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Oscillation Source Location and Mitigation Measures in Daily ISO-NE Operations

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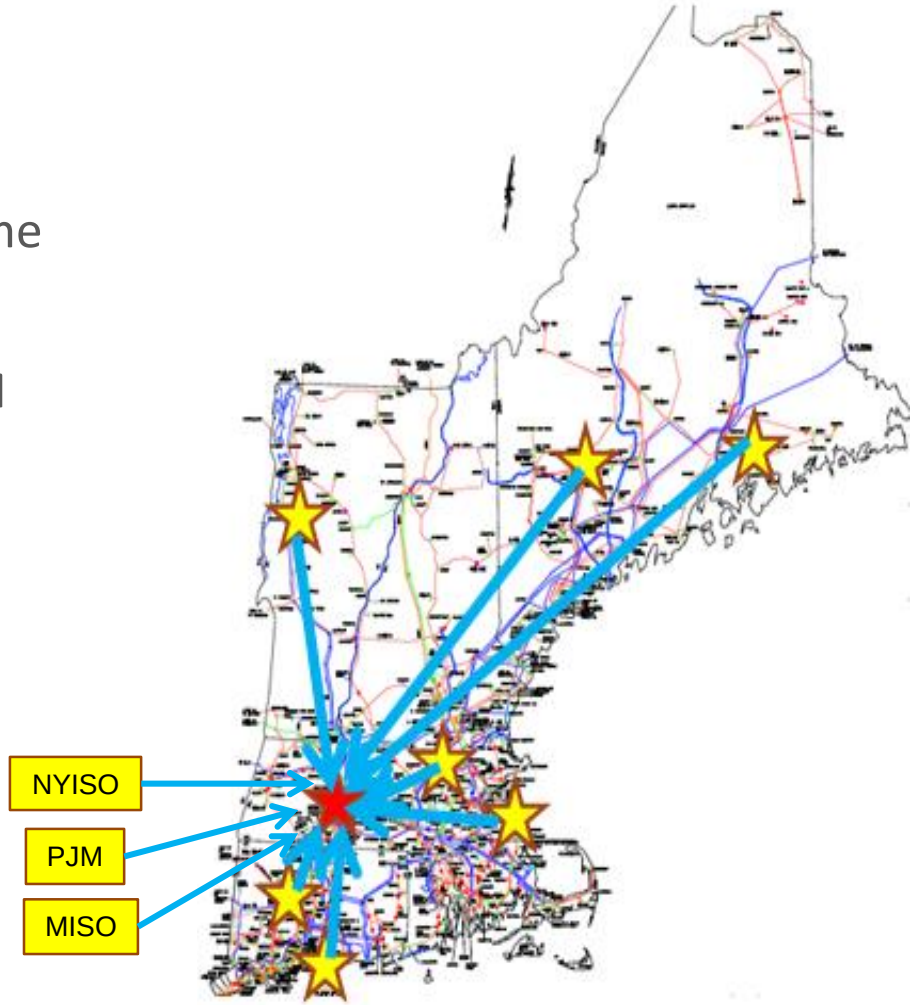
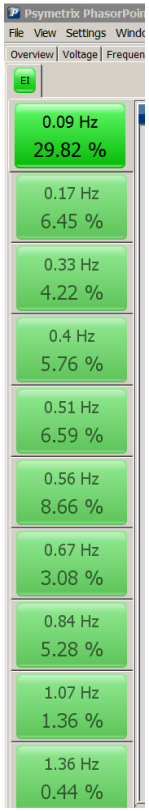
PMU Infrastructure at ISO New England

- 86 PMUs at 45 locations
- Full observability of 345 kV with some redundancy
- Selected PMU data from NYISO, PJM and MISO
- 30 samples/s



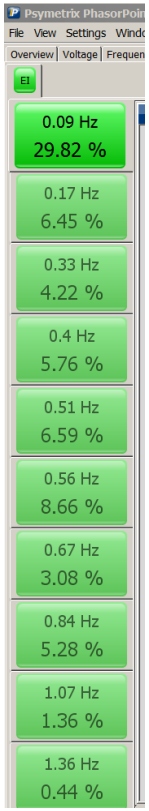
Detection of oscillations



- PhasorPoint (GE application) automatically detects oscillations
  - ✓ Detection
  - ✓ Characterization (Frequency, Damping, Mode shape)
  - ✓ Alarming and Alerting
- Results are updated every 5 seconds
- Reliable detection of oscillations with magnitude larger than white noise

High confidence level that all potentially dangerous oscillations are detected and nothing important is missed

Detection of oscillations



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High confidence level that all potentially dangerous oscillations are detected and nothing important is missed

Sending oscillatory Alarm to the system Operator without specific mitigation instructions is useless and even destructive

