JULY 23RD, 2019

Use PMU Data as A Backup of SCADA for Operation

NASPI CRSTT July Meeting

Song Zhang

SENIOR ANALYST

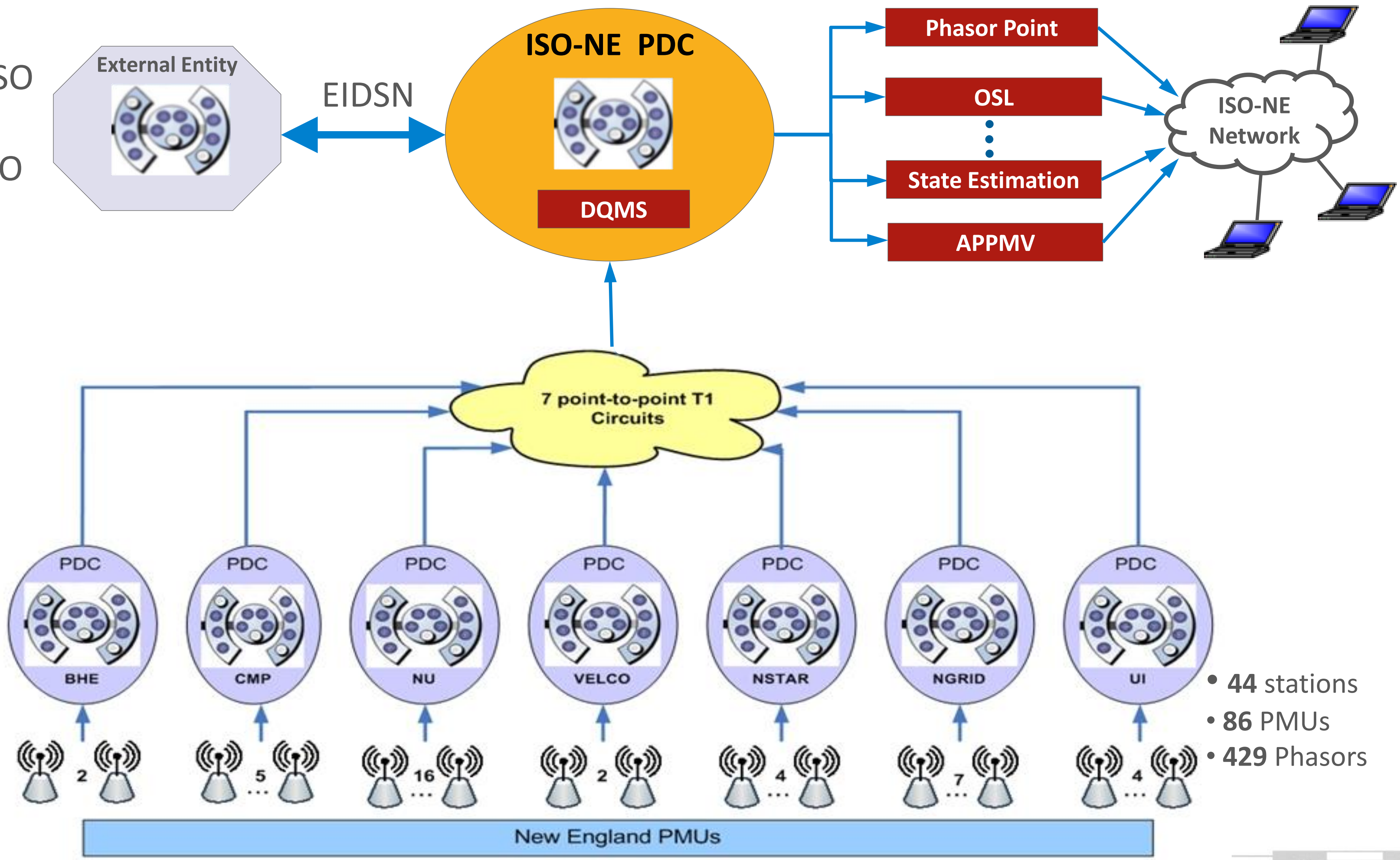
BUSINESS ARCHITECTURE & TECHNOLOGY

USE CASES

- Hybrid State Estimation
  - Online SE with all PMU measurements enabled
  - Online Parallel SE: one with SCADA only and the other with both PMU and SCADA
- Situational Awareness
  - Automatically populate a spreadsheet with PMU measurements on tie-lines, key generators and buses
- PMU-based Emergency Dispatch for Area Balancing
  - Automatic Generation Dispatch
  - 5-minute Economic Dispatch

New England Synchrophasor System

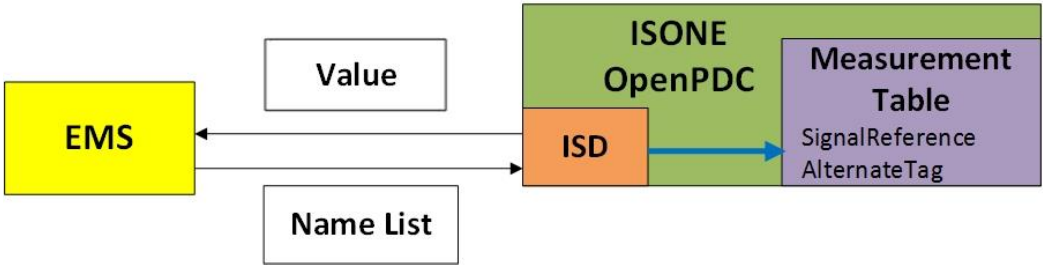
- NYISO
- PJM
- MISO



- **44** stations
- **86** PMUs
- **429** Phasors

Hybrid State Estimation

- Project goals:
  - Establish the process to feed PMU data into SCADA/SE
  - Evaluate the impact of PMU on SE performance (accuracy and robustness)
  - Investigate if introduction of PMU data improves SE at loss of SCADA
  - Determine the possible integration into production in the future



- Configuration
  - Install and Configure the openPDC ISD action adaptor for direct feed of PMU data into GE EMS
  - Map SCADA analog names to openPDC PMU measurements (SCADAMOM changes)
  - SCADA to NETMOM mapping and validation
  - Four type of PMU measurements are modeled: Voltage Magnitude, Voltage Angle, Current Magnitude and Current Angle

Hybrid State Estimation Evaluations

- Phase I: off-line based on SE savecase snapshot
- Phase II: enable PMU data as primary measurements in SE and run 24 x 7
- Phase III: parallel State Estimators, one with only SCADA, and one with both SCADA and PMU

Hybrid State Estimation Evaluations

- Phase I: Use "Real-Time Network Debug" to manipulate SE Savecase snapshots off-line using scripts
  - Without PMU
  - With PMU
    - Enabling voltage magnitude only
    - Enabling both voltage magnitude and angle
    - Try different weights
- Compare performance metrics:
  - Solution cost
  - Iteration number
  - CPU time
  - Largest mismatch

Observations of Phase I

- Introduce PMU data with proper weights will not hurt SE solution performance
  - Solution cost
  - Iteration number
  - CPU time
  - Largest mismatch
- If we have confidence on the accuracy of PMU data, the SE with PMU enabled will bring the solution closer to raw PMU data (keep in mind that PMU measures directly the power system states)

Hybrid State Estimation Evaluations (Phase II)

- Phase II: Enable all PMU measurements in SE (24 X 7)
  - Compare the angle solution of Hybrid SE with raw PMU data for a period of time
  - Compare the angle solution of Hybrid SE with conventional SE using only SCADA data for a period of time

