NASPI, NOVEMBER 3-5, 2020

Practical Use of Synchrophasor Technology in New England

Xiaochuan Luo

Slava Maslennikov

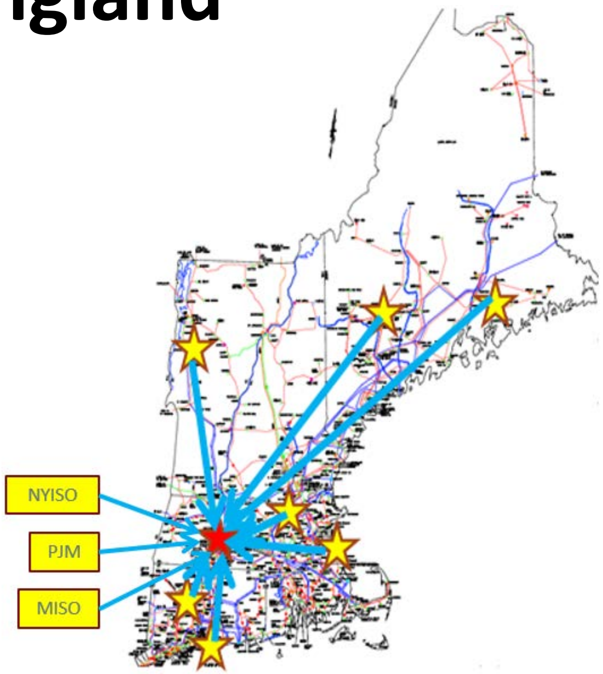
Frankie Zhang

Song Zhang

THE LATE Eugene Litvinov

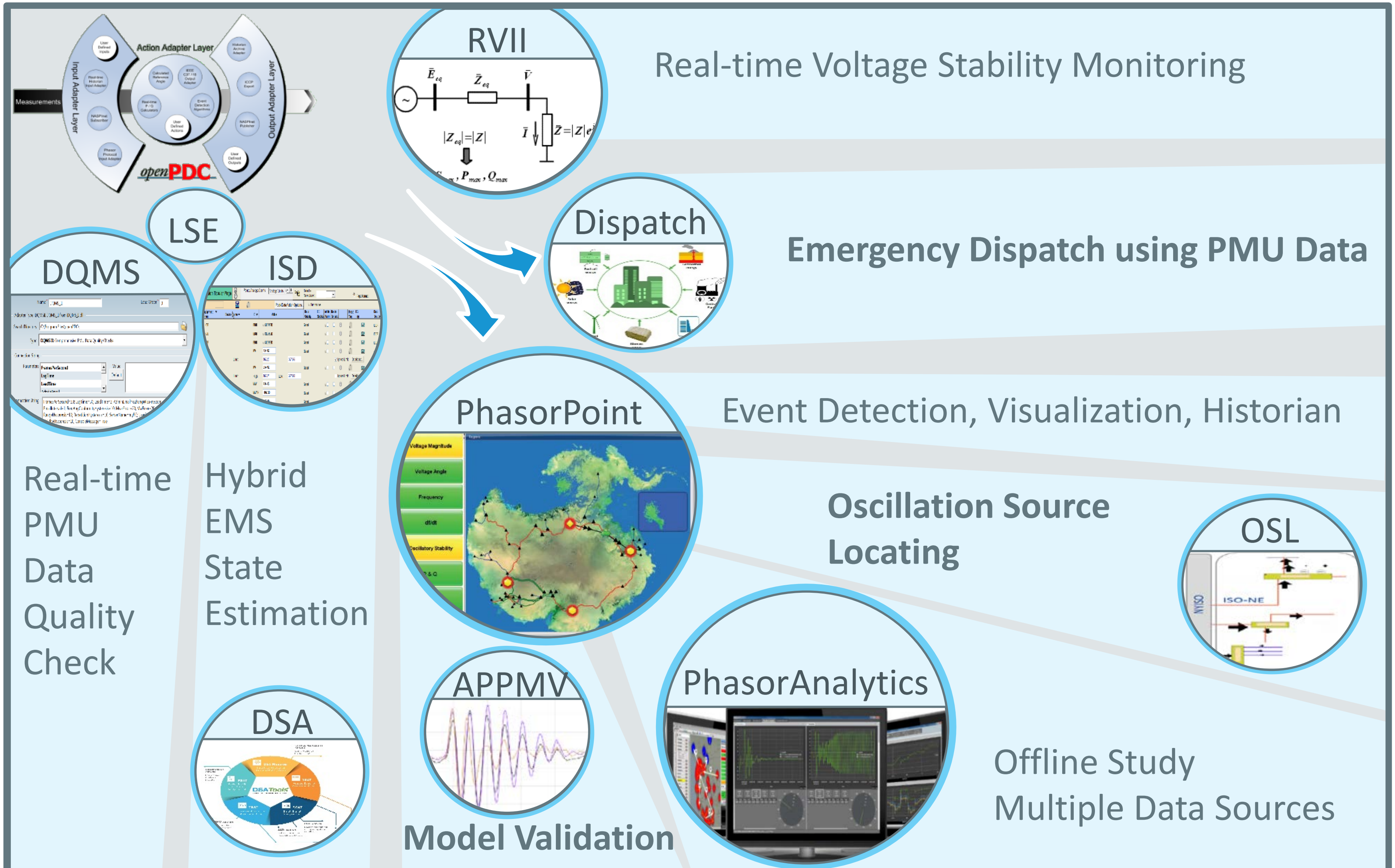
PMU Infrastructure at ISO New England

- Operational since 2012
- Full observability of 345 kV network
- Selected PMU data from NYISO, PJM and MISO
- December 2017: change in Operating Procedure 22 (OP-22) requiring new PMUs
  - ✓All new 345 kV stations
  - ✓Point Of Interconnection (POI) for all new & existing generators 100 MVA and above



Stage	Source PDC	Station	PMU	Storage Length	Storage Size
1: DOE SGIG (2009 – 2012)	7	45	73	3 years	20 TB
2: External Data (2017 – present)	10	121	227	3 years	40 TB
3: OP-22 Change (2017 – 2024)	10	~177	~300	3 years	60 TB

Synchrophasor Applications



OSCILLATION SOURCE LOCATING (OSL)

Why we are concerned?

- Since 2012, 1000+ oscillatory events were observed
  - ✓ Majority of these have small magnitude 5-10 MW peak-to-peak, but few events had large magnitude > 100 MW
- Sustained oscillations (forced and poorly damped natural) can cause
