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Experience with Oscillations in ISO New England

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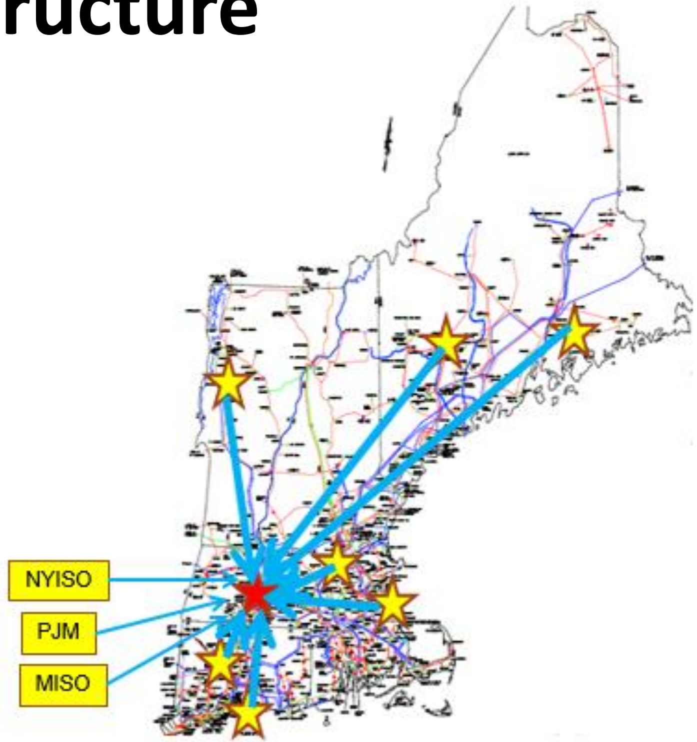
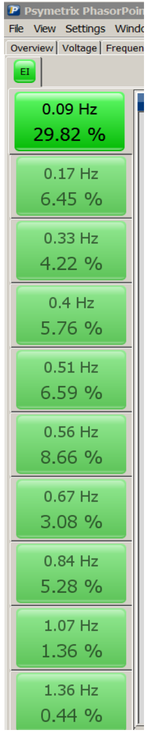
Measurements: PMU Infrastructure

- ~100 PMUs and constantly growing
- Full observability of 345 kV with some redundancy
- Selected PMU data from NYISO, PJM and MISO; adding TVA, SOCO,SPP
- 30 samples/s
- New: requirement to add PMU at every utility scale IBR installation



Good system observability for oscillations

Detection of Oscillations: PMU processing

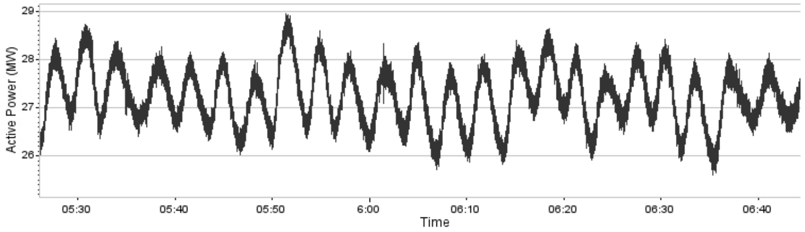


- Front end application continiously processing PMU data
  - Detection of oscillations
  - Characterization (Frequency, Damping, Mode shape)
  - Alarming and Alerting
- Results are updated every 5 seconds
- Reliable detection of oscillation with magnitude larger than white noise and frequency from 0.05Hz up to 4-7Hz.

High confidence level that all potentially dangerous oscillations within measurement frequency range are detected

Observed Oscillations: Statistics since 2013, >1200 events

Property	Description
Frequency	Typical range: 0.05 … 1.5 Hz; Some instances of 0.004 and 8 Hz
Damping	0 … 20 %
Magnitude	Up to 150 MW, peak-to-peak Majority of instances <10MW
Observability	Local and Wide-spread
Duration	From few seconds to hours



- Natural oscillations
  - Always well damped so far
- Forced Oscillations (FO)
  - **Almost 100% of observed sustained oscillations are FO originating from synchronous generators**
- IBR-based oscillations
  - Practically not detected yet at 10-13% generation from renewables
- 1-2 MW sustained oscillation with period 3-5 min observed in area with multiple wind farms

