Electric Power Group Presents

Maximizing Use of Synchrophasor Technology for Everyday Tasks

Welcome!

The meeting will begin at

2:00 p.m. EDT / 11:00 a.m. PDT
Sept. 21, 2016

Registration URL: https://electricpowergroup2.webex.com/
Webinar Teleconference Number: 1-650-479-3208
Access code: 665 878 354

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We will encourage discussion at planned QA session.
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Electric Power Group

Maximizing Use of Synchrophasor Technology for Everyday Tasks

Quickly Creating Reports on Grid Performance and Events for Operators, Engineers and Managers

Webinar

Sept 21, 2016

Presented by
Kevin Chen, Neeraj Nayak, EPG
Sidharth Rajagopalan, Patrick Gravois, ERCOT

Outline

- **Reports - Needs & Solutions**
  - > Daily Operations Performance
  - > Event Reports & Root Cause Diagnosis – Generation Trip, Oscillations, Faults, Line Trips etc.
    - – Real-Time report for Operators
    - – On Demand report for Reliability Coordinators & Managers
    - – Offline analysis report for Engineers & Planners
  - > Reports - Summary
- **ERCOT Experience**
- **Discussion**
  - > Your Practice, Use Cases, Suggestions
- **Summary**

Reports That Operators, Engineers and Managers May Need

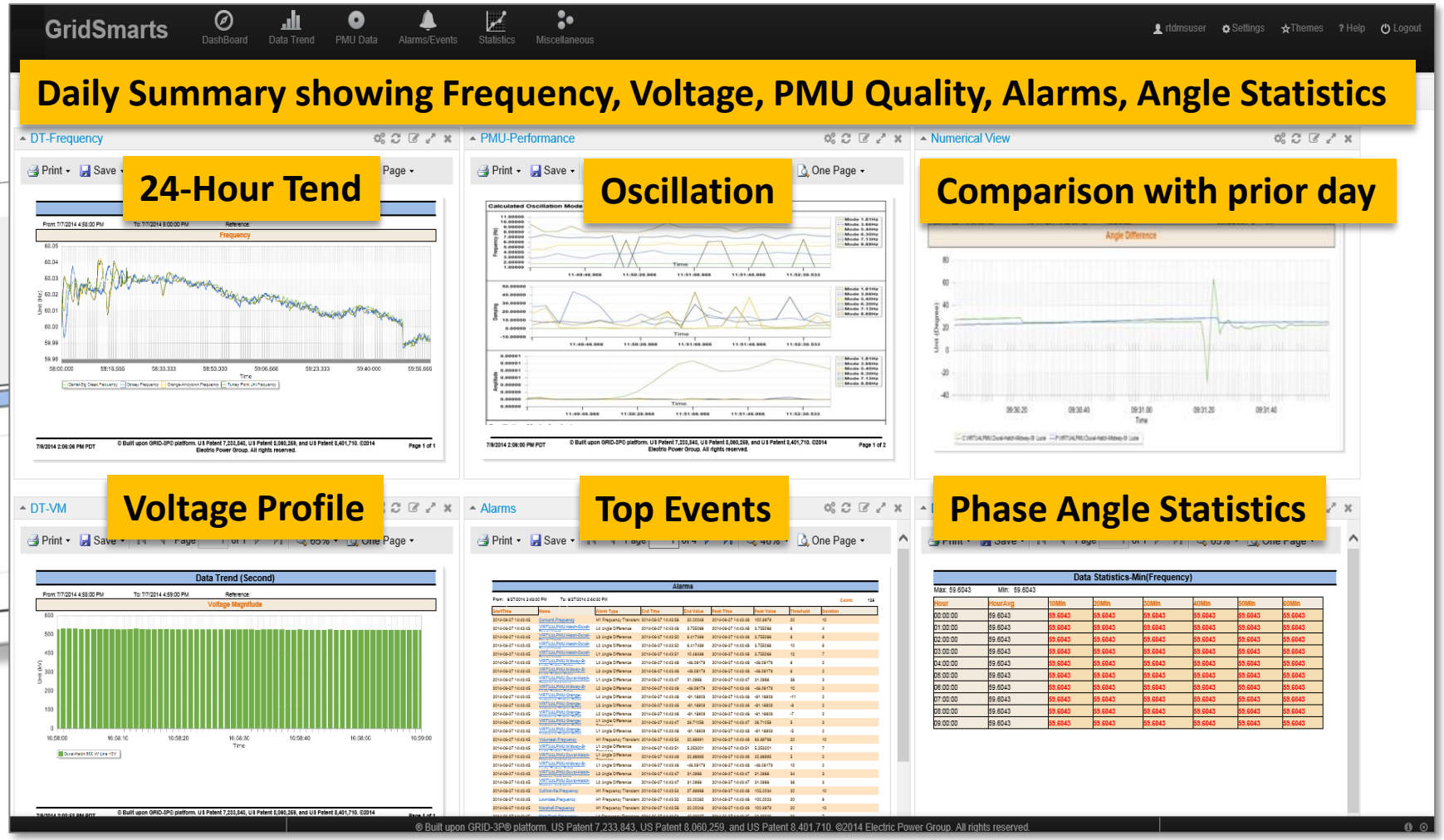
- Daily Operation Performance – Highlights from Previous Day
- Event Root Cause Diagnostics
- Gen Trip and Frequency Response
- Oscillation Events Root Cause Analysis
- Model Validation
- Fault Analysis
- Data Quality

Daily Operations Performance

Daily Operations Performance

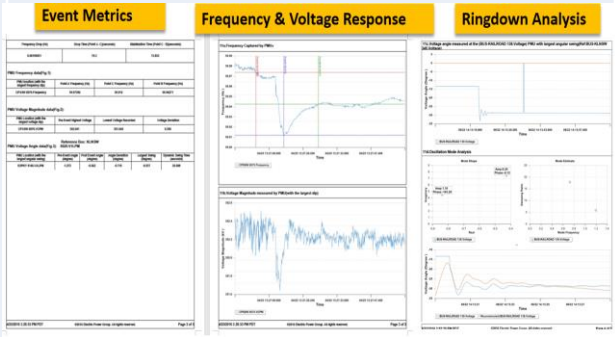
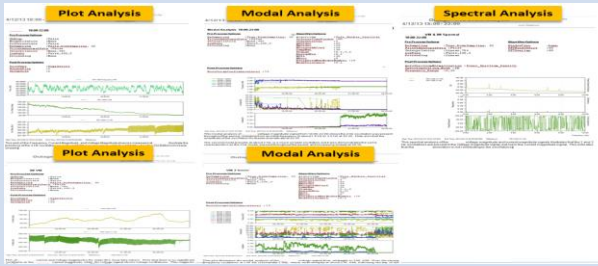
- **Need – Quick Review of Previous Day's Operating Highlights**
- **Sample Daily Report Content**
  - > Top 10 Events
  - > System Alarm Summary
  - > Oscillation Events
  - > Max/Min Phase Angles
  - > Frequency, Voltage Daily Performance
  - > Key Substation PMU Data Quality Performance
- **Automatic Distribution by Email**

Sample Daily Operation Reports



Event Reports & Root Cause Diagnosis

Event Reports

Type of Report	Primary User	Need	Report Info	Example
Real-Time	Operator	• Monitor • Diagnose • Act	Location of the event Type of event Current Situation Severity of the event Key Metrics	
Near Real-Time/ On Demand	Operating Engineer Reliability Coordinator, Management	• Stay Informed on current system conditions & events • On demand customized reports e.g., PMU performance over last 3 -months • Periodic system alarms and event summary e.g., How many events in last 3-months?	**Generation Trip**: Location of the Unit trip Largest voltage dip & largest voltage deviation, Largest angle swing NERC Frequency response points A,B,C Ringdown analysis results – mode estimate (frequency, damping) and mode shape **Oscillation Event**: Modal Frequencies present in the signal, Identify root cause e.g., control system issues. Damping % and Energy of the oscillation **Data Quality, PMU Performance**	
Offline Analysis	Operating Engineer Planner Protection Engineer	• Validate system performance • Alarms and Settings • Relay Operation • Fault Analysis • Validate models	Plot Analysis, Modal Analysis, Spectral Analysis, Ringdown analysis, Frequency response, Fault analysis, model validation, Statistical analysis, sensitivity analysis	

Event Root Cause Diagnostics

Real Time Report for Operators

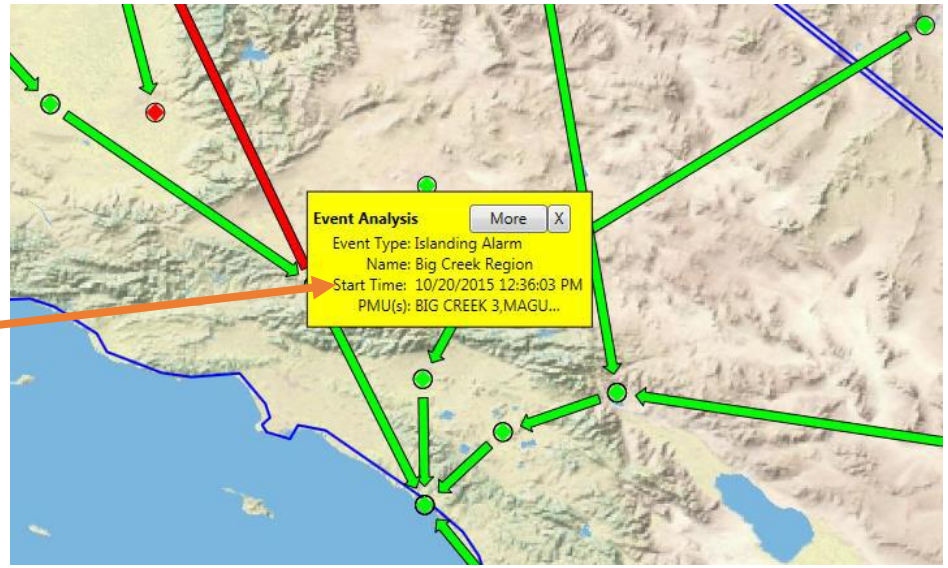
Real-Time Needs

- Be aware of the current situation – Monitor
- Diagnose the event when it happens
  - > Where did the event occur – location?
  - > What is the type of the event?
  - > How severe is the event and what action might be required?
- Take action to bring the system back to normal conditions
- Event metrics at operators' fingertips

