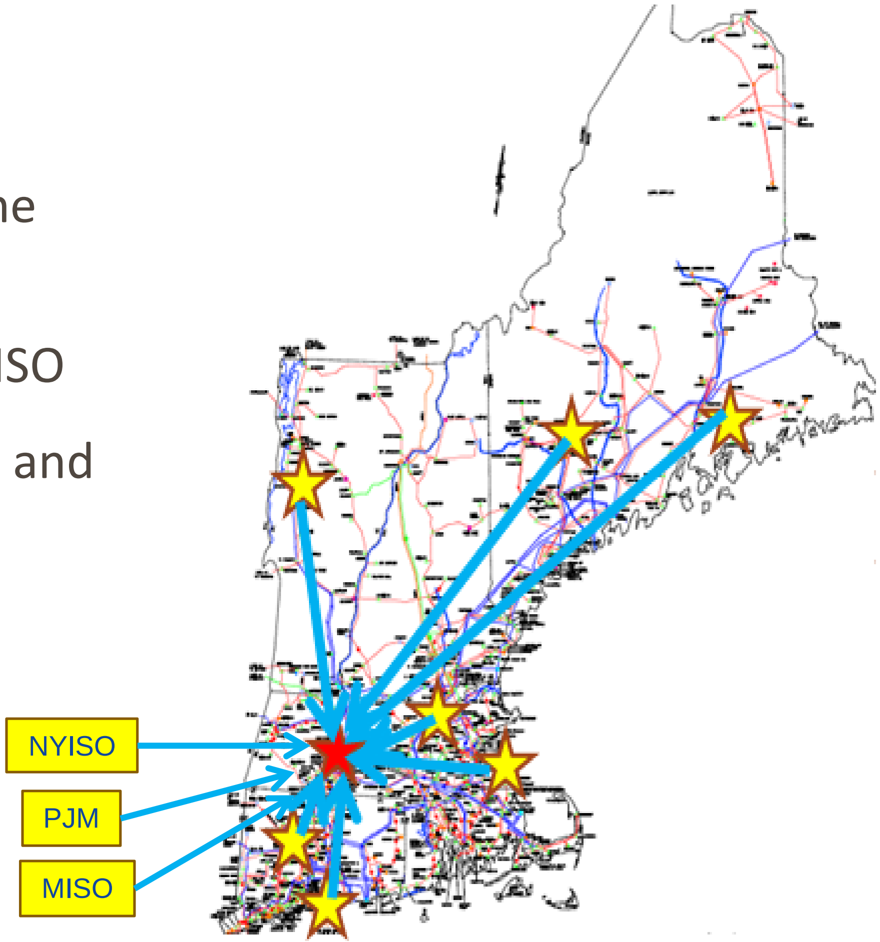
NASPI. SEPTEMBER 27,2017

Online Oscillation Management at ISO New England

SLAVA MASLENNIKOV
XIAOCHUAN LUO
FRANKIE ZHANG
IZUDIN LELIC
EUGENE LITVINOV

PMU Infrastructure at ISO New England

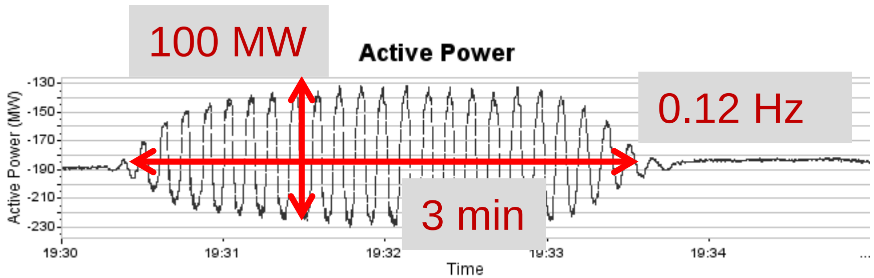
- Installed in 2012
- 86 PMUs at 45 locations
- Full observability of 345 kV with some redundancy
- Seven open PDCs at TOs and one at ISO
- Selected PMU data from NYISO, PJM and MISO; added in 2017

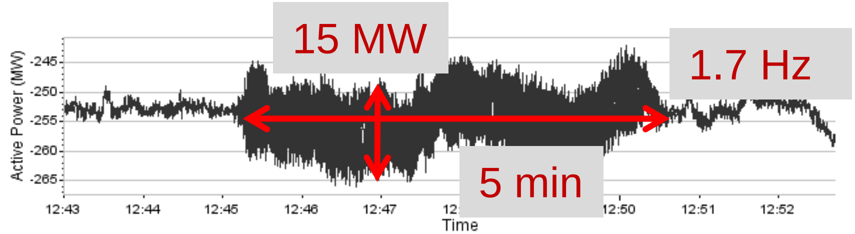


Oscillation Monitoring

- PhasorPoint application automatically processes PMU data 24/7 and does the following
  - ✓ Detects and characterizes oscillations
  - ✓ Generates Alarms/Alerts per pre-defined magnitude/damping thresholds
- Multiple instances of poorly damped oscillations with high MW magnitude and frequency from 0.03 Hz to 2 Hz have been detected since 2012
- Almost all oscillation Alarms are caused by Forced Oscillations (FO)

Examples of FO:





ISO was unaware of FO before the installation of PMU

Do Oscillations Impose Any Threat?