  - ✓ At large magnitude : Potential uncontrolled cascading outages
  - ✓ For all magnitudes: Undesirable mechanical vibrations in system components

Catastrophic consequences of hydro-generator rotor's vibration at the Sayano–Shushenskaya power plant in 2009*

Before and after photos of the plant turbine gallery

- ✓ 75 people died
- ✓ Large blackout
- ✓ 6400 MW power plant out of service for 3 years

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

Objective

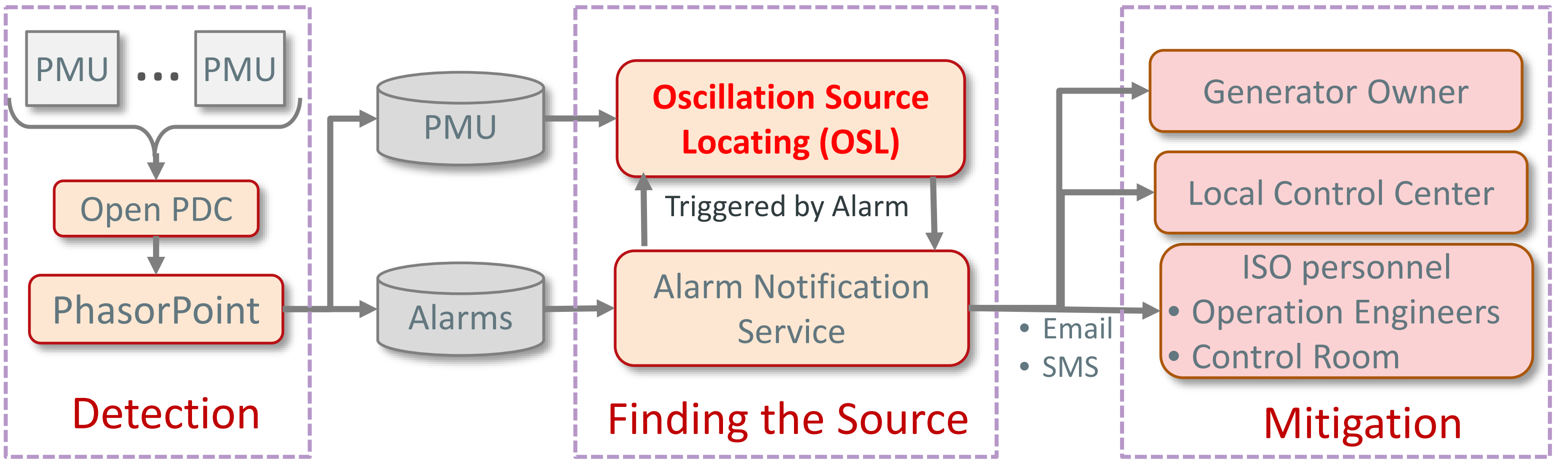
- Need to constantly monitor the power system for the presence of sustained oscillations and promptly mitigate them
- The vast majority of observed oscillations are Forced Oscillations (FO) originating from generators and caused by
  - ✓ Failure of equipment or control systems
  - ✓ Abnormal operating conditions
- The most efficient mitigation of FO is to find the source and apply an action to eliminate the primary forcing signal
  - ✓ A number of actions available depending on situation
- The key actionable information for mitigation is finding the source of oscillation

