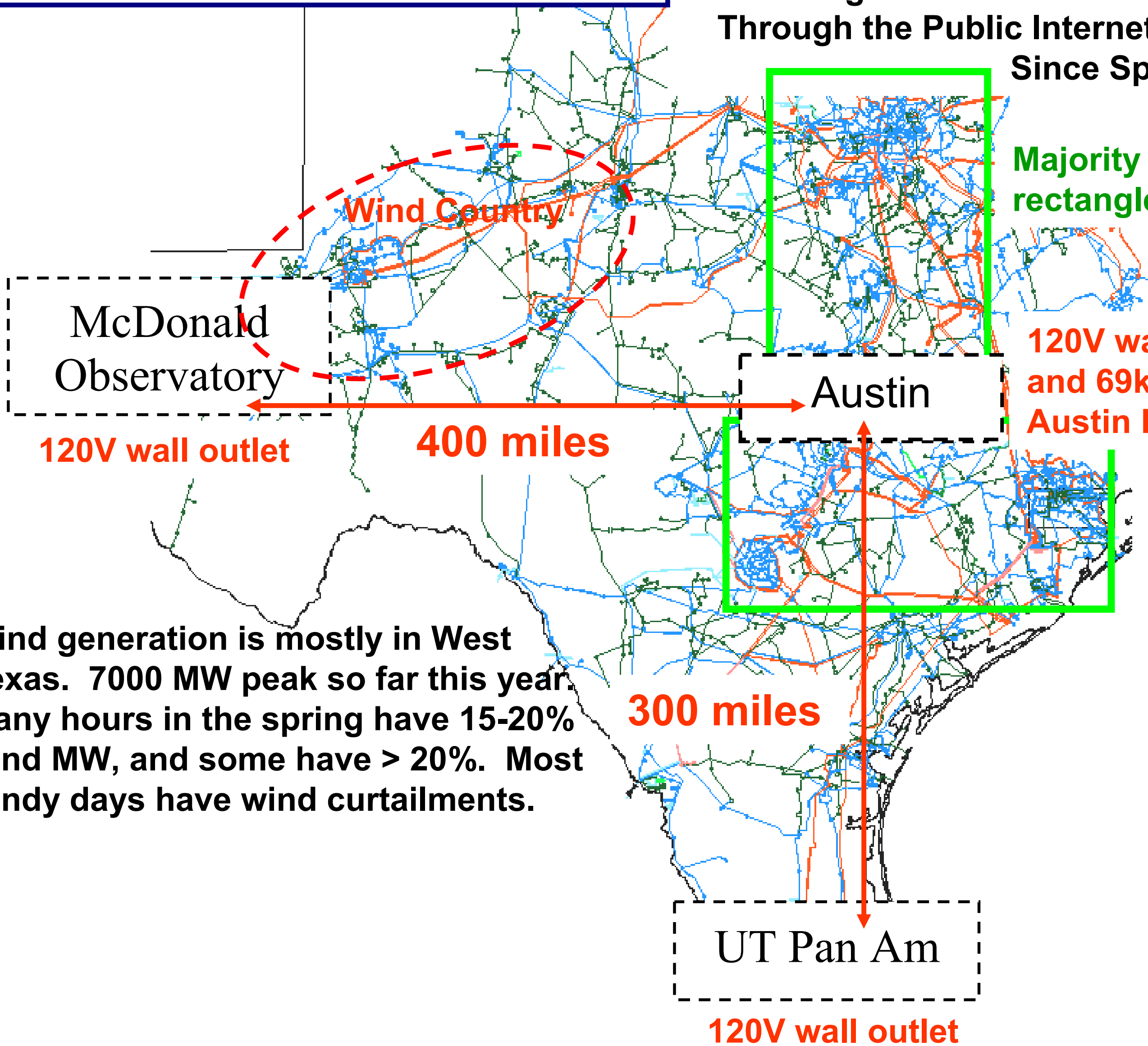
Observations From the Texas Synchrophasor Network

Presentation prepared by Prof. Mack Grady and Graduate Research Assistant Moses Kai, U.T. Austin, for the "Breaking News" Session at the IEEE-PES Annual Meeting, Minneapolis, Monday afternoon, July 26, 2010.

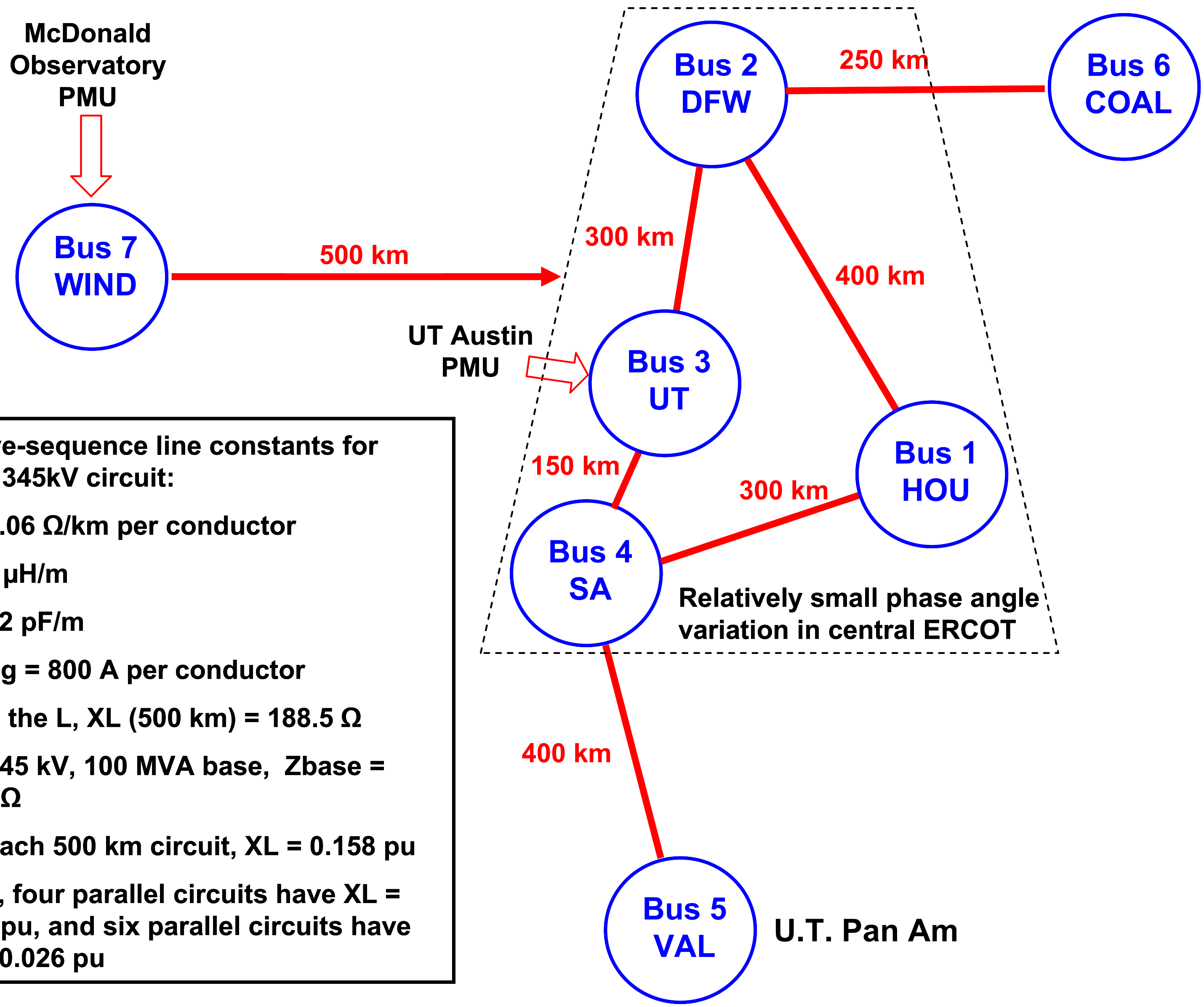
Monitoring 120V Wall Outlet Voltages and Communicating Through the Public Internet at 30 Readings per Second Since Spring 2009



Wind generation is mostly in West Texas. 7000 MW peak so far this year. Many hours in the spring have 15-20% wind MW, and some have > 20%. Most windy days have wind curtailments.

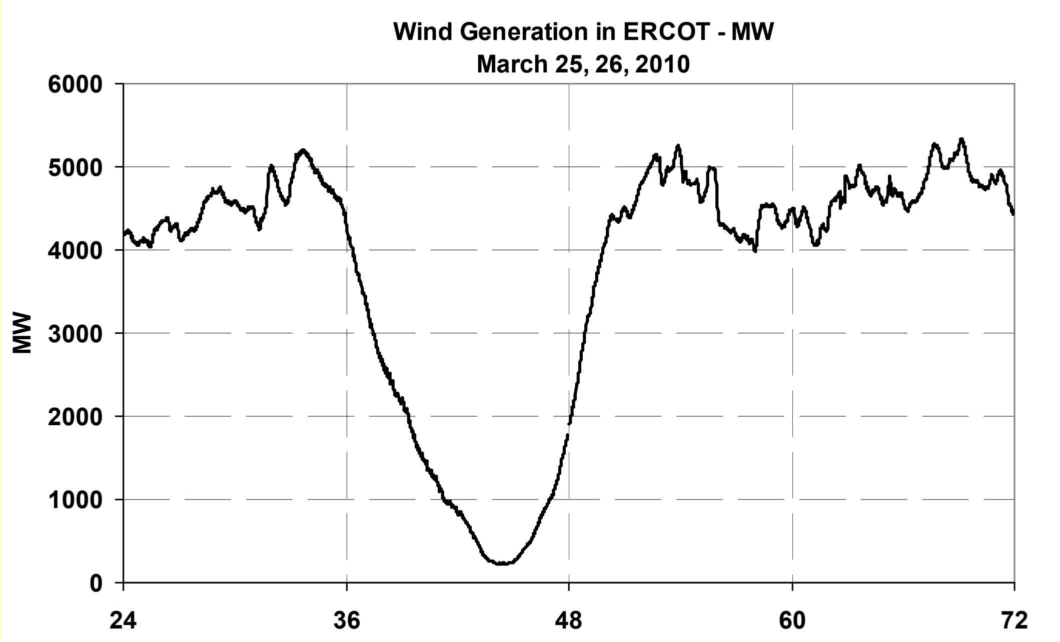
- Funding provided by EPRI
- Equipment provided by Schweitzer Engineering Labs
- Start-up funds provided by Governor's Emerging Technology Fund through CCET
- 69kV grid monitor provided by Austin Energy
- Independent. Not affiliated with ERCOT or any utility except Austin Energy
- Will soon have one or more wind farm members

