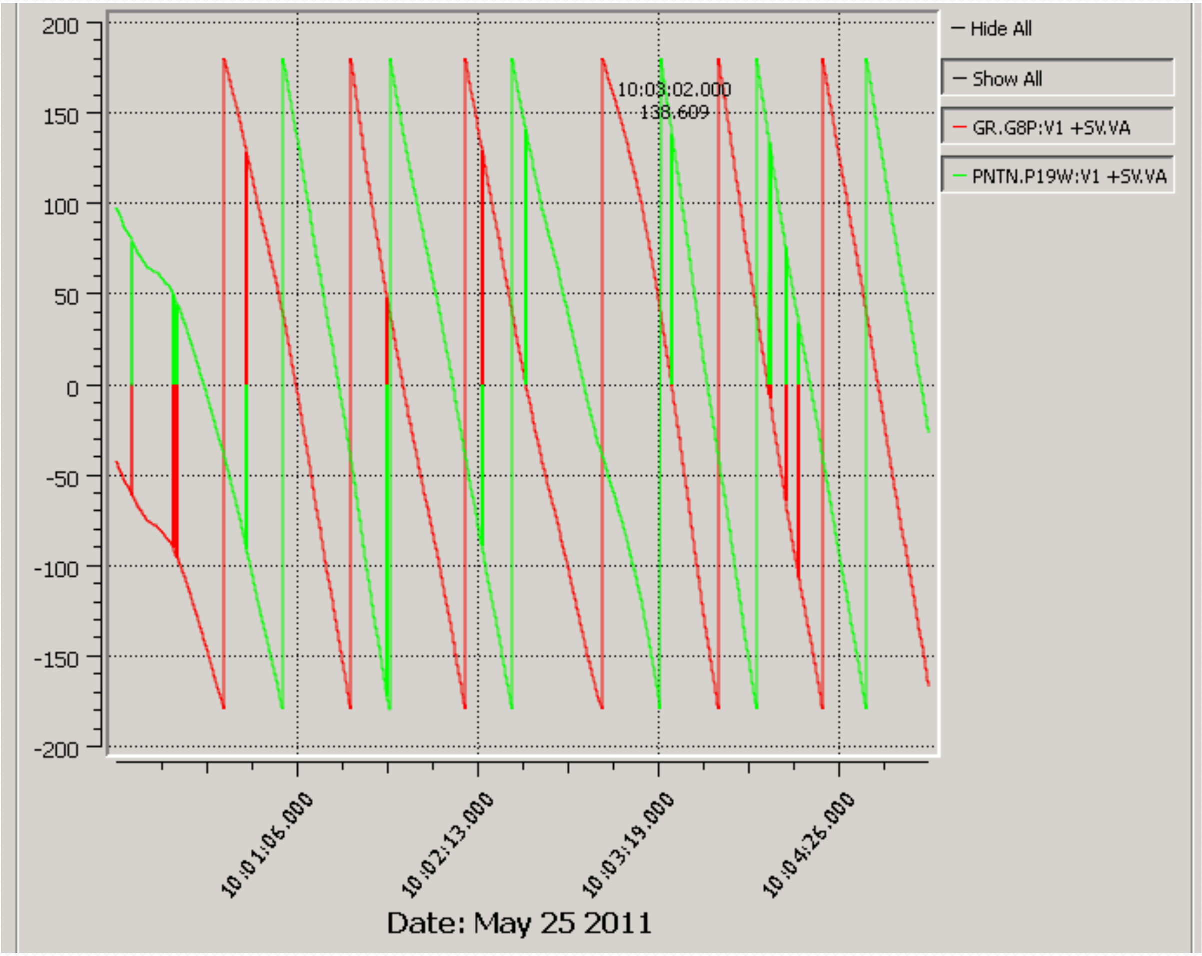
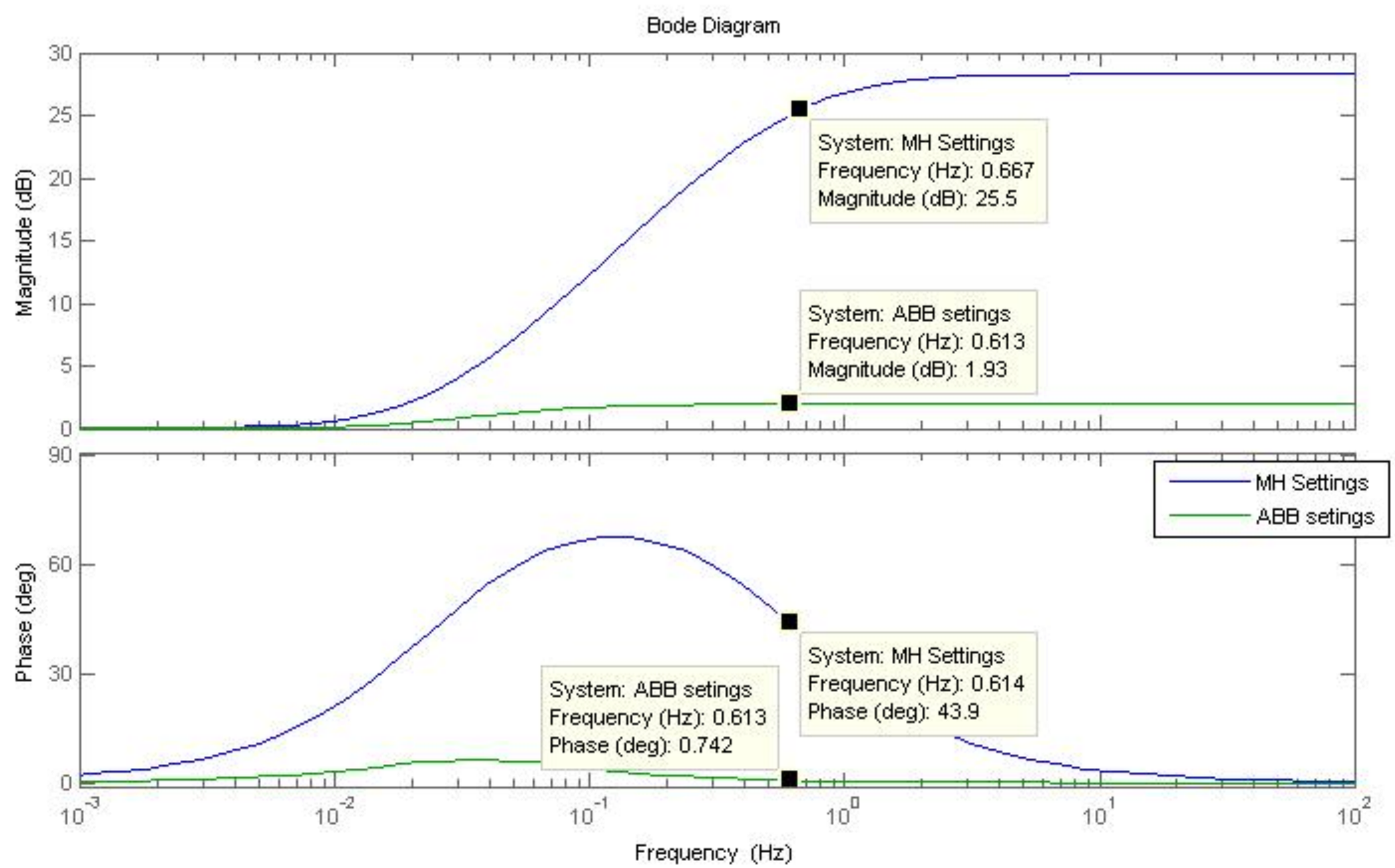
Cont…..System Baselining

