Implementing PMU-based Systems for Transmission and Distribution System Analysis

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1. TNB's Experience Deploying a PMU-Based EMS System

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Head of Power System Unit at TNB Research
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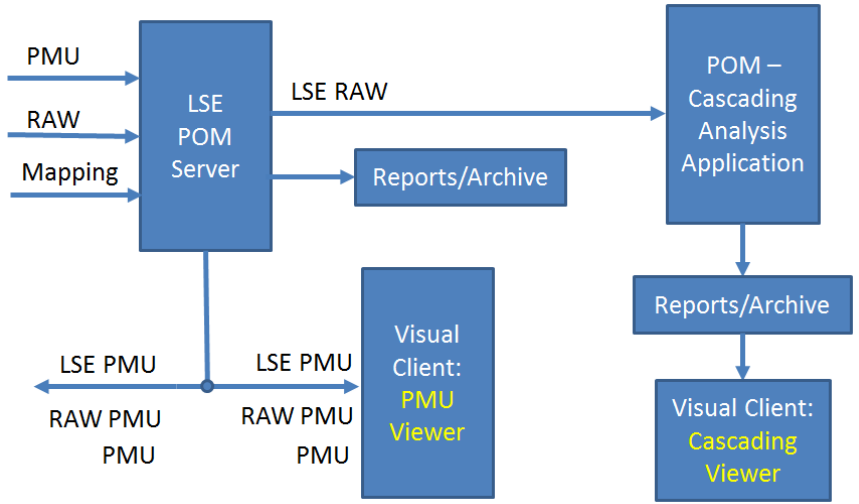
Background

- Tenaga Nasional Berhad (TNB) is the largest electricity utility in Malaysia serving 9.2 million customers
  - TNB owns 57.2% of the 26.296 MW generation installed capacity, and operates transmission network with a total circuit length of 23,082 km and distribution network with a total circuit length of 660,038 km
  - TNB has recorded the highest demand of 18,566 MW and the highest energy demand of 391.85 GWh/day
- TNB Research has been instrumental in implementing the Wide-Area Intelligent System program at TNB which explores the potential benefits of PMU
  - Several real-time PMU-based applications have been successfully developed
- TNB aims for full network observability with PMUs for voltage levels of 500 kV and 275 kV by 2021

PMU-Based EMS System

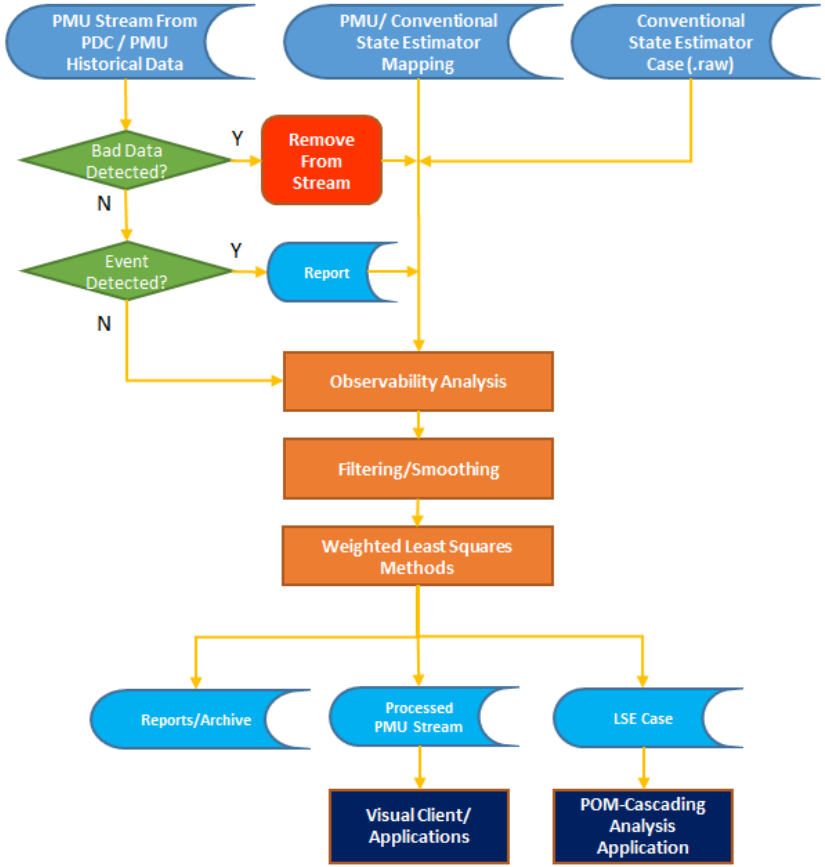
- **TNB PMU ROSE** is PMU-based EMS system developed by V&R Energy
- Consists of multiple integrated applications:
  - LSE POM Server
  - POM-Cascading Analysis application
  - POM-OPM remedial actions application
  - TNB PMU Viewer
  - TNB Cascading Viewer



-	LSE	Linear State Estimation;
-	LSE RAW	PMU-based State Estimator cases in Siemens PTI PSS/E .raw data format;
-	POM	Physical and Operational Margins Suite;
-	PMU	Phasor Measurement Unit streaming data;
-	RAW	Conventional State Estimator (CSE) cases;
-	LSE PMU	Conditioned and expanded PMU streaming data
-	RAW PMU	Voltage magnitude and phase from CSE cases

LSE POM Server Analysis Framework

- Multi-step process:
  - Bad data detection
  - Event detection
  - Filtering and smoothing
  - LSE (e.g, weighted least squares method)
  - Creation of expanded and conditioned PMU data stream
  - Creation of PMU-based State Estimator cases (e.g., LSE Case)