Observed Oscillations

Number of oscillatory Alerts and Alarms

Period	# Alerts	# Alarms
June 2018	78	14
May 2018	250	17
April 2018	64	24

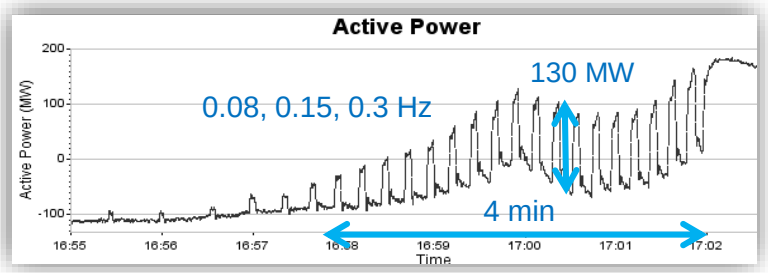
Characteristics of detected oscillations; statistics since 2012

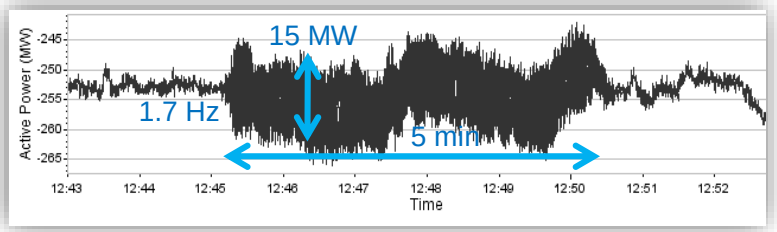
Property	Description
Frequency	0,05 … 2 Hz
Damping	0 … 10 %
Magnitude	2 … 70 MW, RMS
Observability	Local and Wide-spread
Duration	From few seconds to hours

Overwhelming majority of evens are Forced Oscillations

Sustained Oscillations Impose a Threat

- The sustained oscillations can cause
  - ✓ Potential uncontrolled cascading outages
  - ✓ Undesirable mechanical vibrations in equipment
    - Increased probability of equipment failure
    - Reduces the lifespan of equipment
    - Increased maintenance requirements and cost



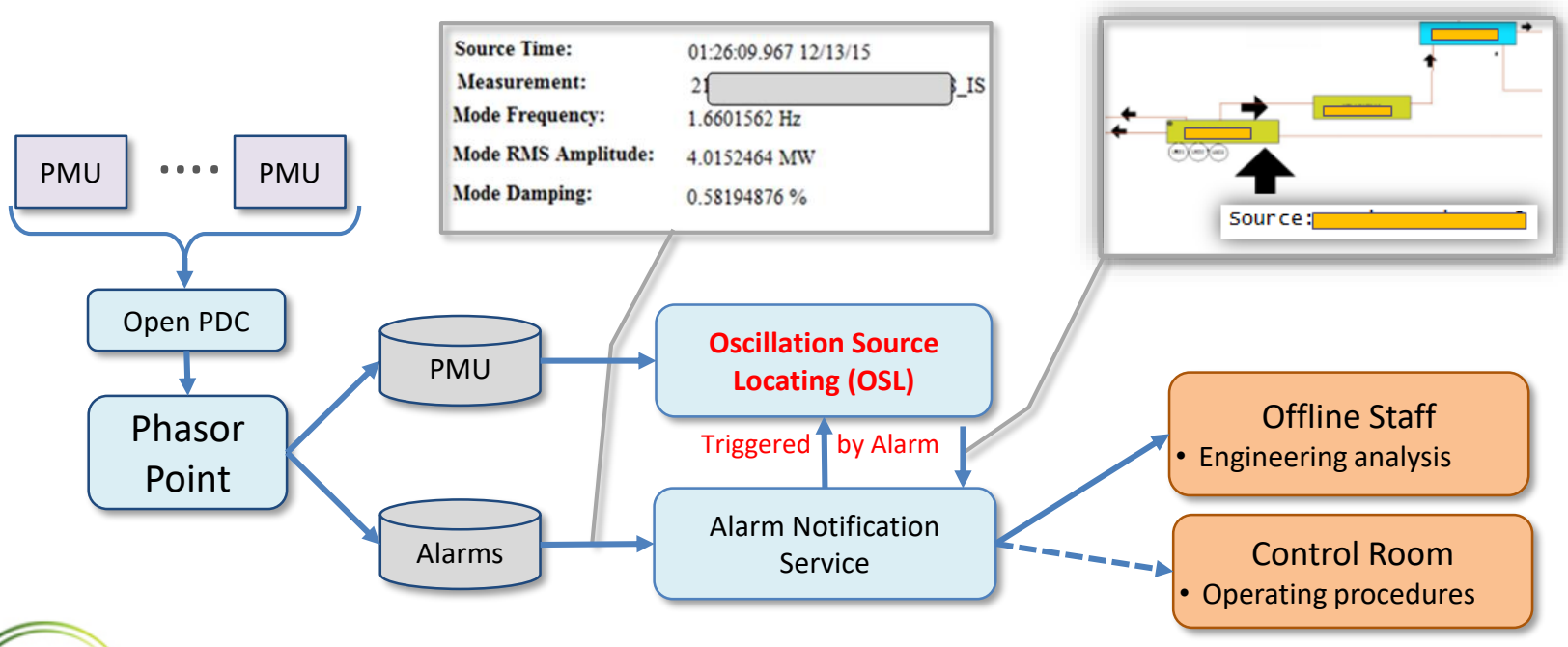


- The key step in the mitigation of sustained oscillations is to find the Source of oscillations. The Source is typically a generator.
- The capability to find the Source ONLINE means providing the Operations with actionable information

