MB Hydro Experiences with Synchrophasor Implementations

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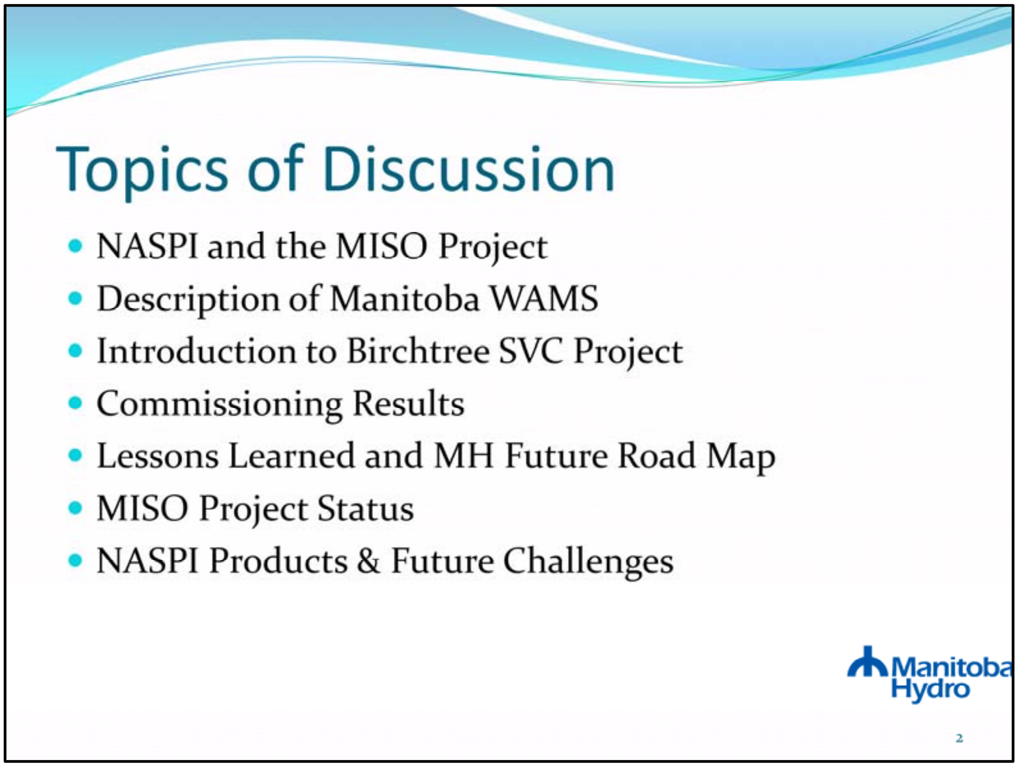
Tony Weekes is the principal HVdc System Support engineer for Controls and Protection of System Performance in MH has been the corporate representative for EIPP (eastern Interconnection Phasor Project) since 2006 through its transition to NASPI (North American Synchrophasor Initiative).

Husam Al Hadidi is the ac controls engineer in Controls and Protection of System Performance in MH and performed simulator studies for Brichtree SVC present settings that are being used.

Brian Archer is the section head for Controls and Protection of System Performance in MH and his Phd research identified the best places to place our PMUs in order to capture known northern ac modes.



A brief introduction to NASPI and MISO, followed by our first synchrophasor application, followed by an update on MISO and NASPI.

NASPI and MISO Projects

- NASPI (North America Synchrophasor Initiative)
  - Overall goal to improve power system stability reliability through wide-area measurement and control in North America
  - First steps to create a synchronized data measurement infrastructure.
  - Second step to include analysis and monitoring tools for better planning and operation and improved reliability
- MISO Synchrophasor Project
  - To provide an infrastructure of synchronized data measurement in the MISO area presently funded by SGIG (smart grid initiative grants)
  - Work with NASPI for an overall North American effort.

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Previously, convincing utilities to use synchrophasors had to be based strictly on a business case but with the smart grid funding that changed. There will be in the order of 1000 PMU sites when the SGIG funding ends in approximately 2013.

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**

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MISO ISOs that are involved in the MISO Synchrophasor Project are shown. MH is a leader in the overall initiative.

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

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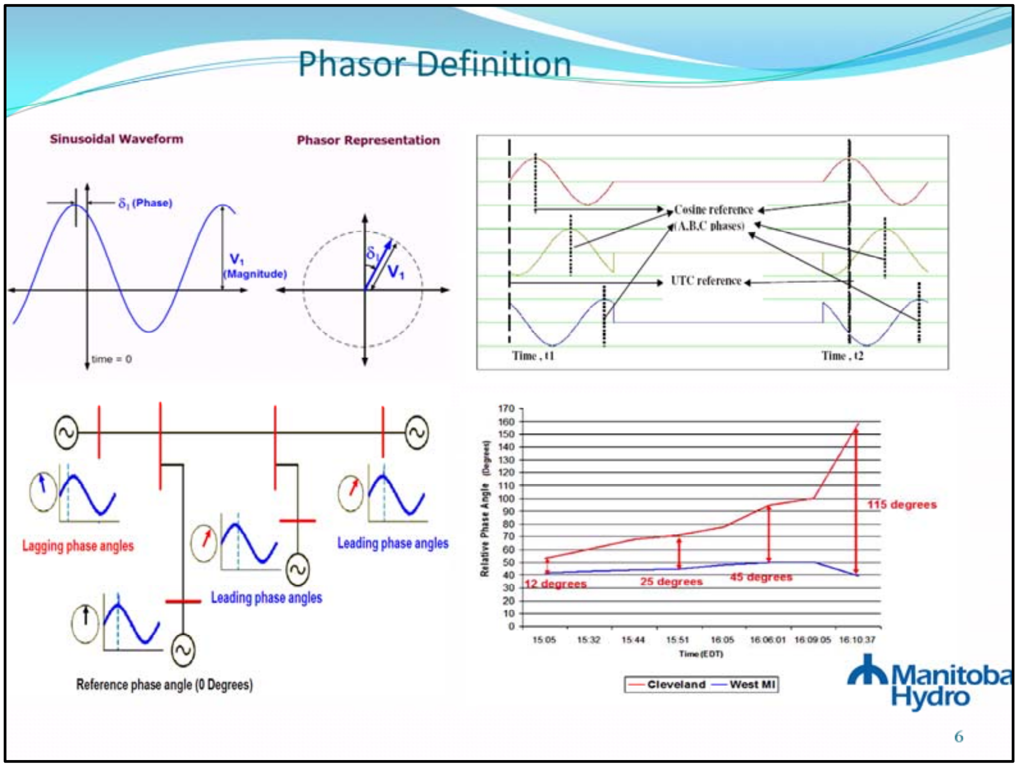
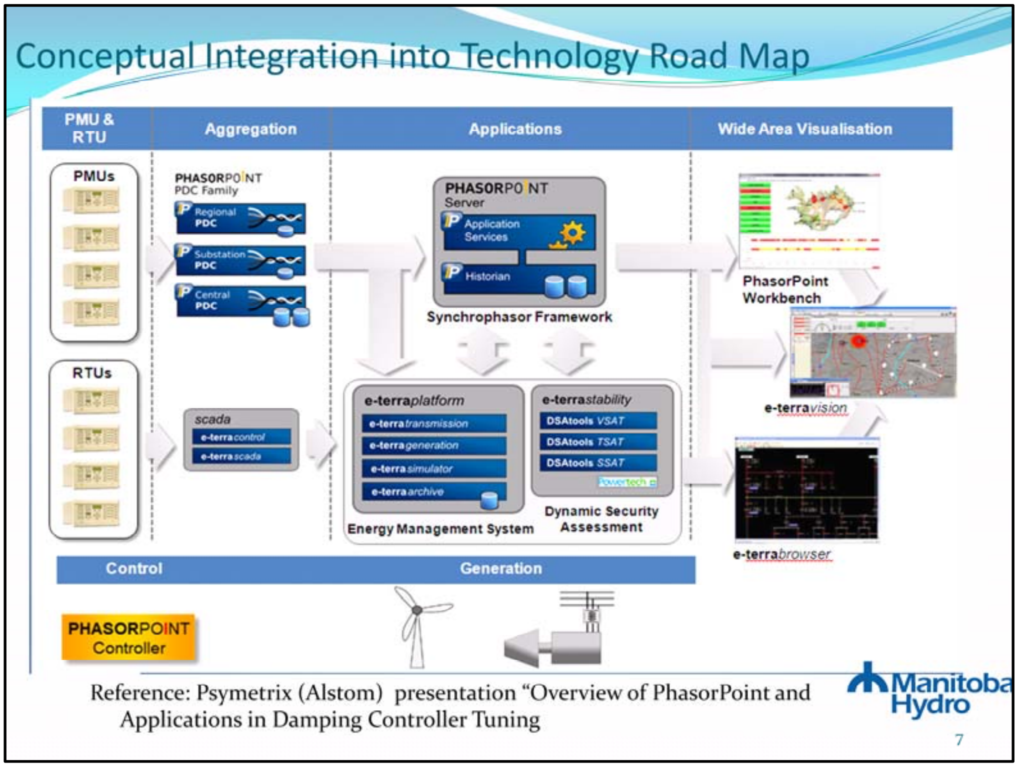
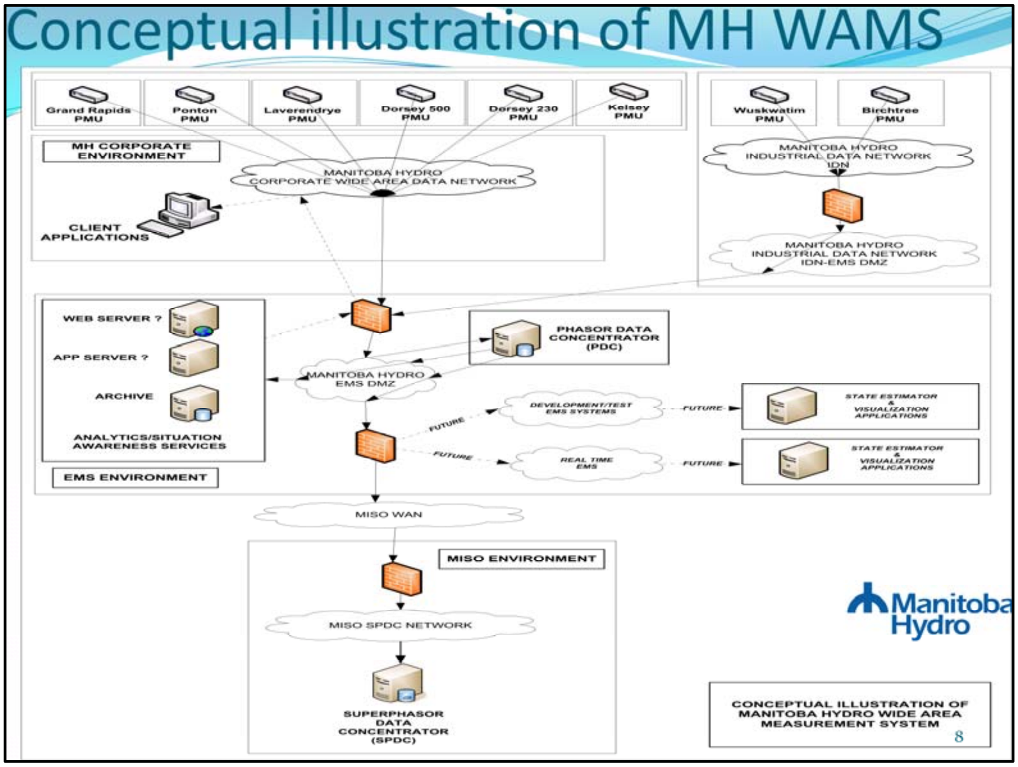
A brief description of why our first application of WAMS was justified.