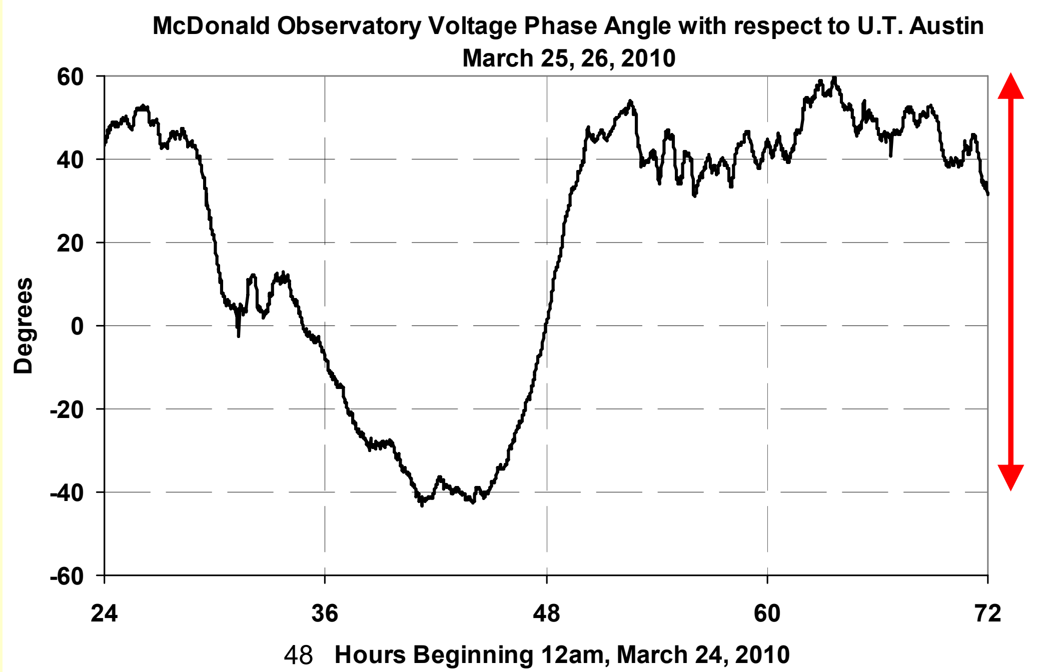
Synchrophasor Homework Network for ERCOT



Positive-sequence line constants for each 345kV circuit:

- **R = 0.06 Ω/km per conductor**
- **L = 1 μH/m**
- **C = 12 pF/m**
- **Rating = 800 A per conductor**
- **From the L, XL (500 km) = 188.5 Ω**
- **For 345 kV, 100 MVA base, Zbase = 1190 Ω**
- **For each 500 km circuit, XL = 0.158 pu**
- **Thus, four parallel circuits have XL = 0.040pu, and six parallel circuits have XL = 0.026 pu**



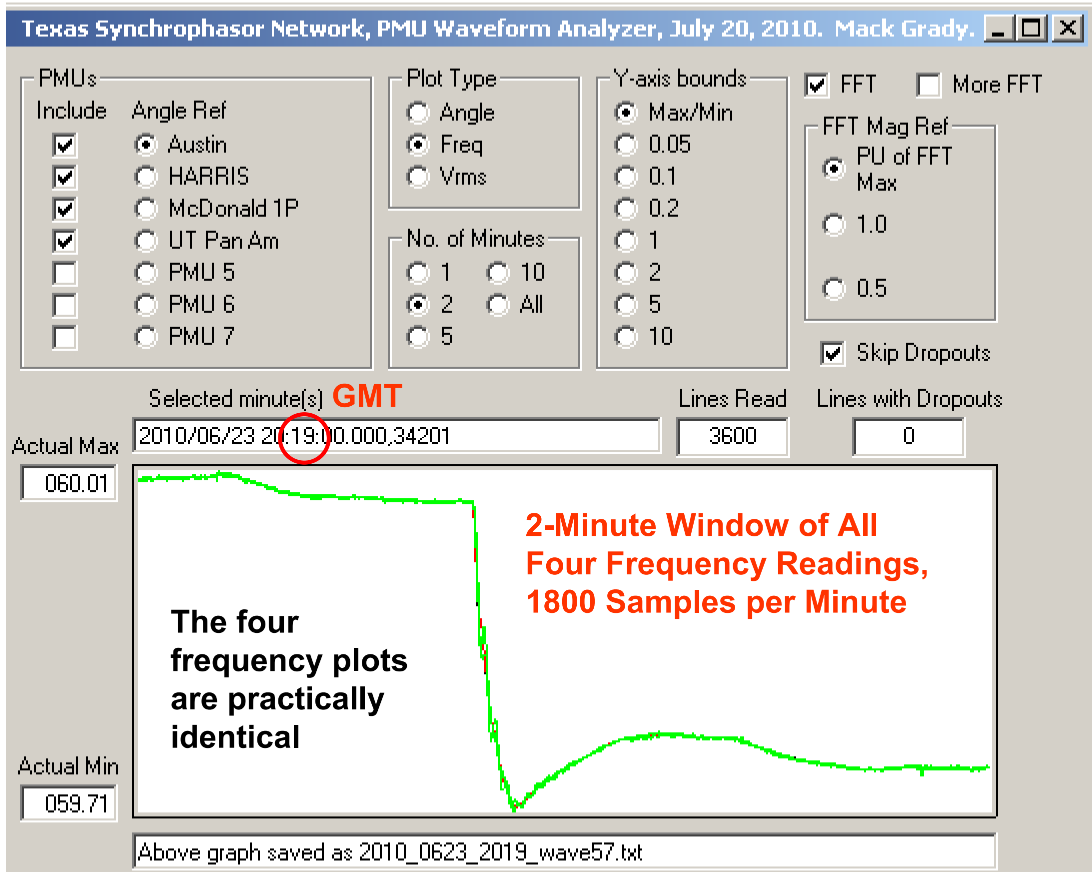


Synchrophasor Detective – EVERY day has surprises and clues

Wind generation and West Texas phase angle can go through large daily swings

West Texas voltage phase angle swings nearly 100º and back with respect to U.T. Austin in about 24 hours

Event 1. Large Unit Trip. Freq. Drops to 59.71 Hz. Afternoon of June 23, 2010.

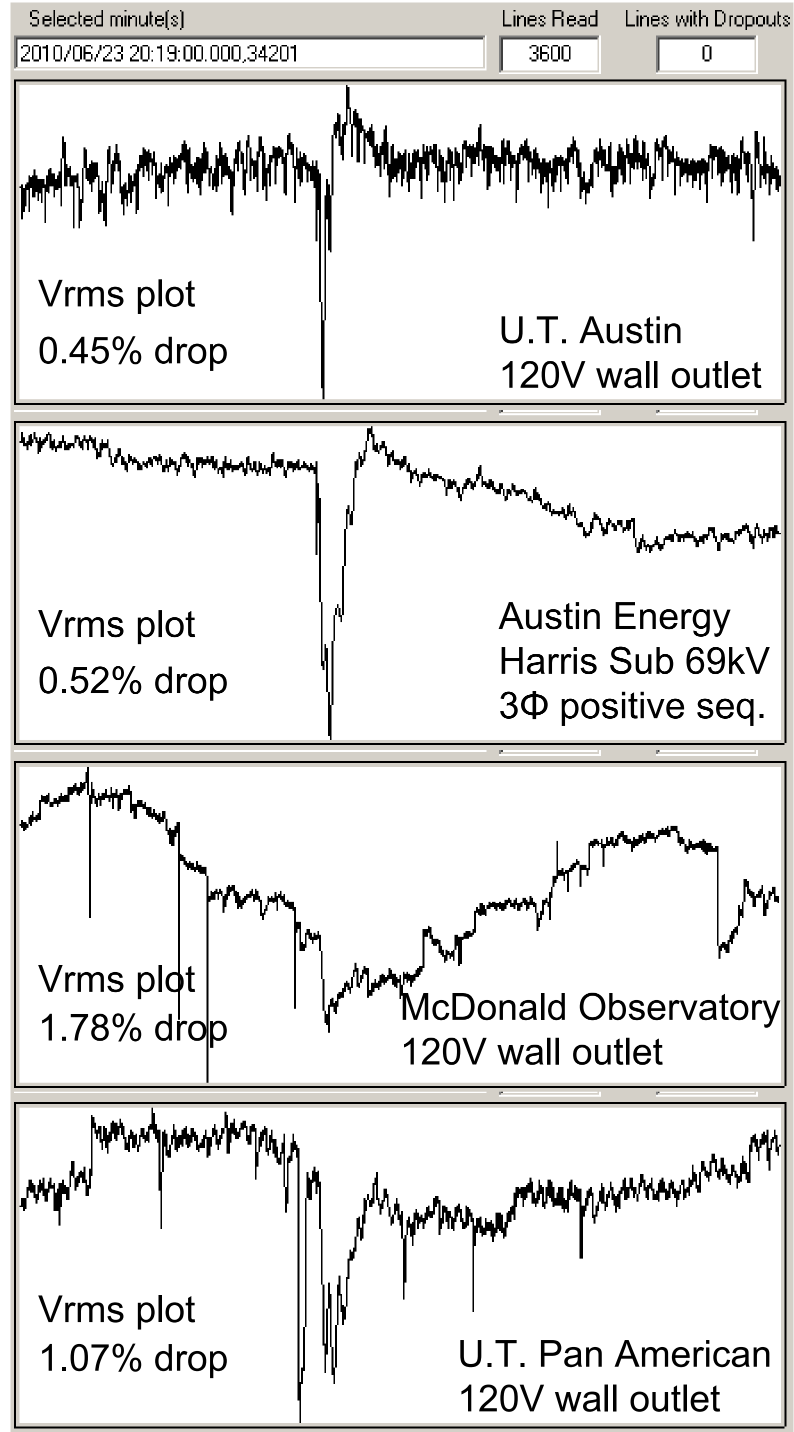


ERCOT Log. June 23, 2010, 15:20 15:49. Deployed 1150 MW of Responsive Reserve Service from actual adjusted responsive reserve of 3281 MW with an obligation of 2300 MW when frequency dropped to 59.716 Hz due to XXXX and XXXX and XXXX tripped with 1213 MW, issued fleet up of 550 MW. ERCOT load 58446 MW.