> "Source of oscillation" for ISO is a reasonable minimal part of power system (generator, power plant, load, substation, area) containing a physical source of FO and allowing to apply mitigation actions

Online Oscillations Management

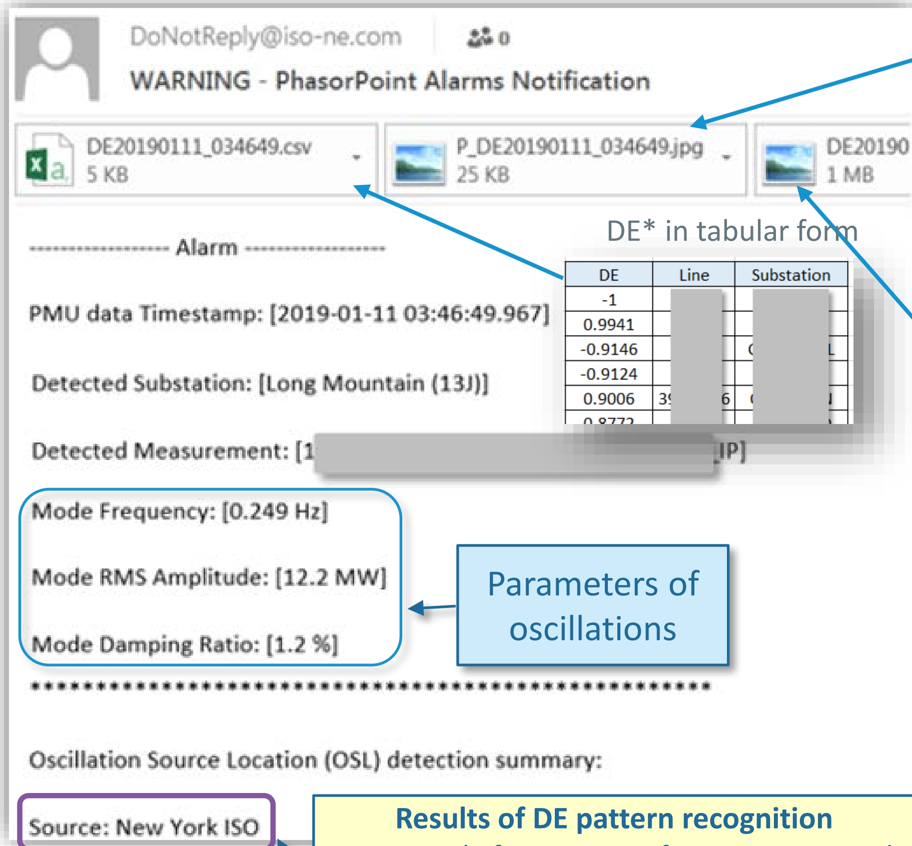
Objective

- Detect all significant oscillatory events and generate Alarms/Alerts
- Estimate the Source of oscillations for every oscillatory Alarm (and Alert) generated by PhasorPoint (GE product) and deliver results to the designated personnel
- Fully automated process, operational since September 2017