Online Oscillation Management at ISO-NE

Objectives:

- Detect all significant oscillatory events and provide Alarms/Alerts for dangerous oscillations
- Estimate the Source of oscillations for every oscillatory Alarm and deliver results to the designated personnel



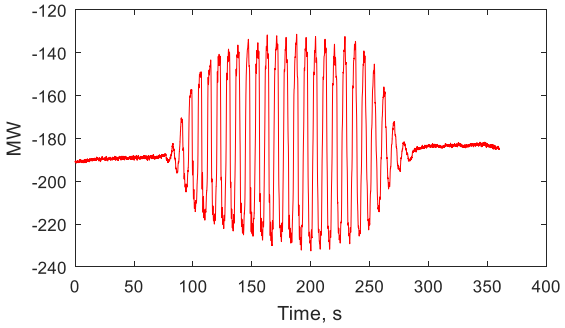
Dissipating Energy Flow (DEF) Method

- The OSL application uses the DEF method* which calculates the rate of change of dissipating energy (DEi) for any branch ij monitored by PMU at bus i.

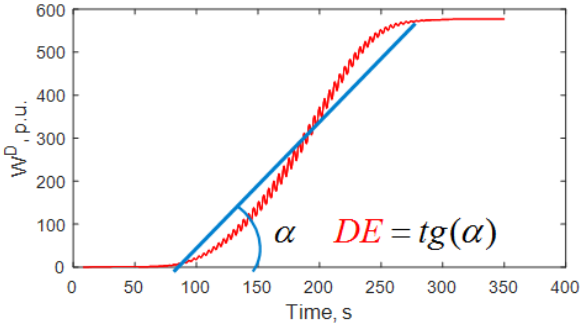
$$W_{ij}^{D} = \int (\Delta P_{ij} \cdot d\Delta\theta_i + \Delta Q_{ij} \cdot d(\Delta \ln V_i))$$

$$= \int (2\pi \cdot \Delta P_{ij} \cdot \Delta f_i \cdot dt + \Delta Q_{ij} \cdot d(\Delta \ln V_i)) \simeq DE_i \cdot t + b_{ij},$$

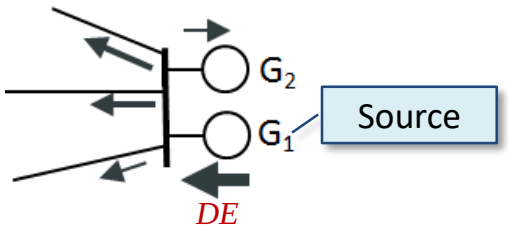
MW flow in a transmission line



Flow of Dissipating Energy in that line



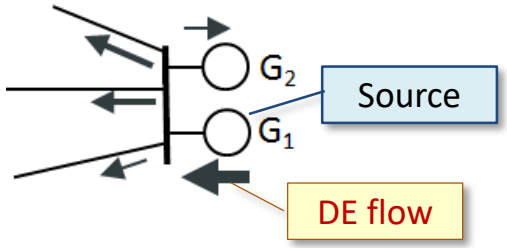
- DE coefficient can be viewed as a regular MW flow in terms of Source-Sink for a flow of the transient energy
- The direction and the value of DE in multiple branches allow tracing the source of oscillations



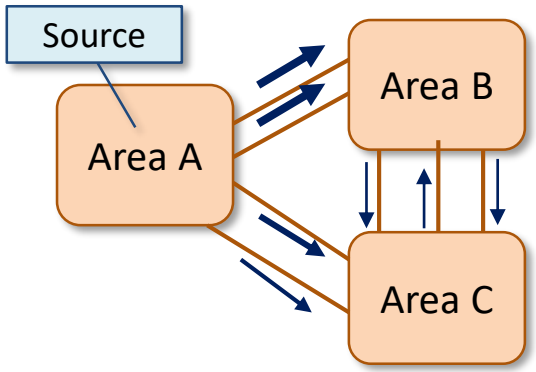
[*] Slava Maslennikov, Bin Wang, Eugene Litvinov "Dissipating Energy Flow Method for Locating the Source of Sustained Oscillations", International Journal of Electrical Power and Energy Systems, Issue 88, 2017, pp.55-62