May 25, 2011

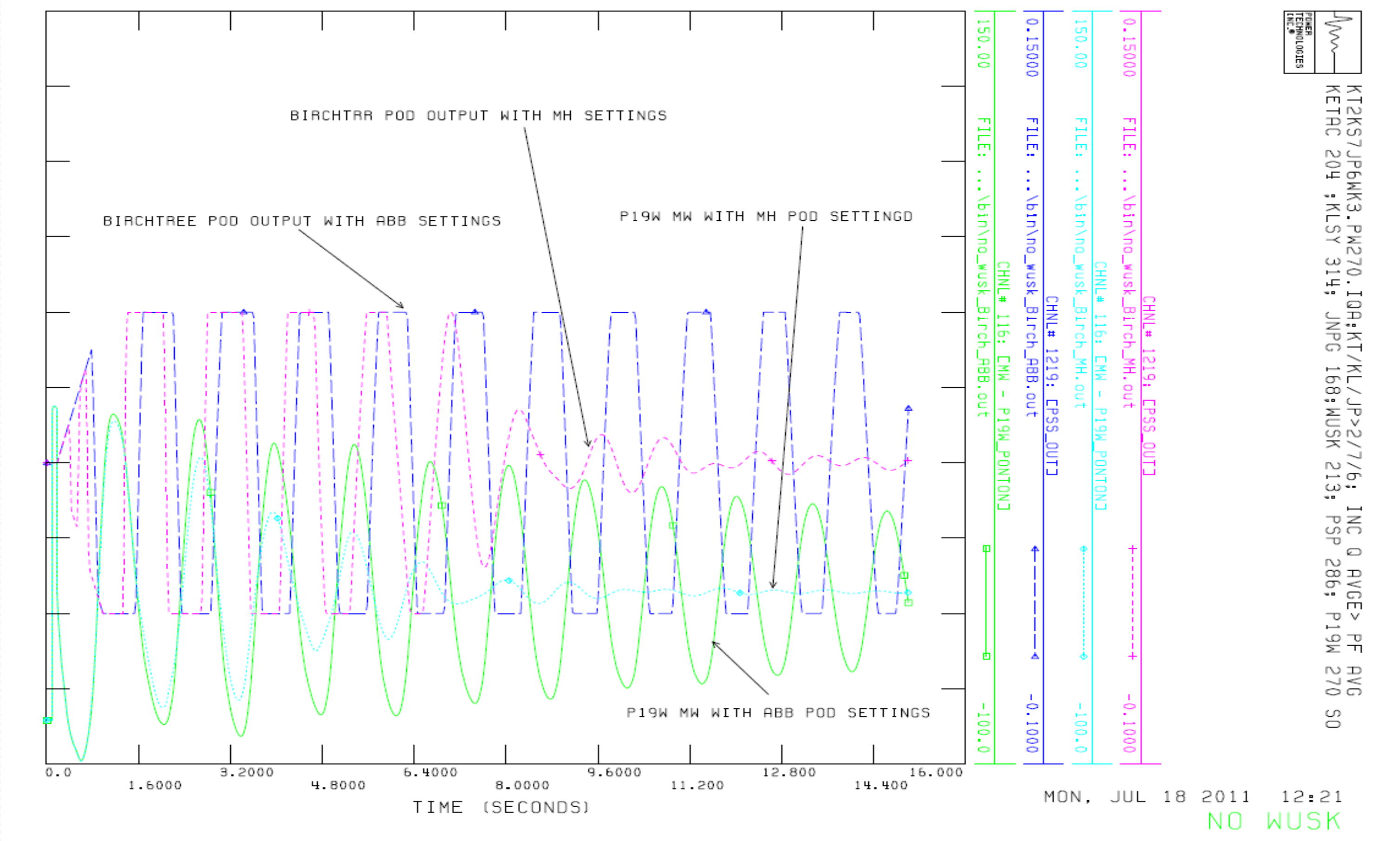


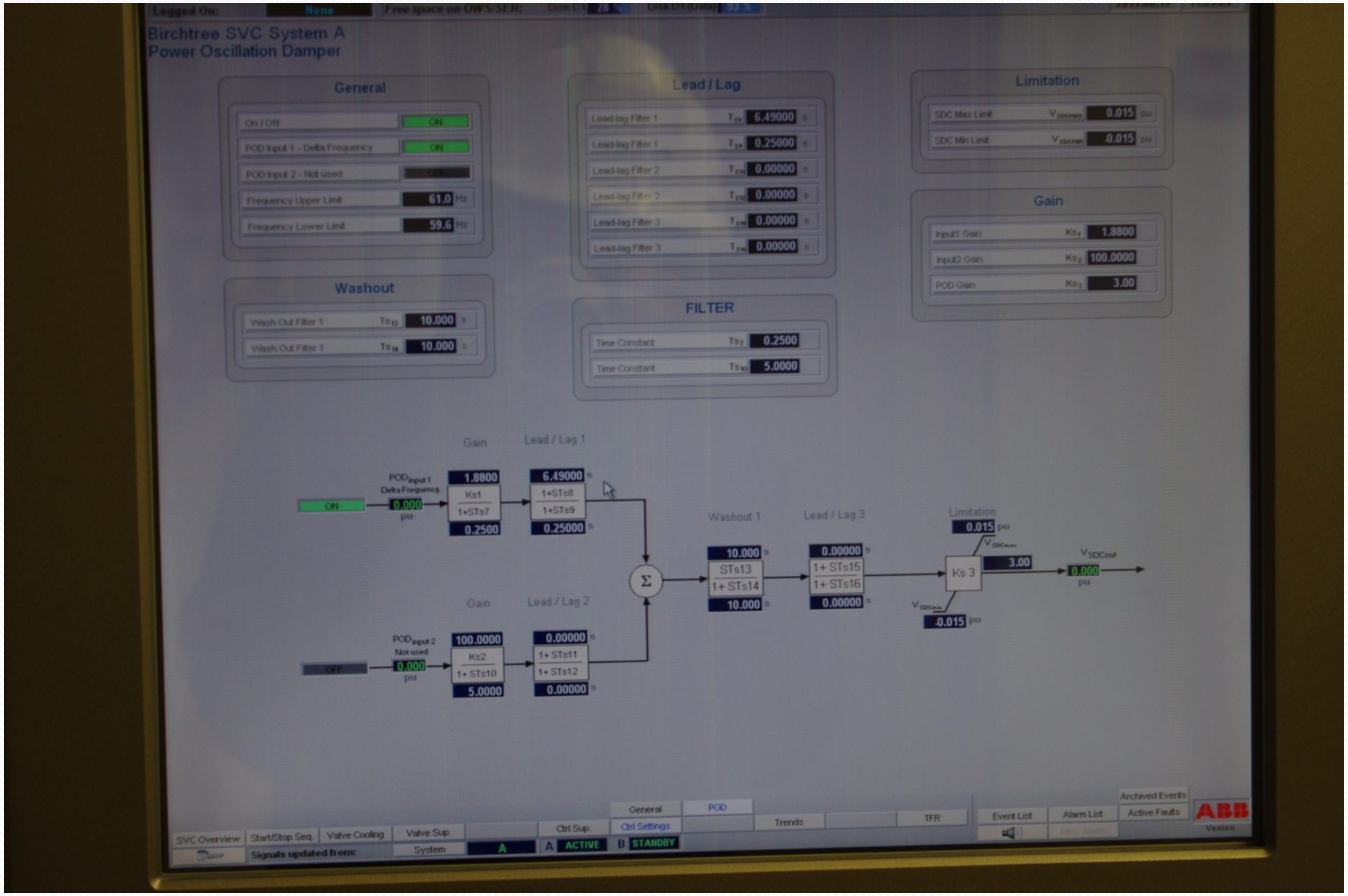
Bode Plot (Lead /lag Block)