- Yes, the sustained oscillations can cause
  - ✓ Potential uncontrolled cascading outages
  - ✓ Undesirable mechanical vibrations in system components, which increases the probability of equipment failure, reduces the lifespan of equipment, and results in increased maintenance requirements

- Catastrophic event of rotor's vibration at Sayano–Shushenskaya hydro power station in 2009*

Before the accident

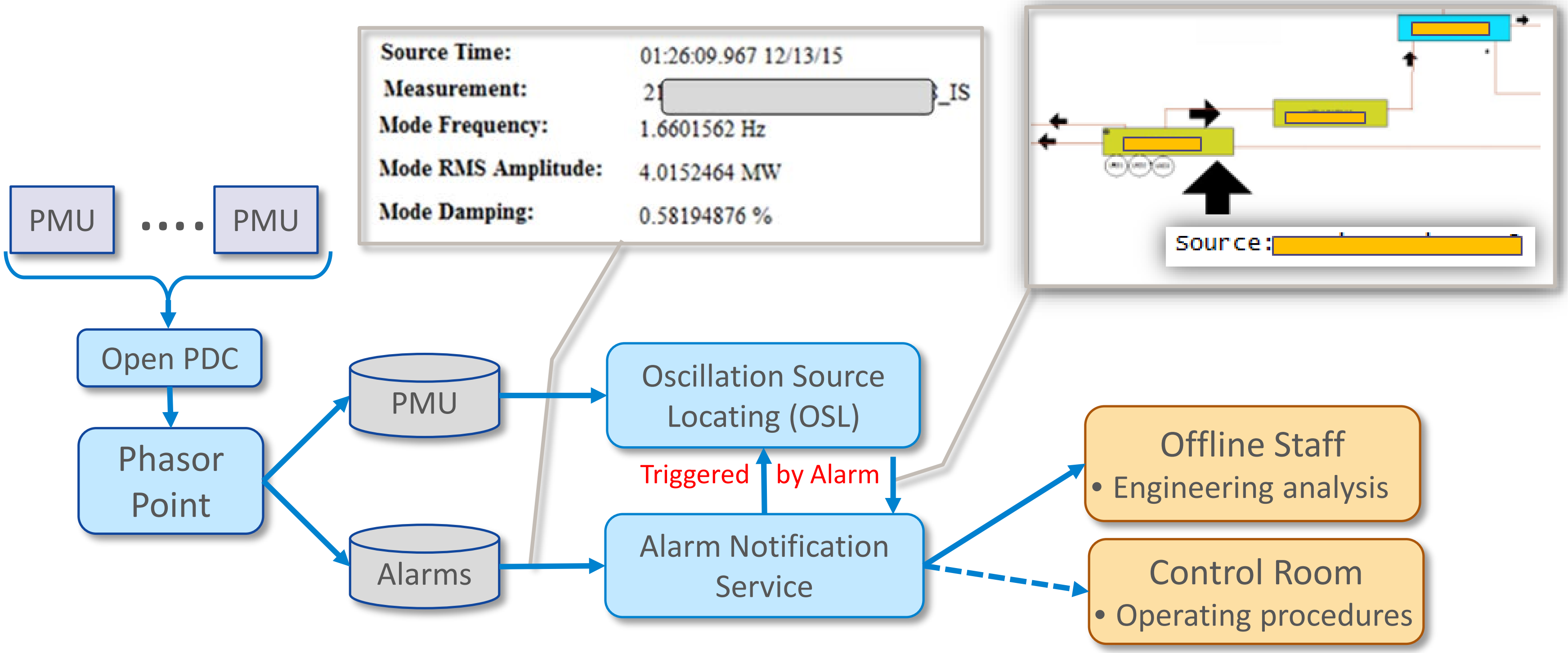
After the accident

* https://en.wikipedia.org/wiki/2009_Sayano%E2%80%93Shushenskaya_power_station_accident

Online Oscillation Management

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



How to Mitigate Forced Oscillations?

- Forced Oscillations exist as long as the Source of forced signal exist
  - ✓ Equipment or control system failure
  - ✓ Wrong settings of control systems
  - ✓ Unplanned operating conditions
  - ✓ Unintended interaction of control systems

- The mitigation approach is to find the Source and:
  - ✓ Disconnect it from the network
  - ✓ Reduce MW output
  - ✓ Communicate to the power plan - to find out what is going on and to develop remedial actions
  - ✓ If the Source is outside of the control area, then communicate to the Operator in the suspected area

A number of mitigation measures can be applied depending on situation

- The key step in the mitigating of sustained oscillations is to find the Source of oscillations

- Source of FO is a generator in practically all observed actual events

What Does it Mean "Find the Source"?

I see sustained oscillations!!

Control Room Operator

Is the Source located in my Control Area?

Yes →

Which substation is the suspect?
Which specific unit is the suspect?

Mitigation Actions applied Inside the control area

No →

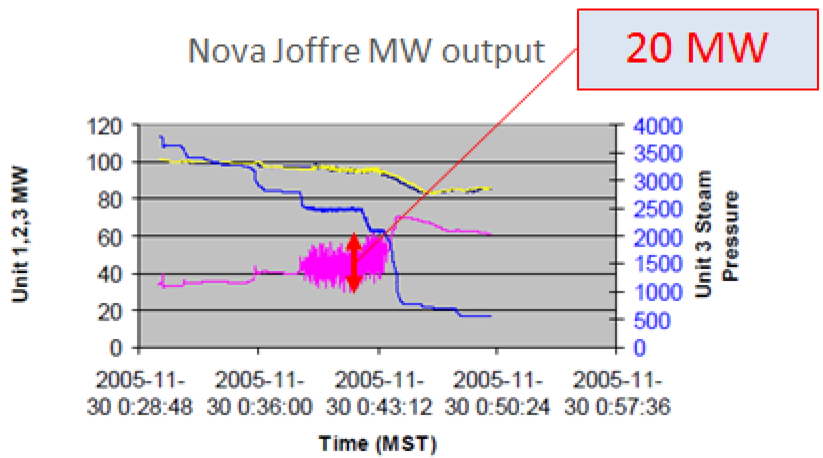
Which of my neighbors is the suspected area?