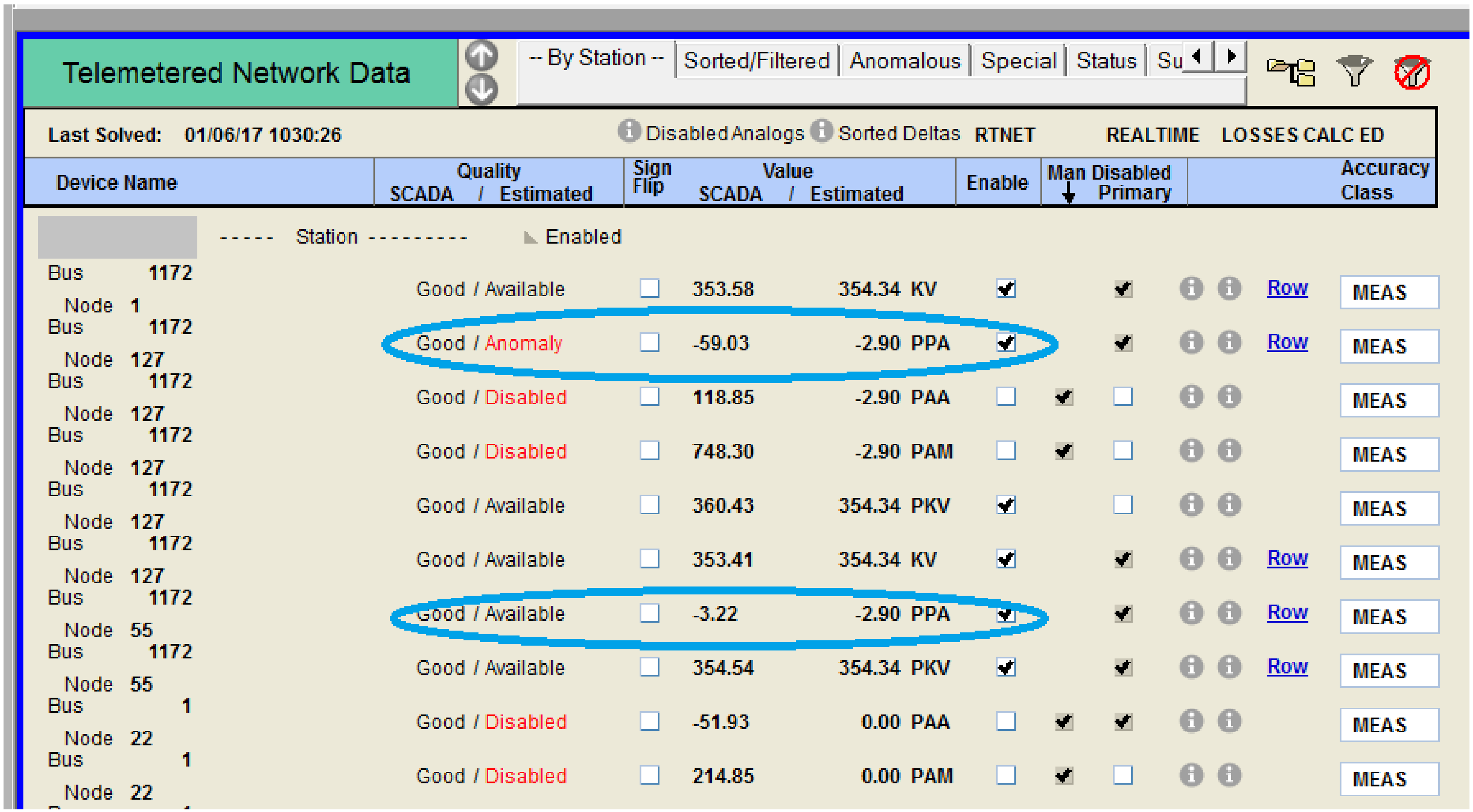
Datasets for SE Evaluation

- Dataset 1: from 1/23/2017 14:01:34 to 1/27/2017 9:12:36 (GMT-5:00)
  - A total of 1801 State Estimation Solutions
  - Invalid solution: 4
  - Solution w/ mismatch: 8
  - Valid solution: 1789

- Dataset 2: from 1/30/2017 10:30:42 to 2/2/2017 21:47:42 (GMT-5:00)
  - A total of 1664 State Estimation Solutions
  - Invalid solution: 0
  - Solution w/ mismatch: 2
  - Valid solution: 1662

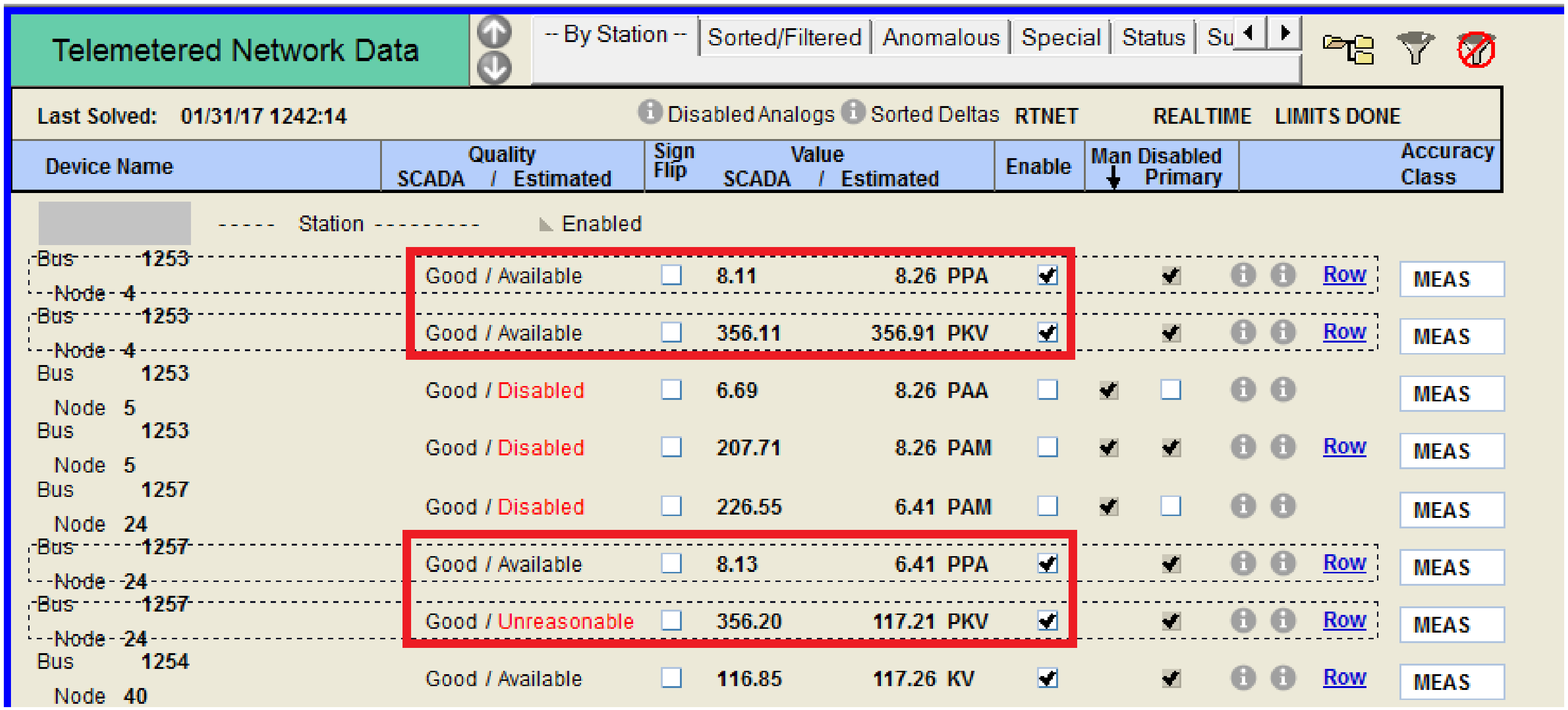
Bad PMU Data Detection

redundant measurement, SE detect the bad one



Bad Data Detection – Wrong PMU Mapping (I)

Transformer high voltage side and low voltage side mapped conversely



Telemetered Network Data

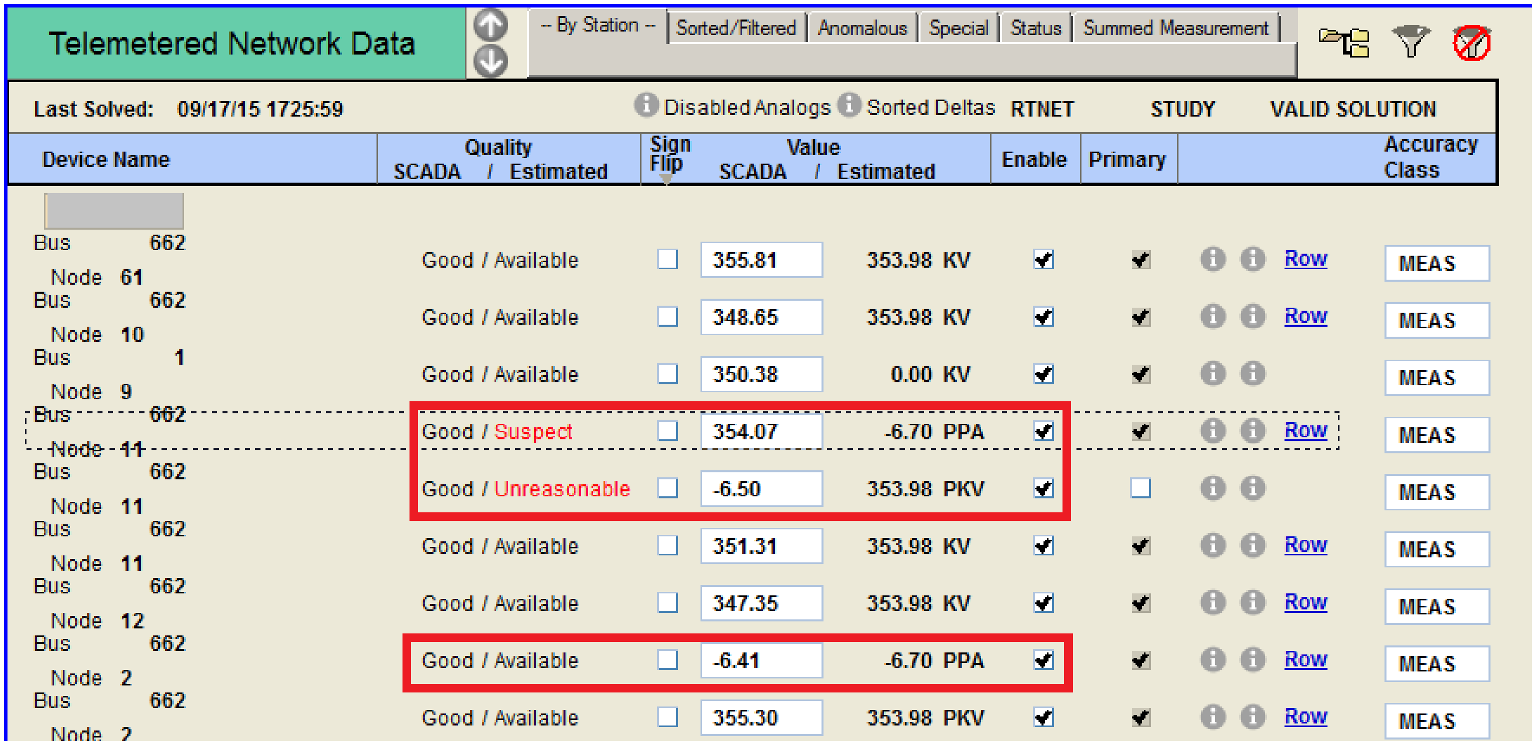
-- By Station -- | Sorted/Filtered | Anomalous | Special | Status | Su