Simulation Results

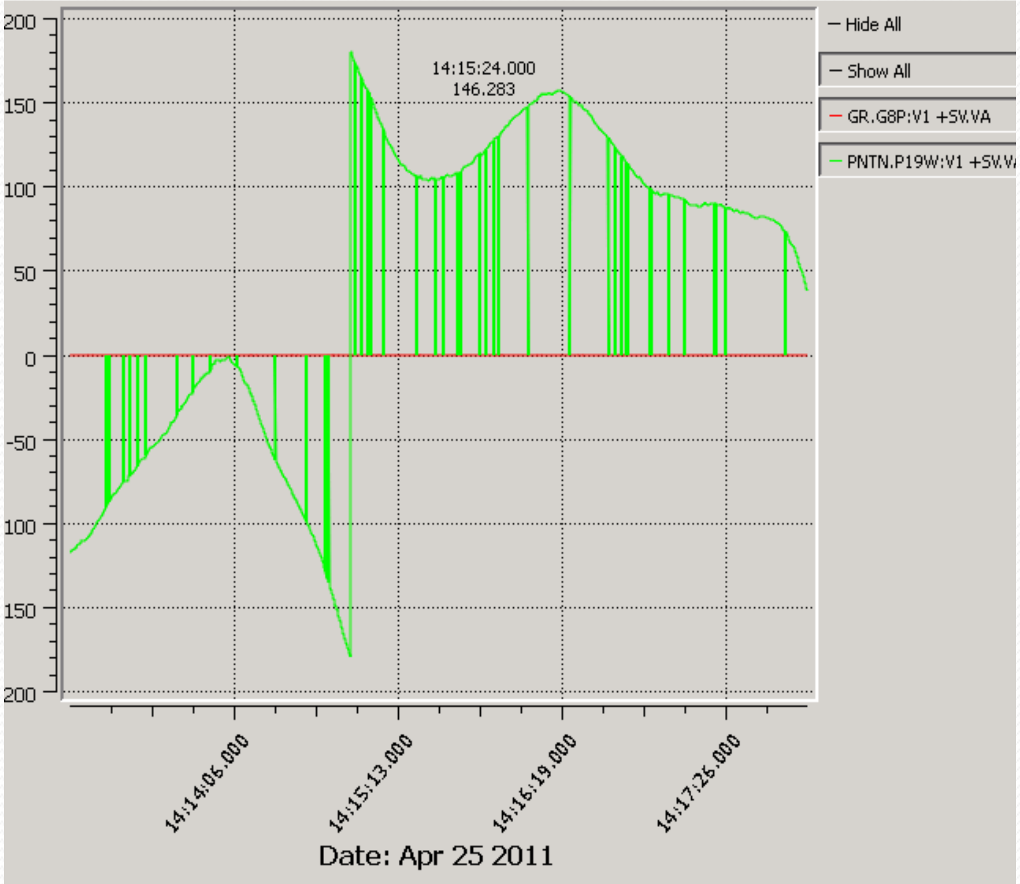
Time Domain




Birchtree SVC System A
Power Oscillation Damper
General
Lead / Lag
Limitation
Gain
Washout
FILTER
ABB