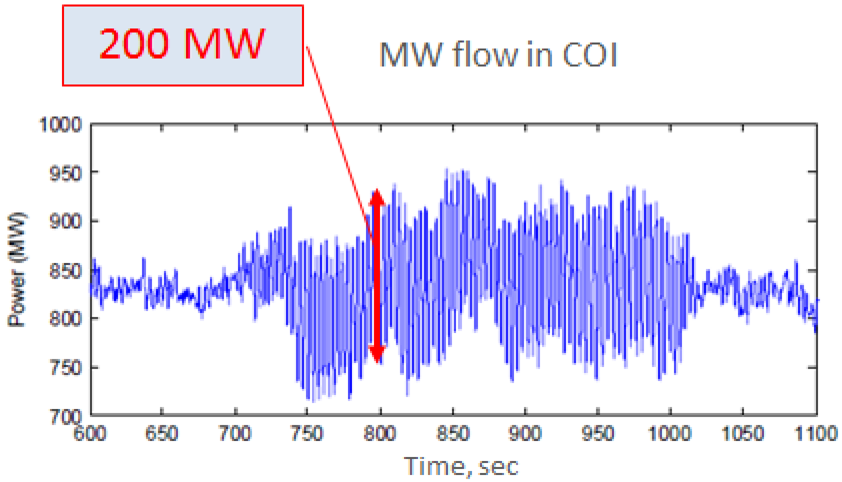
Actions to find the Source outside of the control area

"Find the Source" means to answer the above questions and provide the **actionable information** to the Operator

Magnitude is an Unreliable Indicator of the Source

- November 29, 2005 : 200 MW oscillations on California-Oregon Interface (COI) were caused by 20 MW oscillations at the Nova Joffre generating plant in Alberta, Canada, 1100 miles away due to malfunctioning steam extractor control valve
  - ✓ Resonance conditions for 0.27 Hz interarea mode





(Source: BPA)

Methods for “Finding the Source”

- Variety of methods have been proposed. They are based on different properties of the oscillations:
  - ✓ Magnitude
  - ✓ Phase angle of the mode shape
  - ✓ Propagation speed
  - ✓ Statistical signature
  - ✓ Damping torque
  - ✓ Energy-based method

All these method work well in some situations but do not work in other

Dissipating Energy Flow (DEF) method* = Energy-based method + PMU processing

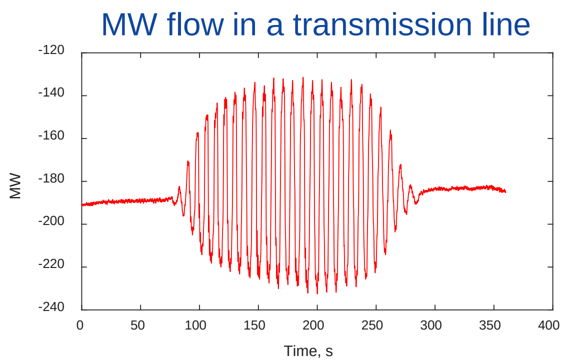
- Pros: - Universally efficient in a variety of practical situations
  - Works in resonance conditions
- Cons: Constant resistance load and resistance in network can impact DE values.
  Nevertheless, tracing DE values of only generators allows detecting generator- source

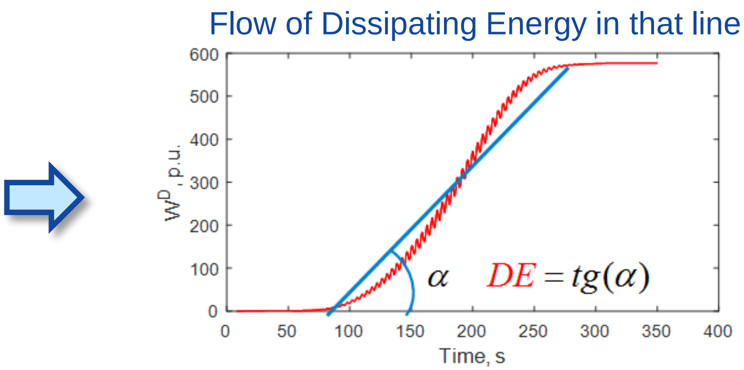
[*] Slava Maslennikov, Bin Wang, Eugene Litvinov “Dissipating Energy Flow Method for Locating the Source of Sustained Oscillations”, International Journal of Electrical Power and Energy Systems, Issue 88, 2017, pp.55-62

The DEF Method

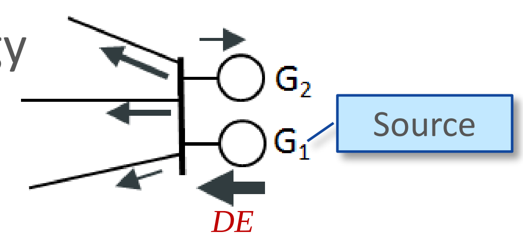
- The rate of change of dissipating energy (DE_i) for any branch ij monitored by PMU at bus i.

