Event Analysis Using Phasor Data

John Adams/Prakash Shrestha, ERCOT
and
John Ballance/Prashant Palayam
Electric Power Group

North American Synchro Phasor Initiative Meeting
June 5-6, 2012, Denver, Colorado
(Draft_05252012)

DOE Smart Grid Demonstration Project

- **Awarded to CCET** - Texas 501(c)6 non-profit formed in 2005
- **CCET Members and Mission**: 21 corporate members and 5 university cooperators. Mission - enhance the safety, reliability, security, and efficiency of the Texas electric transmission and distribution system through research, development and commercialization of emerging technologies (http://www.electrictechnologycenter.com)
- **Awarded Jan 4, 2010**: DE-OE-0000194; Value $27 million (DOE 50%); 17 participants; 3 Components – Synchrophasors, Smart Meter Texas Portal, and Smart Grid Community of the Future; 3 phases – Planning, Design, Demonstration
- **Title**: *Discovery Across Texas*: *Technology Solutions for Wind Integration in ERCOT*
- **Goal**: Demonstrate a synergistic approach to managing fluctuations in wind power (currently 8 GW increasing to 18 GW) in the ERCOT transmission grid through better system monitoring capabilities, enhanced operator visualization, and improved load management
- **Synchrophasor Project Participants:** ERCOT, TOs, Electric Power Group – Lead for Synchrophasor portion of the project

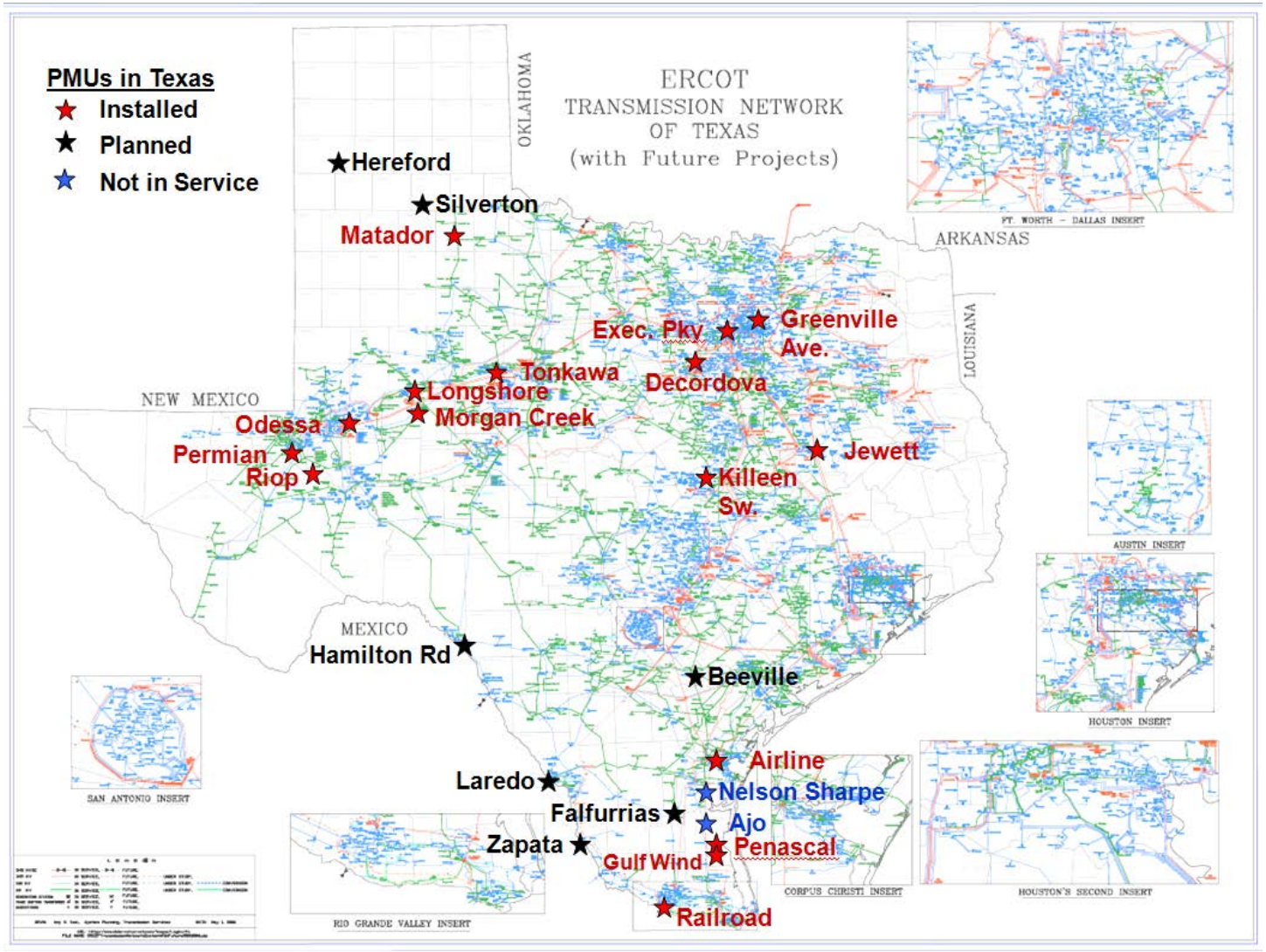
ERCOT Synchrophasor Network

- **Build on Current ERCOT Network started in Fall 2008 with 3 AEP PMUs**
- **Currently 17 PMUs installed at 15 TO locations, and at ERCOT *e*PDC™ for data synchronization, RTDMS® for visualization, and PGDA™ for off-line analysis**
- **Expanding to 23 PMUs, provide TOs access to RTDMS visualization applications**
- **Participating TOs and commitments**
  - AEP TEXAS - 6 new PMUs
  - ONCOR - 4 new PMUs
  - Sharyland Utilities - 3 new PMUs, 1 PDC

Synchrophasor Project Goals

- **Enable ERCOT to *better manage* the transmission grid to accommodate very large quantities of wind generation**
- **Establish and maintain a *reliable synchrophasor network* to provide real time dynamic information on wind resources and their impact on the transmission grid**
- **Use synchrophasor measurements to *identify precursor* conditions to undesirable grid performance and behavior**
- **Identify changes in operating procedures or actions to facilitate integration of intermittent resources, hence *improving grid reliability***
- **Utilize synchrophasor measurements to *recalibrate engineering models***
- **Five examples of ERCOT events that exhibited oscillations caused by units trip and control systems are presented. These were monitored in real time using RTDMS, and for offline analysis PGDA was used. The events being presented are:**
  - ✓ November 3, 2010 (High wind conditions)
  - ✓ September 2011 (Wind controller driven oscillations – modeling issues identified)
  - ✓ January 25, 2012 (Spontaneous wind generation oscillations)

