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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.

Topics of Discussion

- NASPI and the MISO Project
- Description of Manitoba WAMS
- Introduction to Birchtree SVC Project
- Commissioning Results
- Lessons Learned and MH Future Road Map
- MISO Project Status
- NASPI Products & Future Challenges

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		PMU	
	Contracted	Connected	Confirmed Sites	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

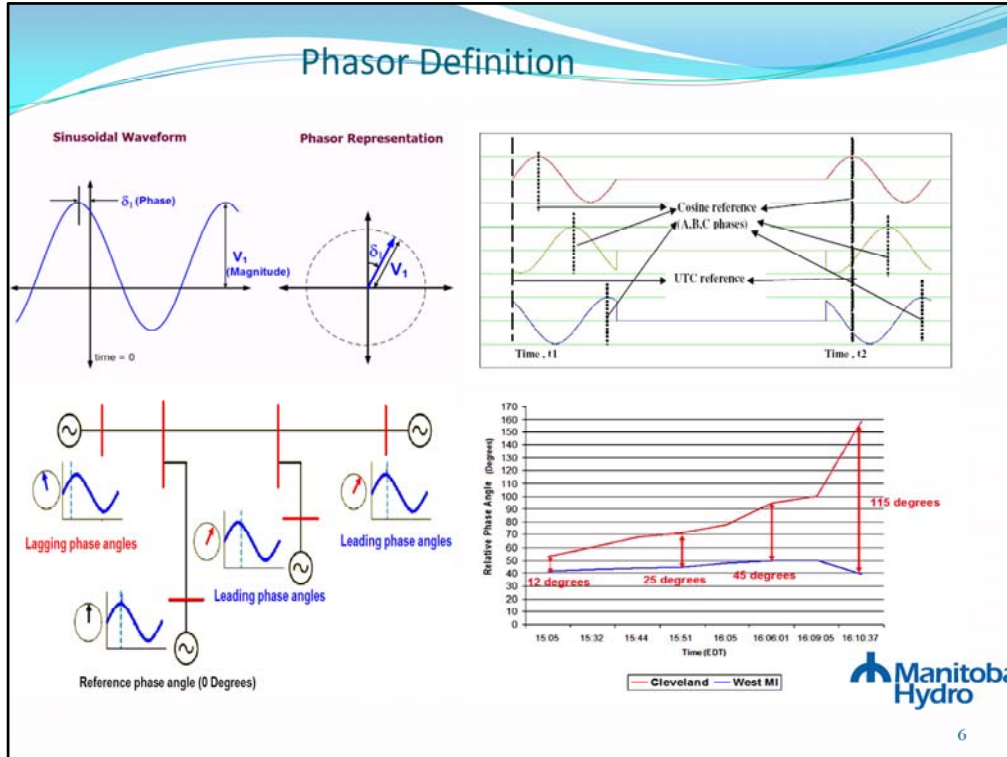


MISO ISOs that are involved in the MISO Synchrophasor Project are shown. MH is a leader in the overall initiative.