The cosine reference is defined in C37.118 as Va=-90 degrees when positive sequence UTC phase is zero. By Using UTC absolute time as a reference one can always later find relative phase angle differences and ultimately find when the system is near instability.



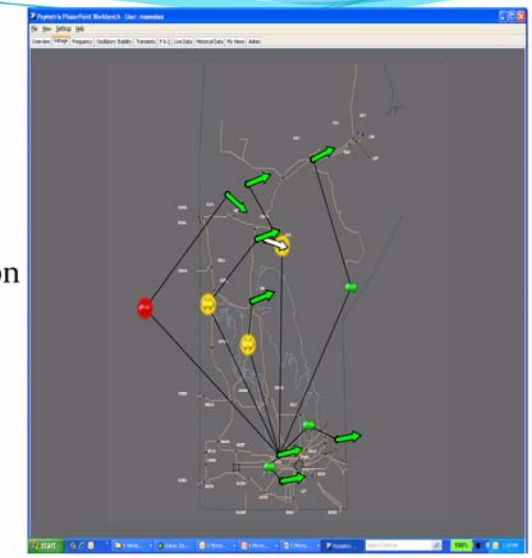
This slide shows how applications will roll out to the users.



Our MH WAMS architecture (conceptual only).

WAMS

- Phasorpoint tool used primarily to see the modes on the system
- Initial R&D WAMS used in 1997 at MH (non-PMU based)



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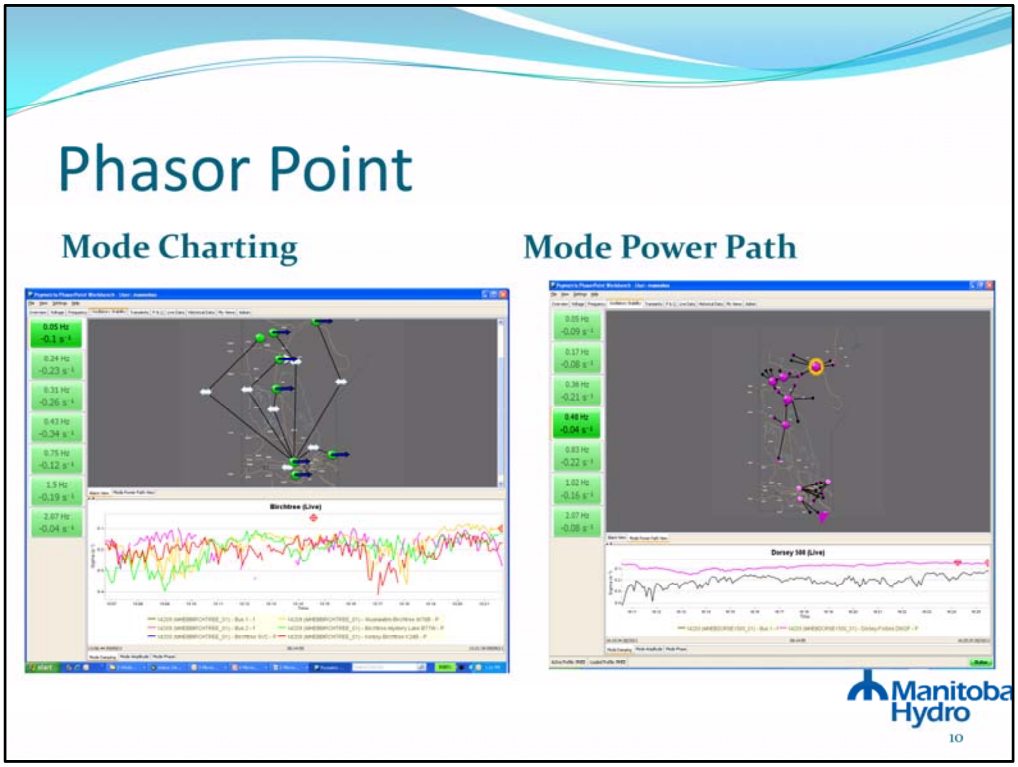
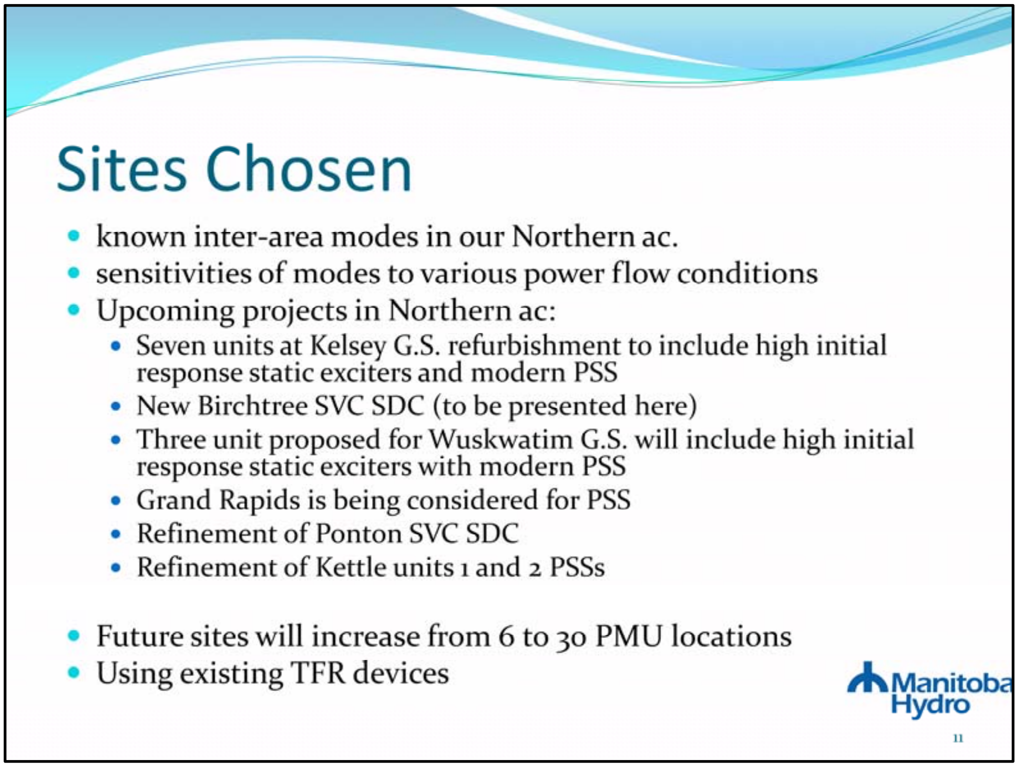
Our visualization tool.

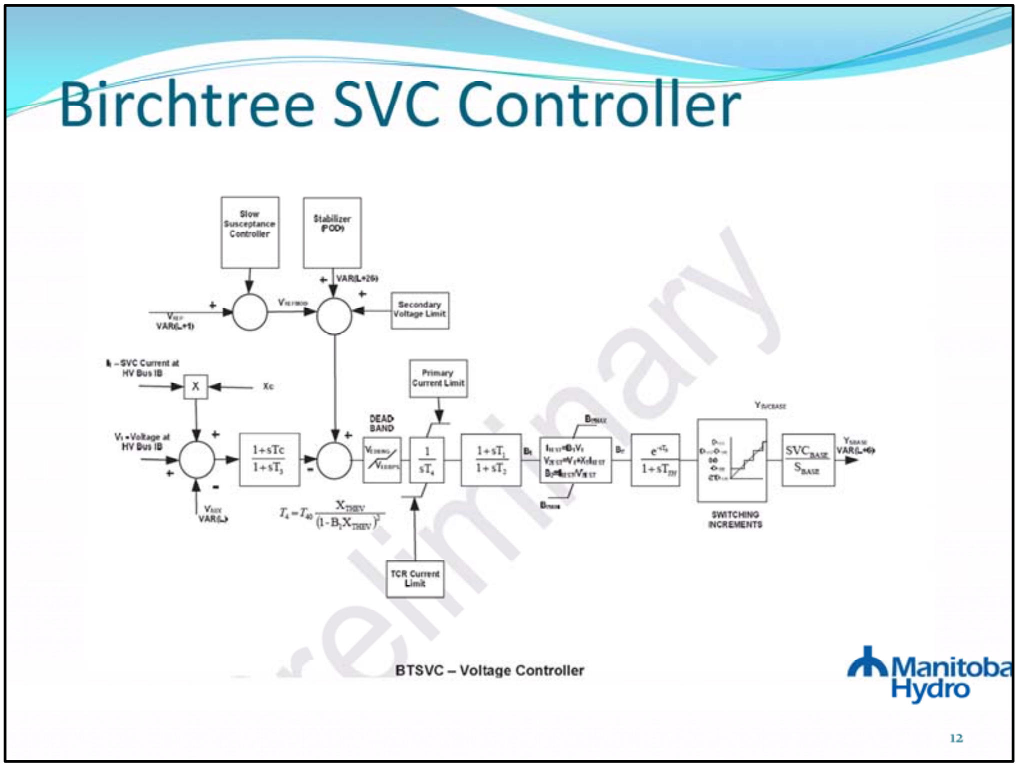


The energy of the mode is correlated to the mode and a function similar to controllability and is computed (Mode Power Path). This allows one to know where the mode is coming from. Color codes on modes indicate severity (margin to poor damping is represented as small values for |σ| (damping coeficient) which is the inverse of the decay time and can be related back to damping ratio (ζ).

All the modes we saw had been seen before in other studies but the persistence of the mode was not necessarily known. We noted some modes were poorly damped but remained very low in magnitude so they did not cause concern. Alarms were set so that if the magnitude on these poorly damped modes ever increased we would be notified.