Last Solved: 01/31/17 1242:14 Disabled Analogs Sorted Deltas RTNET REALTIME LIMITS DONE

Device Name	Quality SCADA / Estimated	Sign Flip	Value SCADA	/ Estimated	Enable	Man Disabled	Primary		Accuracy Class
----- Station ---------	Enabled								
Bus 1253 Node 4	Good / Available	☐	8.11	8.26 PPA	✔		✔	Row	MEAS
Bus 1253 Node 4	Good / Available	☐	356.11	356.91 PKV	✔		✔	Row	MEAS
Bus 1253 Node 5	Good / Disabled	☐	6.69	8.26 PAA	☐	✔	☐		MEAS
Bus 1253 Node 5	Good / Disabled	☐	207.71	8.26 PAM	☐	✔	✔	Row	MEAS
Bus 1257 Node 24	Good / Disabled	☐	226.55	6.41 PAM	☐	✔	☐		MEAS
Bus 1257 Node 24	Good / Available	☐	8.13	6.41 PPA	✔		✔	Row	MEAS
Bus 1257 Node 24	Good / Unreasonable	☐	356.20	117.21 PKV	✔		✔	Row	MEAS
Bus 1254 Node 40	Good / Available	☐	116.85	117.26 KV	✔		✔	Row	MEAS

Bad Data Detection – Wrong PMU Mapping (II)

Magnitude and angle are mapped conversely



Telemetered Network Data

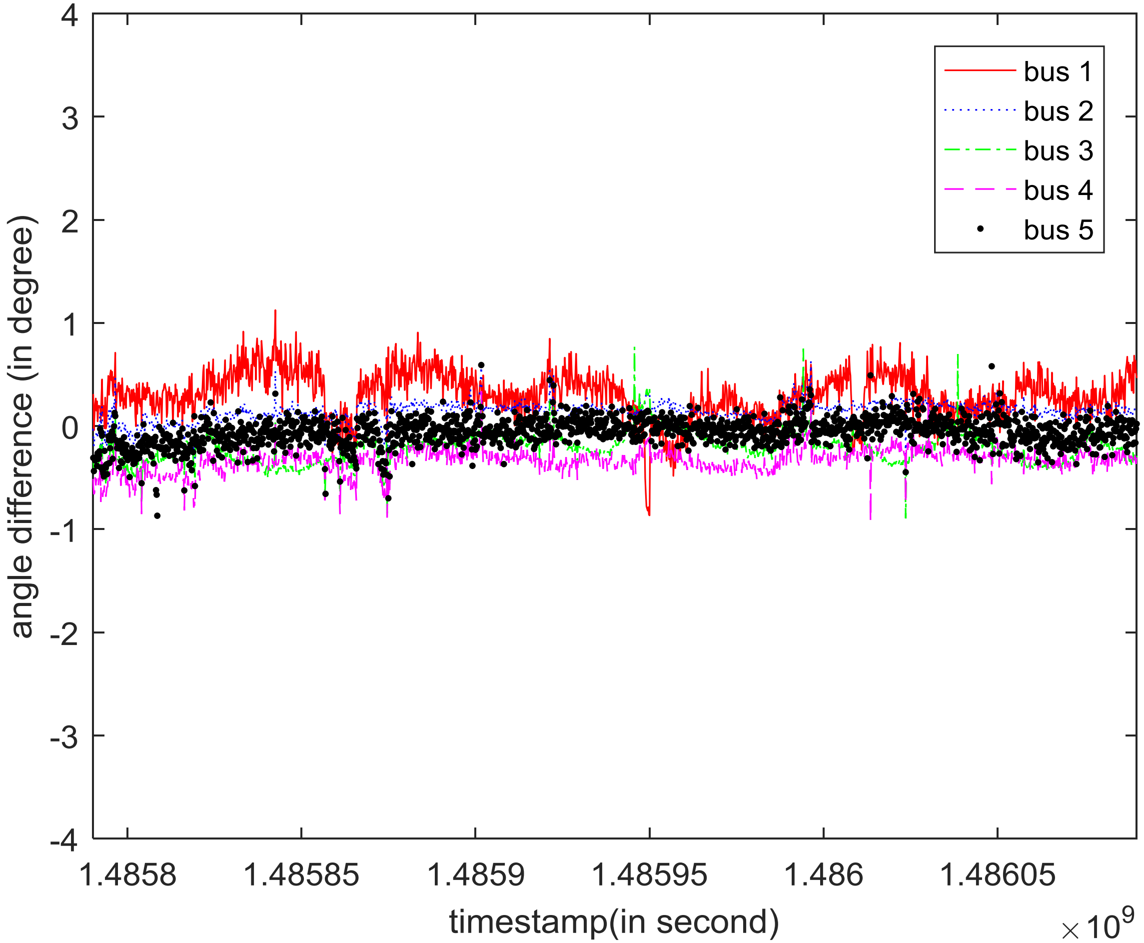
-- By Station -- | Sorted/Filtered | Anomalous | Special | Status | Summed Measurement

Last Solved: 09/17/15 1725:59 | Disabled Analogs | Sorted Deltas | RTNET | STUDY | VALID SOLUTION

Device Name	Quality SCADA / Estimated	Sign Flip	Value SCADA	Value Estimated	Enable	Primary		Accuracy Class
Bus 662 Node 61	Good / Available	☐	355.81	353.98 KV	☑	☑	Row	MEAS
Bus 662 Node 10	Good / Available	☐	348.65	353.98 KV	☑	☑	Row	MEAS
Bus 1 Node 9	Good / Available	☐	350.38	0.00 KV	☑	☑		MEAS
Bus 662 Node 11	Good / Suspect	☐	354.07	-6.70 PPA	☑	☑	Row	MEAS
Bus 662 Node 11	Good / Unreasonable	☐	-6.50	353.98 PKV	☑	☐		MEAS
Bus 662 Node 11	Good / Available	☐	351.31	353.98 KV	☑	☑	Row	MEAS
Bus 662 Node 12	Good / Available	☐	347.35	353.98 KV	☑	☑	Row	MEAS
Bus 662 Node 2	Good / Available	☐	-6.41	-6.70 PPA	☑	☑	Row	MEAS
Bus 662 Node 2	Good / Available	☐	355.30	353.98 PKV	☑	☑	Row	MEAS