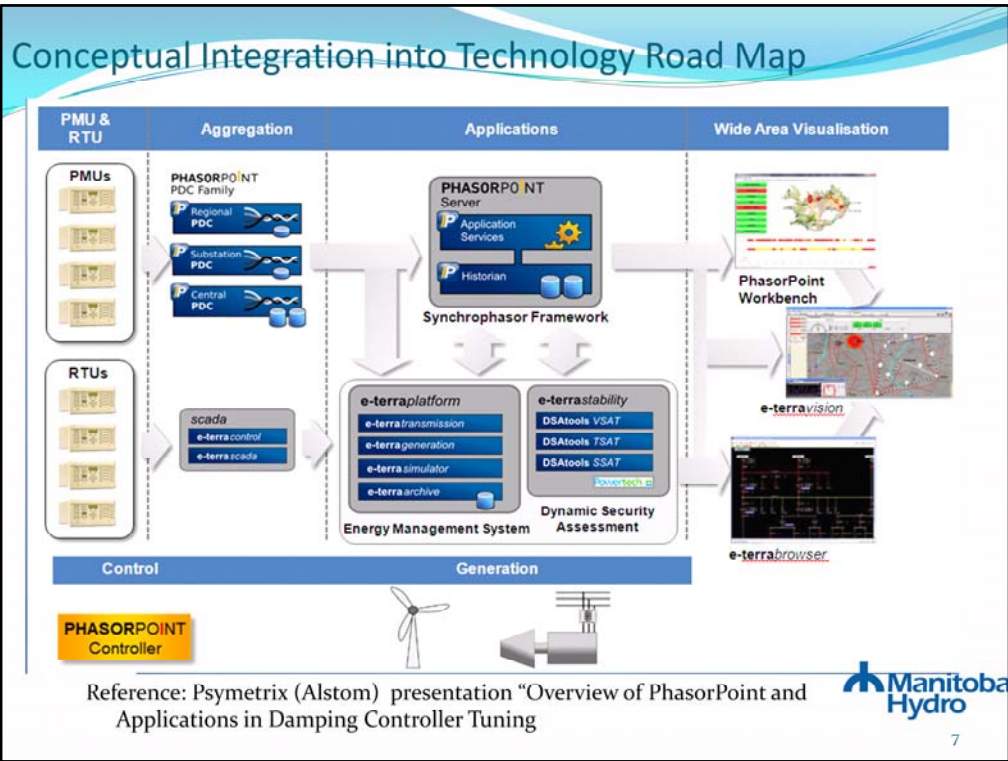
Need for wide Area Measurements

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

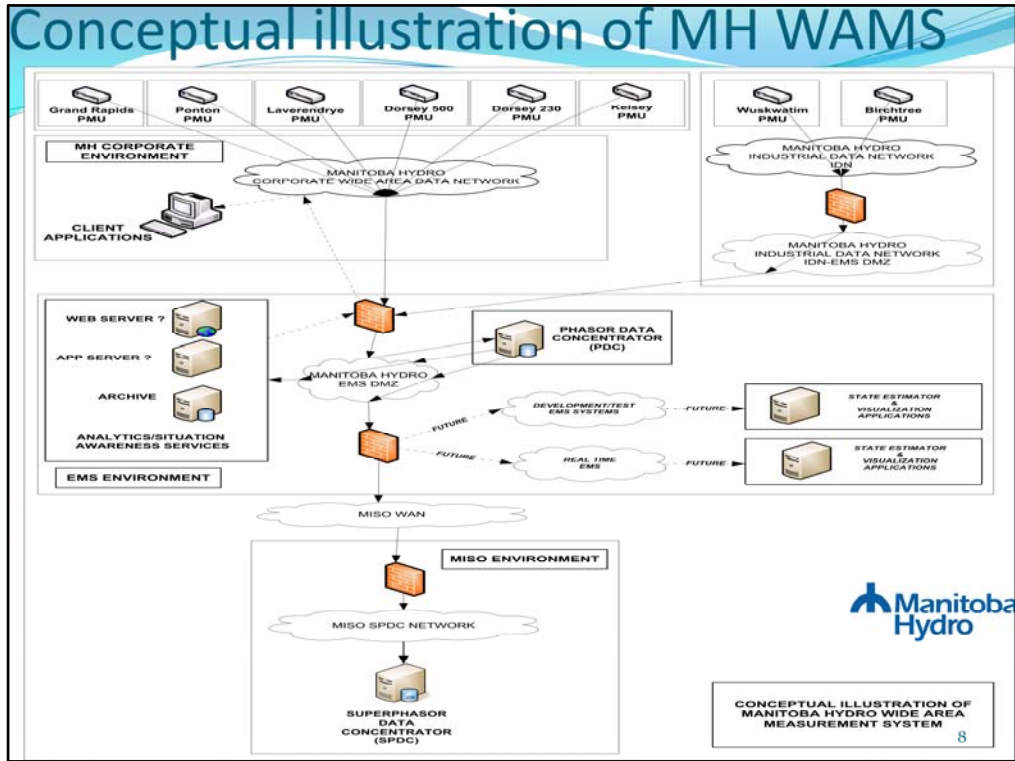
A brief description of why our first application of WAMS was justified.



The cosine reference is defined in C37.118 as $V_a = -90$ 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.



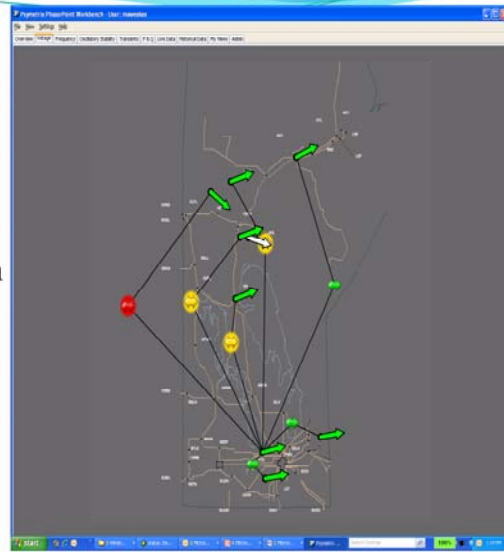
This slide shows how applications will roll out to the users.



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)



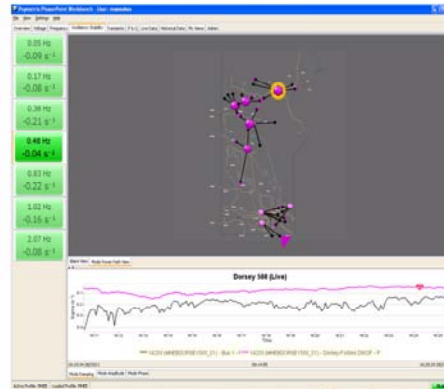
Our visualization tool.

Phasor Point

Mode Charting



Mode Power Path



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 $|\sigma|$ (damping coefficient) which is the inverse of the decay time and can be related back to damping ratio (ζ).

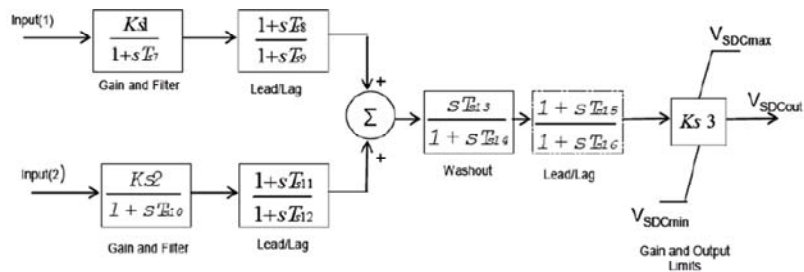
All the modes we saw had been seen before in other studies but the persistence of the mode was not necessarily known. We noted some modes were poorly damped but remained very low in magnitude so they did not cause concern. Alarms were set so that if the magnitude on these poorly damped modes ever increased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

Sites Chosen

- known inter-area modes in our Northern ac.
- sensitivities of modes to various power flow conditions
- Upcoming projects in Northern ac:
 - Seven units at Kelsey G.S. refurbishment to include high initial response static exciters and modern PSS
 - New Birchtree SVC SDC (to be presented here)
 - Three unit proposed for Wuskwatim G.S. will include high initial response static exciters with modern PSS
 - Grand Rapids is being considered for PSS
 - Refinement of Ponton SVC SDC
 - Refinement of Kettle units 1 and 2 PSSs
- Future sites will increase from 6 to 30 PMU locations
- Using existing TFR devices

Background reasons for site choices were given.

