Some Observations from FNET Measurements of 3 Major Interconnections

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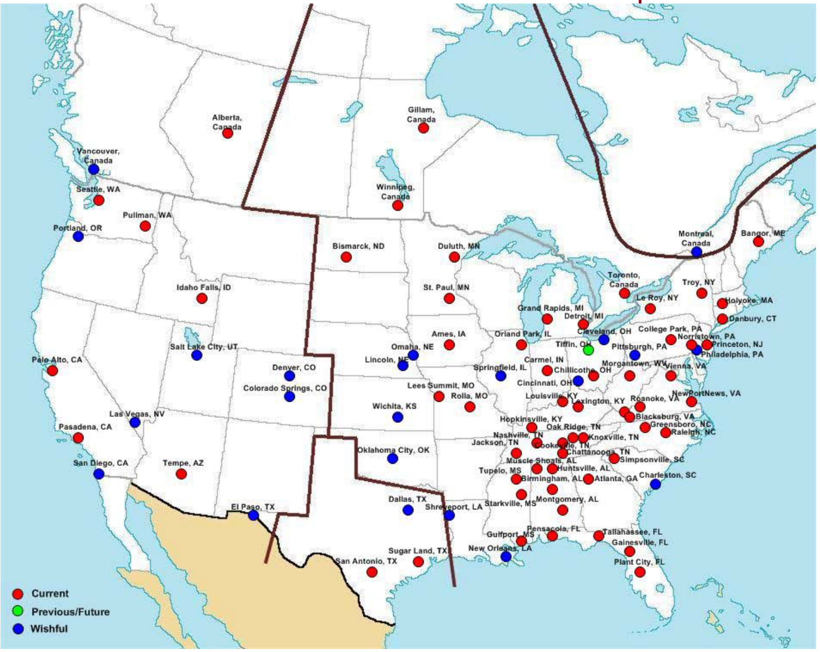

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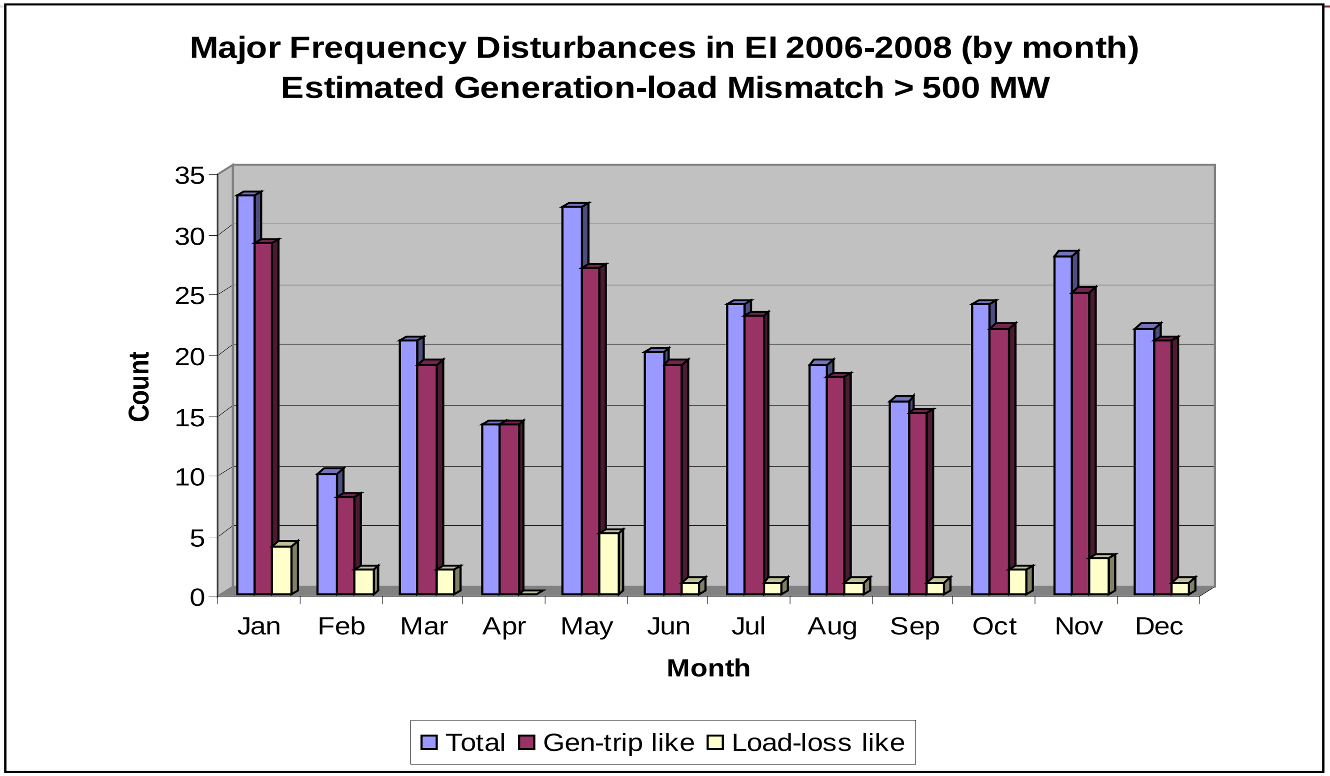
Outline

- Statistical analysis of disturbances
- Islanding Detection
- Wireless PMU
- Situation Awareness --- information delivery format survey

Statistics of Disturbances between 2006 and 2008

- 960 major disturbances were identified in the three North America Interconnections from Jan. 23, 2006 to Jan. 31, 2008.
- 263 disturbances in EI, 468 in WECC, 229 in ERCOT.
- On average, every 3 days, the EI sees a disturbance in ($\Delta P > 500MW$).
- The WECC sees a disturbance in almost every 1.5 days ($\Delta P > 200MW$).

Event Distribution in the EI (by month)



- Number of generation-loss like events: 240. Number of load-loss like events: 23. Estimated amount > 500MW.
- The peak of generation-loss like events: not in summer

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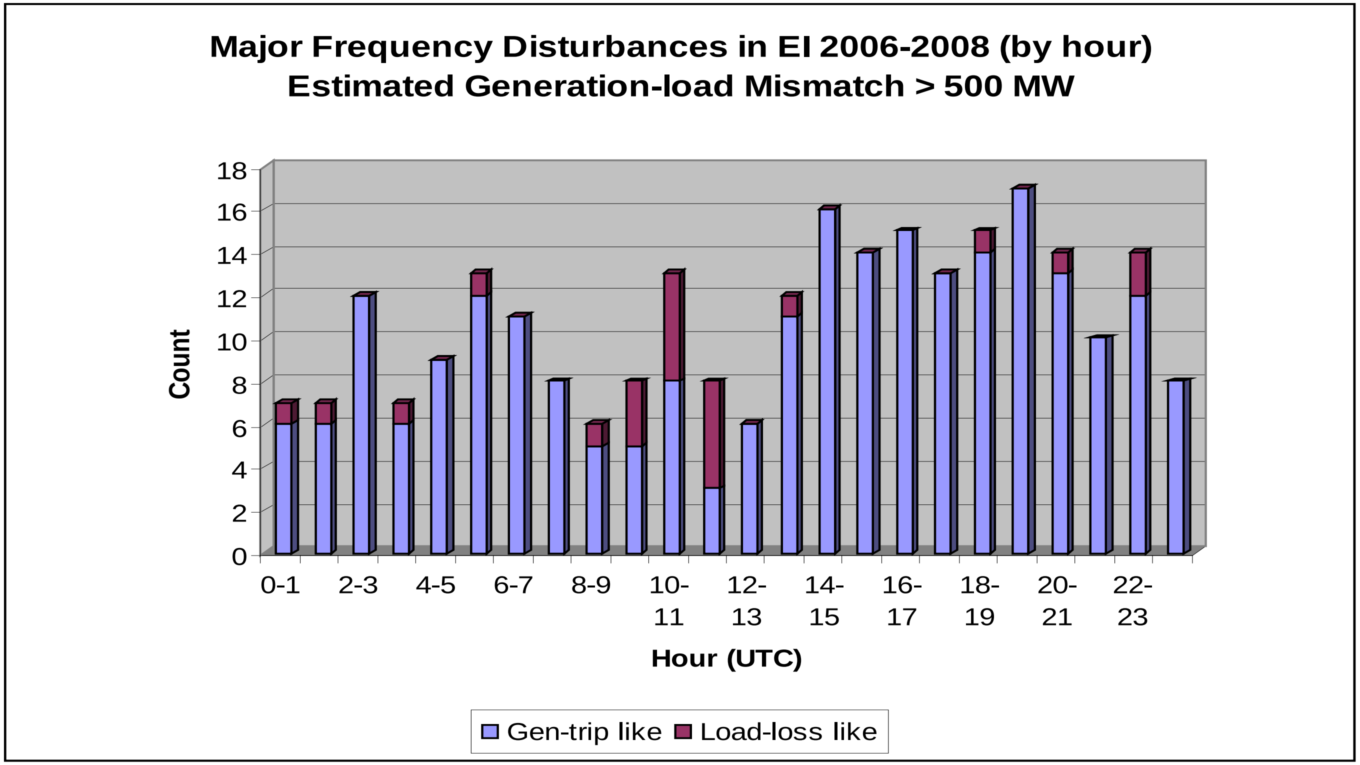
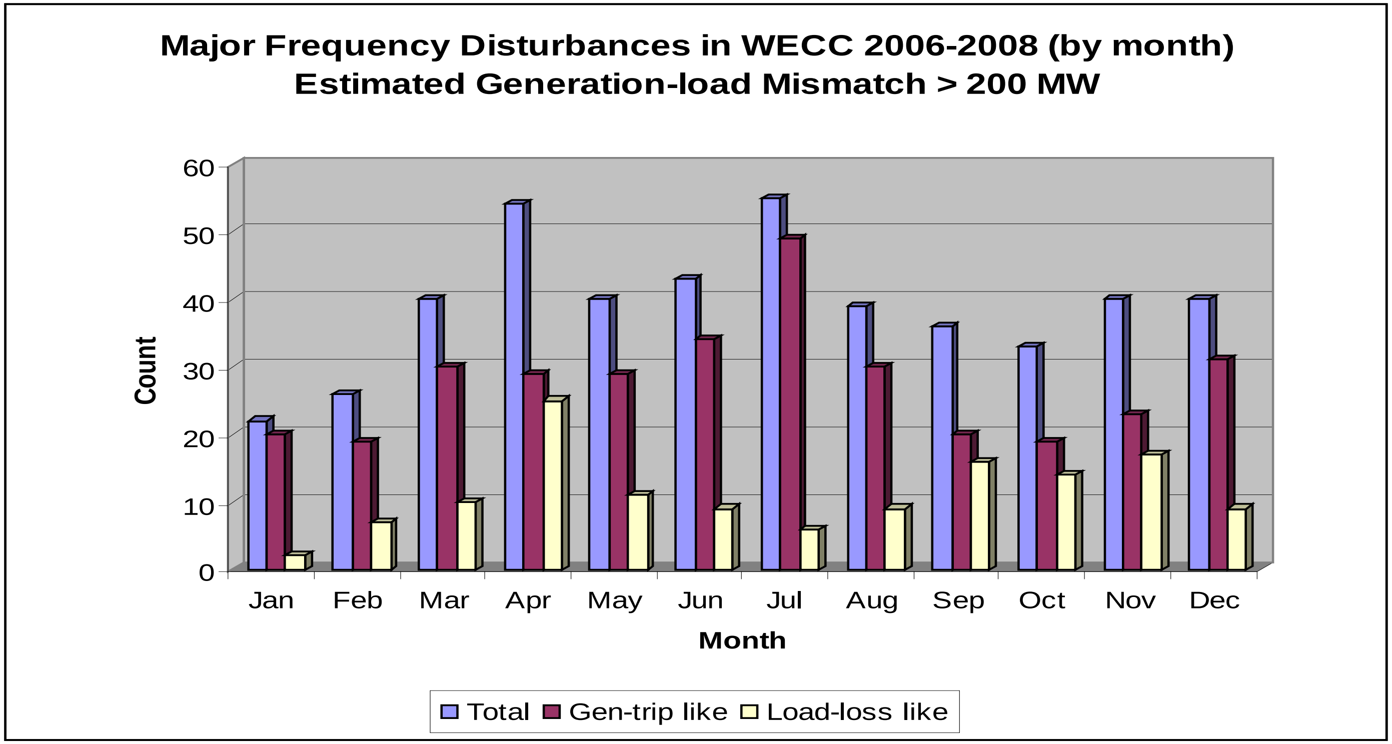
Event Distribution in the EI (by hour)