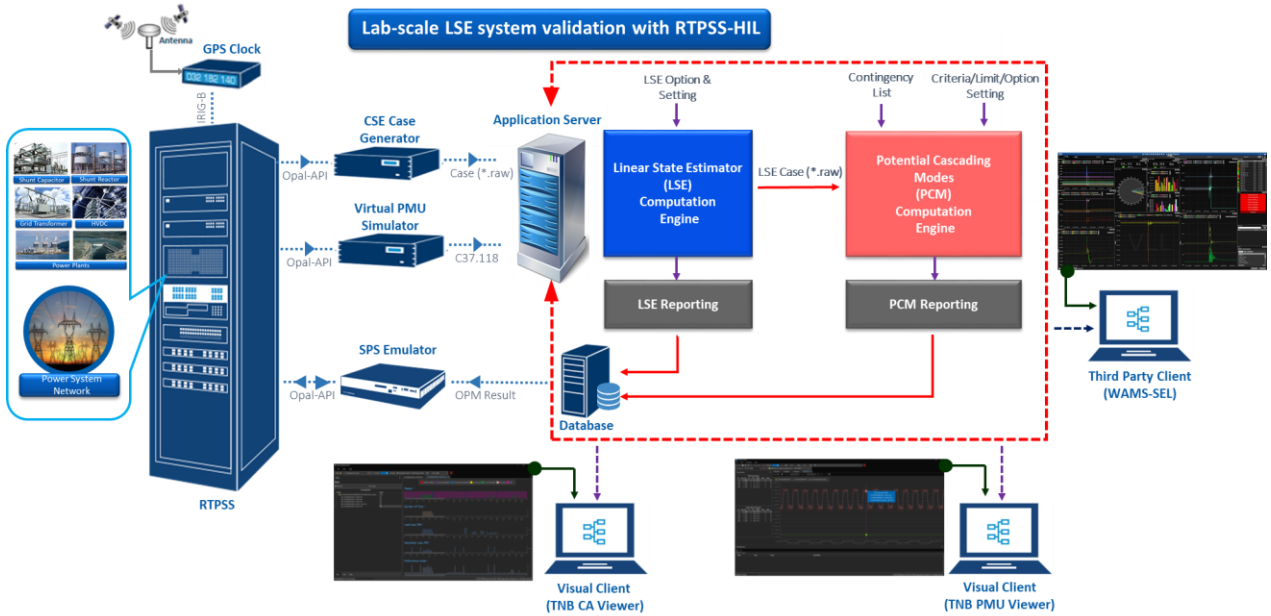


TNB PMU ROSE System Facts

- The conventional State Estimator (CSE) cases represent TNB system operational model with over 1,500 buses/2,800 branches after topology processing
- Signals from 1218 PMUs / 7 PDCs are sent to TNB PMU ROSE at the rate of 25 samples/second
- Linear state estimation and all related computations are performed at the rate of 25 samples/second
- LSE cases are created at a user-defined intervals, when bad data is detected for longer then a certain interval, or an Event is detected by TNB PMU ROSE

Testing and Validation of TNB PMU ROSE

- The conventional State Estimator (CSE) and the PMU are emulated using real-time data from the real-time simulator of OPAL-RT
- TNB PMU ROSE is run on a dedicated server
- Control signals are sent to the real-time simulator for remedial action



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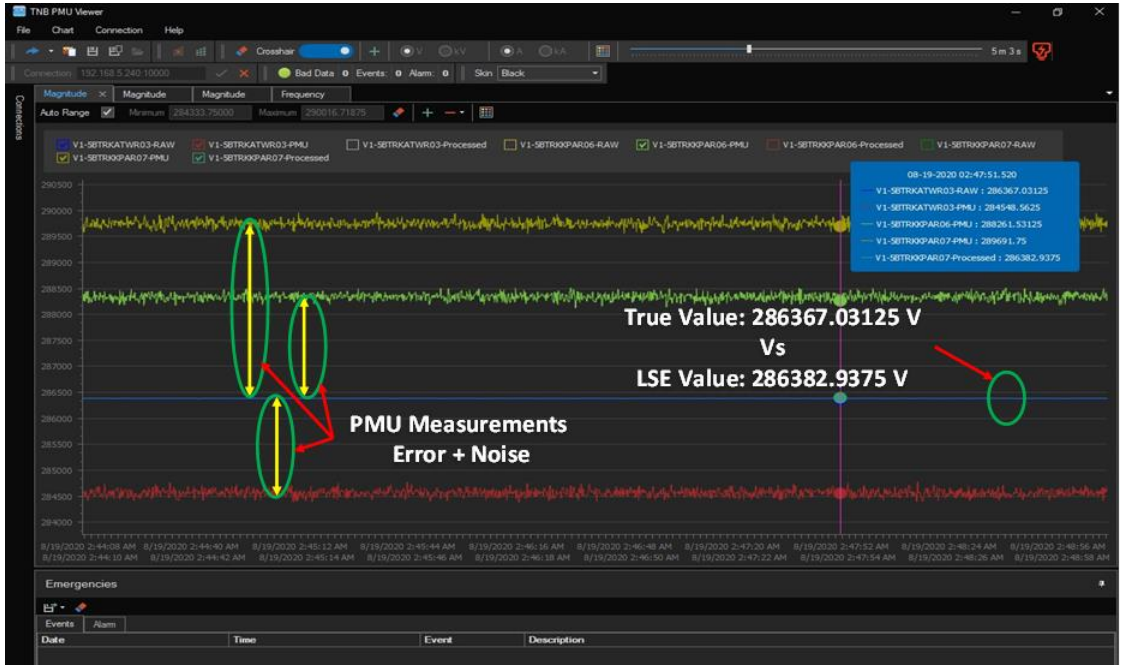
Estimating Values Using LSE

- The results show that LSE (dark green line) successfully suppress the error and provides voltage estimates with a difference of less than 0.01% compared to the true value
- Substation with multiple PMU measurements with random errors and noise denoted by yellow, light green and red lines
- The true value is blue line

