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Success?!

A Journey to Full Distribution Situational Awareness

Ben Kregel, PE
Heng (Kevin) Chen, PE
Smart Grid & Technology

ComEd PMU History

In 2015, ComEd initiated development of a road map and strategy for wide-scale operational use of Phasor Measurement Units (PMUs) in its transmission and distribution system.

In this roadmap, many distribution functions/applications were identified for PMUs in the following five categories:

Distributed Energy Resource (DER) Integration	Distribution System Operations	Wide-Area Monitoring, Protection, Automation and Control (WAMPAC)	Asset Management and Reliability	Planning and Analysis

There were also several benefits and deployment challenges identified and qualitatively compared for the distribution applications.

Key Distribution Synchrophasor Functions

- Pilots focused on demonstrating key synchrophasor capabilities at various levels of complexity
  - Microgrid operation
  - Distribution state estimation
  - Voltage and current profile monitoring
  - Real-time system operations (limited scope)
  - DER monitoring (Solar PV and Energy Storage)
  - Condition monitoring and asset management
  - Smart inverter monitoring and control
  - Incipient fault and failure detection
  - Root-cause and post-mortem analysis
  - Monitoring of critical infrastructure and large customers

Where it began: 2018 Pilot Installations

- ComEd targeted installation of distribution PMUs, PDCs (Phasor Data Concentrators), and other associated equipment at 7 key locations:
  - Substations feeding ComEd's ICC-approved microgrid
  - Substation serving a 10MW solar farm in Southeast Chicago
  - Substations feeding Chicago's two international airports

- Synchrophasor data is collected by substation PDCs and sent to a central PDC and synchrophasor data management system.
- In addition to the above pilots, the project team has installed a Proof-of-Concept (PoC) synchrophasor data system in a laboratory environment for troubleshooting and demonstration purposes.

A Three-Tier Approach

SUBSTATION LEVEL PMU

- 12kV and 34kV feeder relays
- Transformer relays
  - Situational awareness of feeder heads and medium voltage busses

FEEDER MAIN-STEM PMU

- Distribution automation devices (in-development)

FEEDER EDGE PMU

- Standalone microPMU
- Distributed generation

Programmatic Deployment Strategy

2018
7 substations
59 PMU streams
$1.6M

2019
11 substations
25 microPMU's
147 PMU streams
$3.5M

2020
8 substations
67 PMU streams
$2M

2021
$2M

2022
$2M

2023
$2M

2024
$2M

Success?!

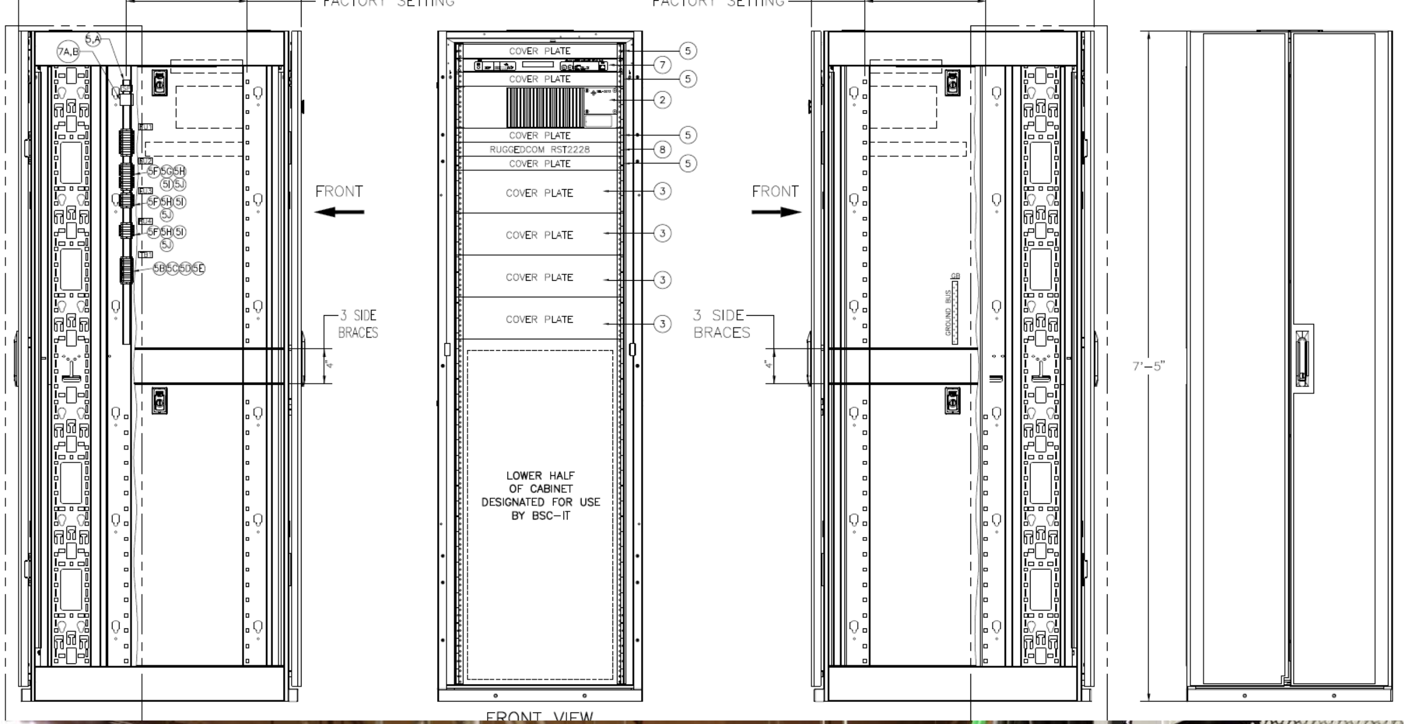
Over 100 D-PMU streams program to date

Programmatic approach
- Currently 5 year forecast in budget

Pre-screening of candidate sites
- Ease of deployment
- Availability of fiber backhaul & adequate capacity

Wholistic approach
- General design documents (GDD) for standardization
- Cookie-cutter process