Event 1. Large Unit Trip, June 23, 2010, cont.

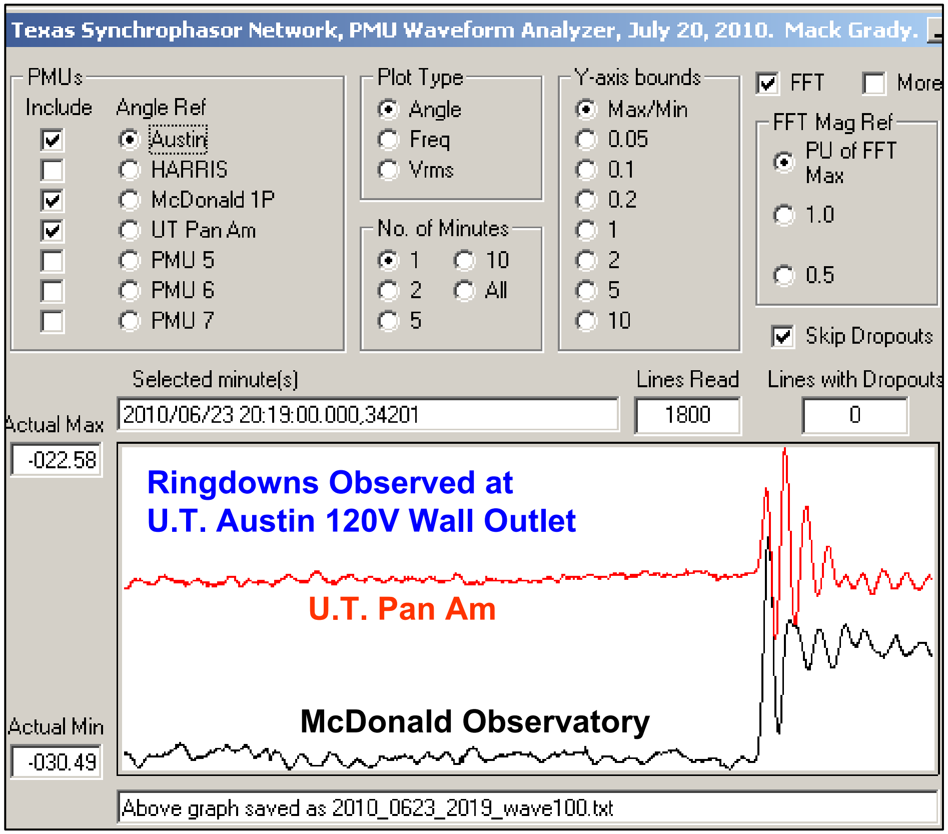
2-Minute Windows of All Four Vrms Readings, 1800 Samples per Minute

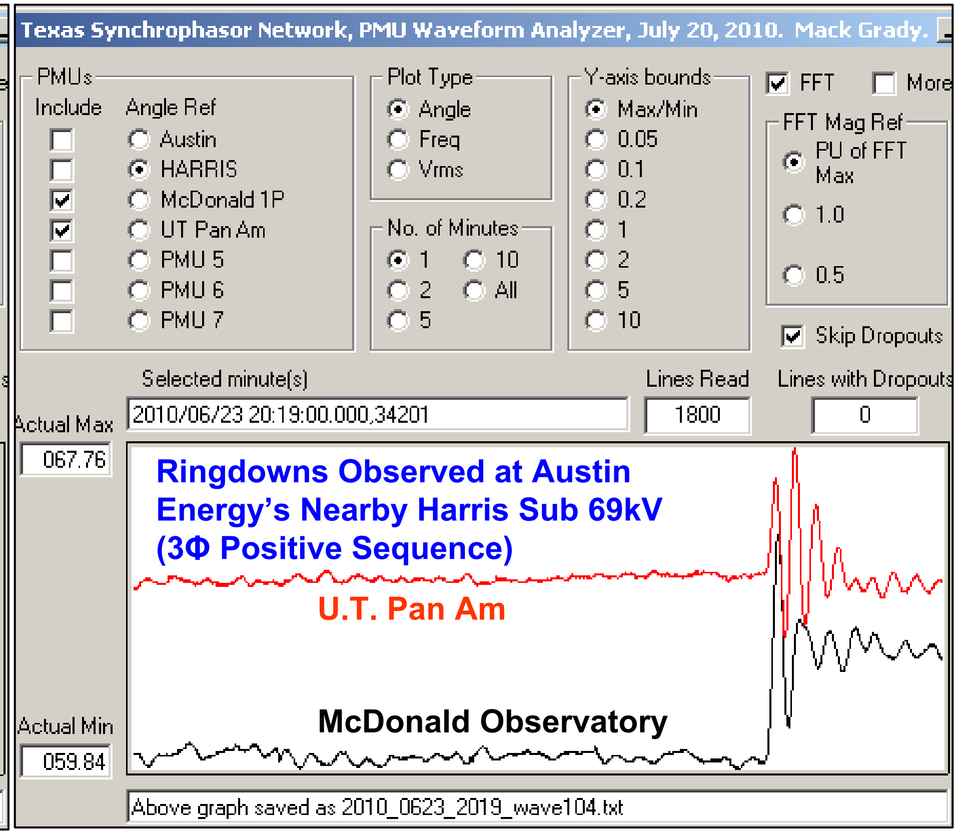
120V wall outlet voltages are clearly more noisy than 69kV grid, but nevertheless 120V wall outlets together with Schweitzer relays provide reliable phase angle measurements



Event 1. Large Unit Trip, June 23, 2010, cont.

