2018-10-23 | PHILADELPHIA, PA

Success Story: Practical Use of Synchrophasor Technology in ISO-NE Operations

NASPI Work Group Meeting

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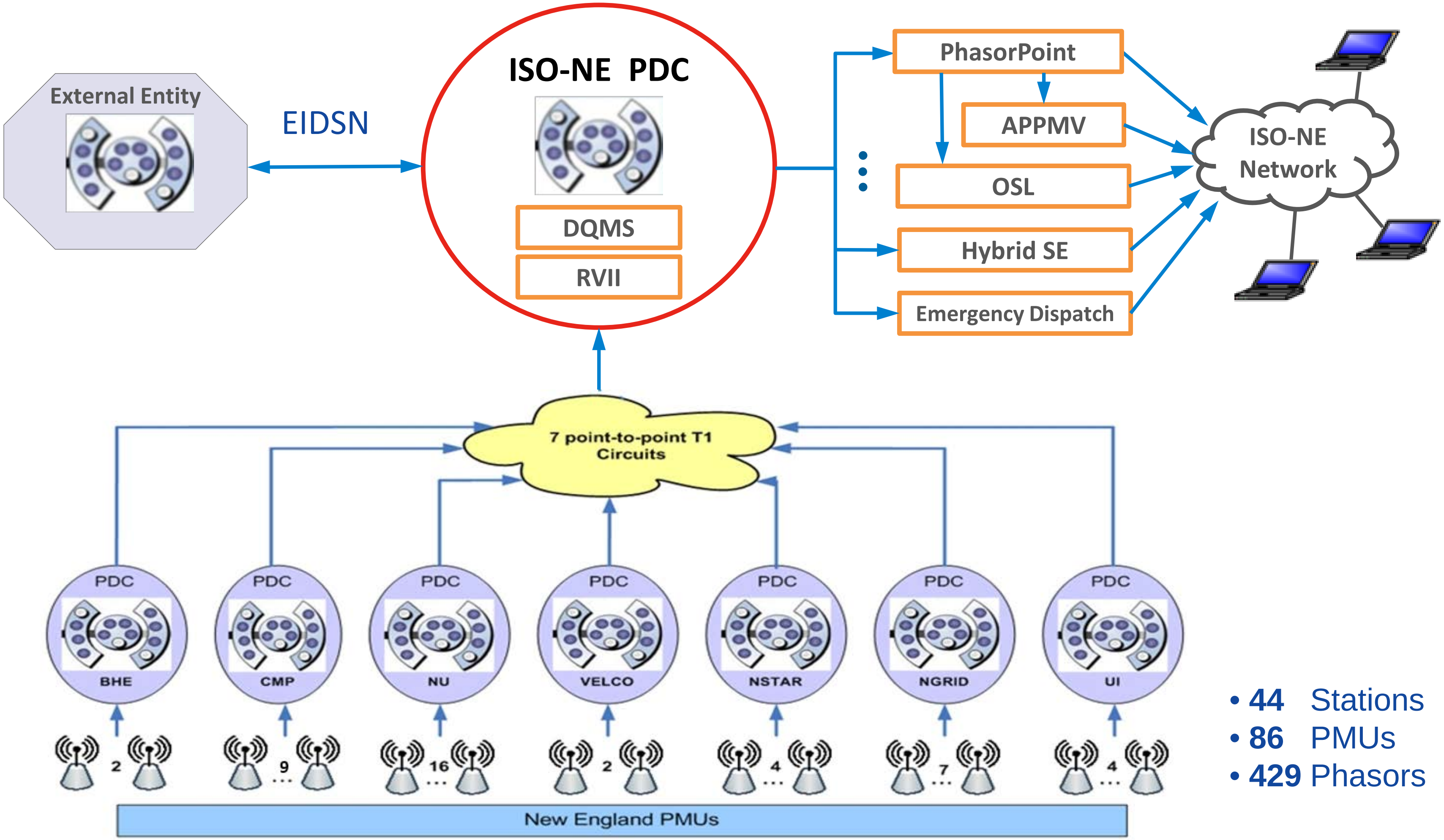
BUSINESS ARCHITECTURE AND TECHNOLOGY

Outline

- New England Synchrophasor Infrastructure
- Online Oscillation Management
- Automated Power Plant Model Verification (APPMV)
- Synchrophasor-based Emergency Dispatch

New England PMU Infrastructure

- NYISO
- PJM
- MISO



- **44** Stations
- **86** PMUs
- **429** Phasors

New England Synchrophasor System (Cont.)

- Approved Operating Procedure 22 changes (effective Dec. 2017) to require new PMU installations by Transmission Owner (TO):
  - Point of Interconnection (POI) with generation interconnections above 100 MW, both new and existing generating units
  - All new TO 345 kV stations, or new elements at existing 345 kV stations
  - Other TO locations as designated by ISO, mainly for IROL and SOL monitoring
- OP 22 changes will double the existing number of PMUs in the next five years.

Online Oscillation Management

Observed Oscillations

Characteristics of detected oscillations; statistics since 2012

Property	Description
Frequency	0.05, … , 2.0 Hz
Damping	0, … ,10 %
Magnitude	2, … ,70 MW, RMS
Observability	Local and wide-spread
Duration	From few seconds to hours

Number of oscillatory Alerts and Alarms

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

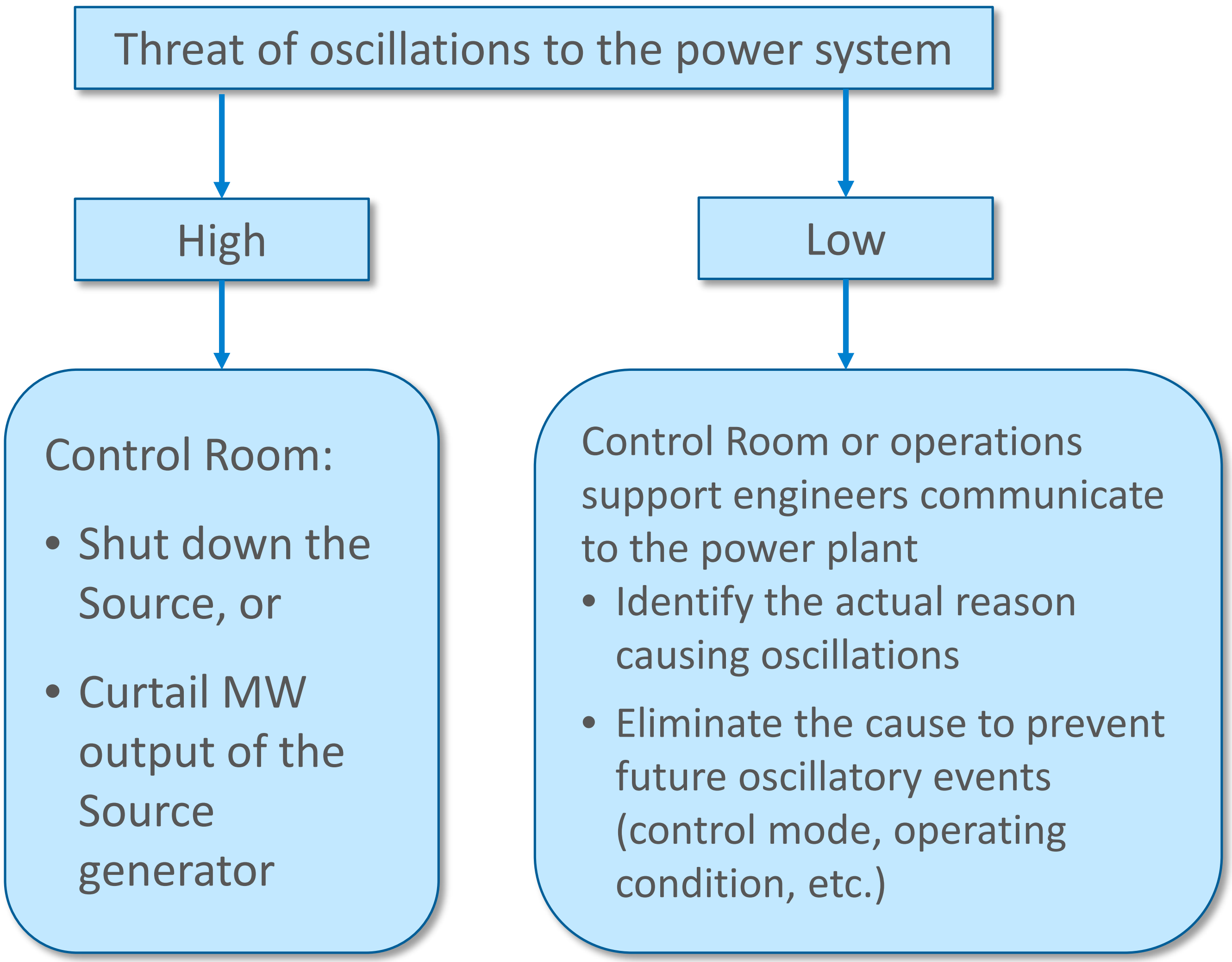
Majority oscillation events are Forced Oscillations