Power Oscillation Damper (POD)



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)

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



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

Risks and Mitigations

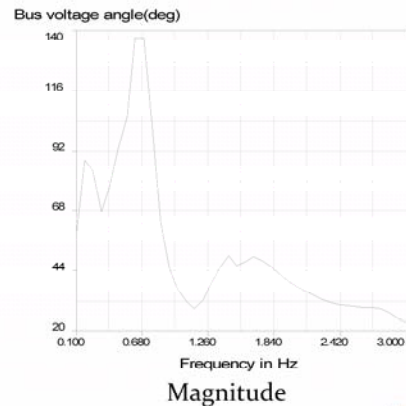
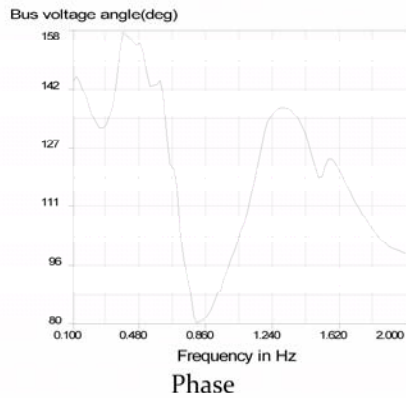
- Output is correctly controlled from input, as expected
- Check the degree of movement in the rest of the system in response to a step change
- Confirm consistency with time-domain measurements
- Decide criteria for “unacceptable” oscillations.
- Switch controllers off one-by-one or plant-by-plant,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

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.

System Frequency Response

- Model verification (frequency response) of SVC POD design



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



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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.

Cont....Simulation Results

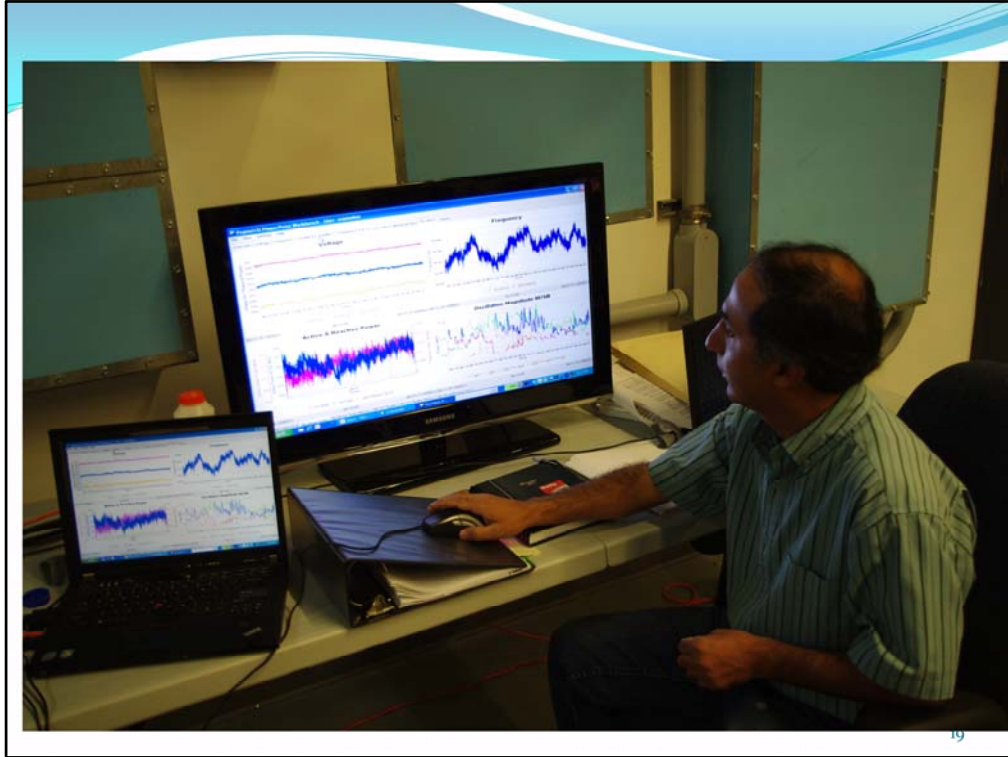
- Frequency Domain

MODAL COMPONENTS					
COMP. NO	EIGENVALUE		EIGENVECTOR		REMARKS
	REAL	IMAGINARY	MAGNITUDE	ANGLE	
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.