Distribution PDC Cabinet and GPS Standardization



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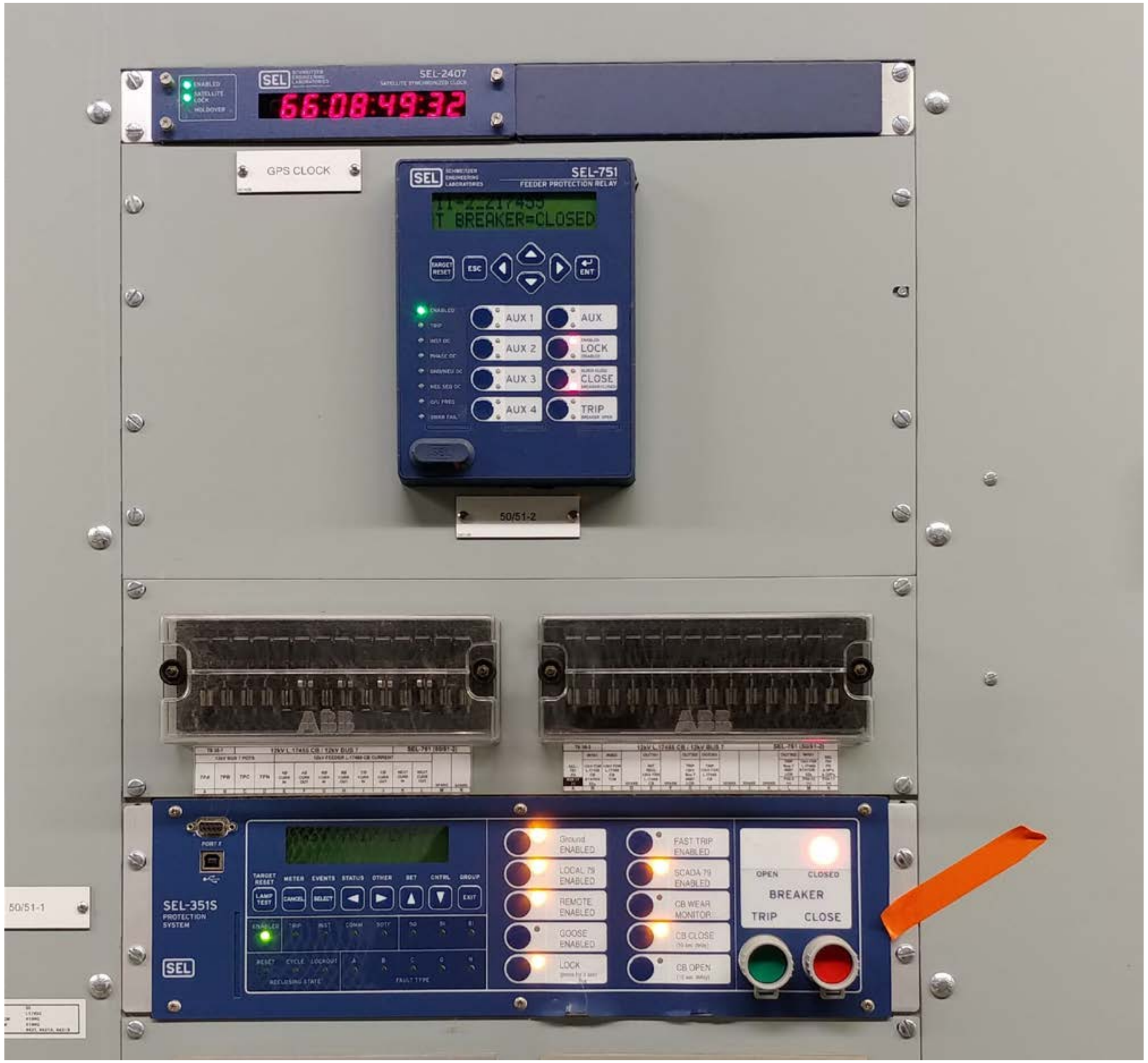
Relay Standardization



Project Scope: Substation

- Project mostly mirrors transmission PMU deployment
- A new PDC cabinet is deployed in each substation. Cabinet includes GPS clock and network switch
- PMU functionality is enabled on existing relays when possible. Some relays may need firmware upgrade.
- New relays are installed if PMU functionality not available.

S&C Vista Gear With SEL Relays

- The gear will be operated by SEL 751 relays instead of S&C controls providing protection functionality
- The Remote Supervisory functionality will remain in the S&C 6802 control
- PMU C37.118 streams will be supported

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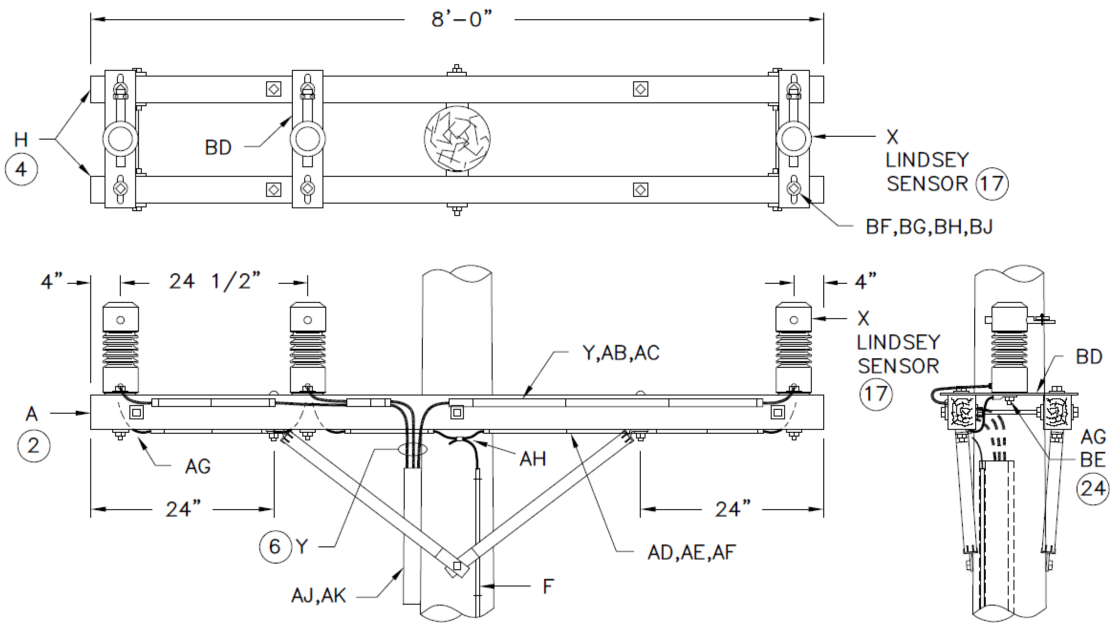
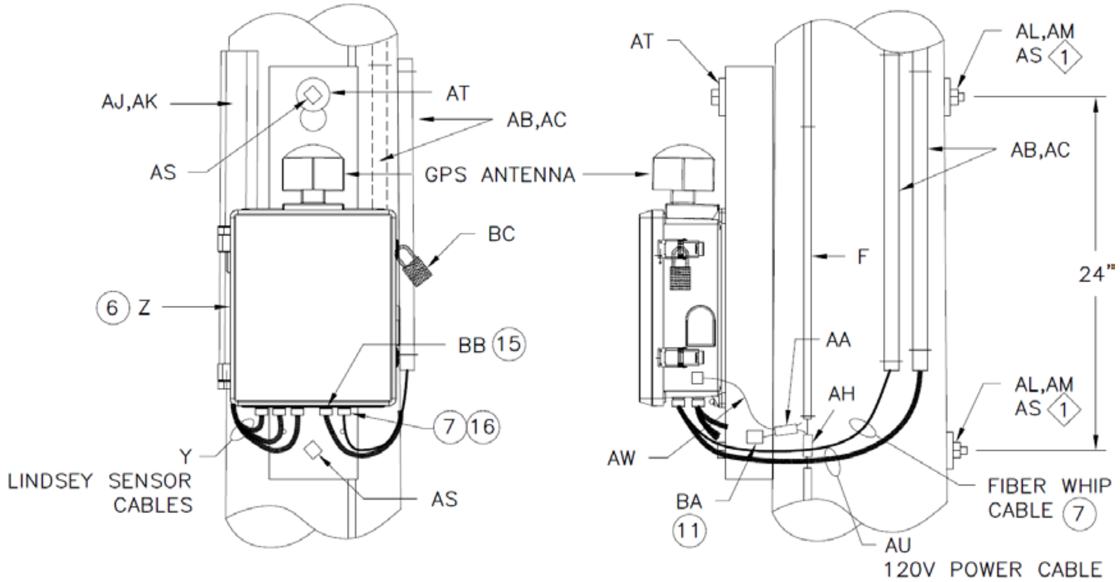