Why do we need to mitigate oscillations?

- The sustained oscillations can cause
  - Potential uncontrolled cascading outages
  - Undesirable mechanical vibrations in system components
- The key step in the mitigating of sustained oscillations is to find the Source of oscillations, typically a generator.
- The capability to find the Source ONLINE means providing the Operations with actionable information

Sending oscillatory Alarm to the system operators without actionable information is not useful

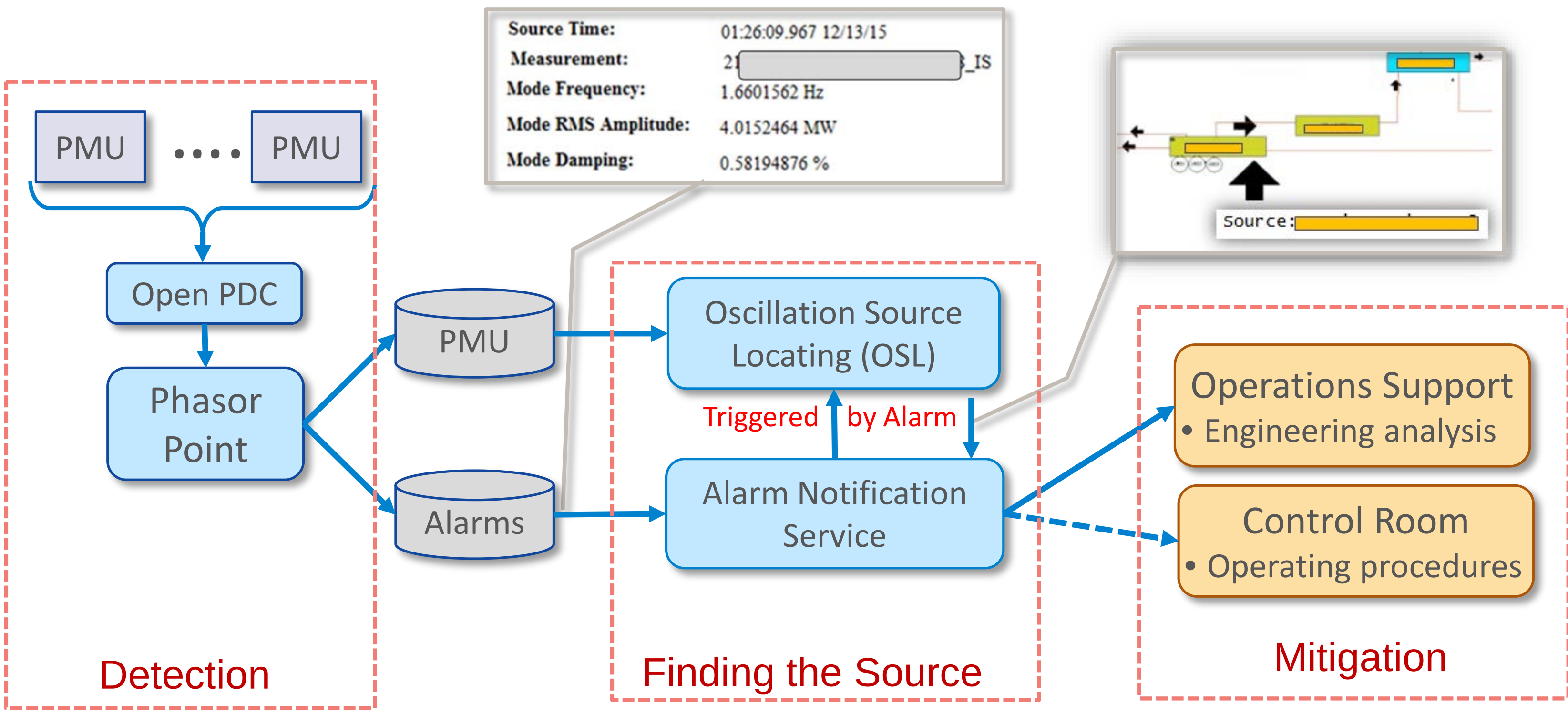
Mitigation of Oscillations



ISO-NE's Online Oscillation Management

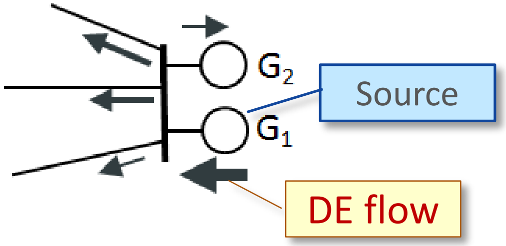
Objectives:

- Detect all significant oscillatory events and provide alarms/alerts
- Estimate the Source of oscillations and deliver results to operations
- Fully automated process

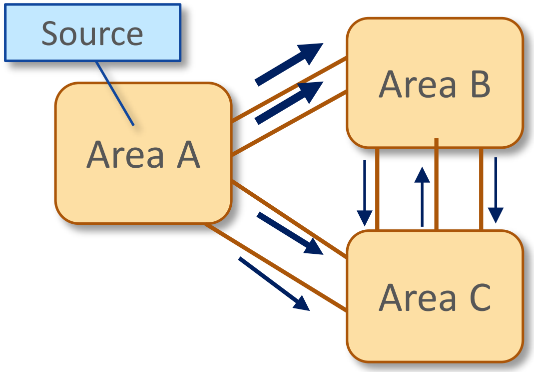


Interpretation of Dissipating Energy Flow (DEF) Patterns from OSL

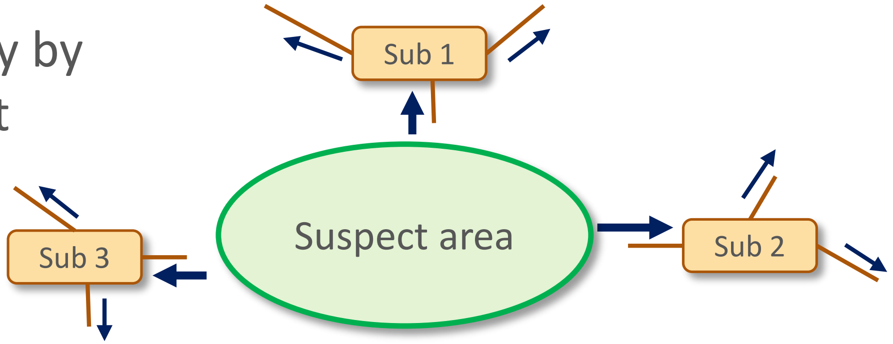
- PMU measurements at the Point Of Interconnection (POI) allow to trace specific power plant or generator