SE Evaluation Results

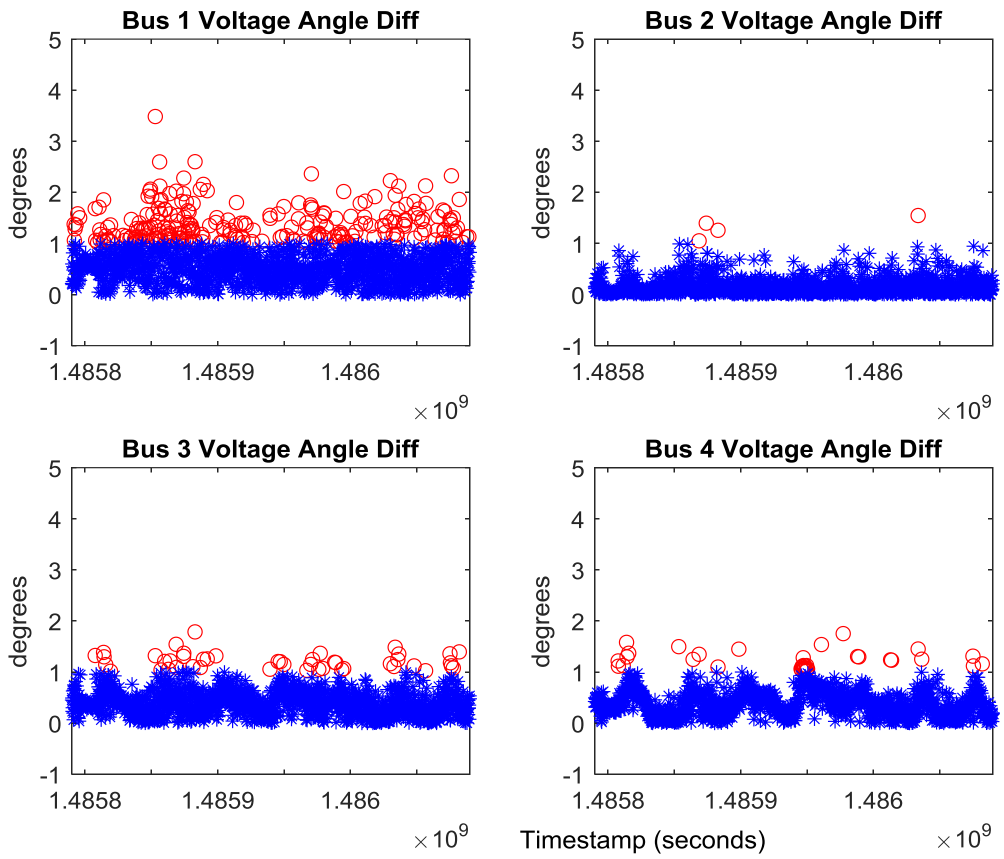
Difference between SE and PMU value of key buses



Small angle diff →
SE solution is close to
PMU measurement

SE Evaluation Results

SE angle difference between development (hybrid SE) and production (conventional SE)



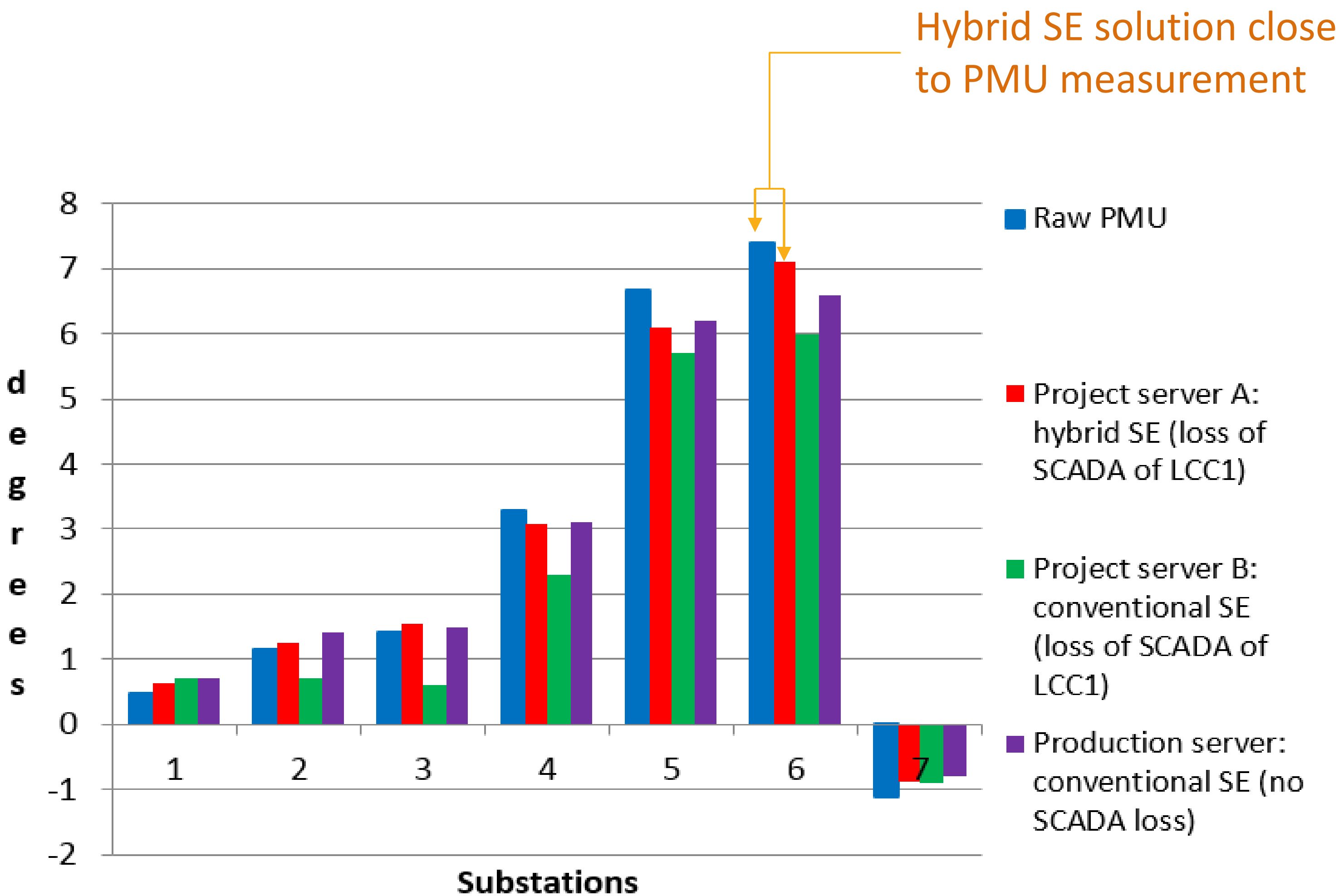
- Blue: ≤ 1 degree
- Red: > 1 degree

- Most of the larger angle differences are due to the non-synchronized solution time between hybrid SE and conventional SE running on two different servers

Hybrid State Estimation Evaluations (Phase III)

- Phase III: parallel State Estimators in development environment, one with only SCADA, and one with both SCADA and PMU
  - Loss of ICCP link of one local control center (LCC1)
  - Loss of the whole New England ICCP link