DETAIL – 1
LINDSEY SENSOR INSTALLATION ON DOUBLE CROSSARM



DETAIL – 4
microPMU CABINET

microPMU Standardization

MicroPMU Construction

- Out-of-substation PMUs (microPMUs) are housed on outdoor rated enclosures and have:
  - GPS module for time synch
  - Network communications interface
  - Backup battery
- Voltage/current sensors integral part of system
- Adequate communications required (fiber)
- Data streamed to Phasor Data Concentrator (PDC) then to archive and applications

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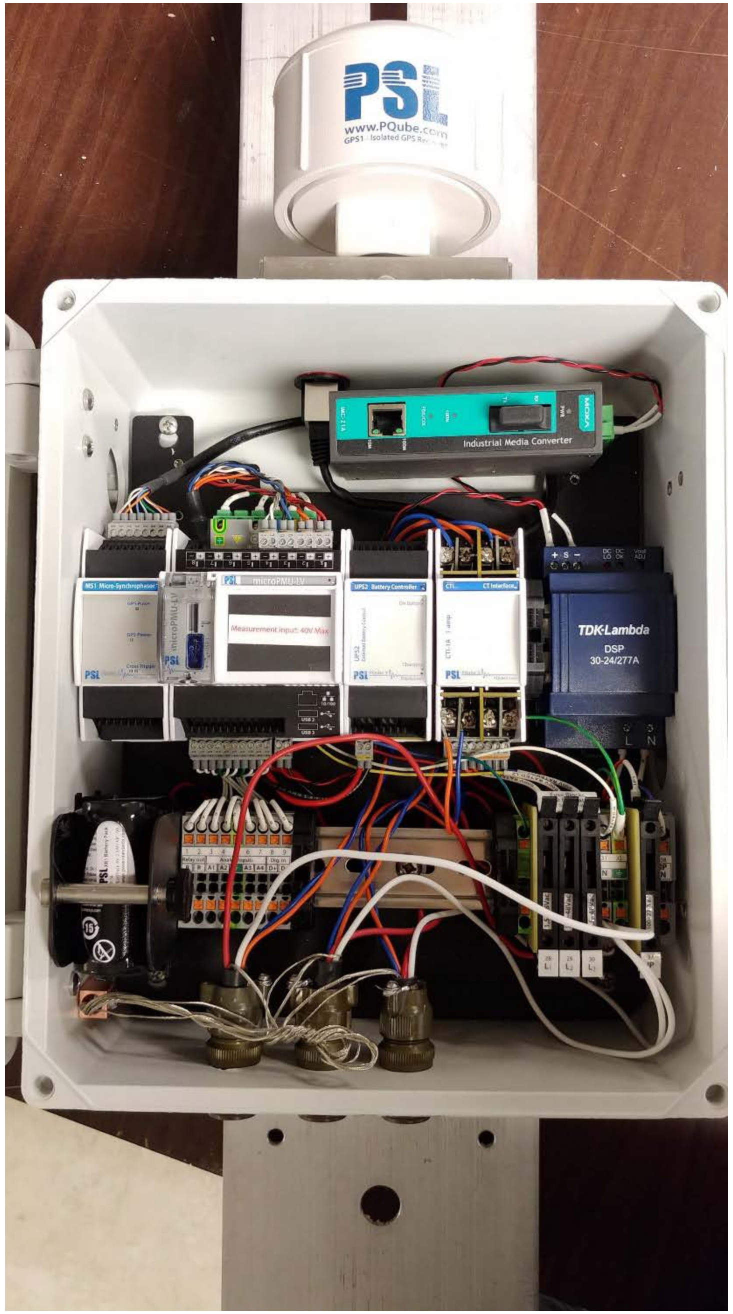
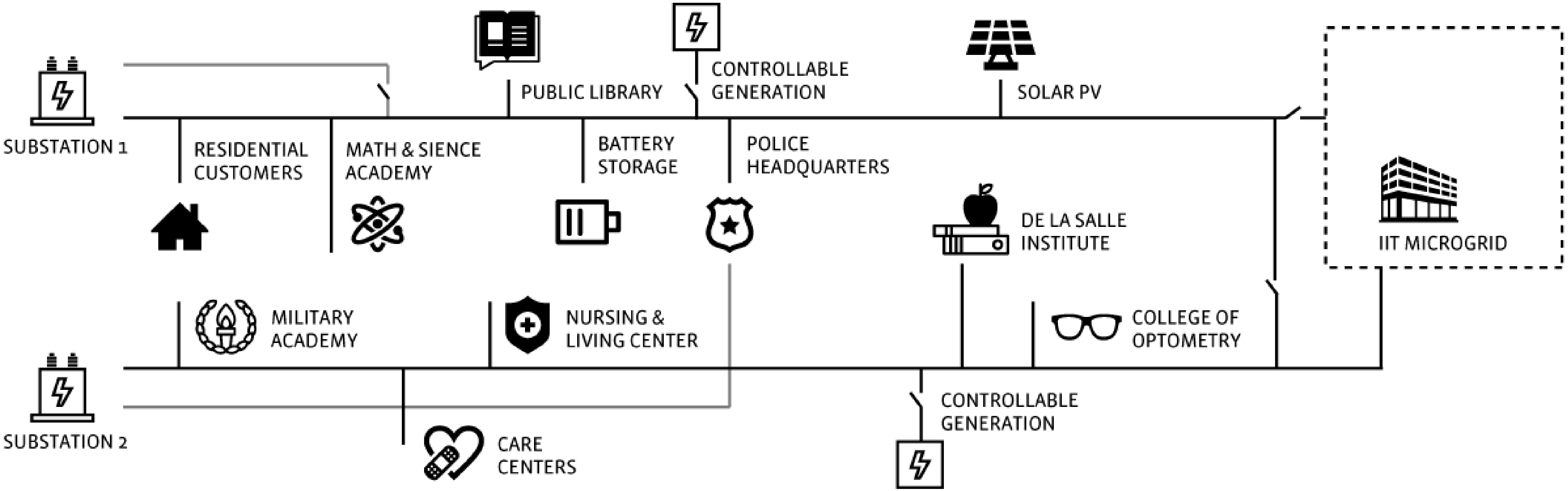




Bronzeville Community Microgrid (BCM)

- Will Serve more than 1300 residences, businesses and public institutions
- 7.3 MW aggregate load
- Phase I – 2.5 MW load, solar PV and Battery Energy Storage System, mobile diesel generation for testing
- Phase II – 4.5 MW load, 7-MW of controllable generation
  - Clustering demonstration with existing microgrid at the Illinois Institute of Technology (IIT)

Microgrid Operation with PMU Data

- Linear state estimation
- Islanding
- Load and generation balance
- Re-synchronization
- Situational awareness
- DG-Load disaggregation
- Asset management and value optimization

Distribution Linear State Estimator (D-LSE)