PMU Location in ERCOT Grid



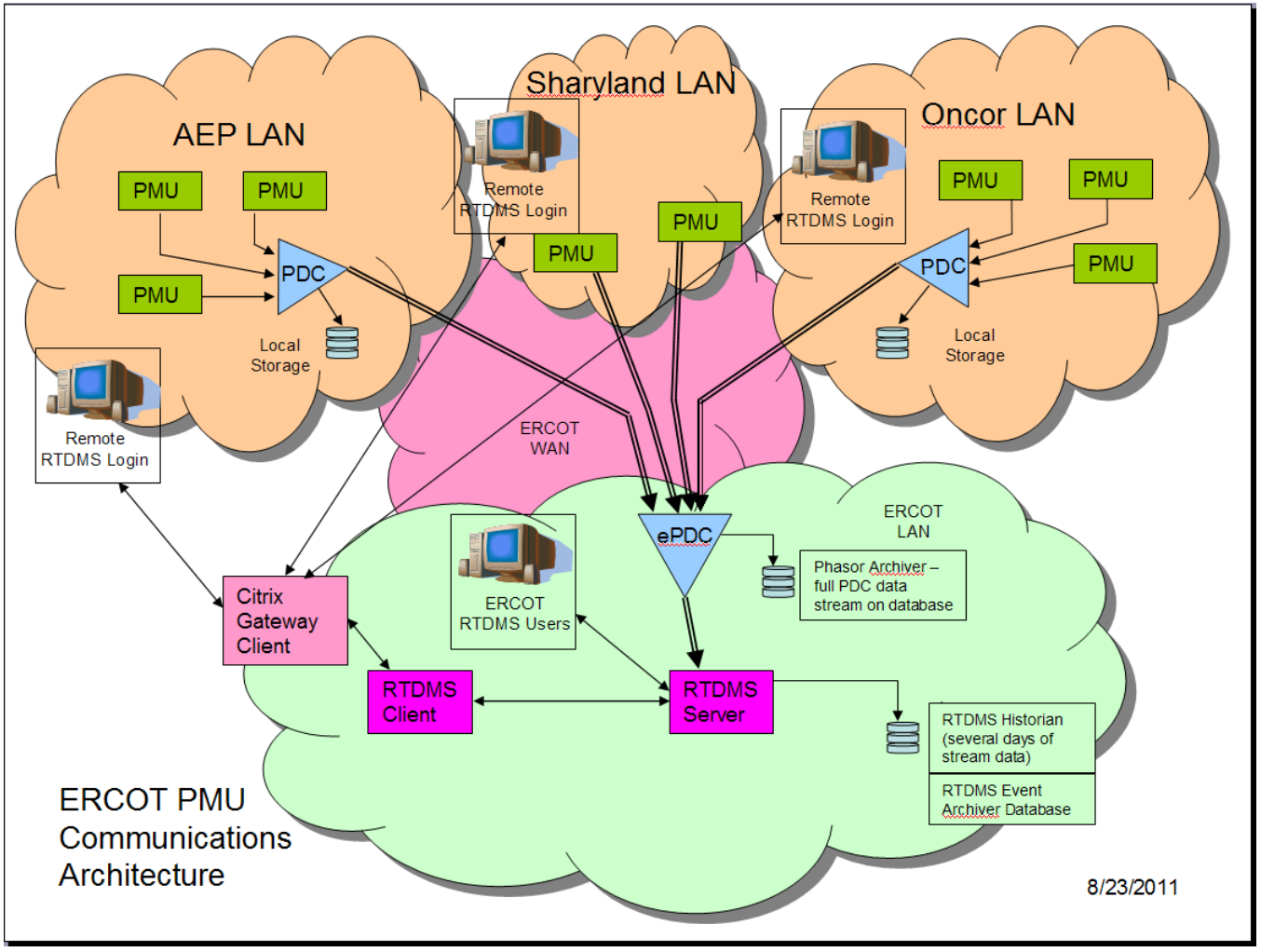
ERCOT

CCET

Center for the Commercialization of Electric Technologies

Electric Power Group

Phasor Data Communication Architecture

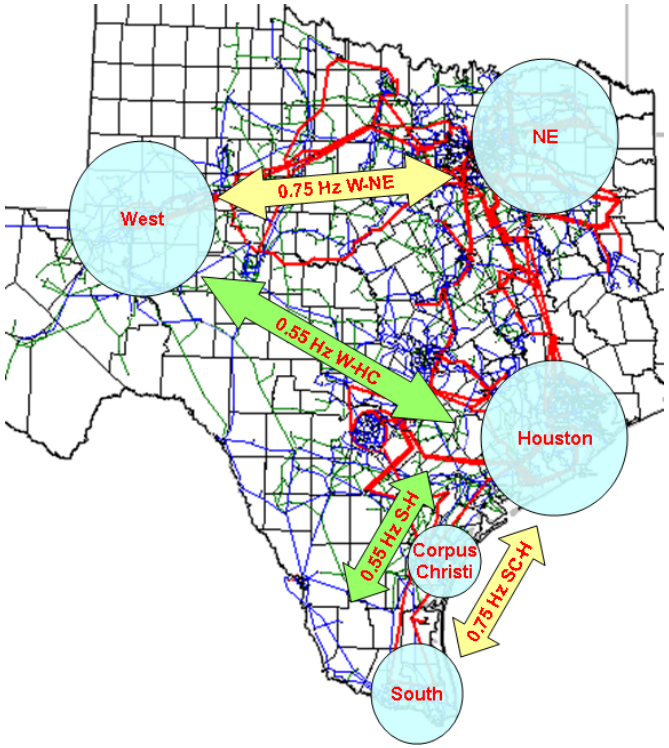


Application of Phasor Measurement

- **Phasor measurement data has been used in ERCOT system mainly for the following purposes:**
  - **Real time system monitoring**
  - **Post-event analysis**

Post-Event Analysis

- **The installation of PMUs allowed ERCOT to observe system-wide transient condition changing before, during and after event disturbances.**
- **In ERCOT dynamic simulation studies, system inter-area oscillations have been observed as two major modes.**



September 22, 2010 – High Wind Conditions

- **Time: 23:33 CDT**
- **Wind Conditions: High (4835 MW)**
- **Trigger Event: Generation Trip – 552 MW**

