# NASPI Working Group Meeting

## Success Stories

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MISO

# Agenda

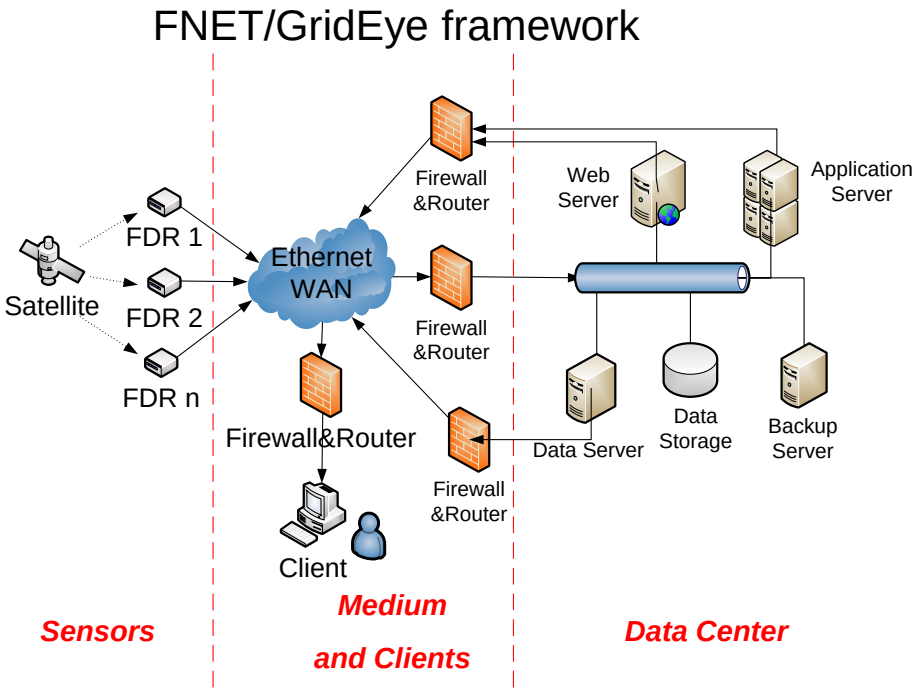
- FNET/GridEye Overview
- MISO's Smart Grid Investment Grant (SGIG) project
- FNET/GridEye Existing Tools
- Recent Developments
  - Improved estimates of Interconnection Frequency Response and event size
  - Rate of frequency change to detect low inertia
- Opportunities

# FNET/GridEye System Overview

- FNET/GridEye, Frequency Monitoring Network, is a low-cost, GPS-synchronized, wide-area distribution level phasor measurement system

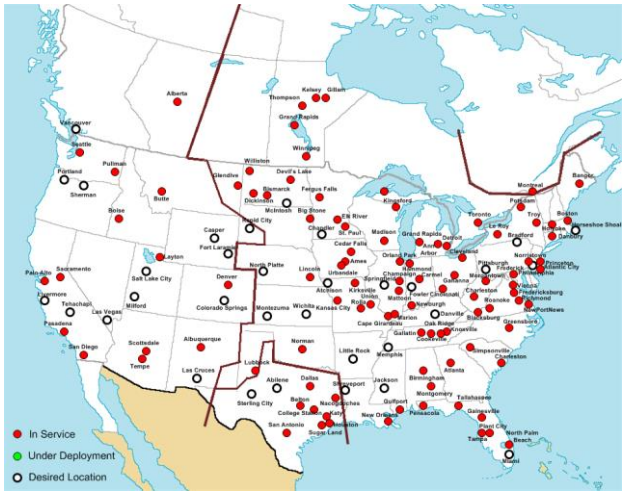
- GPS-based synchronized sensor known as a Frequency Disturbance Recorder (FDR)

- Information Management System (IMS)



# Frequency Disturbance Recorder (FDR)

- GPS-synchronized single-phase PMU installed at ordinary 120 V outlets
- Measures **power system frequency, voltage magnitude and voltage angle** 10 samples per second
- Transmits data to the FNET data center via the Internet
- Over 300 FDRs installed in North America and 20 other grids over the world