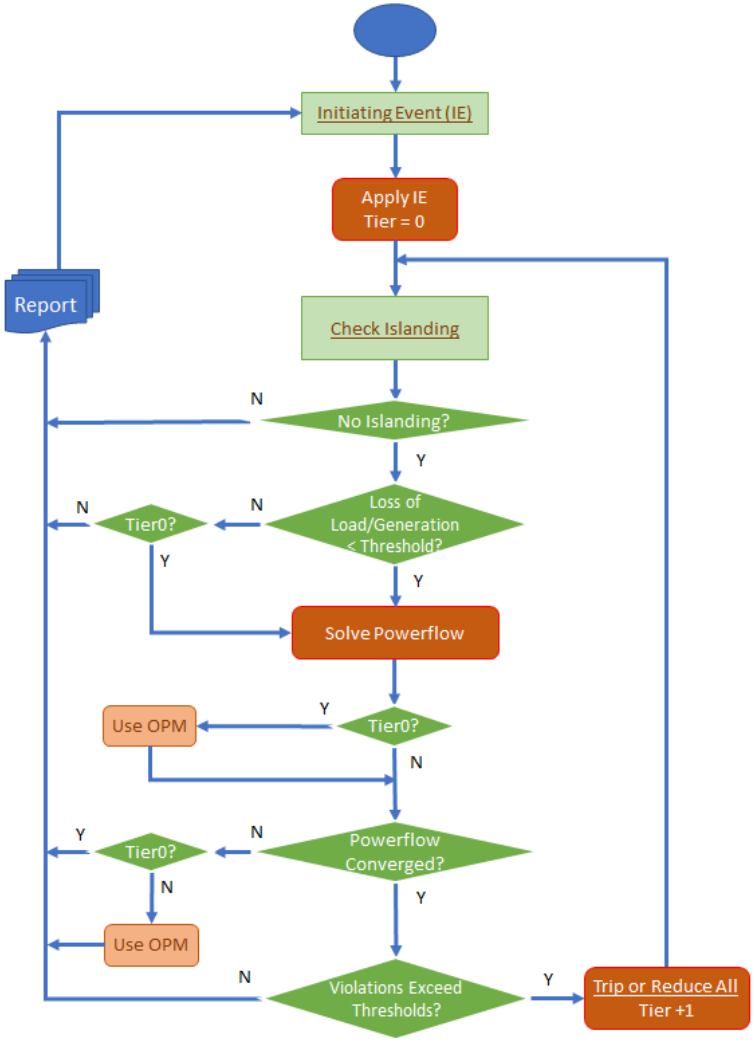


POM – Cascading Analysis Application

- Performs automated cascading analysis using LSE Cases created by the LSE POM
- Cascading outages are simulated based on consecutive AC contingency analysis
- Two cascading scenarios are incorporated:
  - "Thermal" scenario
    "Voltage" scenario
- Cascading analysis may be performed with and without remedial actions

Cascading Analysis Framework

- There are three approaches to use OPM (Optimal Mitigation Measures) remedial actions during execution of cascading analysis:
  - (1) Determine remedial actions after an Initiating Event (IE);
  - (2) Determine remedial actions at the last tier (e.g., at the end of cascading process);
  - (3) Determine remedial actions after an IE and at the last tier.