So far, FO is the major thread to ISO-NE power system

FO is the Thread to Power System

- Potential instability and uncontrolled cascading outages
- Undesirable mechanical vibration in system components.
  - Example: 2009 Disaster at 6400 MW Hydro Power Plant*

- Mitigation is necessary for reliable operation of bulk power system and the key step is finding the Source of FO

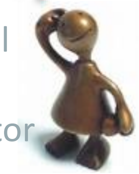
Source of FO = “Bad actor”

* https://www.powermag.com/investigating-the-sayano-shushenskaya-hydro-power-plant-disaster/

What Does it Mean "Find the Source"?

I see sustained oscillations!!

Control
Room
Operator



Is the Source located in my Control Area?

Yes

My problem, I have to solve it

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

Source: Area, Substation, Unit

Mitigation: Actions applied inside the Control Area

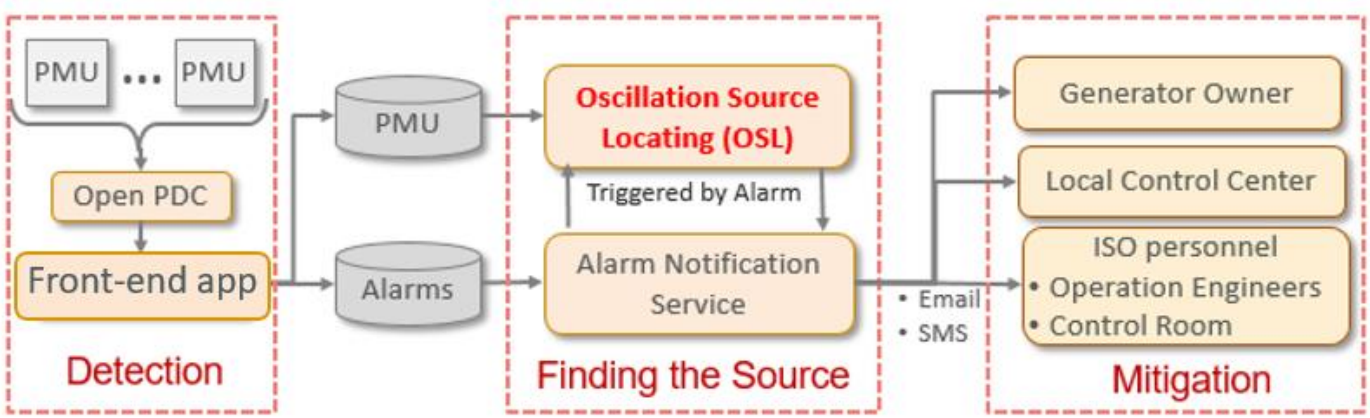
No

I cannot mitigate that oscillation

"Find the Source" means providing <u>actionable information</u> to the Operator

On-line Oscillation Management

- Objective
  - Detect significant oscillatory events and generate Alarms/Alerts.
  - Estimate the Source and deliver results to the designated personnel.

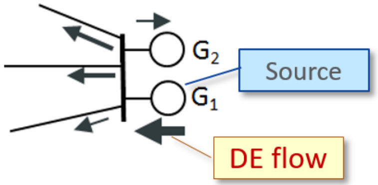


Fully automated 24/7 process, operational since September 2017

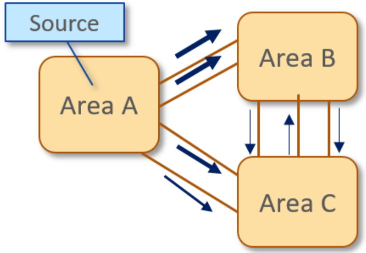
Oscillation Source Locating (OSL) Is the Key

- OSL calculates the flow of Dissipating Energy (DE) in any branch monitored by PMU
- Similar to regular MW, *DE* flows from Source to Sink
- Use cases of *DE* pattern:

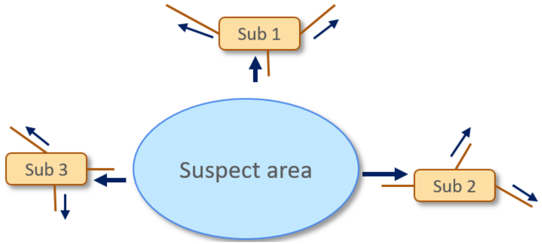
1. PMU at the Point Of Interconnection allows to trace specific power plant or generator



2. PMU in tie-lines between control areas allow to identify which area contains the source

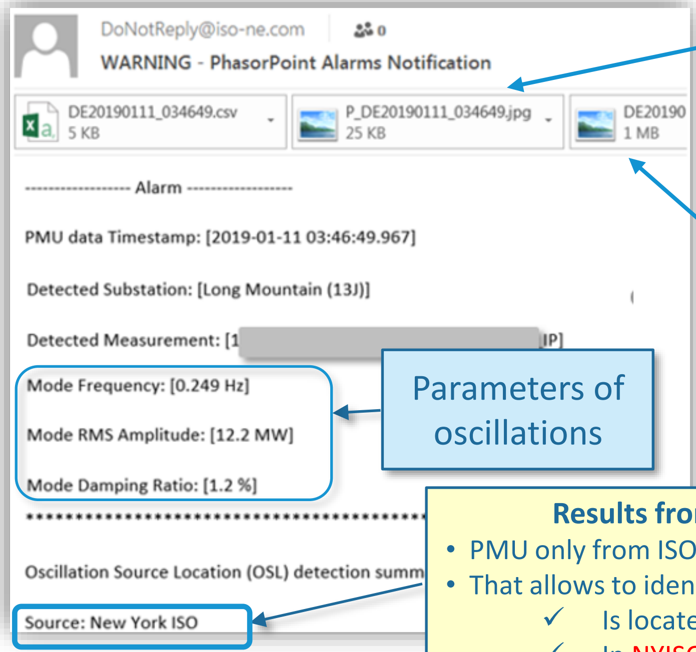


3. Even limited number of PMUs allows greatly localize the suspect area



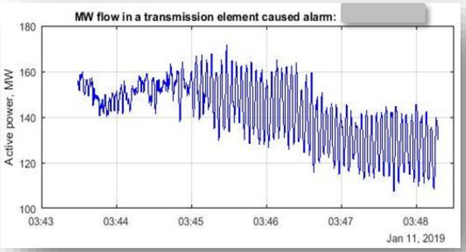
Example: January 11, 2019 Event

- Near-resonance conditions with inter-area mode around 0.25 Hz have caused the propagation of oscillation across the entire Eastern Interconnection



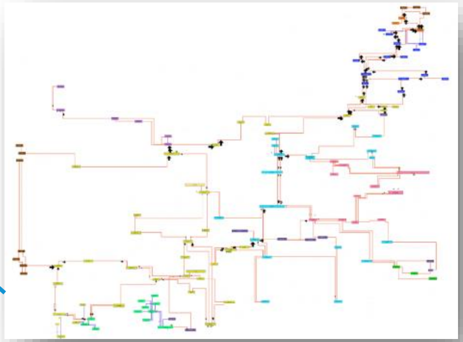
Parameters of oscillations

NYISO – ISO-NE tie line flow



- Email was sent in real-time, during the developing event
- Source is 1000+ miles away from ISO-NE

DE visualization on oneline diagram



Results from DE pattern

- PMU only from ISO-NE footprint are used
- That allows to identify that the Source:
  - ✓ Is located outside and
  - ✓ In NYISO direction

Dissipating Energy Pattern Recognition (DR-PR)

- A human makes the source identification by looking at DE pattern visualized on oneline diagram.
- A useful feature is an automatic Source identification based on DE pattern

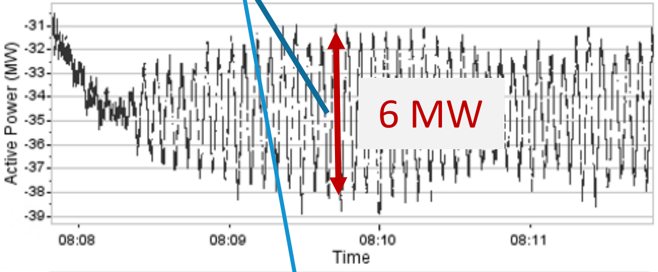
DE pattern: DE values for every PMU → DE-PR → Source:

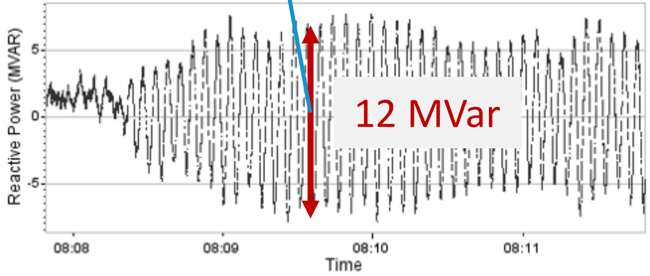
- Area
- Substation
- Unit ID

DR-PR greatly increases selectivity of Source identification for non-observable by PMU areas

DE-PR Example: 7/2/2023: 0.2Hz oscillation caused by excitation system

MVar magnitude 2x of MW



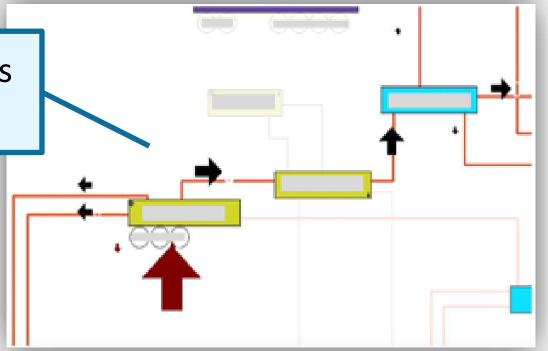


OSL Results

The source of oscillation is likely located in: **Voltage control loop**

Type of control loop with the Source

DE pattern traces the Source

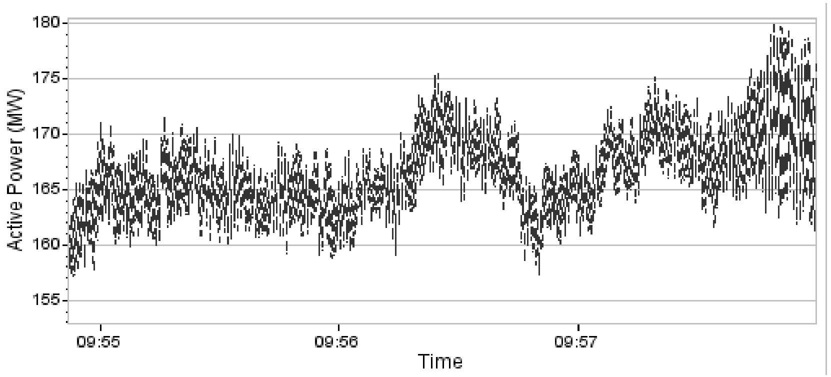


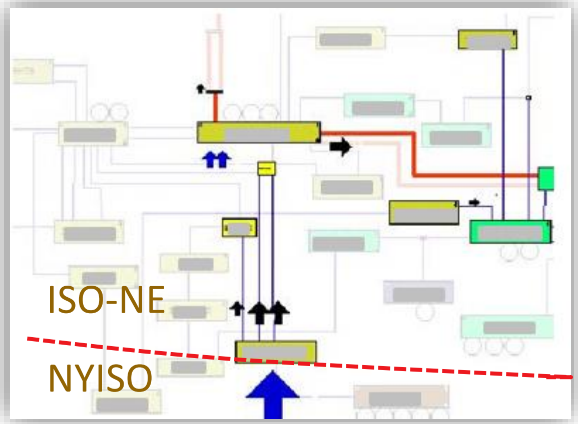
Source: Area=NEPEX (confidence=100%); Station= ; Unit=
Correlation between DE and DEtemplate with the highest rank is: 0.955