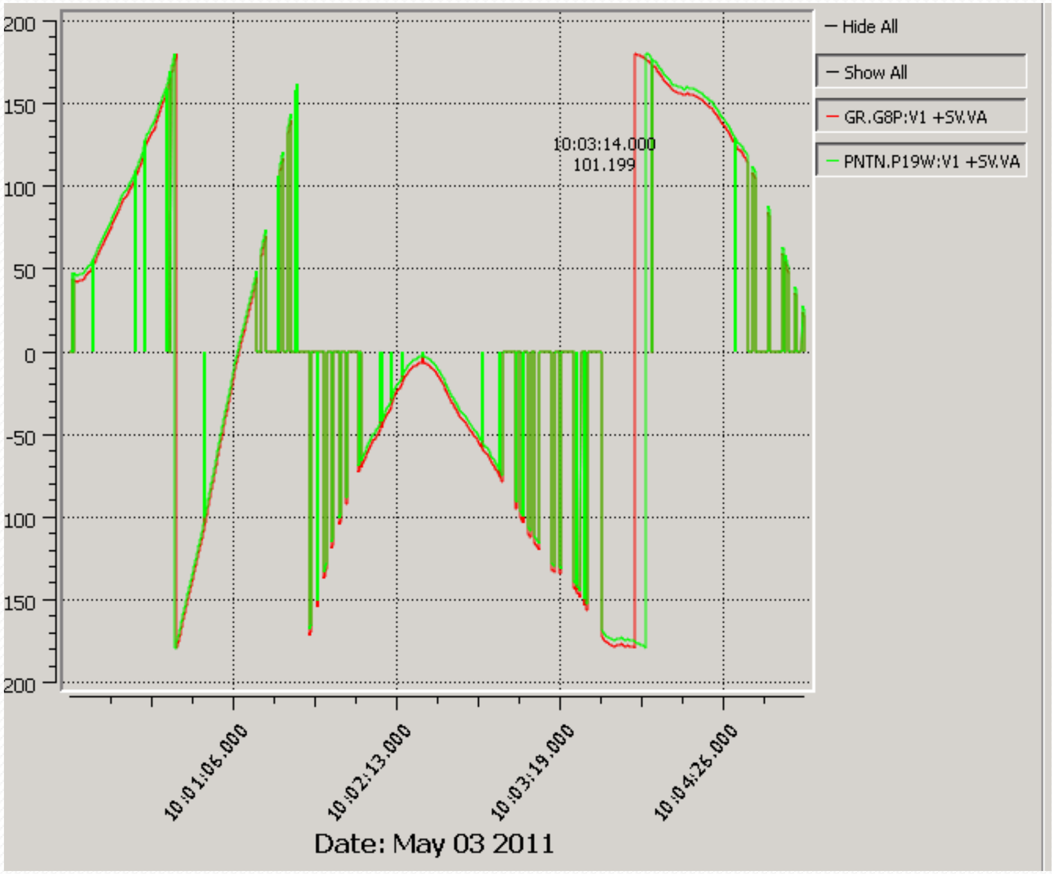
Cont…..System Baselining

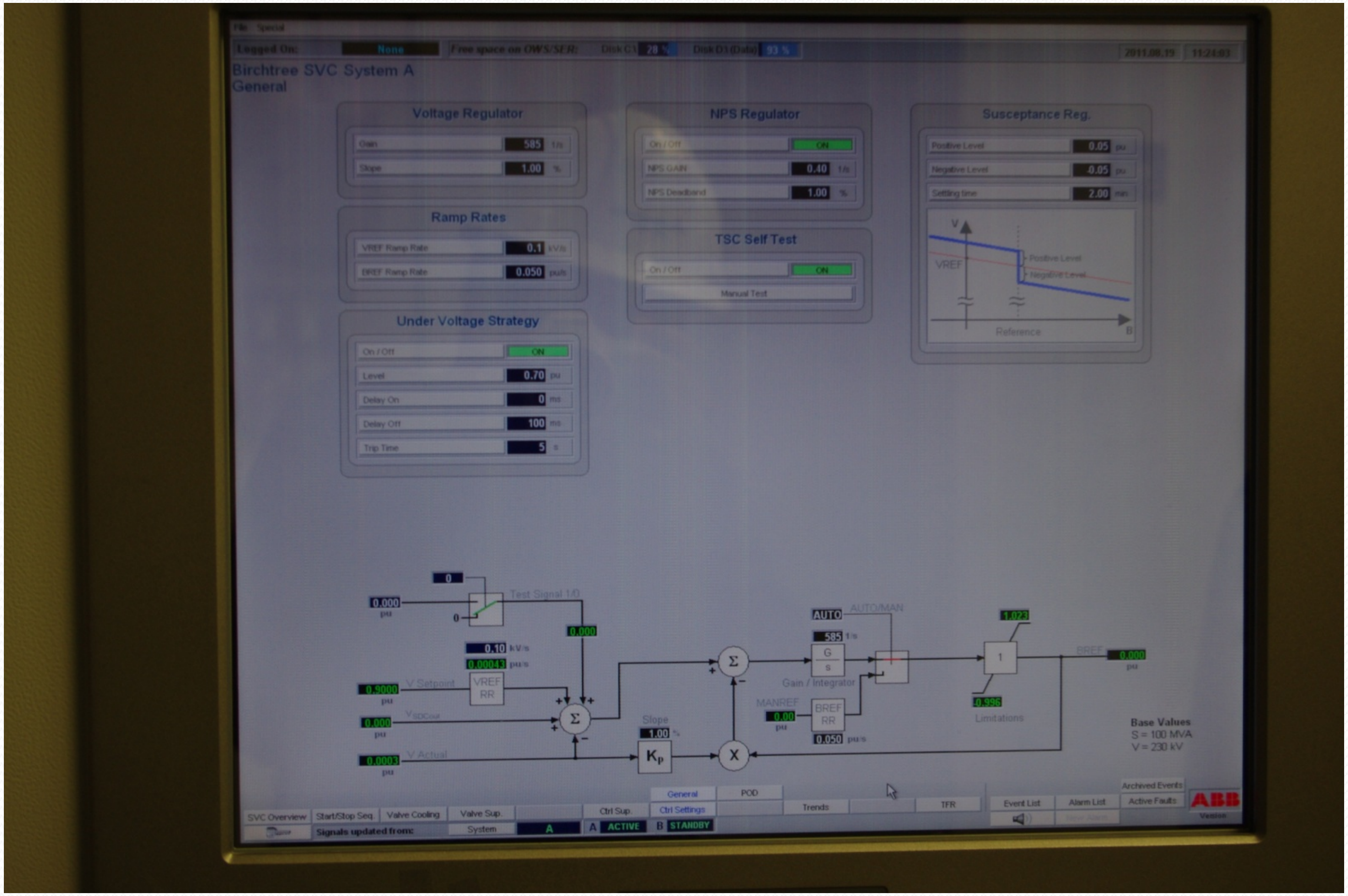
April 25, 2011 – 13:13:00 to 13:18:00 – During the time of the Event