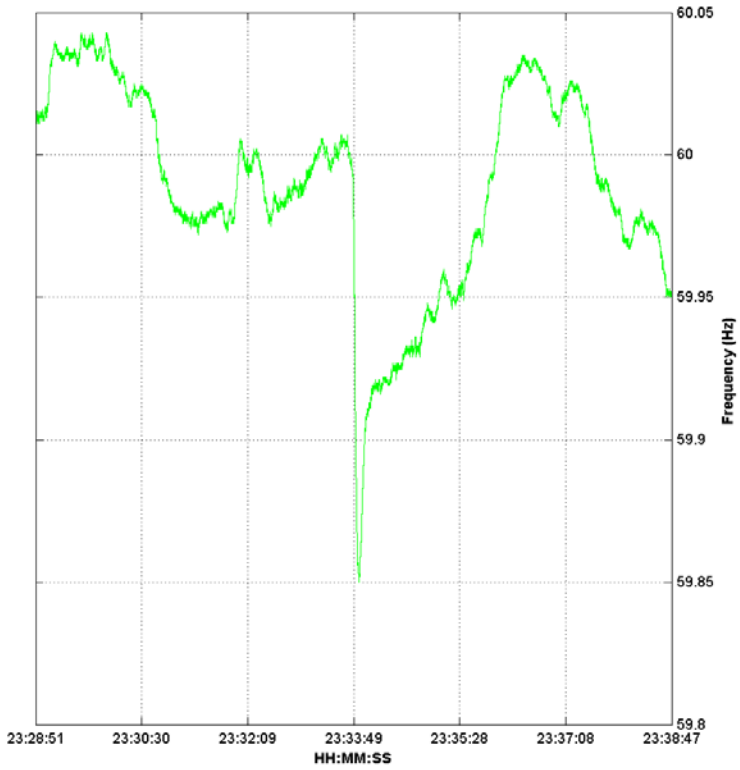
Observations:

Frequency dips and recovers quickly

Oscillations evident near wind generation:

0.28 and 0.67 Hz oscillations are ERCOT post-event electro-mechanical grid oscillations

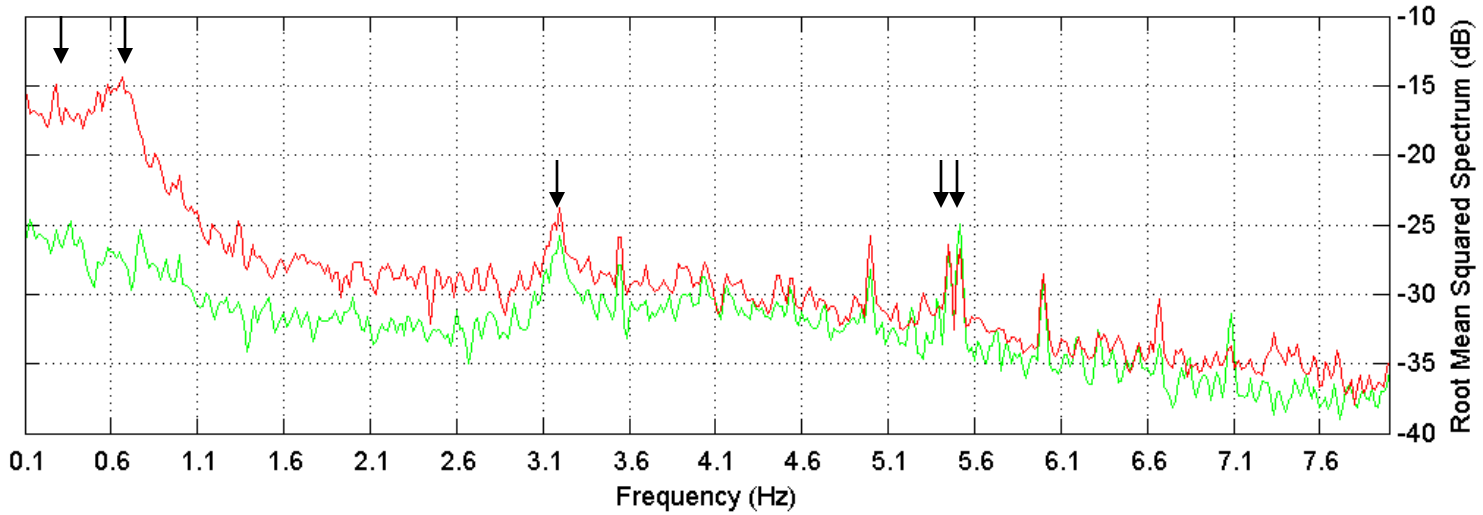
3.2, 5.0, 5.4 and 5.5 Hz oscillations are present in both pre- and post-event voltage magnitude and angle near wind generation



September 22, 2010 – 23:33 CDT

Post disturbance spectral analysis shows oscillations in PMU voltage magnitude and angle near wind generation at:

- 0.28 Hz – natural ERCOT frequency
- 0.67 Hz – natural ERCOT frequency
- 3.2 Hz – only apparent in wind generation areas
- 5.0 Hz – only apparent in wind generation areas
- 5.4 Hz – only apparent in wind generation areas
- 5.5 Hz – only apparent in wind generation areas



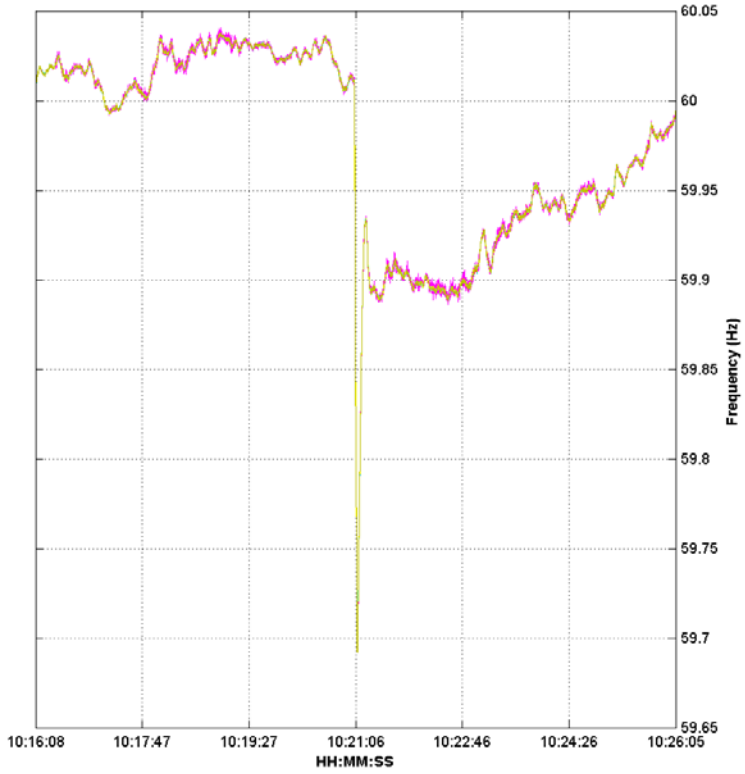
November 3, 2010 – High Wind Conditions

- **Time: 10:21 CST**
- **Wind Generation: 4642 MW (13% of total generation)**
- **Trigger Event: Generation Loss – 1353 MW**