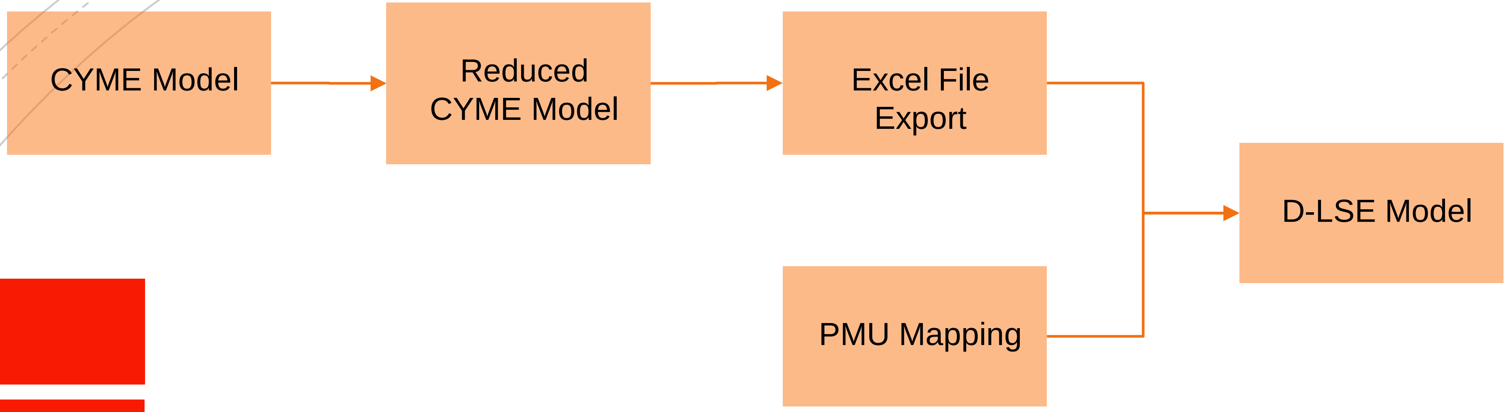
Outline

- Project Scope
- D-LSE Model Integration
- RTDS Test System Setup and Scenarios
- Test Results
- Key Take-aways

Project Scope

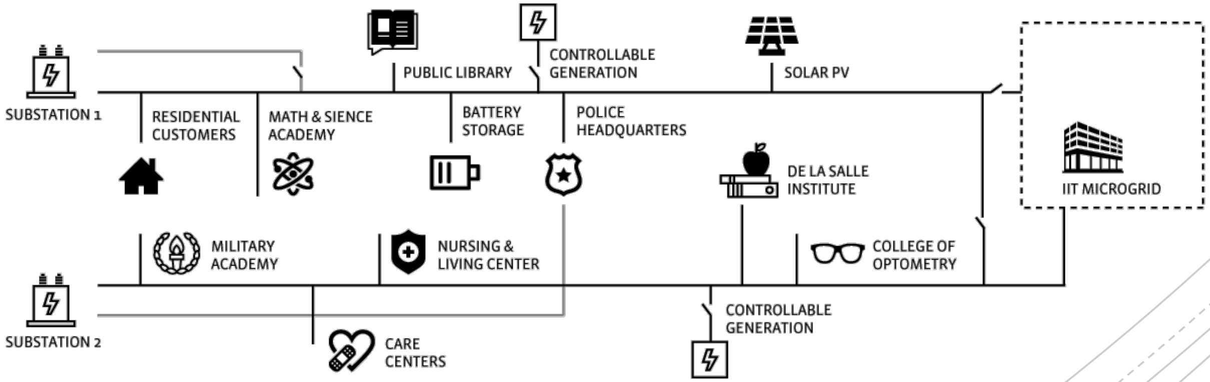
- R&D focused on showing core functionality in a lab environment:
  - D-LSE application development and customization to ComEd microgrid
  - Testing and demonstration in the Grid of The Future Lab using RTDS
  - Functionality enhancement based on test results and user feedback

- Immediate functions of interest:
  - A three-phase distribution linear state estimator utilizing PMU data
  - Three-phase observability analysis and observable node/line identification
  - Bad PMU data detection and correction
  - Monitoring the microgrid and microgrid controller (a starting use case)
  - Alarming/archiving and metrics gathering and reporting
  - Visualization and creating situational awareness wall
  - Identifying limited switching events (topology changes)
    - More advanced event detection to be developed



Model Integration with D-LSE

- CYME model reduction to get equivalent BCM model
- Convert reduced CYME Model to D-LSE model via exported excel file
- Mapping File Creation: PMU signal mapping to D-LSE model



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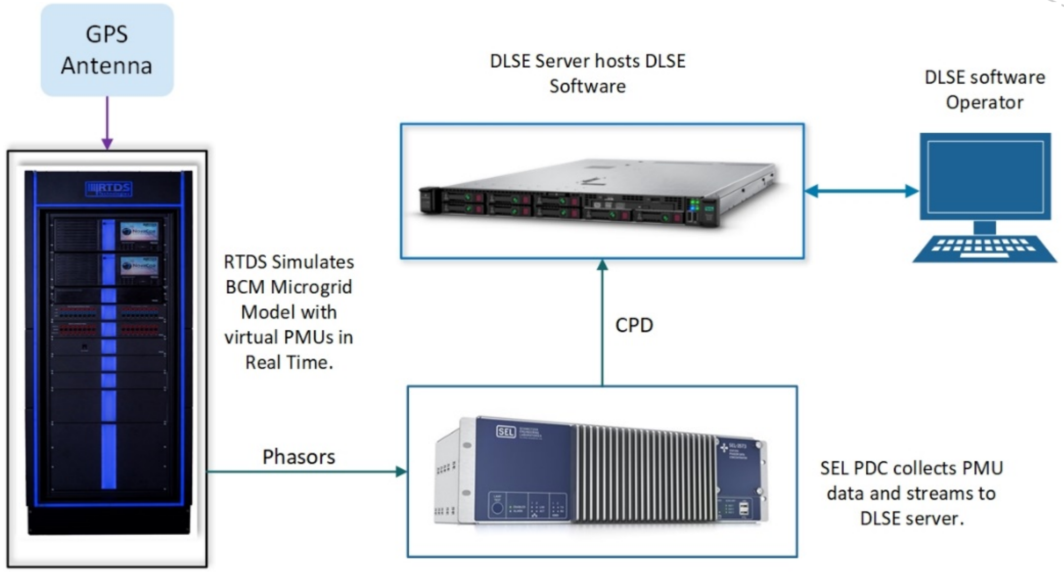
Test System Setup and Scenarios