- The generation-loss events are more likely to occur between 1400 to 2000 UTC.
- Most load-loss like events occur between 0900 to 1100 UTC. Pumped storage turn off may play a major role

Event Distribution in the WECC (by month)



- Number of generation-loss like events: 333. Number of load-loss like events: 135. Estimated amount > 200MW.
- The peak of all disturbances and also generation-loss like events: July.
- Load-loss like events in WECC are more likely to occur in April.

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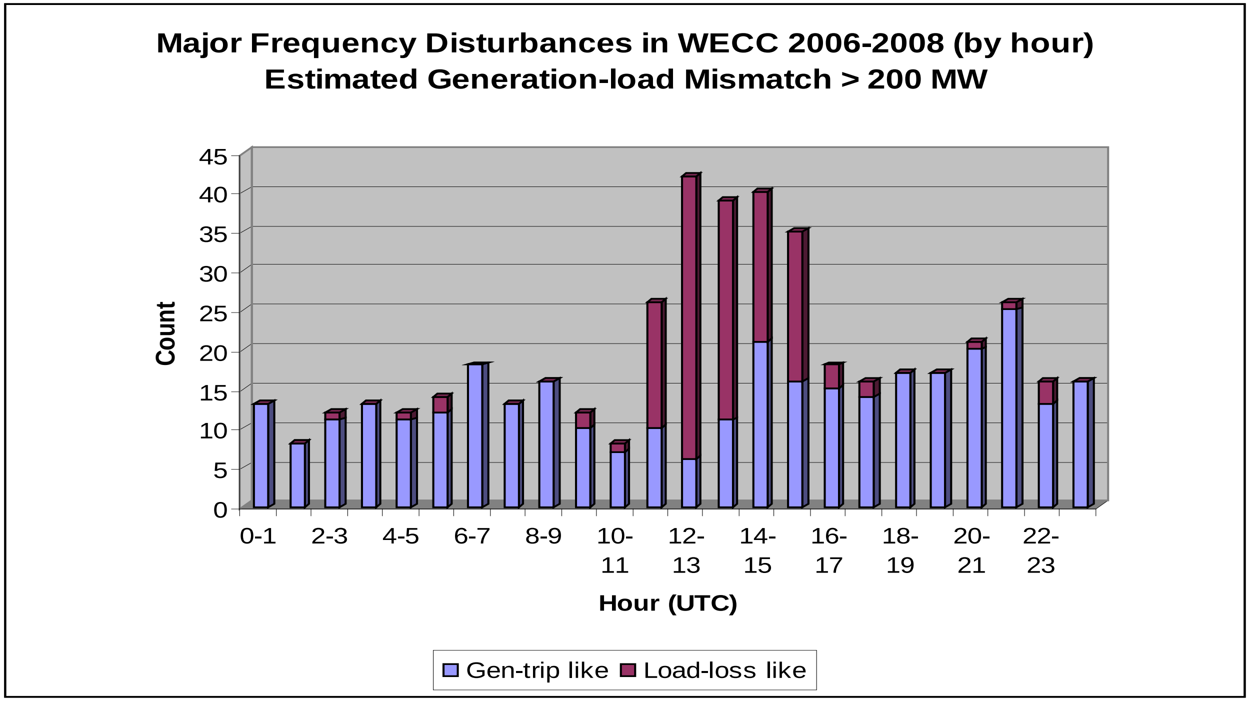
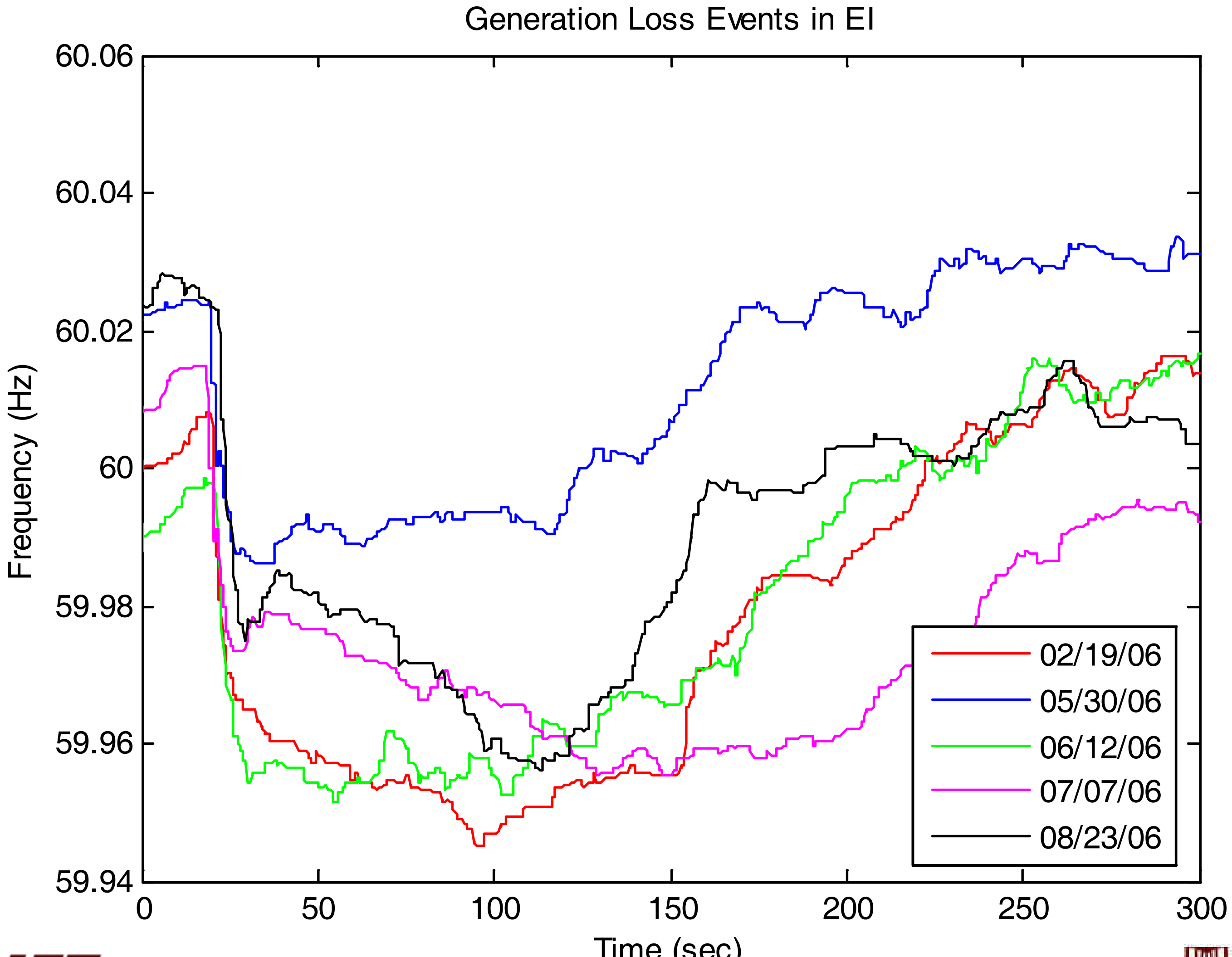
Event Distribution in the WECC (by hour)



- One peak of disturbances occurred between 0400 and 0500 PST.
- Generation-loss like events are more evenly distributed though likely to occur between 1300 -1400 PST.
- Most (118 out of 135) load-loss like events occur between 0300 - 0800 PST.

Five Generation Loss Events in the EI (five minutes of data)