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



- Even limited system observability by PMUs allows localize the suspect area



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

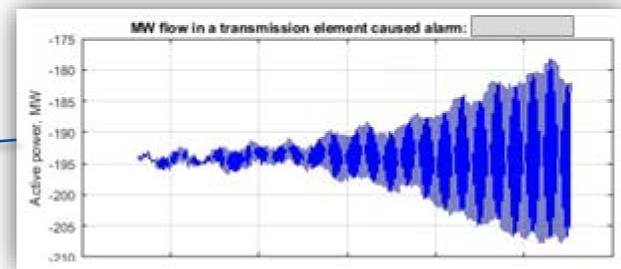
PMU data can be used for the DEF method

No tripping was detected

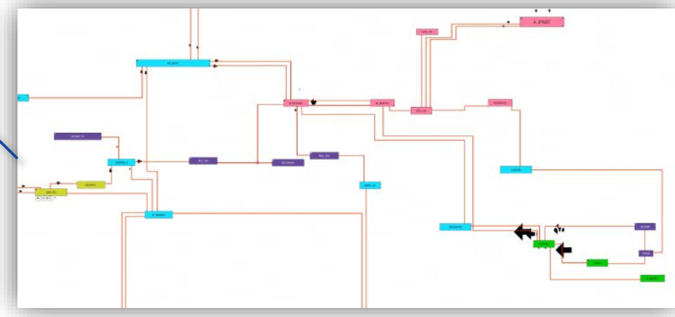
Parameters of oscillations

Results of DE pattern recognition

MW flow in line causing Alarm



DE visualization



DE pattern and identified source

2017-

0.610

Source

Sufficient time interval for the DEF method

PMU data can be used for the DEF method

No tripping was detected

-1.0000,

-0.5896,

0.3858,34

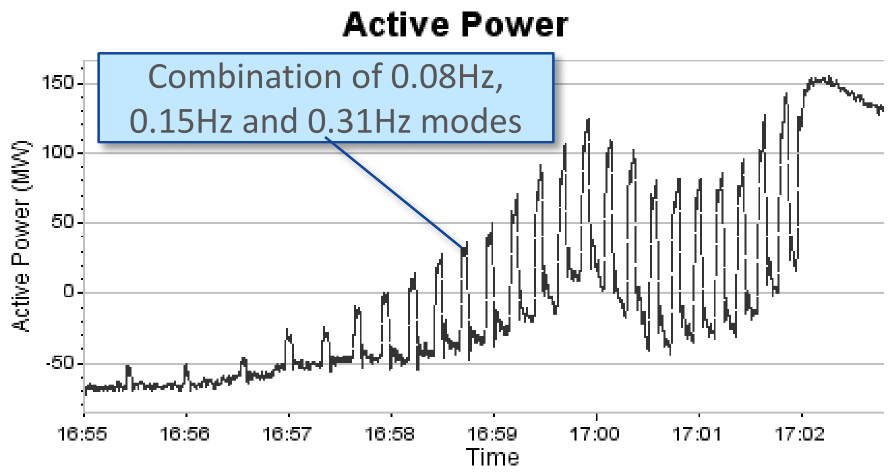
-0.3197,

0.2746,33

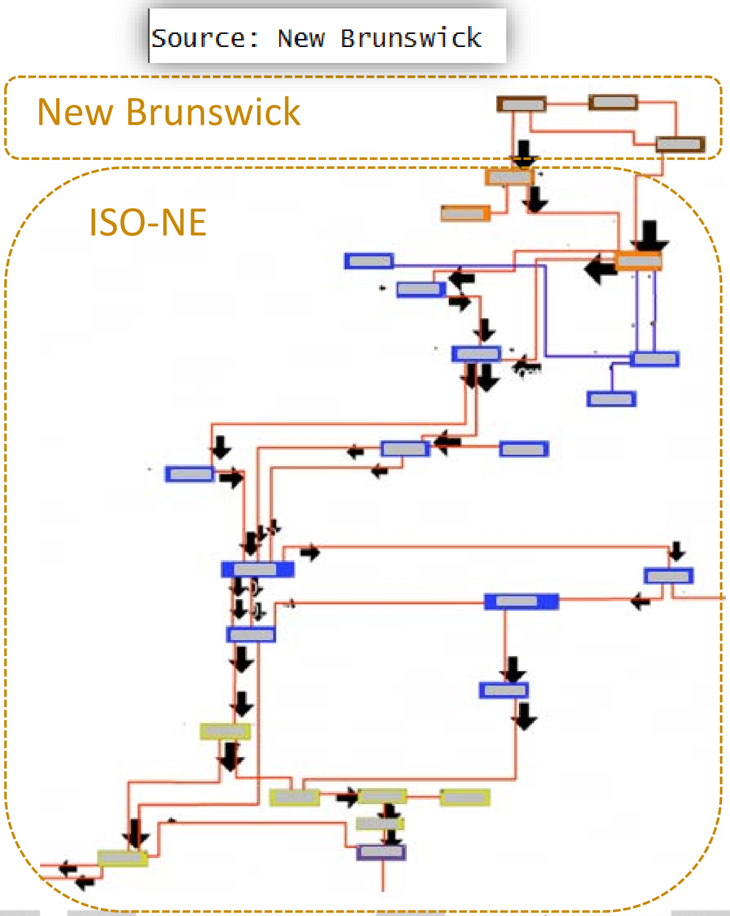
0.2544,35

FO Originated from New Brunswick (Canada)

- October 3, 2017: a problem with a large New Brunswick generator's governor caused multi-frequency oscillations up to RMS=70 MW and alarms in ISO-NE.



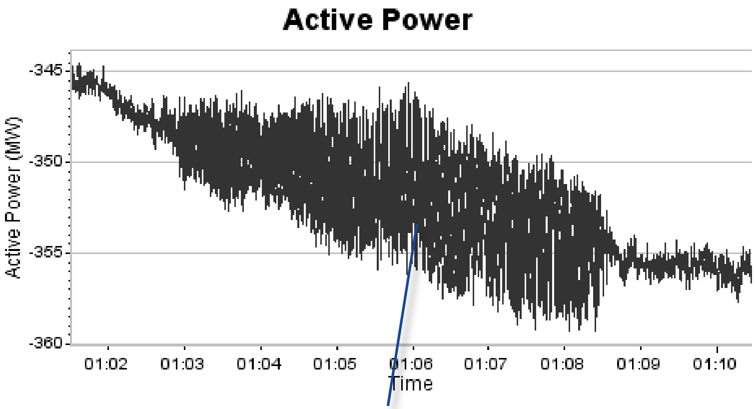
Results of the OSL for 0.08Hz mode



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

FO Caused by ISO-NE generator

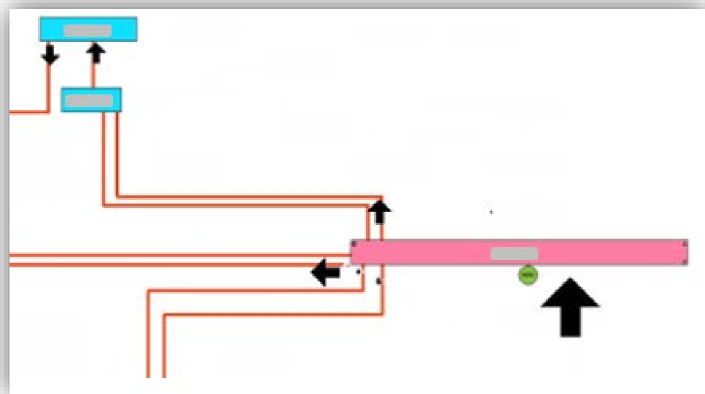
- February 6, 2018: a large ISO-NE generator created multi-frequency oscillations with magnitude RMS=3MW during 5 min