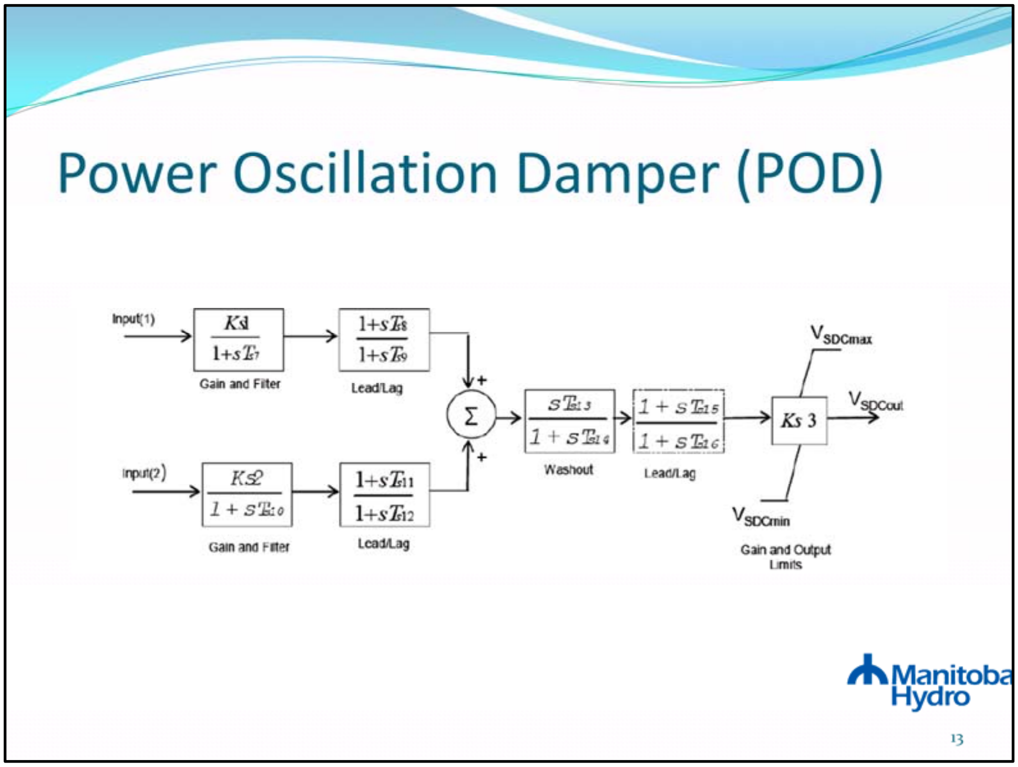


Background reasons for site choices were given.

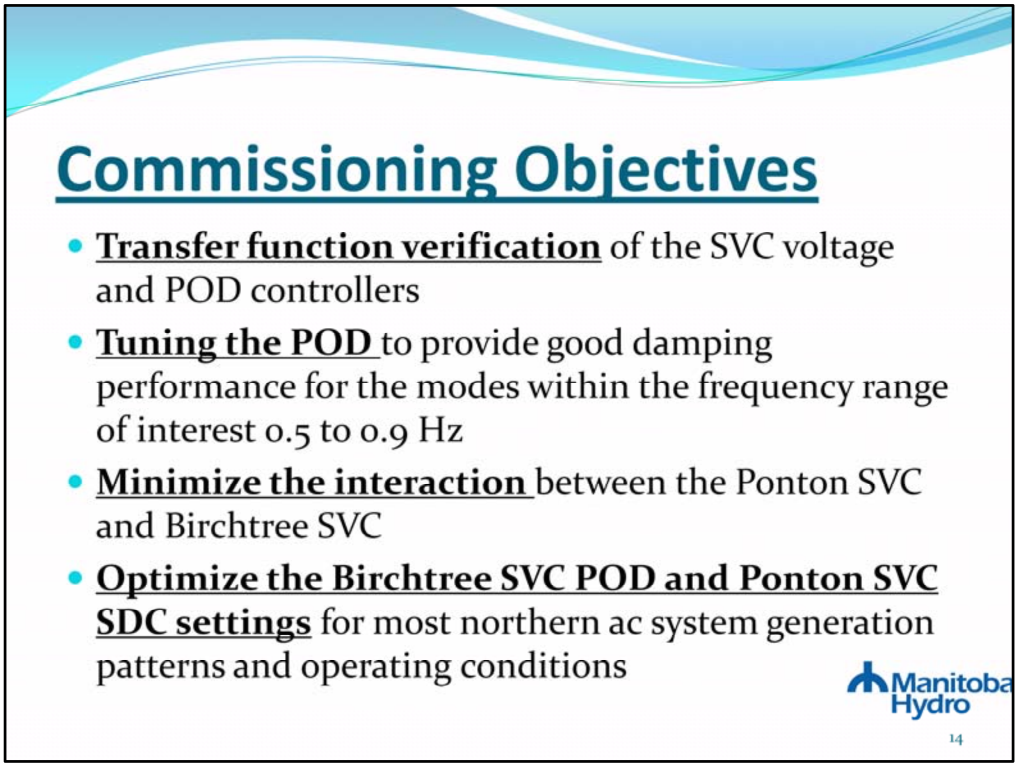


Transfer function path of primary controls which is voltage control is shown as well as where the power oscillation damper (POD) would be input.

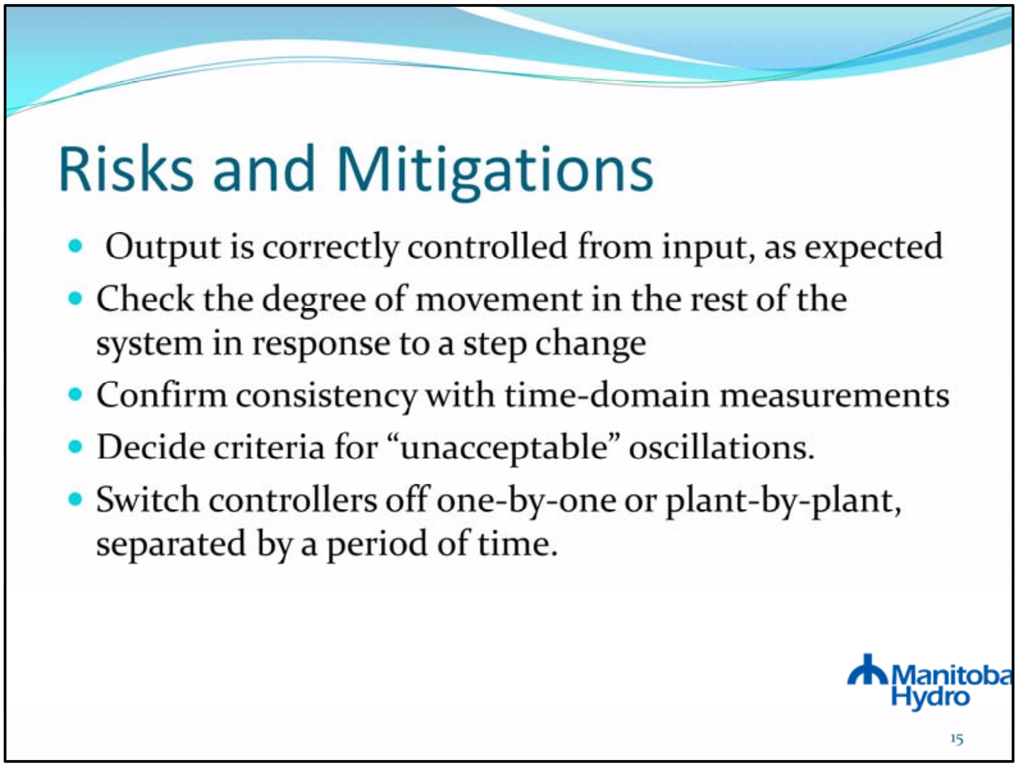
It is noted that the primary function of the SVC was voltage control and the damping controller was a supplementary function. It is noted that the SVC, in contrast to a generator or a DC link supplying power, applies damping by changing the voltage and thus actually works through the power to the load and through fast acting generator exciters that would have to be in that area to be affective. It is noted that similar to Power System Stabilizers on generators the Power Oscillation Damper (POD) targets the mode of interest and supplies some lead compensation to overcome any lags in the system response.



POD second input was not used except when the system frequency injection tests were performed. The second input was actually left as an input for PMU capability (this would be real time control over a wide area – possible future application)

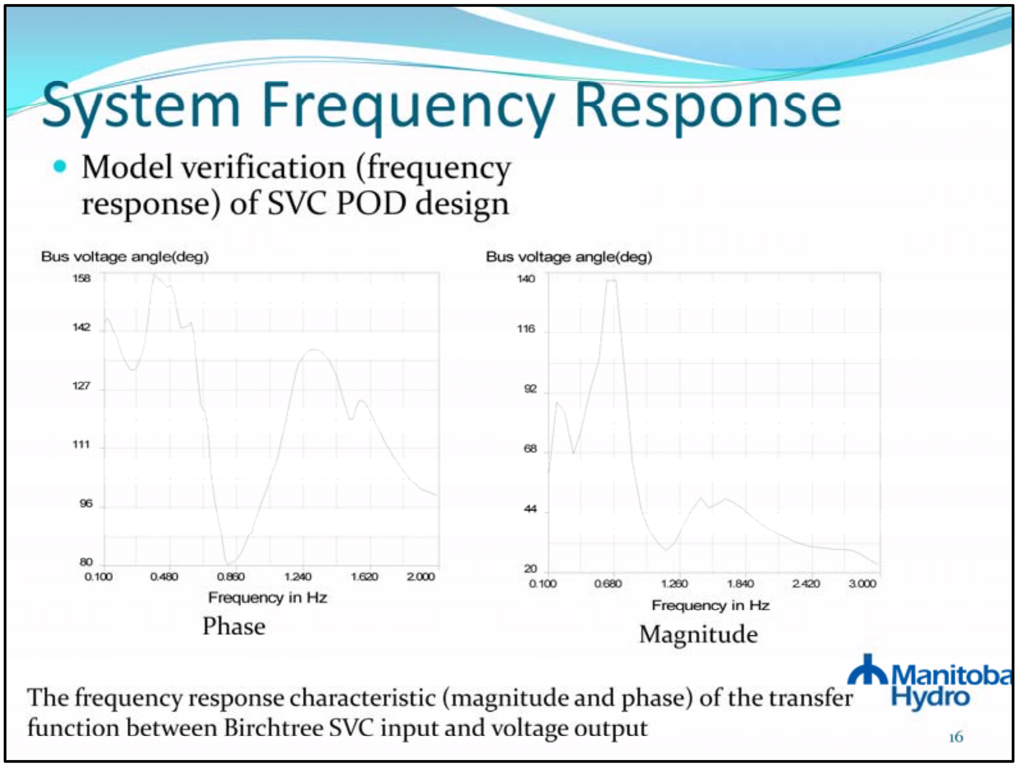


Model verification through the system frequency injection tests was very important.
Tuning optimization through real time synchrophasor feedback was very important.