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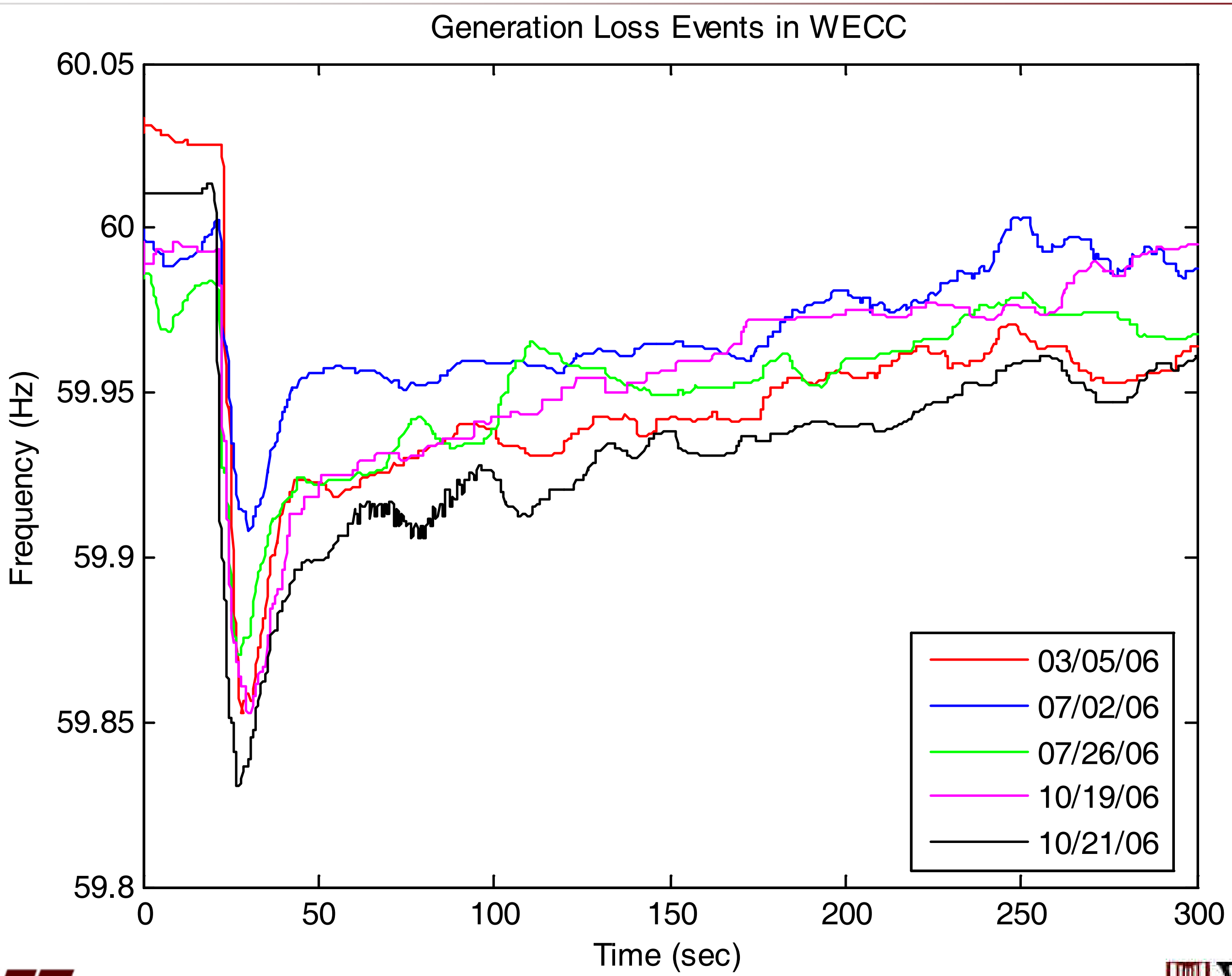
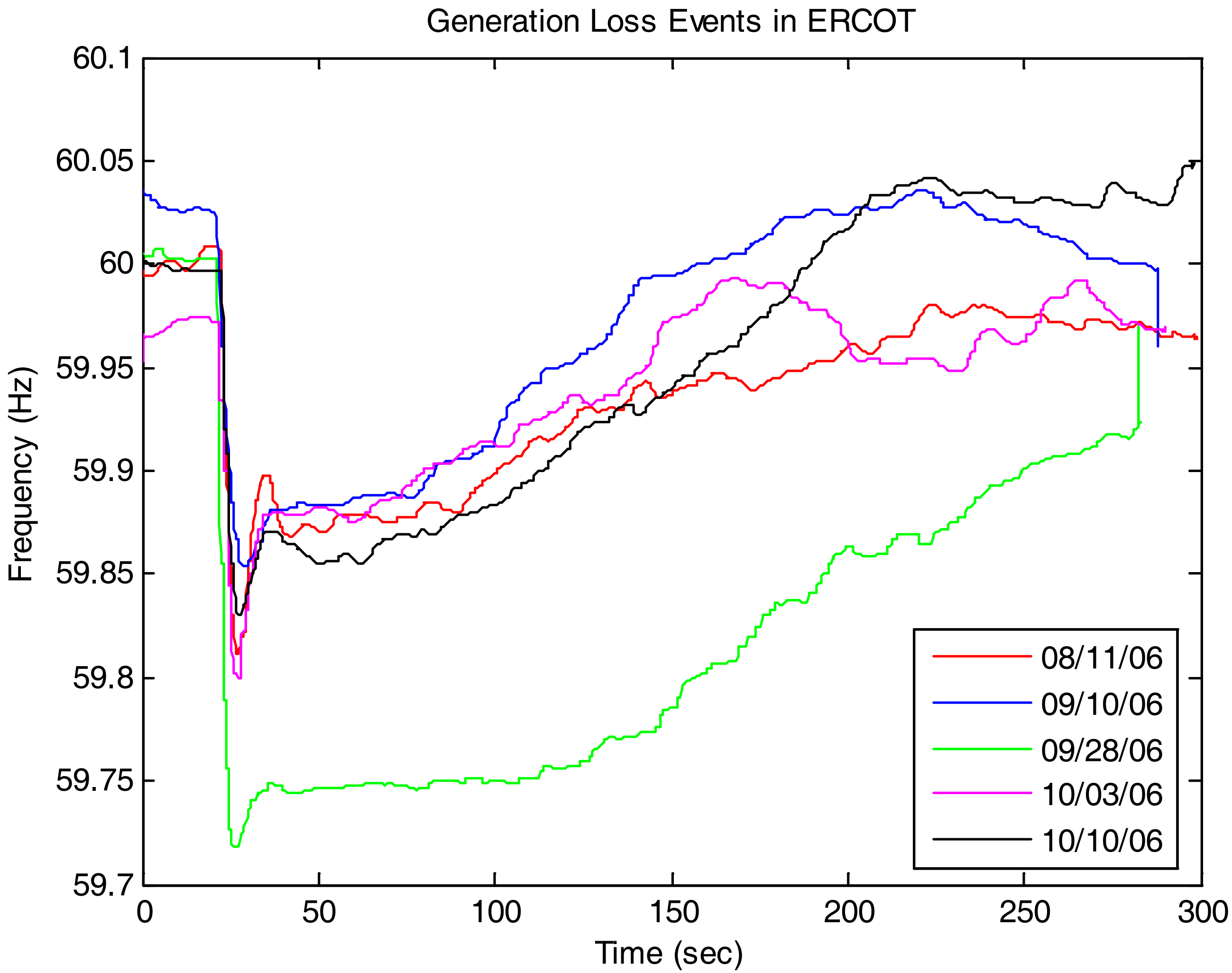
Five Generation Loss Events in the WECC (five minutes of data)



Five Generation Loss Events in the ERCOT (five minutes of data)



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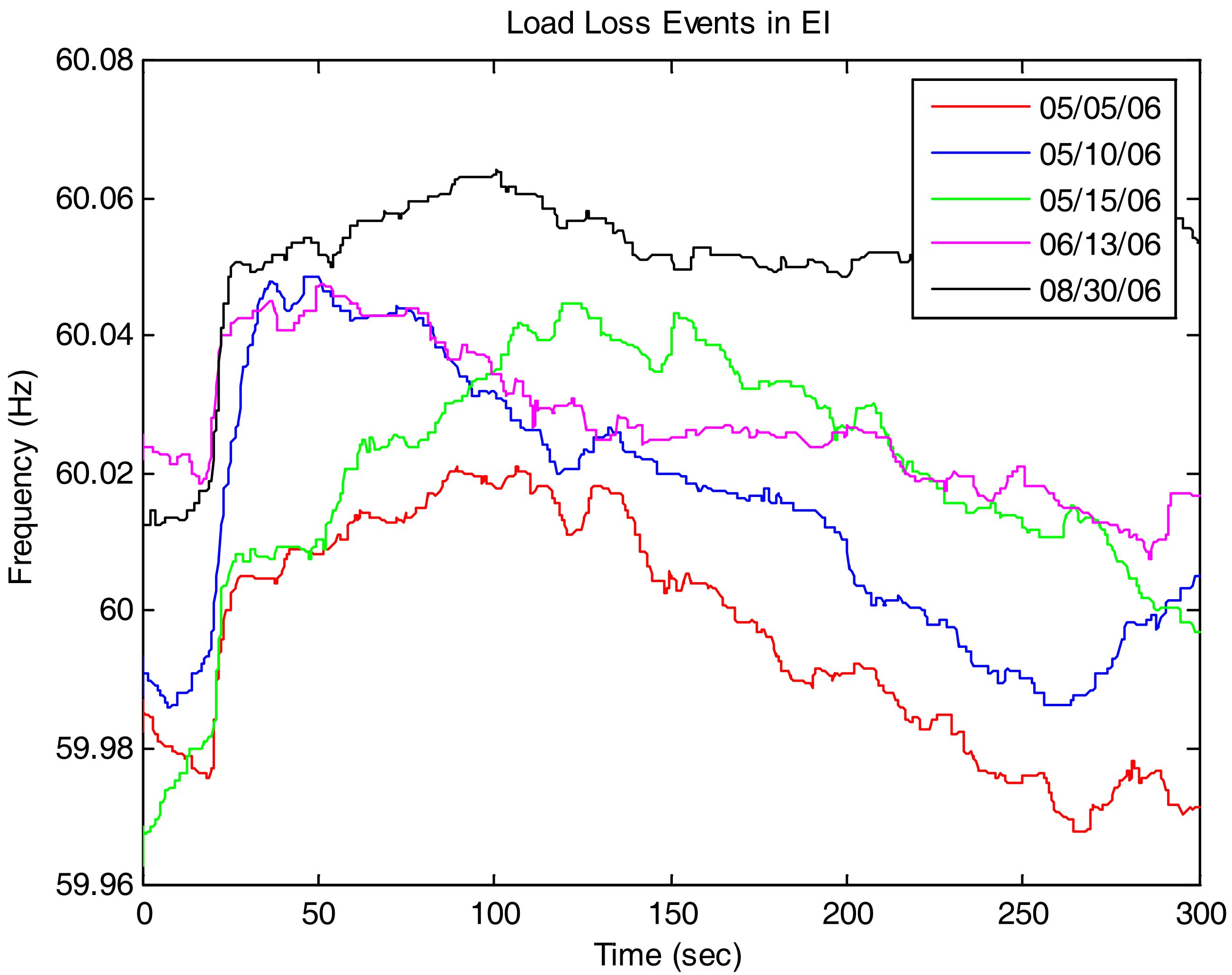
Five Load Loss Events in the EI (five minutes of data)