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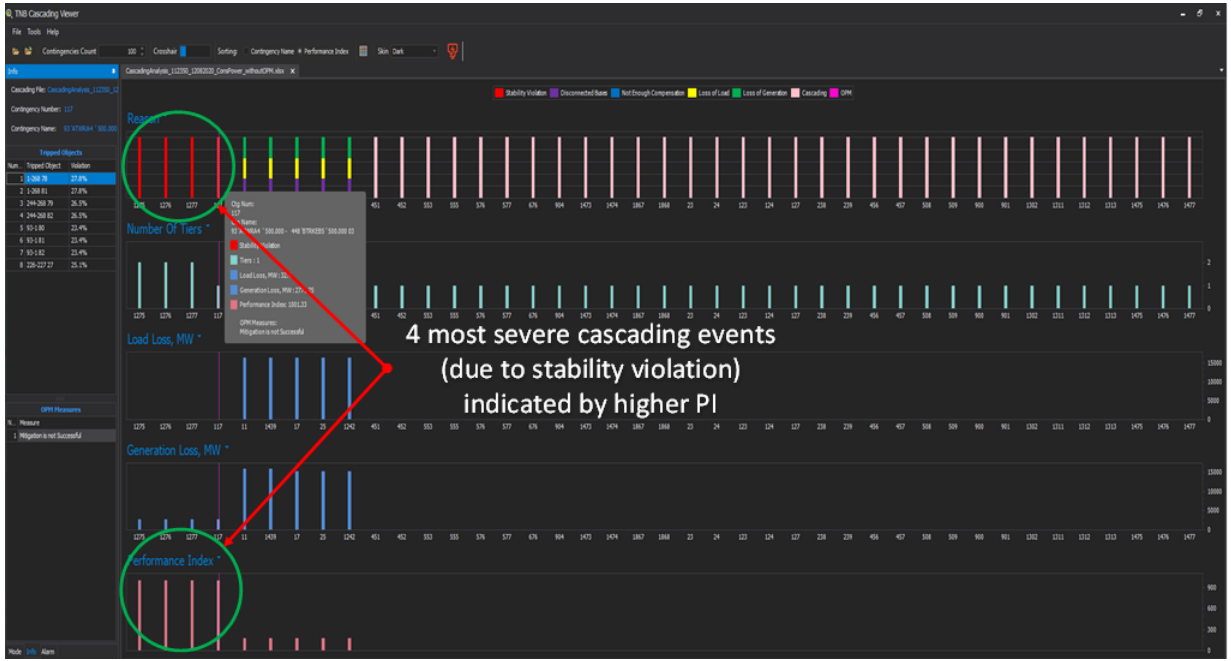
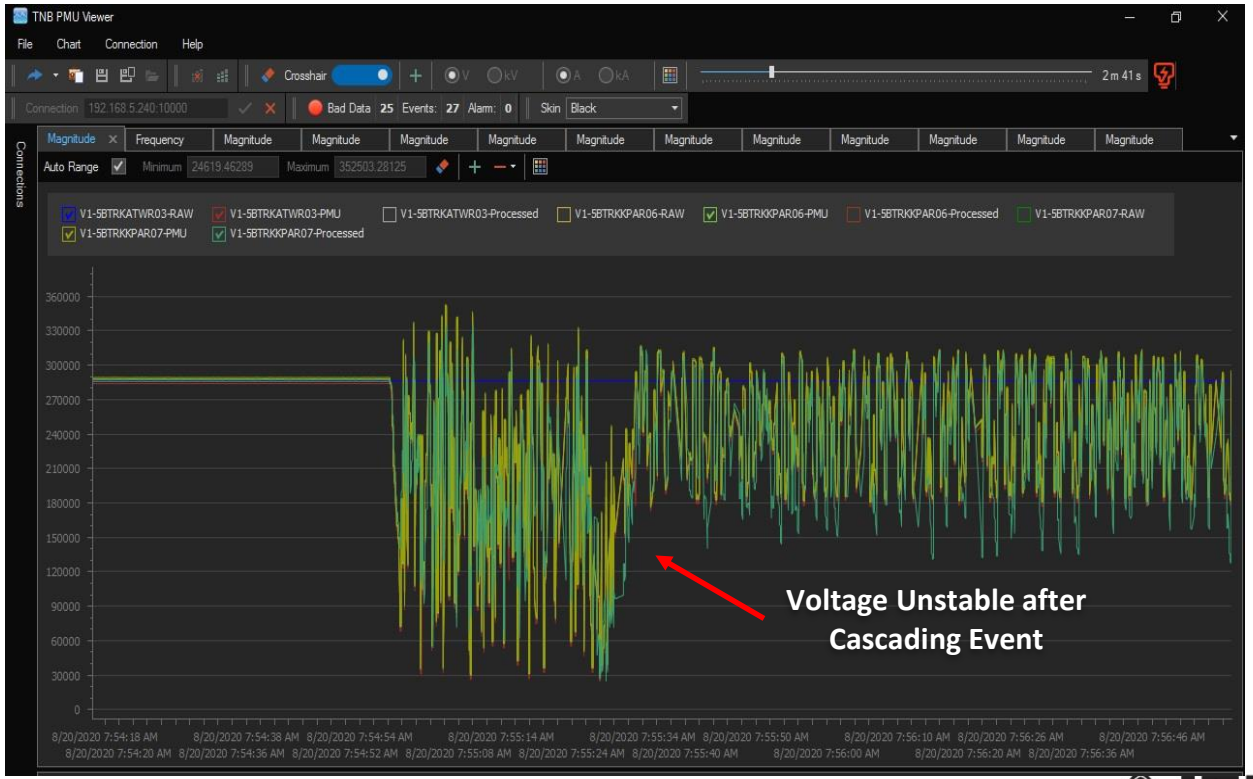
Cascading Analysis

- Cascading Viewer visualizes results of online cascading analysis
- 1877 N-1 initiating events are analyzed in one run
- 41 critical cascading events were identified and ranked based on severity measured using the performance index



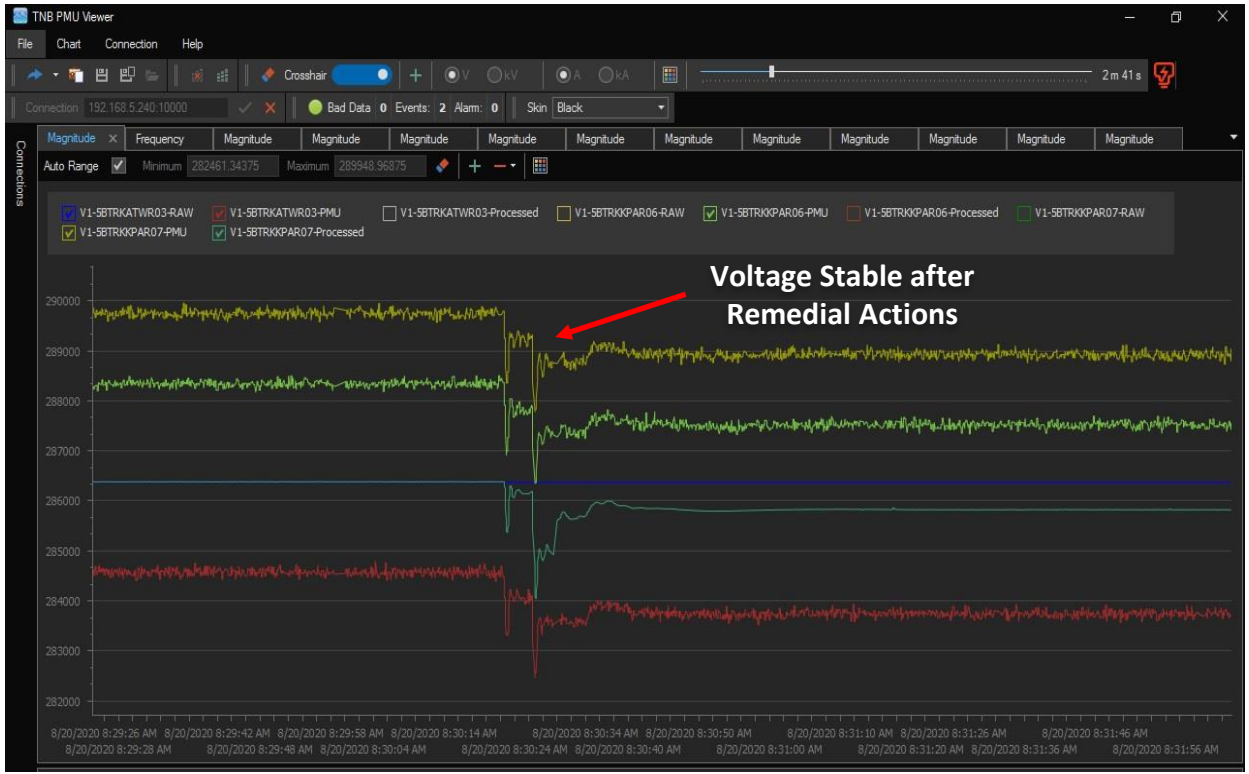
Stability Violation as a Result of Cascading