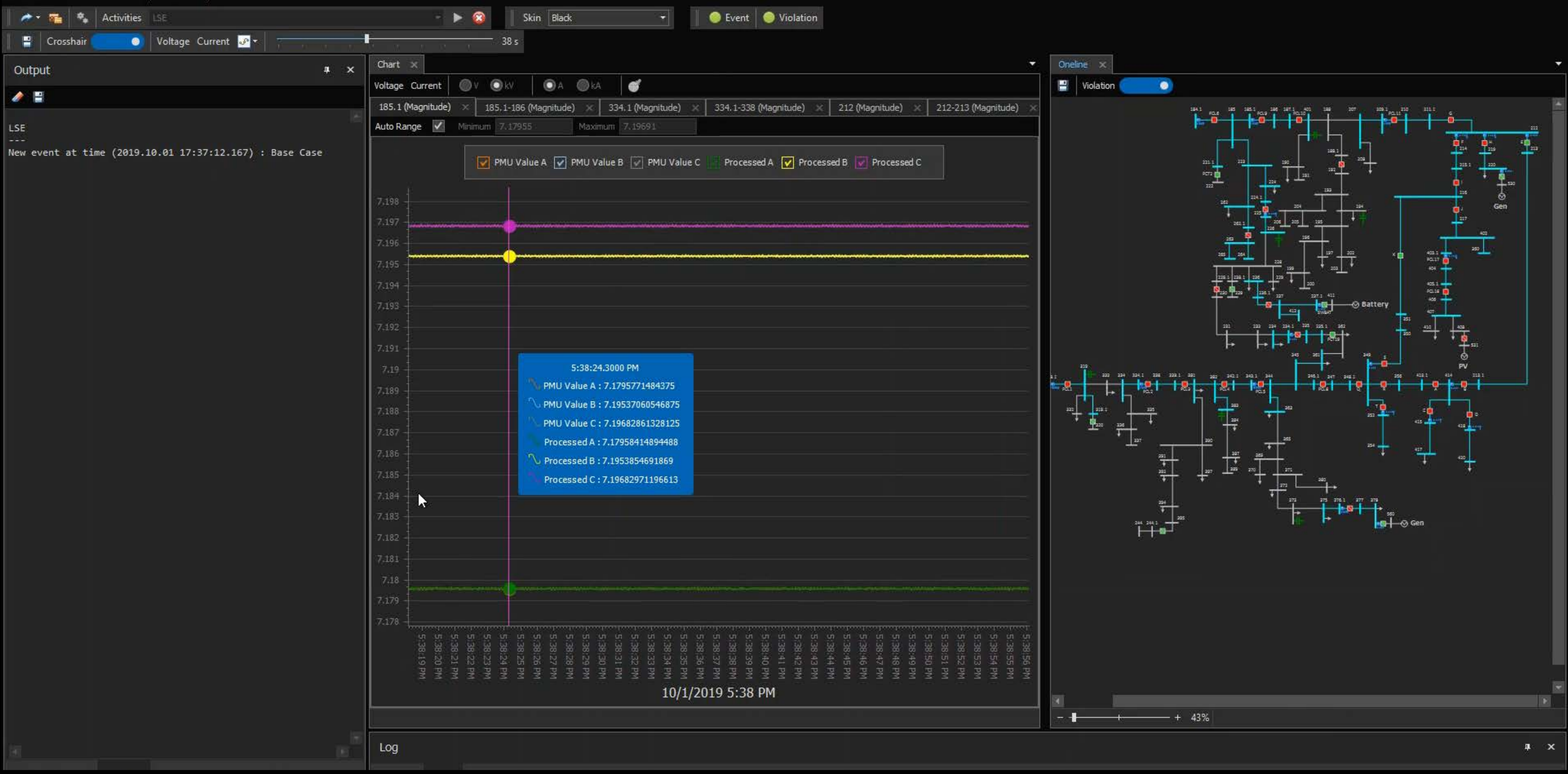
- Simulated different operating conditions and system topology
- Tested both offline and in real-time

- Lab Setup:



- Scenarios:

No.	Test Cases	Description
1	Base Case	Previously provided, no new data set required
2	Load variation	Base Case with injected load variation
3	Observability analysis	Adding/removing PMUs
4	Change of PV profile	Use High Variable PV Profile for PV output
5	Alarming capability on violations	Trigger Under Voltage and Over Voltage
6	Under bad data conditions	Data dropout for 2 seconds, All phases, Voltage and Current
		Data dropout for 0.5 second, Only A phase, Current
		Noisy data, 5-10%, All phases, Voltage and Current
		Measurement constantly dropping to an offset of normal value and immediately comes back every 1-3 samples, repeating for 1 min, All phases, Only Voltage and Current
7	Under topology change conditions	Base Case → DER on
		DER on → Sub-Island 1
		DER on → Sub-Island 2
		DER on → Transfer 1 → Full Island
		DER on → Transfer 2 → Full Island


Activities LSE
Skin Black
Event
Violation
Crosshair
Voltage Current
38 s
Output
LSE

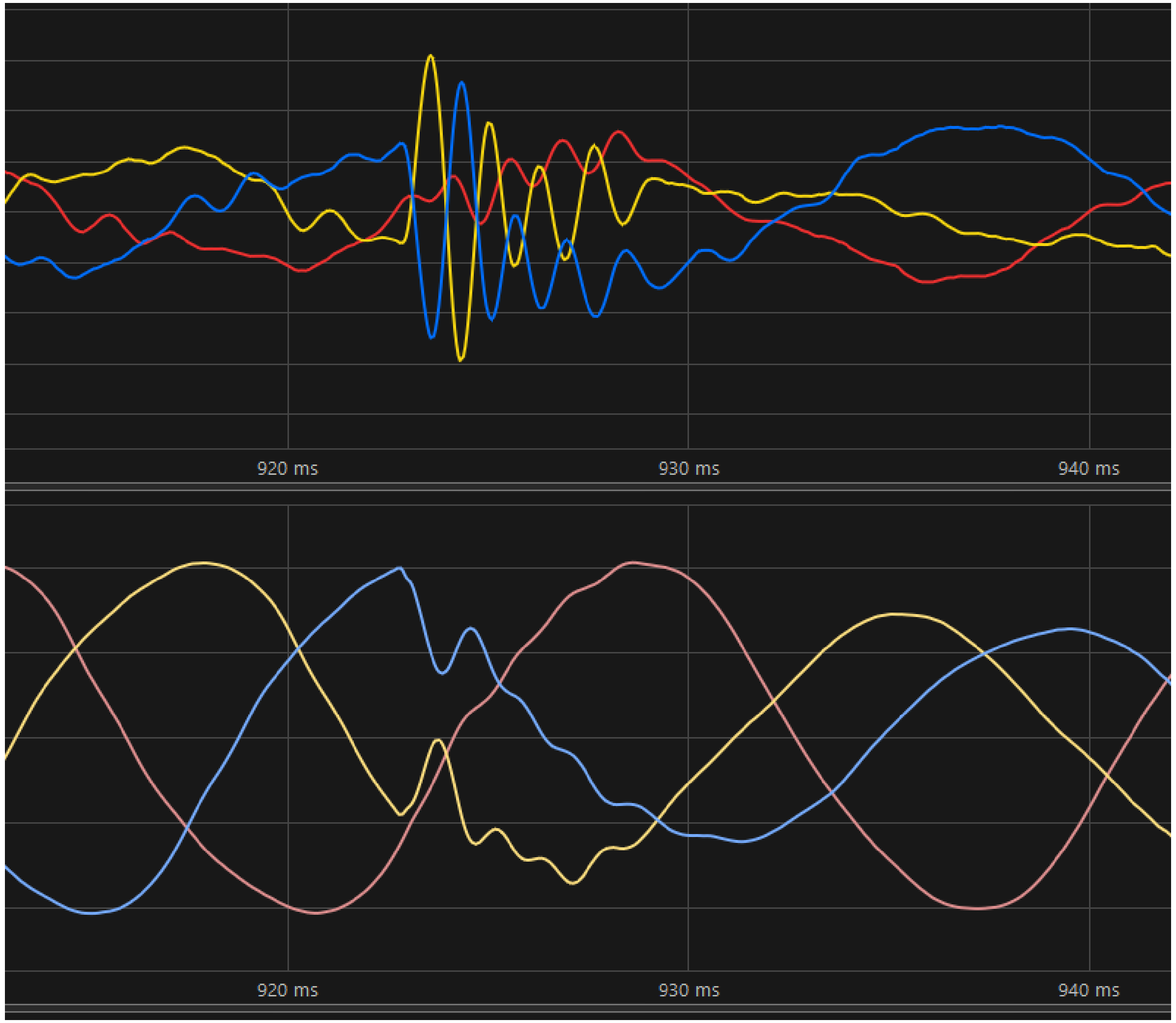
New event at time (2019.10.01 17:37:12.167) : Base Case
Chart
Voltage Current
V kV A kA
185.1 (Magnitude)
185.1-186 (Magnitude)
334.1 (Magnitude)
334.1-338 (Magnitude)
212 (Magnitude)
212-213 (Magnitude)
Auto Range
Minimum 7.17955
Maximum 7.19691
PMU Value A
PMU Value B
PMU Value C
Processed A
Processed B
Processed C
5:38:24.3000 PM
PMU Value A : 7.1795771484375
PMU Value B : 7.19537060546875
PMU Value C : 7.19682861328125
Processed A : 7.17958414894488
Processed B : 7.1953854691869
Processed C : 7.19682971196613
10/1/2019 5:38 PM
Oneline
Violation
Battery
Gen
PV
43%
Log