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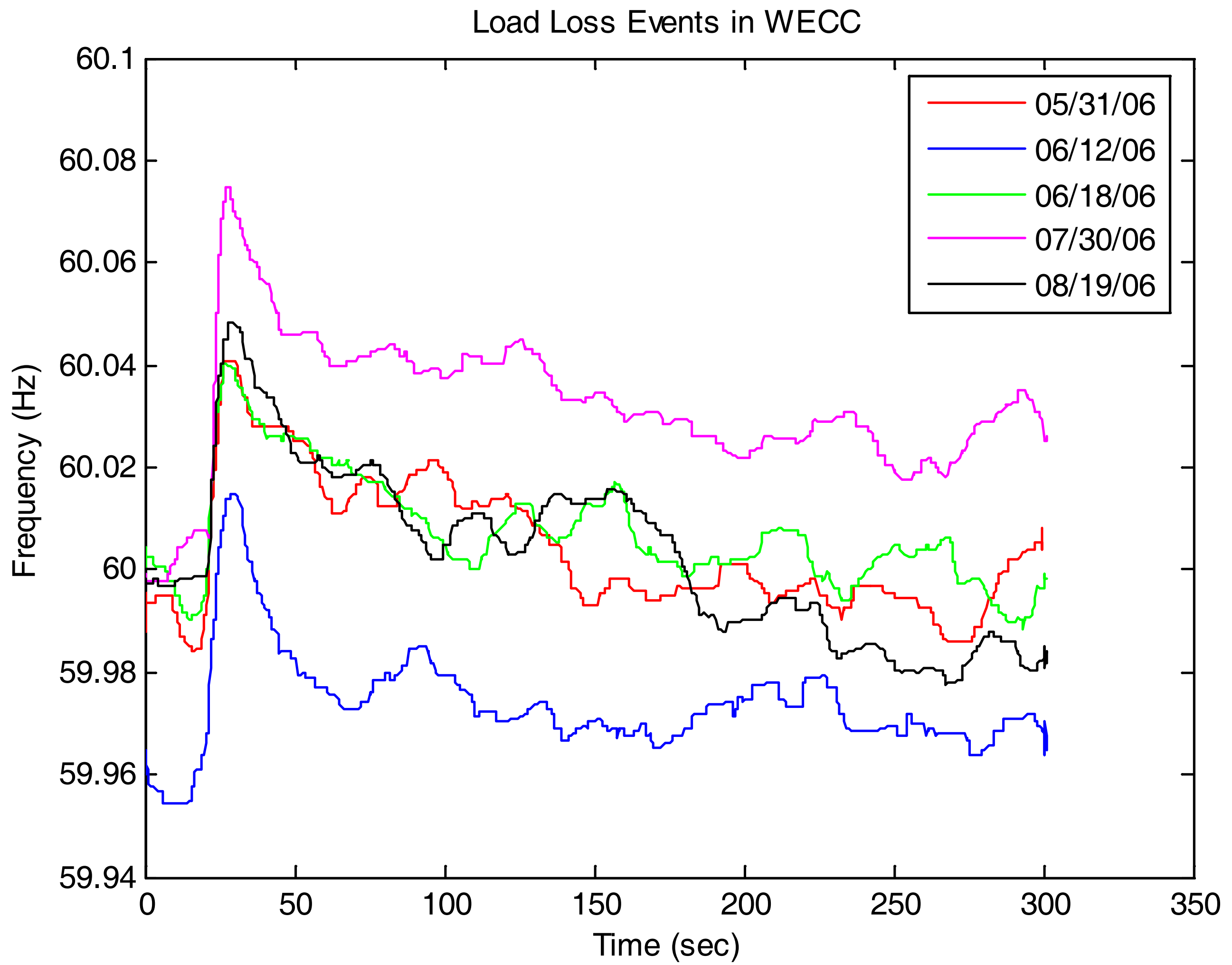
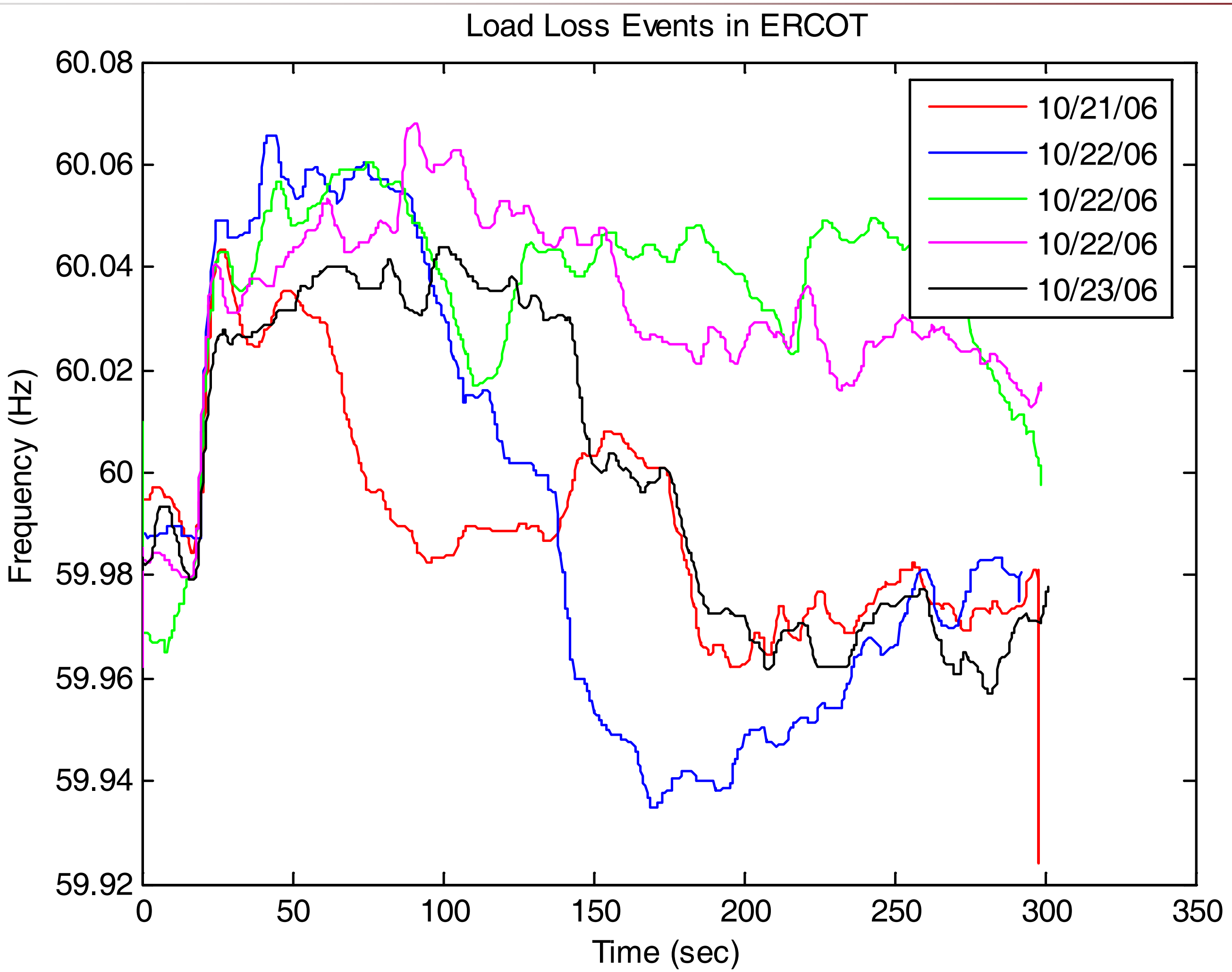
Five Load Loss Events in the WECC (five minutes of data)



Five Load Loss Events in the ERCOT (five minutes of data)



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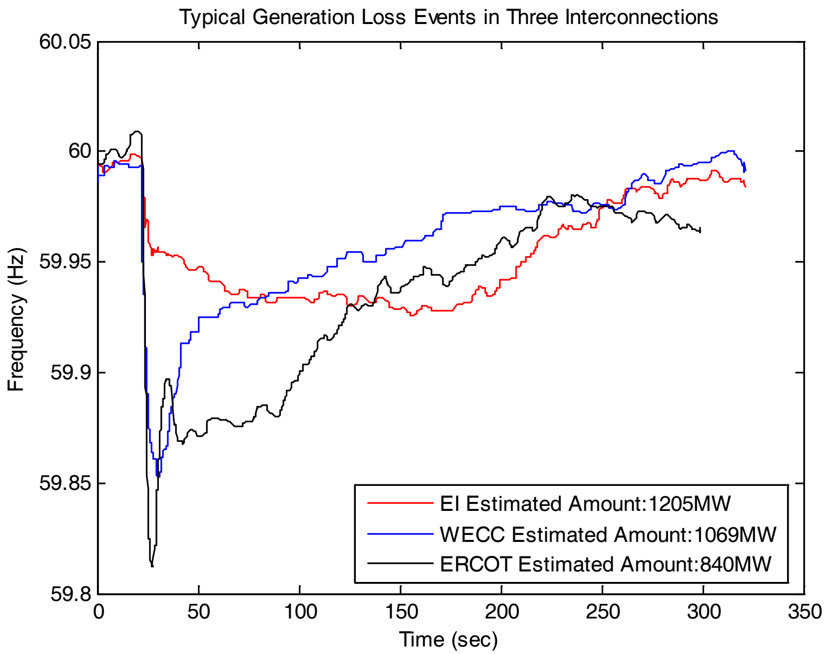
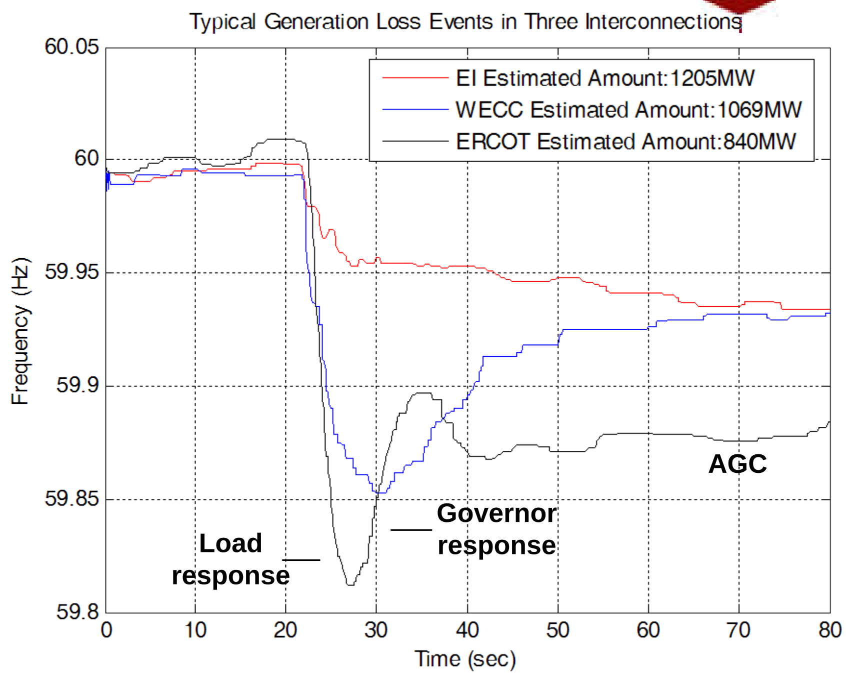
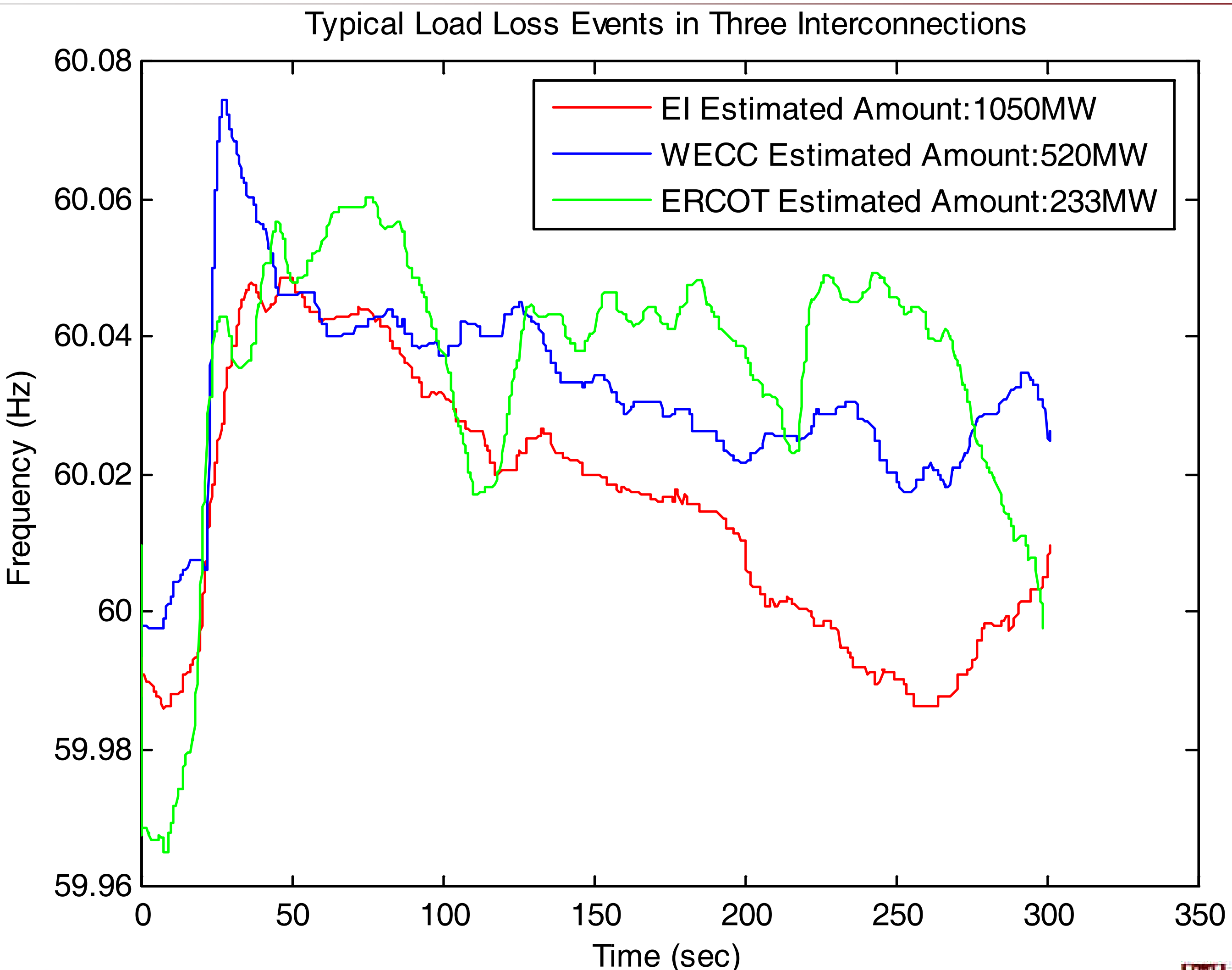
Generation Loss Events in Three Interconnections