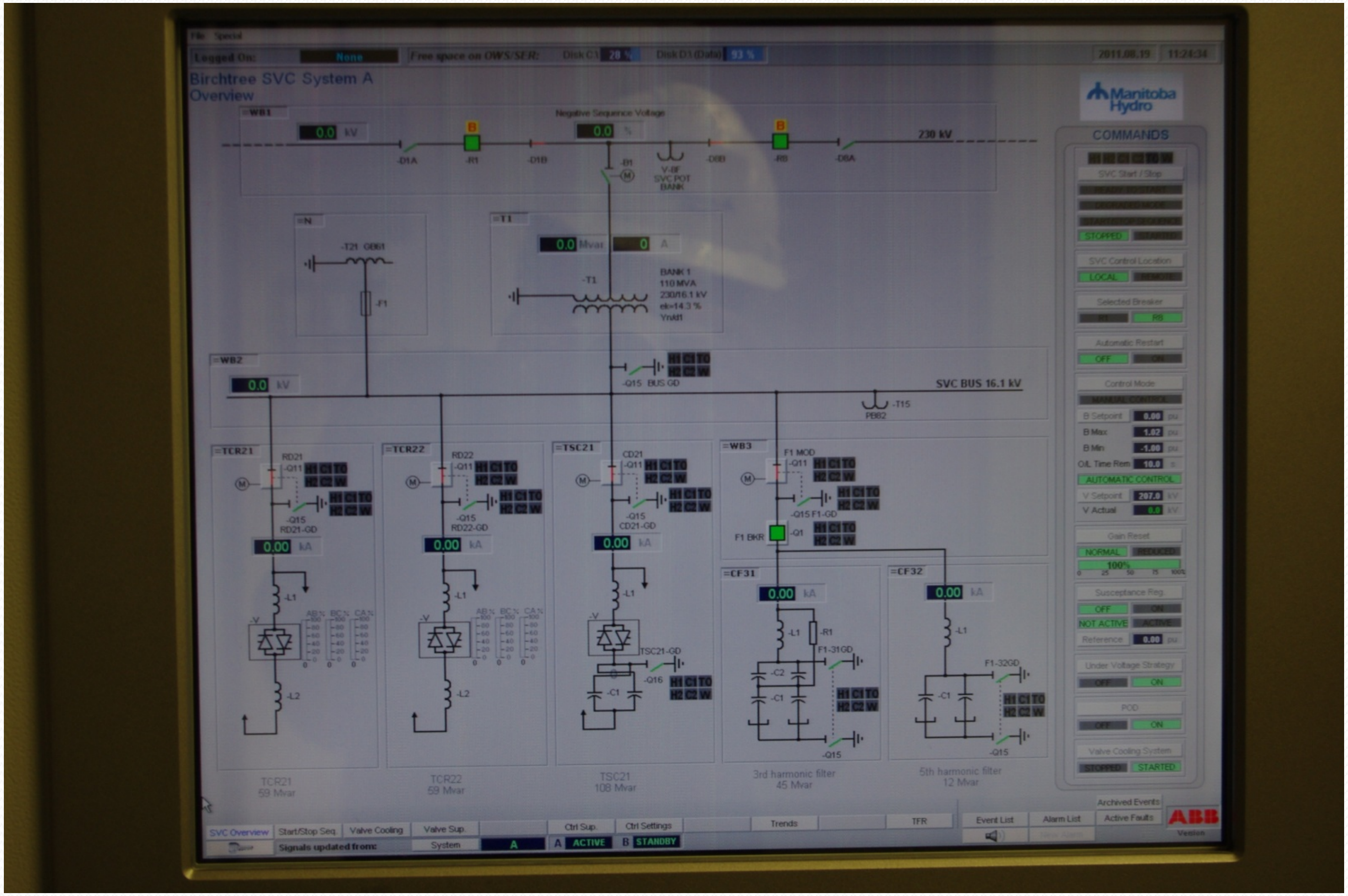


Cont…..System Baselining

May 3, 2011 – 09:00:00 to 09:05:00 – About a week after the event




Birchtree SVC System A
General
Voltage Regulator
NPS Regulator
Susceptance Reg.
Ramp Rates
TSC Self Test
Under Voltage Strategy
Base Values
S = 100 MVA
V = 230 kV
ABB


Birchtree SVC System A
Overview
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COMMANDS
Negative Sequence Voltage
230 kV
BANK 1
110 MVA
SVC BUS 16.1 kV
TCR21
59 Mvar
TCR22
59 Mvar
TSC21
108 Mvar
3rd harmonic filter
45 Mvar
5th harmonic filter
12 Mvar
ACTIVE
STANDBY
ABB