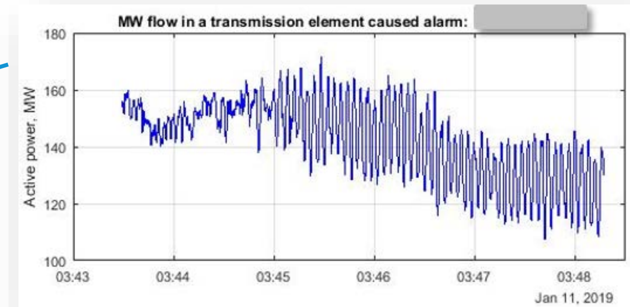


The content of E-mail with OSL results

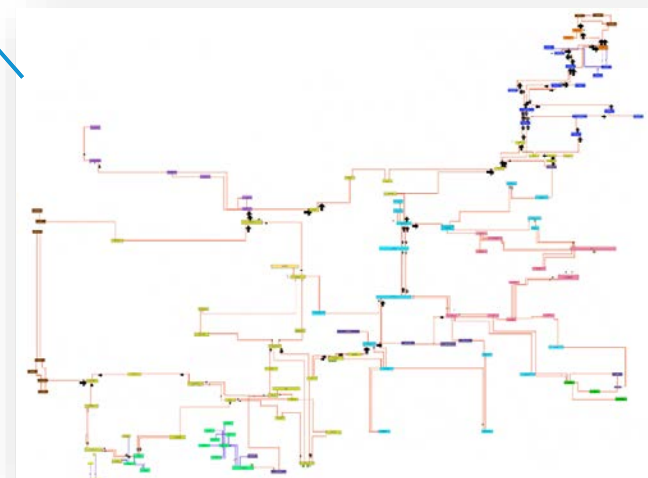
- Example of January 11, 2019 event. Email was sent in real-time, during the developing event.



DE	Line	Substation
-1	[redacted]	[redacted]
0.9941	[redacted]	[redacted]
-0.9146	[redacted]	[redacted]
-0.9124	[redacted]	[redacted]
0.9006	[redacted]	[redacted]
0.8772	[redacted]	[redacted]



DE* visualization on oneline diagram



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

* Dissipating Energy (DE)

Statistics of the OSL performance

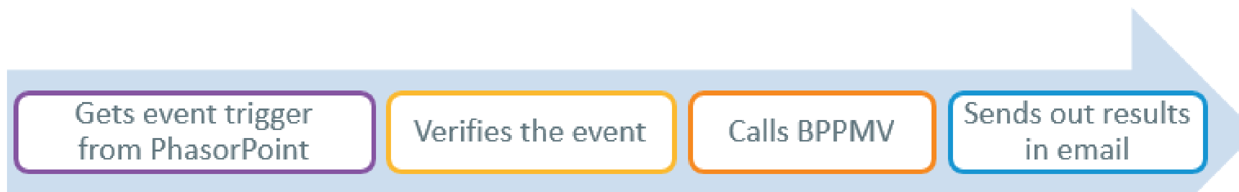
- Automatically processed 1200+ oscillatory Alerts and Alarms generated by the PhasorPoint application
- Correctly identified the source (generator and area) for all instances of oscillations with known sources inside and outside of ISO-NE

- **Existing Online Oscillation Management satisfies 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

AUTOMATIC POWER PLANT MODEL VERIFICATION (APPMV)

“PMU Playback” process

- Objective: Determine generator dynamic model accuracy
  - ✓ Confidence in generator models for all types of dynamic studies
  - ✓ Support NERC MOD-26/27
- Limitation of a typical “PMU playback”: time consuming manual process
- Need an automated, online process to verify as many as possible models with every qualified system disturbance
- Live since 2018



  - ✓ Demonstration of actual case proving wrong combined cycle generator model by using PMU playback technology
  - ✓ Identification of a need to exclude specific disturbances from model validation because the model does not account for actual physical process

Often model validation online serves as early detection of equipment failure/malfunctioning

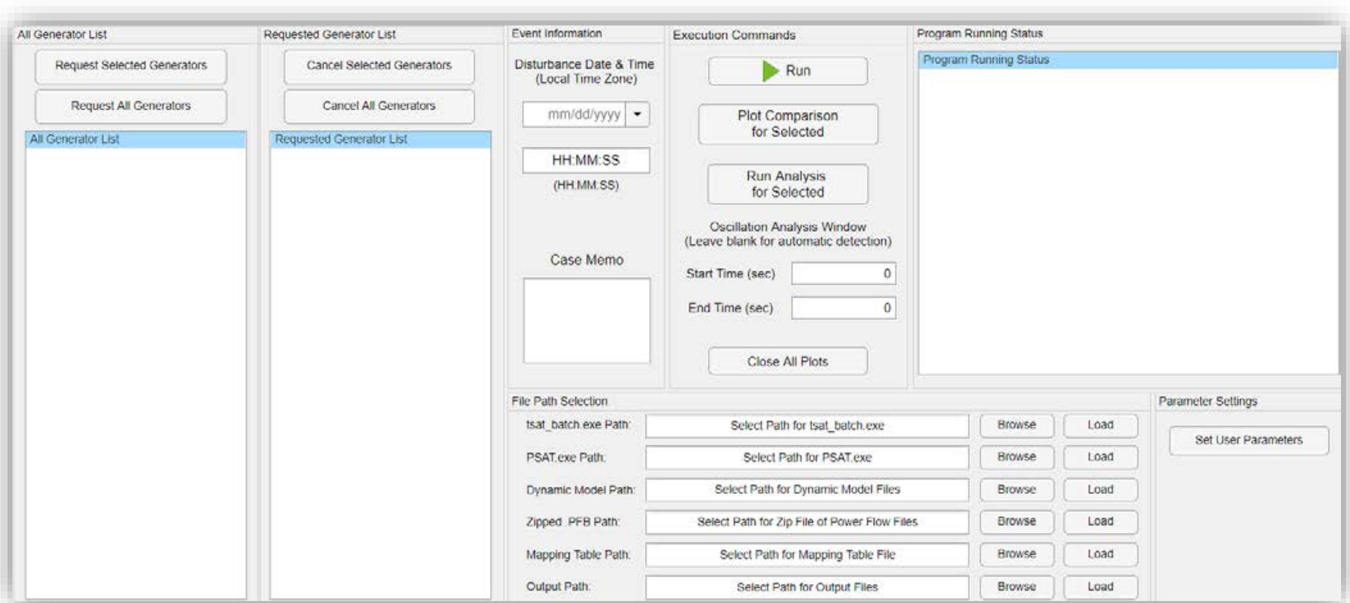
Batch Power Plant Model Verification (BPPMV)