- Generation/load loss amount ΔP=βΔf. β-frequency response characteristic. Larger β means smaller Δf for certain amount of power mismatch.
- Frequency excursions indicate control practices: governor control to arrest frequency drop; reserve development and AGC to replace the loss of generation.

Load Loss Events in Three Interconnections



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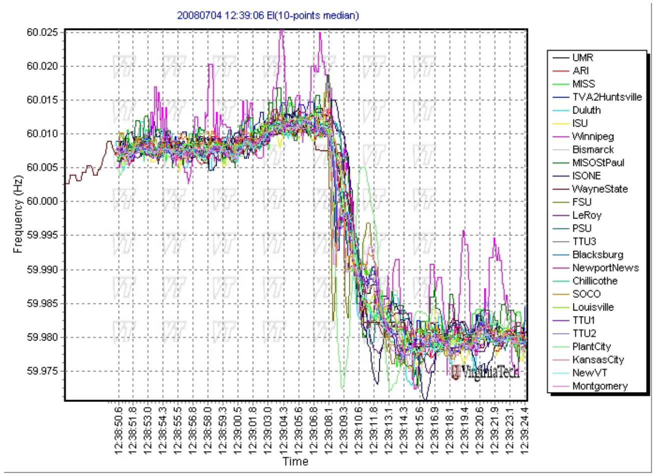
Conclusions

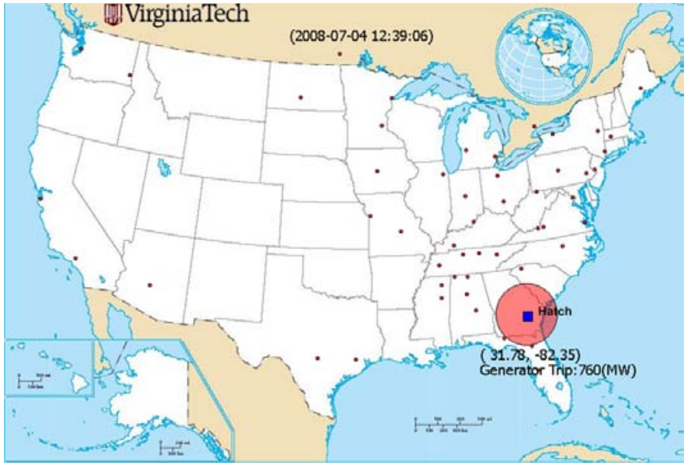
- Typical frequency excursions of disturbances differ from each other in three interconnections. Possible reasons include different frequency responses, contingency reserve distribution, reserve development and AGC actions.
- Plenty of information about systems' response to disturbances, as well as to control actions and protection schemes is reflected in measurements from FNET.

Situation Awareness- information delivery format survey

- Now: E-mail to FNET consortium members
- Future: IM, Text messaging?

From: Virginia Tech FNET Event Trigger [mailto:xiat@vt.edu]
Sent: Friday, July 04, 2008 8:39 AM, To: EvtRcvr
Subject: 760MW EI Generator Trip at 07/04/2008,12:39:06UTC
Event Estimation:760MW EI Generator Trip at 12:39:06UTC, on 07/04/2008 near Edwin I Hatch>power plant (SERC).(Appling,GA 31513; Latitude: 31.7837, Longitude: -82.3486)
PLEASE KEEP THIS INFORMATION CONFIDENTIAL.. This is just an ESTIMATE and Virginia Tech DOES NOT guarantee the accuracy of information which SHOULD NOT be used without secondary verification.





Power System Islanding Detection

Characteristics of Power System Islanding

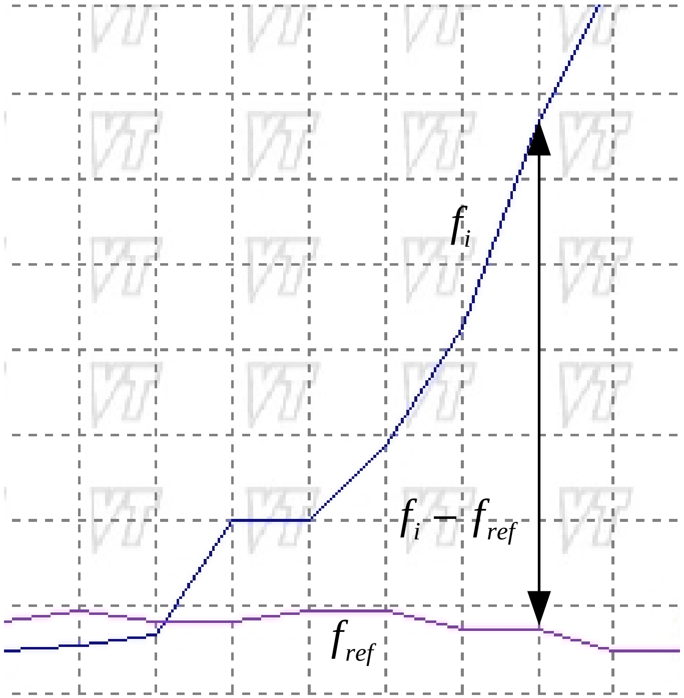
- Islanding is the situation in which a part of a power system becomes electrically isolated from the remainder of the power system.
- The power system of the islanded region undergoes severe frequency and power angle changes.
- The severity of transient and the frequency difference between the two isolated systems after transient is proportional to the generation to load imbalance.

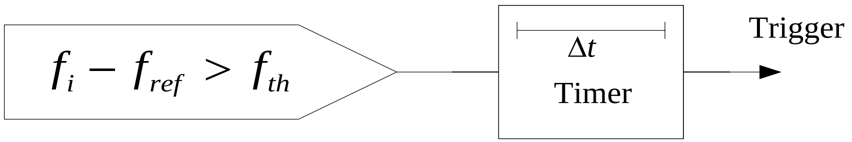
Commonly Used Islanding Detection Methods

- df/dt
- Frequency Variation Example Follows
- Angle Difference
- Change of Angle Difference Example Follows