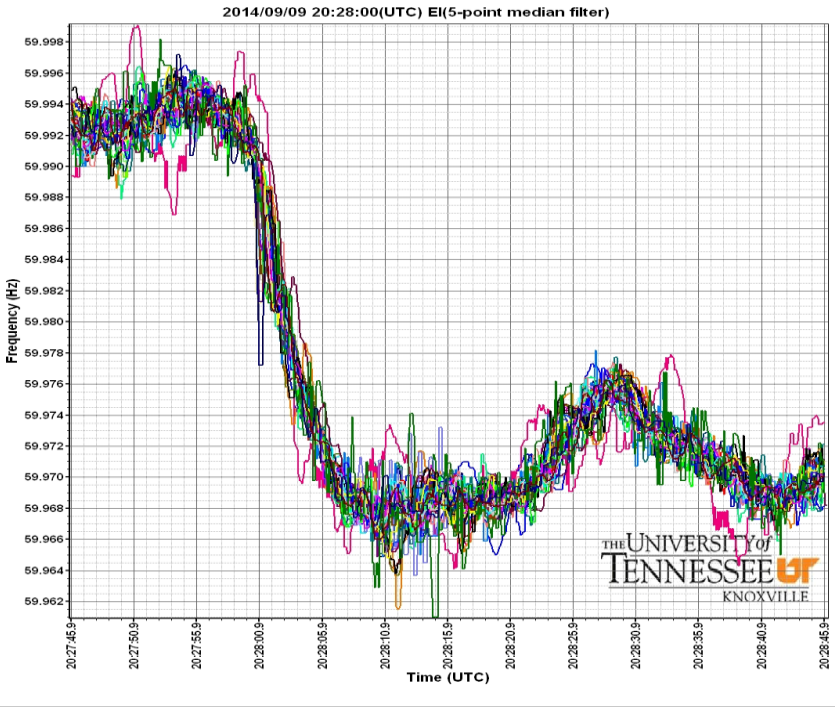

# MISO's FNET/GridEye Project

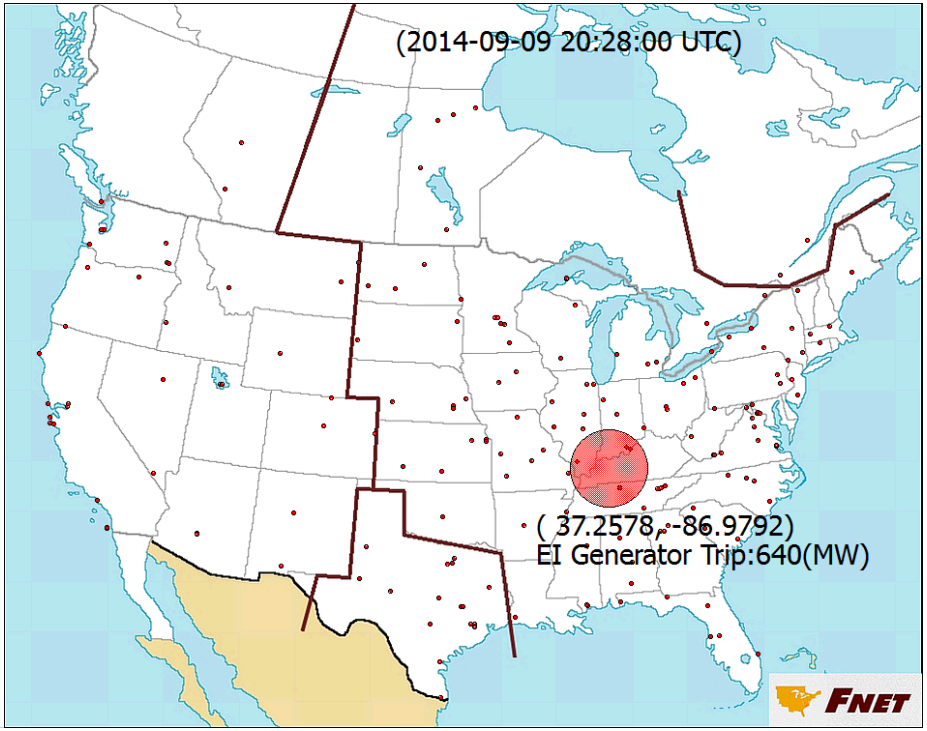
- One of two MISO SGIG research projects
- Automated disturbance reports
- Beta tested real-time displays/tools (including real time movie generation and posting)
- Formatting FDR data output to mesh with other SynchroPhasor data
- Implemented an oscillation trigger notification and report
- Installed over 20 FDRs in MISO's footprint
- Examples of tools in following slides

# Automatic Event Detection and Alerts

Event Estimation:
640MW EI Generator Trip at 20:28:00UTC, on 09/09/2014 near Paradise power plant (SERC)
((Muhlenberg,KY,42337; Latitude:  37.2578,  Longitude: -86.9792)

PLEASE KEEP THIS INFORMATION CONFIDENTIAL.