Observations:

Frequency dips to 59.69 Hz and recovers quickly

Oscillations mode of 0.7 Hz and 8% of damping ratio was observed

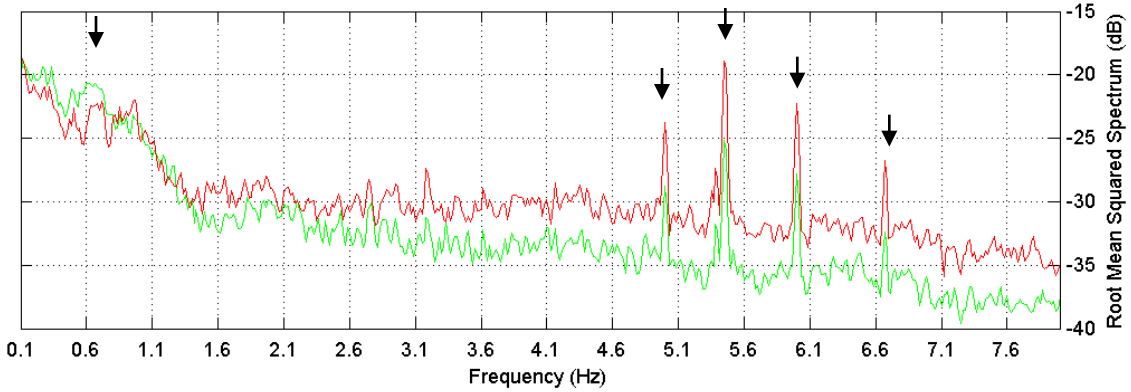


November 3, 2010 – 10:21 CST

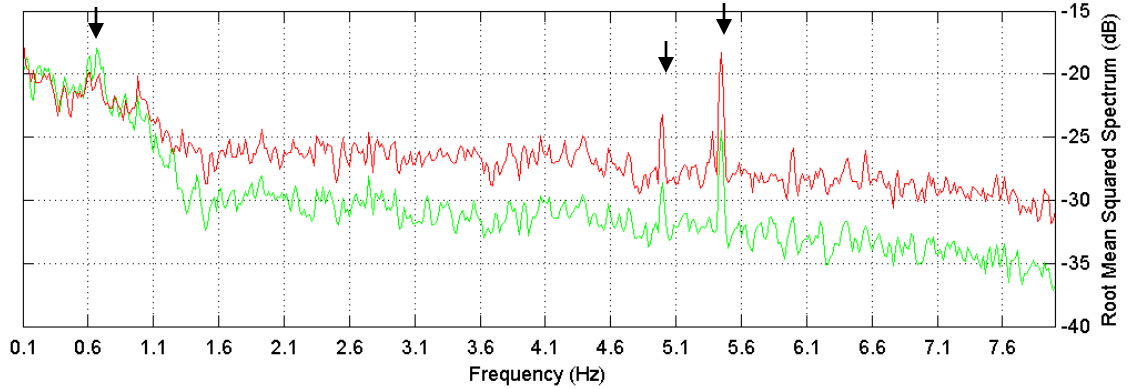
Spectral analysis reveals several oscillation frequencies in voltage magnitude and angle signals near wind generation:

- 0.7 Hz natural ERCOT grid oscillation
- 5.0 & 5.4 Hz oscillations in pre- and post-event records, near wind
- 6.0 & 6.7 Hz oscillations show in pre-event only

Pre-event



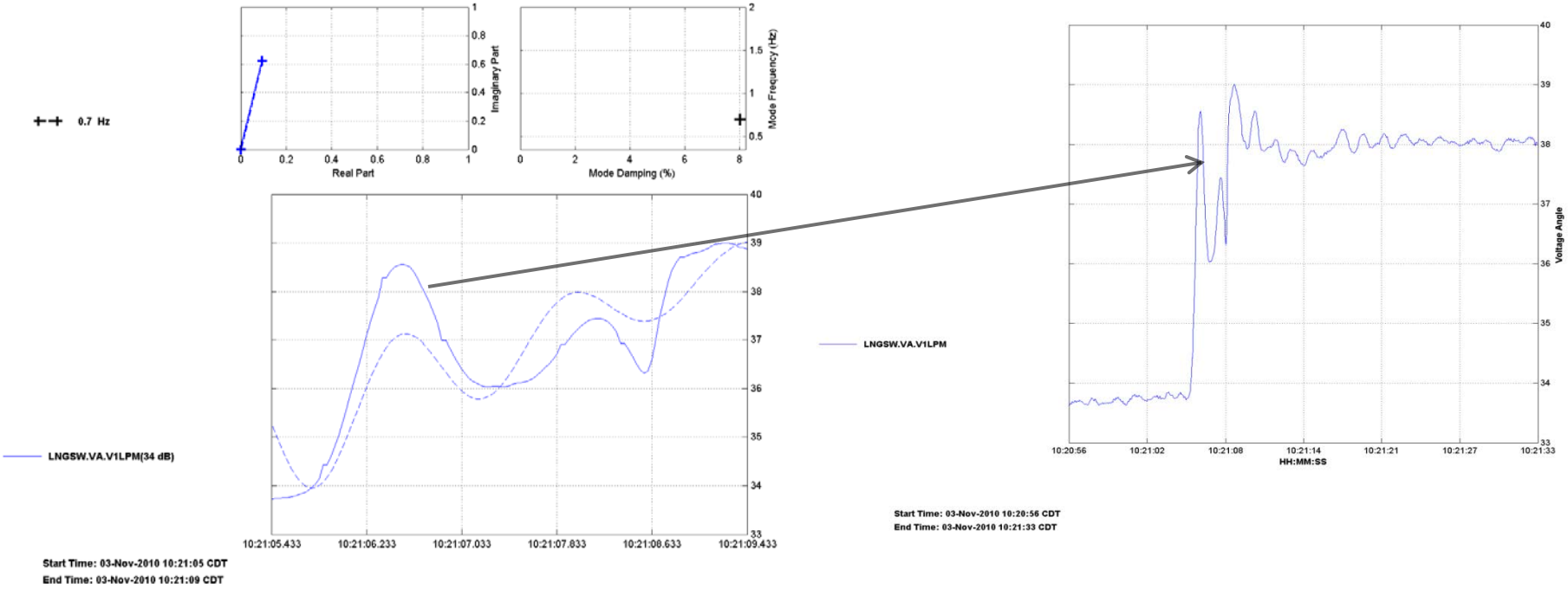
Post-event



November 3, 2010 – 10:21 CST

Modal analysis was performed to determine the oscillation mode and damping ratio :