FNET Islanding Detection Approaches

Frequency Variation

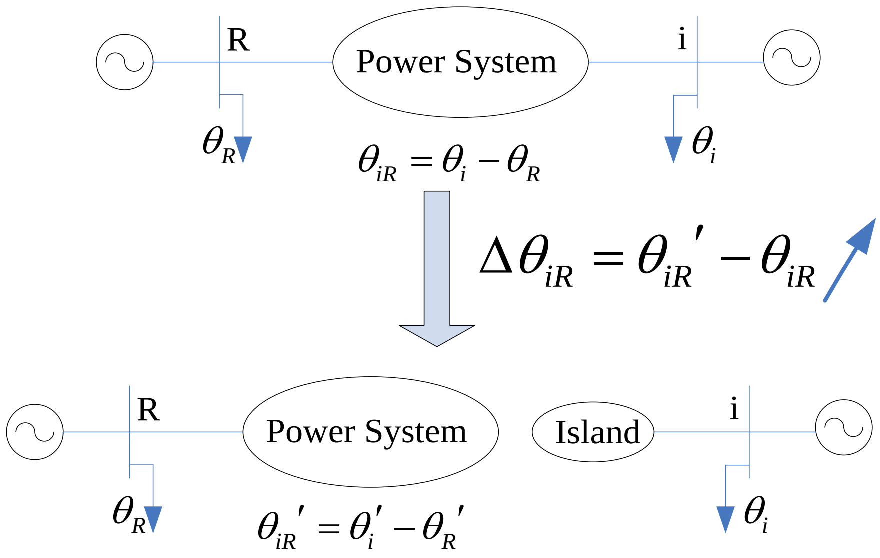


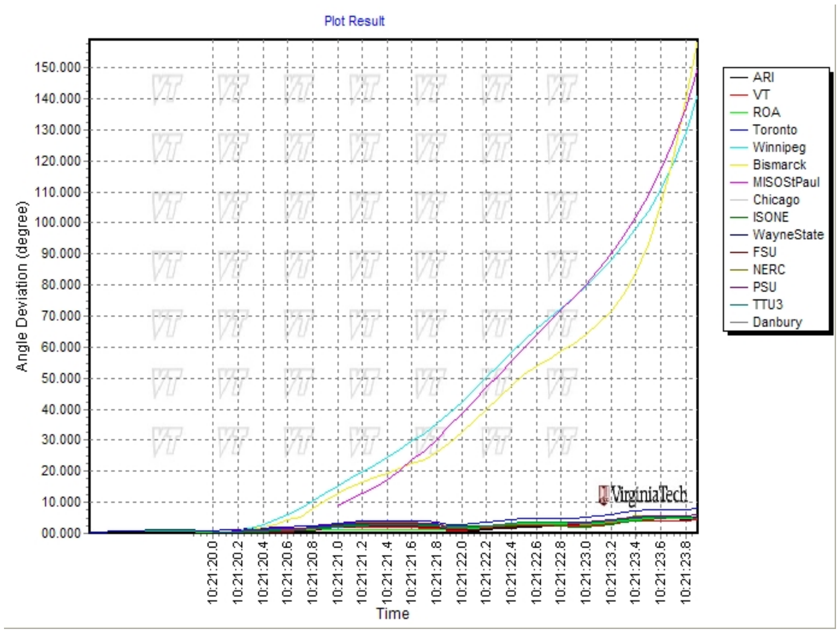


$$f_{th} = 20mHz \qquad \Delta t = 3s$$

FNET Islanding Detection Approaches

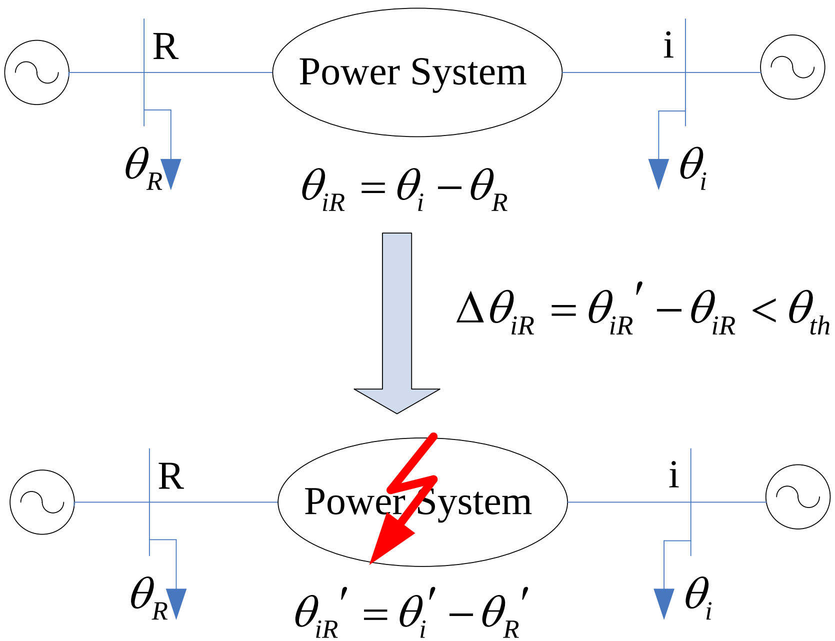
Change of Angle Difference





FNET Islanding Detection Approaches

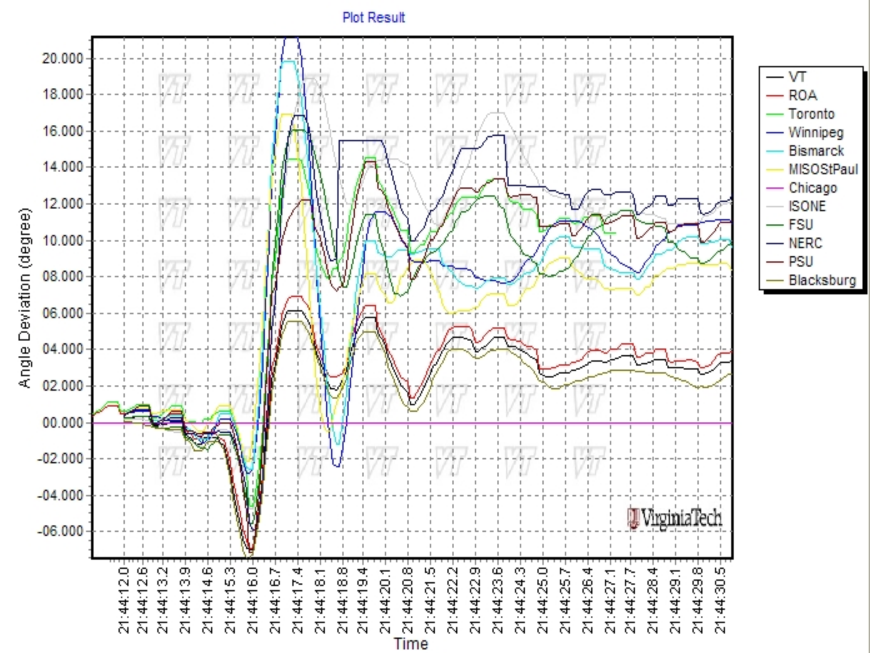
Change of Angle Difference



$$\theta_{iR} = \theta_i - \theta_R$$

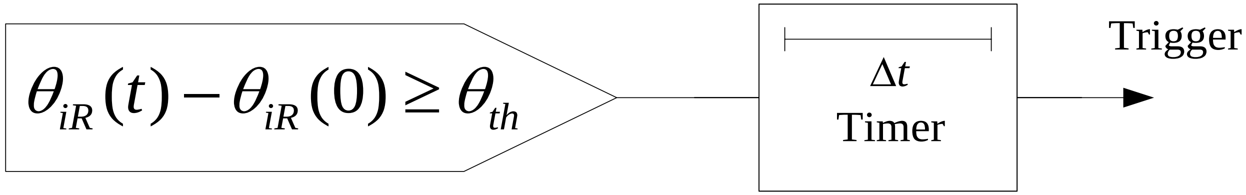
$$\Delta\theta_{iR} = \theta_{iR}' - \theta_{iR} < \theta_{th}$$

