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April 2022

Distribution Linear State Estimation to Improve Distribution Network Observability: ComEd Experience

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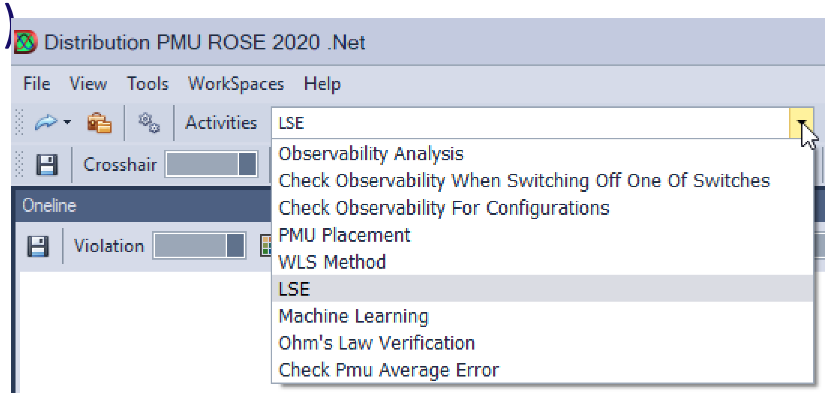
V&R Energy
The POWER to make a right decision!

Real-Time Distribution System Monitoring Platform

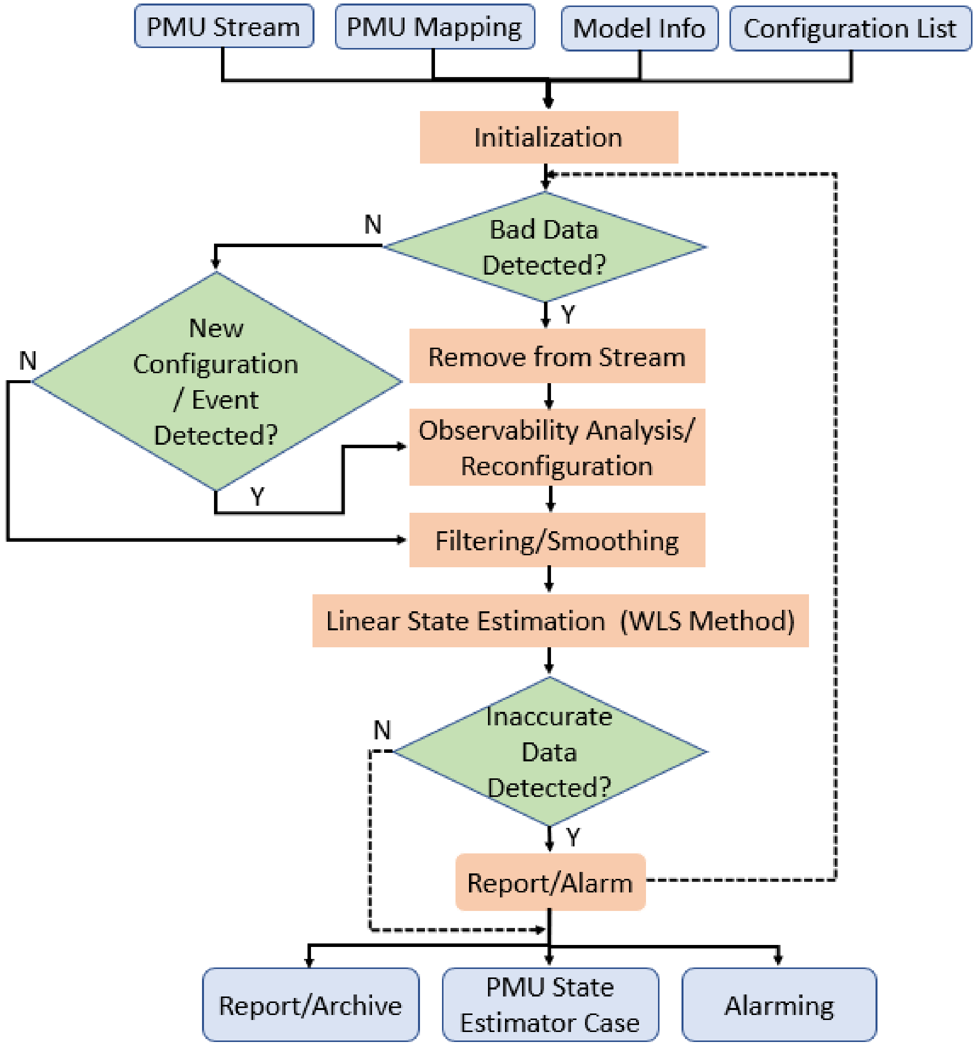
- The platform is a key “quality control” layer between the sensors providing raw measurement data, and the application software requiring reliable trustworthy data
  - Provides real-time situational awareness in order to improve resilience of the distribution grid and enhance its reliability
- **D-PMU ROSE** platform consists of the following functionalities:
  – Three-phase distribution linear state estimation (D-LSE)
  – Bad PMU data detection and correction
  – **Observability analysis**
  – Identifying switching events
  – Advanced visualization of distribution grid state, archiving and alarming
  – Validating model and PMU measurements
  – **Optimal PMU placement for full distribution grid observability (off-line)**