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



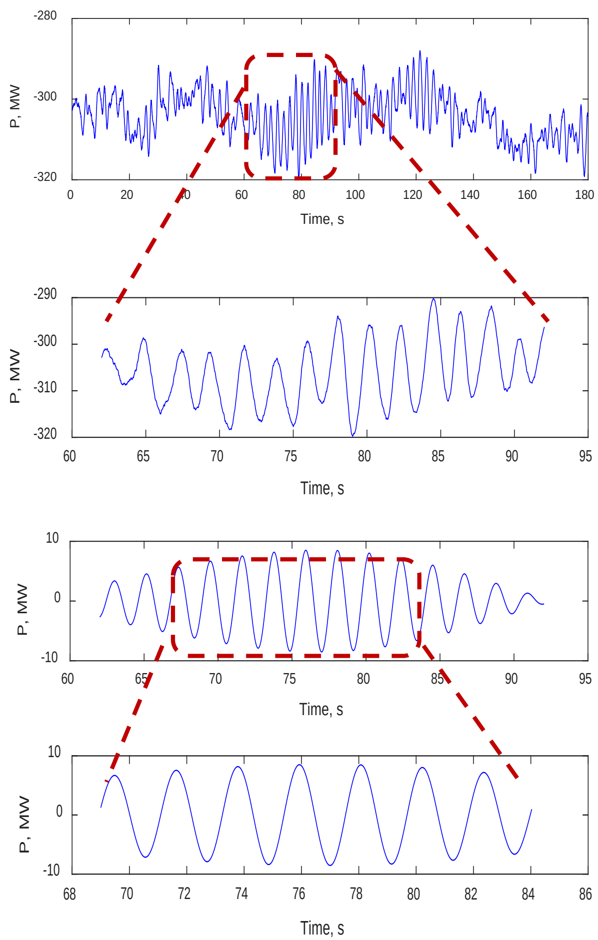


- DE coefficient can be viewed as a regular MW flow in terms of Source-Sink for a flow of the transient energy
- The Direction and the value of DE in multiple branches allow tracing the source of oscillations



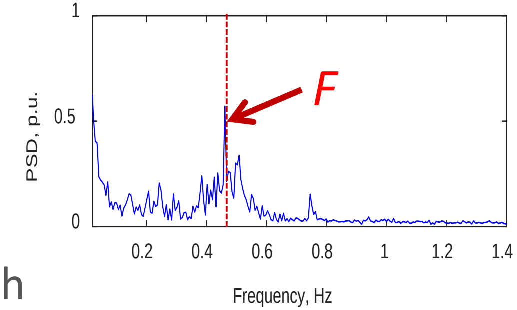
PMU Processing for all PMU signals

- Need to calculate "the deviation from steady-state value" for a specific mode
- Steady-state practically does not exist in actual systems



Step 1: Raw PMU data

Select frequency of interest *F*



Step 2: Select time interval with significant magnitude of oscillation at frequency F

Step 3: Band pass filtering

$$f_{BAND} = F \cdot (1 \pm \varepsilon), \varepsilon = 0.1$$

Step 4: Select middle of interval only for calculation of *DE* coefficient

The DEF Method Test Results

- Simulated cases*: test case library of sustained oscillations – a set of representative cases which can be expected in actual systems

Description	Test Results
All 9 cases of poorly damped natural oscillations	Pass ✓
All 14 cases of forced oscillations	Pass ✓

- Actual events in ISO New England and WECC

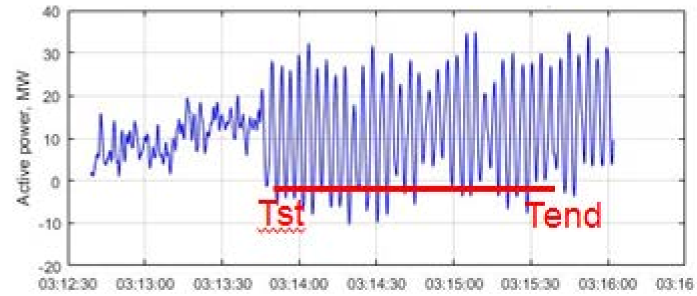
Description	Test Results
More than 30 cases from ISO-NE	Pass ✓
Two cases from WECC	Pass ✓

The DEF method was implemented in the Oscillation Source Locating (OSL) application

* http://curent.utk.edu/research/test-cases/

Features of online OSL application

- Automatic selection of the study period

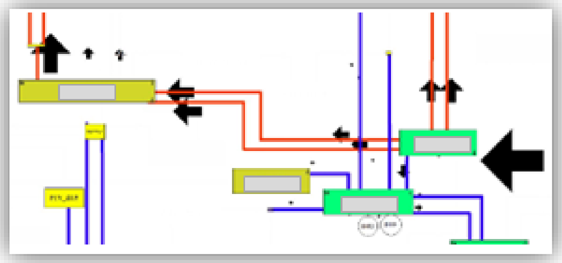


- Filtering out false Alarms caused by
  - ✓ Bad PMU data
  - ✓ Tripping events
- Dissipating Energy (DE) flow pattern recognition
  - ✓ DE flow in the network is converted into a text message on a specific Area/Substation/Generator which is the suspect source of oscillations

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@

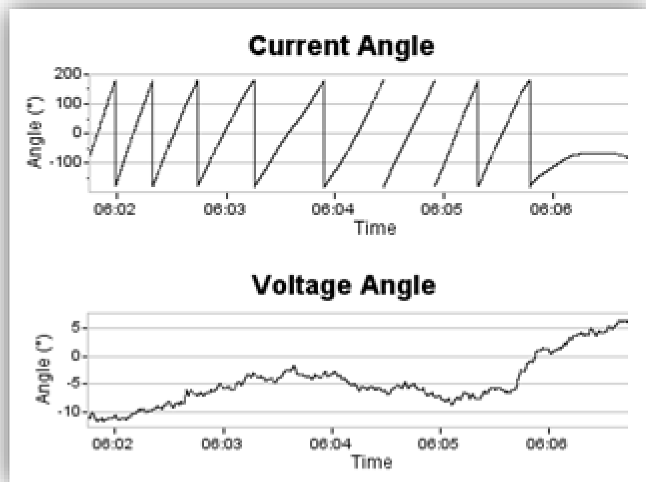
Source:
Area: xxxxxx
Substation xxxxx
Unit xxxxxx