Input

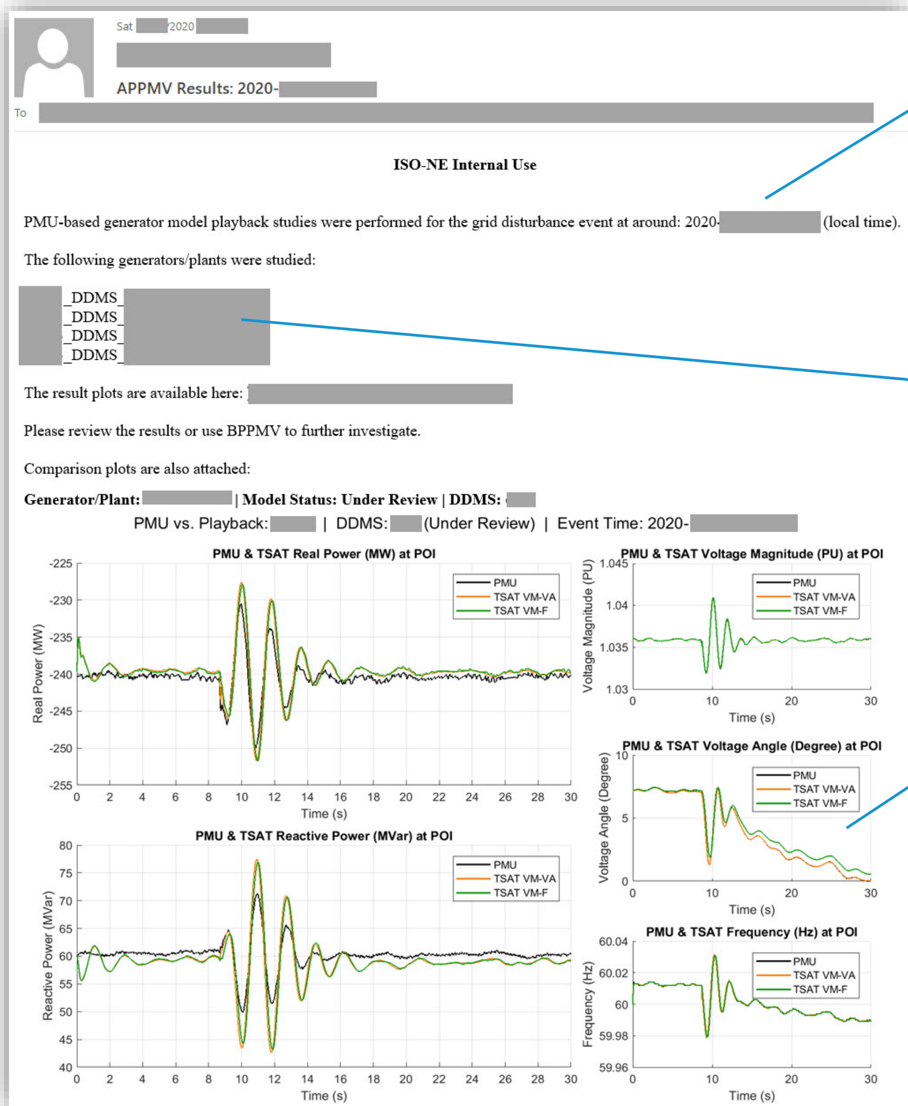
- ✓ Disturbance parameters
- ✓ Generators to validate
- ✓ PMU at POI
- ✓ SCADA for multi-generator power plants

Process

- ✓ Pull PMU and SCADA data
- ✓ Set the initial conditions
- ✓ Run playback simulation in TSAT
- ✓ Generate plots and Key Performance Indices (KPI)



APPMV Results – example of Email



Sat [redacted] 2020 [redacted]

[redacted]

APPMV Results: 2020-[redacted]

To [redacted]

ISO-NE Internal Use

PMU-based generator model playback studies were performed for the grid disturbance event at around: 2020-[redacted] (local time).