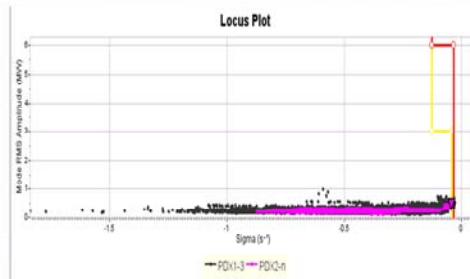


A large screen displaying synchrophasor information in real time visible to commissioners armed with the “kill switch” were invaluable. (Dr. Al-Hadidi shown)

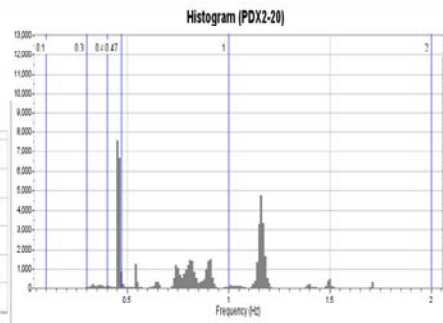
Mode Trending

Root locus of mode

- Trending and verification of damping controller performance



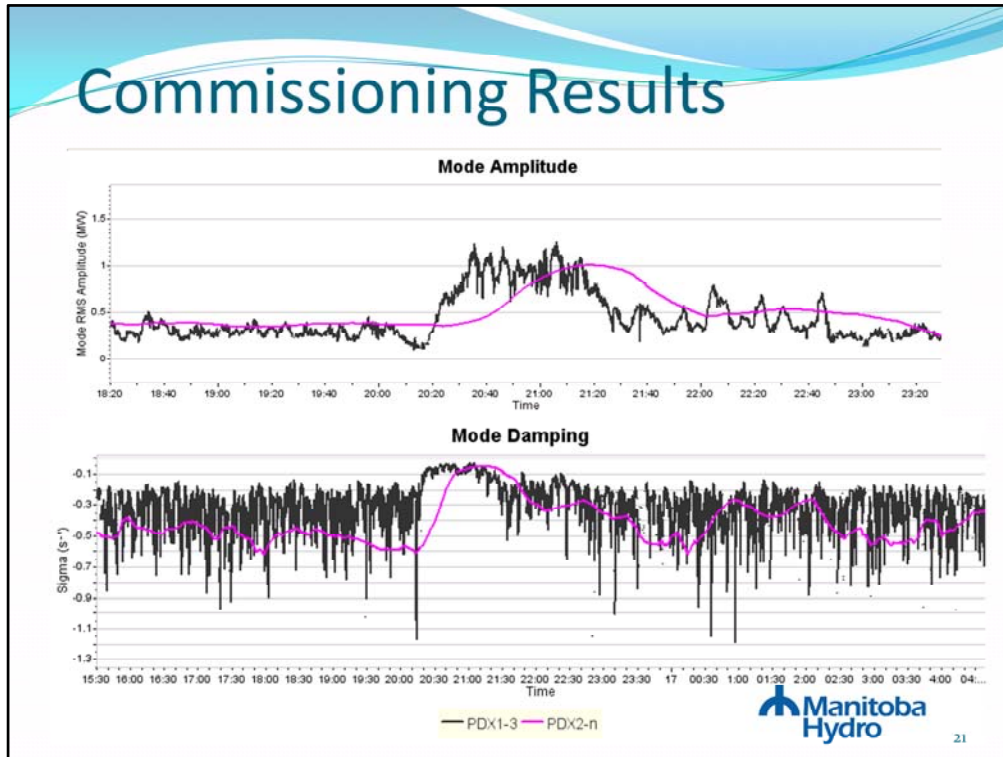
Observability of the mode over time



Manitoba
Hydro

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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.

Unexpected Results Captured

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

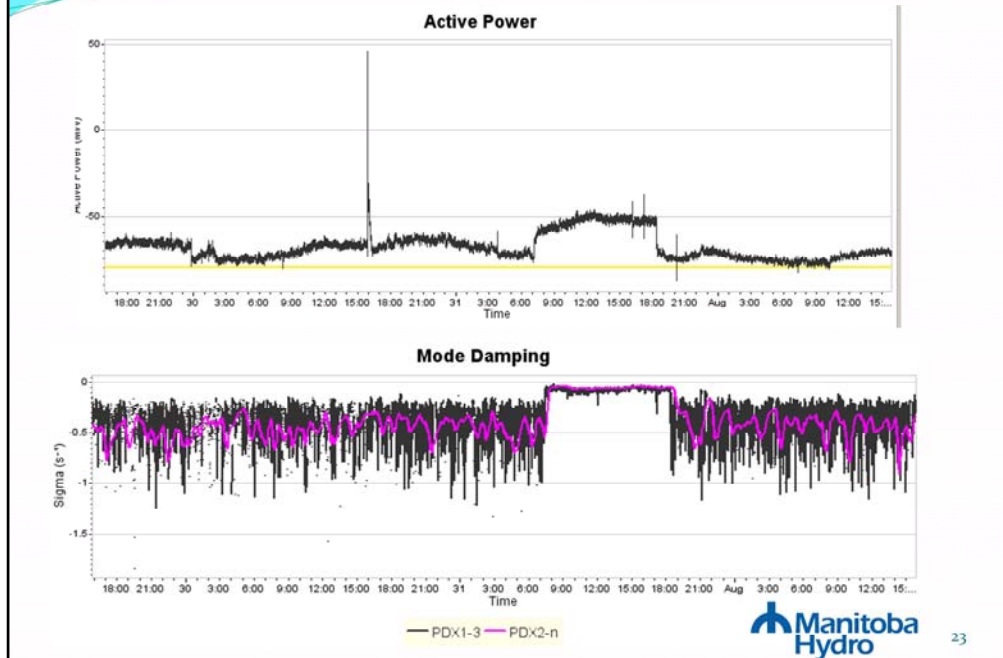
One explanation of the unexpected result of mode increases with lower power is some power system stabilizers do not turn on when the generator is operating at low power in the rough zone. This leads to better damping as the generator power is increased.