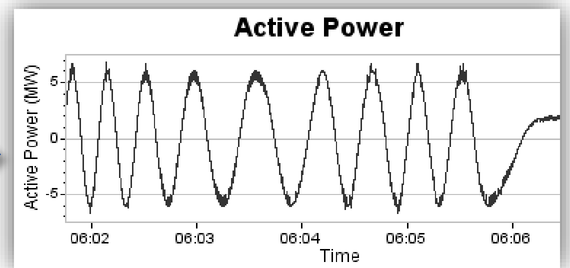
- Visualization of DE flow on oneline diagram
  - ✓ Efficient way to deliver OSL results for limited system's observability by PMU when DE pattern recognition is difficult



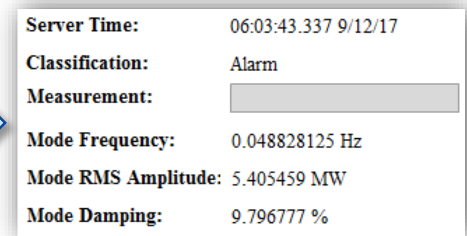
Identification of False Alarms

- PhasorPoint can generate false alarms caused by bad PMU data or by tripping events. False Alarms are identified by the OSL.
- Example: “Stalled” current’s angle measurement at not-nominal frequency results in oscillatory shape of calculated MW

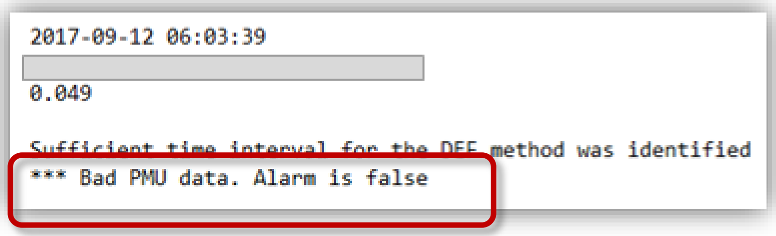




False Alarm

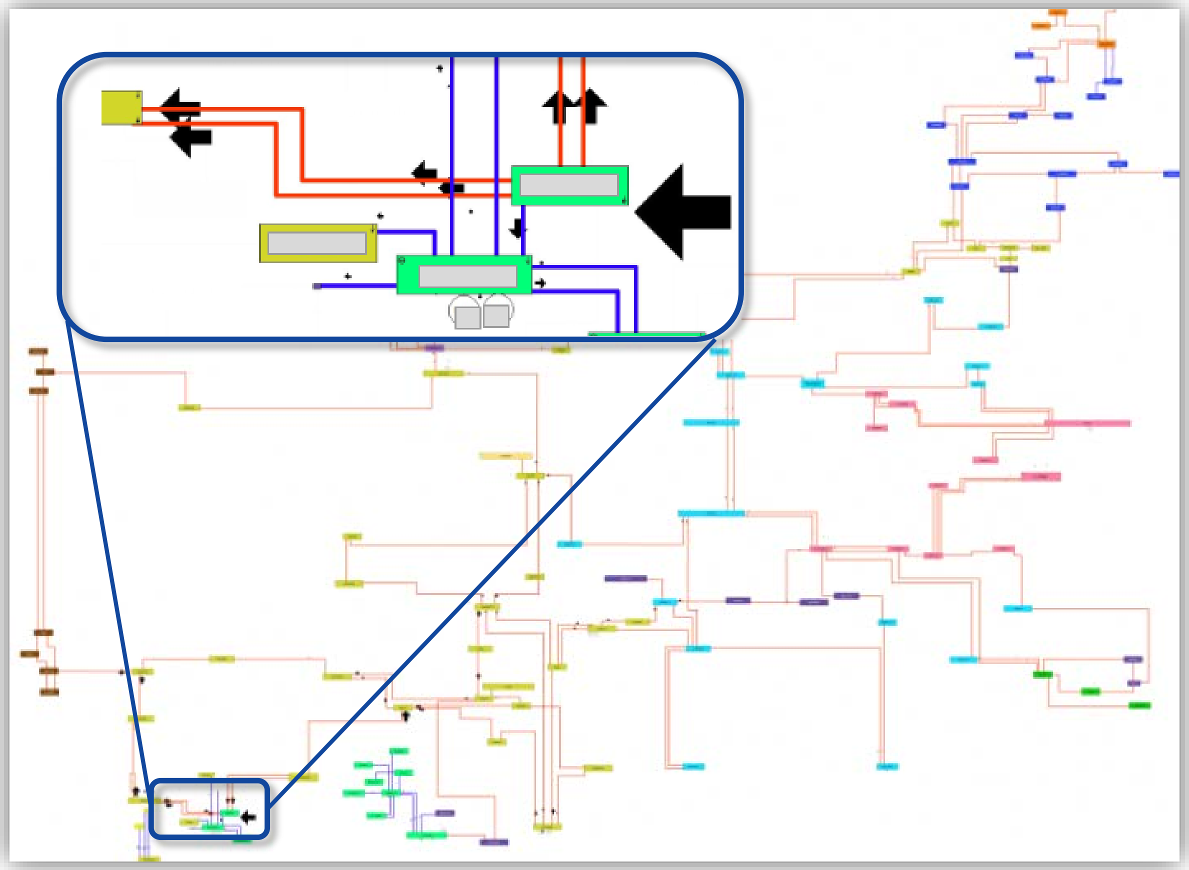


- OSL results:

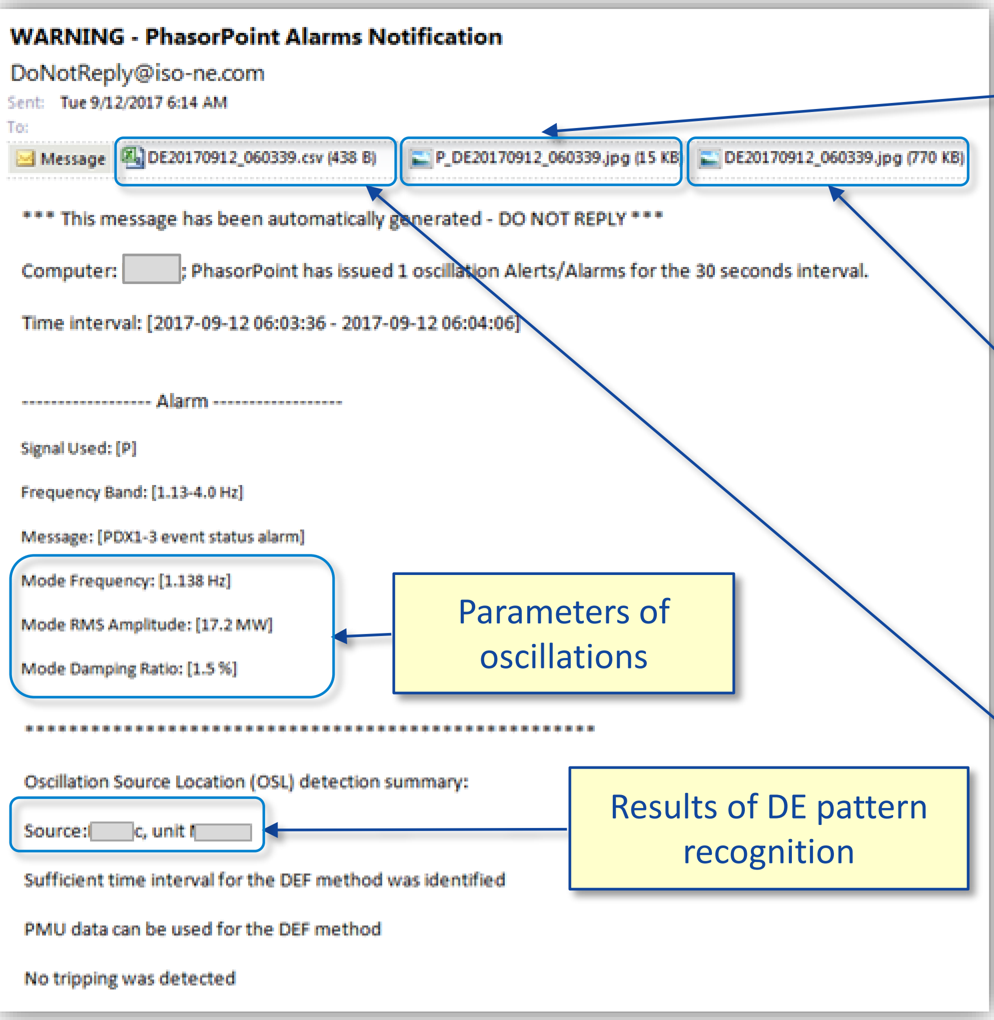


Visualization of DE flow

- Automatically generated online diagram with DE flow
  - ✓ JPEG file is created by PowerWorld Simulator and SimAuto
- High resolution picture with capability to zoom in



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: ; 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 %]

****

Oscillation Source Location (OSL) detection summary:

Source: c, unit

Sufficient time interval for the DEF method was identified

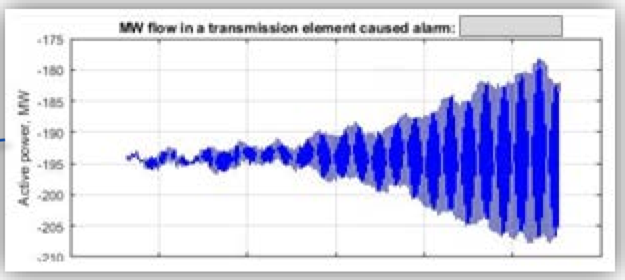
PMU data can be used for the DEF method

No tripping was detected

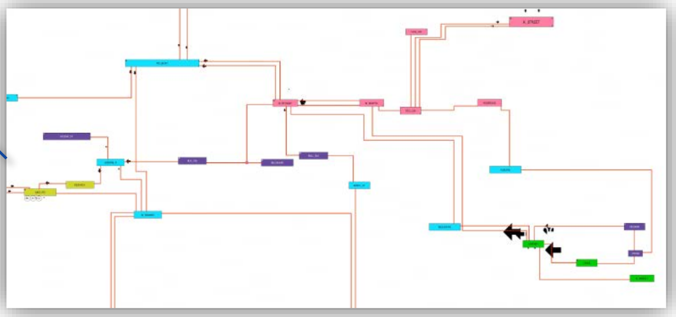
Parameters of oscillations

Results of DE pattern recognition

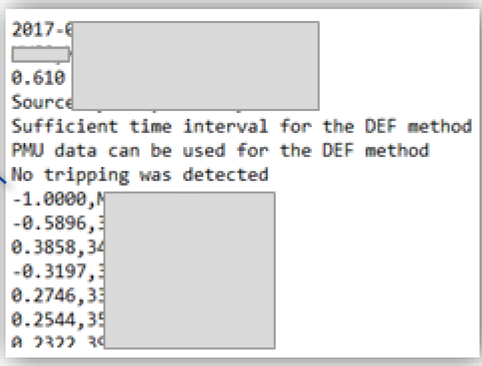
MW flow in line causing Alarm



DE visualization



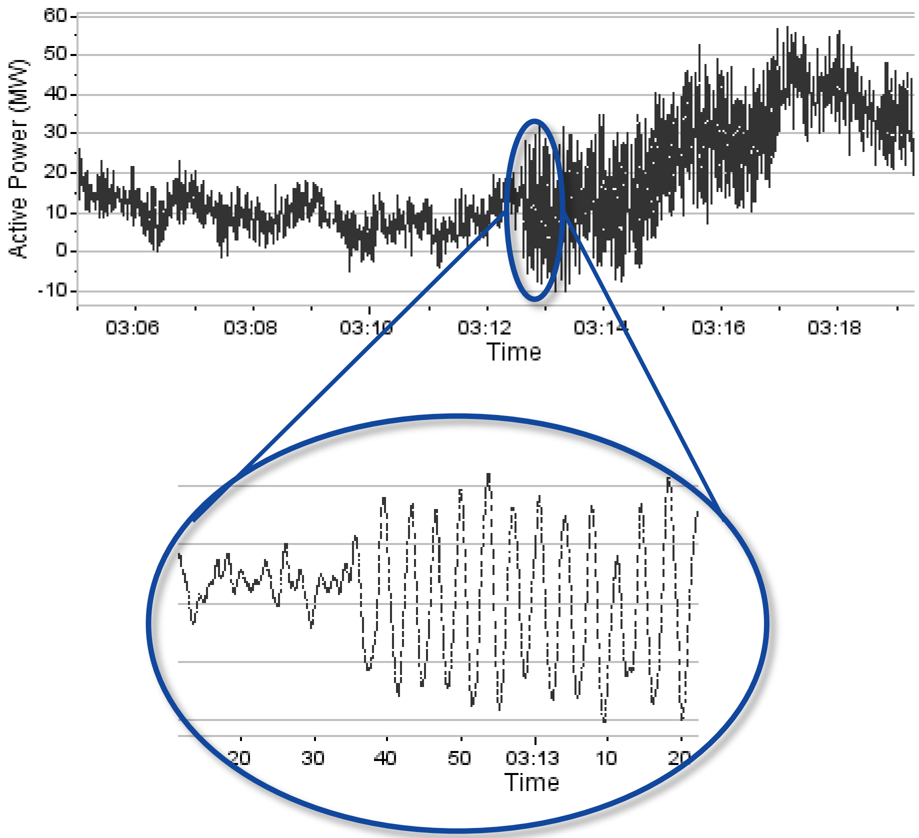
DE pattern and identified source



FO Originated Outside ISO-NE (1200 miles away)

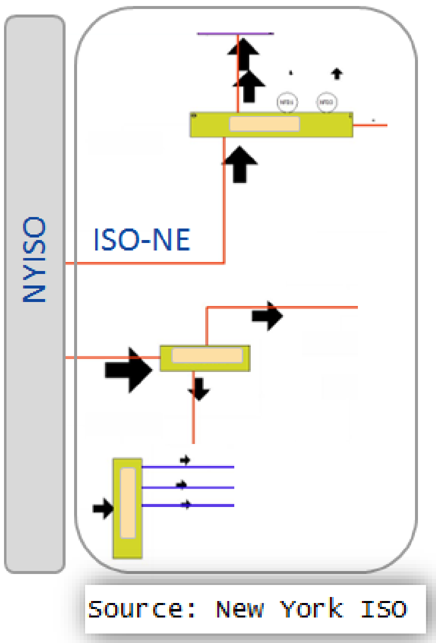
- June 17,2016; interarea oscillations of 0.22-0.28Hz, up to RMS=11MW caused multiple alarms in ISO-NE during 45 minutes

Time domain data



Results of the OSL

DE flow in 345kV lines at NE-NY border



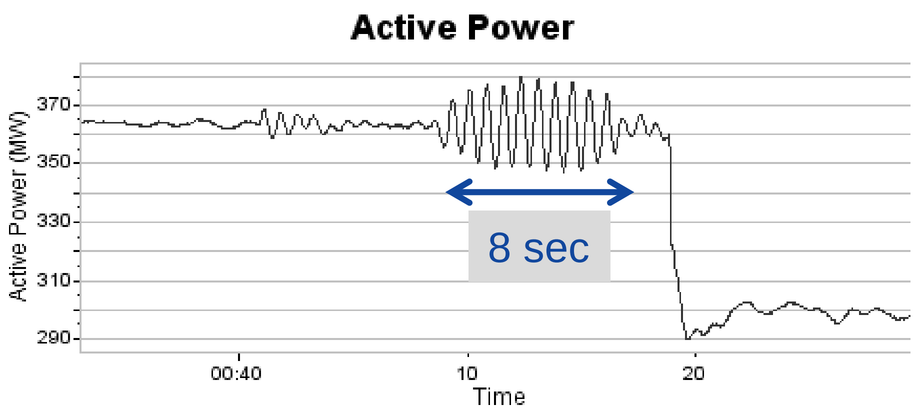
DE flow indicates that the source is located outside ISO-NE in NYISO direction

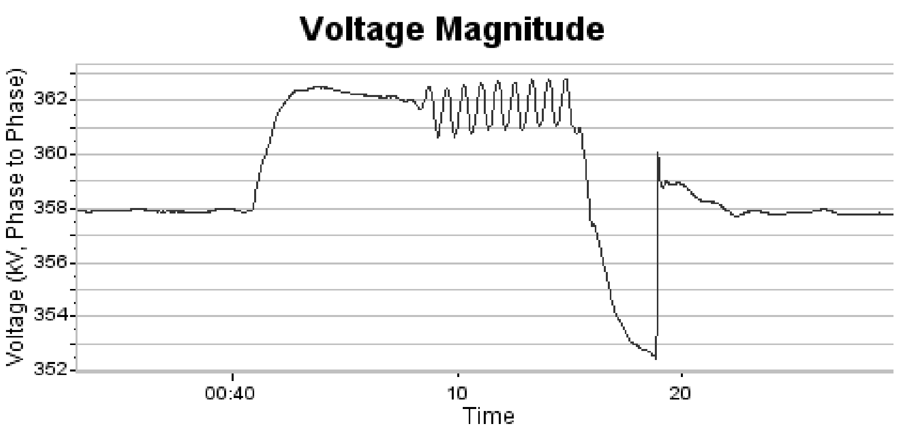
Ability to identify whether the Source located Inside or Outside of control area

FO Originated From the Excitation Failure

- June 15, 2016; oscillations of 1.32Hz were caused by the failure of the excitation system of G_3 - one of three units operating at the same conditions. All units were monitored by PMU.