The following generators/plants were studied:

[redacted] _DDMS_ [redacted]
DDMS
DDMS
DDMS

The result plots are available here: [redacted]

Please review the results or use BPPMV to further investigate.

Comparison plots are also attached:

Generator/Plant: [redacted] **| Model Status: Under Review | DDMS:** [redacted]

Event Time

New in 2020: Improved event selection process

List of Verified Plant Models

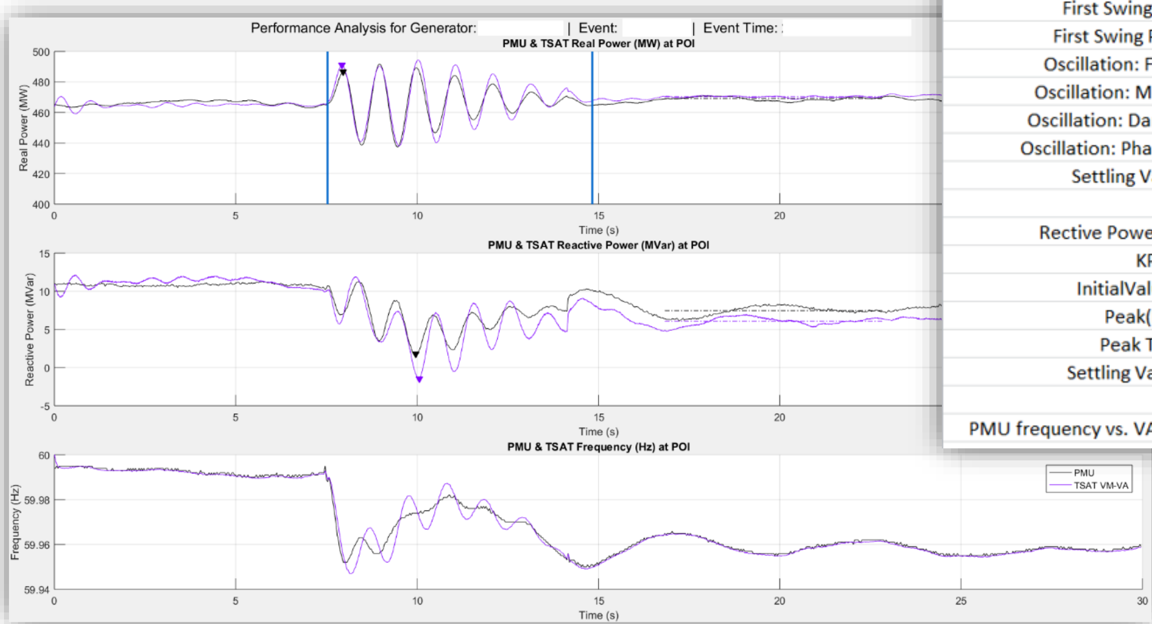
New in 2020: The same generator can have several models

Plots for Each Model

Results Analysis -KPI

- Key Performance Indices (KPI) are based on engineering quantities and parameters of transient

- Analysis based on multiple events (New in 2020, under integration)
  - ✓ Designed an event database and overall Scoring System



Performance Analysis for Generator:	| Event:	Event Time:	
Active Power Comparison			
KPIs	PMU	TSAT VM-VA	Difference
Initial Value(MW)	465.4	465	-0.4
First Swing Peak(MW)	486.7	491	4.3
First Swing Peak Time(s)	8	7.9	0
Oscillation: Frequency(Hz)	0.9	0.9	0
Oscillation: Magnitude(MW)	11.6	15.6	4
Oscillation: Damping Ratio(%)	5.1	3.6	-1.5
Oscillation: Phase Shift(Degree)	0	-5.8	-5.8
Settling Value(MW)	469.1	470.3	1.2
Rective Power Comparison			
KPIs	PMU	TSAT VM-VA	Difference
InitialValue(MVar)	10.9	10.8	-0.2
Peak(MVar)	1.8	-1.5	-3.2
Peak Time(s)	10	10.1	0.1
Settling Value(MVar)	7.5	6.1	-1.4
PMU frequency vs. VA calcualted frequency	Different (may be due to PMU frequency errors)		