- A critical Initiating event results in stability violation
- The initiating event was tripping a transformer which leads to overload on other branches



Effect of Remedial Actions

- Optimal mitigation measures are identified to alleviate this stability violation
- The effect of these measures can be seen in the PMU Viewer



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Conclusions and Future Work

- PMU-based EMS system was successfully deployed at TNB
- The LSE increases network visibility with accurate state estimates derived based on a set of observable PMU measurements:
  - PMU measurements are smoothed and bad data are filtered, and bus fault and line trip events are detected
- The online cascading analysis application has been demonstrated as the use case of LSE utilizing the PMU-based state estimator case
  - Fast AC contingency analysis solved with the full Newton method
- Remedial actions were demonstrated to be effective in alleviating thermal, voltage and stability violations
- Future work will involve integration with production SCADA/EMS system and PMUs, and exploring other potential applications that will benefit from the LSE

Thank you!

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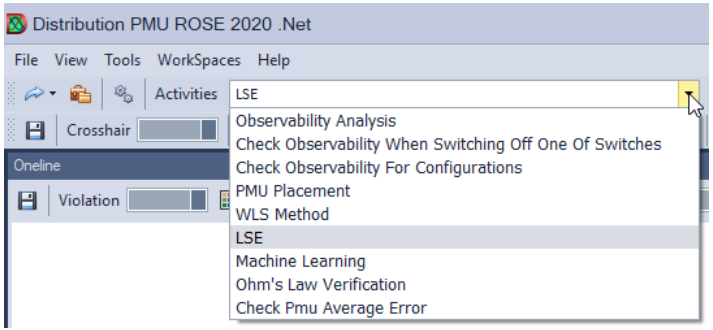
2. Real-Time PMU-based Distribution System Monitoring Platform

Marianna Vaiman, CEO at V&R Energy

Real-Time Distribution System Monitoring Platform

- Provides real-time situational awareness in order to improve resilience of the distribution grid and enhance its reliability
- **D-PMU ROSE** platform consists of the following functionalities:
  - Three-phase distribution linear state estimation (D-LSE)
  - Bad PMU data detection and correction
  - Observability analysis for real-time situational awareness
  - Identifying switching events
  - Archiving and alarming
  - Advanced visualization of distribution grid state
  - Optimal PMU placement for full distribution grid observability
  - Validating model and PMU measurements



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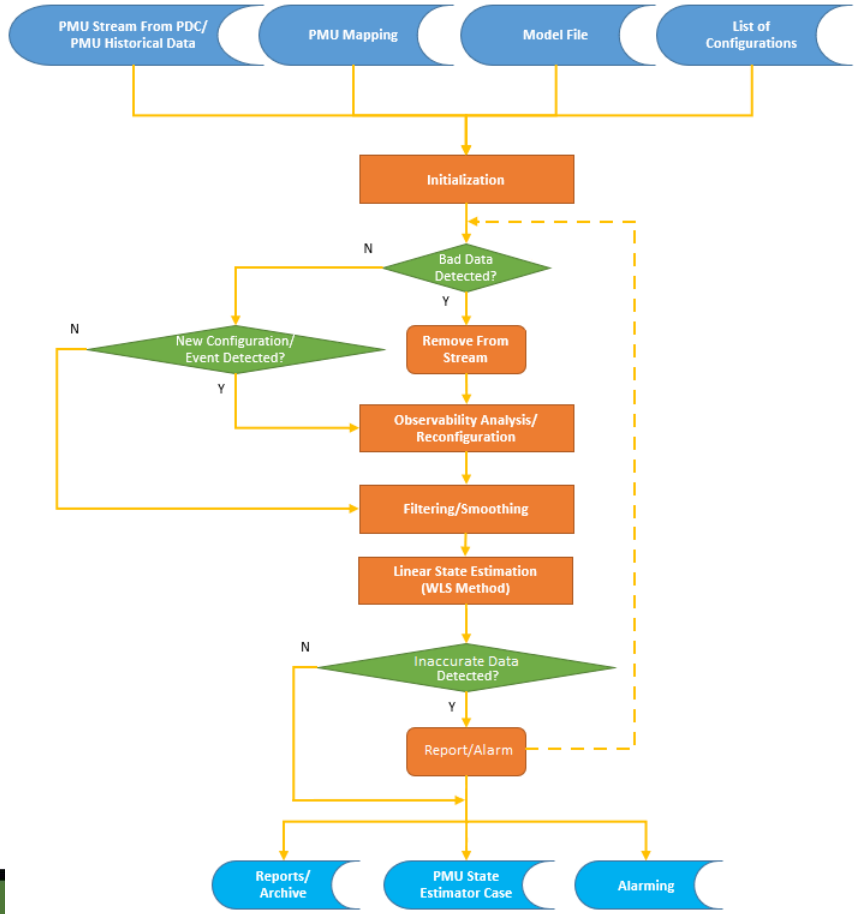
Components of D-LSE Framework

- Multi-step process:
  1. Bad data detection, correction, alarming, reporting
  2. Combination of filtering and smoothing techniques
  3. Observability analysis
  4. Three-phase Distribution Linear State Estimation
  5. Detection of switching events (only based on PMU data)
  6. Real-time system monitoring (voltage and thermal)
  7. Visualization, archiving