Real-Time Event Analyzer Report

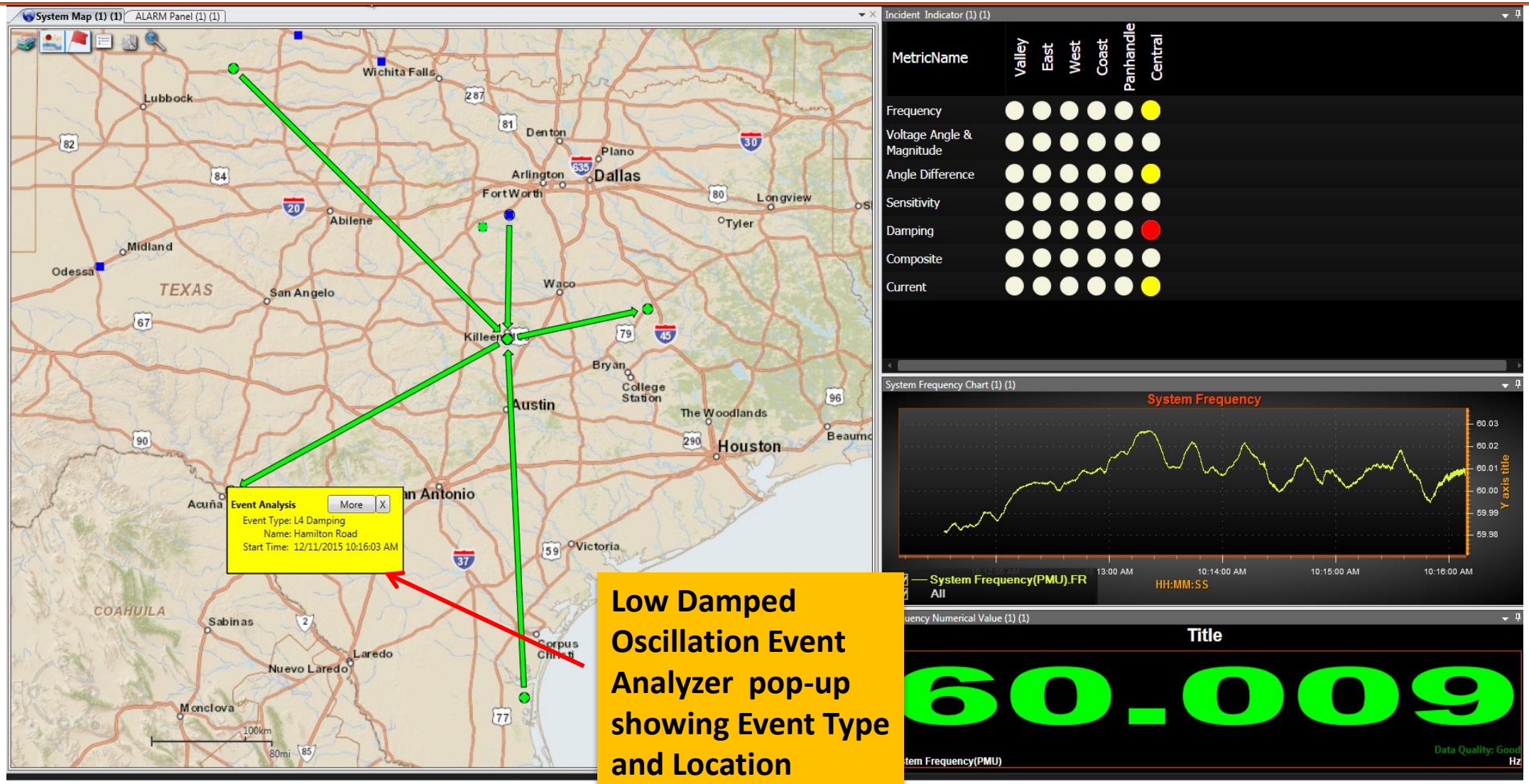
Event Metrics at A Glance for Operator Assessment and Action

- **Monitor multiple events**
  - > Oscillations
  - > Voltage and Angle Sensitivity
  - > Islanding
  - > Generation/Load Trip
  - > Composite Alarms
- **Show associated event information**
  - > Location
  - > Type
  - > Occurrence time
  - > Participating PMUs
- **Present relevant information only**
- **Displays**
  - > Templates of critical metrics
  - > Dynamic signals
  - > Automated on the fly



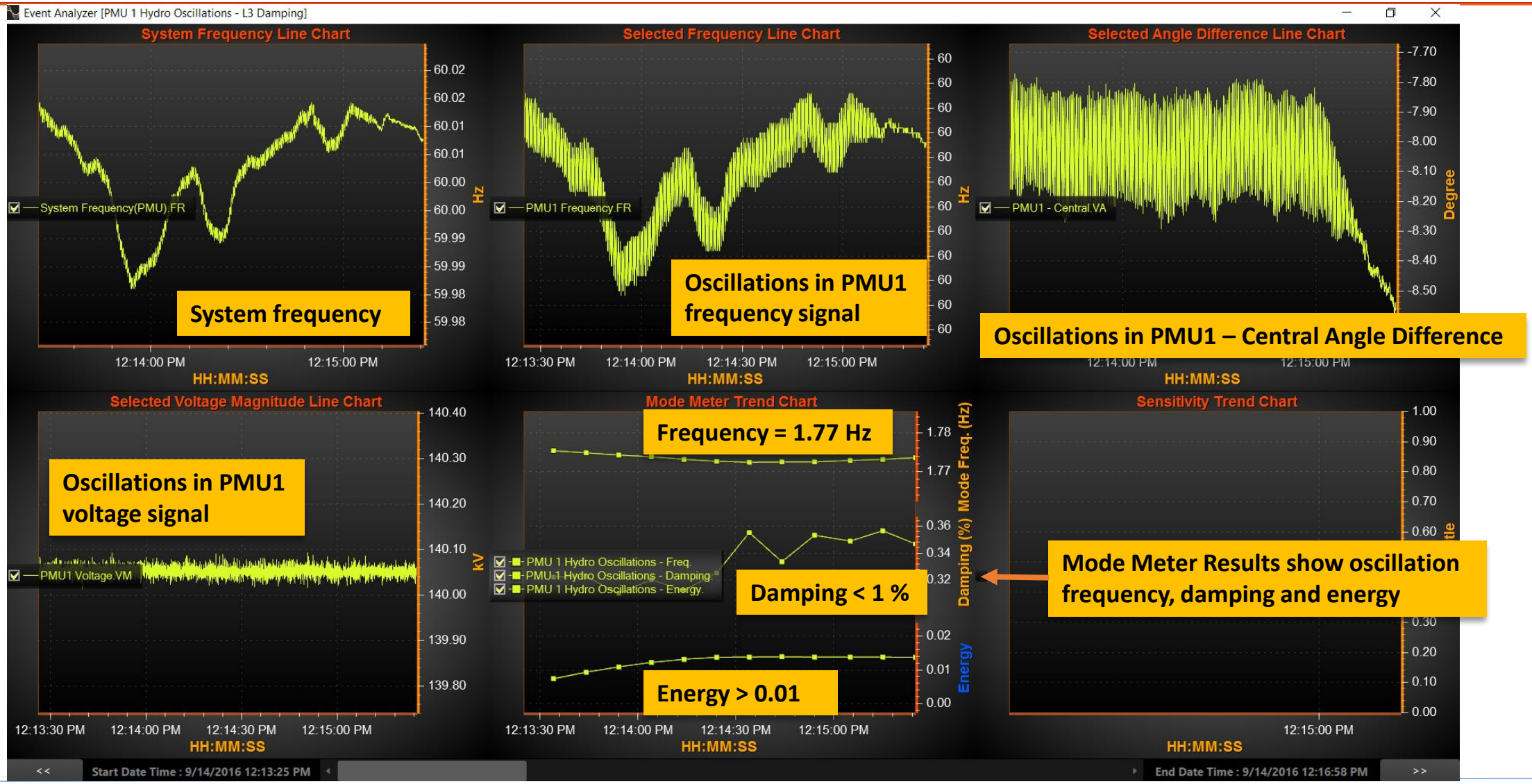
Event Analyzer Pop-up Shows Event Type & Location

Example: Detection of Oscillations



Low Damped Oscillation Event Analyzer pop-up showing Event Type and Location

Event Analyzer Report - Event Location, Metrics, Severity



Event Reports

On Demand Report for Reliability Coordinators & Managers

On-Demand & Near Real-Time Needs

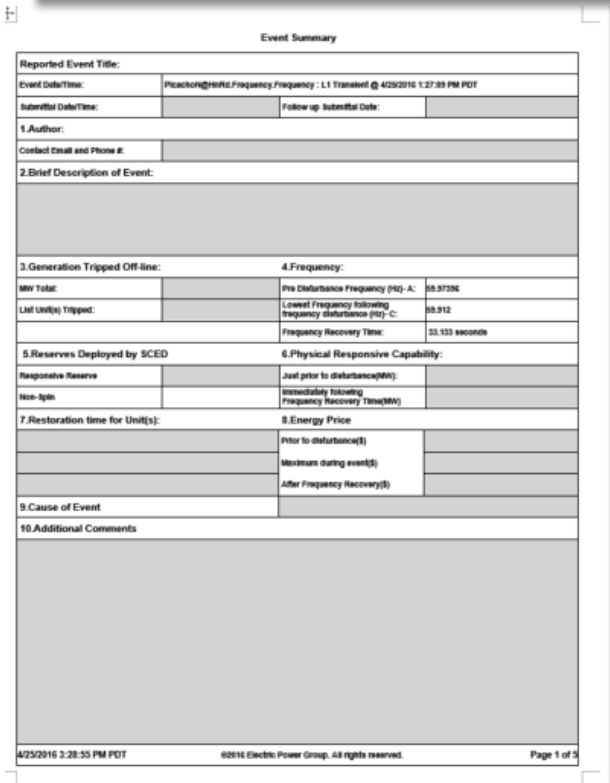
- Comparison Performance
  - > Prior Day vs. Today
  - > Peak Day vs. Today
- Quick Review of Recent Performance
  - > Last Hour, Last Shift, Last 24-Hours
- Periodic Performance Trends – weekly, monthly
  - > Events, Alarms
  - > Types, Severity
  - > Key Substation Locations
- Detailed Event Report
  - > Frequency Response, First Responding PMU, Largest Swing
  - > Oscillation Location, Damping, Energy

On Demand Event Reports Contents

- **Generation Trip Report**
  - > Location of the generation trip – First responding PMU
  - > Largest voltage dip and largest voltage deviation
  - > Largest angle swing and location
  - > NERC frequency response points A,B,C (Lowest point)
  - > Ringdown analysis results – mode estimate (frequency, damping) and mode shape
- **Oscillation Report**
  - > Oscillation type – Inter-area, local controller
  - > Damping %
  - > Energy of the oscillation
  - > Source of oscillations – Wind farms, HVDC, Nuclear, Hydro