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,

Cont.....System Baseline

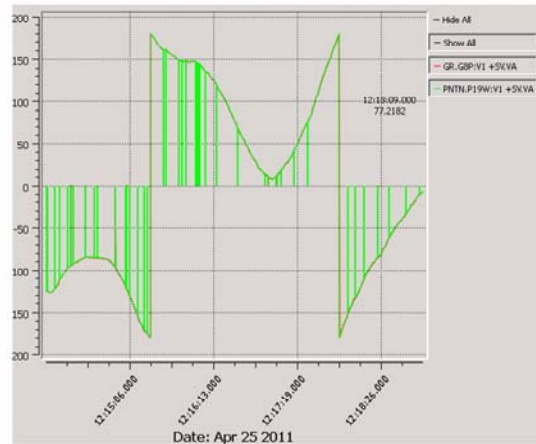


Example of mode increasing with lower power. As explained earlier, one explanation can be PSSs turned off while generators are in the rough zone of lower power and thus less damping on the system.

Cont....System Baseline

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

Clock Errors

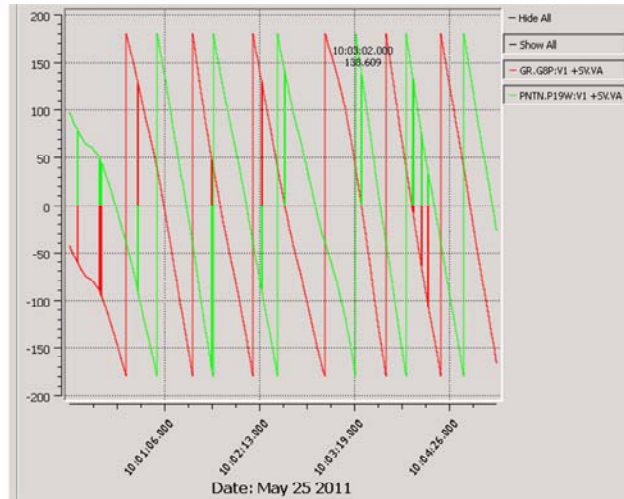


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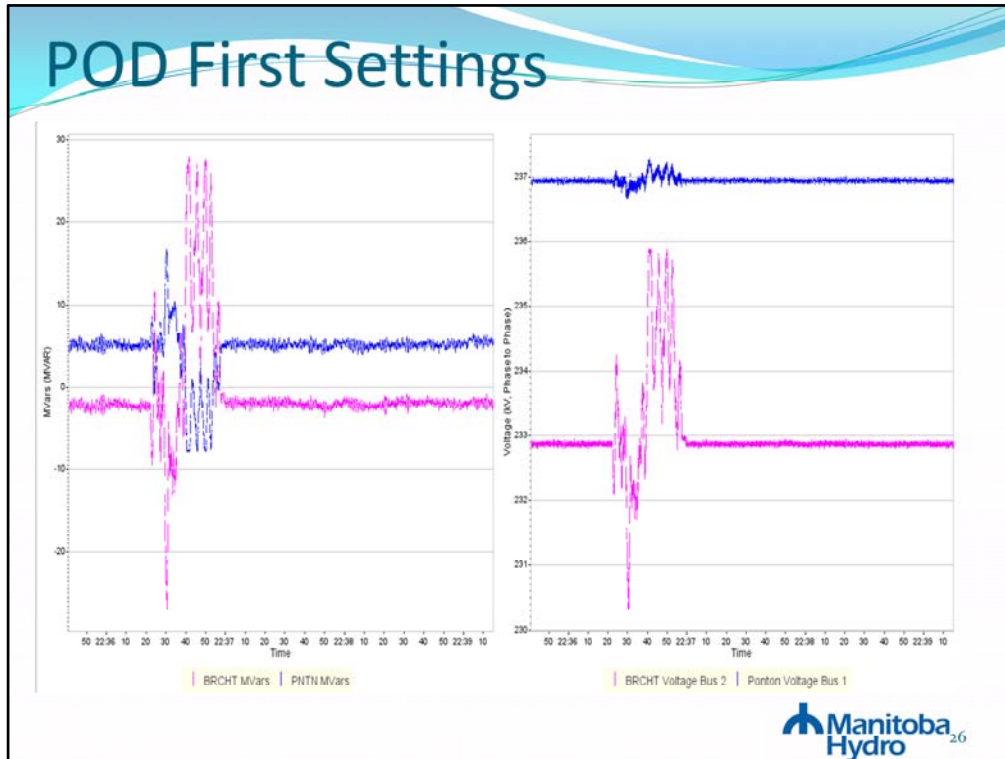
Prior to the disturbance the angles from the two nearby stations of Ponton and Birchtree overlap as expected. The vertical lines are due to times that data is lost (higher level software like the PhasorPoint tool can filter these out but raw MISO data is shown here).