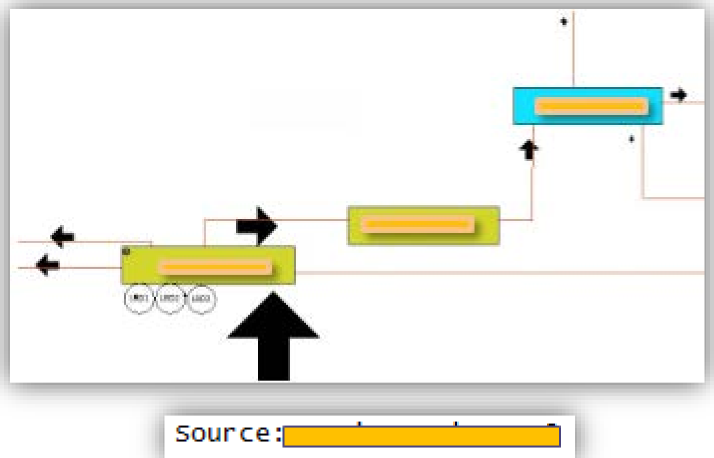
Time domain data





Results of the OSL

DE flow in 345kV lines around suspect area



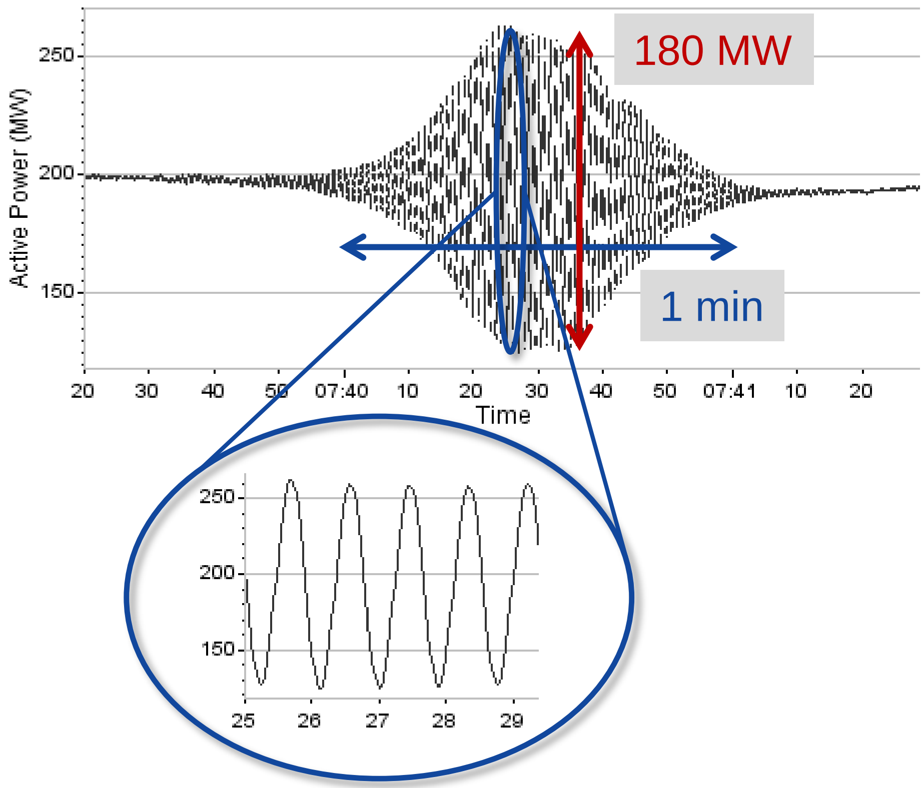
DE pattern recognition identified G_3 as the source

Ability to identify a specific generator within power plant as the Source if generator is monitored by PMU

Unexpected FO During a Standard Test

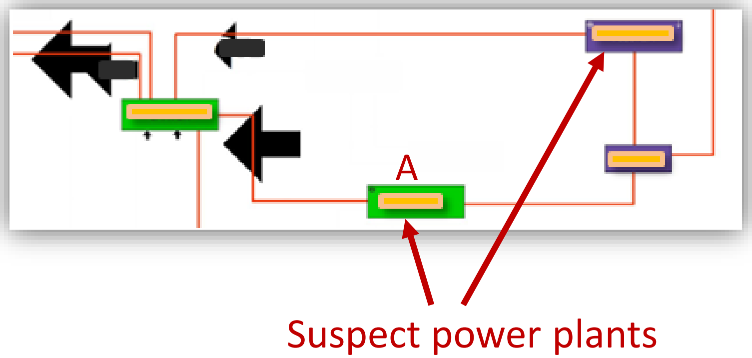
- July 20, 2017; unexpected oscillations of 1.13Hz as the result of a standard test at a power plant. This power plant is not monitored by PMU.

Time domain data



Results of the OSL

DE flow in 345kV lines around suspect area



Ability to localize a suspect power plant with limited PMU observability

Power plant A is the actual source of oscillations

Conclusions

- Online oscillation management provides the following
  - ✓ Detects and characterizes oscillations
  - ✓ Estimates the suspect-source
  - ✓ Sends notifications to designated personnel
- The OSL applications provides **actionable information** to Operations
  - ✓ Identification on whether the source is located **inside** or **outside** of control area
  - ✓ Identification of a **suspect substation**
  - ✓ Identification of a suspect **specific generator** within power plant
- The prototype online OSL application has been deployed in September 2017

Questions