Interpretation of DE pattern

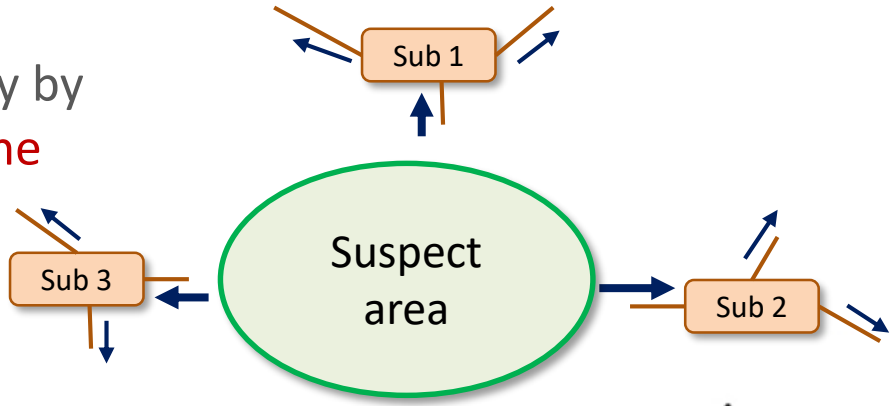
- PMU measurement at the Point Of Interconnection allows to trace specific power plant or generator



- PMU measurements of tie-lines between control areas allow to identify which area contains the source



- Even limited system observability by PMU still allows localization of the suspect area accurately



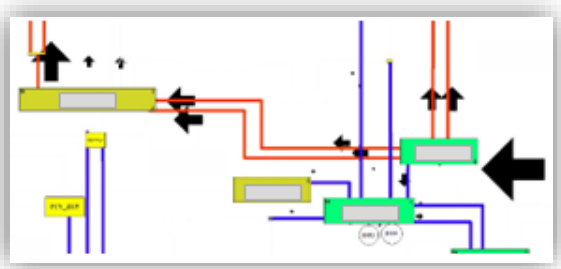
Features of online OSL application

- Fully automated run. No human in the loop. Designated personnel receive emails with all results attached
- Filtering out “bad” PMU data and false Alarms caused by (a) Bad PMU data and (b)Tripping events
- Dissipating Energy (DE) flow pattern recognition
  - ✓ DE flow in the network is converted into a text message on a specific Area/Substation/Generator which is the suspect source of oscillations

DE, p.u.	LineID
-1.00	3533@
0.50	376@
-0.39	t1x@
-0.38	3424@
0.36	3041@
-0.31	3041@
0.26	3827@
-0.24	362@
0.21	398@
-0.18	3619@
0.18	329@
-0.18	3165@

Source:
Area: xxxxxx
Substation: xxxxx
Unit: xxxxxx

- Visualization of DE flow on oneline diagram
  - ✓ Efficient way to deliver OSL results for limited system’s observability by PMU when DE pattern recognition is difficult



Example of Alarm Notification by Email

WARNING - PhasorPoint Alarms Notification

DoNotReply@iso-ne.com

Sent: Tue 9/12/2017 6:14 AM

To:

Message | DE20170912_060339.csv (438 B) | P_DE20170912_060339.jpg (15 KB) | DE20170912_060339.jpg (770 KB)

*** This message has been automatically generated - DO NOT REPLY ***

Computer: [redacted]; PhasorPoint has issued 1 oscillation Alerts/Alarms for the 30 seconds interval.

Time interval: [2017-09-12 06:03:36 - 2017-09-12 06:04:06]

---------- Alarm ----------

Signal Used: [P]

Frequency Band: [1.13-4.0 Hz]

Message: [PDX1-3 event status alarm]

Mode Frequency: [1.138 Hz]

Mode RMS Amplitude: [17.2 MW]

Mode Damping Ratio: [1.5 %]

Parameters of oscillations

****

Oscillation Source Location (OSL) detection summary:

Source: [redacted]

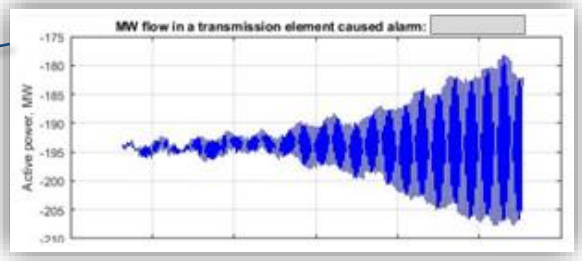
Sufficient time interval for the DEF method was identified