Cont....System Baseline

May 25, 2011



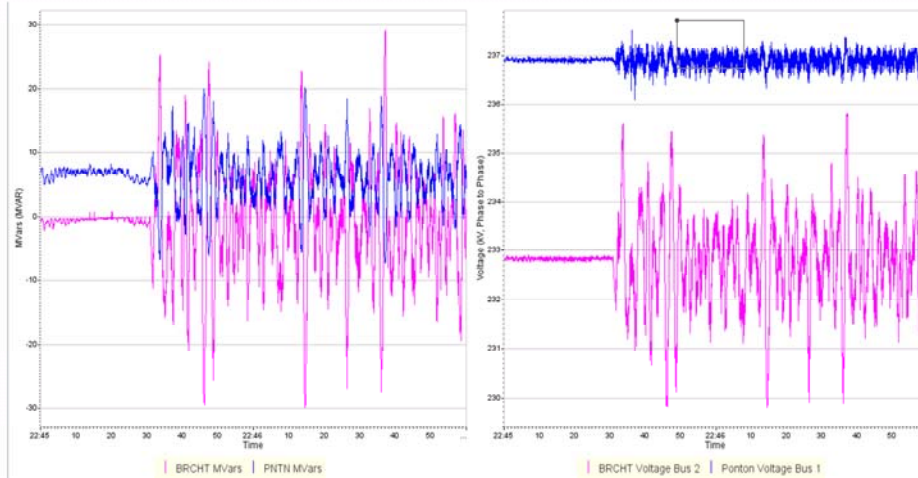
Unexpected 120 degree phase error aligned with what we thought was line transposition but was actually clock error caused by a faulty antenna. The phase re-aligned correctly once the antenna was replaced. Future mitigation and maintenance become real issues especially if the error was only 5 degrees.



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.

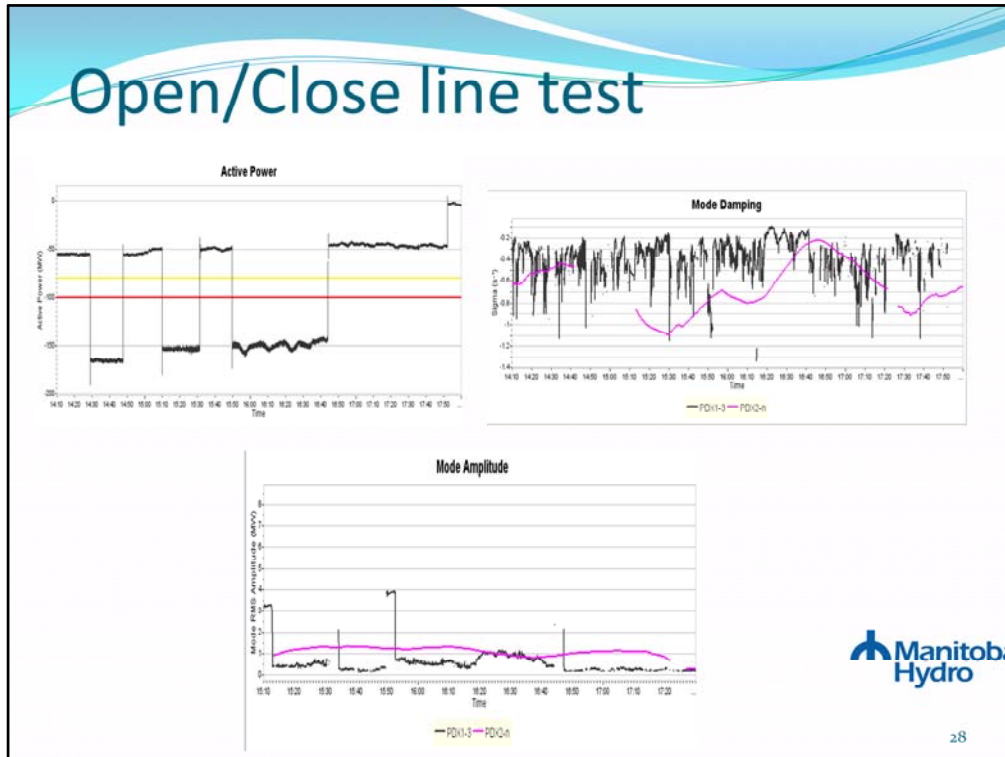
POD Second Settings



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.

Open/Close line test



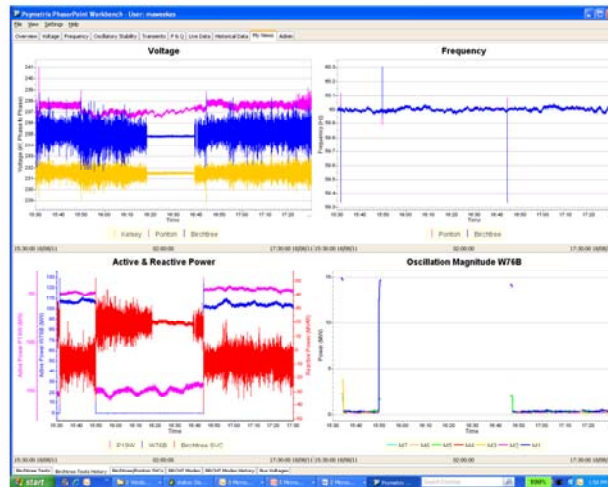
POD “ON” and “OFF” as well as switching of lines is shown. 0.7 Hz mode is seen rising when the POD is OFF and coming down when the POD is on (pink trace).

Settling time could have been longer but trending of the mode was the main concern. The damping was clearly noted improving 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).