Combination of 0.60Hz and 0.86Hz modes

Results of the OSL for 0.6Hz mode

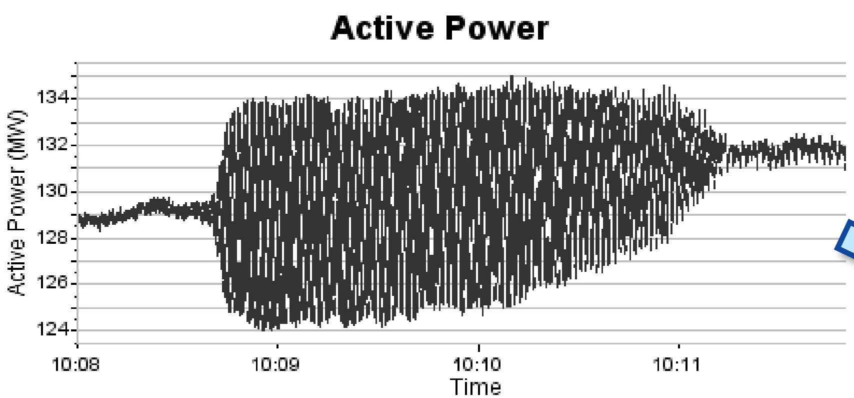
Source: , unit



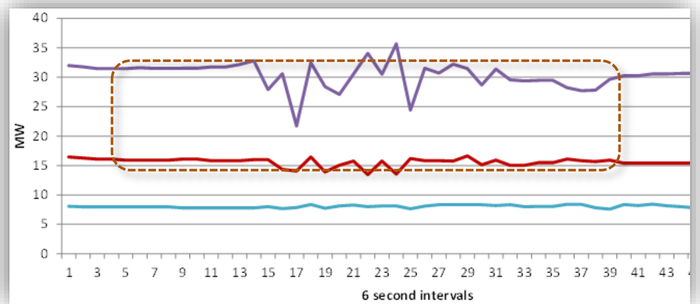
This example illustrates the ability to identify an individual generator if it is monitored by PMU

FO Coming From Non-Observable Area

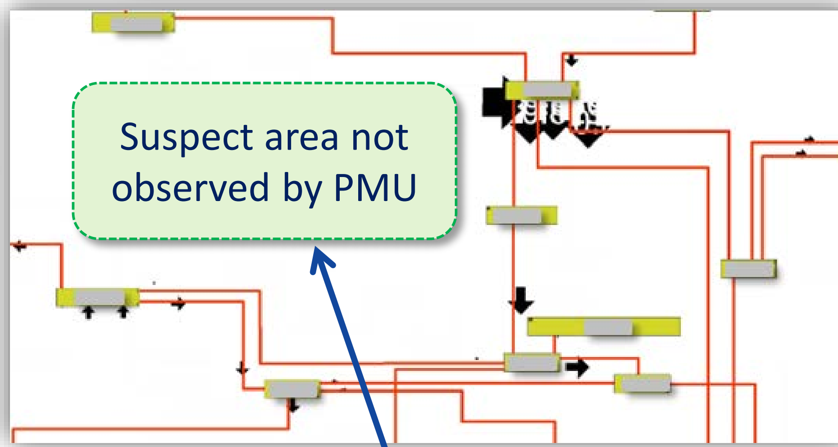
- December 7, 2017: 1.3 Hz oscillations with RMS=5MW magnitude coming from the ISO-NE area not observed by PMUs



SCADA data for 3 suspect generators



Source is not identified



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

This example illustrates the ability to localize the suspect area not observable by PMU

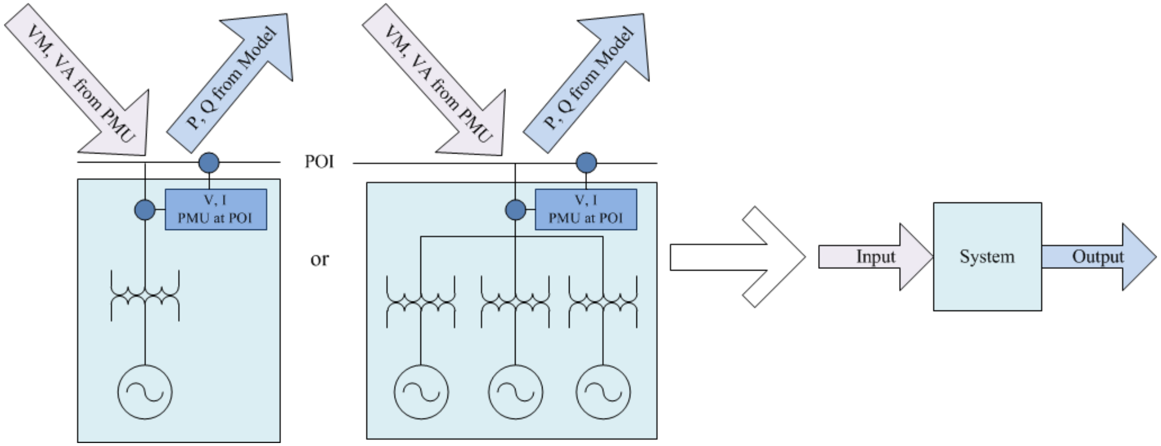
Statistics of online OSL since September 2017

- Automatically processed 1100+ oscillatory Alerts and Alarms generated by PhasorPoint application
- Correctly identified the source for all oscillations within the ISO-NE
- Verified three oscillatory events caused by known sources located outside of the ISO-NE
- Each RC, if having an OSL like tool, would allow an interconnection wide coordinated oscillation management

Automated Power Plant Model Verification (APPMV)

Power Plant Model Verification (PPMV)

- PPMV is a mature technology, and implemented in several commercial software products: TSAT, PowerWorld, PSS/E, PSLF, EPRI, PNNL
- Major challenges with PPMV: time and effort
  - Manual process
  - One at a time
  - 1 to 2 hours



Automated Power Plant Model Verification (APPMV)