- Machine learning is used to improve accuracy of event detection in real-time



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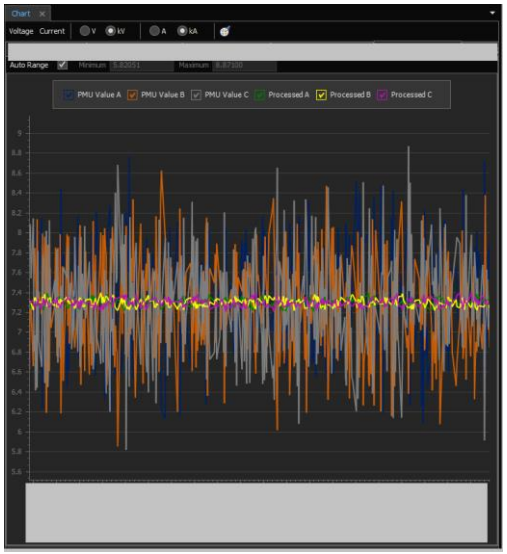
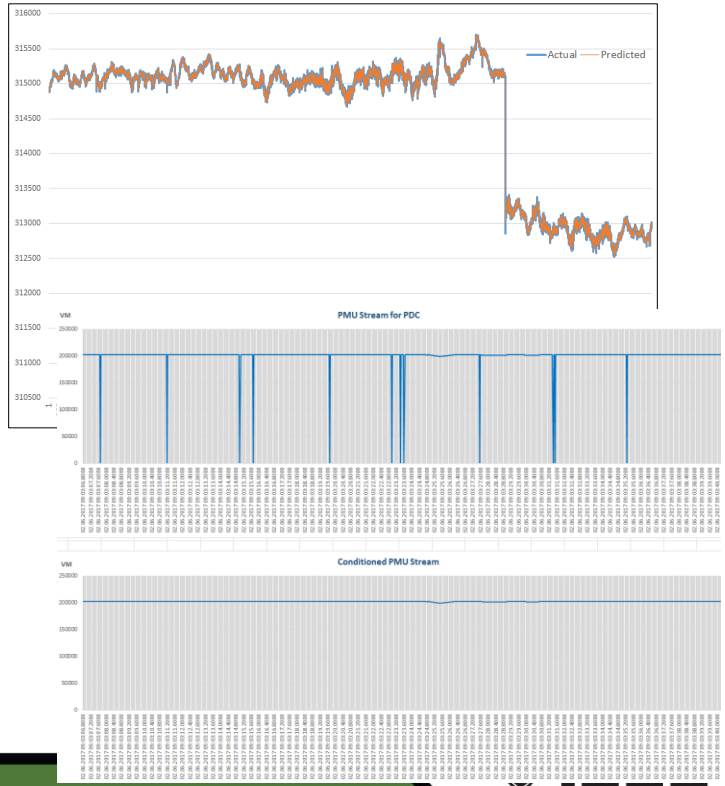
Bad Data Detection and Conditioning

- Step 1: Data pre-screening
- Step 2: Filtering & smoothing
- Step 3: LSE
  - Considers relationship between signals
  - Based on WLS method





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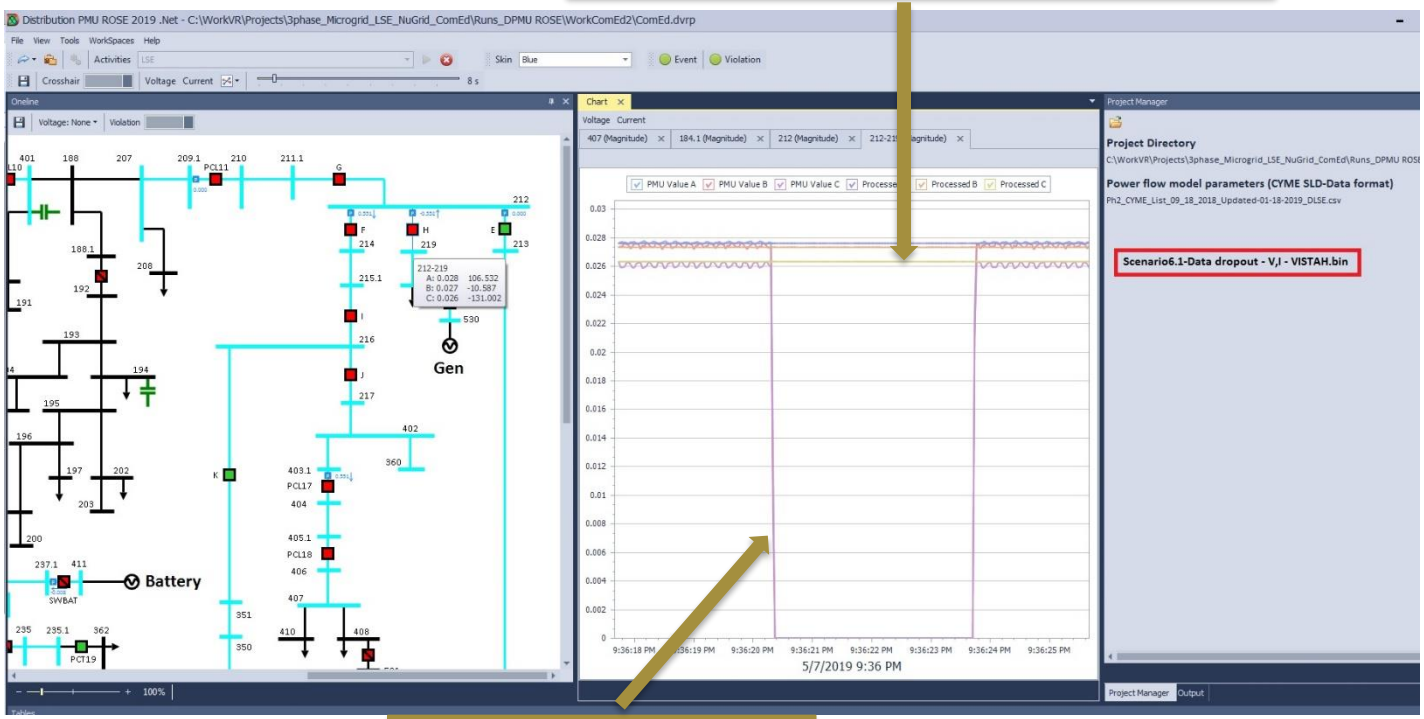
Bad Data Detection and Conditioning