1-Minute Windows of Phase Angle Ringdowns, 1800 Samples per Minute

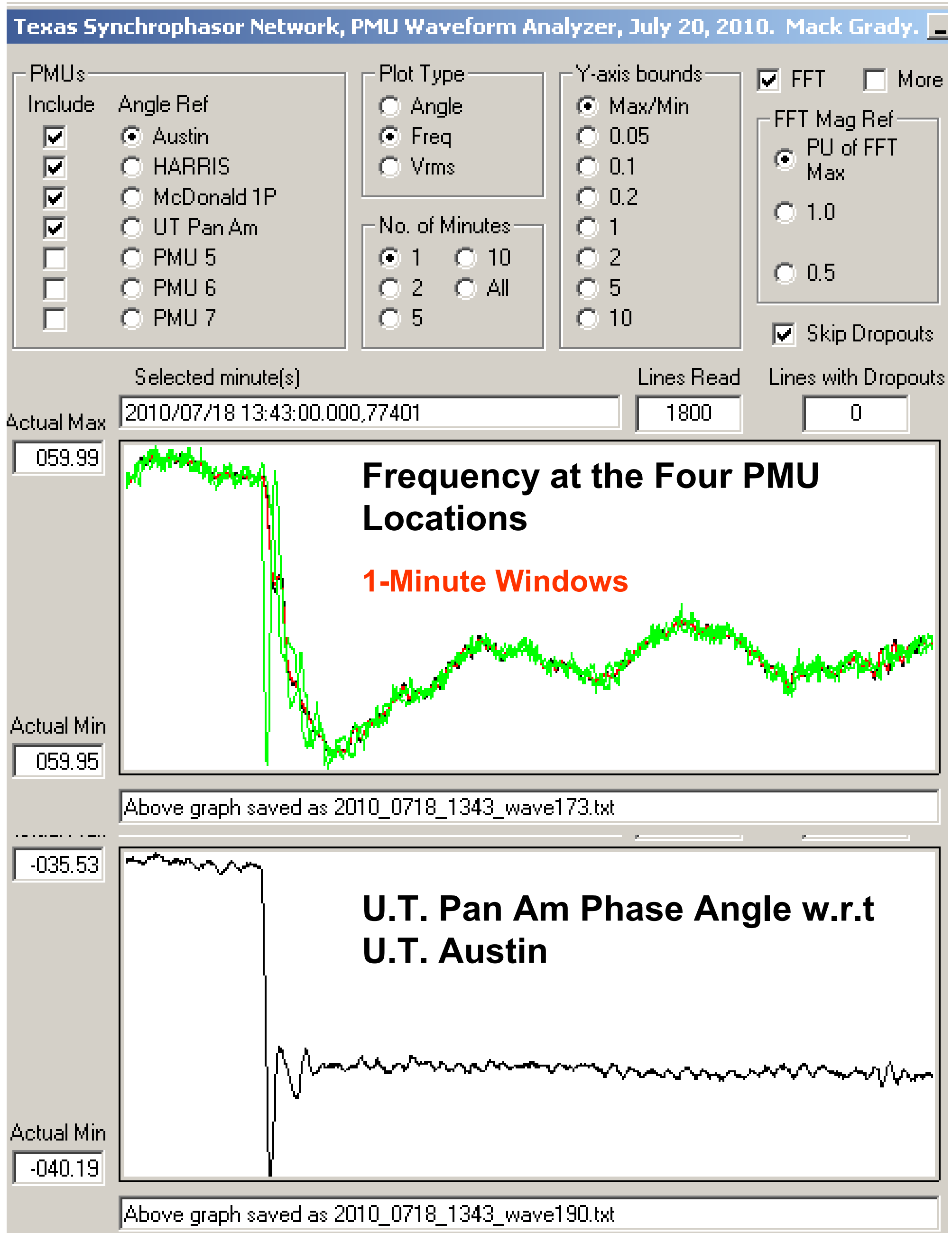




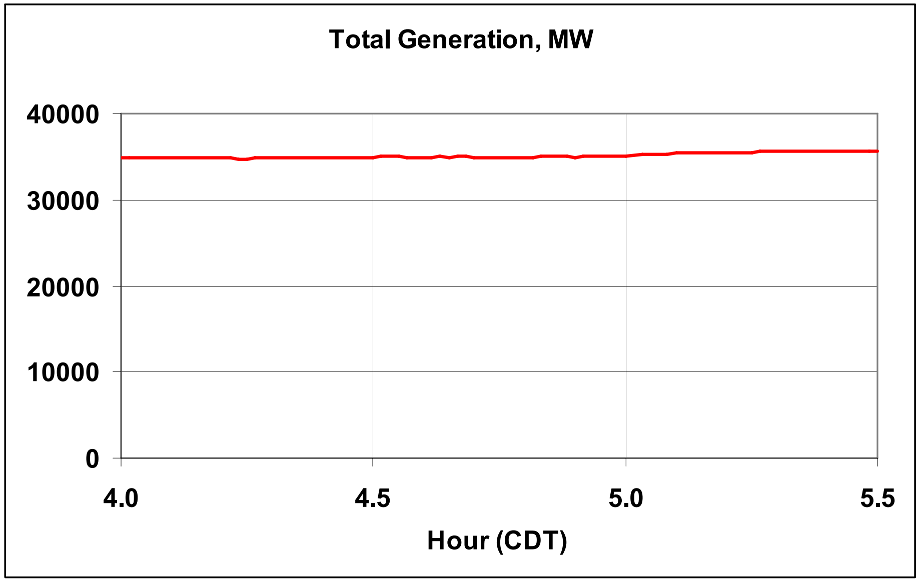
- **The data stream in from 300 and 400 miles away and are then time synchronized.**
- **Can you see any difference in the ringdowns observed by the 120V wall outlet on campus and the 69kV grid monitor near campus? (The correct answer is NO!)**
- **Essentially the only difference is the fixed 90º transformer-related offset plus a 0.3º power flow shift through the substation transformer.**
- **What conclusions can be made about the location of the tripped generator?**

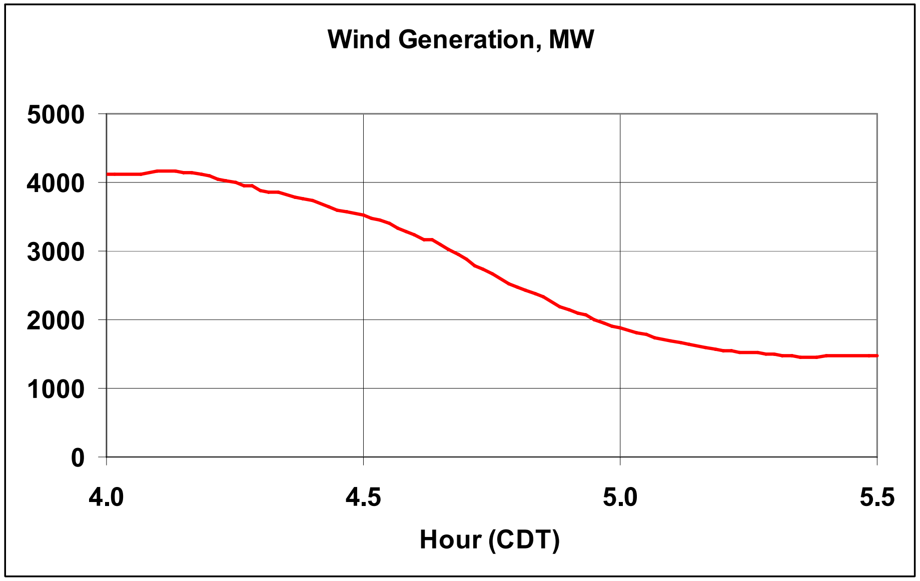
Event 2. Small Unit Trip in South Texas. Morning of July 18, 2010.

- **Insignificant frequency event – too small to be logged.**
- **But very significant response in South Texas voltage phase angle.**
- **Illustrates the sensitivity of synchrophasors.**
- **Shows that South Texas was importing P because the phase angle dropped.**

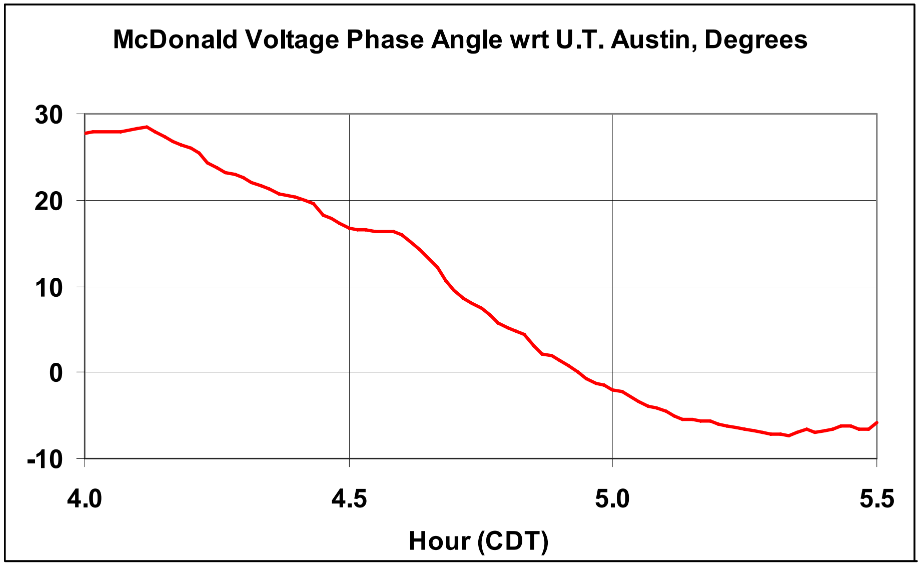


Event 3. Wind MW Backdown Invoked. Early Morning of July 15, 2010. Thevenin Impedance Calculation.

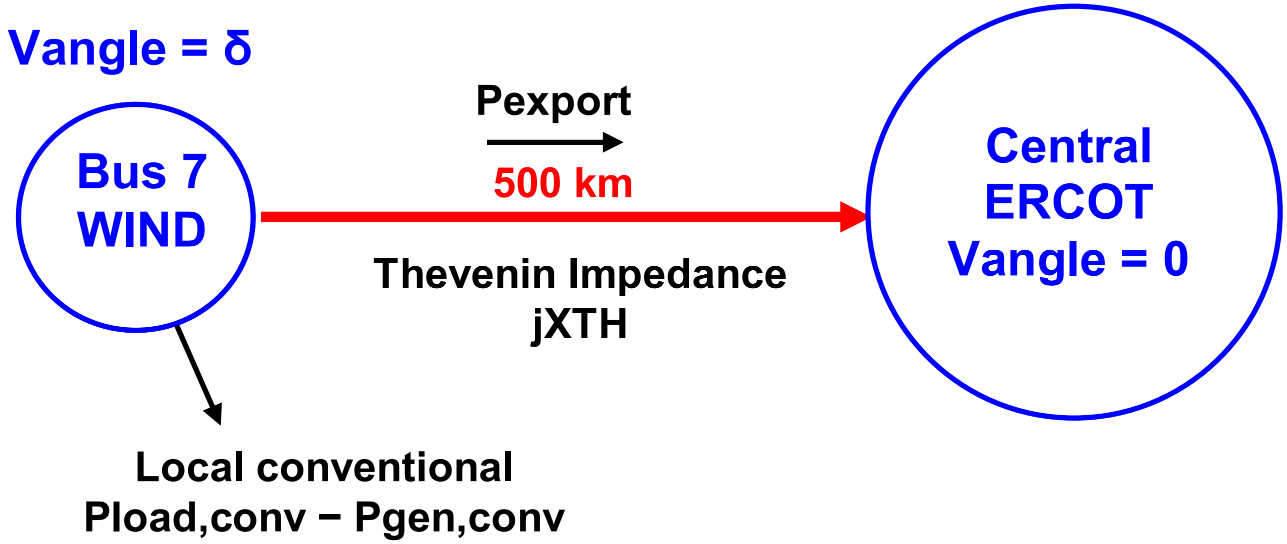




ERCOT Log. Frequency dropped to 59.920 Hz due to wind generation dropped 1400 MW after off-set was calculated. Issued fleet up of 400 MW due to out of Up Regulation. ERCOT load 35153 MW.



Event 3. Wind MW Backdown. July 15, 2010. Thevenin Impedance Calculation, cont.



Use the Excel Solver with the 90 minutes of readings to minimize least-squared error and determine Xth

Event 3. Wind MW Backdown. July 15, 2010. Thevenin Impedance Calculation, cont.