Components of D-LSE Framework

- Multi-step process:
  1. Bad data detection, correction, alarming and 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

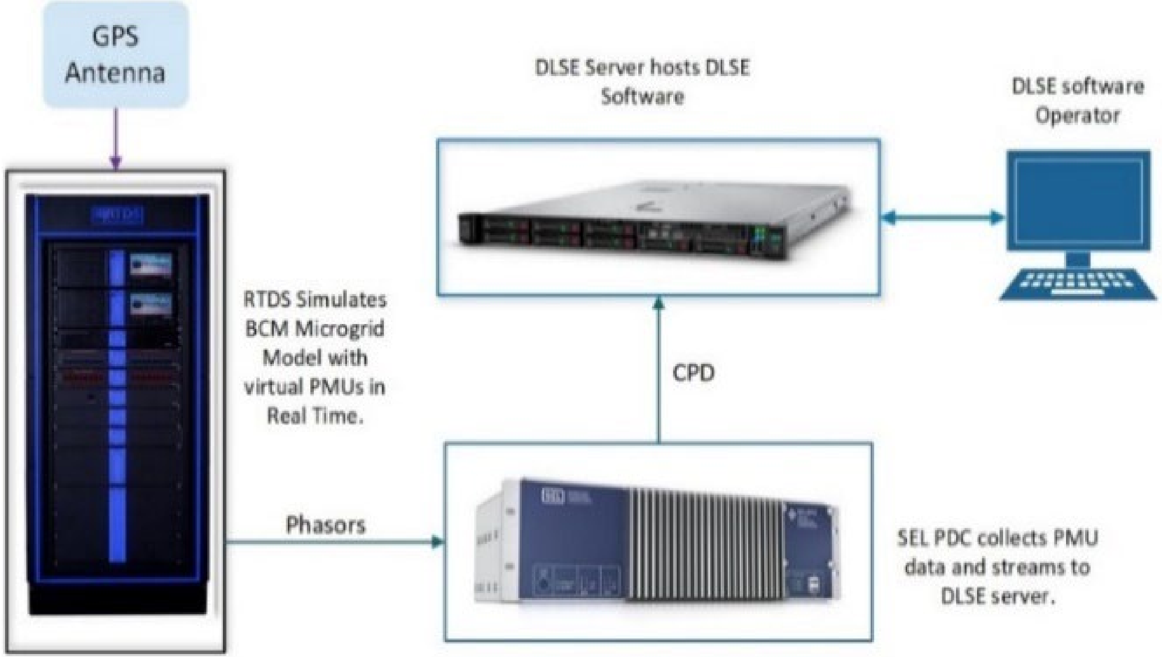


Network Model for DLSE

- Model:
  - Bronzeville Community Microgrid (BCM):
    - A 7-MW community microgrid
    - Two feeders
    - Over 200 nodes in BCM
- PMUs:
  - 46 PMUs
- Testing environment:
  – ComEd's Grid Integration and Technology (GriT) Lab using real-time digital simulation (RTDS)

Test Setup

- DLSE has been validated and tested for its accuracy and real-time performance (at the PMU streaming rate of 60 times per second) in GriT Lab
- Created a test setup that emulates realistic field operations
  - PMU measurements are aggregated into a PDC
  - A real-time synchrophasor stream is established over TCP-IP protocol
  - Sent to the DLSE for state estimation



Optimal PMU Placement and Observability Analysis

- PMU placement problem refers to the minimum number of PMUs to be placed in the network while maintaining observability of the entire system network
  - Multiple definitions of power system network observability
  - 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