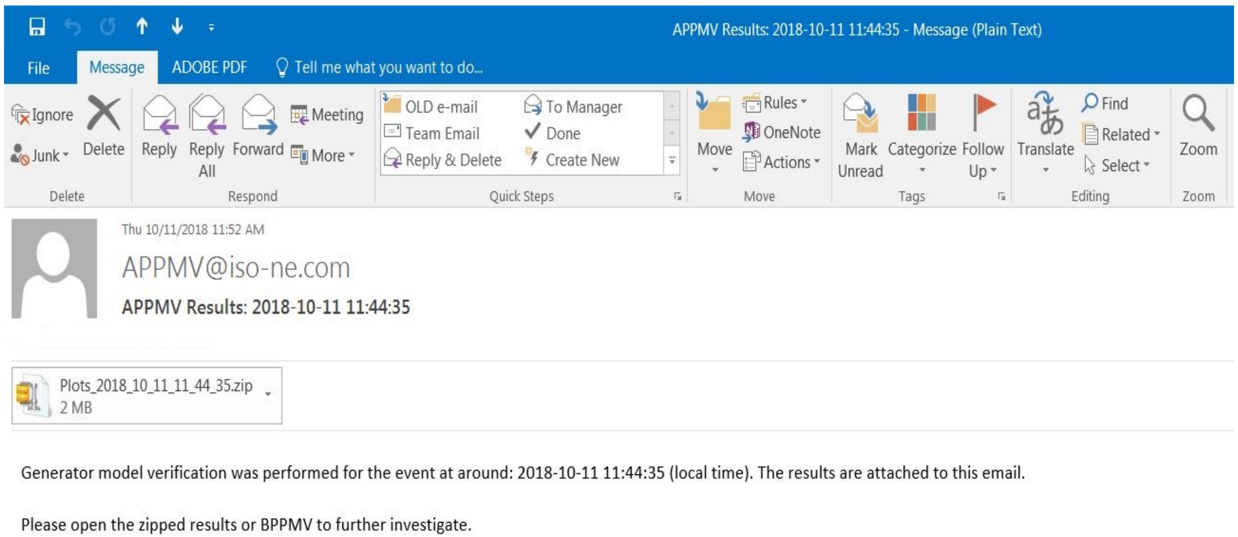
Online automated service, runs 24 by 7

Gets event trigger from PhasorPoint → Verifies the event → Performs model verification → Sends out results in email

- Automatically retrieves PMU from PhasorPoint and SCADA data from PI
- Runs model verification for ALL on-line generators monitored by PMUs
- Generates comparison plots between simulation and PMU measurements
- Generates Key Performance Indices (KPI)
    - Initial value, first swing peak value and time, settling value
    - Oscillation frequency, damping ratio, and phase shift

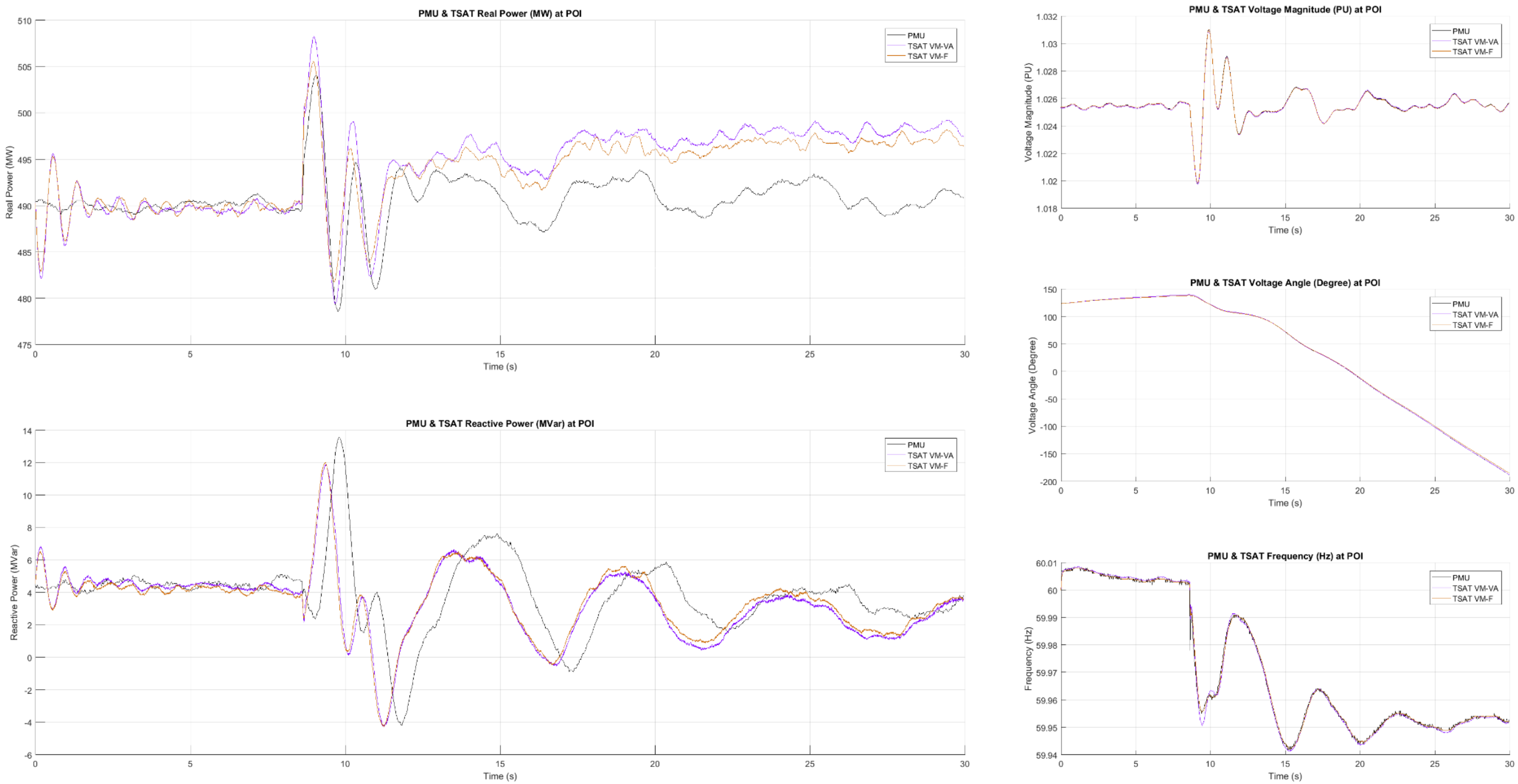
APPMV Results

- Email with PPMV results attached
  - Only from sizable events and online generators