Example: Gen Trip Report

Event Location and Description



Event Summary

Reported Event Title:			
Event Date/Time:	PicachoN@HinRd.Frequency.Frequency : L1 Transient @ 4/25/2016 1:27:09 PM PDT		
Submittal Date/Time:		Follow up Submittal Date:	
1.Author:			
Contact Email and Phone #:			
2.Brief Description of Event:			
3.Generation Tripped Off-line:		4.Frequency:	
MW Total:		Pre Disturbance Frequency (Hz)- A:	59.97356
List Unit(s) Tripped:		Lowest Frequency following frequency disturbance (Hz)- C:	59.912
		Frequency Recovery Time:	33.133 seconds
5.Reserves Deployed by SCED		6.Physical Responsive Capability:	
Responsive Reserve		Just prior to disturbance(MW):	
Non-Spin		Immediately following Frequency Recovery Time(MW)	
7.Restoration time for Unit(s):		8.Energy Price	
		Prior to disturbance($)	
		Maximum during event($)	
		After Frequency Recovery($)	
9.Cause of Event			
10.Additional Comments			

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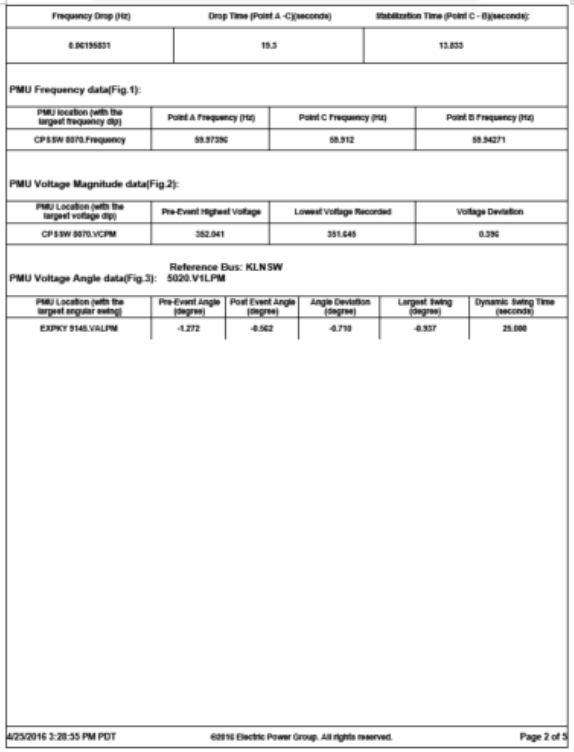
Event Metrics



Frequency Drop (Hz)	Drop Time (Point A -C)(seconds)	Stabilization Time (Point C - B)(seconds):
0.06156831	19.3	13.833

PMU Frequency data(Fig.1):

PMU location (with the largest frequency dip)	Point A Frequency (Hz)	Point C Frequency (Hz)	Point B Frequency (Hz)
CPSSW 8070.Frequency	59.97356	59.912	59.94271

PMU Voltage Magnitude data(Fig.2):

PMU Location (with the largest voltage dip)	Pre-Event Highest Voltage	Lowest Voltage Recorded	Voltage Deviation
CPSSW 8070.VCPM	352.041	351.645	0.396

PMU Voltage Angle data(Fig.3): Reference Bus: KLNSW 5020.V1LPM

PMU Location (with the largest angular swing)	Pre-Event Angle (degree)	Post Event Angle (degree)	Angle Deviation (degree)	Largest Swing (degree)	Dynamic Swing Time (seconds)
EXPKY 9145.VALPM	-1.272	-0.562	-0.710	-0.937	25.000

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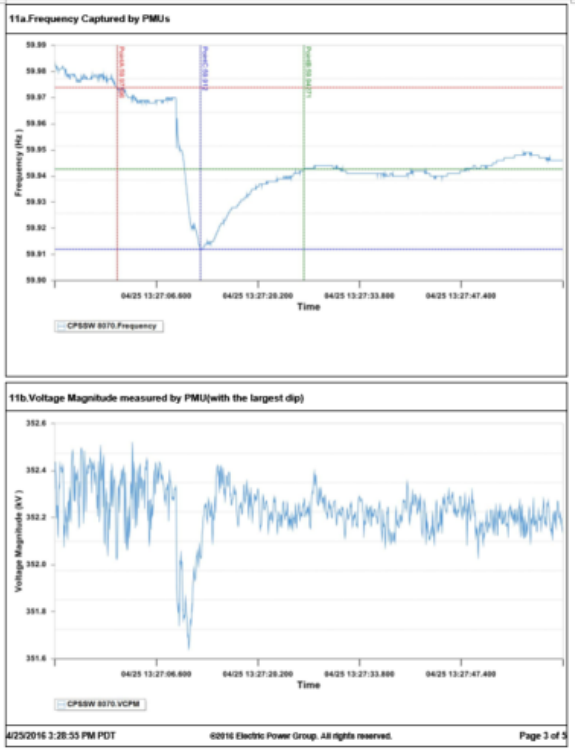
Frequency & Voltage Response



11a.Frequency Captured by PMUs

11b.Voltage Magnitude measured by PMU(with the largest dip)

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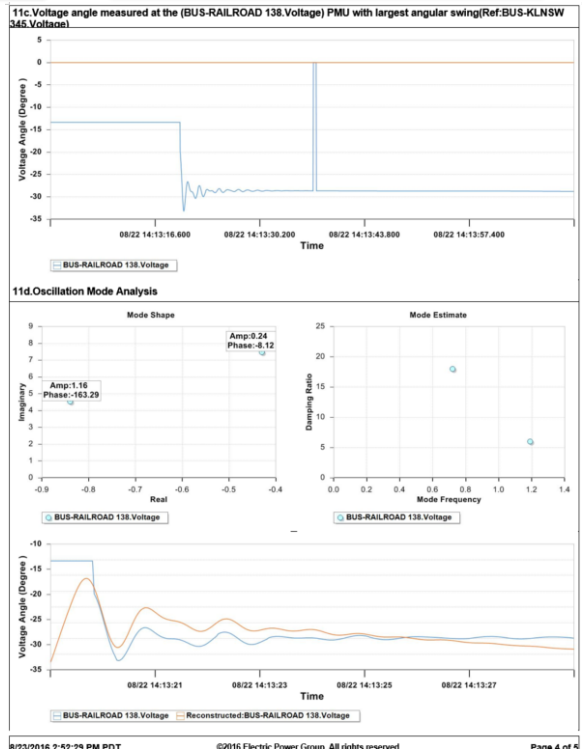
Ringdown Analysis



11c.Voltage angle measured at the (BUS-RAILROAD 138.Voltage) PMU with largest angular swing(Ref:BUS-KLNSW 345.Voltage)

11d.Oscillation Mode Analysis

8/23/2016 2:52:28 PM PDT ©2016 Electric Power Group. All rights reserved. Page 4 of 5

Event Root Cause Diagnostics

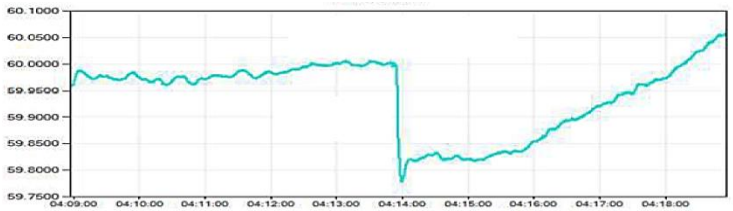
Offline Analysis Report for Engineers & Planners

Offline Analysis Needs

- Did the Grid Perform as Planned?
- Are Alarm & Parameters Set Correctly?
- Are the System and Power Plant Models Valid?
- Are the Protection Settings Correct?
- What's the Root Cause and Sequence of the Event?

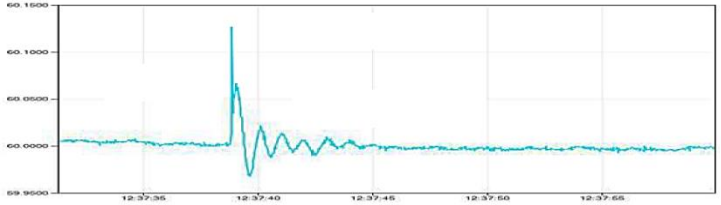
Offline Analysis – PGDA

Using PMU Event Signatures for Classification of the Event

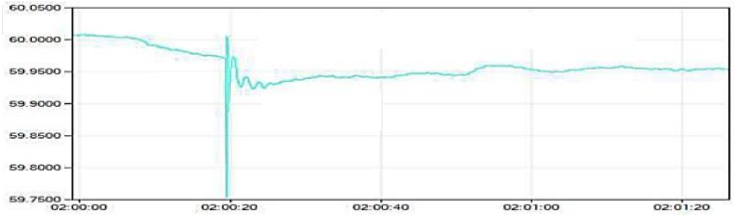


A: Drop, Rebound and Slow Recovery - Generation Trip

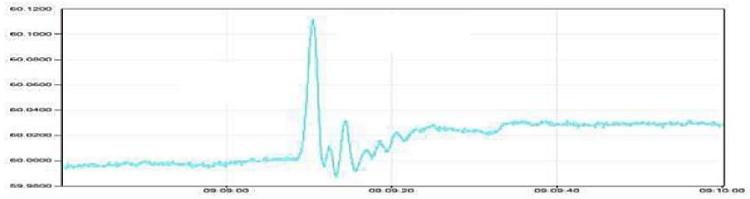
B: Sharp Change and Immediate Recovery



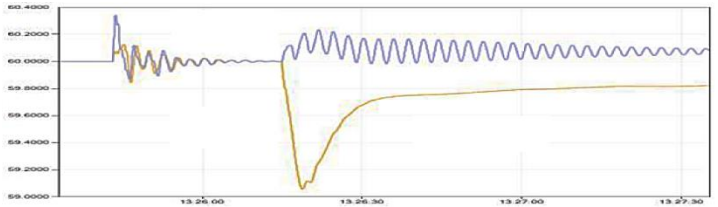
C: Transient and Ringdown - Line Trip



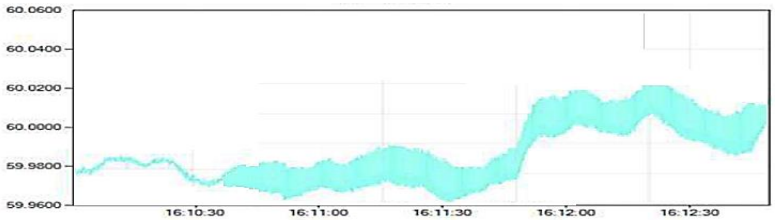
D: Transient and Drop - Line Trip and Generation Trip