PMU data can be used for the DEF method

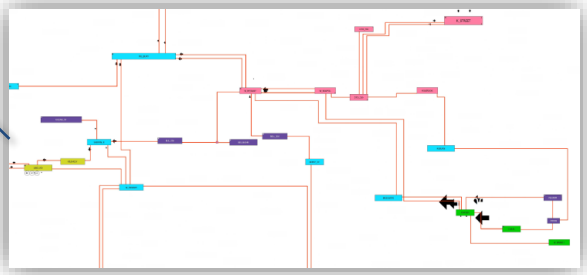
No tripping was detected

Results of DE pattern recognition

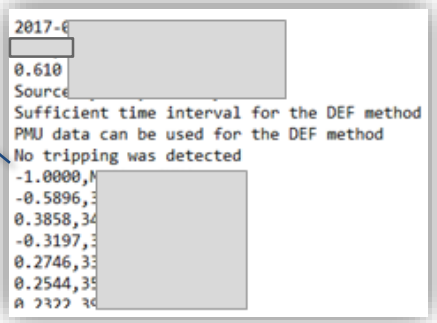
MW flow in line causing Alarm



DE visualization

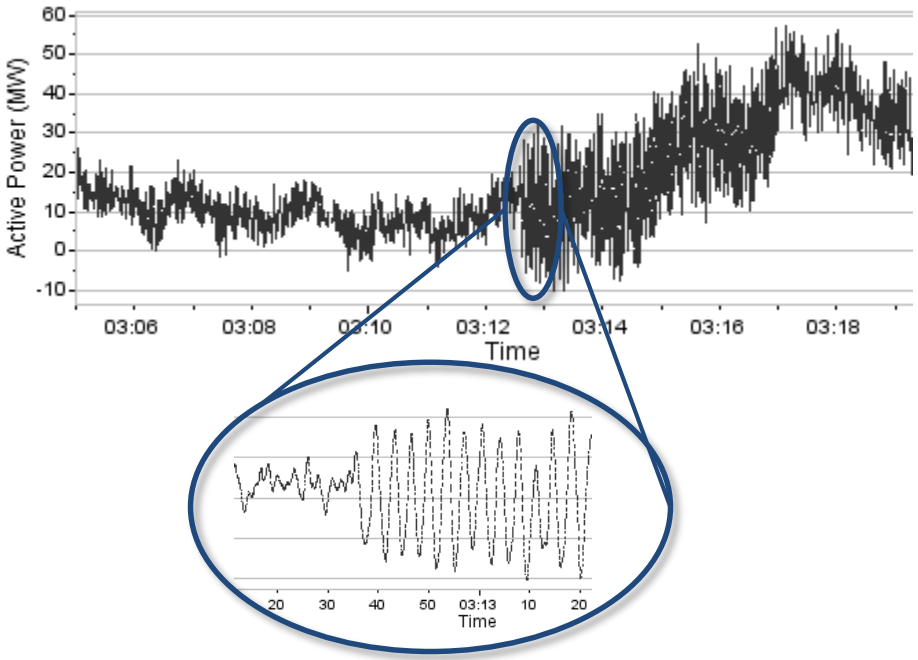


DE pattern and identified source

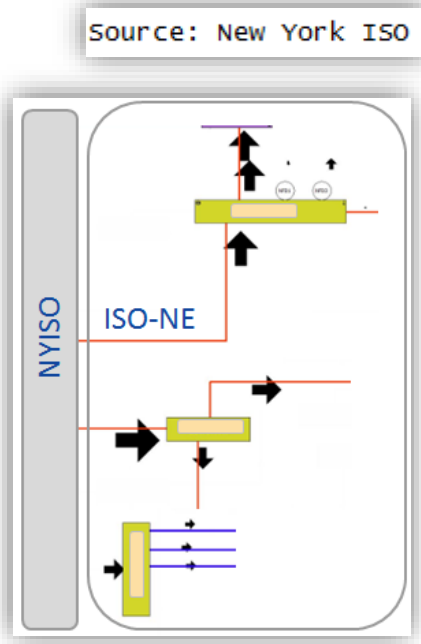


FO Originated Outside ISO-NE (1200 miles away)

- June 17,2016; interarea oscillations of 0.22-0.28Hz, up to RMS=11MW caused 8 alarms in ISO-NE during 45 minutes



Results of the OSL

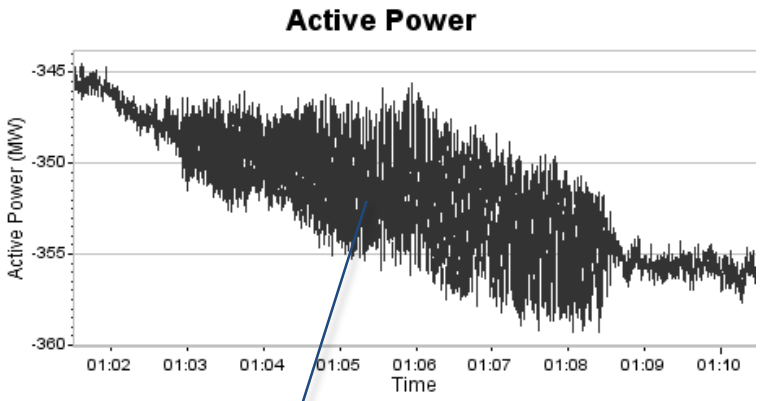


DE flow patterns for all 8 Alarms were almost identical

This example illustrates the ability to identify on whether the Source is located inside or outside of control area