EMERGENCY DISPATCH

Objective

- Emergency scenario: loss of SCADA and/or major EMS functions
- ISO-NE's emergency operation procedure MLCC/21 requires "man staffing" all key substations and dispatchable units
  - ✓ Field staff manually read the field measurements to the ISO's control room via secure phone calls
  - ✓ ISO provides manual dispatch instructions via secure phone calls by using approximately calculated MW dispatch quantities
- Potential issues of the existing emergency dispatch
  - ✓ Subject to human error
  - ✓ Time skew of field measurements and dispatch instructions

Need to utilize PMU infrastructure, which is independent from SCADA, for automated and efficient backup emergency dispatch

PMU-based Emergency Generation Dispatch

- PMU data are used instead of manual reading from field staff
- PMU data is used to calculate the Area Control Error (ACE) instead of SCADA

$$ACE = (P_{tie}^{schedule} - P_{tie(p)}) + 10B(f_{area}^{schedule} - f_{area\,(p)})$$

- An optimization procedure calculates dispatch instructions for available dispatchable generators

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

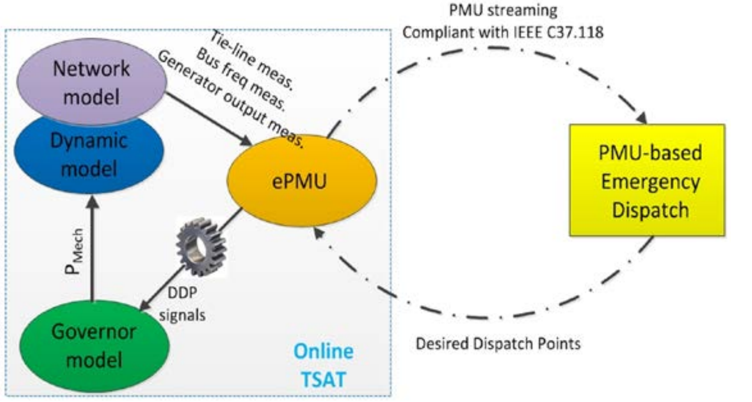
$$s.t.\ \sum \Delta P_i = \Delta L(T) - ACE$$

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

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

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

Validation - A Closed-Loop Simulation Platform



PMU-based Emergency Operation Options

- Emergency scenario: loss of SCADA and/or major EMS functions

Type of Control	ED network is available	ED network is unavailable
PMU-based AGC	Yes (every 4 sec)	No
PMU-based Emergency Dispatch for PMU monitored units only	Yes; automated delivery dispatch instructions (every 5… 10 min)	Yes; manual delivery dispatch instructions over phone

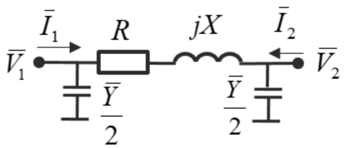
* ED stands for Electronic Dispatch

SERIES-CAPACITOR AND LINE PARAMETER ESTIMATION

(USE CASES)

Line Parameters Estimation

- Parameters of a transmission line monitored by PMU from both ends can be estimated, but the accuracy of the estimation is a concern

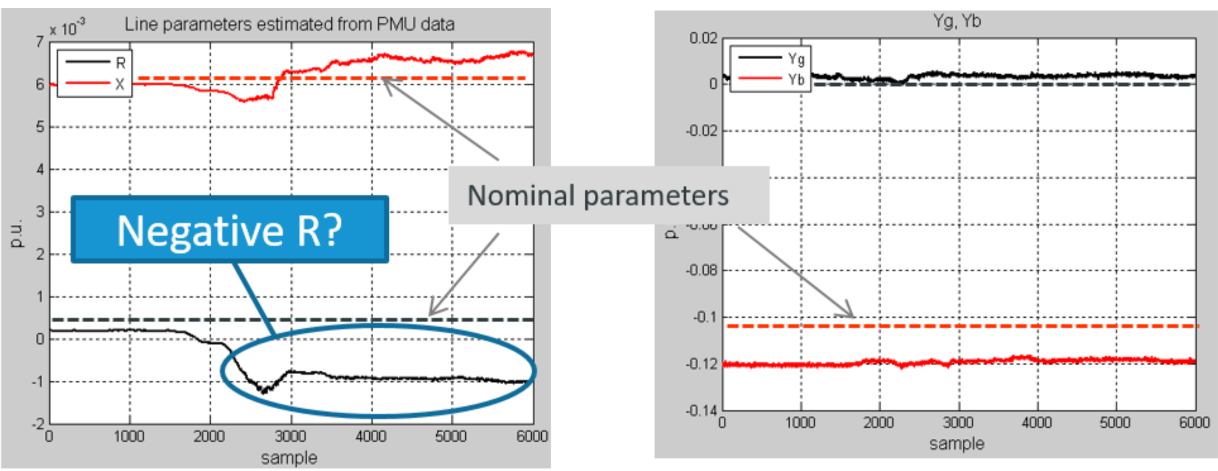


$$\bar{V}_1 - \bar{V}_2 = (R + jX)(\bar{I}_1 - \frac{\bar{Y}}{2}\bar{V}_1)$$

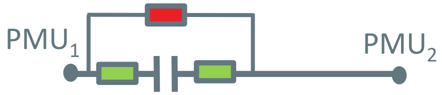
$$\bar{V}_2 - \bar{V}_1 = (R + jX)(\bar{I}_2 - \frac{\bar{Y}}{2}\bar{V}_2)$$