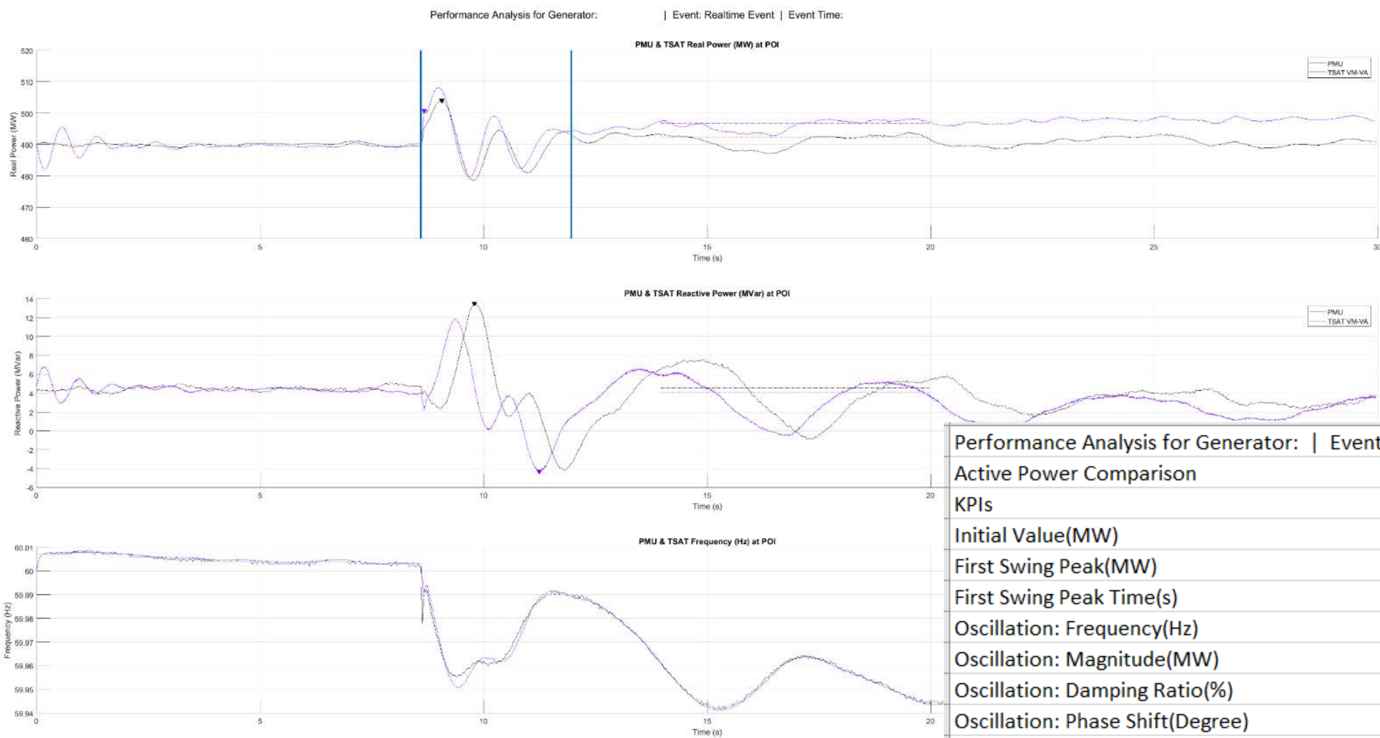


APPMV Results, continued

PMU and Playback Comparison for Generator: | Event: Realtime Event | Event Time:



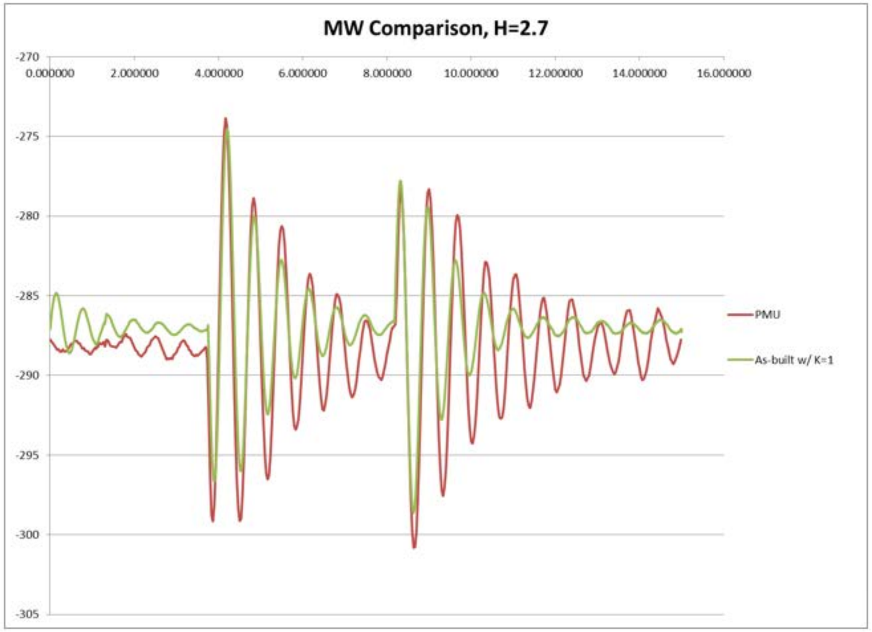
APPMV Results, continued

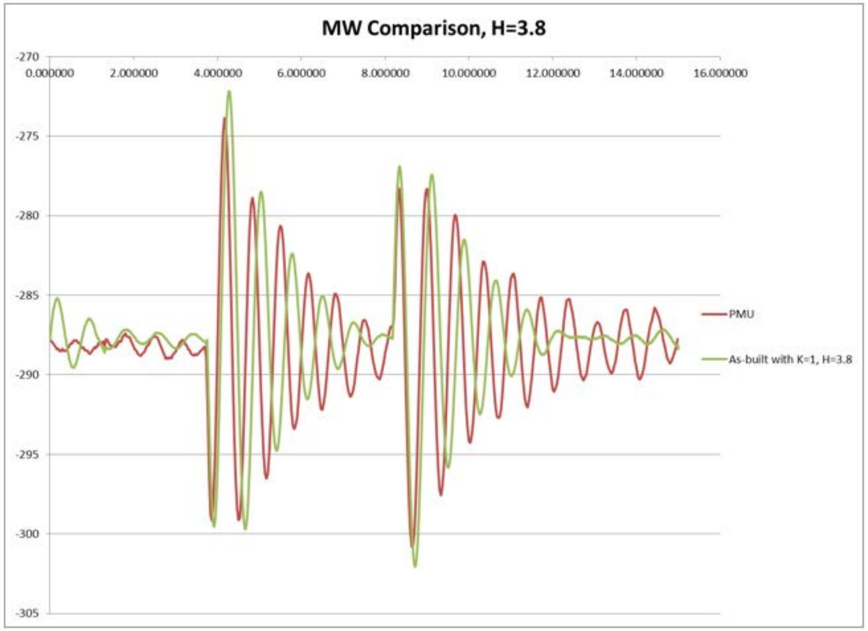


Performance Analysis for Generator: | Event: Realtime Event | Event Time:			
Active Power Comparison			
KPIs	PMU	TSAT VM-VA	Difference
Initial Value(MW)	490.3	489.7	-0.7
First Swing Peak(MW)	504.1	500.8	-3.2
First Swing Peak Time(s)	9.1	8.7	-0.4
Oscillation: Frequency(Hz)	0.7	0.7	0
Oscillation: Magnitude(MW)	7.2	6.7	-0.5
Oscillation: Damping Ratio(%)	3.5	5.1	1.6
Oscillation: Phase Shift(Degree)	0	-15.5	-15.5
Settling Value(MW)	492.2	496.9	4.6
Reactive Power Comparison			
KPIs	PMU	TSAT VM-VA	Difference
InitialValue(MVar)	4.4	4.2	-0.2
Peak(MVar)	13.6	-4.3	-17.9
Peak Time(s)	9.8	11.2	1.4
Settling Value(MVar)	4.6	4.1	-0.5
PMU frequency agrees with VA calculated frequency?	No.		