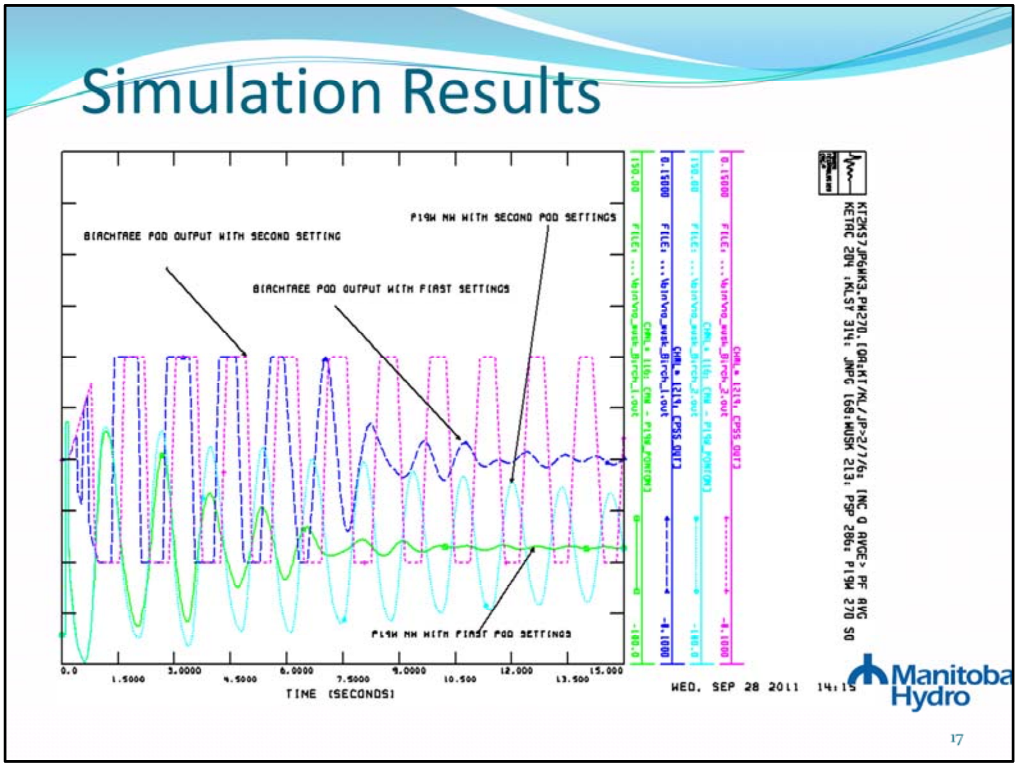


We had two POD settings so criteria on what constituted an unacceptable oscillation were important since we expected both settings to work but we also expected to be able to see a difference in performance.

By using many permutations of which system damping controllers were on in the area we could evaluate how the new SVC damping control was working with the other damping controls in the area.



The frequency response shown through simulation above was checked against the real system frequency response when we injected different voltage frequencies into the SVC input at the actual site. These system frequency response tests confirmed the off-line model. It is to be noted that the actual SVC damping control in normal operation (not system frequency tests mode) uses delta frequency as an input and the frequency response for delta frequency would be different to this voltage angle frequency response above. The voltage angle frequency response was easy to reproduce (compared to delta frequency) on the real system and that is why it was compared.



1st and 2nd settings for the Birchtree SVC damping contorls (POD) showed different responses in the off-line studies above. From this we expected the 2nd settings to perform better.

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.

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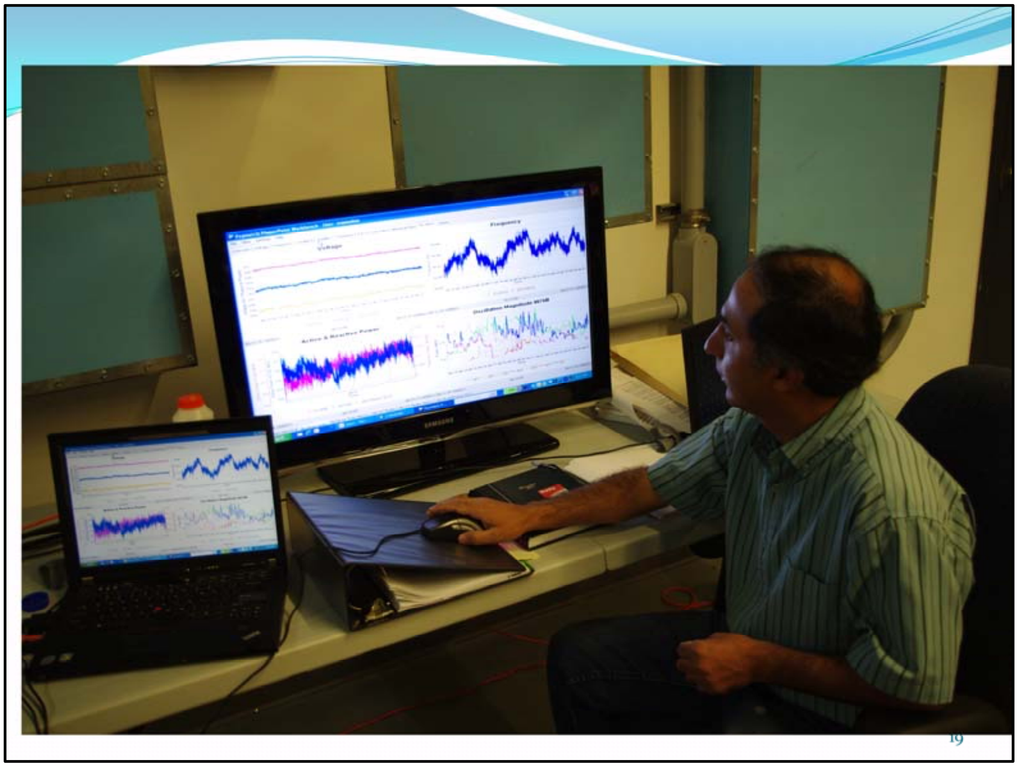
In component #2 (0.7 Hz), sigma of -0.149 translates into 3% damping ratio , heavy 230 MW transfer on P19W + W76B and all damping controls off. Normal BRCHT SVC gain.

Offline studies confirmed 0.7 Hz mode as the dominant mode.

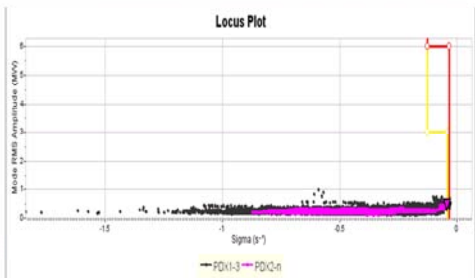


A large screen displaying synchrophasor information in real time visible to commissioners armed with the “kill switch” were invaluable. (Dr. Al-Hadidi shown)

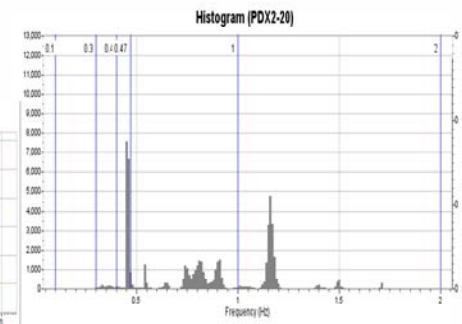
Mode Trending

Root locus of mode

- Trending and verification of damping controller performance



Observability of the mode over time



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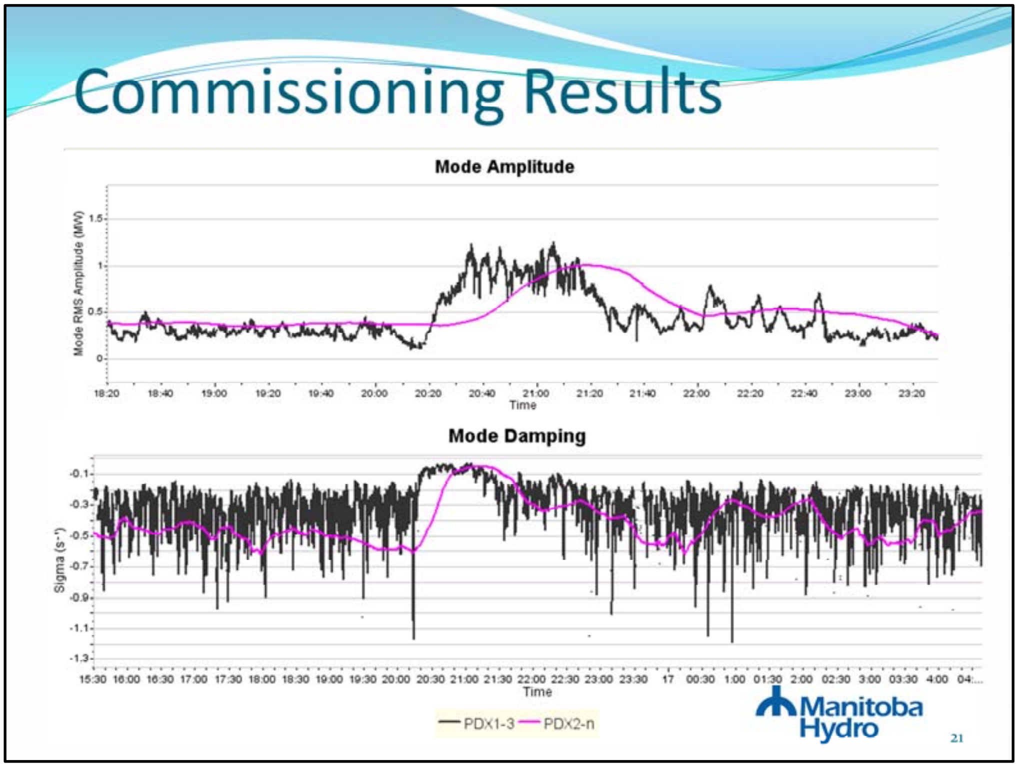
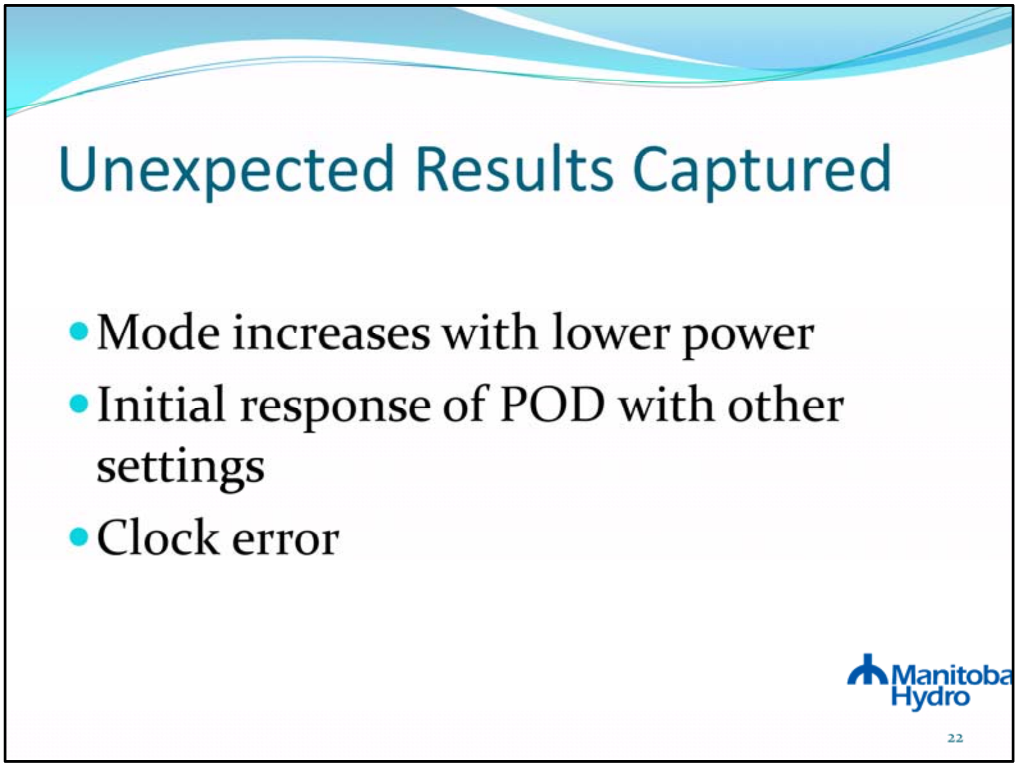
Baselining is essential. A good idea of modes on the system before testing began is shown.