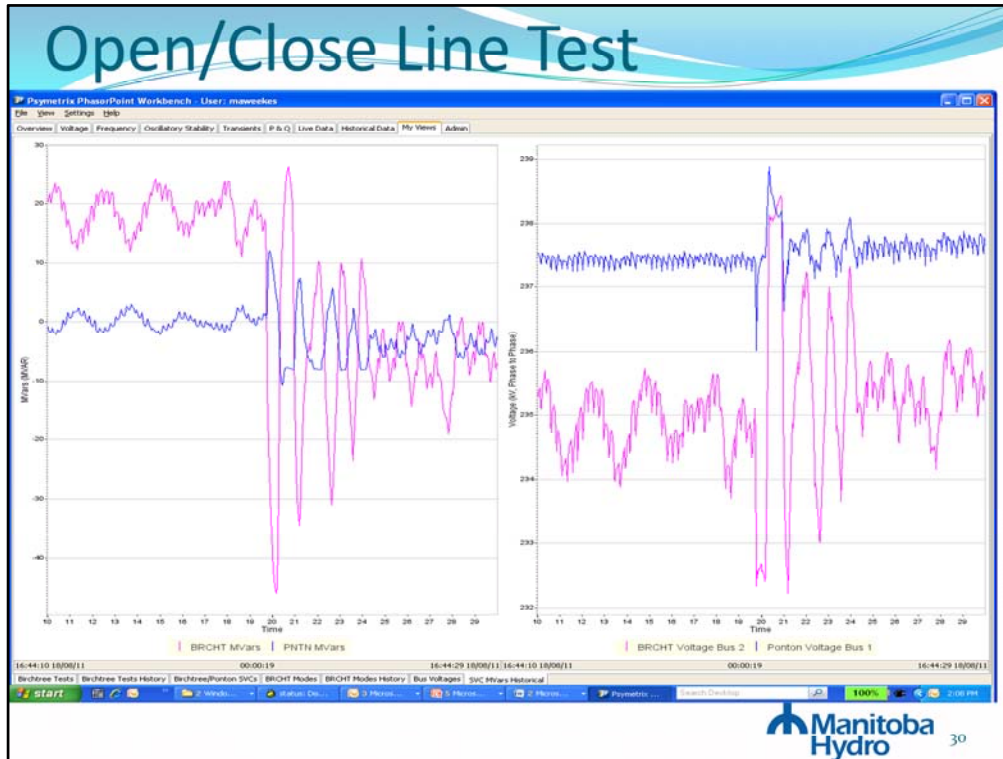
It is noted that the pink trace is a 20 minute window and the black trace is a 1-3 minute window and while the black trace is best for picking up the mode for line switching transients the pink trace is best for picking up the mode for POD “ON” - “OFF” changes (over longer times).

Open/Close Line Test



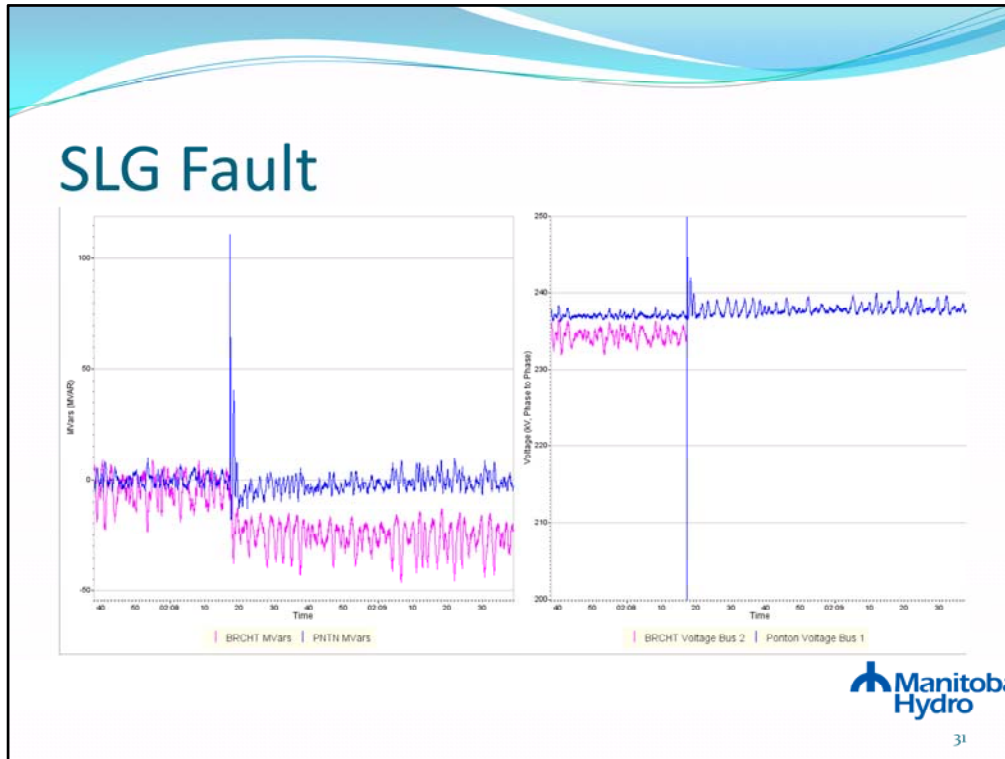
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For the plot on the right bottom corner, one can note the power mode on line P19 W disappear as line is opened since signal is lost – importance of choosing signals correctly is emphasized. The mode is very quickly damped when the line is closed in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

- **Channel Selection** (problem with power calculation if switching occurs)
- Importance of doing a **frequency response** initially 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

Lessons learned are highlighted.