Key Takeaways

- Developed 3-Phase D-LSE prototype
- Tested and validated prototype in lab environment
- Optimal PMU placement work provided guidance for future distribution PMUs deployment
- Identified limitations
  - Manual model integration process
  - Limited topology change identification
  - Limited robustness of bad data impact
- Evaluated potential enhancements and plan moving forward

Lessons Learned

- Accurate labor forecasts are essential
  - Engineering for substation prints and designs
  - Internal substation crews
  - Internal testing engineers
  - Contracted resources
- Scheduling volatility
  - Critical feeders → hard to take outages
  - Normal work schedules
- Material availability
  - Long-lead items
  - Backorders and delays
  - Lost material



What's Next

- Leverage point-on-wave data
  - Predictive modeling
  - Pre-event detection
- 5 year programmatic strategy
- Stream C37.118 data from capable DA devices
- Three-tiered approach
  - Substation
  - Distribution main-stem
  - Feeder edge

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Thank You!

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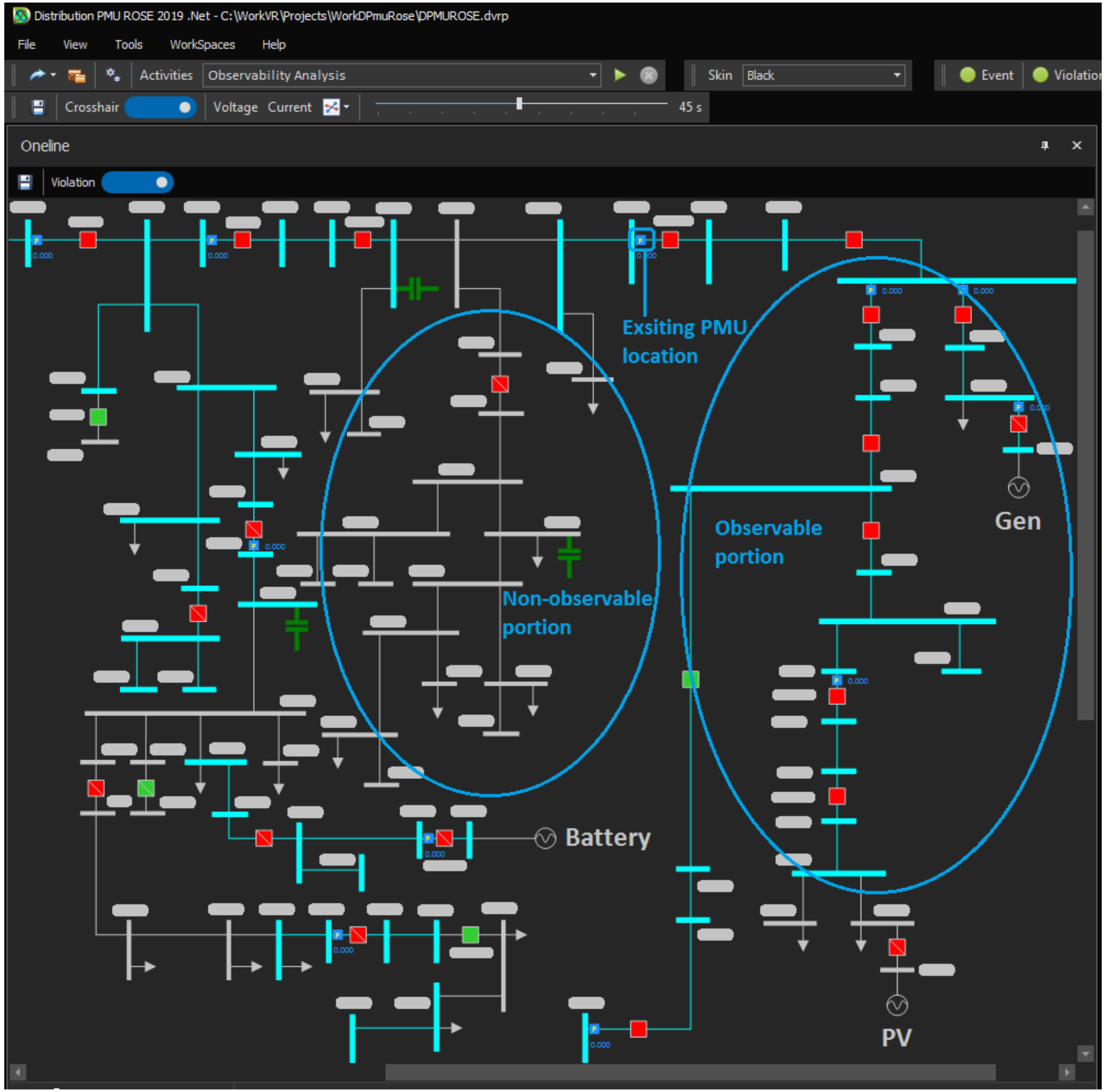
Appendix