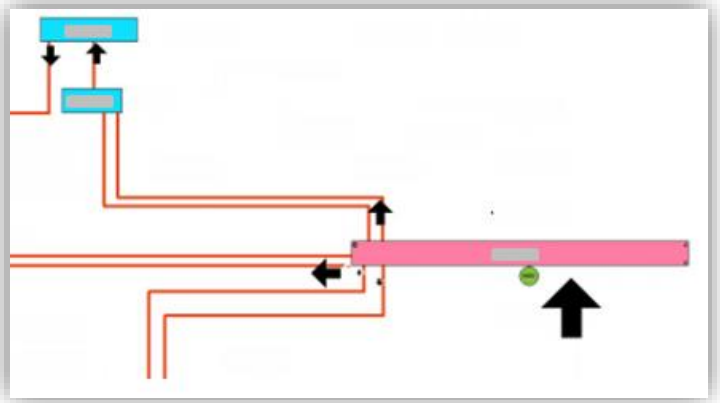
FO Caused by ISO-NE generator

- February 6, 2018; a large ISO-NE generator creates multi-frequency oscillations with magnitude up to RMS=3MW during 5 min



Combination of 0.60Hz and 0.86Hz modes

Results of the OSL for 0.6Hz mode

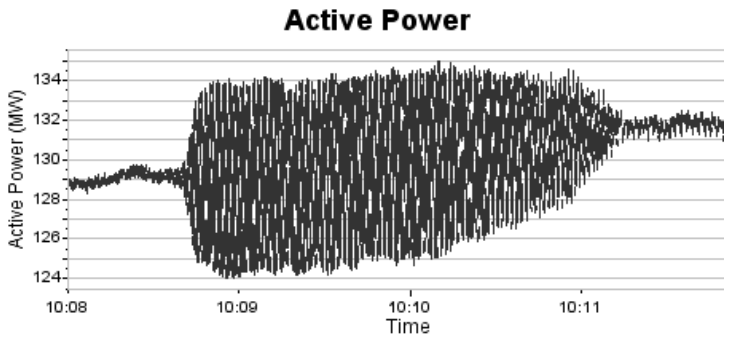


DE pattern for 0.86Hz is practically the same

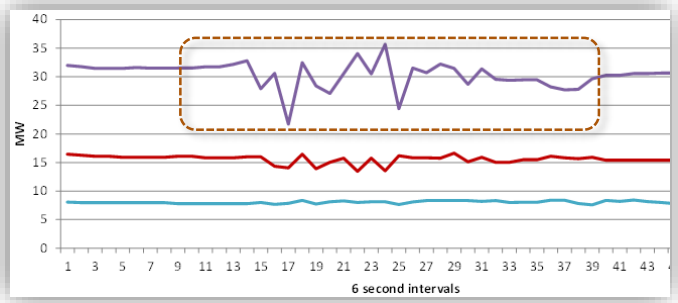
This example illustrates the ability to identify an individual generator if it is monitored by PMU

FO Coming From Non-Observable Area

- December 7, 2017; 1.3 Hz oscillations with RMS=5MW magnitude coming from the ISO-NE area not observed by PMUs

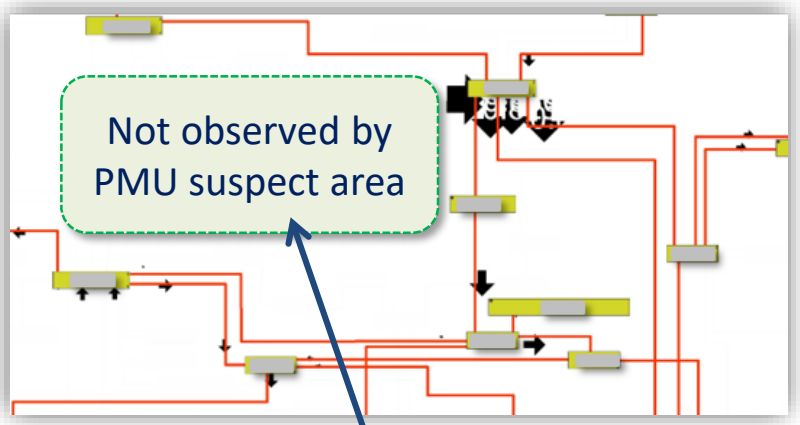


SCADA data of 3 suspect generators



Results of the OSL

Source is not identified

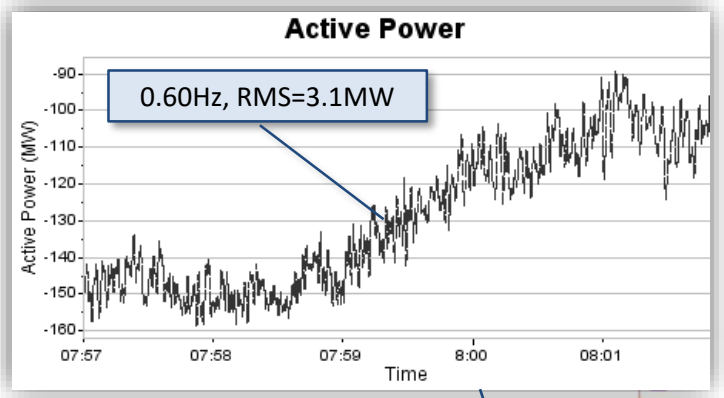


- This area contains only 3 generators
- SCADA data for these 3 generators helps to find the source - generator