All PSSs on initially, then Kelsey PSS OFF at 20:00, BRCHT PSS ON only at 21:30, at 00:30 BRCTH PSS OFF

The black indicates mode calculations based on a 1-3 minute window as opposed to the pink which is based on a 20 minute window. They both can help to identify different information about the mode of interest which in this case is the 0.7 Hz mode. The mode is not shown as an oscillation since it is the result of a calculation from the synchrophasor data of mode damping (sigma) and mode amplitude. The actual oscillation of the power could also have been shown if chosen but instead just the key parameters of damping and amplitude were needed.

The settling time could have been improved if we left the conditions of various PSSs On or OFF longer but what we were looking for is the trending of the mode damping or amplitude as opposed to exact absolute values. One lesson we learned after acquiring the phasorpoint tool is absolute values are difficult to assess but trending is important, and it is important to be able to know if the additional controller is improving or making the damping worse.

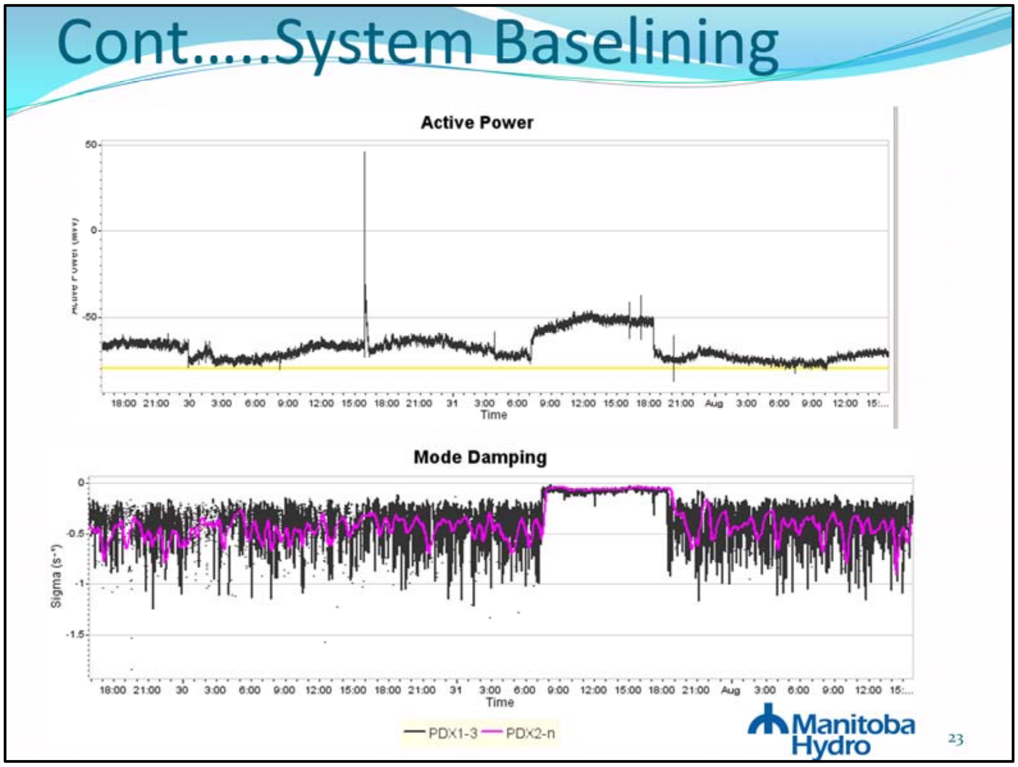


One explanation of the unexpected result of mode increases with lower power is some power system stabilizers do not turn on when the generator is operating at low power in the rough zone. This leads to better damping as the generator power is increased.

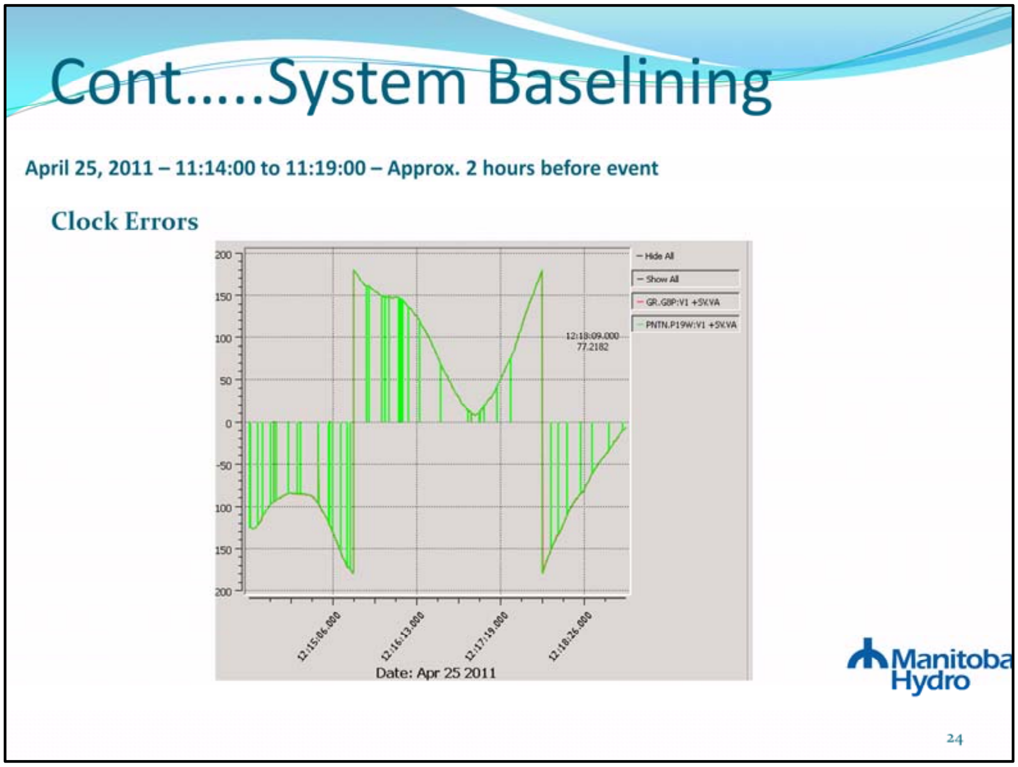
The initial response of the POD with 1st settings was worse than expected. Criteria for deciding which setting was performing better was trivial.

Clock errors are a hidden issue which need mitigation both in real time and on a continuing maintenance basis.

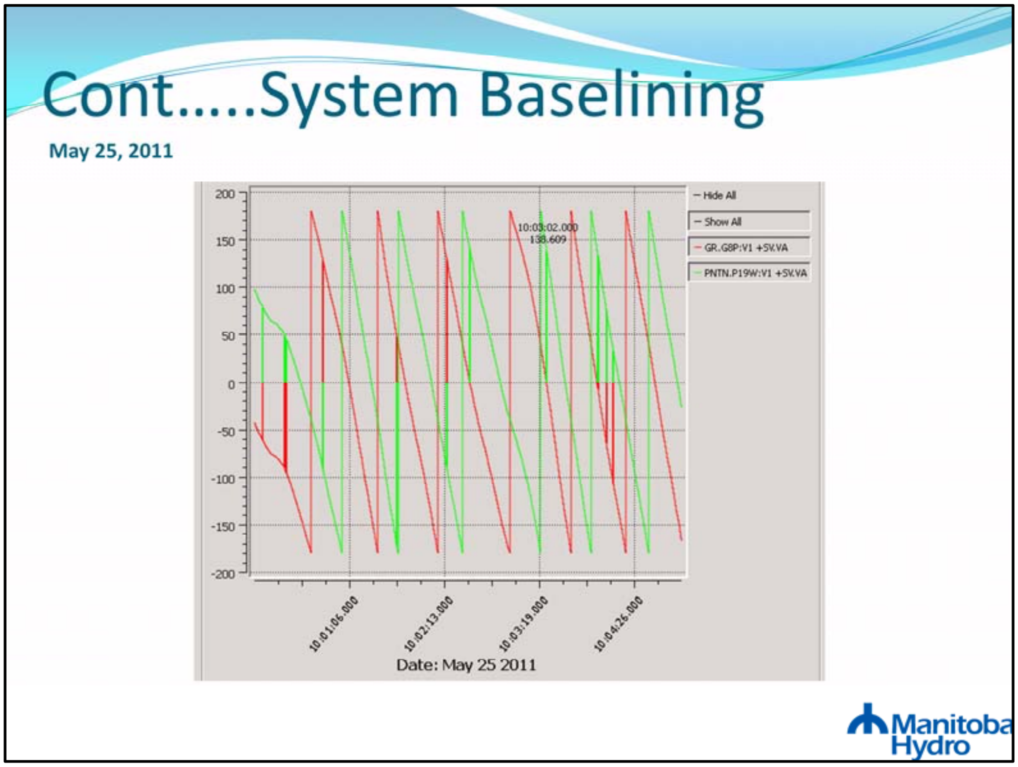
These unexpected results are shown in the next slides,