- 0.7 Hz oscillation was observed



Modal Analysis

Multiple Events – Spectra in vicinity of wind generation

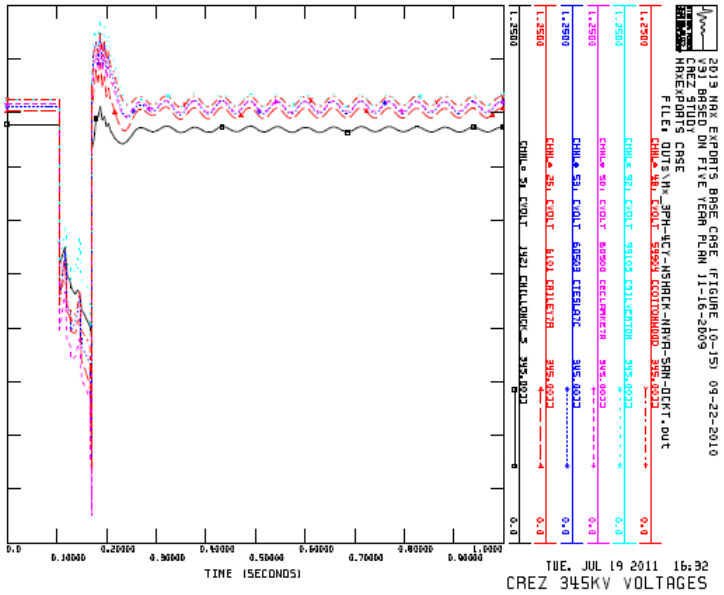
Date	MW	Wind %	Modal f	Other spectra observed
9/22/2010	552	11%	0.28, 0.67	5.0 -26 db 5.3 -27 db 5.5 -27 db
11/3/2010	1353	13%	.7 Hz	5.0 -23 db 5.4 -18 db
10/13/2011	450	1%	.28	5.4 -24 db 6.0 -23 db

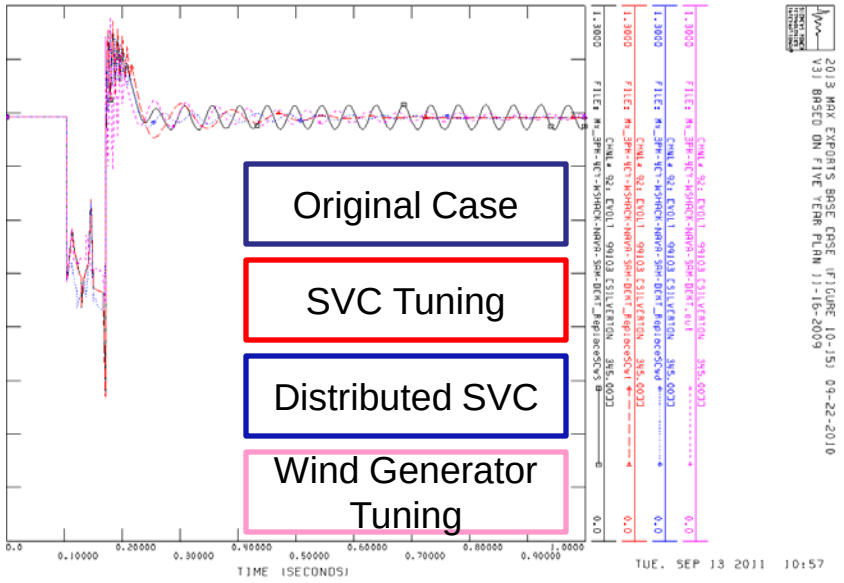
September 2011 – Wind Controller-Driven Oscillations

- **Wind Farm**
  - ~60MW, (type 4 turbines)
  - Connect to main grid through two 69kV lines.
  - Connect to the weaker grid compare to the existing wind farms.
  - SCR is 4 under normal operations
- **One of the 69kV lines has been out of service since September 1st, 2011 for a scheduled transmission project.**
  - SCR is reduced to 2 after the 69kv line outage
- **Several operation events (poor damping, negative damping) had been observed and captured by the PMU (phasor measurement unit) located at the remained 69kV line.**
  - 30~40MW, poor damping
  - >40 MW, negative damping

    (Also subjected to the magnitude of the disturbance)