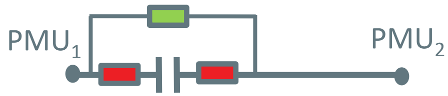
Calculate R, X, Y_g, Y_b for every PMU measurement

- Due to PMU errors, calculation of R could be unreliable; X and Y values are reasonable



Series-Capacitor (SC) Parameter Estimation

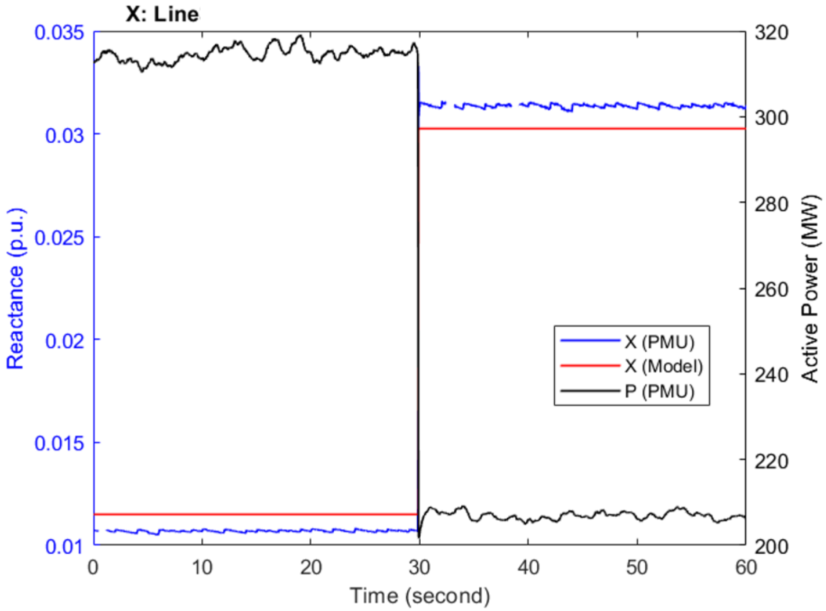




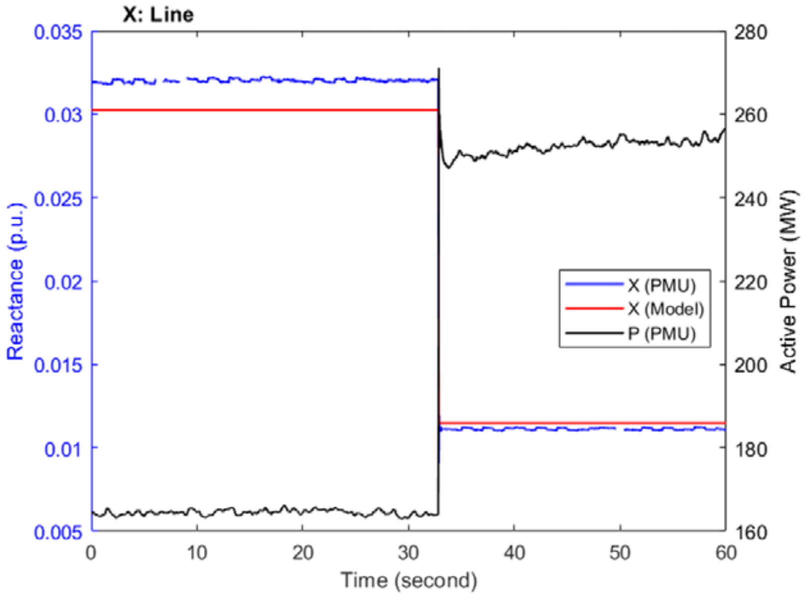
- SC impedance can be estimated at the change of topology: "SC off" → "SC on" or "SC on" → "SC off"; X_{line} is estimated from PMU 1&2

$$X_{SC} = X_{line}^{SC\ on} - X_{line}^{SC\ off}$$

"SC on" → "SC off"



"SC off" → "SC on"



Questions