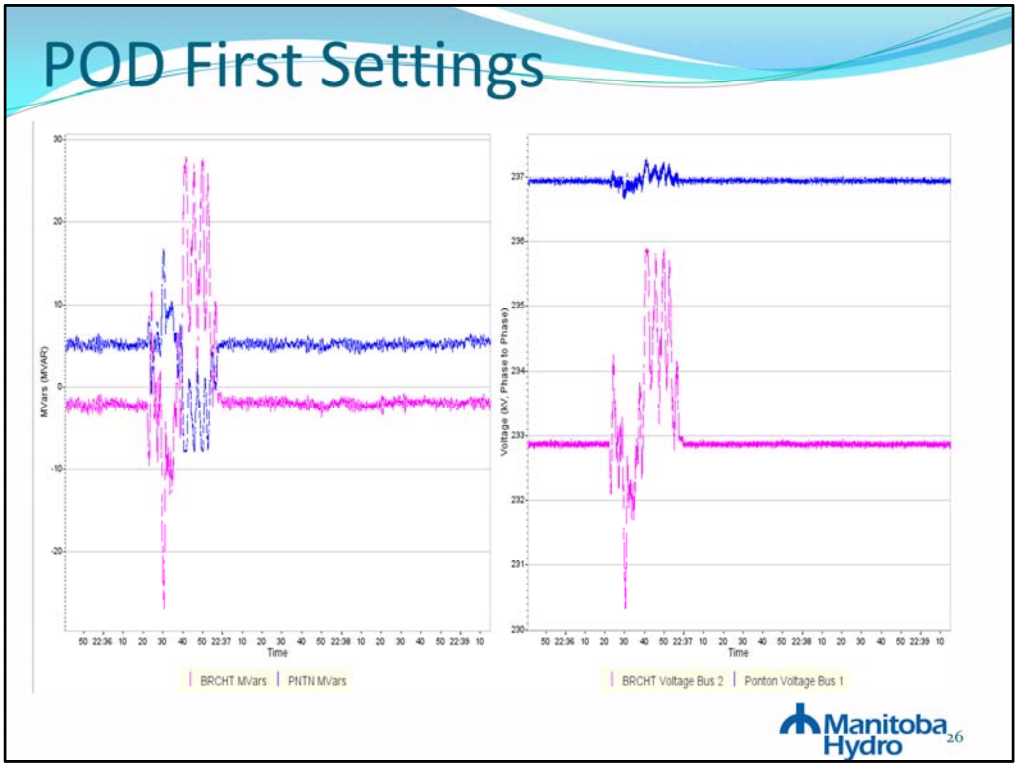
Example of mode increasing with lower power. As explained earlier, one explanation can be PSSs turned off while generators are in the rough zone of lower power and thus less damping on the system.



Prior to the disturbance the angles from the two nearby stations of Ponton and Birchtree overlap as expected. The vertical lines are due to times that data is lost (higher level software like the PhasorPoint tool can filter these out but raw MISO data is shown here).

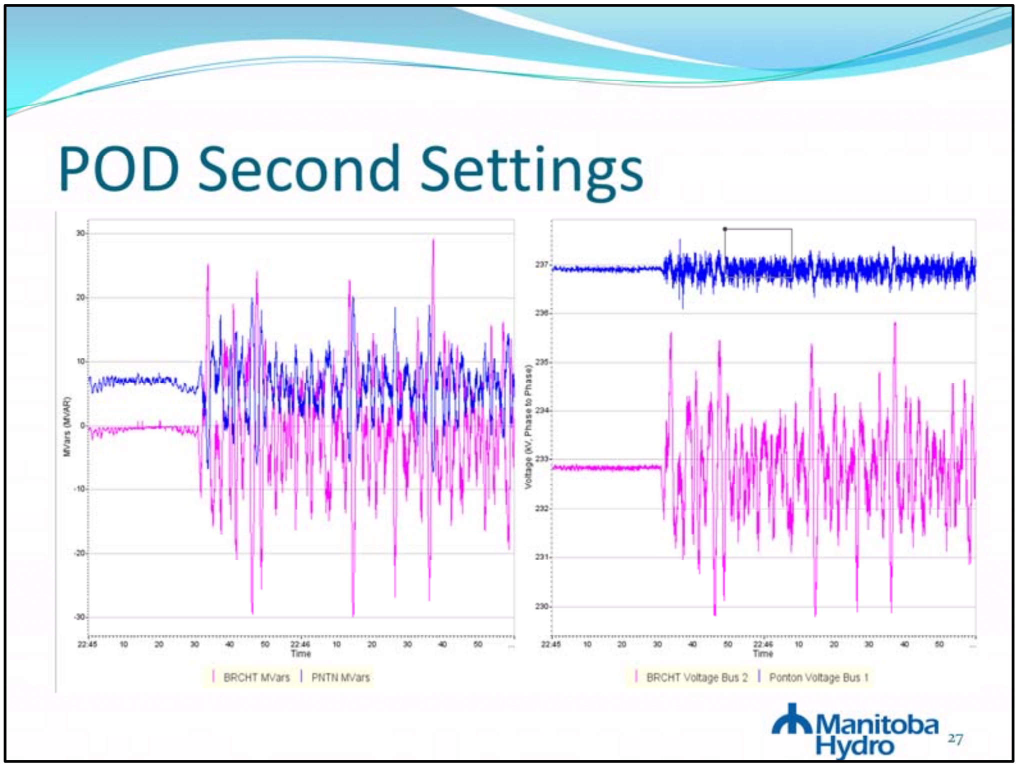


Unexpected 120 degree phase error aligned with what we thought was line transposition but was actually clock error caused by a faulty antenna. The phase re-aligned correctly once the antenna was replaced. Future mitigation and maintenance become real issues especially if the error was only 5 degrees.



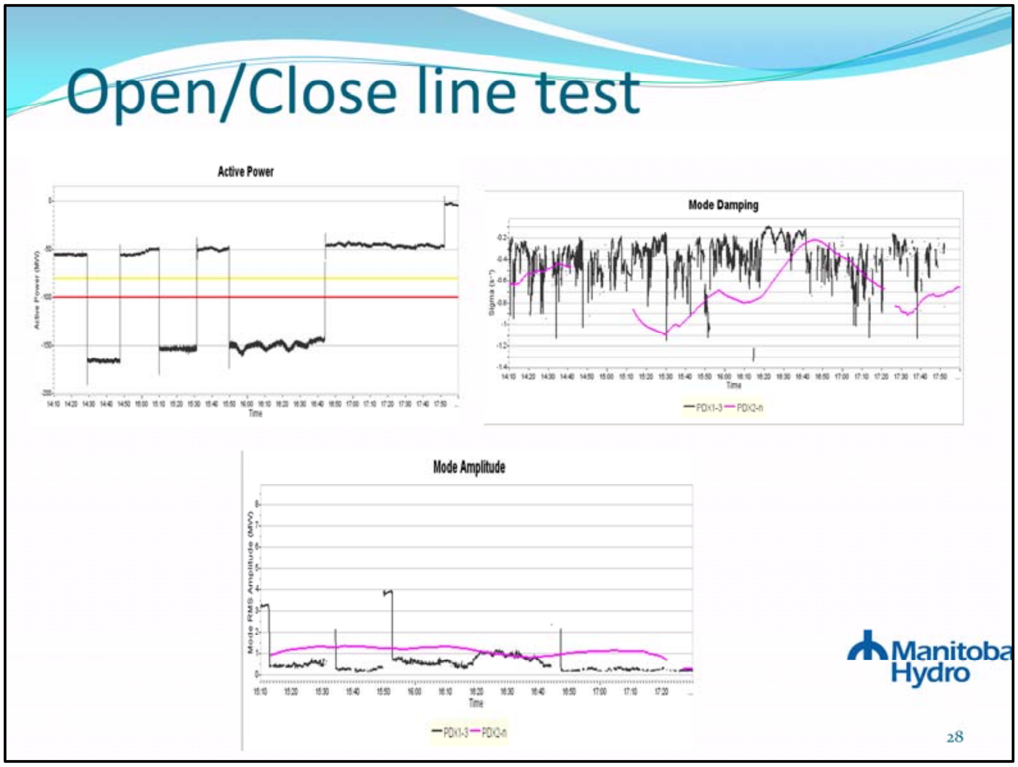
Our first testing of the 1st settings for the POD at Birchtree

A slow increase of voltage caused us to throw the “kill” switch after only a few seconds of operation with these initial settings. It can be noted that the settings were creating an instability for a frequency not targeted by the settings.



Our first testing of the 2nd settings for the POD at Birchtree.

POD “on” moves the voltage around a lot but the result is stable and not increasing.



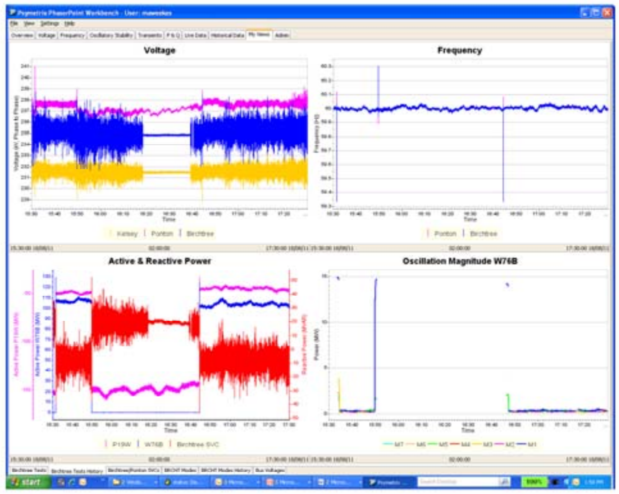
POD “ON” and “OFF” as well as switching of lines is shown. 0.7 Hz mode is seen rising when the POD is OFF and coming down when the POD is on (pink trace).

Settling time could have been longer but trending of the mode was the main concern. The damping was clearly noted imporving when the Birchtree POD was “ON” and conversely getting worse with the Birchtree POD “OFF”.

When line switching occurred the 0.7 Hz mode jumped on the transient but later very quickly reduced when the Birchtree POD was “ON” (black trace).

It is noted that the pink trace is a 20 minute window and the black trace is a 1-3 minute window and while the black trace is best for picking up the mode for line switching transients the pink trace is best for picking up the mode for POD “ON” - “OFF” changes (over longer times).