$$\theta_{iR}' = \theta_i' - \theta_R'$$



FNET Islanding Detection Approaches

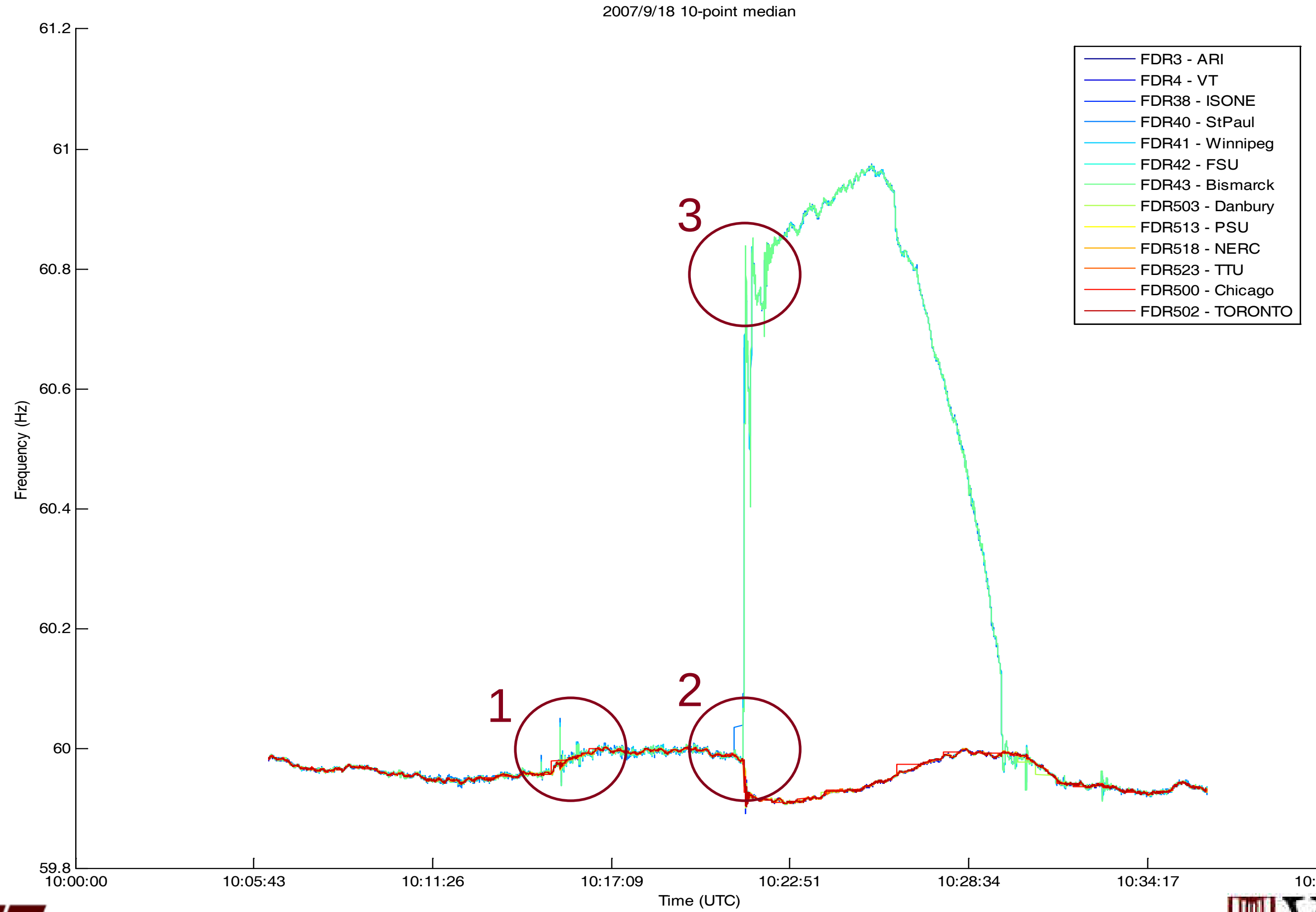
Change of Angle Difference



$$\theta_{th} = 80^{\circ} \qquad \Delta t = 3s$$

Algorithm Analysis

09/18/2007 EI Islanding



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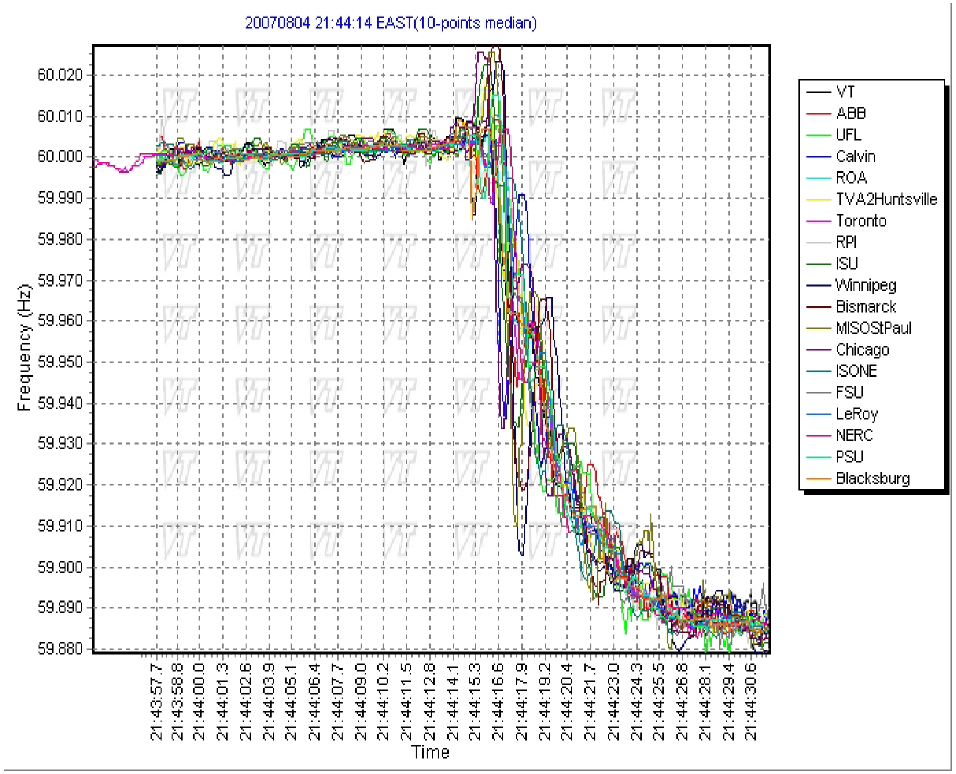
Detection Time

Method / FDR Location	Frequency Variation	Change of Angle Difference
Winnipeg	3.4 s	6.2 s
Bismark	3.6 s	6.5 s
St.Paul	4.0 s	6.1 s

Generation Drop Example

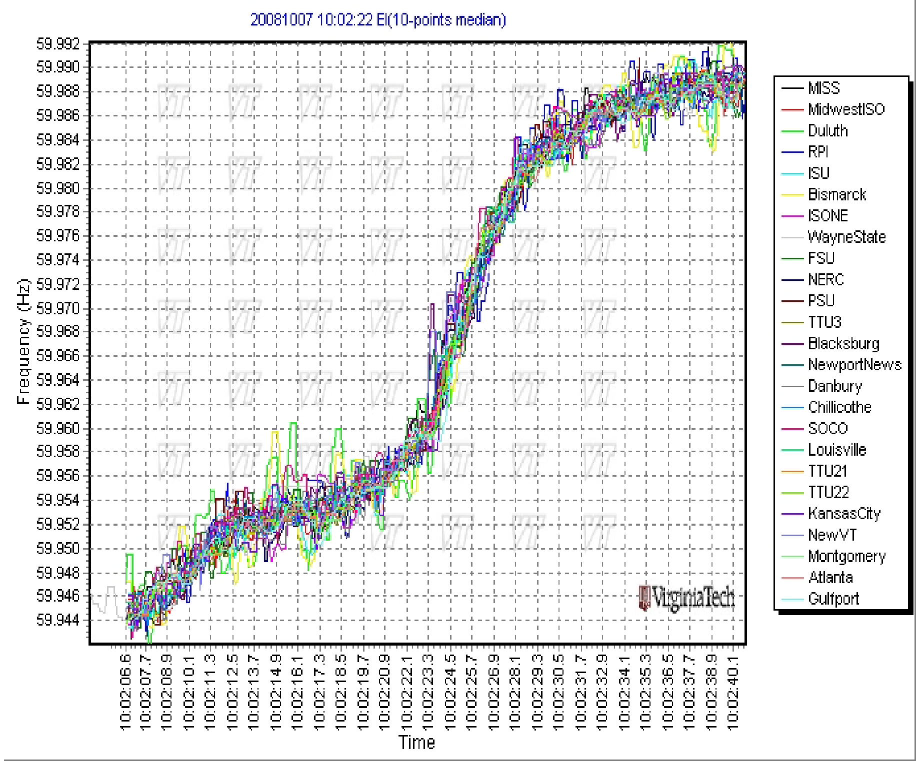


$$\Delta f_{\max} = \text{91.2 mHz}$$

$$(t_{\Delta f \geq f_{th}})_{\max} = \text{1.02 s}$$

$$\Delta \theta_{\max} = 12^{\circ}$$

Load Shedding Example



$$\Delta f_{\max} = \text{9.3 mHz}$$

$$(t_{\Delta f \geq f_{th}})_{\max} = 0$$

$$\Delta \theta_{\max} = 2.6^{\circ}$$

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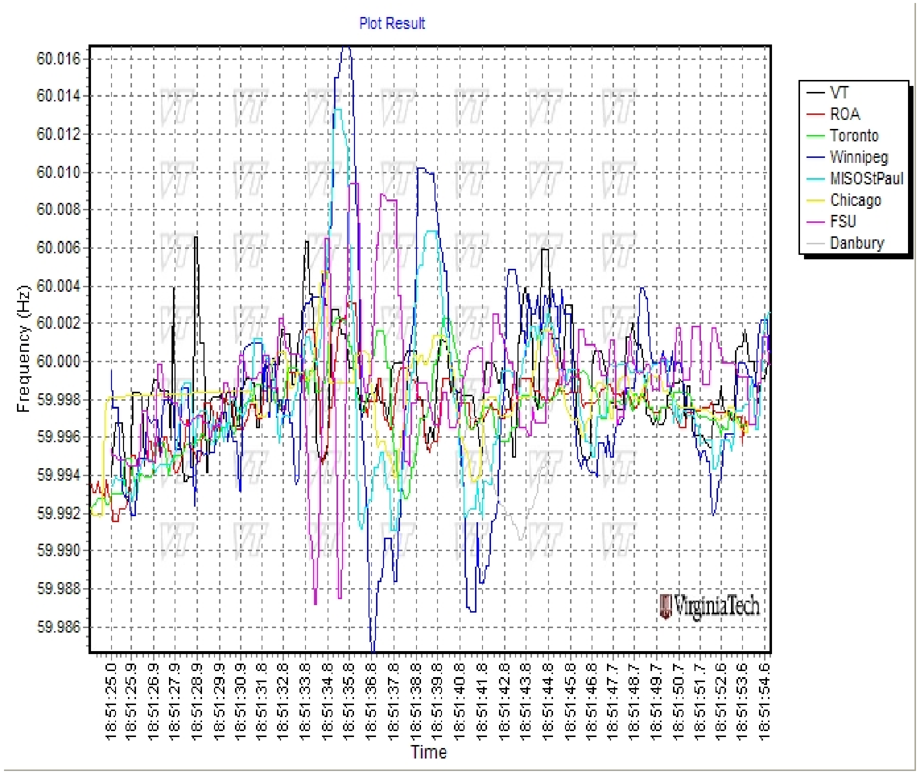
Line Trip Example