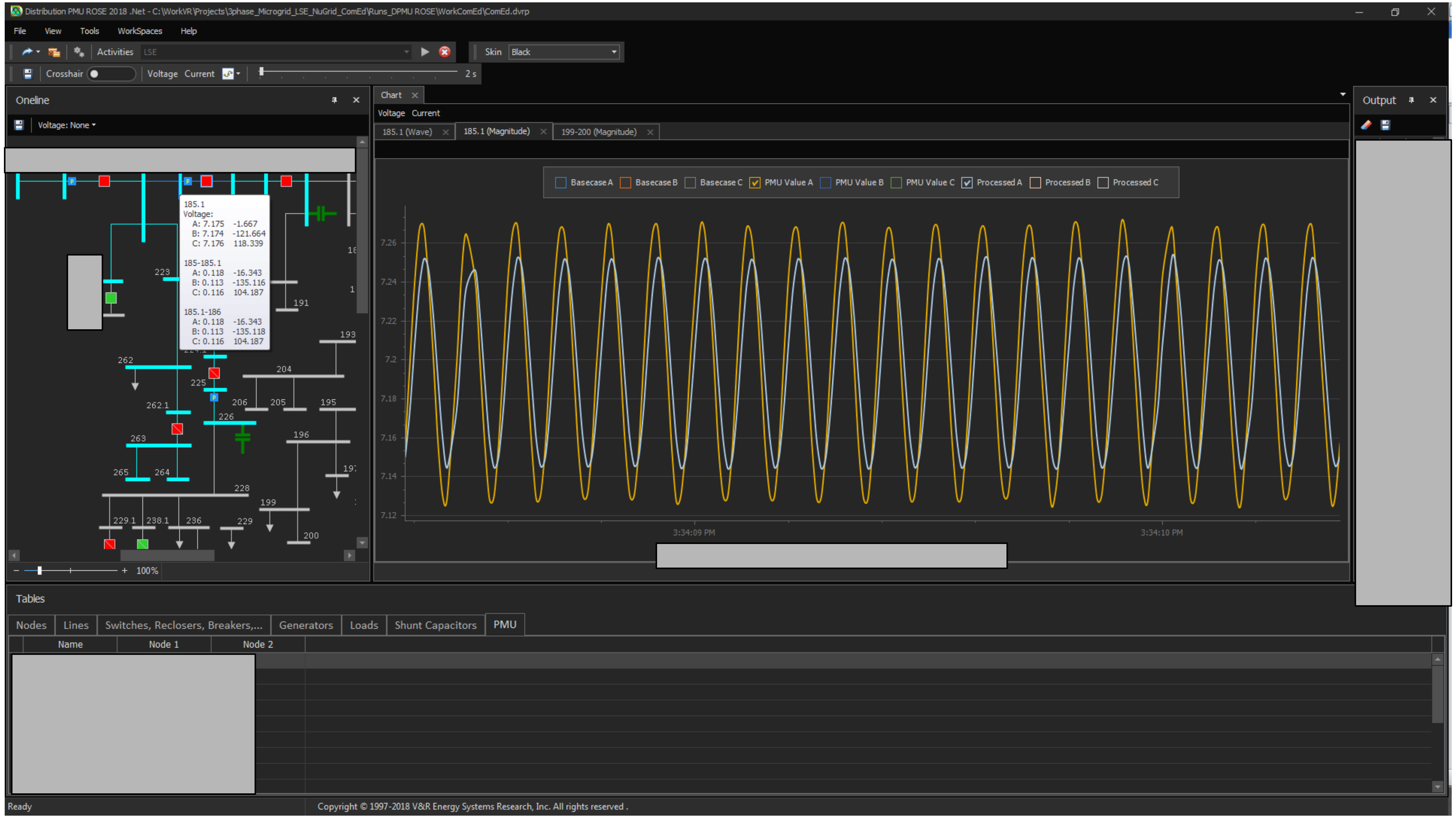
D-LSE Result – Observability Analysis & Visualization



D-PMU ROSE considers a power system network to be observable for a given network topology if voltage vector at each node can be calculated based on the PMU measurements

Blue – nodes and branches that are observable with planned PMU installations (for current network topology)
Black – non-observable nodes and branches
P – Planned PMU installations

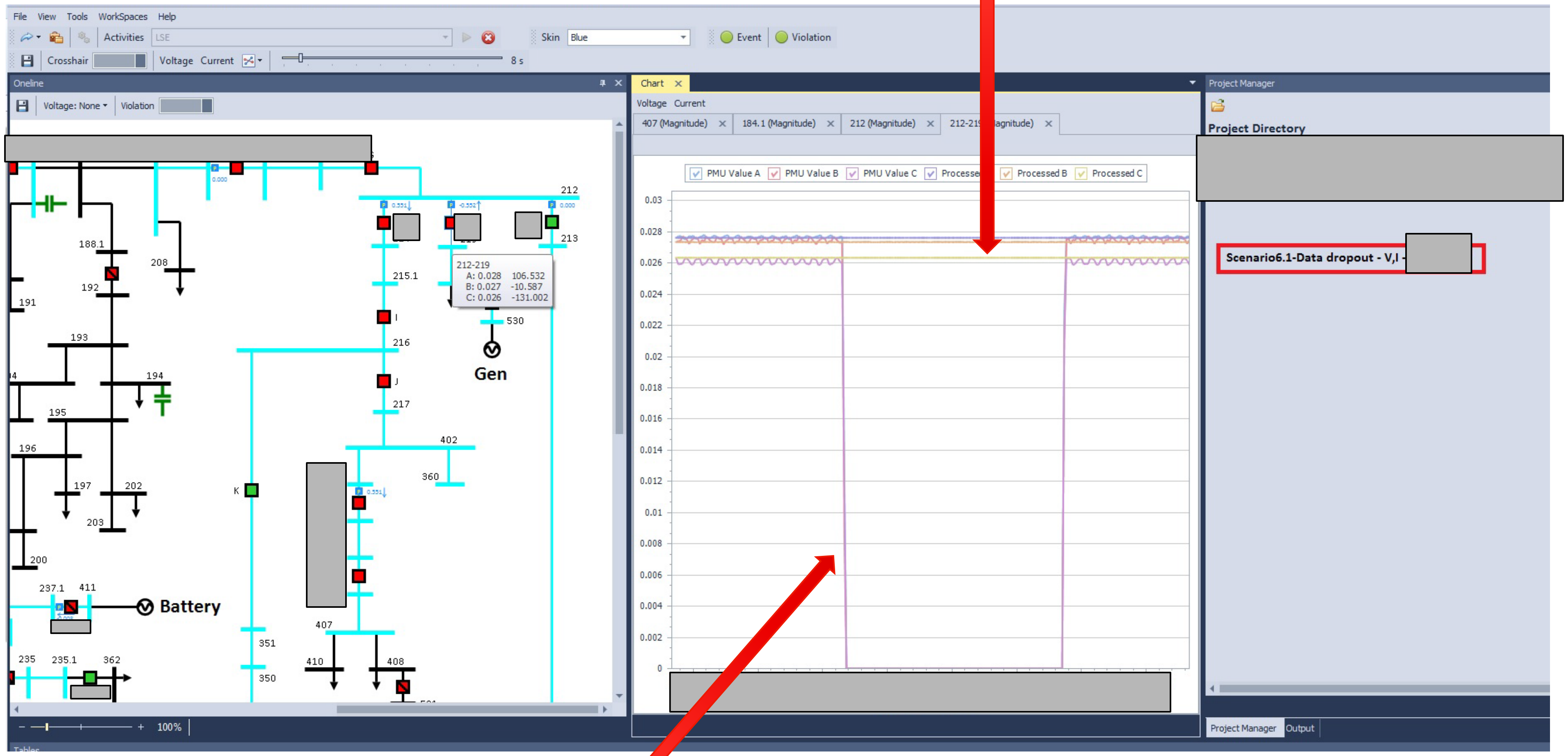
D-LSE Result – Estimated vs. Raw Data Visualization



- Yellow – raw PMU values
- Light Blue – estimated values after the LSE (filtering and weighted least square method)
- Estimated values of voltages and currents (for all phases) are also shown on single line diagram by placing mouse pointer over a node/branch