Cont….Simulation Results

- Frequency Domain

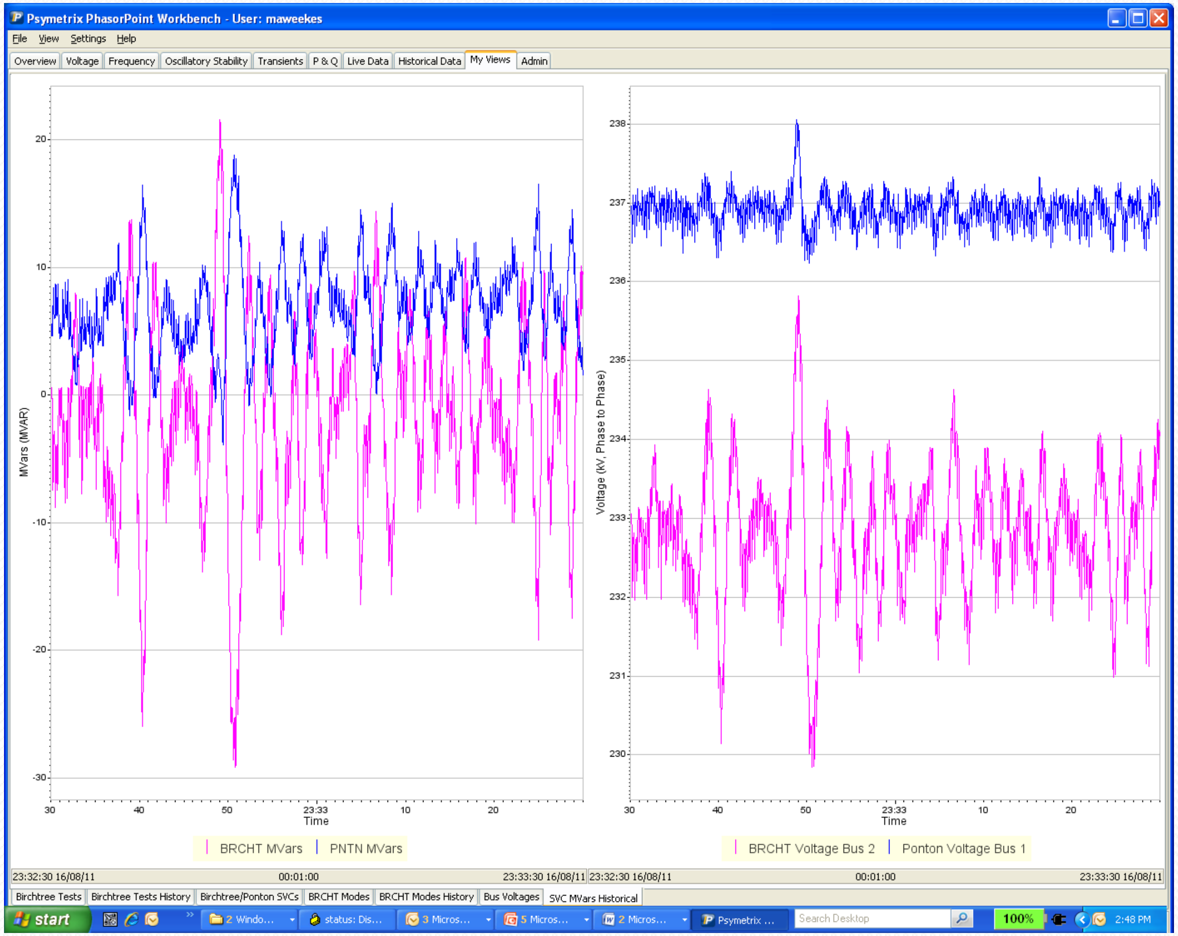
MODAL COMPONENTS

COMP. NO	EIGENVALUE REAL	EIGENVALUE IMAGINARY	EIGENVECTOR MAGNITUDE	EIGENVECTOR ANGLE	REMARKS	
1	0.810635E-04	--	-104.72	--		
2	-0.149205	4.66803	16.997	-43.39	FREQ.:	0.743 HZ.
3	-9.23642	25.3357	2.1226	-85.51	FREQ.:	4.032 HZ.
4	-8.97202	42.6287	2.0465	-47.19	FREQ.:	6.785 HZ.
5	-0.212545	6.82925	1.4056	98.87	FREQ.:	1.087 HZ.
6	-7.89161	57.9493	0.98096	71.41	FREQ.:	9.223 HZ.
7	-5.64456	39.4219	0.66522	138.48	FREQ.:	6.274 HZ.
8	-0.895488	10.2439	0.47889	-124.57	FREQ.:	1.630 HZ.
9	-4.86058	61.9287	0.20336	-138.38	FREQ.:	9.856 HZ.
10	-1.22760	17.8970	0.17606	-20.57	FREQ.:	2.848 HZ.
11	-3.04154	50.4016	0.13071	9.49	FREQ.:	8.022 HZ.

Commissioning tests

- **Frequency sweep and discrete frequency injection**
- **MW transfer change**
- **5% Step response of genertor exciter**
- **Open/ close line switching**
- **SLG Fault**

Kettle Exciter Step Change



Small-signal stability problems

- **Local plant mode oscillations**: Rotor angle oscillations of single generator or single plant against the rest of the system (0.7 to 2.0 Hz).
- **Intermachine/Interplant mode of oscillations**: Rotor angle oscillations between a few generator close to each other (0.7 to 2.0 Hz).
- **Interarea mode oscillations**: Oscillations of groups of generators in one area swinging against a groups of generators in another area (0.1 to 0.7 Hz).
- **Control mode oscillations**: Associated with control of equipment such as generator excitation systems (2.0 to 5.0 Hz).