The knowns (all are given in one-minute average):

- Wind generation MW
- Wind generation phase angle δ with respect to central ERCOT (i.e., U.T. Austin)
- ERCOT total generation

The unknowns

- jXTH
- Local conventional load minus generation in West Texas wind country
- Pexport

The equations

The balance equation: want left-hand side ≈ right-hand side for all 90 readings

- Ignoring losses, power balance requires that

$$P_{wind} - \left(P_{load,conv} - P_{gen,conv}\right) = \frac{V_{wind} \bullet V_{ERCOT}}{X_{TH}} \sin(\delta)$$

Other assumptions

- Having access to no other information, assume that local net conventional ($P_{load} - P_{gen,conv}$) varies with ERCOT total generation according to

$$P_{load,conv} - P_{gen,conv} = A \bullet P_{ERCOT\ \ Total\ Gen} + B$$

Excel Solver Setup

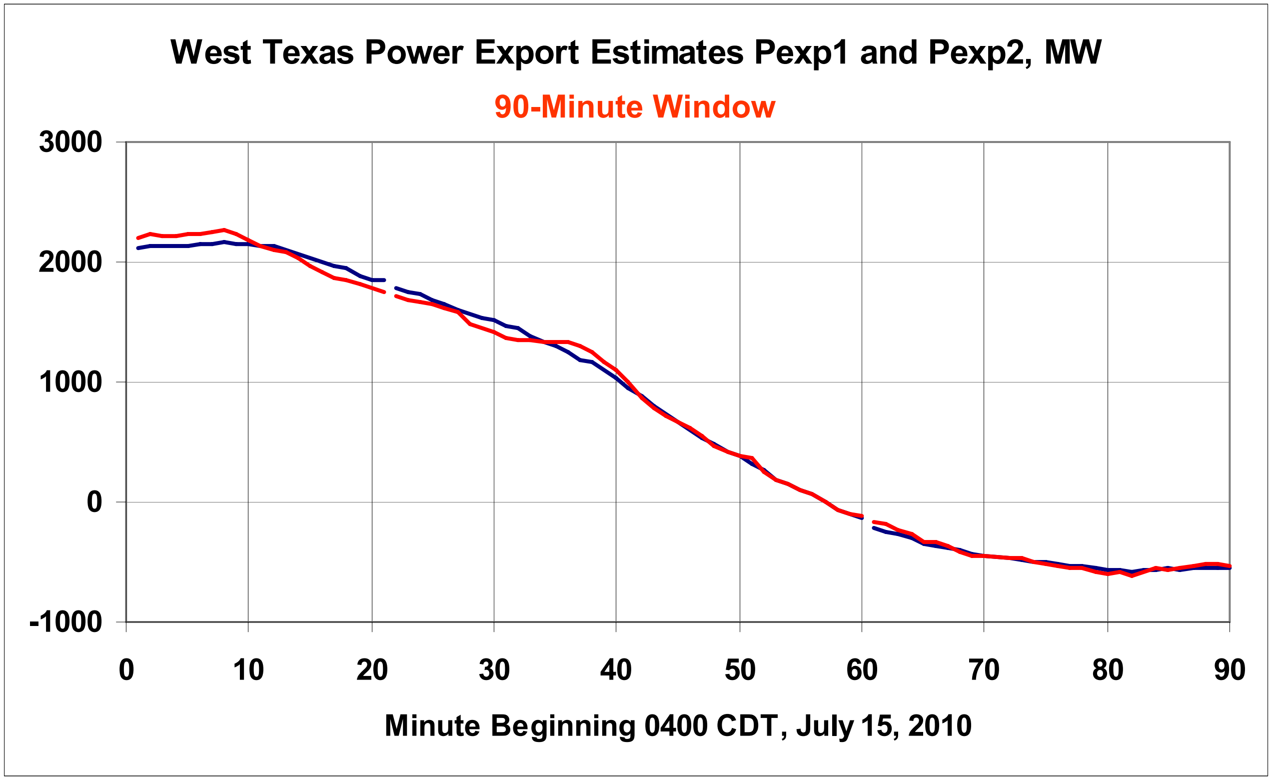
Three unknowns

- Define $C = \frac{V_{wind} \bullet V_{ERCOT}}{X_{TH}} = \frac{1 \bullet 1}{X_{TH}(pu)}$
- Instruct Excel Solver to vary coefficients A, B, and C to minimize the sum of squared error

$$\sum_{n=1}^{N} \left[P_{wind} - \left(P_{load,conv} - P_{gen,conv}\right) - C\sin(\delta)\right]^2 ,$$

n = minutes, for either the entire interval

Event 3. Wind MW Backdown. July 15, 2010. Thevenin Impedance Calculation, cont.



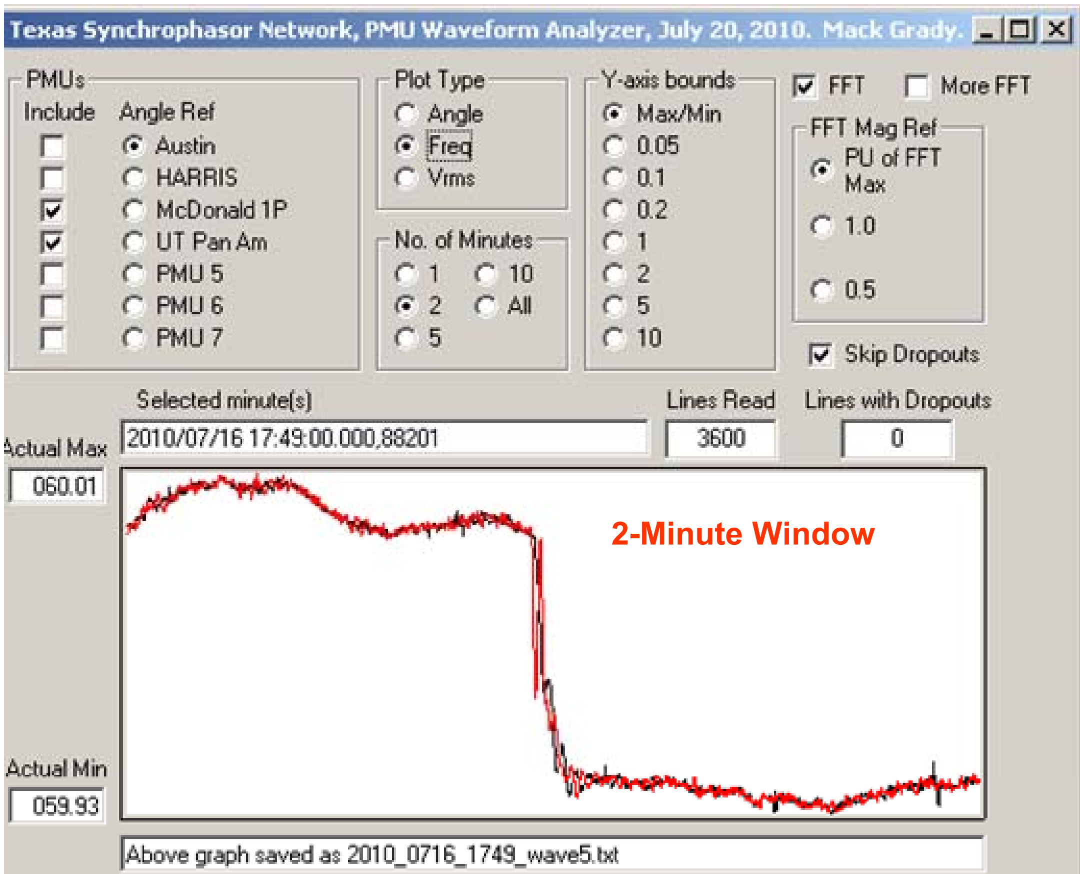
Squared area between the two curves is minimized when

A = -0.0471

B = 356

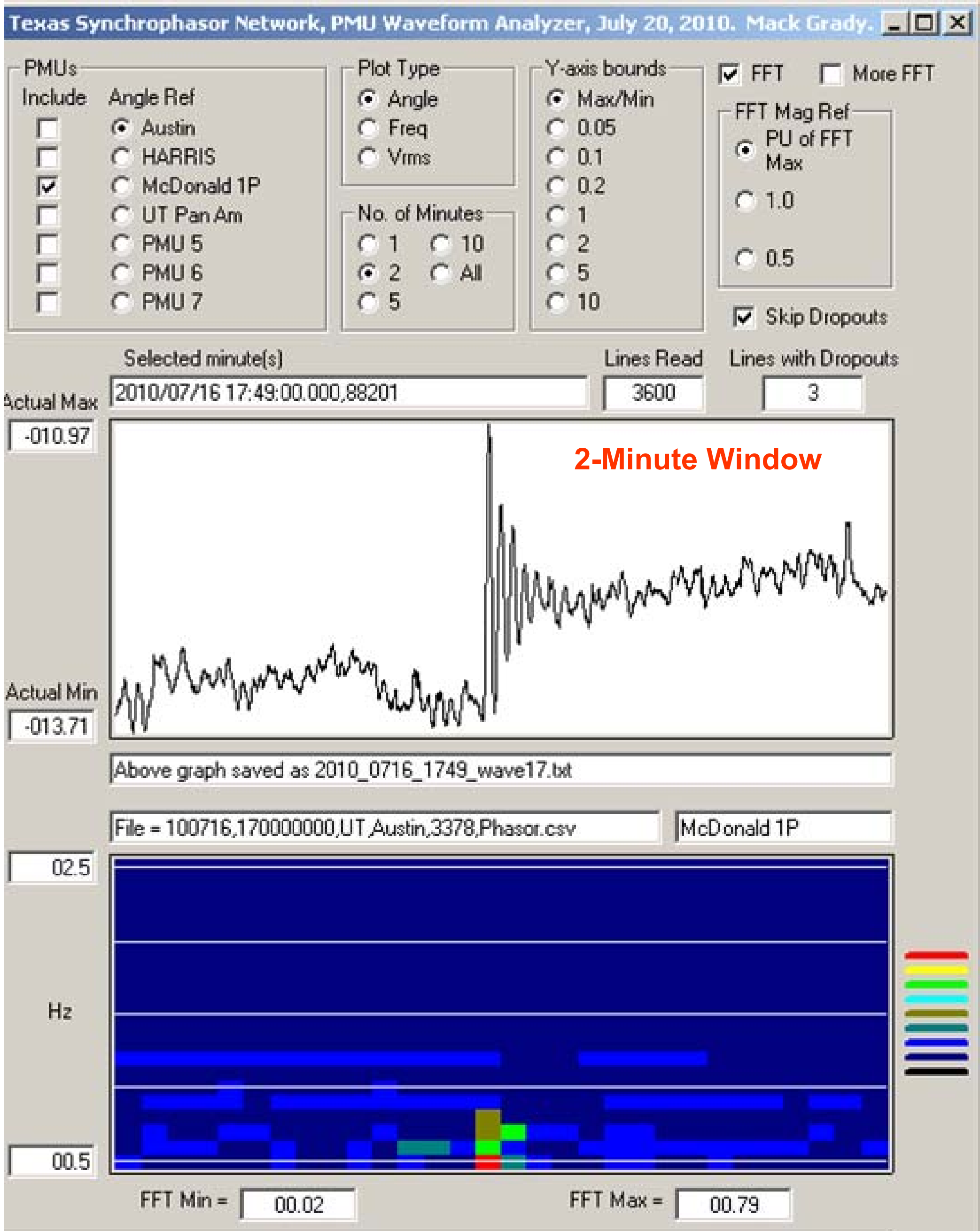
Xth = 0.0211 pu on 345kV, 100MVA base

Event 4. Small Unit Trip. Early Afternoon of July 16, 2010. Ringdown Analysis.