CREZ High Frequency Oscillations at High Wind Output

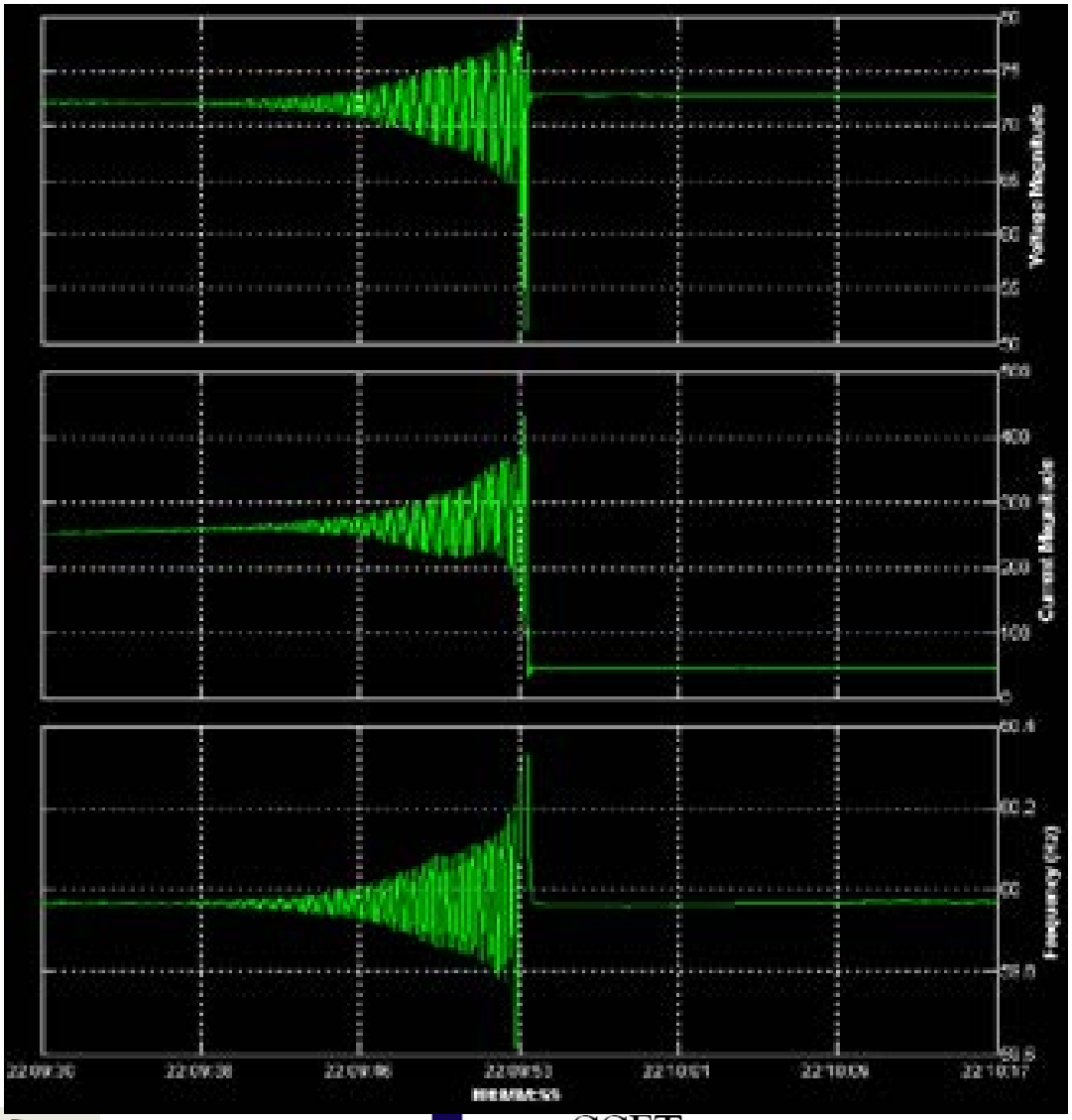




- **Cause: Weak Grid + High Wind Output + Fast Voltage Control**
- **Solutions: Wind Controller Tuning, Grid Enhancement**

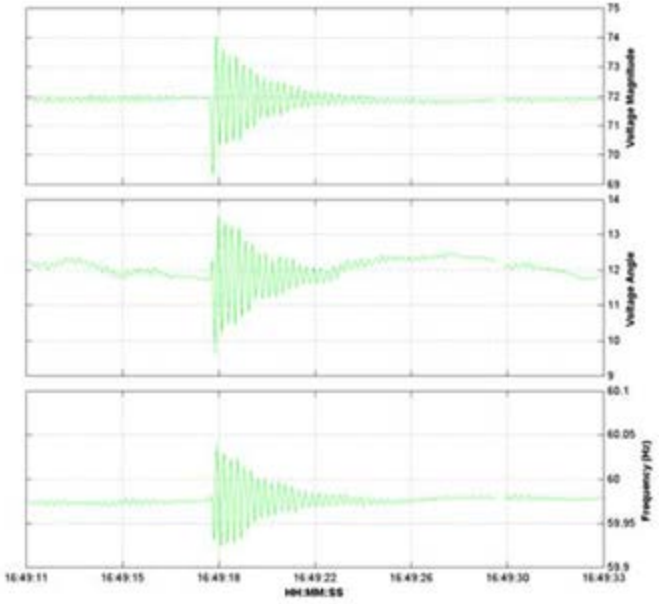
Can these high frequency oscillations be real?

ERCOT Synchrophasor observed voltage event near wind turbine



Event Analysis: Dynamic study using identical conditions

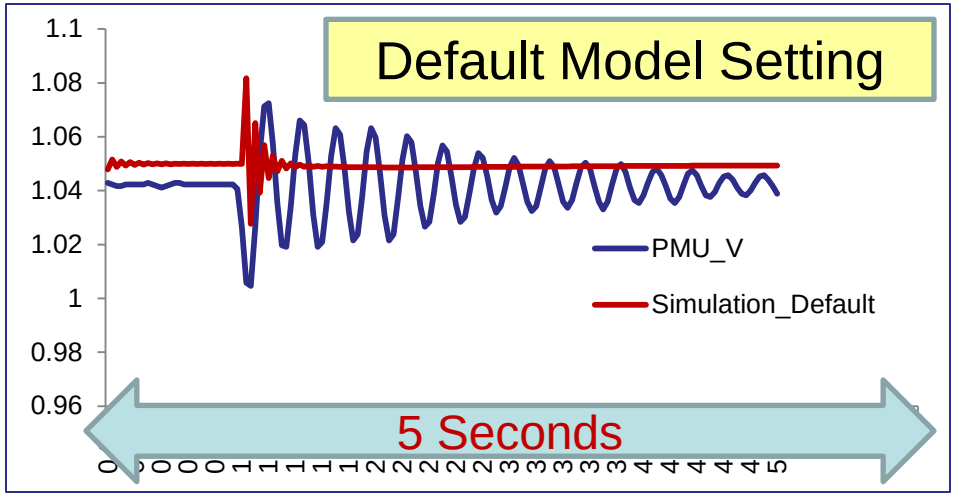
- **A real time EMS snapshot was used for the analysis**
  - A poor damping event
  - Full ERCOT system topology

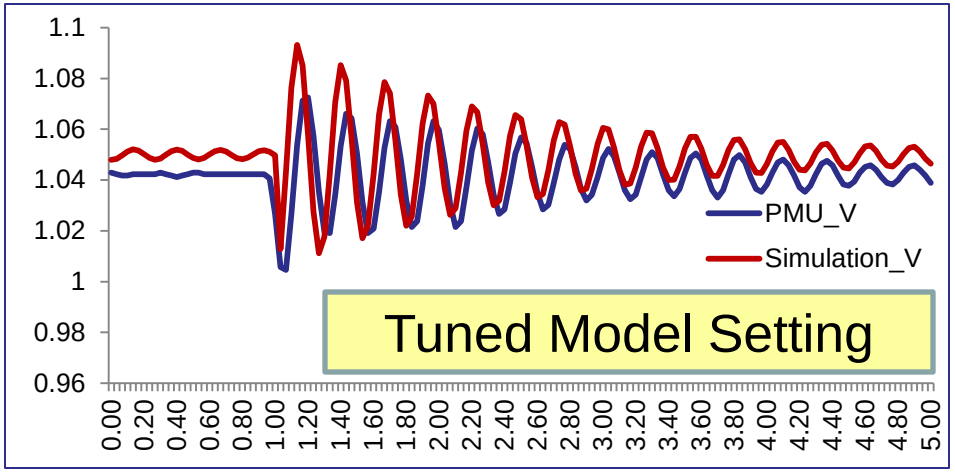


Event Analysis:

- **Goal**
  - Can we re-create the poor damped high frequency oscillations in the simulations?
  - Can we re-create the negative damped high frequency oscillations in the simulation by increasing the wind output?
  - Can we find out the potential solutions to mitigate these oscillations?