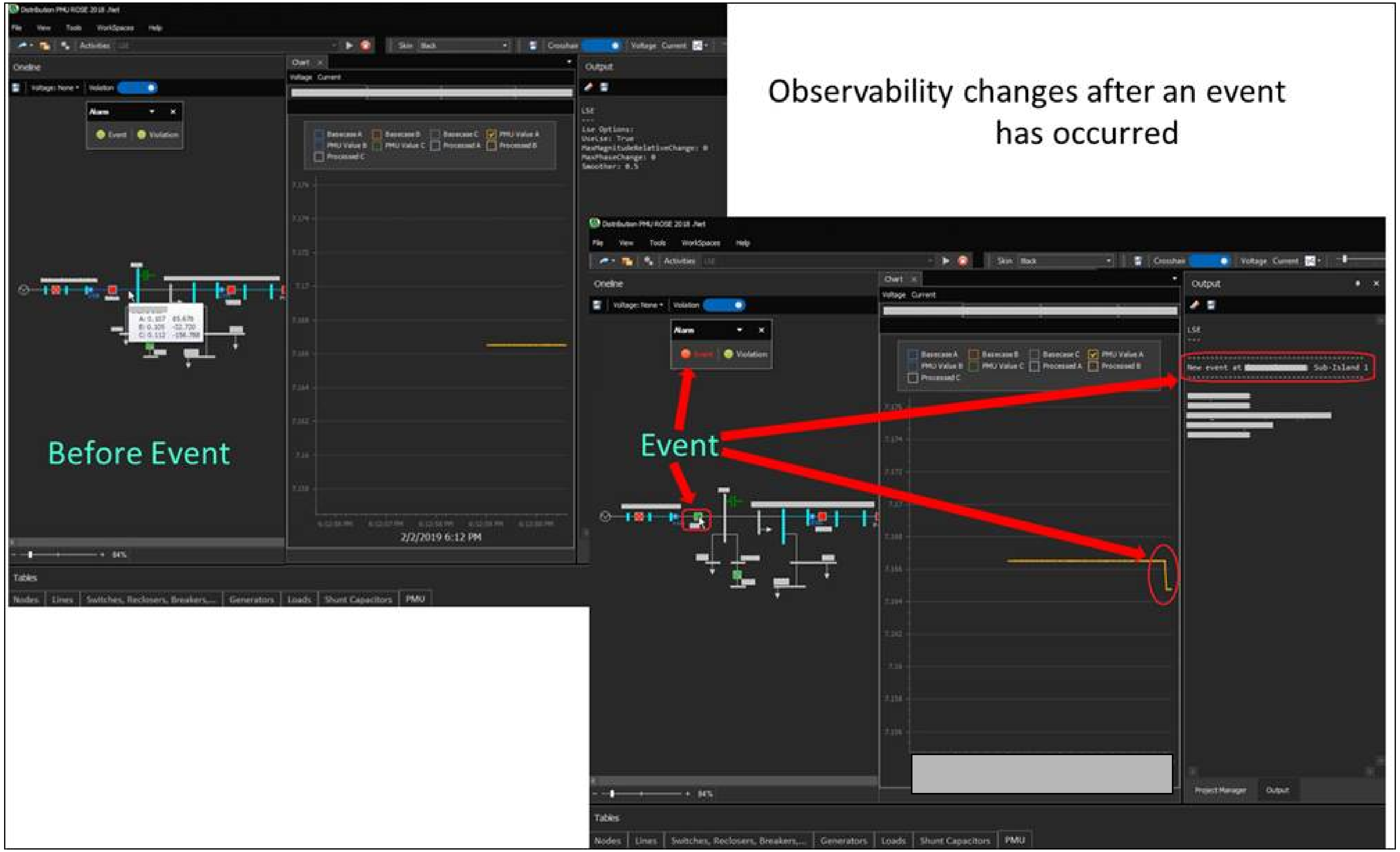
Bad Data Detection and Conditioning

Estimated values after the D-LSE (filtering and weighted least squares method): Yellow

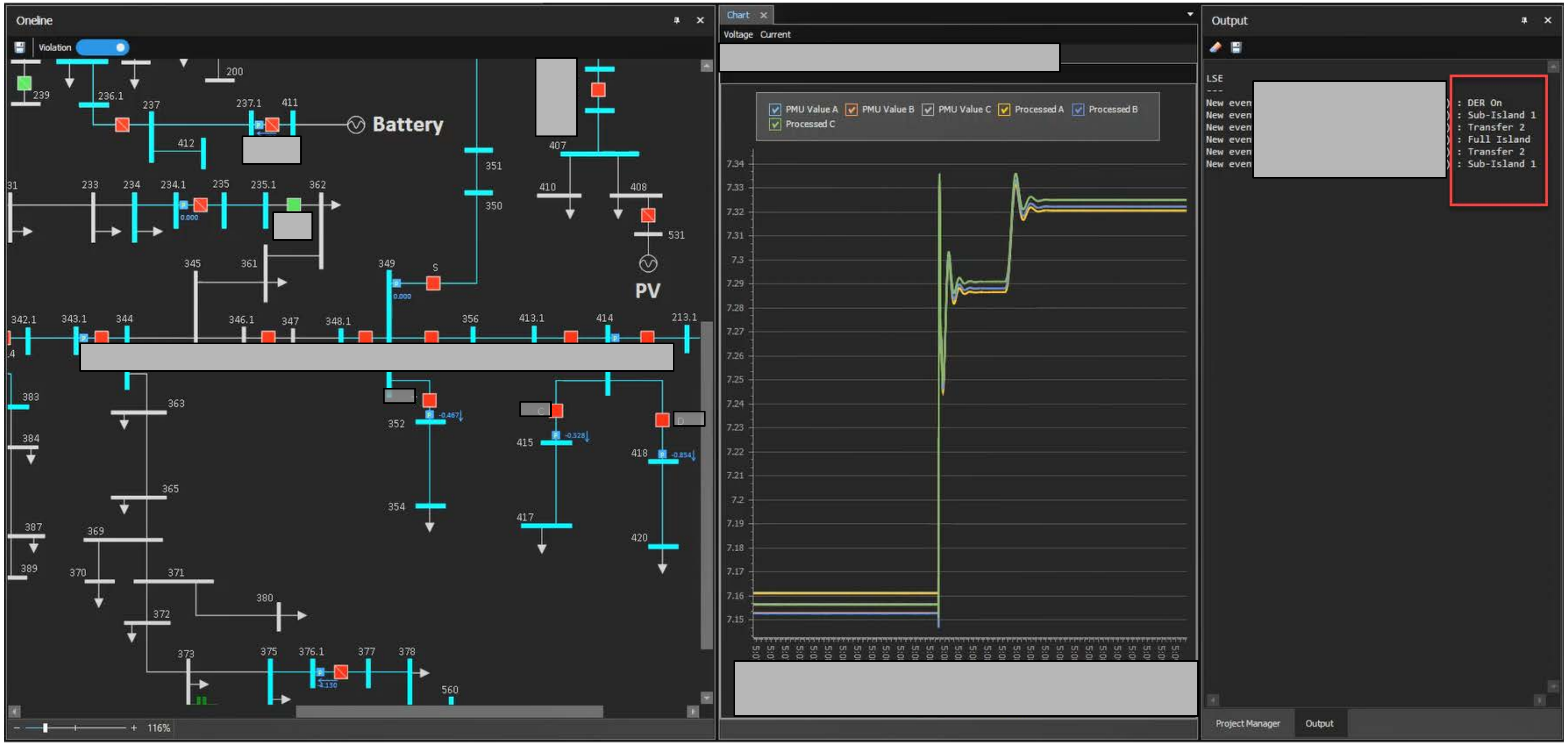


Raw PMU values (phase B)

Detecting and Alarming on Switching Events



Topology Changes



- Estimated value follow raw data during both steady state and transient conditions
- D-LSE identifies defined topology changes correctly