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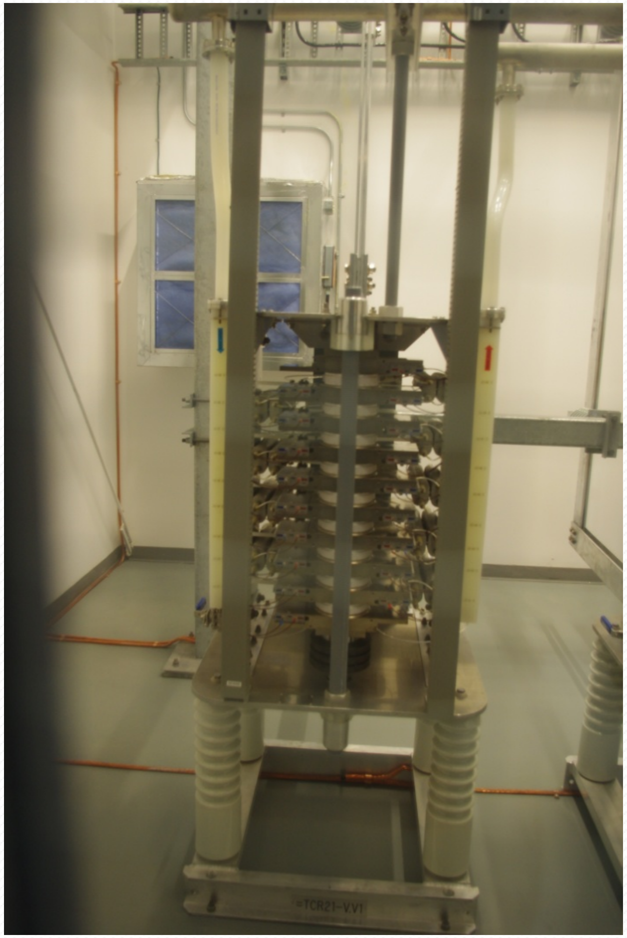
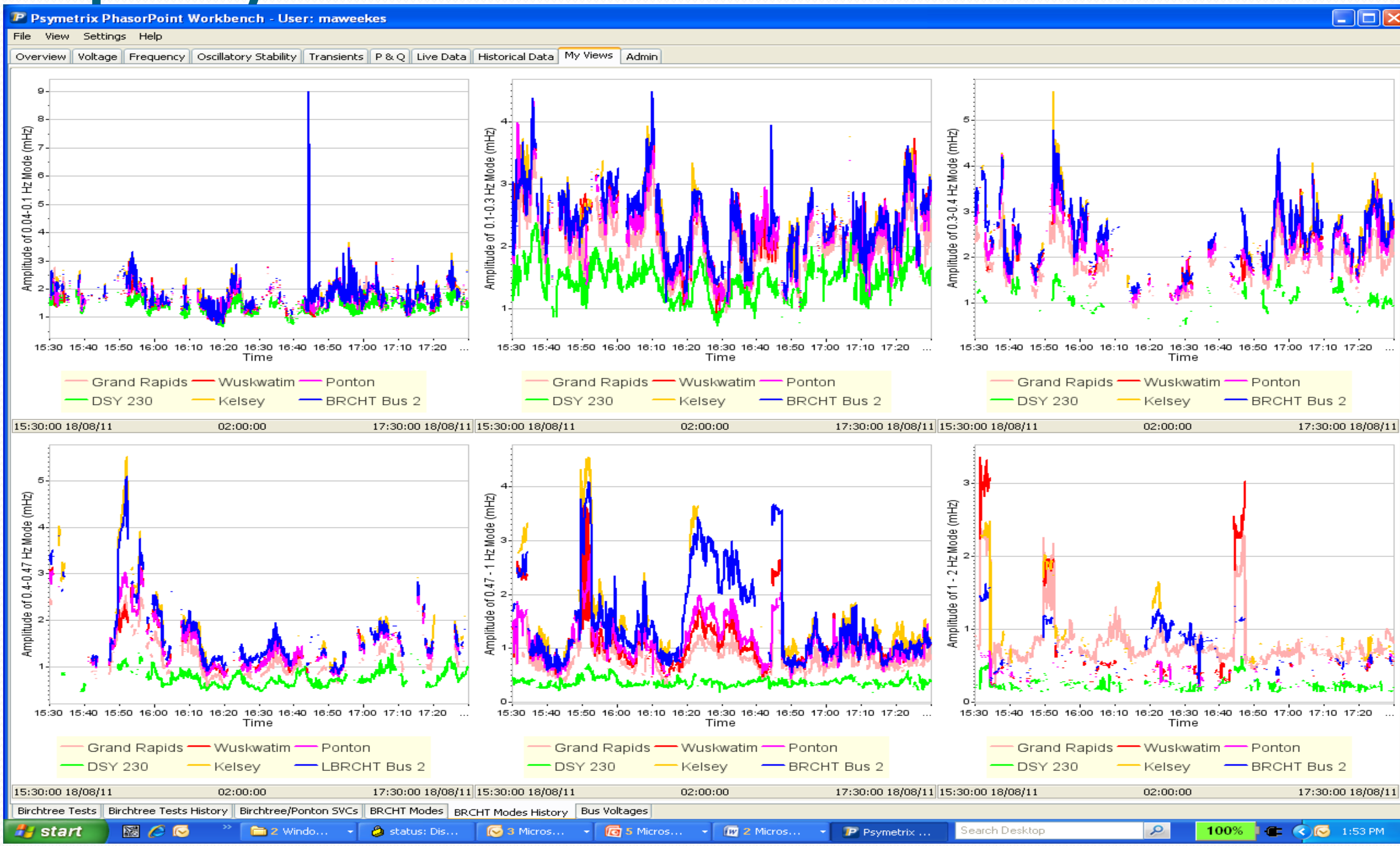
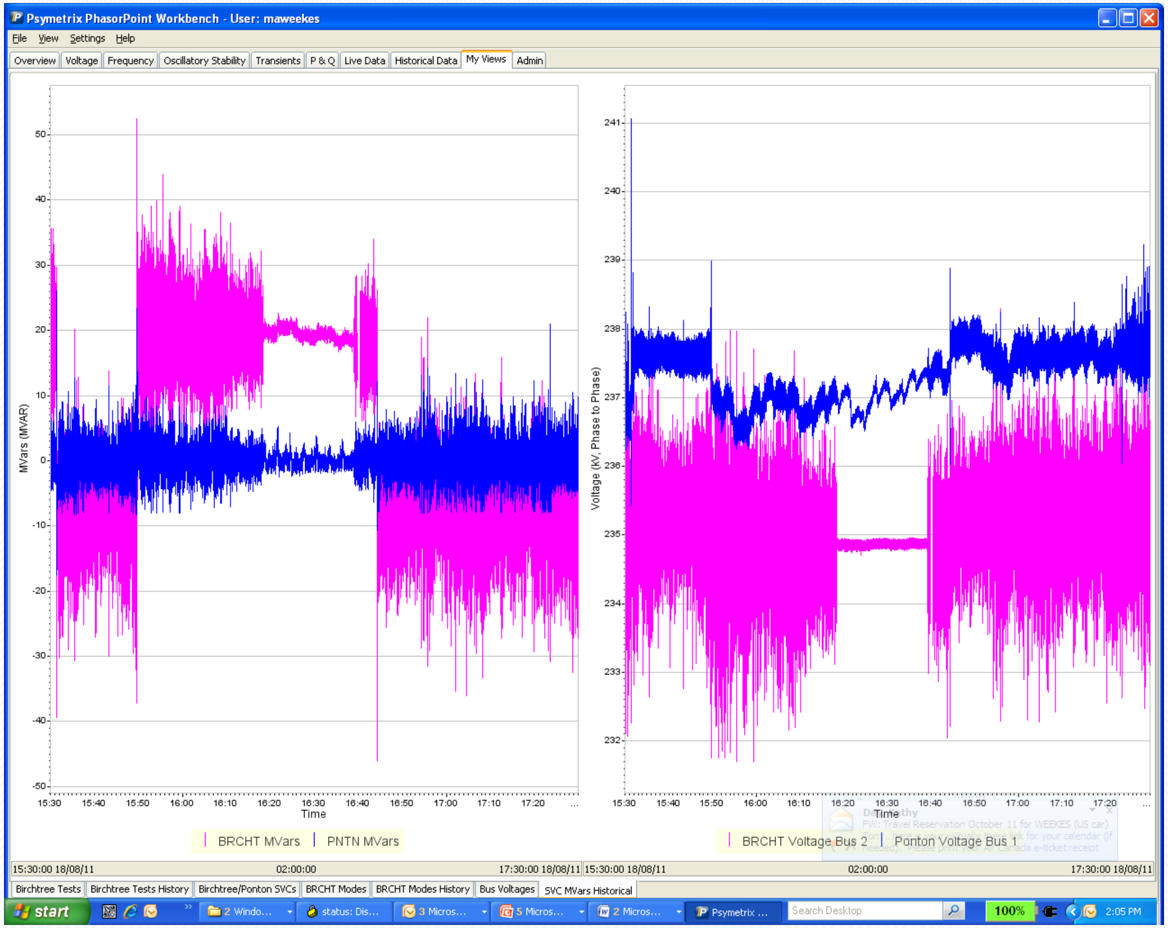

=TCR21-VV1

Open/Close Line Test



Open/Close Line test



Commissioning Plan

- Time domain and frequency domain simulation studies
- System Baselining (using the PMU and Psymetrix tools)
- Test schedule & planning
- Commissioning test process
- Results analysis