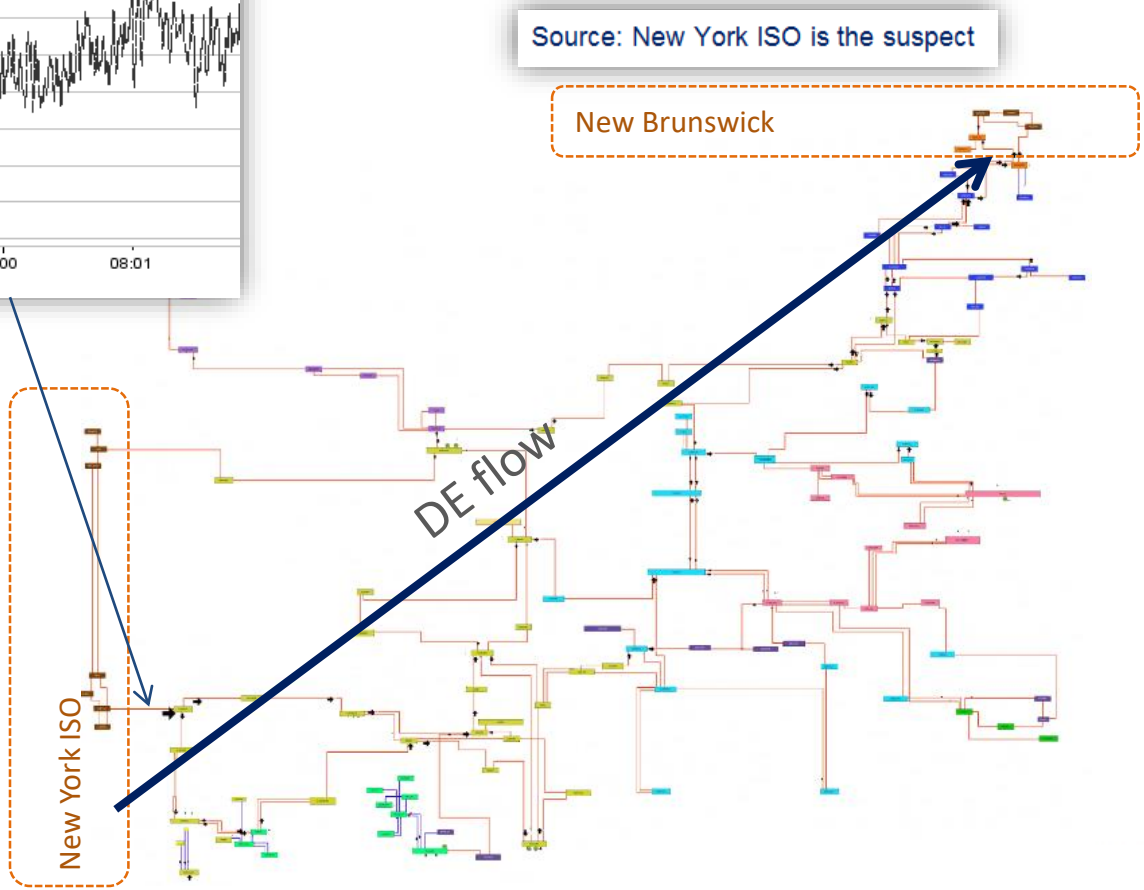
This example illustrates the ability to localize the suspect area non-observable by PMU