Loss of ICCP link of LCC1

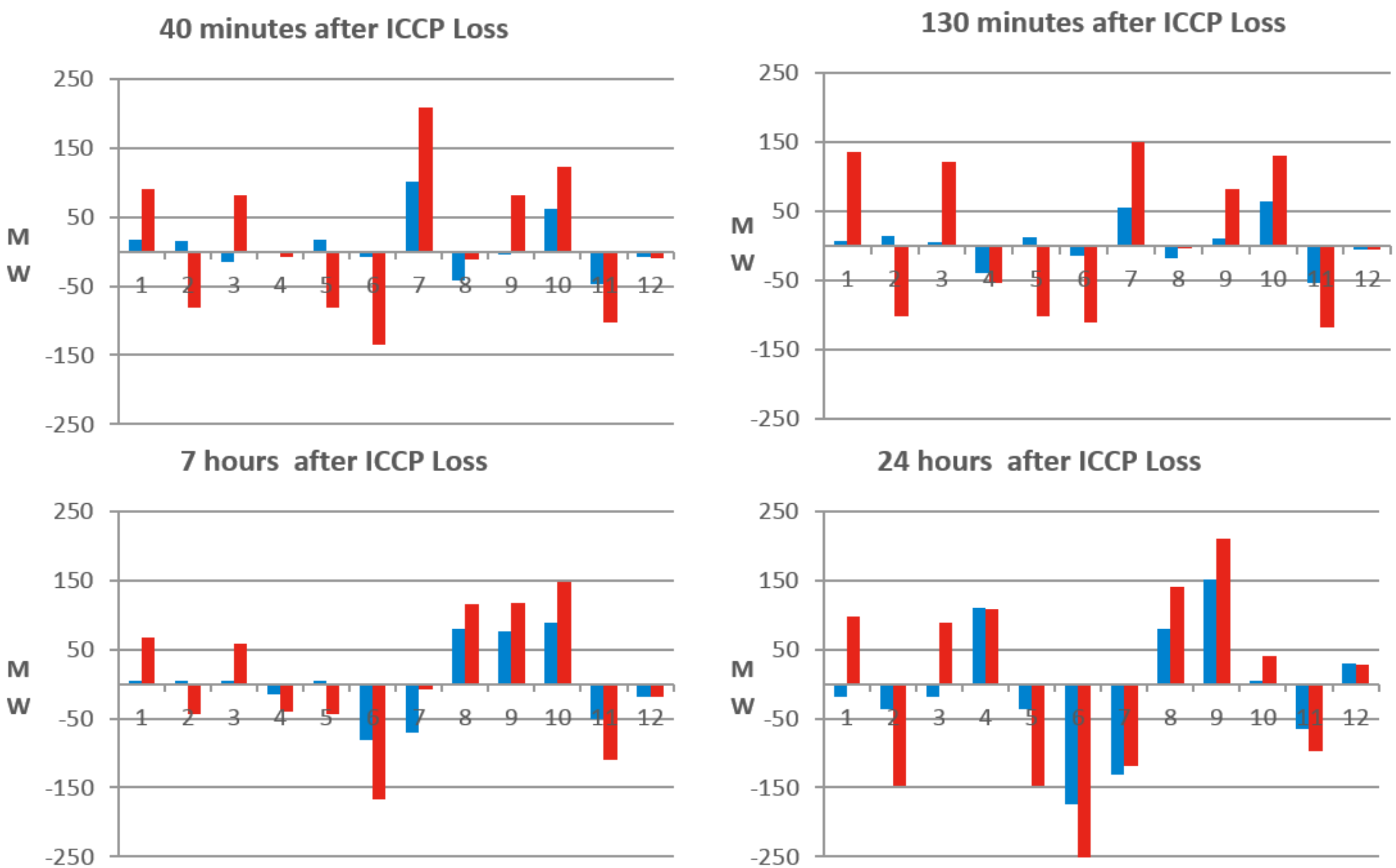


Voltage angles at various substations at loss of ICCP link of LCC1

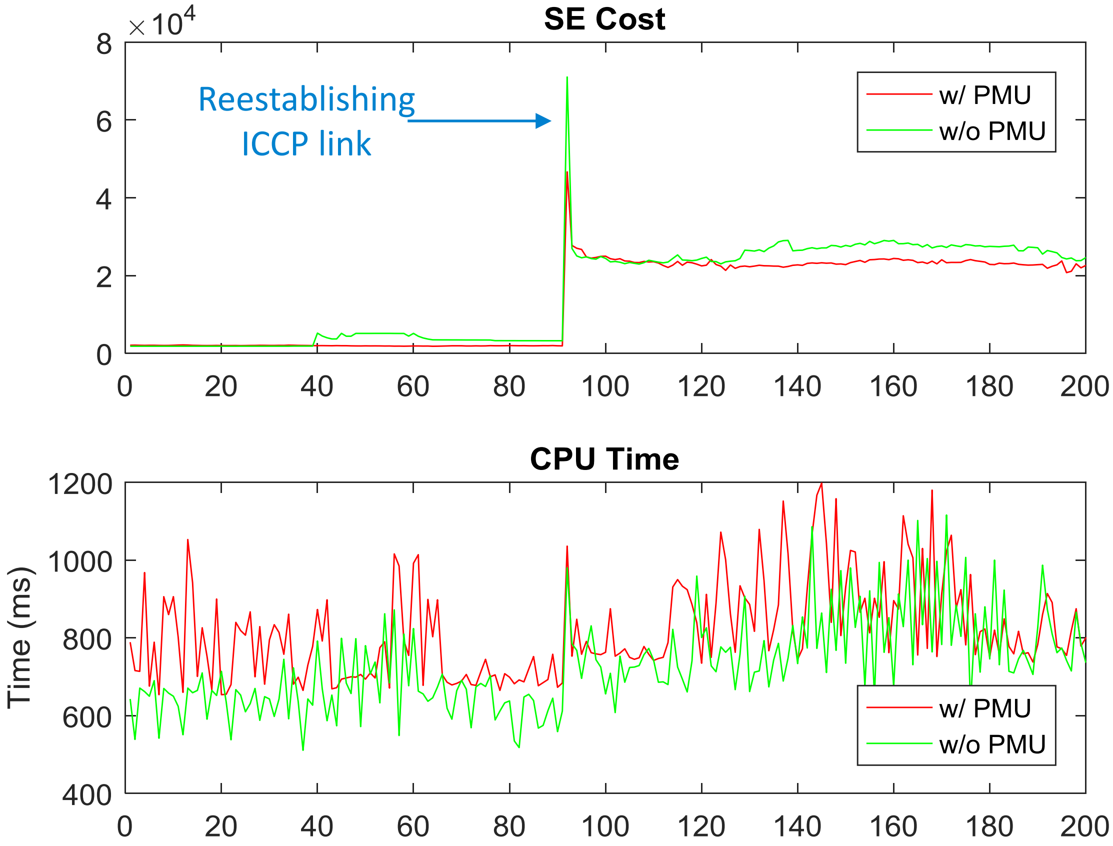
Loss of the Whole New England ICCP Link

Blue Bars: Line flow(hybrid SE w/ PMU data, loss of SCADA) – Line flow(conventional SE)

Red Bars: : Line flow(conventional SE, loss of SCADA) – Line flow(conventional SE)



Loss of the Whole New England ICCP Link



Smaller solution cost for hybrid SE

Conclusions and Findings

- The performance of hybrid SE has been satisfactory in terms of accuracy and robustness
  - Hybrid SE will solve voltage angles more accurately (angle is one of the systems states)
  - Marginal improvement though with today's PMU penetration level
  - Didn't observe better convergence rate primarily due to limited number of PMU measurements
- The benefits are more noticeable when there is a loss of SCADA
  - With limited PMU penetration, the improvement is significant in a relatively short time window right after loss of SCADA
  - As time evolves, the improvement is less and less because majority of data is outdated

PMU-based Emergency Dispatch for Area Balancing

Current Practice for Emergency Dispatch

- × Rely on substation staffing and manual data acquisition in case of loss of SCADA
- × Calculate ACE based on the manually read data
- × Estimate desired dispatch point of generators for area balancing
- × Perform the dispatch verbally via phone calls
- × Deeply human-involved, subject to human errors and may lead to a very bad area balancing control performance

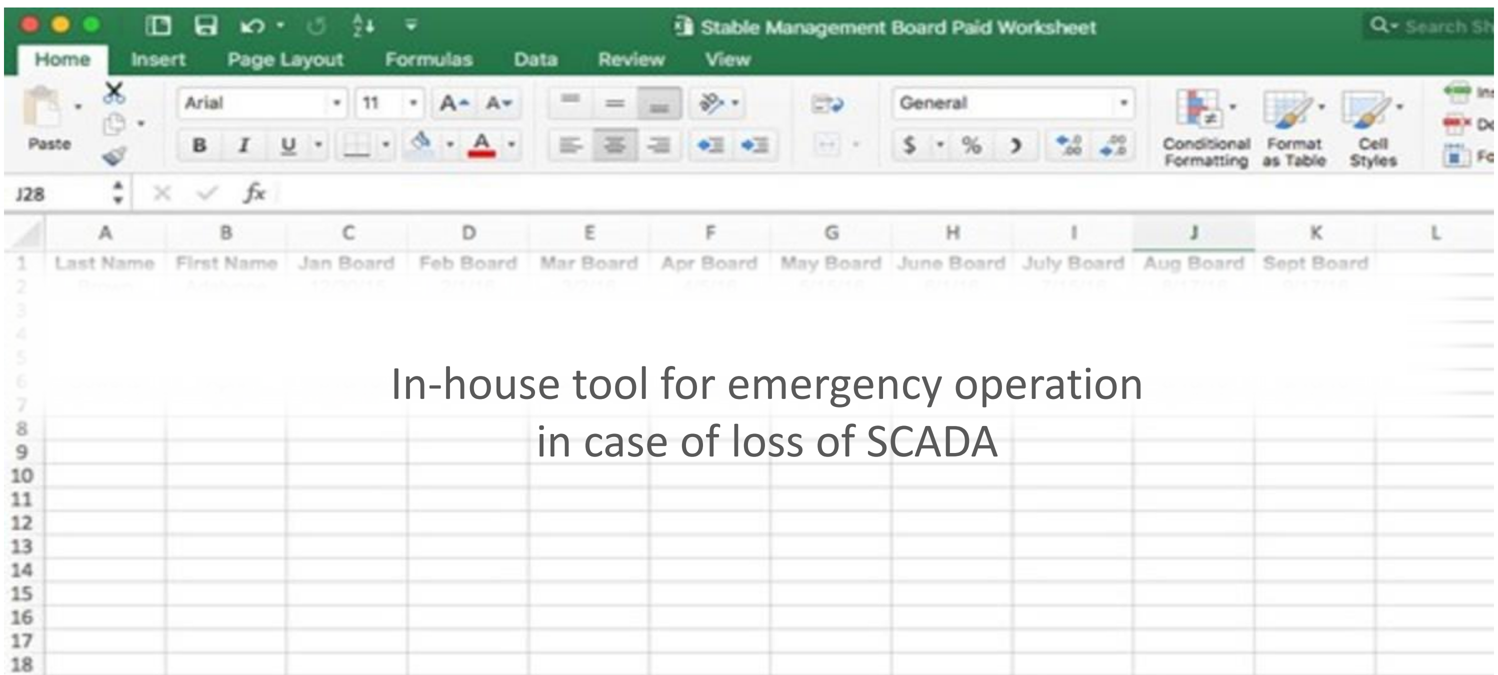
✓ Solution: The synchrophasor infrastructure is independent from the SCADA/EMS system. It's Ideal as a backup for emergency monitoring and control when there is a complete loss of SCADA/EMS