E: Rise and Slow Recovery - Load Trip



F: Separation – 2 Signals : Islanding

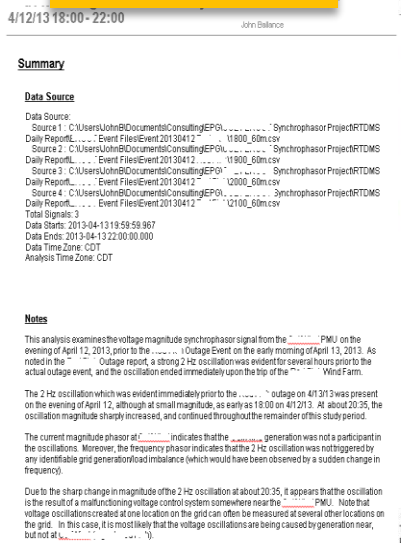


G: Oscillations

7 Typical Event Signatures from Event Analysis

Example of PGDA Report

Event Summary



4/12/13 18:00 - 22:00

John Ballance

Summary

Data Source

Data Source:
Source 1 : C:\Users\JohnB\Documents\Consulting\EPG\ Synchrophasor Project\RTDMS
Daily Report\L Event Files\Event 20130412 \1800_60m.csv
Source 2 : C:\Users\JohnB\Documents\Consulting\EPG\ Synchrophasor Project\RTDMS
Daily Report\L Event Files\Event 20130412 \1900_60m.csv
Source 3 : C:\Users\JohnB\Documents\Consulting\EPG\ Synchrophasor Project\RTDMS
Daily Report\ Event Files\Event 20130412 \2000_60m.csv
Source 4 : C:\Users\JohnB\Documents\Consulting\EPG\ Synchrophasor Project\RTDMS
Daily Report\ Event Files\Event 20130412 \2100_60m.csv
Total Signals: 3
Data Starts: 2013-04-13 19:59:59.967
Data Ends: 2013-04-13 22:00:00.000
Data Time Zone: CDT
Analysis Time Zone: CDT

Notes

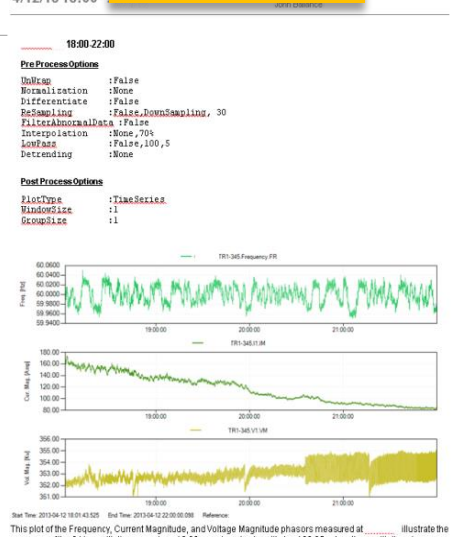
This analysis examines the voltage magnitude synchrophasor signal from the PMU on the evening of April 12, 2013, prior to the Outage Event on the early morning of April 13, 2013. As noted in the Outage report, a strong 2 Hz oscillation was evident for several hours prior to the actual outage event, and the oscillation ended immediately upon the trip of the Wind Farm.

The 2 Hz oscillation which was evident immediately prior to the outage on 4/13/13 was present on the evening of April 12, although at small magnitude, as early as 18:00 on 4/12/13. At about 20:35, the oscillation magnitude sharply increased, and continued throughout the remainder of this study period.

The current magnitude phasor at indicates that the generation was not a participant in the oscillations. Moreover, the frequency phasor indicates that the 2 Hz oscillation was not triggered by any identifiable grid generation/load imbalance (which would have been observed by a sudden change in frequency).

Due to the sharp change in magnitude of the 2 Hz oscillation at about 20:35, it appears that the oscillation is the result of a malfunctioning voltage control system somewhere near the PMU. Note that voltage oscillations created at one location on the grid can often be measured at several other locations on the grid. In this case, it is most likely that the voltage oscillations are being caused by generation near, but not at).

Plot Analysis



4/12/13 18:00 -

18:00-22:00

Pre Process Options

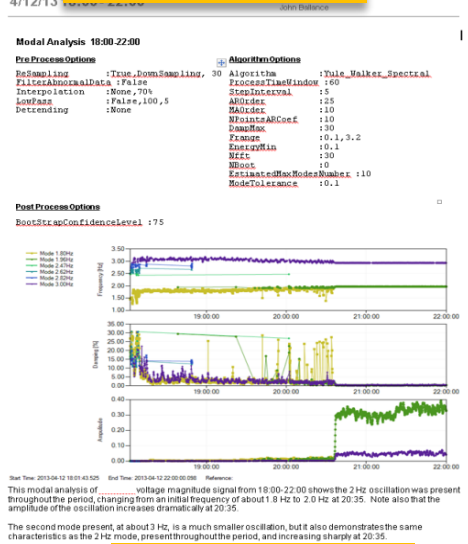
UnWrap :False
Normalization :None
Differentiate :False
ReSampling :False,DownSampling, 30
FilterAbnormalData :False
Interpolation :None,70%
LowPass :False,100,5
Detrending :None

Post Process Options

PlotType :TimeSeries
WindowSize :1
GroupSize :1

This plot of the Frequency, Current Magnitude, and Voltage Magnitude phasors measured at illustrate the presence of the 2 Hz oscillation oscillations increase sharply.

Modal Analysis



Modal Analysis 18:00-22:00

Pre Process Options

ReSampling :True,DownSampling, 30
FilterAbnormalData :False
Interpolation :None,70%
LowPass :False,100,5
Detrending :None

Algorithm Options

Algorithm :Yule_Walker_Spectral
ProcessTimeWindow :60
StepInterval :5
AROrder :25
MAOrder :10
NPointsARCoef :10
DampMax :30
Frange :0.1,3.2
EnergyMin :0.1
Nfft :30
NBoot :0
EstimatedMaxModesNumber :10
ModeTolerance :0.1

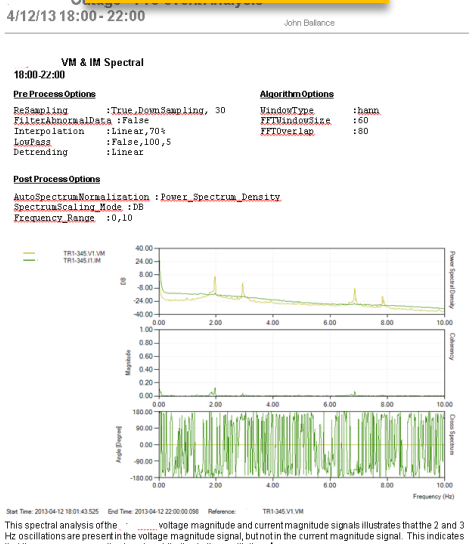
Post Process Options

BootStrapConfidenceLevel :75

This modal analysis of voltage magnitude signal from 18:00-22:00 shows the 2 Hz oscillation was present throughout the period, changing from an initial frequency of about 1.8 Hz to 2.0 Hz at 20:35. Note also that the amplitude of the oscillation increases dramatically at 20:35.

The second mode present, at about 3 Hz, is a much smaller oscillation, but it also demonstrates the same characteristics as the 2 Hz mode, present throughout the period, and increasing sharply at 20:35.

Spectral Analysis



4/12/13 18:00 - 22:00

John Ballance

VM & IM Spectral

18:00-22:00

Pre Process Options

ReSampling :True,DownSampling, 30
FilterAbnormalData :False
Interpolation :Linear,70%
LowPass :False,100,5
Detrending :Linear

Algorithm Options

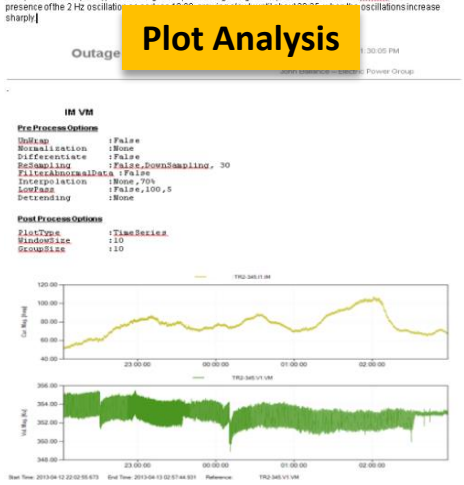
WindowType :Hamm
FFTWindowSize :60
FFTOverlap :80

Post Process Options

AutoSpectrumNormalization :Power_Spectrum_Density
SpectrumScaling_Mode :DB
Frequency_Range :0,10

This spectral analysis of the voltage magnitude and current magnitude signals illustrates that the 2 and 3 Hz oscillations are present in the voltage magnitude signal, but not in the current magnitude signal. This indicates that the generation is not contributing to the oscillations.

Plot Analysis



IM VM

Pre Process Options

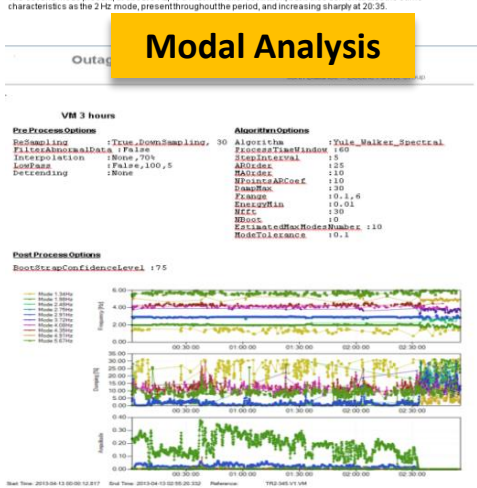
UnWrap :False
Normalization :None
Differentiate :False
ReSampling :False,DownSampling, 30
FilterAbnormalData :False
Interpolation :None,70%
LowPass :False,100,5
Detrending :None

Post Process Options

PlotType :TimeSeries
WindowSize :10
GroupSize :10

Plot of current and voltage magnitudes for entire five hour data extract. Note that there is no significant oscillation in the current magnitude, while the voltage signal shows voltage oscillations. This suggests that the generators were not the source of the oscillations.