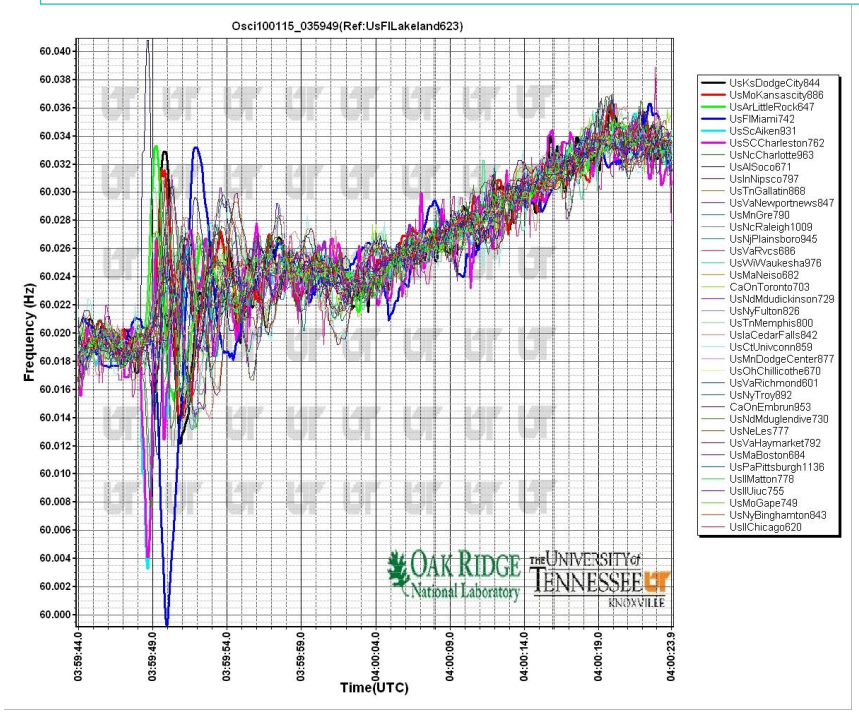


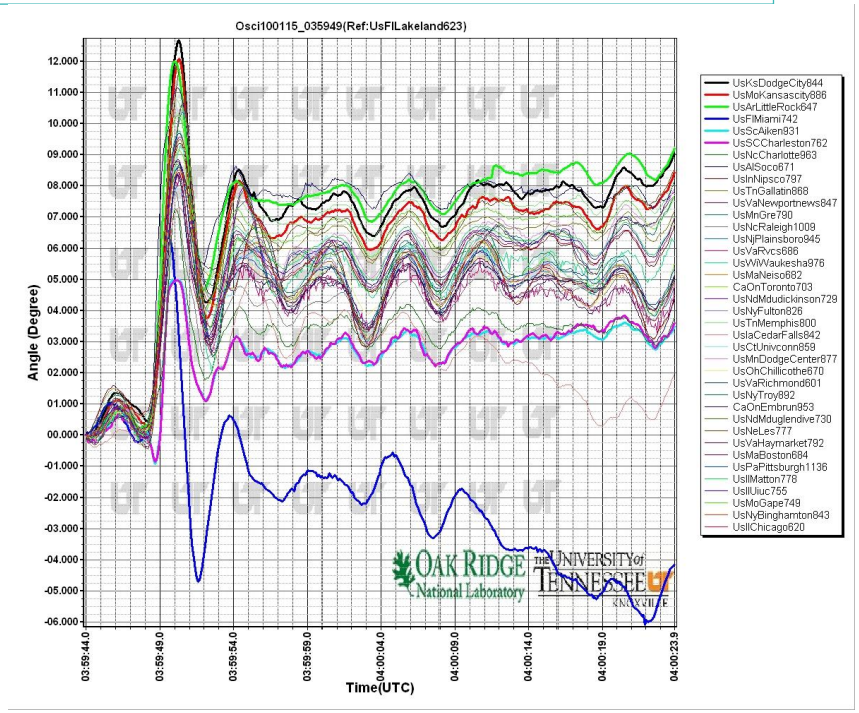
# Automatic Oscillation Detection and Alerts

InterConnection: EI Event Date: 2015-10-01 Event Time: 03:59:49 UTC
Dominant Frequency (Average): 0.2162 Hz
Largest Negative Amplitude Oscillation: -4.7089 Deg
Largest Positive Amplitude Oscillation: 12.6747 Deg

PLEASE KEEP THIS INFORMATION CONFIDENTIAL.