Use APPMV to Verify Inertia H

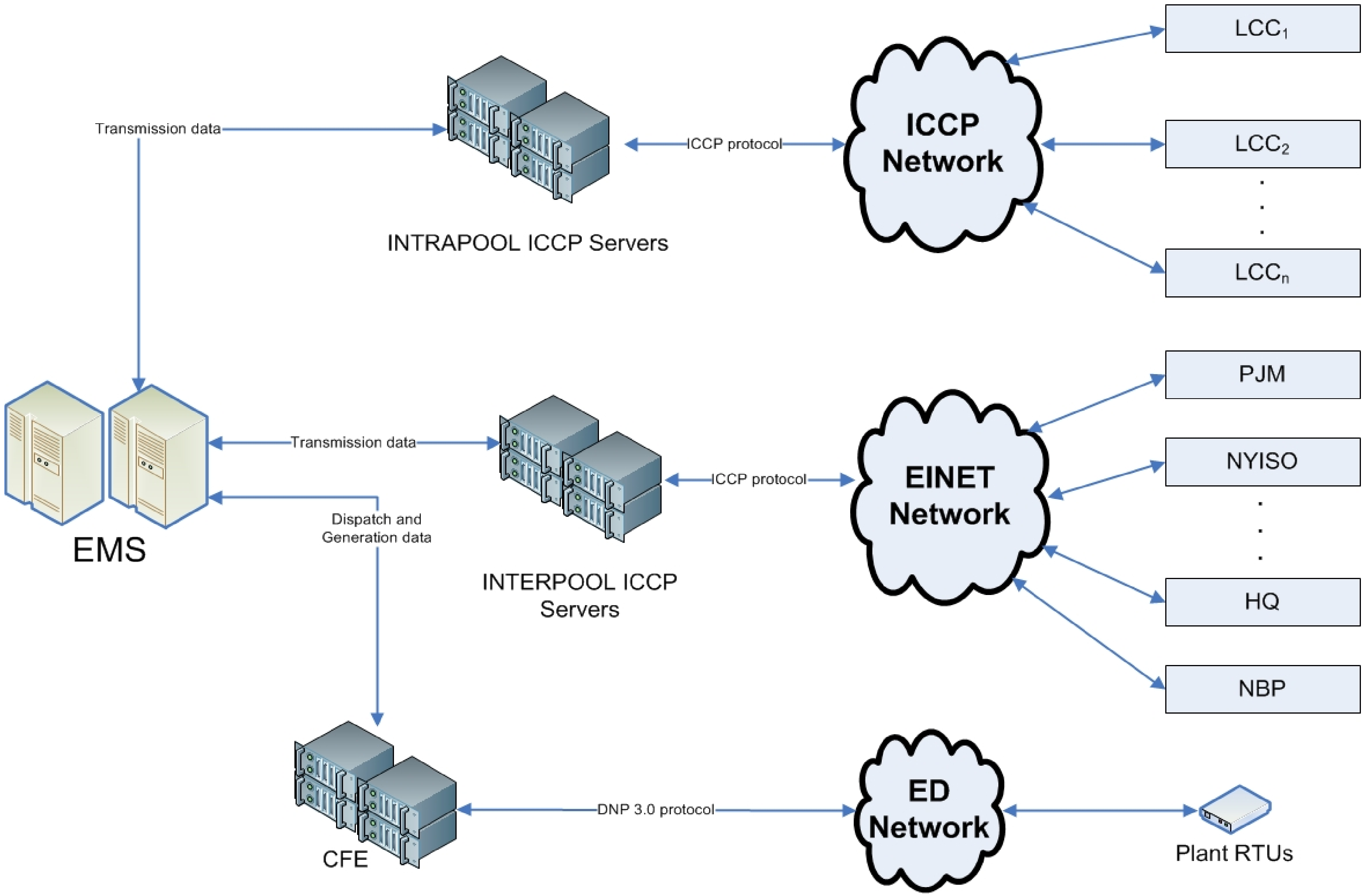
- A hydro unit was uprated with a full re-wind of the machine
- Question as to the validity of the inertia constant H = 2.7 or 3.8
- 13 events were used by APPMV to compare and verify





Synchrophasor-based Emergency Dispatch

Typical EMS Communication Network



Synchrophasor Infrastructure as a Backup for SCADA/EMS Failure

- ISO-NE's current practice - dispatch generators manually to maintain ACE
- The synchrophasor infrastructure is independent from the SCADA/EMS system
- Ideal as a backup for emergency monitoring and control when there is a complete loss of SCADA/EMS

Synchrophasor-based Automatic Generation Control (AGC)

- *Area Control Error (ACE)* is an indicator of a BA to meet its obligation to continuously balance its generation and interchange schedule with its load

$$ACE_p = \left(P_{tie}^{schedule} - P_{tie(p)}\right) + 10B\left(f_{area}^{schedule} - f_{area\ (p)}\right)$$

$P_{tie}^{schedule}$ - Scheduled net interchange

$P_{tie(p)}$ - PMU measured actual net interchange

$f_{area}^{schedule}$ - Scheduled system frequency (60 Hz)

$f_{area\ (p)}$ - PMU measured weight-averaged frequency

B - Frequency bias setting (MW/0.1 Hz)