Modal Analysis



VM 3 hours

Pre Process Options

ReSampling :True,DownSampling, 30
FilterAbnormalData :False
Interpolation :None,70%
LowPass :False,100,5
Detrending :None

Algorithm Options

Algorithm :Yule_Walker_Spectral
ProcessTimeWindow :60
StepInterval :5
AROrder :25
MAOrder :10
NPointsARCoef :10
DampMax :30
Frange :0.1,6
EnergyMin :0.01
Nfft :30
NBoot :0
EstimatedMaxModesNumber :10
ModeTolerance :0.1

Post Process Options

BootStrapConfidenceLevel :75

This plot illustrates the modal analysis of the voltage signal from midnight to 3:00 AM. Note the strong frequency oscillation at 1.98 Hz (essentially 2 Hz), which ends abruptly at about 2:30 AM, following the trip of the wind farm.

Reports - Summary

Reports	Real-Time (RTDMS)	On Demand (GridSmarts)	Offline (PGDA)
Daily Performance		✓	
Event Report	✓	✓	✓
Oscillations	✓	✓	✓
Generation Trip and Frequency Response	✓	✓	✓
Fault Analysis	✓		✓
Model Validation			✓
Data Quality		✓	

ERCOT Experience

ERCOT PMU Event Reporting

Patrick Gravois
Grid Applications Support

EPG Users Group WebEx
September 21, 2016

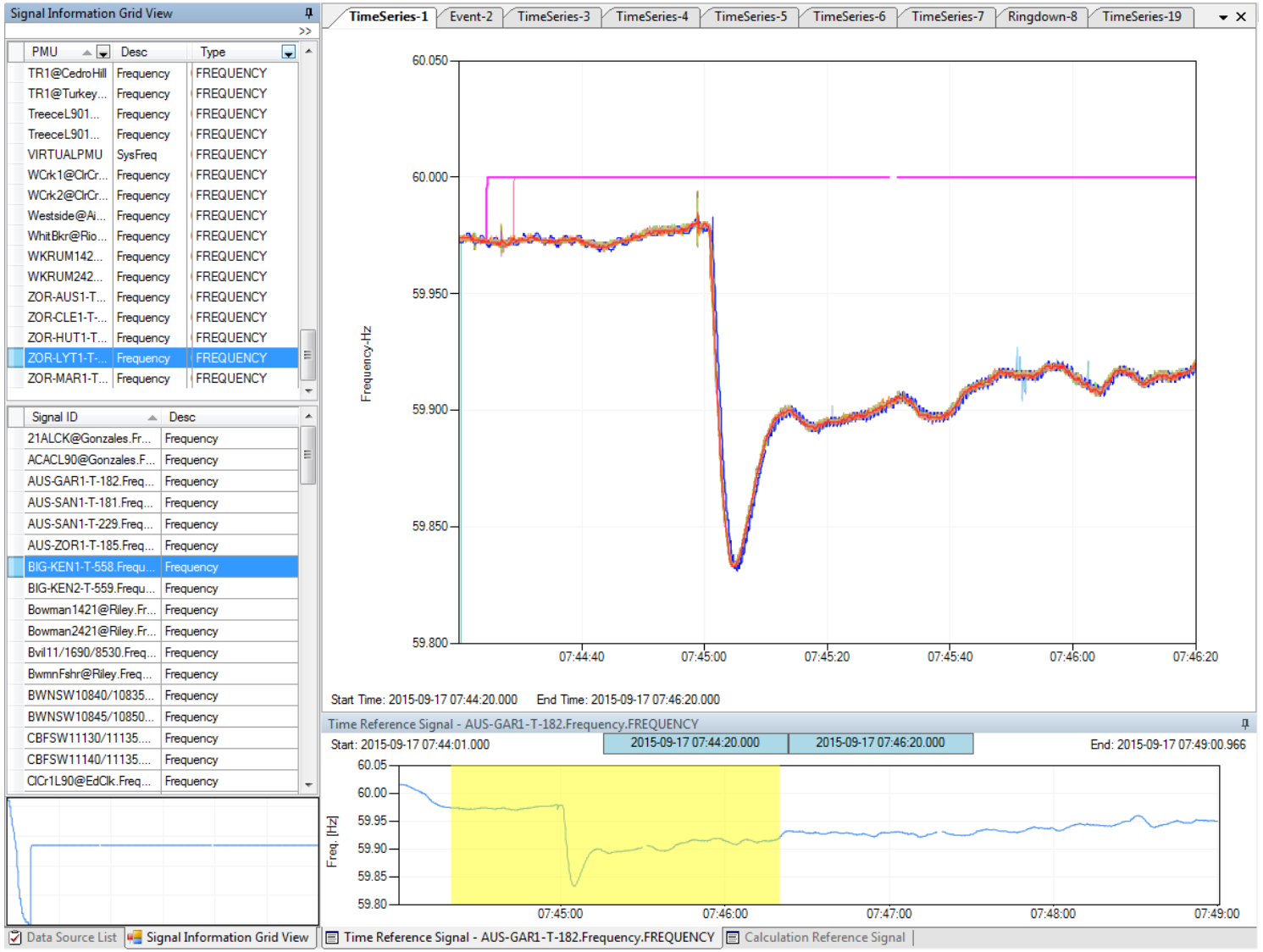
ERCOT PMU Event Reporting

- Four metric analyzed for each event with frequency dropping to 59.9 Hz and below
  - System frequency and location with largest frequency deviation
  - Location with the largest swing in voltage magnitude
  - Location with the largest voltage angle swing with respect to a reference PMU in central Texas
  - Ring-down analysis to calculate associated dominant mode(s) and damping
- The Phasor Grid Dynamics Analyzer (PGDA) application by EPG is used for this analysis
- Report is sent out internally

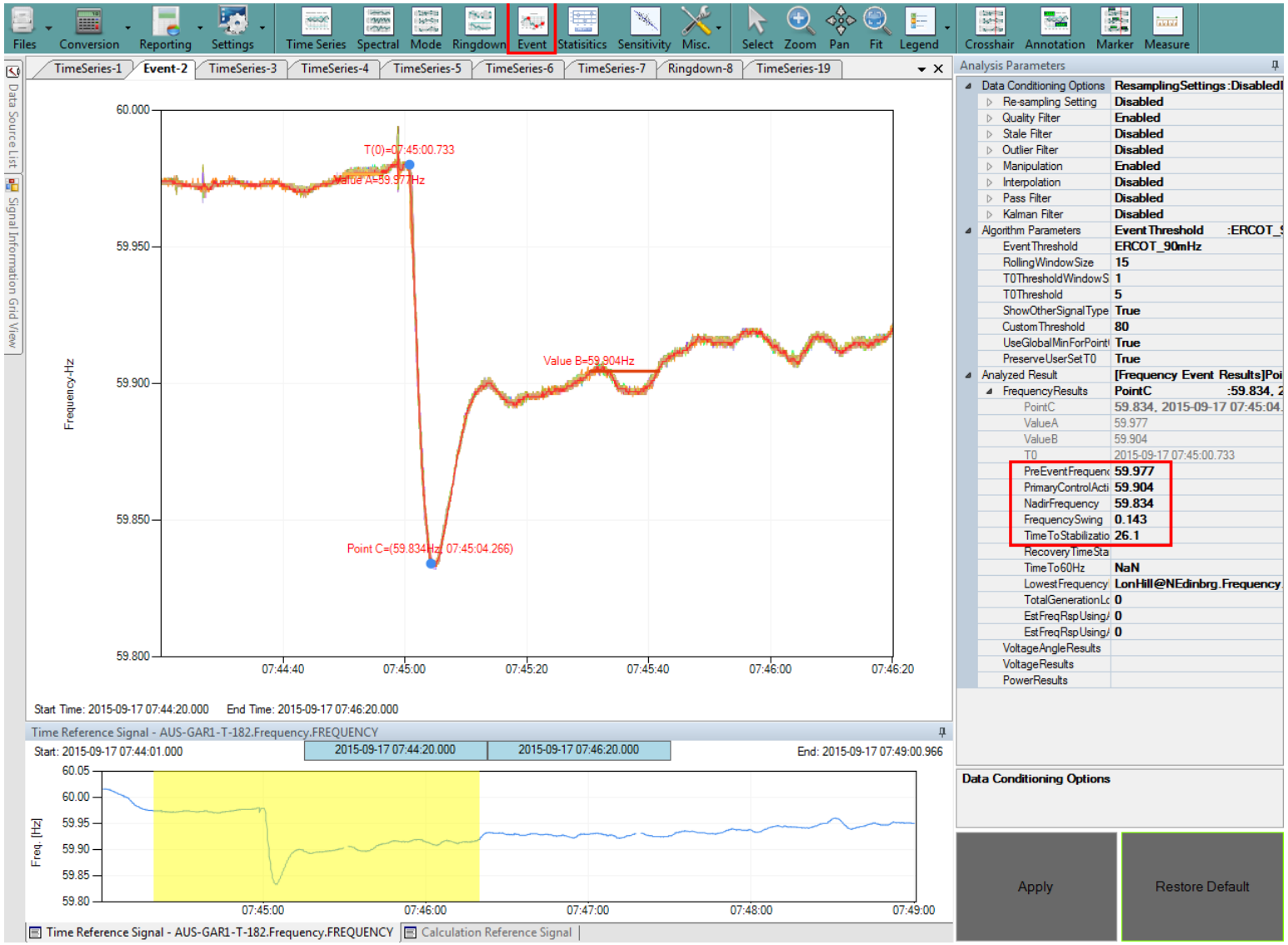
Import PMU Data into PGDA

- For events such that frequency drops to 59.9 Hz or below, event files (COMTRADE) are automatically created by RTDMS
- For rare times that event file is not created, PMU data can be pulled into a .csv file using the ePDC Database Tool
- Either COMTADE file or .csv file is loaded into PGDA
- COMTRADE File is more effective since the majority of bad data is filtered out
- Following slides show an analysis of a ~814 MW trip in September of 2015