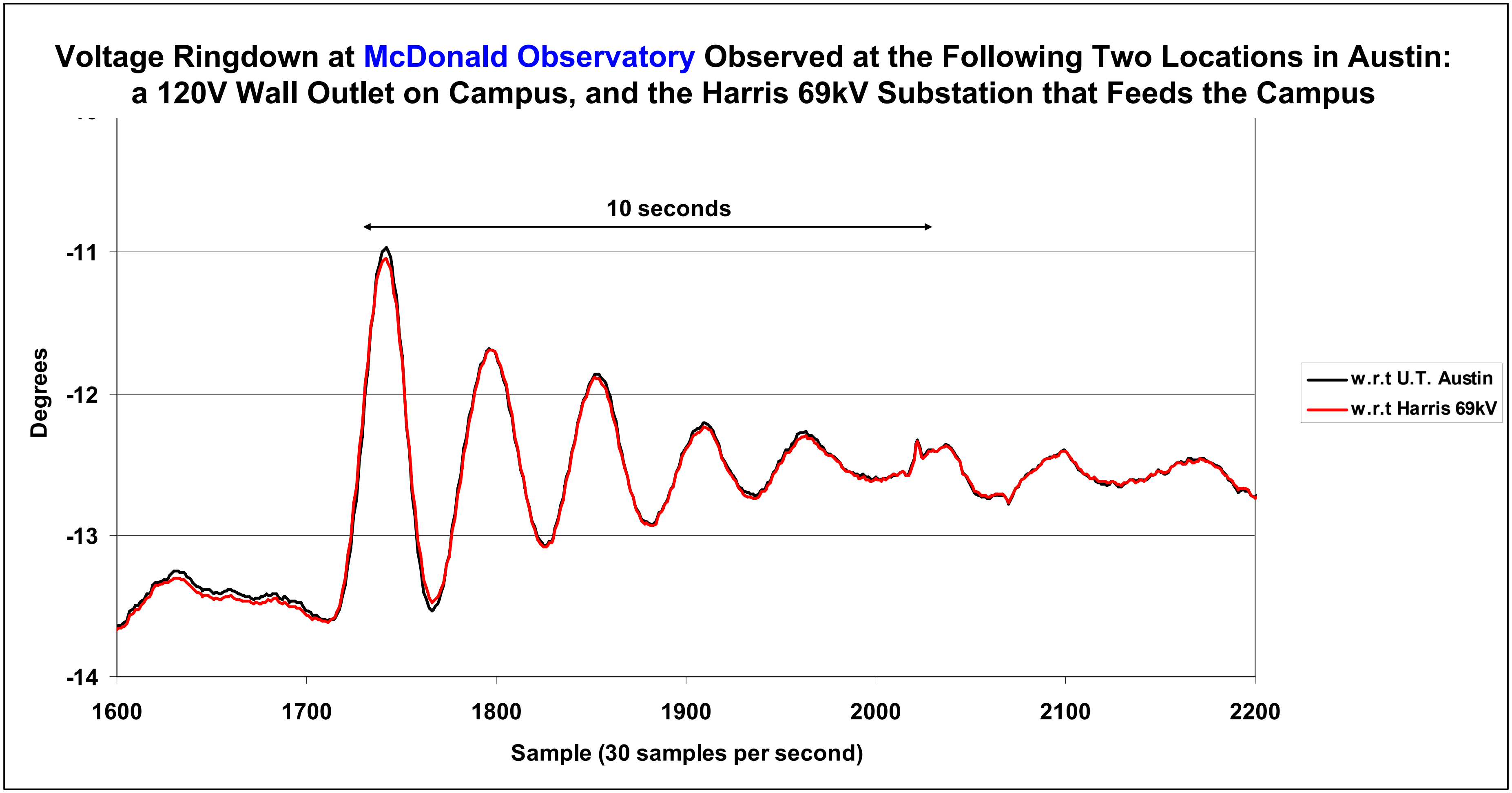


- A unit trip causes a drop of 0.06 Hz, which was not significant enough to be noted on ERCOT's Daily Grid Operation Report.
- However, the phase angle ringdown at McDonald Observatory gives a clear indication of the damped resonant frequency and normalized damping coefficient between West Texas wind country and central ERCOT.

Event 4. Small Unit Trip. July 16, 2010. Ringdown Analysis, cont.

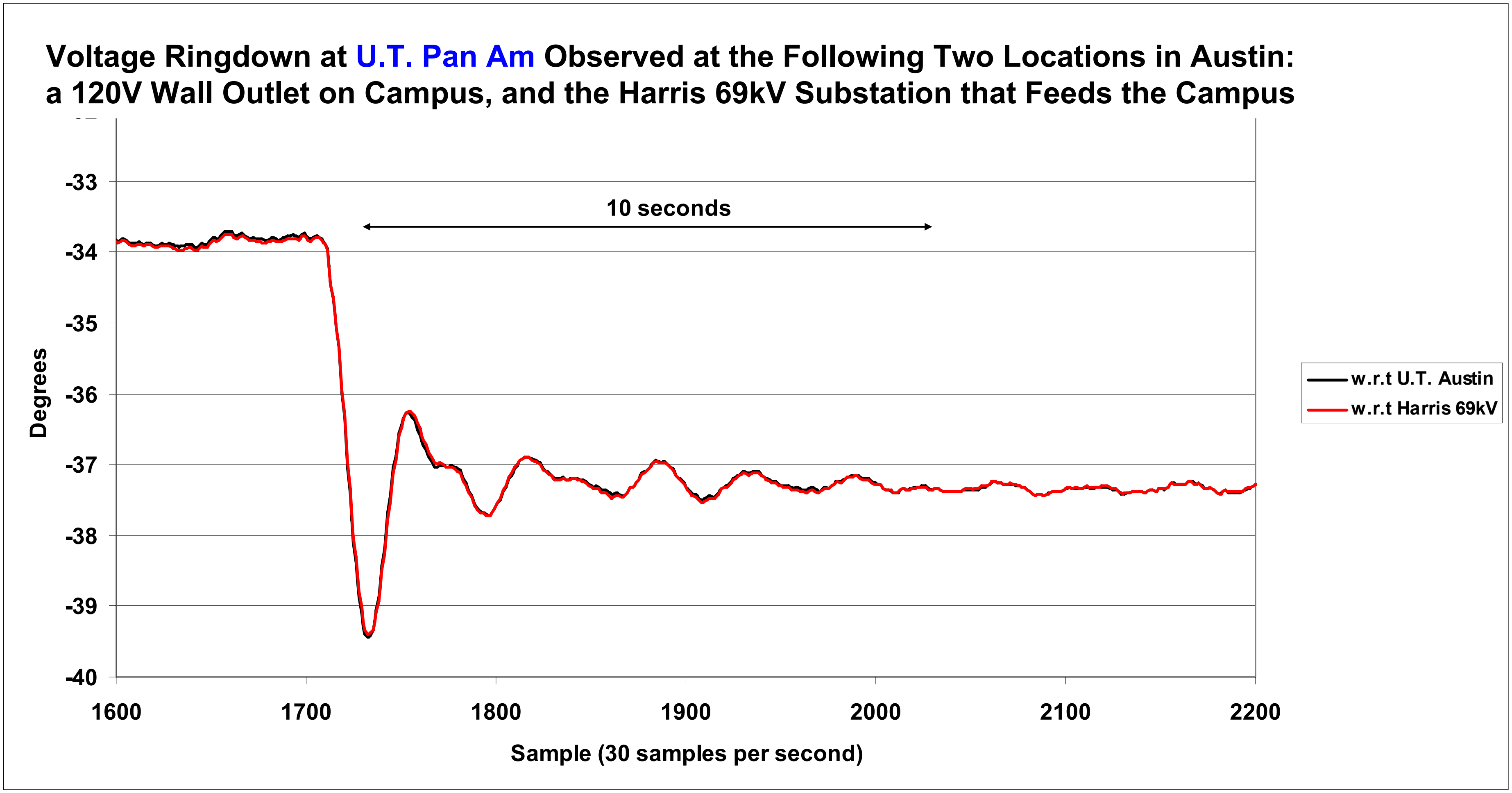


Event 4. Small Unit Trip. July 16, 2010. Ringdown Analysis, cont.



- The fixed net multiple of 30 degree phase shift between U.T. Austin 120V and Harris 69kV has been removed. The variable but steady 0.1 degree power flow phase shift through the substation transformer has also been removed.
- Can you see any significant difference between the waveform seen by the 120V wall outlet (in black) and the waveform seen by the 69kV, 3Φ grid monitor (in red)? (The correct answer is NO!)

Event 4. Small Unit Trip. July 16, 2010. Ringdown Analysis, cont.