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



Raw PMU values (phase B)

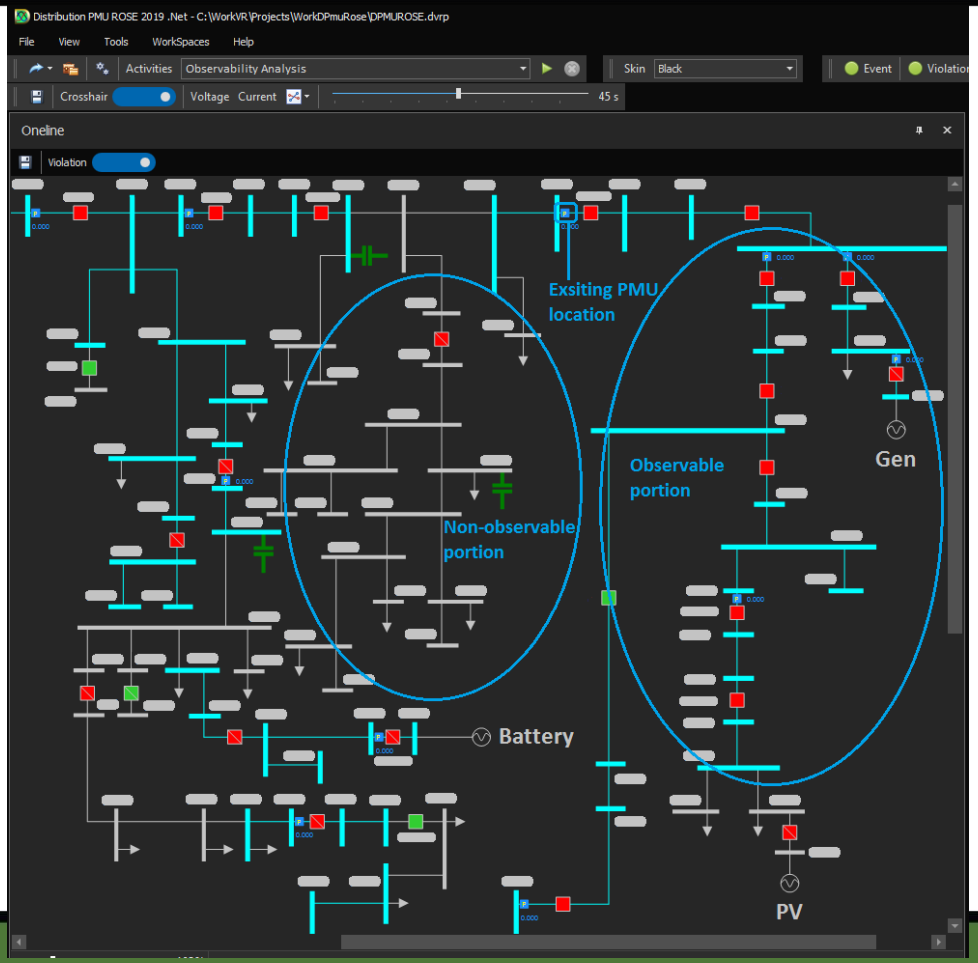
Source: ComEd

Observability Analysis and PMU Placement

- Purpose of observability analysis is to identify portions of the network observable with existing PMUs
  - Performed in real-time
  - Generates observability reports

- Purpose of optimal PMU placement is to determine locations of PMU installations to achieve full system observability
  - Off-line calculation
  - Creates PMU placement file