- AGC: dead band, PI controller, low pass filter, AGC setpoint

Synchrophasor-based Emergency Generation Dispatch

$$\min \sum c_i \Delta P_i$$

Minimize PMU monitored unit re-dispatch cost

$$s.t. \quad \sum \Delta P_i = \Delta L(T) - ACE_{control}$$

Power balance equation

$$\left| \frac{\Delta P_i}{R_i} \right| \leq T$$

Ramp rate constraints

$$P_{min} \leq P_i^0 + \Delta P_i \leq P_{max}$$

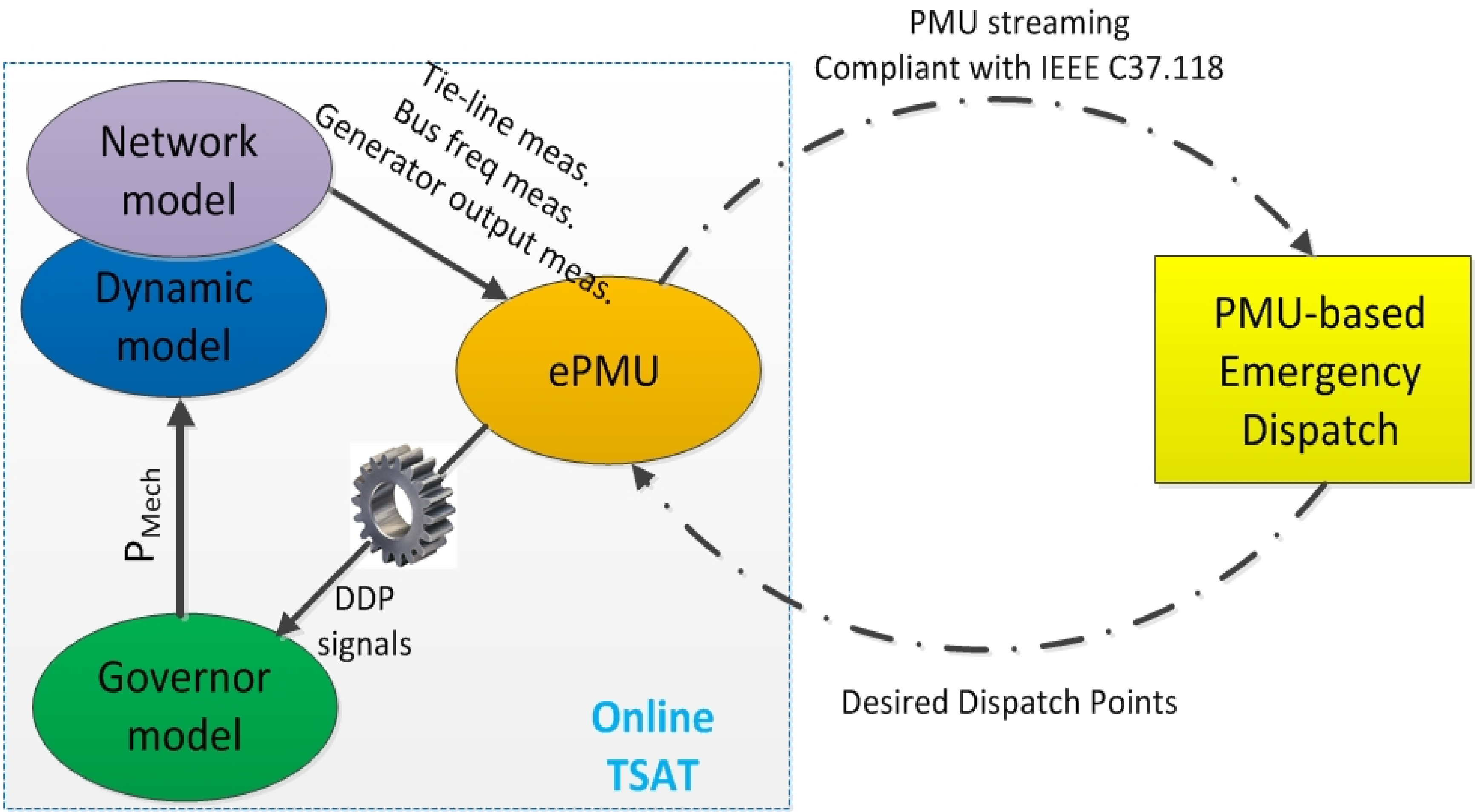
Unit capacity constraints

i -- PMU monitored generators
c_i -- generator incremental cost
ΔP_i -- generator delta dispatch amount
P_i^0 -- generator output
T -- dispatch look ahead time (5 minutes)
R_i -- generation ramp rate
ΔL -- short term forecasted load change
P_{min} P_{max} -- generator economic minimum and maximum operating limits

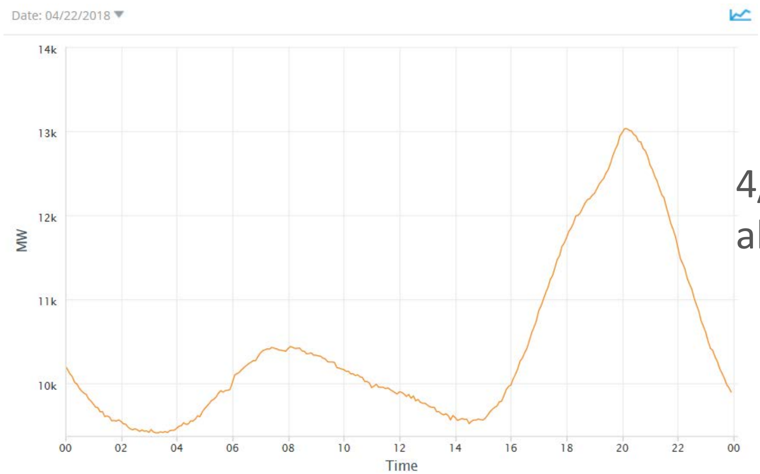
Synchrophasor-based Emergency Operation

	ED network is available	ED network is unavailable
Automatic Generation Control (AGC)	Yes (every 4 seconds)	No
Emergency Dispatch	Yes, automatic (every 5 or 10 minutes to only PMU monitored units)	Yes, verbal manual (every 5 or 10 minutes to only PMU monitored units)

Close-loop Simulation Platform

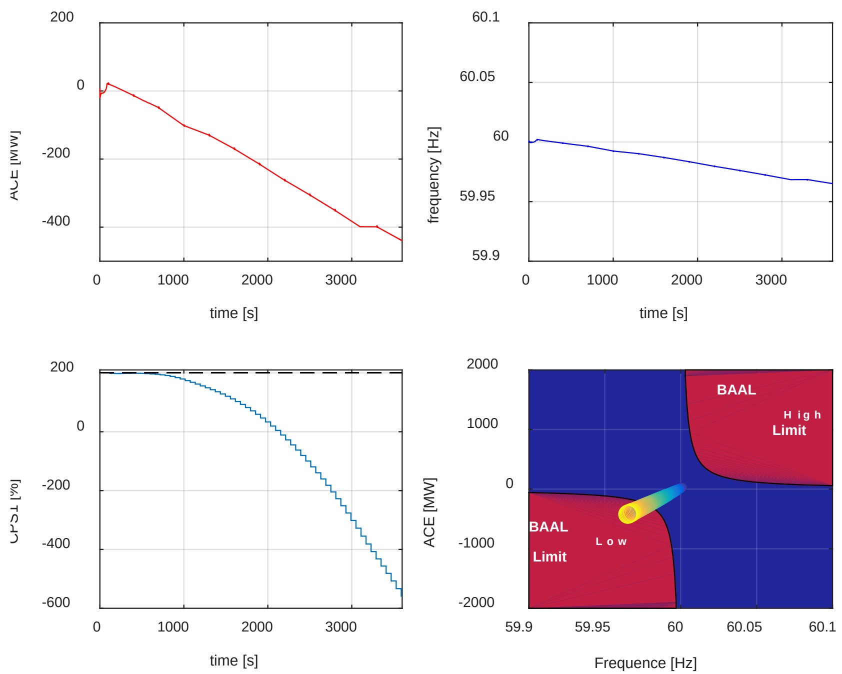


Test Case

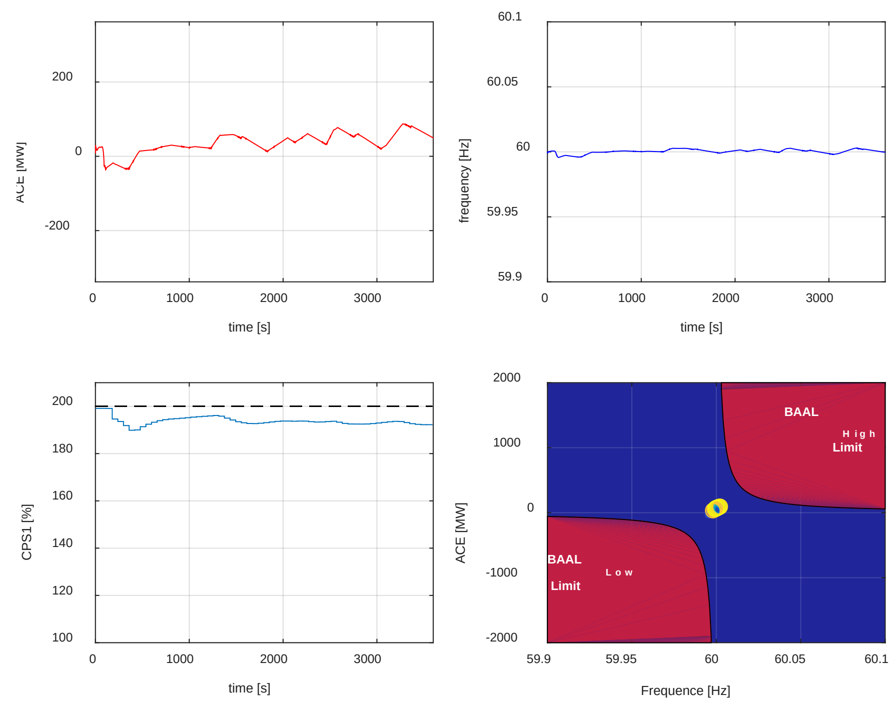


4/22/2018, 16:00 hr. – 17:00 hr., about 900 MW increase

Without PMU-based Emergency Dispatch



With PMU-based Emergency Dispatch



Conclusions

- Three in-house developed synchrophasor applications
  - Oscillation Source Location (OSL)
  - Automated Power Plant Model Verification (APPMV)
  - Synchrophasor-based Emergency Dispatch
- ISO-NE has shared OSL and APPMV with external entities for free with certain legal disclaimer
- Operational use of synchrohasor technology is mainly by Operations Support Services, with visualization displays in control room for situational awareness
- ISO-NE has high quality of PMU data to ensure the successful deployment and use of these applications

Questions