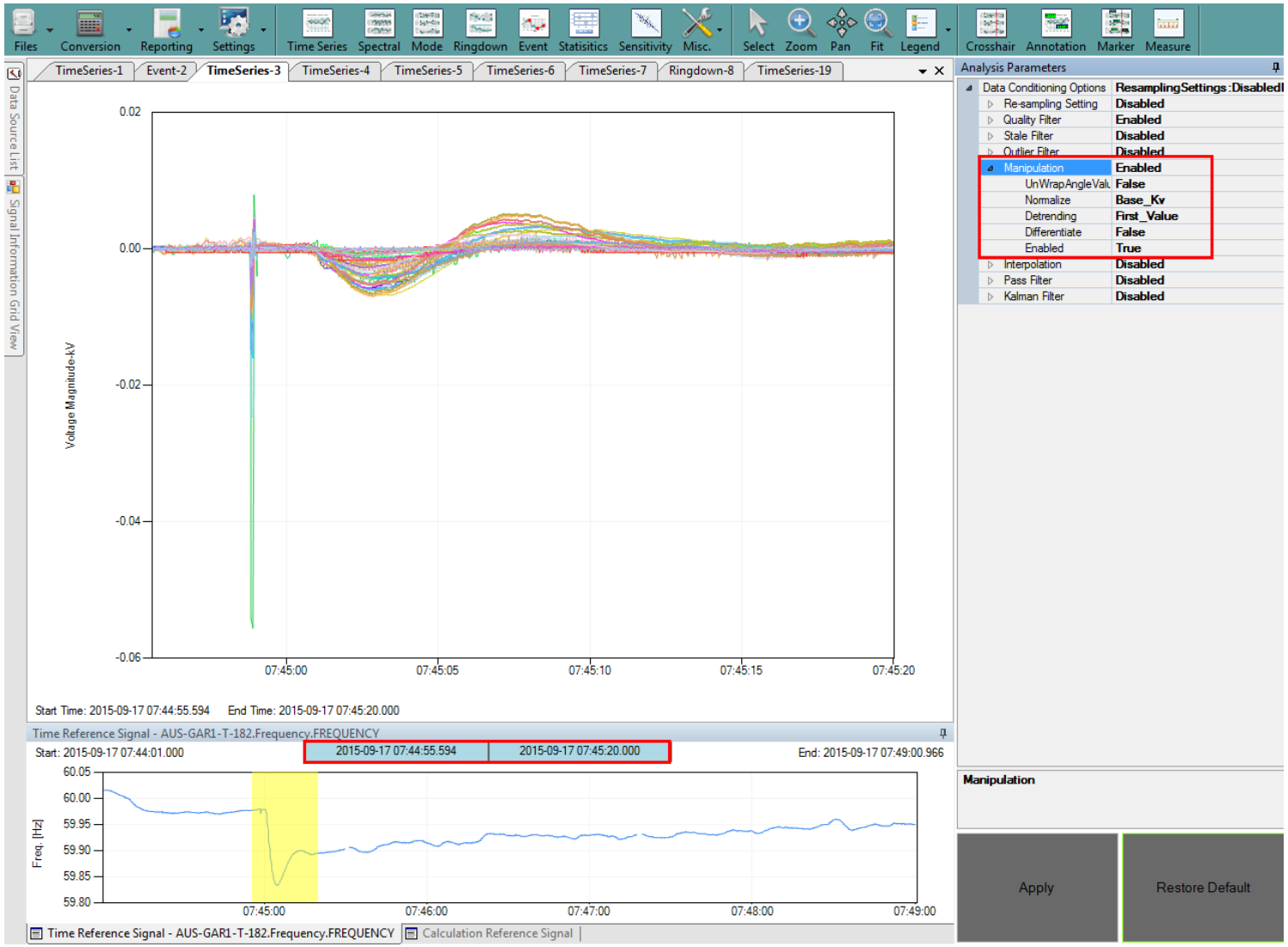
Frequency Time Series



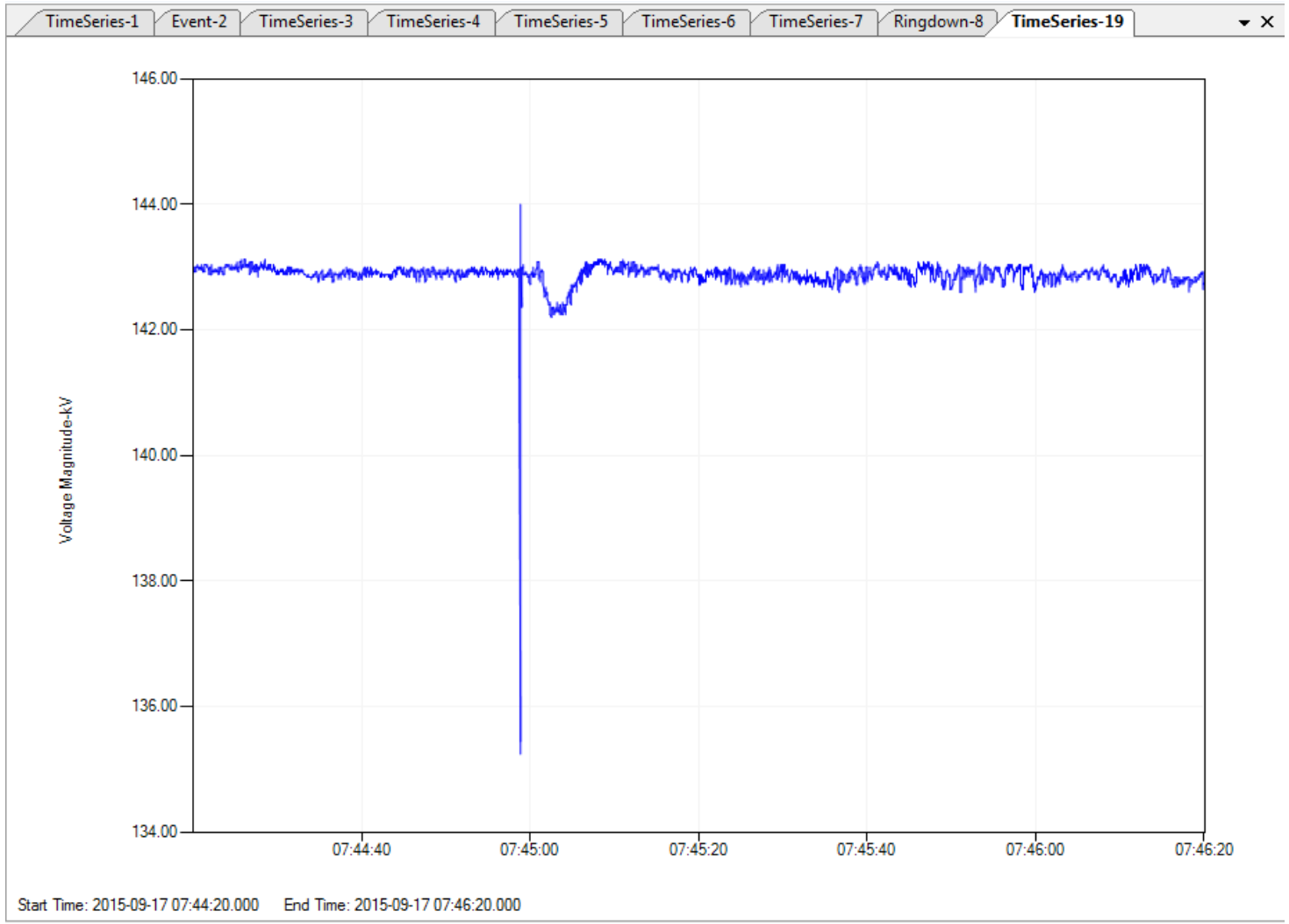
Event Analysis



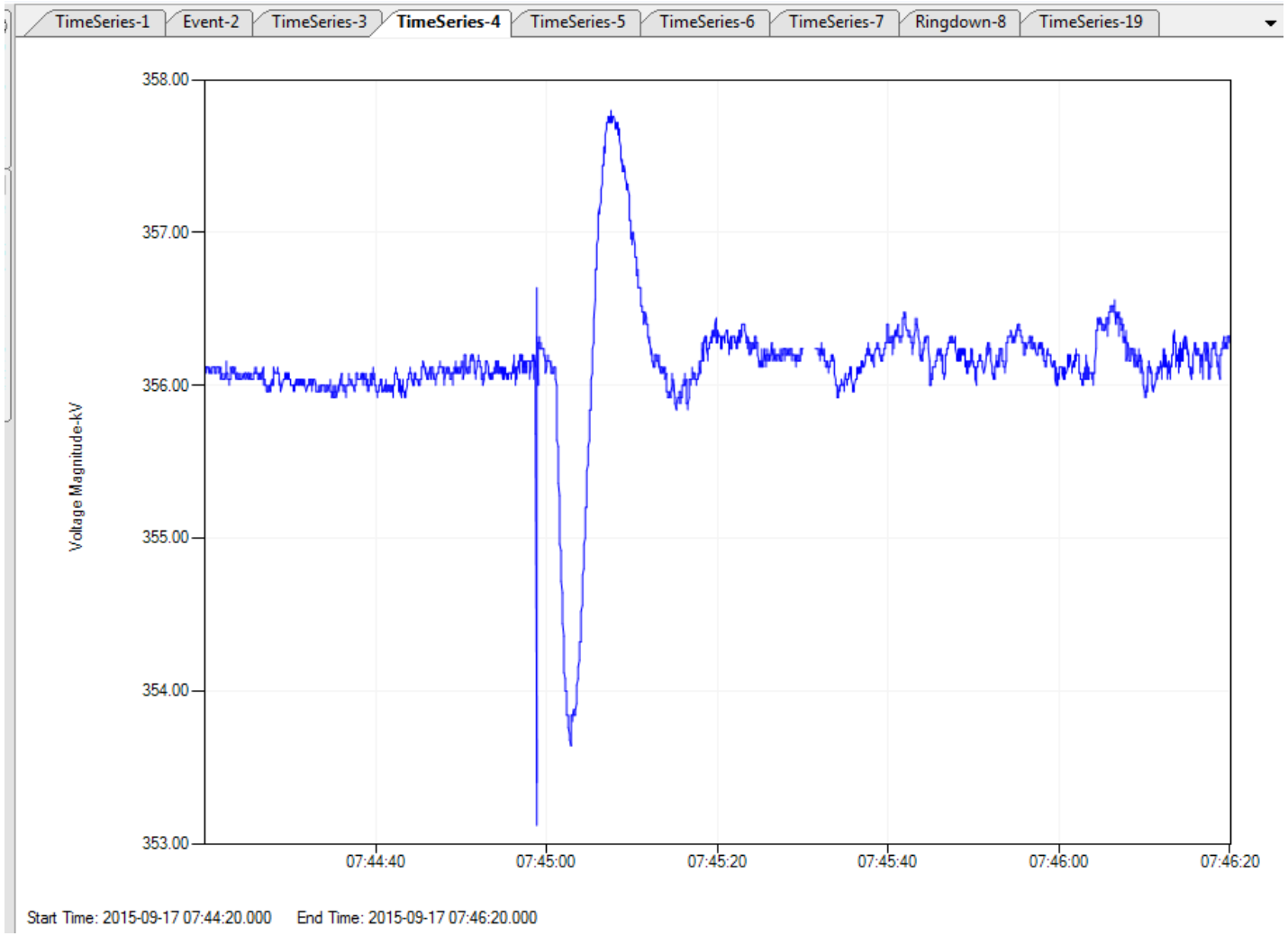
Voltage Magnitude Analysis