Frequency plot of All FDRs



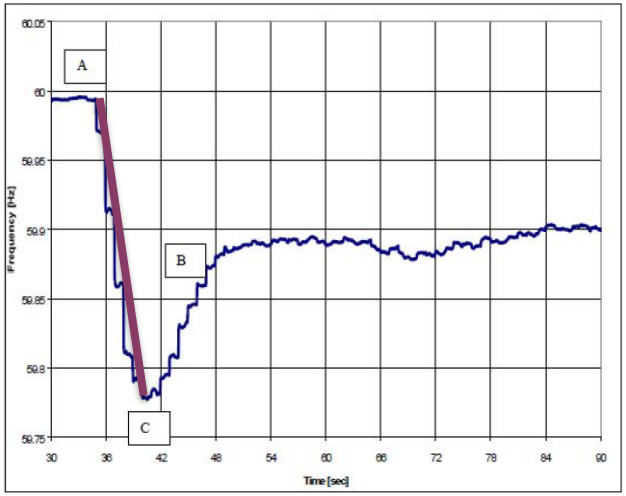

Angle plot of All FDRs

# Recent Work: Improved Event Size Estimator

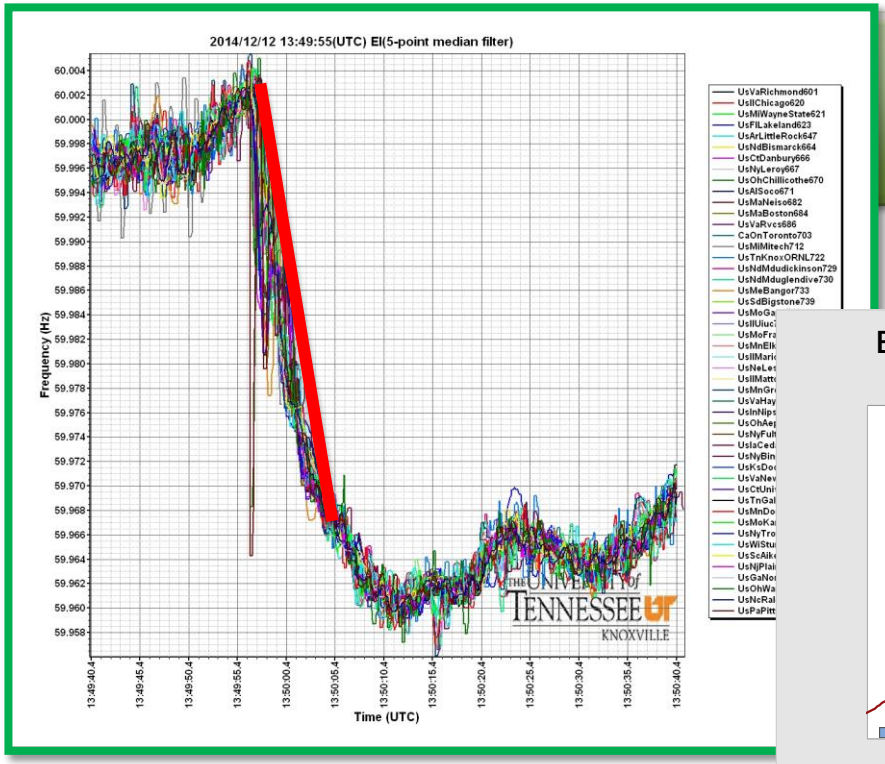
- Used linear regression to quantify most significant predictors in estimating the size of a resource or load loss
  - Seasonal impact (less frequency response in shoulder months)
  - Frequency at onset of disturbance
    - Termed “Point A”
    - Higher starting frequency triggers fewer governors
  - Frequency at nadir or “Point C”
- Could be used for near real-time estimate of frequency response or beta (β)
- Analysis could assist NERC is estimating actual available frequency response for their *State of Reliability Report* benchmarking

# Recent Work: Interconnection Inertia

- Rate of Change of Frequency(ROCOF) during the first few seconds of an event is strongly correlated to Interconnection inertia
- The higher ROCOF, the lower inertia
- Performed initial assessment of ROCOF in the Eastern Interconnection
- Directly supports NERC's Essential Reliability Services benchmarking
- Can provide real-time indication to operators and planners of low system inertia