Specific unit is identified

DE-PR Example: Tracing the source outside of ISO-NE

- March 2024: multiple instances of ~1.2Hz oscillations originating outside of ISO-NE footprint





~~~ DE pattern recognition results
CDEF method: Source: Area=NYPP (confidence=100%); localized within substations: [redacted]

DR-PR allows to trace the source within non-observed by PMU area
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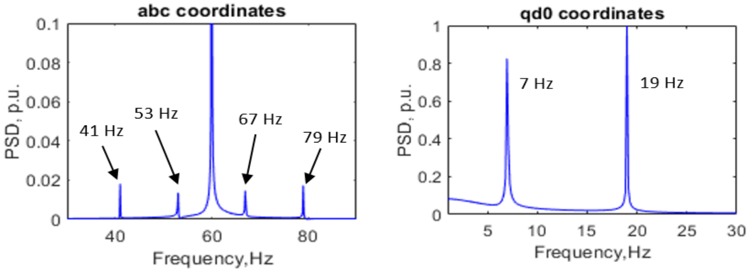
Statistics of Performance

- Since 2017, automatically processed 1200+ oscillatory Alerts and Alarms.
- Correctly identified the source (generator and area) for all instances of oscillations with known sources inside and outside of ISO-NE.

- **Satisfies today's operational needs for online detection of oscillations and efficient mitigation**
  - The process works in the background and automatically provides key analytical information for operations when it is needed without the need for human to monitor raw PMU data

Future Needs: Challenges Related to IBRs

- Emergence of sub- and super-synchronous oscillations (SSO) with frequencies > 2-4Hz
- Existing source locating methods could be insufficient
  - Strong control interaction could be challenging



- Lack of high-speed synchronized measurements to track SSO
  - Existing PMUs with 30 samples/s rate are good for < 4-8 Hz

Which IBR is “bad actor”?

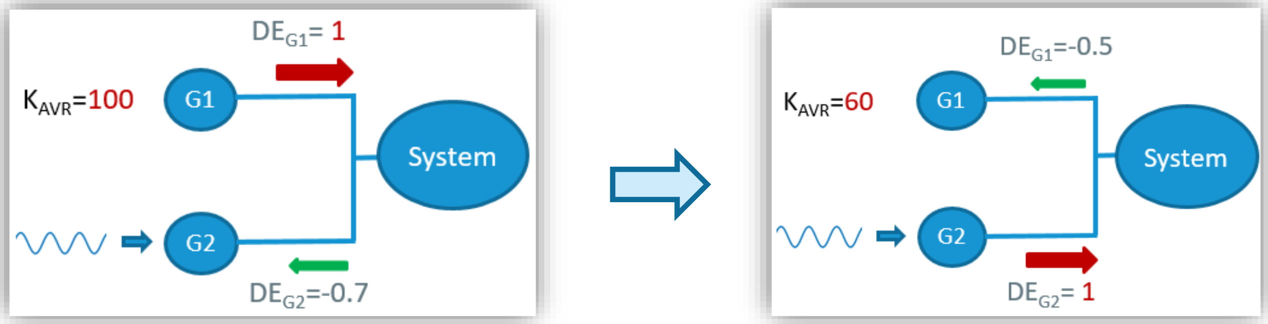
- Need to find specific IBR negatively contributing to the damping of SSO in simulation environment and in actual operation
  - The main focus on natural oscillations, but FO will still exist

Type of oscillation	The Source is…	Mitigation
Forced	“Bad actor”	Remove “bad actor”
Natural without strong control interaction	“Bad actor”	Modify “ bad actor” parameters or remove it
Natural with strong control interaction	Within interacting units	**Is the most contributing unit best for mitigation?**

More research is needed

Control interaction: “Bad actor” and Efficient Mitigation

- G2 contains periodic injection of energy into the Excitation (Actual Source of FO) and AVR of G1 produces negative damping as a reaction to oscillation (Larger Contributor)
  - G1 is deemed as the Source (Source of DE = Negative contributor to damping)
- Mitigation
  - Step 1: Reduce AVR gain at G1 → Now, G2 is identified as the Source
  - Step 2: eliminate the Source



“Largest contributor to negative damping” = “Best for mitigation” ??

Questions?

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