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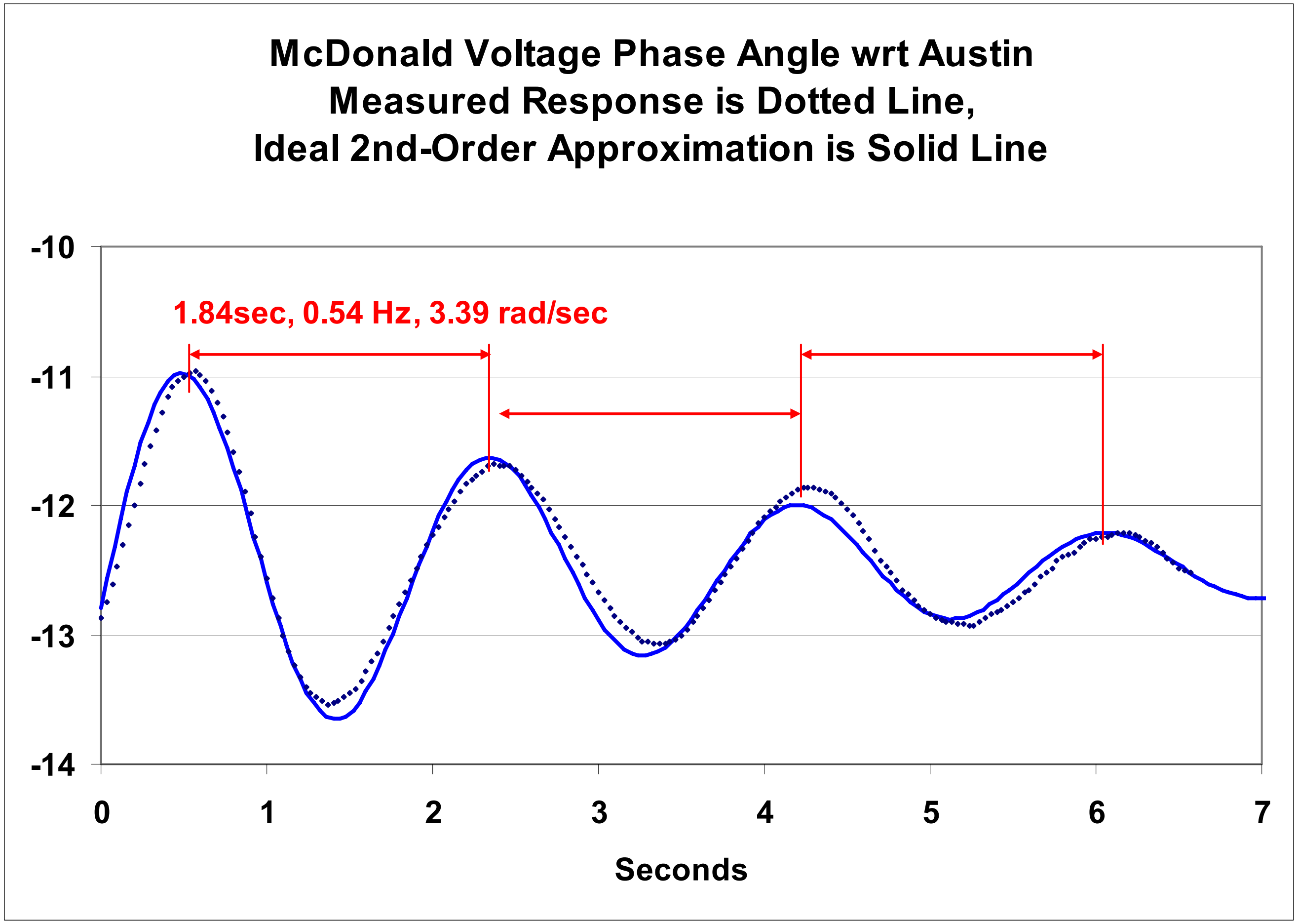
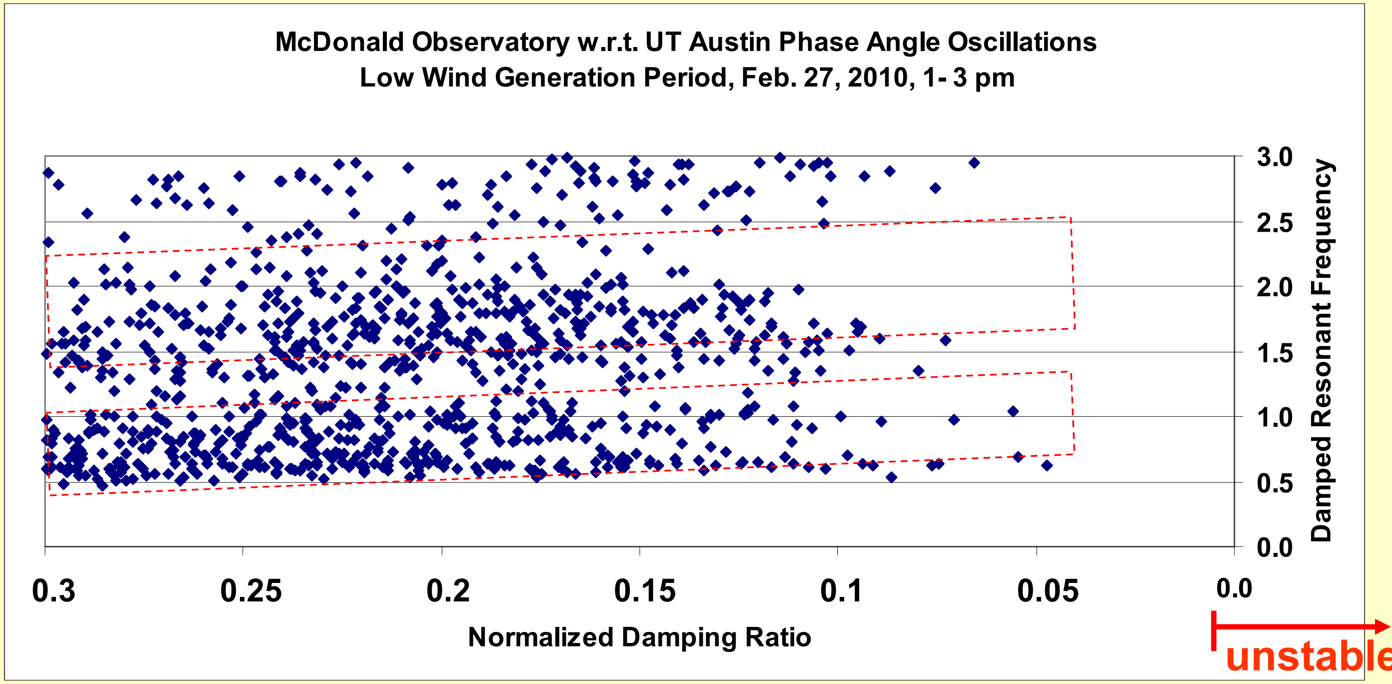
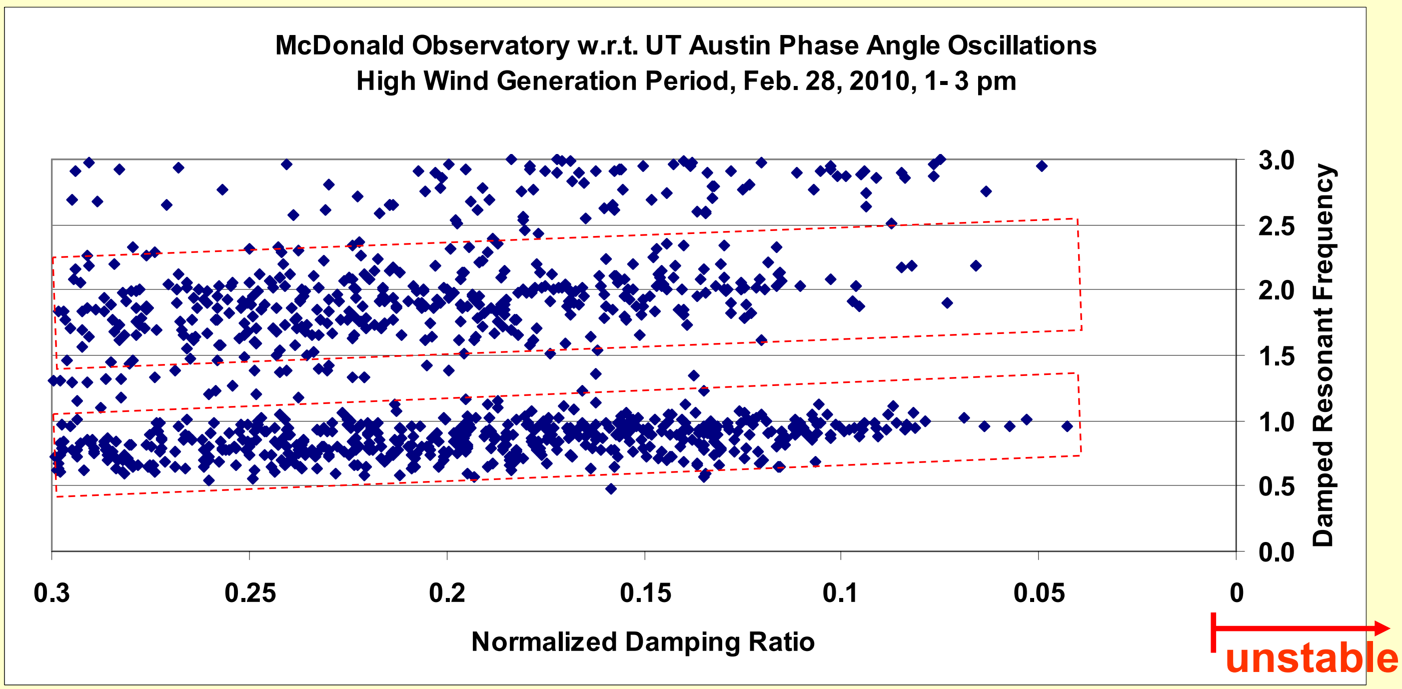