- Separate communication infrastructure with its own circuits, routers, firewalls, etc.
- Time aligned and synchronized with the GPS clock
- MW flow and frequency of tie lines
- MW and MVAr outputs of large power plants at POI (100 MW and above)
- All 345 kV and some 115 kV line flows

PMU for Situational Awareness

Pull PMU data from PhasorPoint/OpenPDC to populate a spreadsheet with

- flows on tie lines
- output of PMU-monitored generators whose capacity ≥ 100 MW
- voltage on all 345 kV key buses



In-house tool for emergency operation
in case of loss of SCADA

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

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

$P_{tie}^{schedule}$	- 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 set points

Synchrophasor-based Emergency Operation

	Loss of SCADA/EMS; ED network is available	Loss of SCADA/EMS; ED network is unavailable
Synchrophasor-based Automatic Generation Control (AGC)	Yes (every 4 seconds)	No
Synchrophasor-based Emergency Dispatch	Yes (every 5 or 10 minutes) ; only PMU monitored units	Yes (every 5 or 10 minutes) ; only PMU monitored units

Synchrophasor-based Emergency Generation Dispatch

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

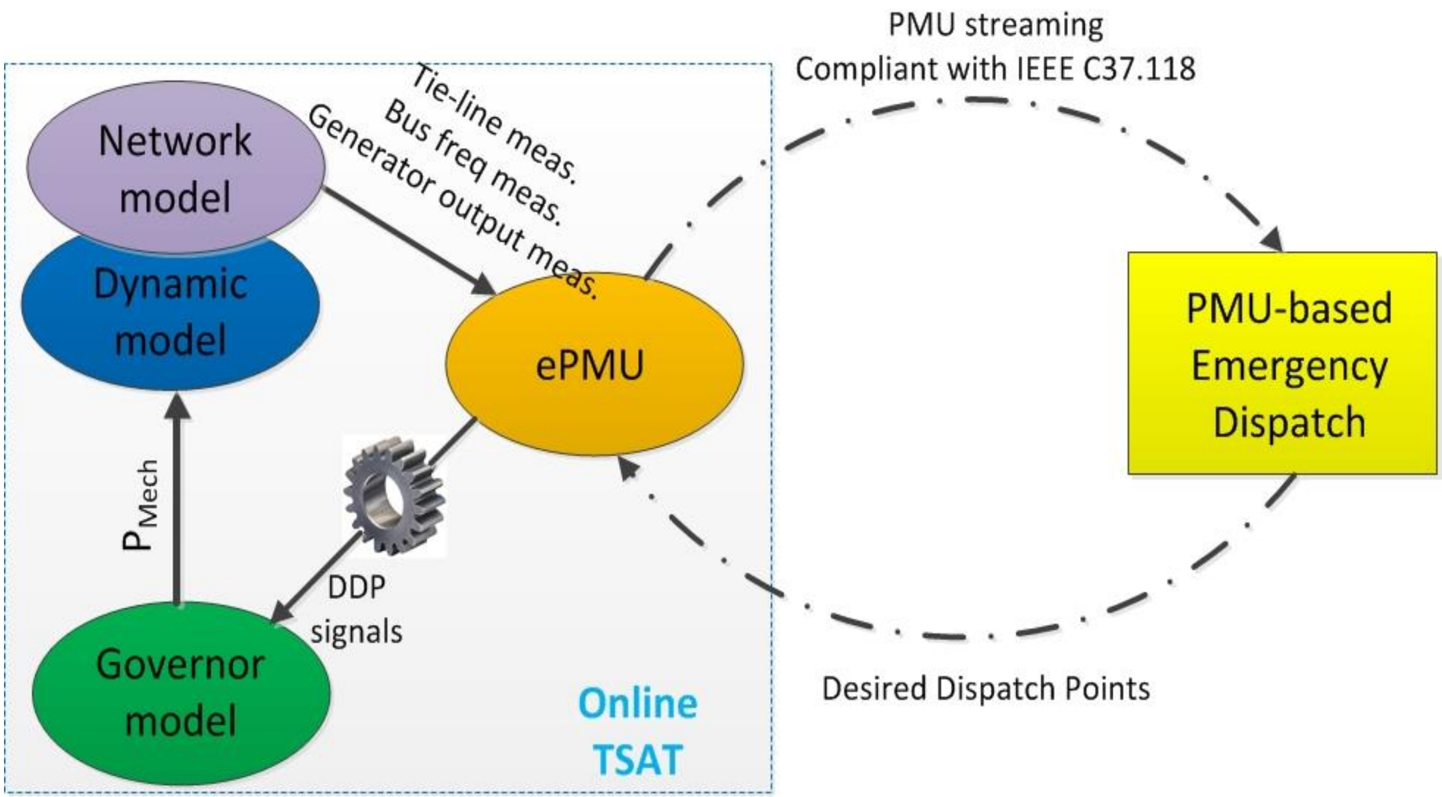
$$s.t. \quad \sum \Delta P_i = \Delta L(T) - ACE_{control}$$

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

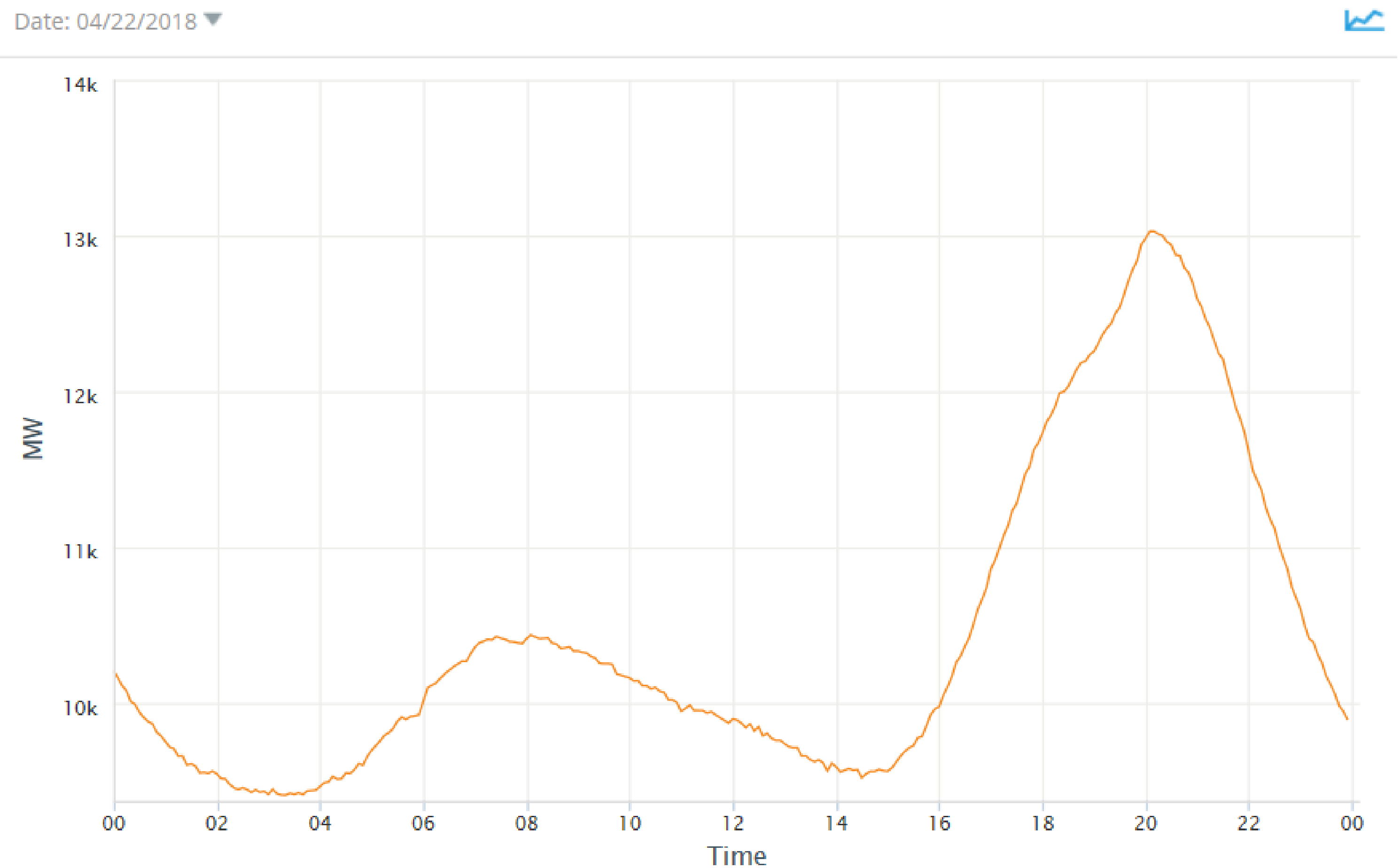
$$P_{min} \leq P_i^0 + \Delta P_i \leq P_{max}$$