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
 - Many current and future research projects which are required to facilitate our MH roadmap
 - R & D supported work (PhD) on generator cohesive cluster visibility- funded , identified future PMU locations
 - Additional R & D needed for wider MH and adjoining network
 - R & D needed in areas of transient stability visibility – 1 proposal to be presented today
 - R & D needed in areas of voltage stability visibility
- Refine/expand system alert and alarm levels
 - R & D needed to refine these levels
 - R & D needed for leading indicators
- Benchmark/develop analytical tools
 - R & D needed to help develop tools
 - R & D needed to develop real-time dynamic equivalent s of the external system using PMU measurementsR & D needed to help develop smart, realistic, accurate optimization techniques for model parameter validation
- More efficient/informative post-event analysis
- Wide Area Controls – 1 R & D project approved – additional research may be needed in this area
- Studying and understanding effects of communication delays, missing data, etc.
 - R & D needed to better model communications and communication delays – 1 proposal to be presented today
 - R & D needed to understand impact of communication delays, missing data and interpolation techniques
 - R & D needed to quantify required communication and measurement redundancies
- Integration with real time tools that use power models, such as DSA tools (benchmarking) – R & D needed
- Off-line studies and extensive (incl. statistical) analysis of on-line data to develop uncomplicated rules for operators – R & D needed
- Intelligent island formation in power system – R & D needed
- Integration into real time
 - Considerations - R & D, PMU dynamic performance standards, cyber security standards, industry pace, ...



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

MISO Project Status

- Transmission Owner Synchrophasor Solutions
 - MISO will provide Transmission Owners with Phasor Grid Dynamics Analyzer (PGDA), Real-time Wide Area Displays and a down-sampled data stream.
 - The project will provide Transmission Owners with a subset of the data being collected by the MISO local and regional PDCs in C37.118 format, down-sampled to 1 sample per second
 - This is a change from the initial approach that called for the data to be provided via ICCP.
 - Providing data in C37.118 format will allow the timestamp to be preserved, which will protect the accuracy of phase angle measurements.
 - MISO will also host a subset of its wide-area visualization capabilities that TOs will be able to access via CITRIX.
 - Real-time Displays have not been finalized by are targeted to be deployed in 2012



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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



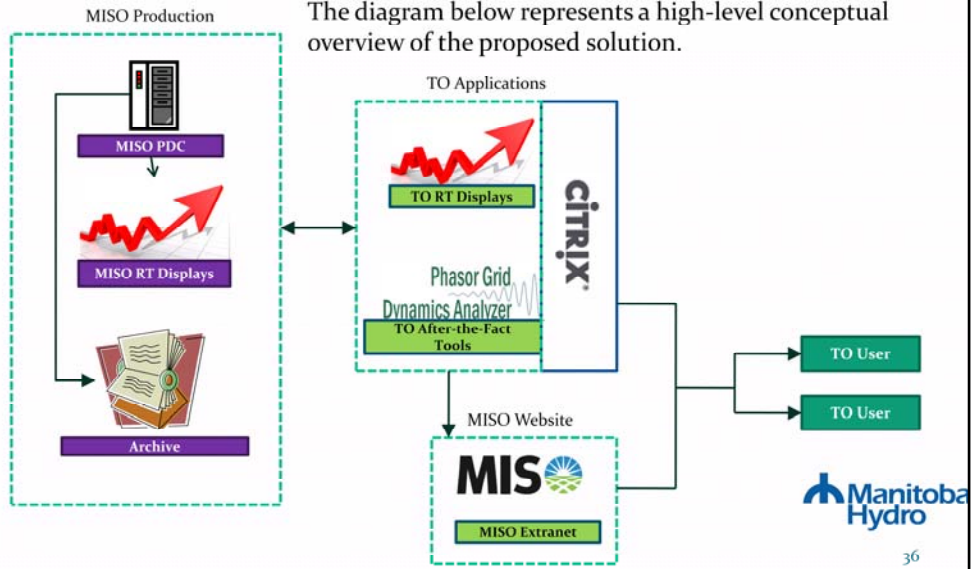
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Training will be provided

MISO Project Status

- **Transmission Owner Solutions (continued)**

The diagram below represents a high-level conceptual overview of the proposed solution.



The applications will roll out to users as above.

NASPI Products (Performance and Standards Task Team)

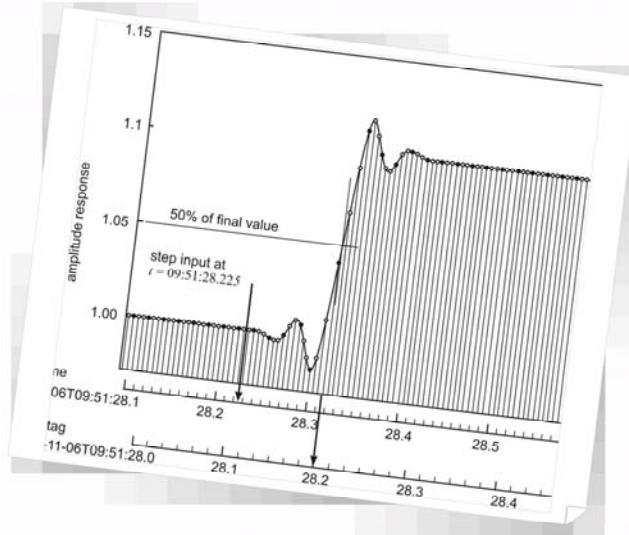
- PSTT has rolled out several standards over the past 2 years:
- C237.118.1 – Class M
- C237.118.2 – Class P
- C37.244 – PDC Requirements
- C37.242 – Synchronization, testing, calibration, and installation
- C37.238 (Communication)
- 61850-90-5 (Station automation Protocol)
- Draft stages (PAR approved) – to be continued in IEEE

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.

Future Challenges for NASPI

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)



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.