Estimated Normalized Damping Ratio $\xi = 0.088$



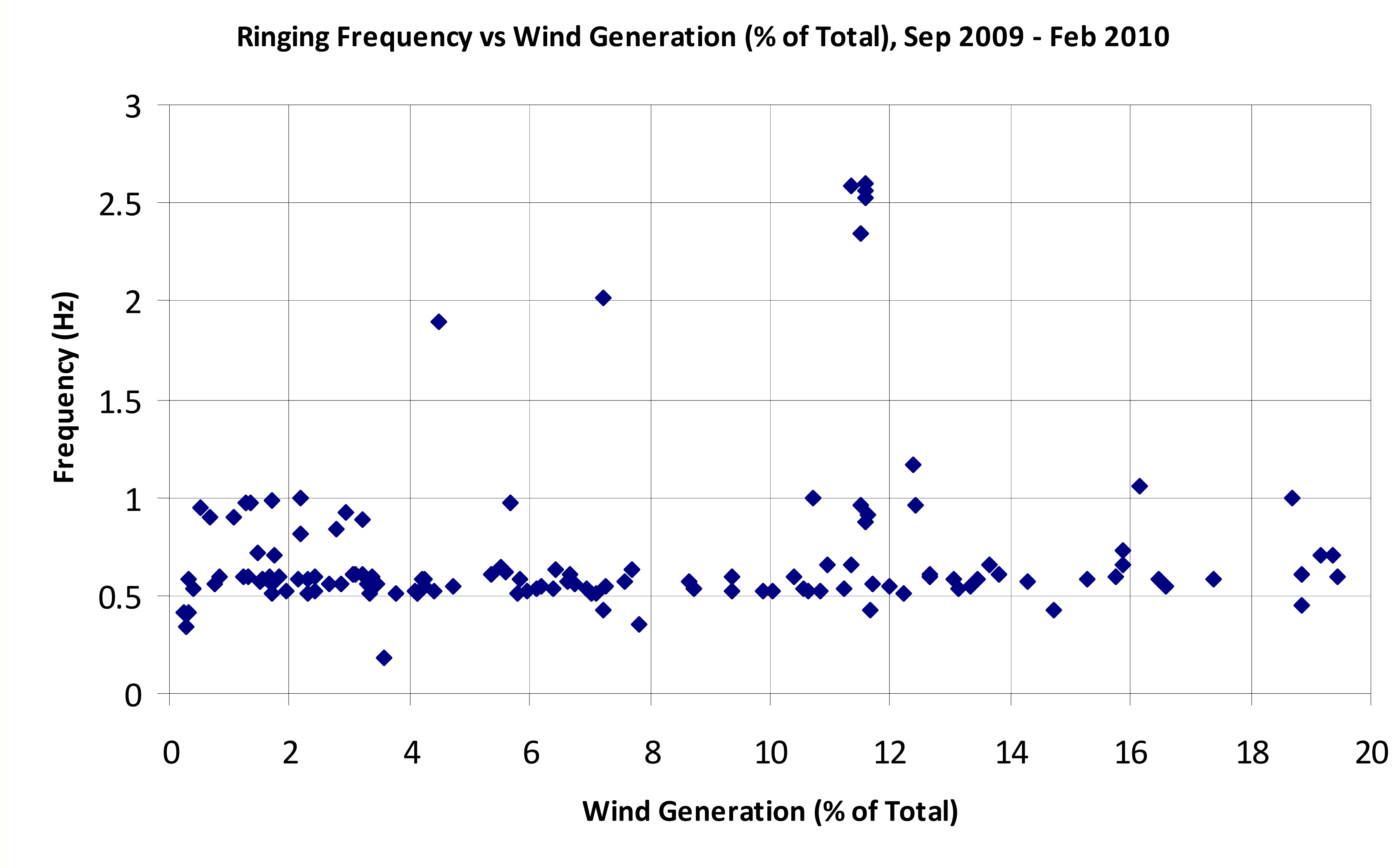


More Observations

From Last Spring: Modal analysis of ambient oscillations show that high wind causes tighter clustering of damped resonant frequency points

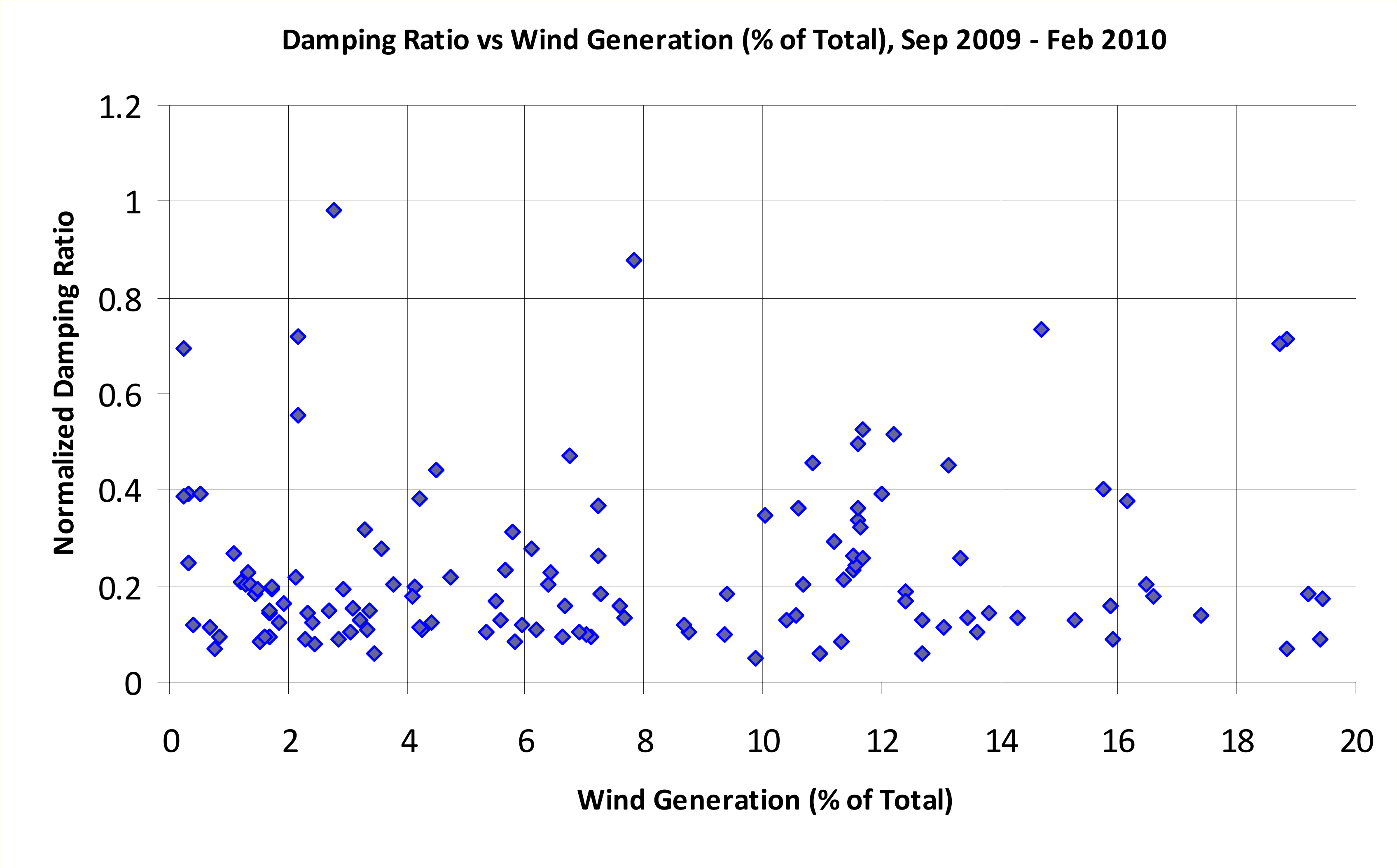
More Observations, cont.

Ringdown Analysis of More Than 100 Unit Trips Yields No Clear Relationship Between Wind MW and Damped Resonant Frequency



More Observations, cont.

Ringdown Analysis of More Than 100 Unit Trips Yields No Clear Relationship Between Wind MW and Normalized Damping Ratio



What Have We Learned Thus Far?

1. **After knowing "are the lights on everywhere," voltage phase angles across a grid (i.e., synchrophasors) are arguably the next most important grid diagnostic measurement.**

2. **While voltage synchrophasors are valuable in steady-state analysis, they are far more valuable in observing the dynamic performance of a grid, e.g. damped resonant frequencies and normalized damping coefficients that indicate grid stress and stability.**

3. **Because voltage synchrophasors are very sensitive to grid disturbances, they can be thought of as the "EKG" of power grids. They quickly point out abnormalities not easily seen in conventional voltage, frequency, and power measurements. Grid "stress tests" come frequently, each time a generator trips off line.**

4. **If Steinmetz had known about GPS time stamping in the early 1900's, synchrophasors would have been in common use for the past 50-60 years.**

What Have We Learned Thus Far, continued ?

5. Excluding redundancy requirements, ten or so strategically-placed synchophasor units in a grid the size of ERCOT are adequate.

6. 120V wall outlets on distribution feeders have proven themselves to provide essentially the same results as transmission voltage measurements.

7. The three reasons that 120V wall outlets are suitable for synchrophasor purposes are that

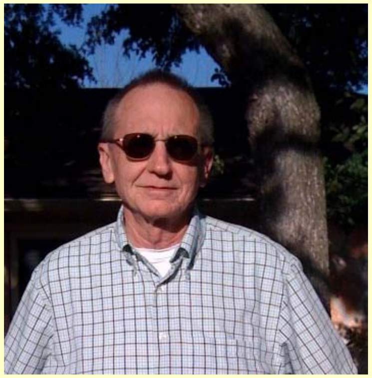
- Grid oscillations are in the 0.5 to 2 Hz range and readily pass through transformers of all sizes,
- Schweitzer relays effectively filter out distribution noise,
- With 30 points streaming in each second from remote monitoring points, occasional dropouts due to deep voltage sags or internet traffic cause no problems.

Texas Synchrophasor Network

Thanks to

- **Schweitzer Engineering Laboratories – for all the equipment and technical support that we have and will need**
- **EPRI – for past, present, and future funding of graduate students and faculty summer support**
- **Startup money in 2008 from the Texas Governor's Emerging Technology Fund through CCET**
- **Austin Energy – for installing the 69kV grid monitor, and providing advice on system operating and protection**

Biographies



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Moses Kai is a Graduate Research Assistant at U.T. Austin, working in the area of synchrophasors and impact of large-scale wind generation on ERCOT. He received his BSEE and MSEE from U.T. Austin in 2007 and 2009, respectively, and is now working toward his PhD. He also serves as a Teaching Assistant for the Power Electronics Lab course, which has an enrollment of more than 130 students per year. He is a student member of IEEE and a U.S. citizen.