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

Prototype - A Closed-Loop Simulation Platform

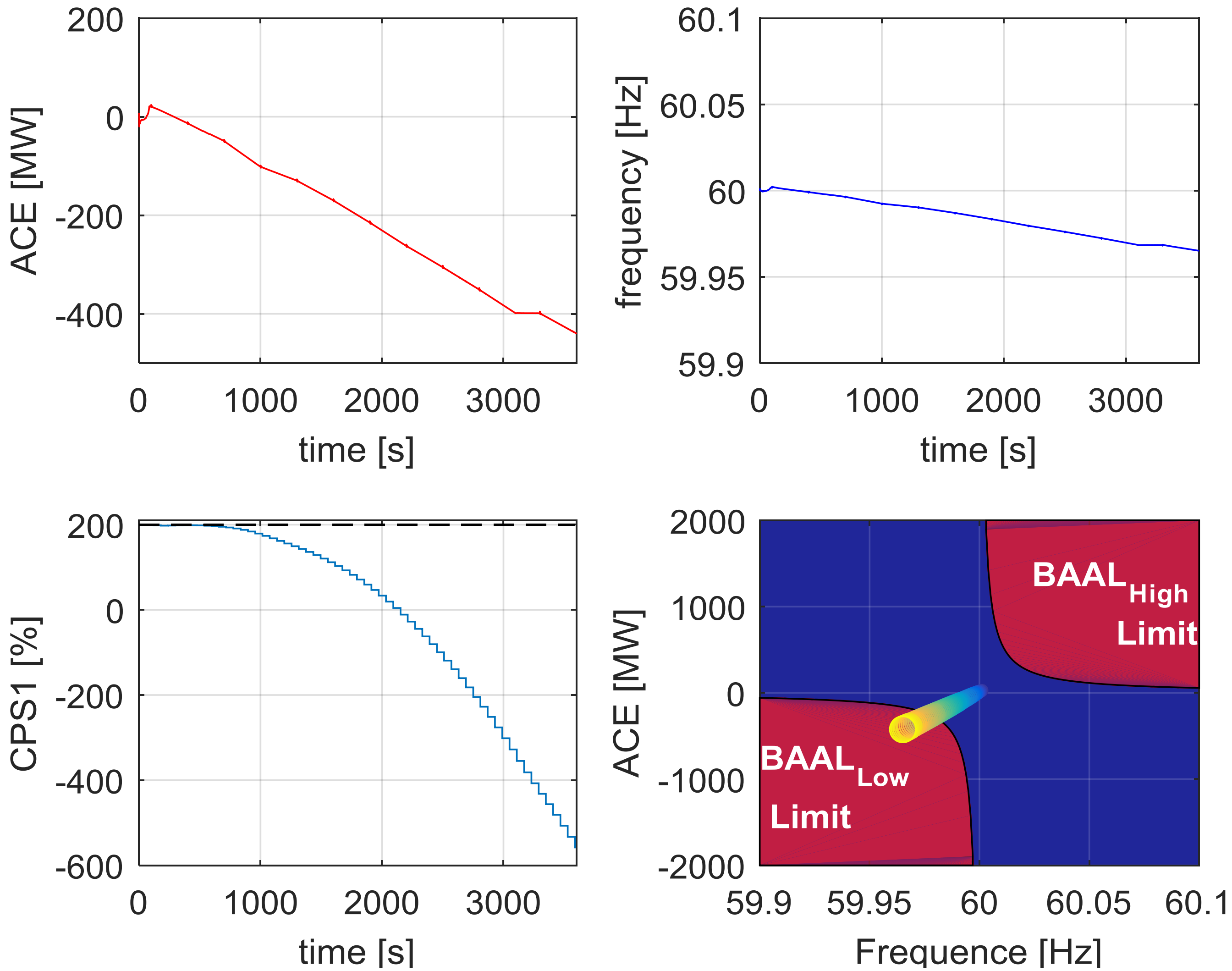


Test Case

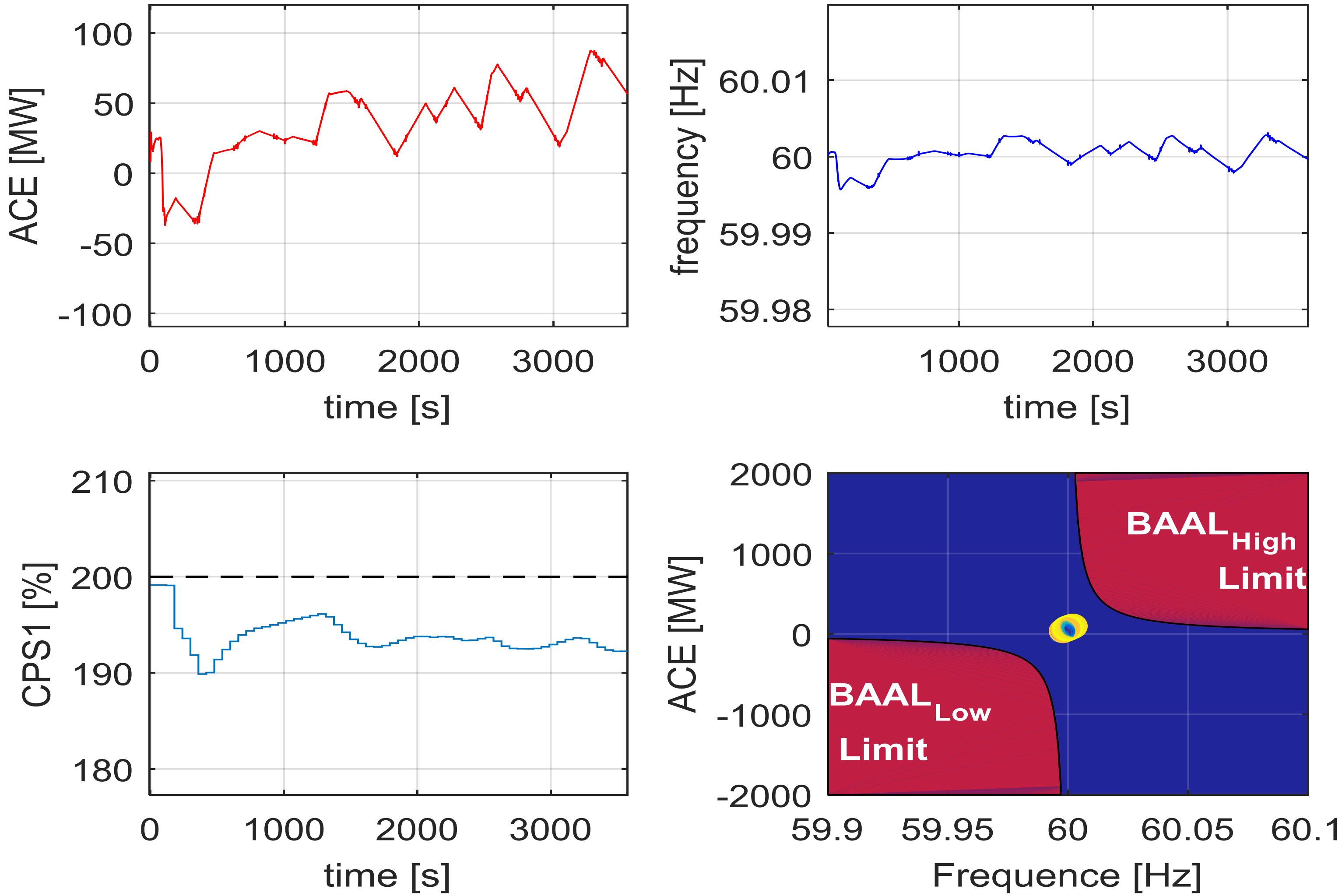


4/22/2018, 16:00 hr. – 17:00 hr., about 900 MW increase

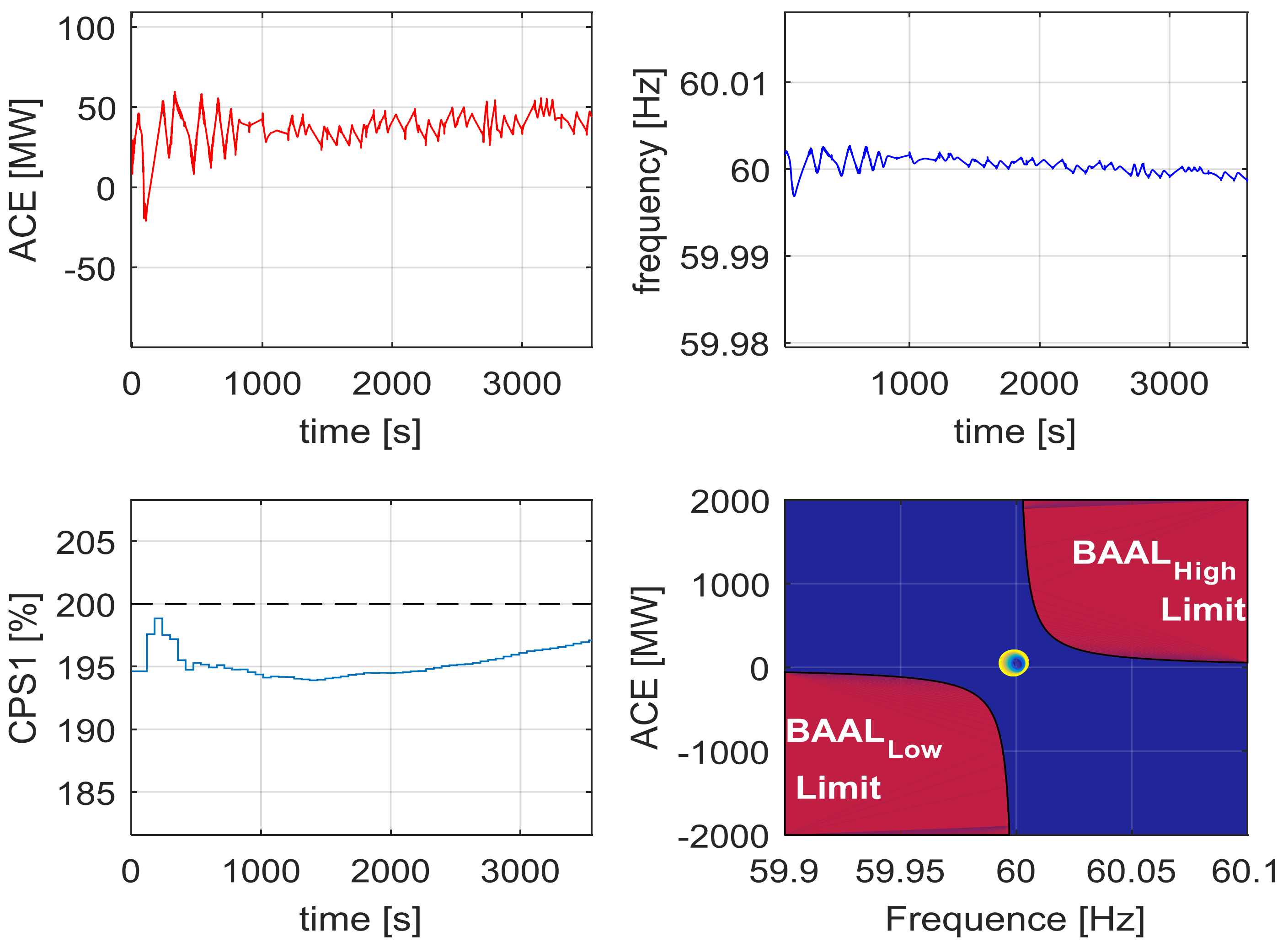
Test Case – w/o Emergency Dispatch



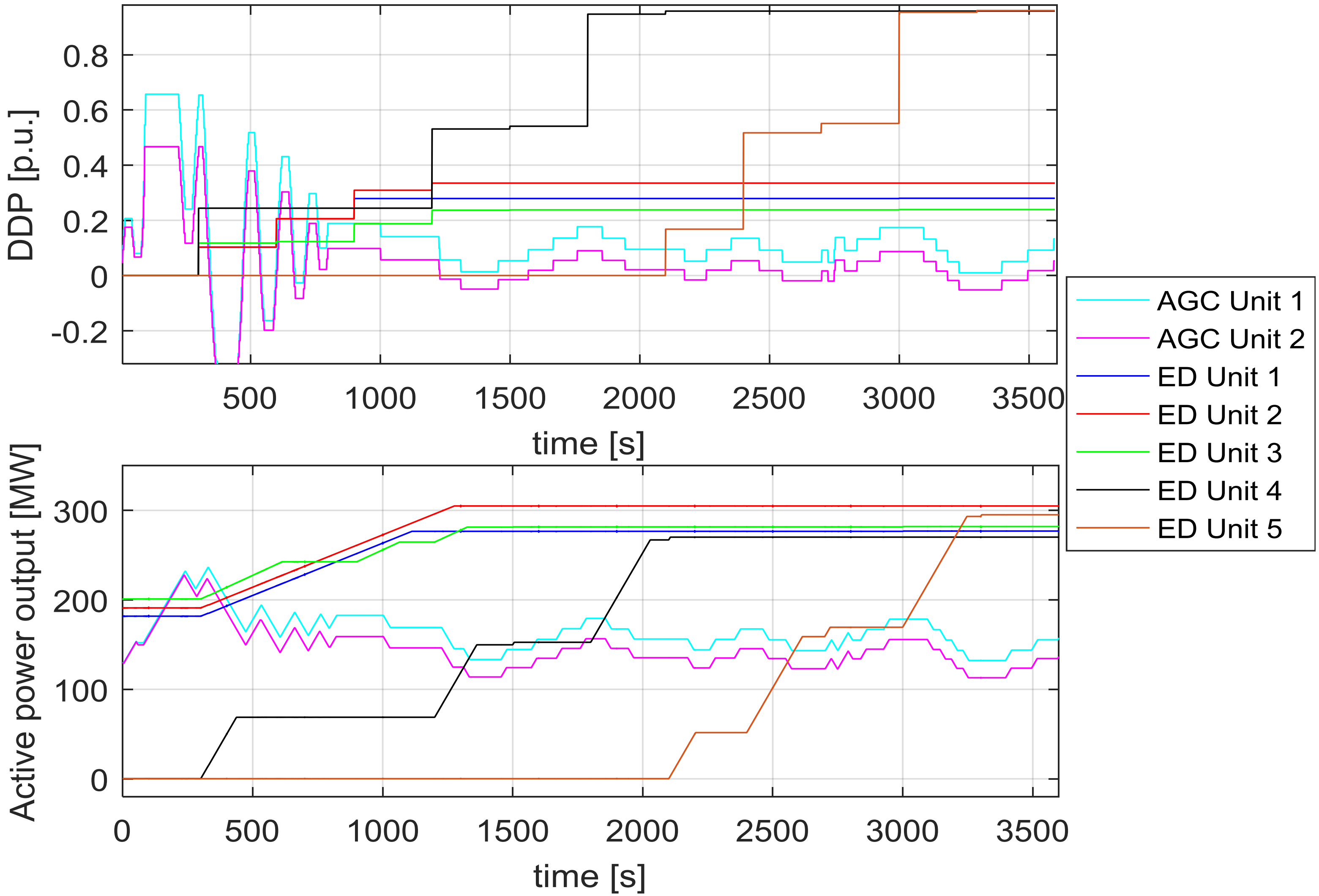
Test Case – Emergency Dispatch, ED network unavailable



Test Case – Emergency Dispatch, ED network available



Test Case – Emergency Dispatch (DDP and active power output), ED network available



Contribution of This Work

- ✓ **Proposed a monitoring and control framework based on synchrophasor infrastructure totally independent of SCADA/EMS**
  - Eliminate substation staffing
  - Eliminate manual data acquisition in the event of loss of SCADA
  - Monitoring frequencies and tie-line flows, therefore ACE
  - Monitoring key BES substations including voltages, line flows, angle difference
  - Monitoring significant generators outputs and their response to the emergency dispatch instructions
- ✓ **Developed a synchrophasor-based bi-level control scheme for area balancing**
  - Accurately calculate AGC set points, based on ACE (ED Network Available)
  - Perform emergency economic dispatch, rather than estimate the dispatch points (ED Network Unavailable)
- ✓ **Created a flexible platform**
  - first configured for closed-loop simulation to validate the PMU-based emergency dispatch scheme
  - then reconfigured for the integration of real PMU stream into area balancing control with minimum migration effort.
- ✓ **The proposed PMU-based area balancing control doesn't require full system observability but just the measurements of tie-line flows, a few key buses and generators**

Questions