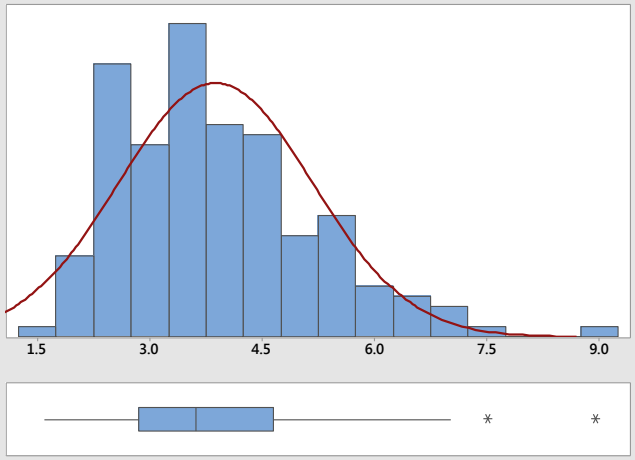
# Interconnection Inertia Notification



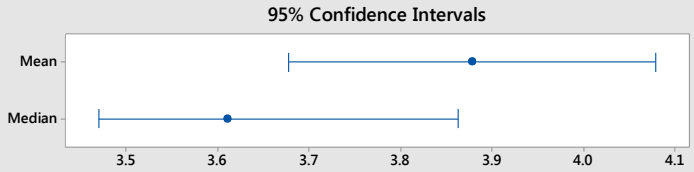

2014-12-12 13:49:55
900 MW power loss in Ohio
ROC=2.22 mHz/s

## Eastern Interconnection Rate of Frequency Change (mHz/Sec)

2014 to Present




| Anderson-Darling Normality Test | |
|---|---|
| A-Squared | 1.85 |
| P-Value | <0.005 |
| Mean | 3.8782 |
| StDev | 1.2974 |
| Variance | 1.6831 |
| Skewness | 0.855946 |
| Kurtosis | 0.804276 |
| N | 163 |
| Minimum | 1.5950 |
| 1st Quartile | 2.8520 |
| Median | 3.6120 |
| 3rd Quartile | 4.6530 |
| Maximum | 8.9590 |
| 95% Confidence Interval for Mean | |
| 3.6776 | 4.0789 |
| 95% Confidence Interval for Median | |
| 3.4702 | 3.8634 |
| 95% Confidence Interval for StDev | |
| 1.1702 | 1.4558 |



# FNet/GridEye Opportunities

- ROCOF
  - Real time “outlier” notification for situational awareness of system inertia status (low-medium-high)
  - “Outlier” record is open source for further research and grid planning
- Other valuable outlier notifications possible:
  - Large generation loss (e.g. 1200MW or more in the East)
  - Large load loss (e.g. 800 MW)
  - Oscillations > [value tbd]
  - Damping < [value tbd]
  - Islanding at two or more locations (it is not unusual for a single FDR to be installed at a site that transfers to a local generator)

# Questions

# Appendix

# Center for Ultra-wide-area Resilient Electric Energy Transmission Network (CURENT)

## NSF ERC typical funding $40 million in 10 years

**The University of Tennessee · Northeastern University**
**Rensselaer Polytechnic Institute · Tuskegee University**

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**National Technical University of Athens · Tsinghua University**
**University of Waterloo**

Director: Kevin Tomsovic

Deputy Director: Yilu Liu

# Related web links:

**FNET Live Display** : http://fnetpublic.utk.edu/gradientmap.html

**UTK Powerit Lab**: http://powerit.utk.edu

**NSF/DOE Center**: http://curent.utk.edu

**Worldwide Measurement Map**: http://powerit.utk.edu/worldmap/

**How to install FDR**: http://www.youtube.com/watch?v=9Vt2OlVoBJc&NR=1

**Sample Oscillation Alert**: http://fnetapp.eecs.utk.edu/FNETOsciEventReport/20120110_202749_EI_OsciSummary.html

**FL Event Movie:** http://www.youtube.com/watch?v=bdBB4byrZ6U&feature=related

**CA Blackout Movie:** http://www.youtube.com/watch?v=YsksUyeLu2Y

**April 27 Storm TVA line trip Movie**: http://www.youtube.com/watch?v=KmK2VMG57gw&feature=related

**2011 Virginia Earthquake Movie:** http://www.youtube.com/watch?v=XUN_h-k8kBg&feature=related

**2003 blackout movie:** http://www.youtube.com/watch?v=eBucg1tX2Q4&feature=related

FNET GridEye

MISO

# UTK smart grid research capabilities:

- Wide area power grid behavior data of the past 6 years
- US power grid dynamic models and simulation tools
- On-line grid monitoring (FNET), generator trip and grid oscillation
- High precision power meters/sensors design experience
- New flat control architecture and infrastructure design
- Intelligent agent for distributed control
- Power electronics capability
- Distribution level power quality analysis
- PHEV and DG grid interface, load frequency control
- Power market research

7 faculty in power area, 80+ graduate students, work sponsored by NSF, ORNL, TVA, EPRI, DOE and 15+ power companies