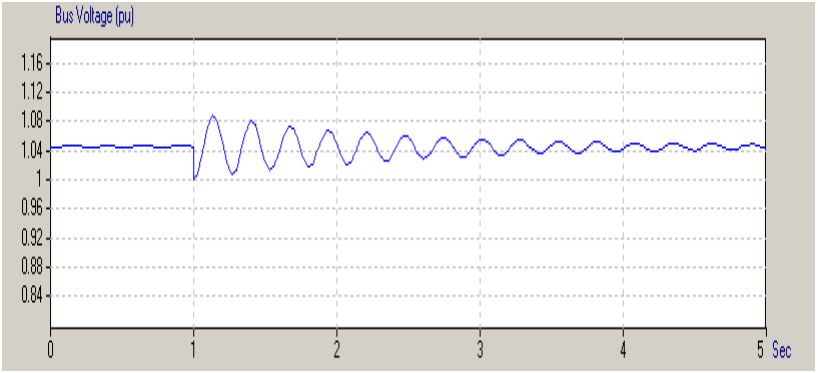
Can we re-create the poor damped high frequency oscillations in the simulations?



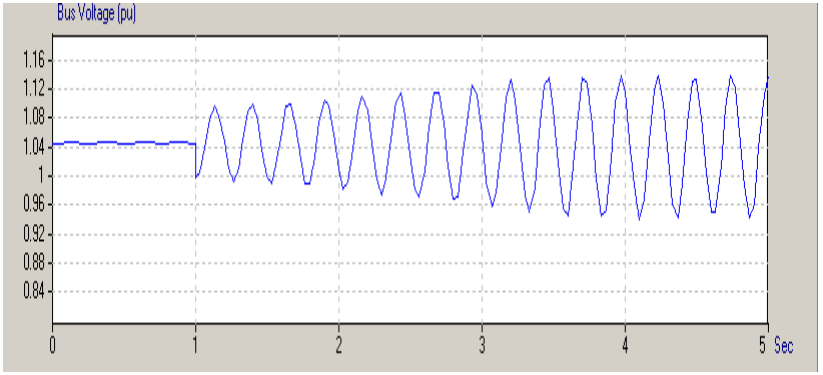


Can we re-create the negative damped high frequency oscillations in the simulation by increasing the wind output?

Original
EMS: 37MW



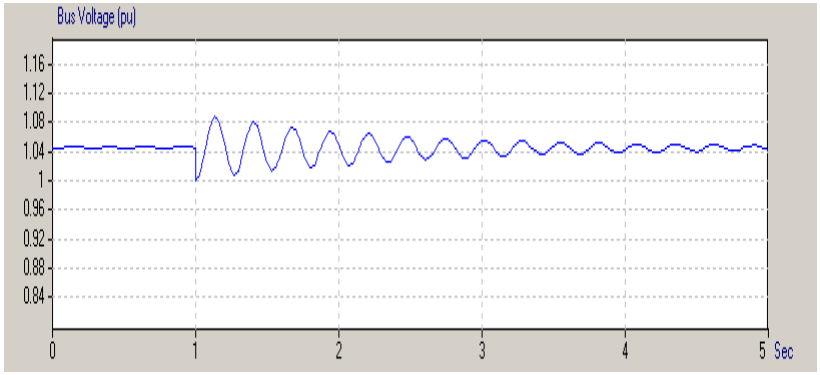
EMS: 45MW



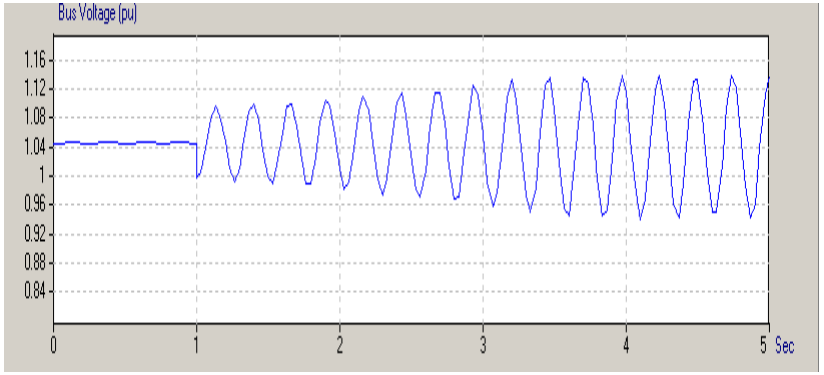
Can we find out the potential solutions to mitigate these oscillations?