Oscillations Originated in Eastern Interconnection

- Oscillations 0.3 – 0.7 Hz with magnitude RMS=2-3MW are often detected



Results of the OSL for 0.6Hz mode



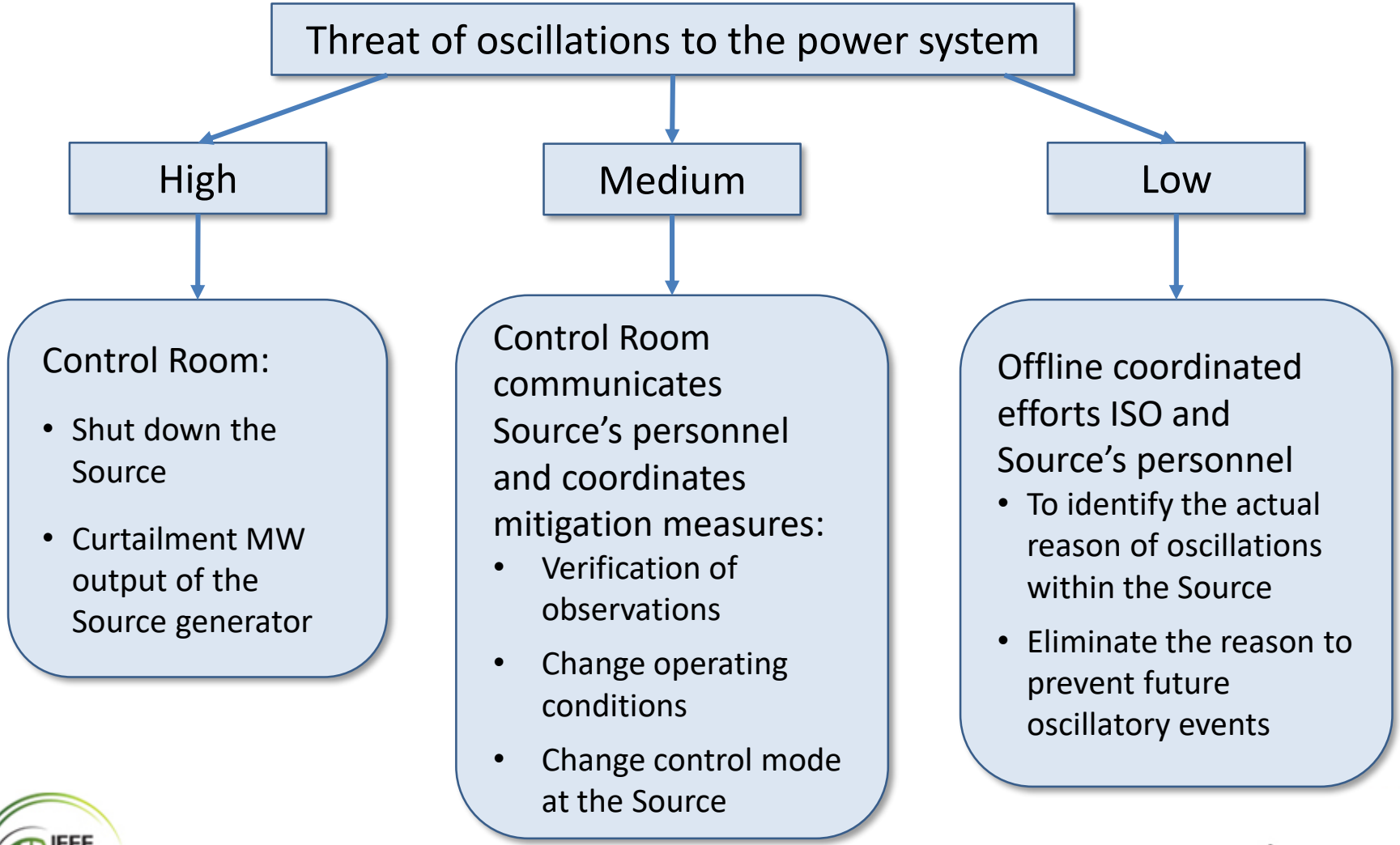
This example illustrates detection of a possible source of oscillations located somewhere in the Eastern Interconnection

Statistics and Lessons Learned

- Online OSL has automatically processed 1000+ oscillatory events since September 2017. Correctly identified the source-generator/area for all instances of known source location
- OSL is a robust online tool for locating the source of oscillations with actual PMU data
  - ✓ Statistical runs did not confirm the concern that the deficiency of energy-based method (constant resistance load and network resistance can be seen as Source of Sink depending on location) can significantly compromise calculated DE pattern
- Automated procedure for filtering and correcting bad PMU data is a must for robust online application

Each utility, having "**like OSL tool**", would be capable to **independently** estimate the Source of oscillations and greatly reducing the need in coordination with other utilities for mitigation

Mitigation of Oscillation



Oscillation Source Locating application

Online version: OSL

Integrated with ISO-NE PMU infrastructure:

- PMU naming convention
- Phasorpoint as PMU source
- Visualization of OSL results on oneline diagram
- Fully automated run triggered by Phasorpoint Alarm/Alert

Offline version: OSLp

Standalone Matlab executable:

- Reads PMU data from a file
- Supports several PMU data formats
- Configurable for fully automated or "research type" runs
- Does not require Matlab license
- Generic application which can use PMU data from any utility
- Can be made available for testing

Conclusions

- Detecting oscillations without providing **actionable information** for mitigation is not much useful for operations
- OSL application is a robust online tool for detecting the source of sustained oscillations and providing **actionable information**
  - ✓ Detects specific source-generator at sufficient PMU observability
  - ✓ Detects suspect-area by using PMU measurements on tie-lines
  - ✓ Greatly localizes suspect-area even at limited PMU observability
- Variety of online and offline oscillation mitigation measures are available as soon as the Source of oscillations is identified

Questions

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