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
– PMU installations

Source: ComEd

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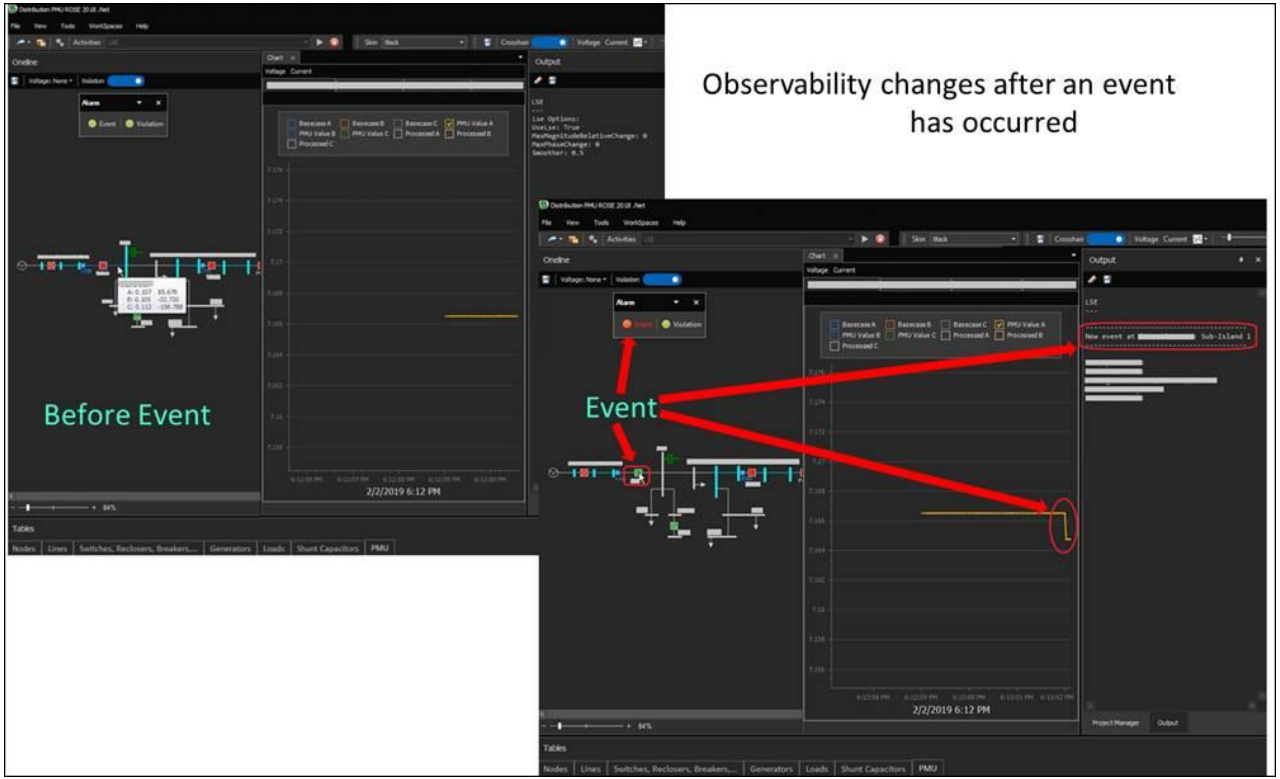
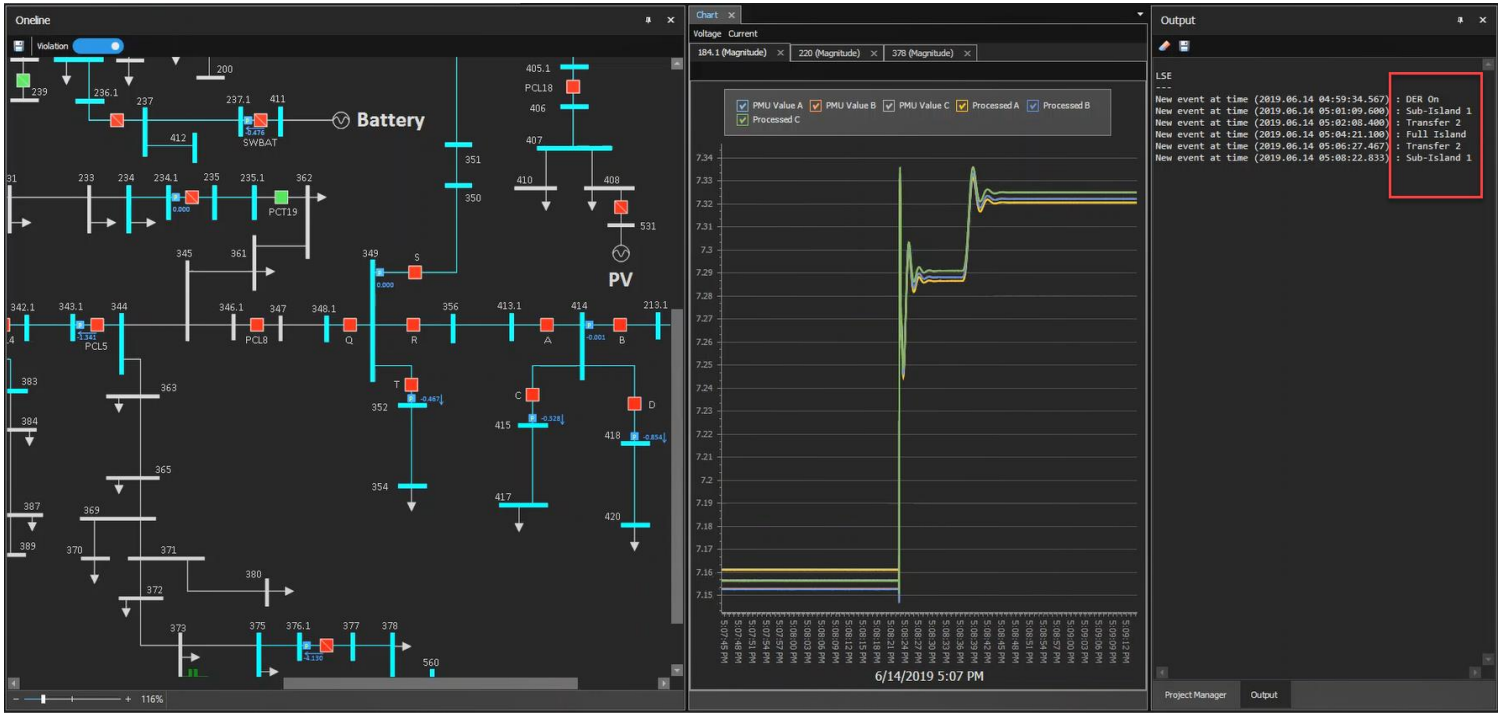
Detecting and Alarming on Switching Events



Source: ComEd

Topology Change



Source: ComEd

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

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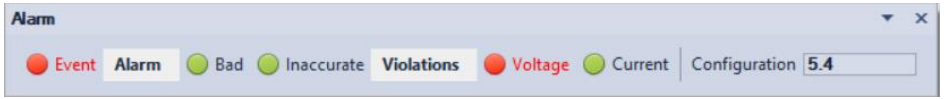
Alarming

- Event Alarm
  - If a switching event is identified, the Event Alarm indicator turns red
- Bad Data Alarm
  - If bad data is identified, Bad Data alarm turns red
- Violation Alarm
  - If a violation of voltage and/or thermal limit occurs, the Violation Alarm indicator turns red
- Multiple types of alarms might be issued simultaneously



Use of the Platform for Grid Modernization Applications

- The platform consists of the following applications:
  - Hybrid State Estimator that uses both PMU and SCADA data
  - Advanced applications:
    - FLISR (Fault Location, Isolation and Service Restoration) enhancement
    - Volt/Var optimization
    - DER dispatch
- NYSERDA demonstration project with Quanta Technology and Central Hudson

Thank you!

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