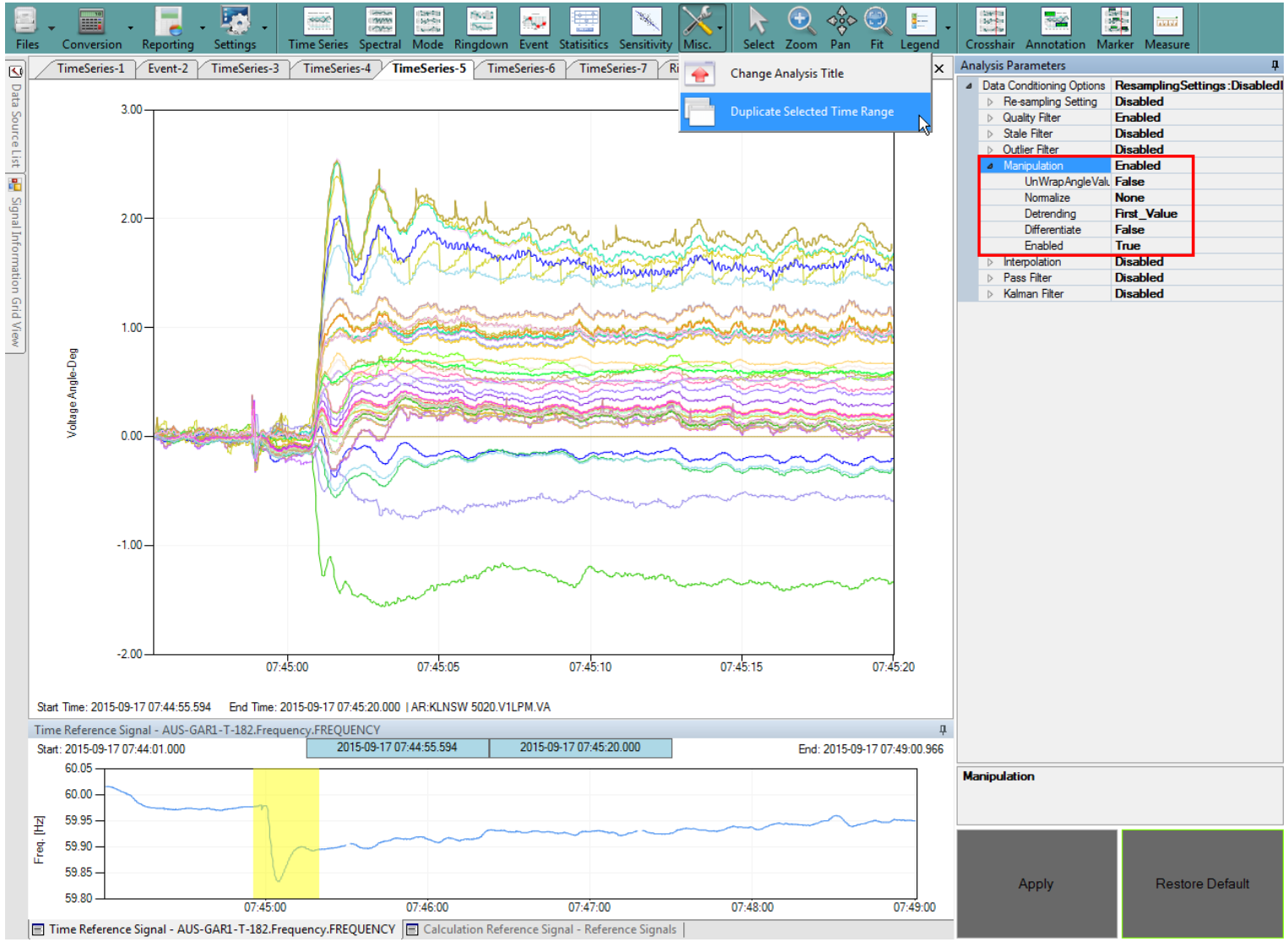
Largest Voltage Sag Due to Fault



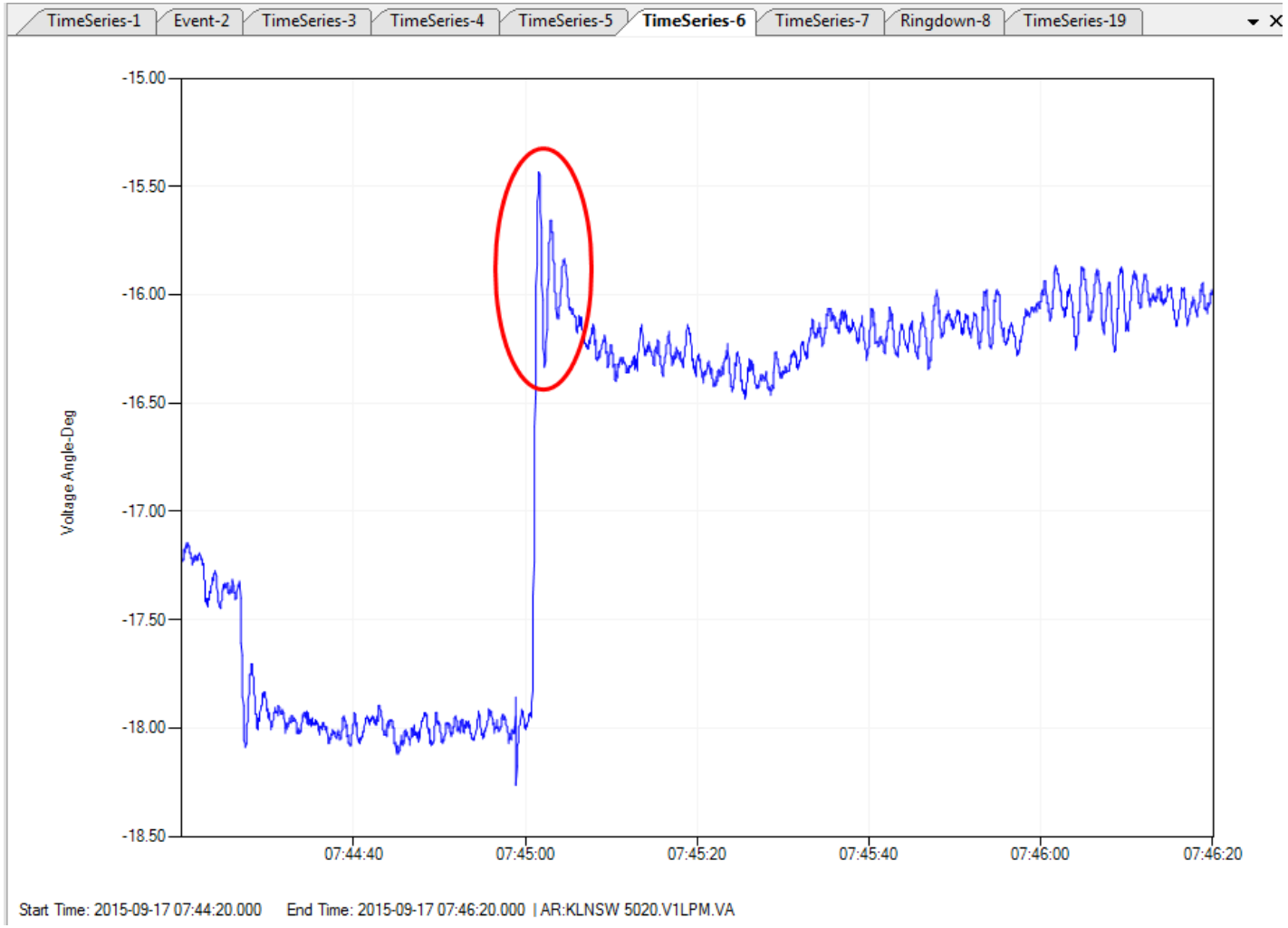
Largest Voltage Sag Due to Loss of Generation