Open/Close Line Test



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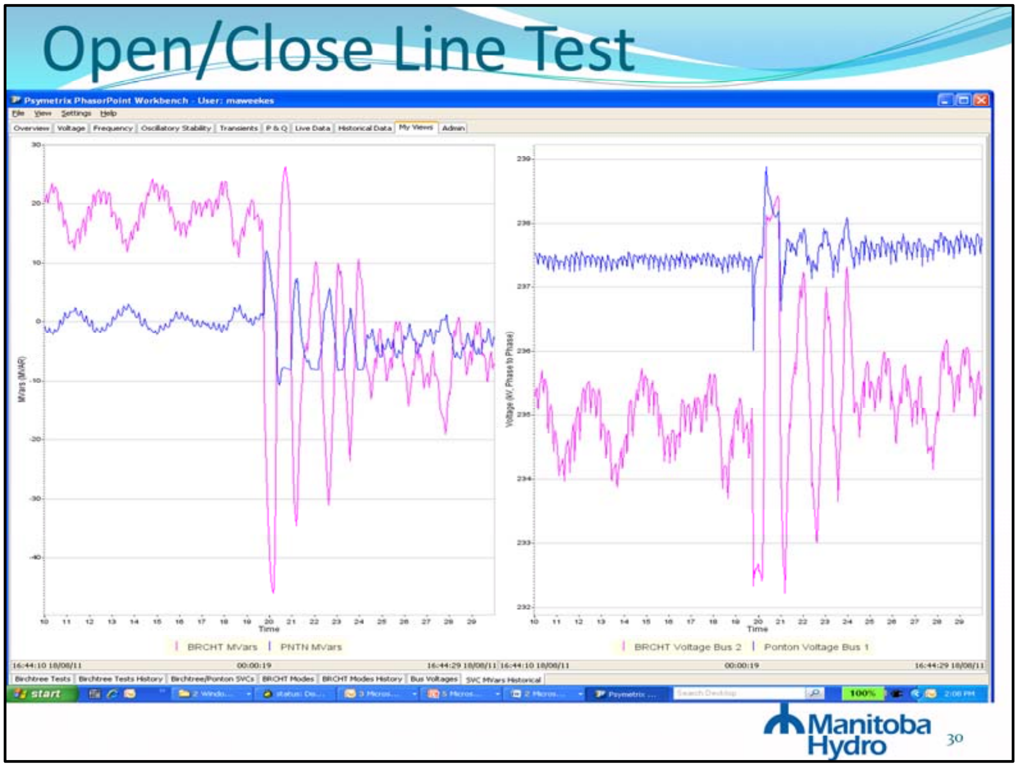
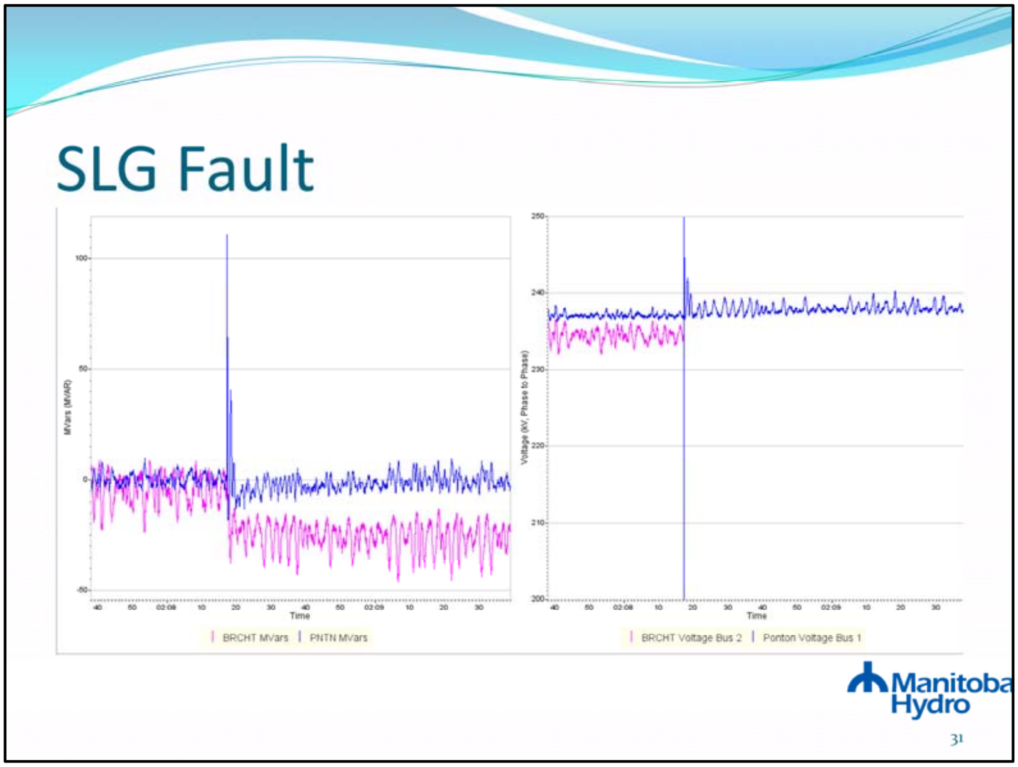
For the plot on the right bottom corner, one can note the power mode on line P19 W disappear as line is opened since signal is lost – importance of choosing signals correctly is emphasized. The mode is very quickly damped when the line is closed in (signal re-appears) and the POD is ON.

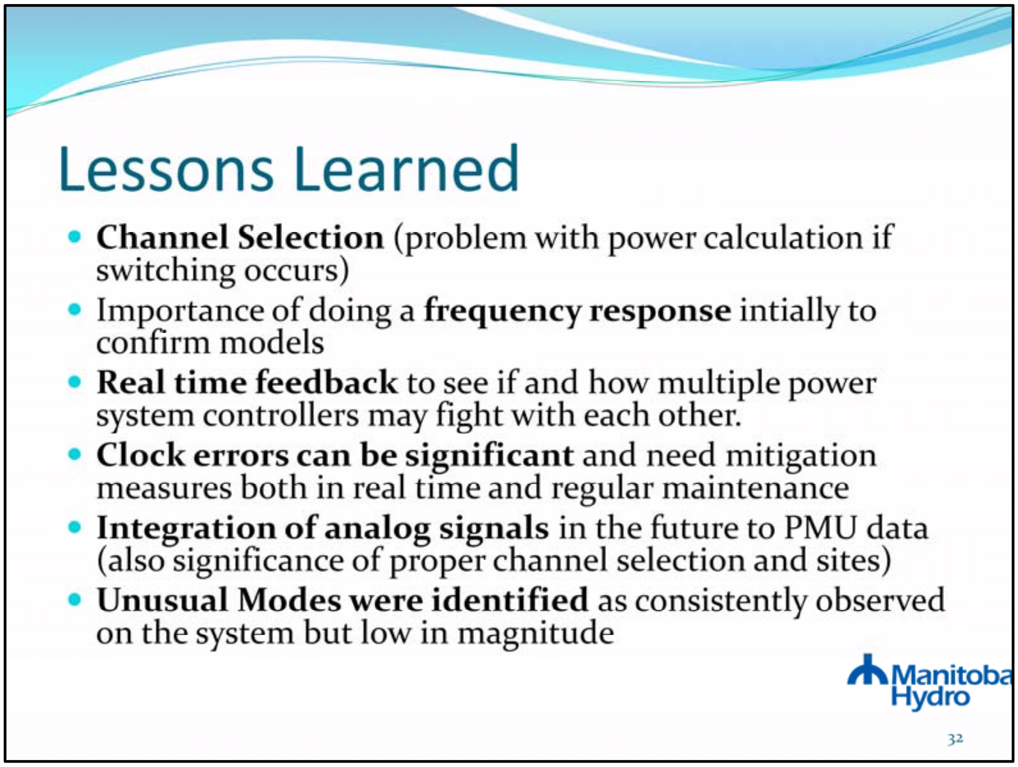


Time 16:44 aug.18 ‘11 – line switching – some fighting between Ponton and BRCHT SVCs.

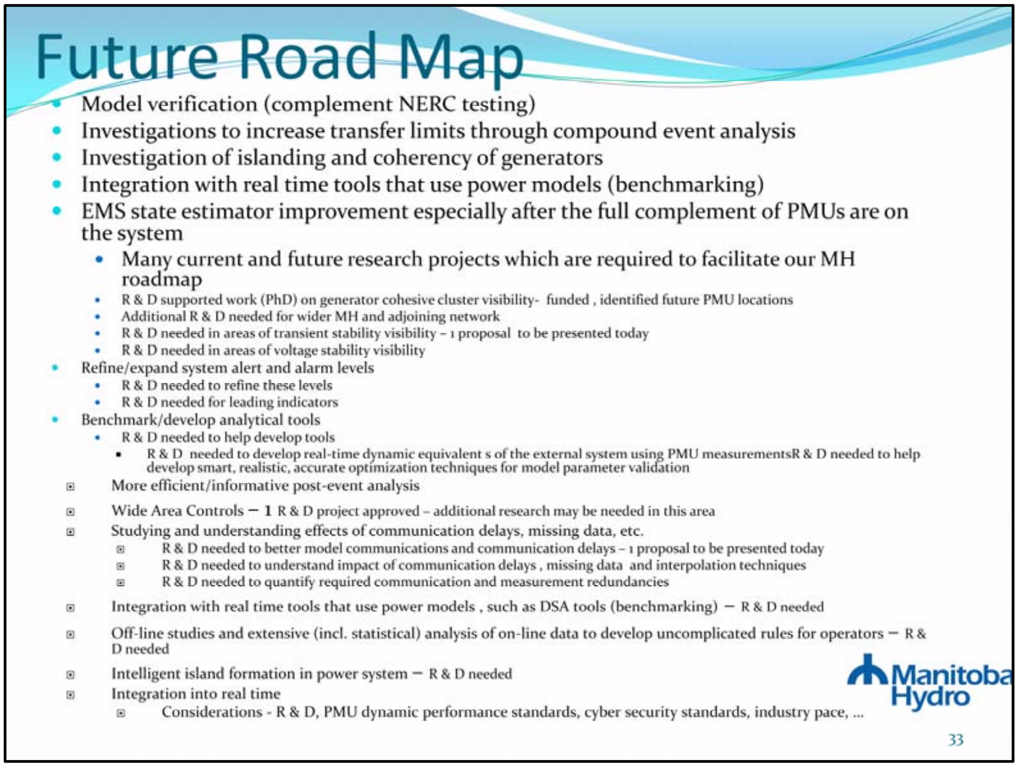
Gains and droop settings on Ponton and Birchtree SVCs were optimized to mitigate fighting in real time.