Wind Controller Tuning

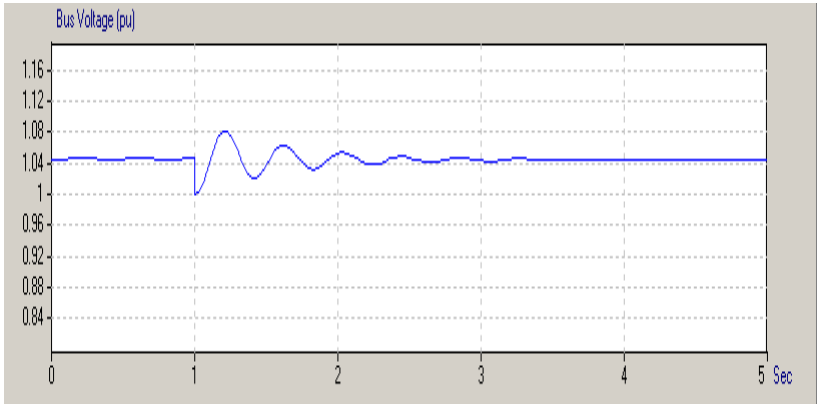
Original
EMS: 37MW



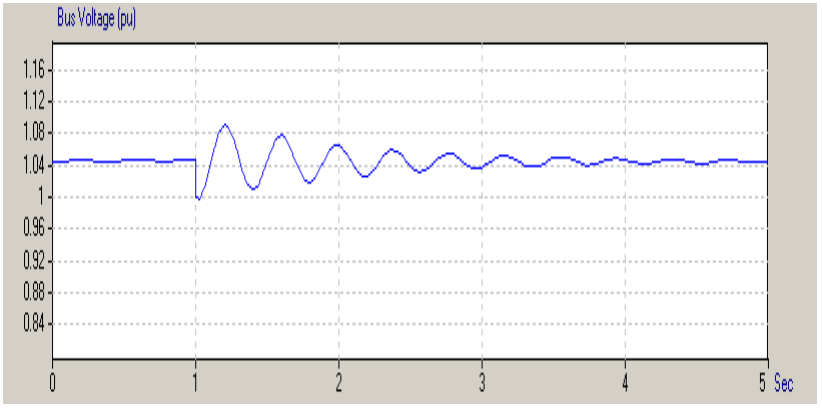
EMS: 45MW



EMS: 37MW, Tuned Wind Controller



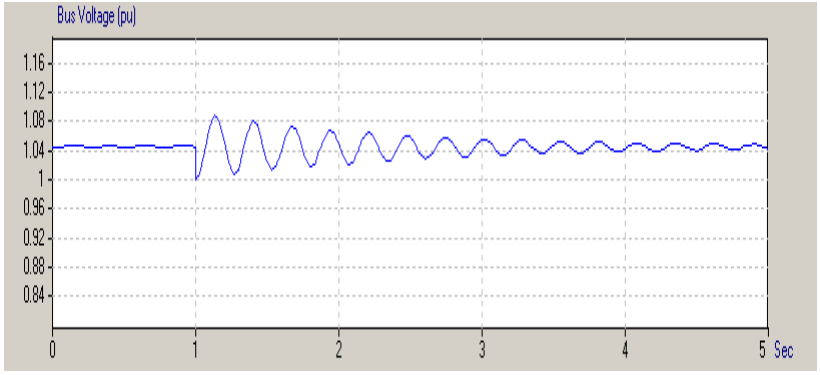
EMS: 45MW, Tuned Wind Controller



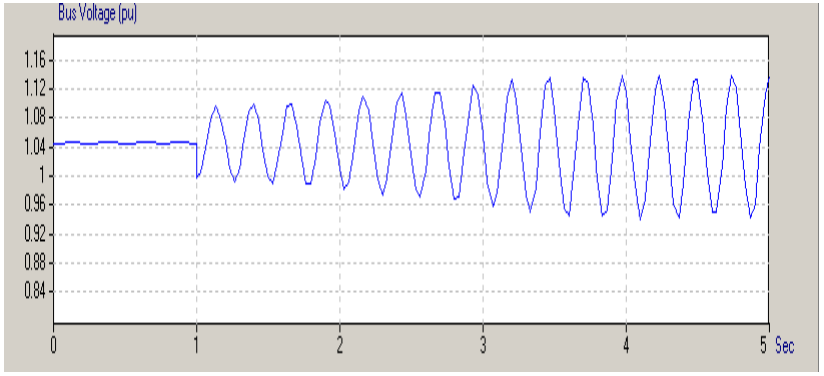
Can we find out the potential solutions to mitigate these oscillations?

Grid Enhancement: put 69kV outage line back in service

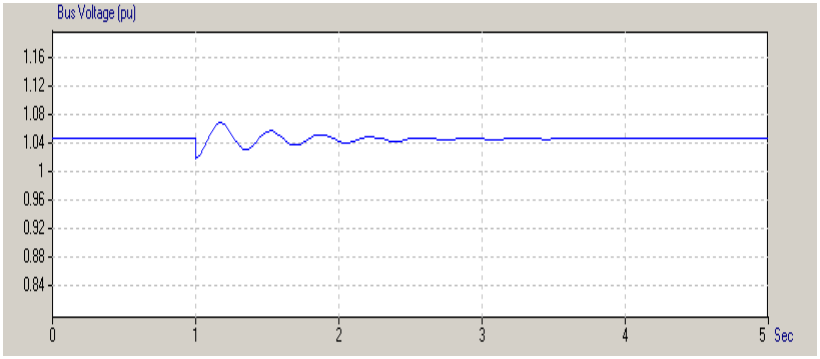
Original
EMS: 37MW



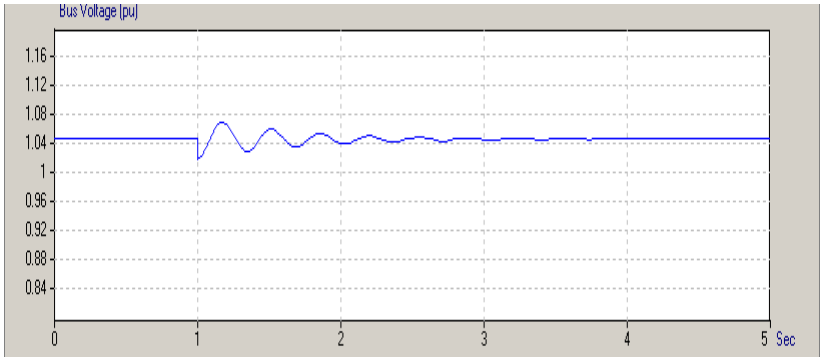
EMS: 45MW



EMS: 37MW,
No 69kV Outage



EMS: 45MW, No 69kV Outage



Are the oscillations predicted by the CREZ planning studies real? Yes

- **Cause: Weak Grid + High Wind Output + Inadequate control**
- **Solutions:**
  - Wind Controller Tuning
  - Grid Enhancement
  - Limit Wind Output (until other solutions can be implemented)

Summary

- **Over 30 generation trip events have been analyzed (3 years)**
  - Using phasor data from ERCOT PMU network
- **Analysis has focused on post-disturbance voltage and frequency performance**
  - Frequency drop and recovery
  - Voltage performance
  - Oscillatory modes and damping
- **Wind-related oscillations events have also been observed**
  - Oscillations have been observed at the wind farm due to the weak grid condition

What we know and what we learn

- **More PMUs**
  - Better understand the system behavior (steady state and dynamic)
  - High resolution data provides good benchmark for model validation and simulation result checking
  - Provides the wide area visualization of the system
  - Helps to understand the dynamic behavior of the system during the events
- **Accurate data set for dynamic models**
  - Default setting is not sufficient
  - Model validation is important
- **Wind generation oscillates against the grid at weak grid condition**
  - Poor damping as well as negative damping has been observed
  - Understanding the causes of these oscillations is essential
  - Mitigation may be needed

Questions?