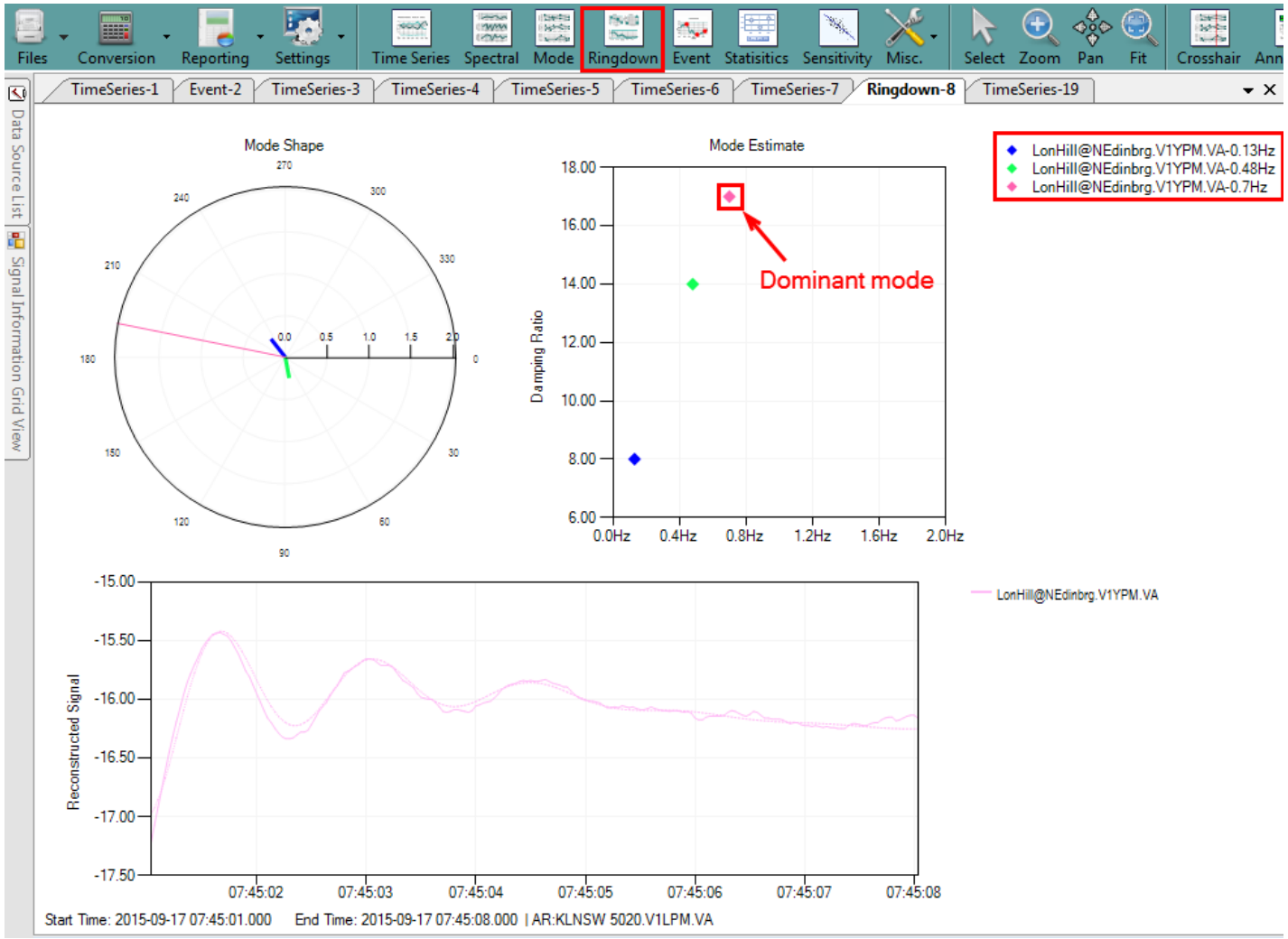
Voltage Angle Analysis



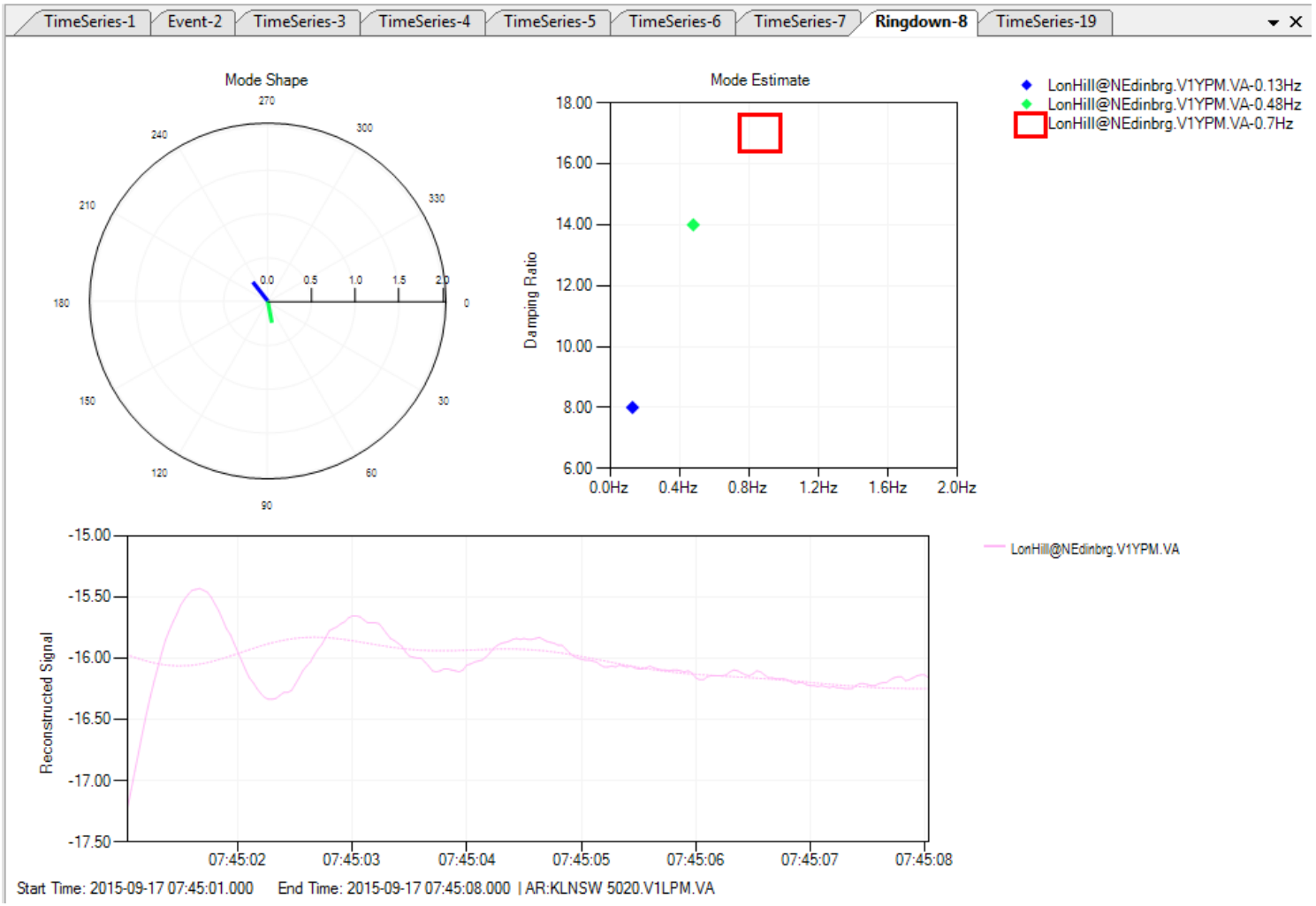
Largest Voltage Angle Swing



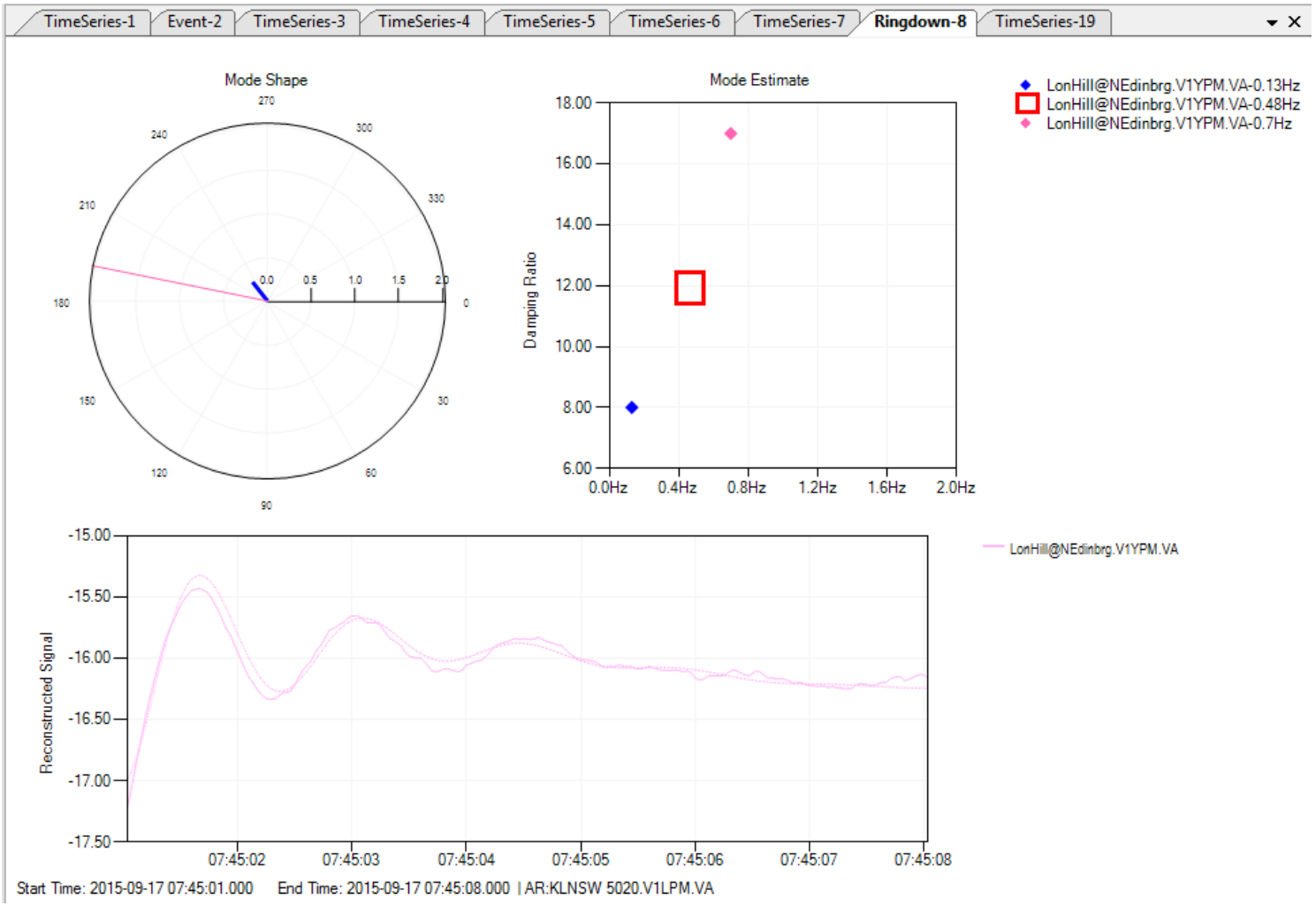
Ring-Down Analysis of Largest Angle Swing



Ring-Down Analysis of Largest Angle Swing



Ring-Down Analysis of Largest Angle Swing



First Frequency Response

Q&A, Discussion

Q&A, Discussion

- **Q&A**
- **Event Report**
  - Your Practices
  - Use Cases
  - Pain Points
  - Suggestions
- **Next Webinar Focus**
  - Priority
  - Other topics

EPG Webinar Series

- **System Model Validation for MOD-33 Requirement (Oct. 12)**
- Configuring alarms and validate parameters to provide meaningful results for operators.
- Mining large data archives for events of different types, e.g. oscillations, generator trips, etc.
- Using alarms & events for proactive actions.
- Providing secure remote access to users in real-time for monitoring and diagnostics during normal times and emergencies.
- Sending data & alarms to EMS.
- Leveraging existing one-line diagrams to map synchrophasor data.
- Extending grid synchrophasor observability with Linear State Estimation technology.
- Other topics?
- Extracting large amounts of synchrophasor data efficiently for offline analysis. (August 2016)
- Quickly creating an event report that could be distributed to operators, engineers and managers. (Sept. 2016)

Summary

- **Reports - Needs & Solutions**
  - > Daily Operations Performance
  - > Event Reports & Root Cause Diagnosis – Generation Trip, Oscillations, Faults, Line Trips etc.
    - – Real-Time report for Operators
    - – On Demand report for Reliability Coordinators & Managers
    - – Offline analysis report for Engineers & Planners
- **Quickly Creating Reports using *RTDMS, GridSmarts, PGDA***
- **ERCOT Experience**
- **Discussion**

Thank you for participating!

If you have any questions regarding any part of the course, please contact us at Contact@electricpowergroup.com

http://electricpowergroup.com/webinars.html

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