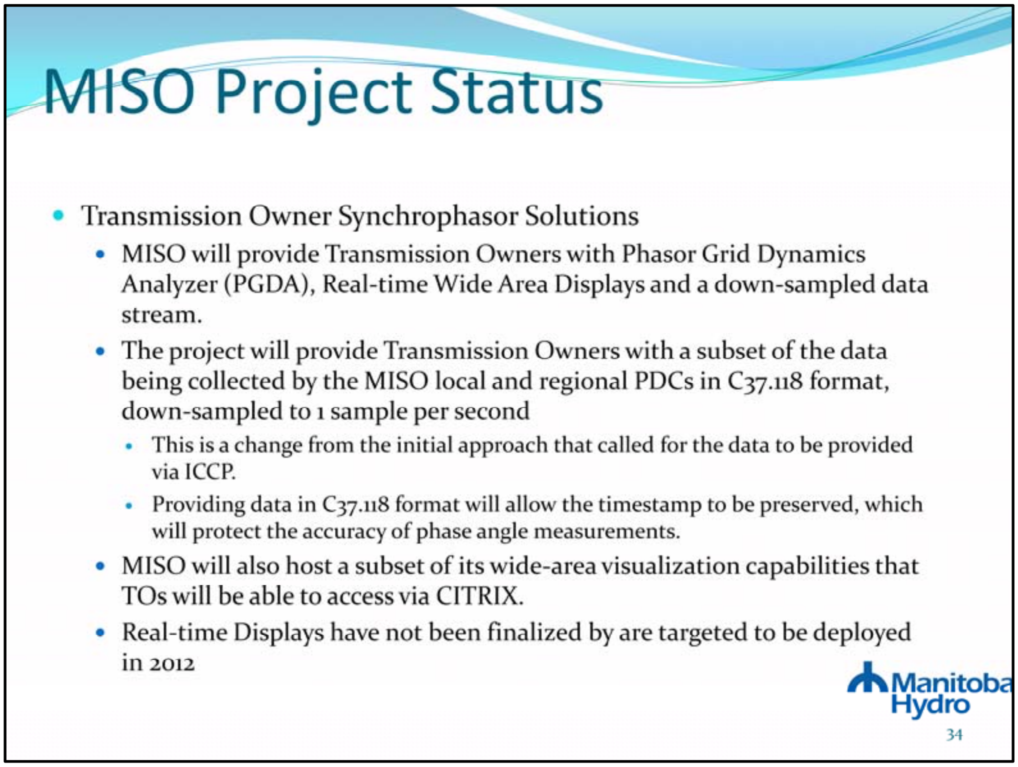
SLG fault tests how the PODs, at both Birchtree and nearby Ponton , interact while the SVC is pushed to the rail. The result is favorable without fighting amongst controllers.



Lessons learned are highlighted.



Research initiatives are highlighted. A busy slide but mainly so others can take copies of slides away later after the presentation.



MISO will allow us to tap into some of their tools both in real time and off-line.

MISO Project Status (continued)

- Transmission Owner Solutions (continued)
  - Host Phasor Grid Dynamics Analyzer (PGDA), an historical phasor-data event analysis tool, and provide TOs with access to the application and data to analyze.
  - Users will be able to analyze events and save them to the MISO Extranet for later access.
  - MISO will be hosting Synchrophasor training for members. PGDA training will occur early next year. The timeline for hosting PGDA includes:
    - Pilot selected events with first TO by Q2 2012, and have deployed to all TOs by the end of 2012.
    - Data archive available for analysis by Q3 2012
    - PGDA training for TOs to start in 2012
      - First session will be instructor-lead, later session will be hands-on

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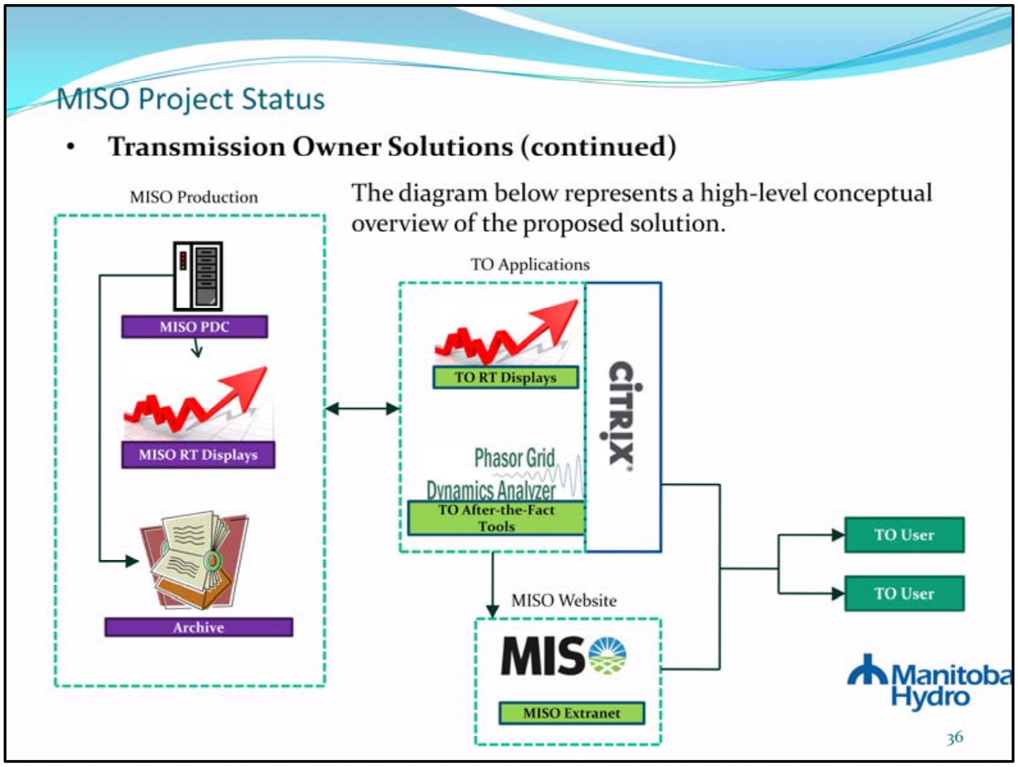
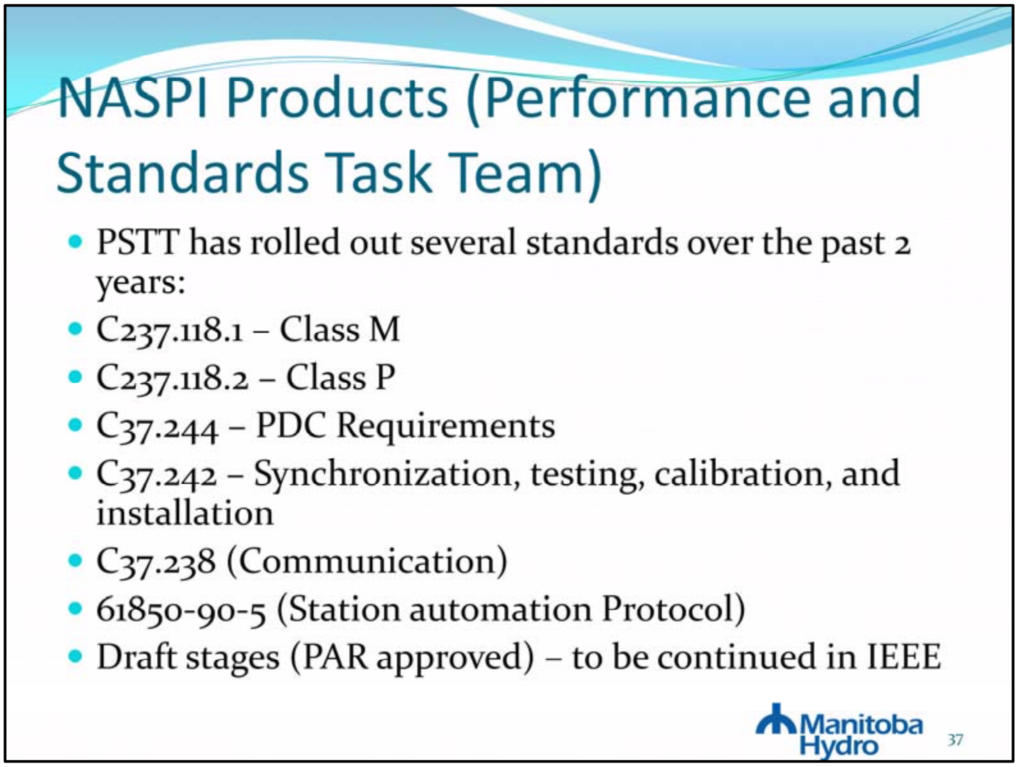
Training will be provided

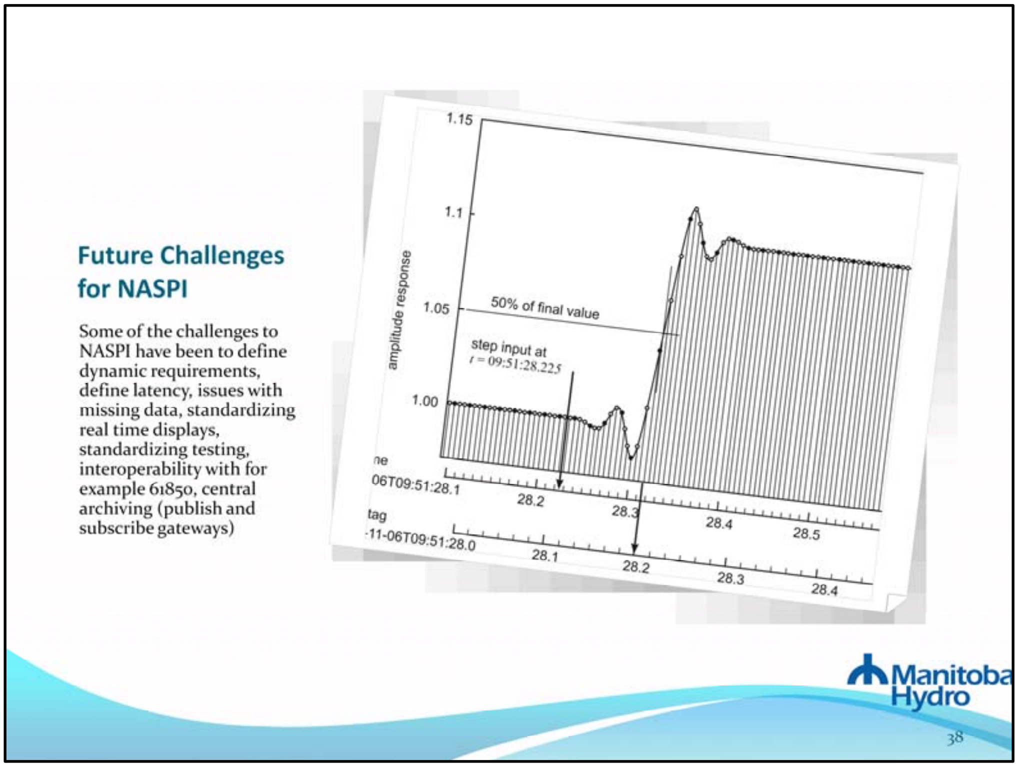


The applications will roll out to users as above.



Some of the challenges to NASPI have been to define dynamic requirements, define latency, issues with missing data, standardizing real time displays, standardizing testing, interoperability with for example 61850, central archiving (publish and subscribe gateways).

NASPI has been directly involved with the literal word for word writing of all of these standards prior to them becoming standards.



Latency becomes difficult to quantize when time stamping introduces its own errors during dynamic response. In the figure, the time stamp is corrected back to when the initial step occurred in real time based on the dynamic response of the PMU to 50% level, but the correction has its own error that will change the latency. The issue is more complicated as the window of the calculation changes the calculation latency.

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