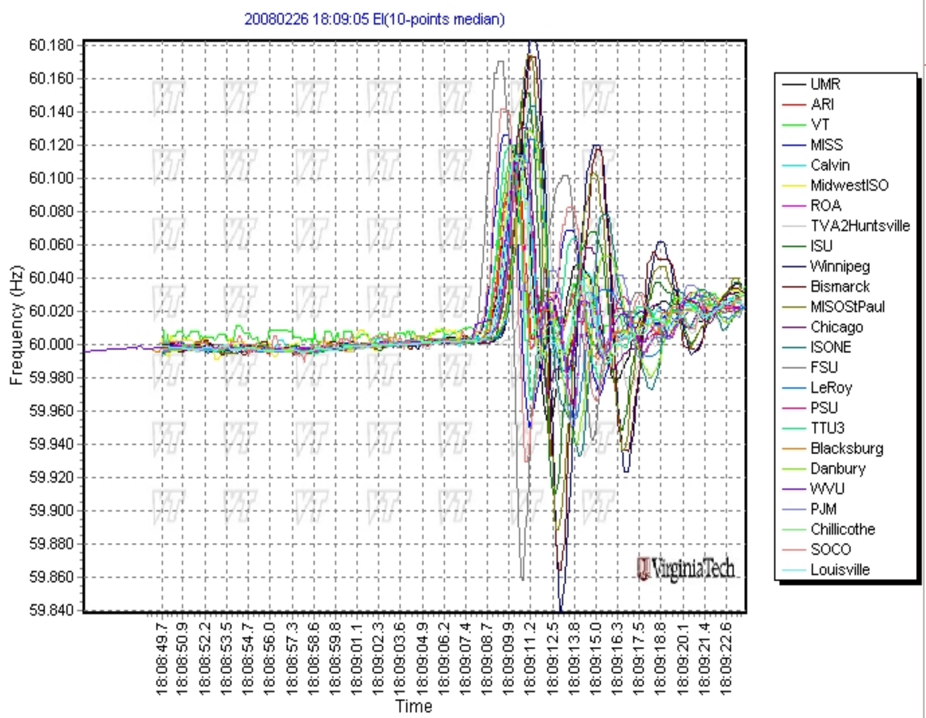


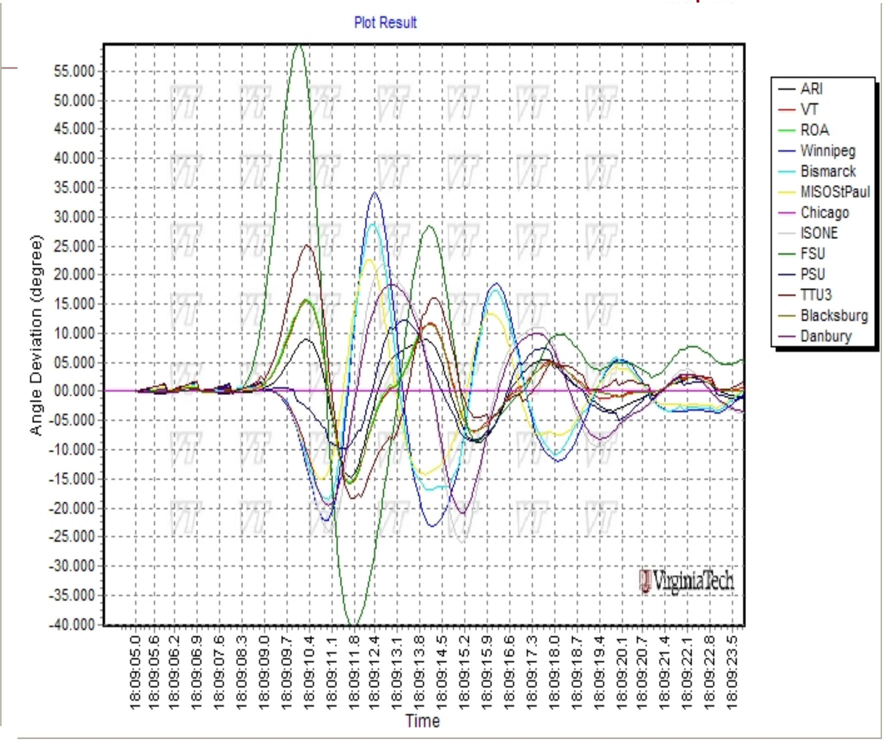
$$\Delta f_{max} = \text{16.0 mHz}$$

$$(t_{\Delta f \geq f_{th}})_{max} = 0$$

$$\Delta \theta_{max} = 8.9^{\circ}$$

Oscillation Example





$\Delta f_{\max} =$ 266 mHz

$(t_{\Delta f \geq f_{th}})_{\max} =$ 2.1 s

$\Delta \theta_{\max} = 58^{\circ}$

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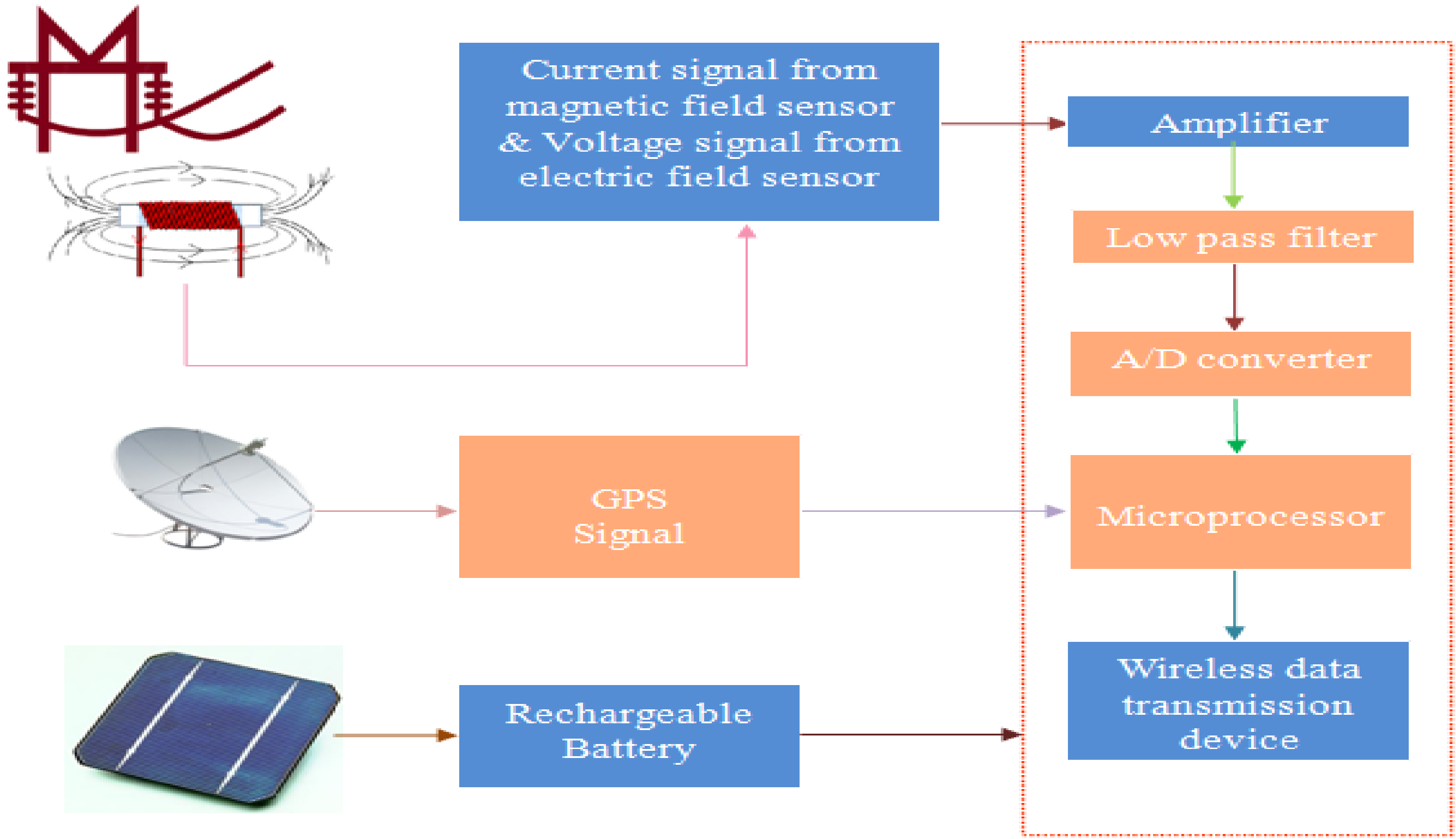
Summary of Disturbance Examples

Maximum / Example	$\Delta f_{\max}$	$(t_{\Delta f \geq f_{th}})_{\max}$	$\Delta\theta_{\max}$
Generation Drop	**91.2 mHz**	**1.02 s**	12°
Load Shedding	**9.3 mHz**	**0**	2.6°
Line Trip	**16.0 mHz**	**0**	8.9°
Oscillation	**266.1 mHz**	**2.09 s**	58°

$$f_{th} = 20mHz \quad \Delta t = 3s \quad \theta_{th} = 80^{\circ} \Longrightarrow$$ No False Trigger

Overview of EPRI Wireless PMU Project



Phase One EPRI project is to complete the current sensor frequency measurement feasibility study

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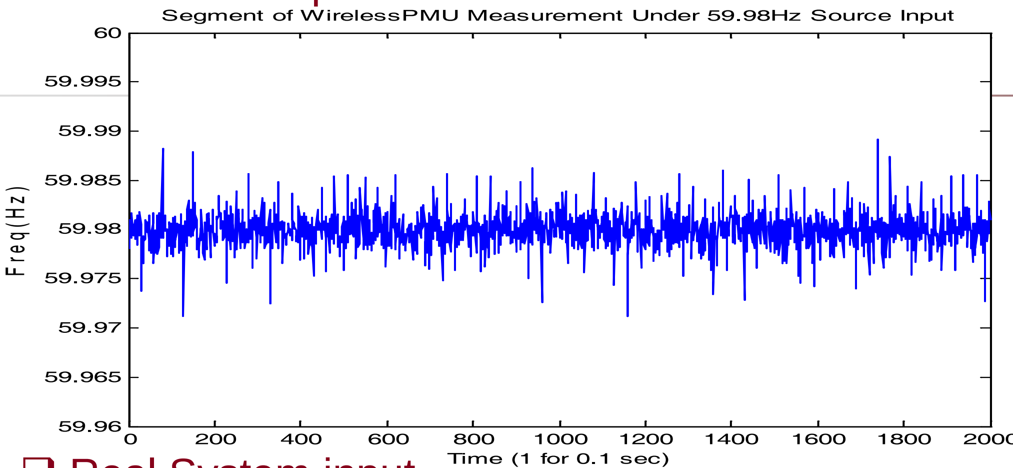
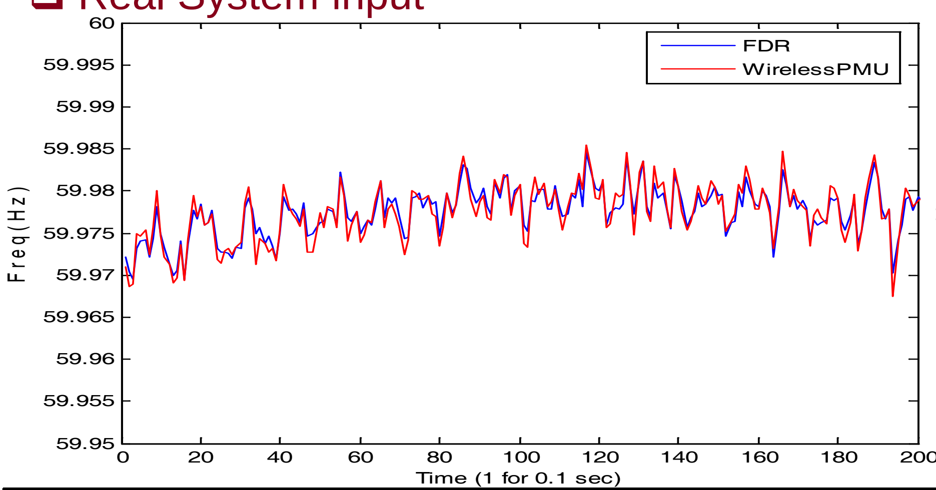
Preliminary Lab Test Results

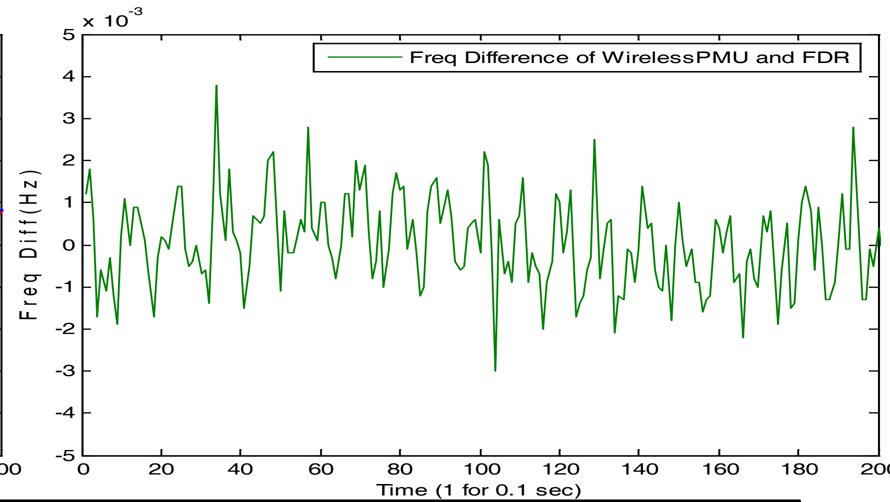
- AC source input



	Input signal Freq (Hz)	Measured Average (Hz)	Maximum Difference (Hz)	Standard Deviation
Measured Frequency (Each category for 200sec)	59.90	59.89996	0.0116	0.001700
	59.98	59.97997	0.0126	0.001631
	60.02	60.01997	0.0175	0.001942
	60.10	60.09994	0.0078	0.001691

- Real System input





Time	21/2/2008 6:00-6:30	21/2/2008 13:00-13:30	21/2/2008 21:00-21:30
RMS of Freq Difference (Hz)	0.0009863	0.0010442	0.0011113
Standard Deviation of Freq Difference (Hz)	0.0009839	0.0010413	0.0011084