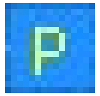
Optimal PMU Placement and Observability Analysis

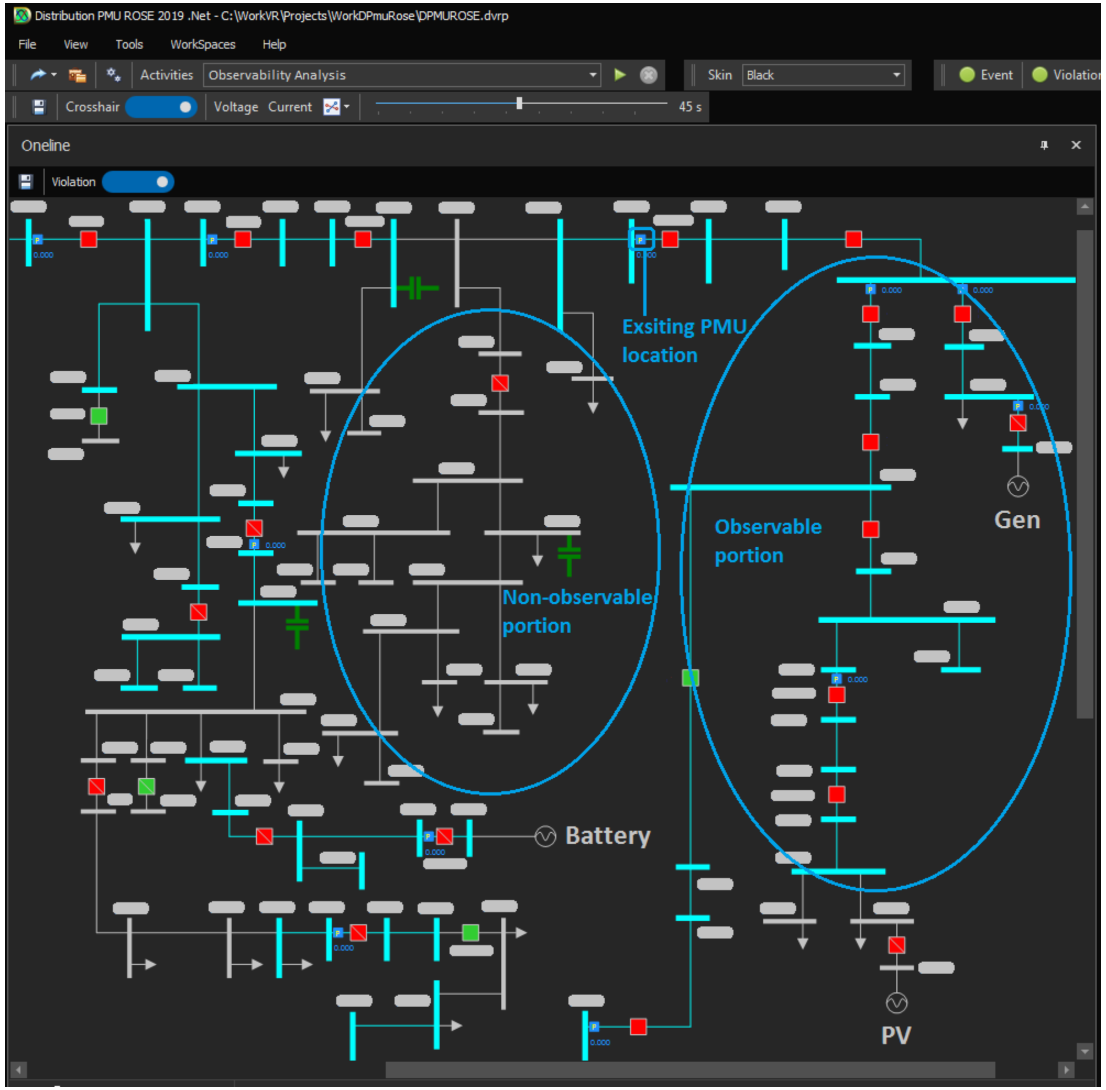
- Formulation of PMU placement problem depends on the definition of a criterion for complete system observability:
  - There are two types of criteria to define system observability - numerical and topological
  - D-PMU ROSE uses topological approach to power system network observability.
    - Topological definition is based on identifying nodes where voltage either is measured by PMU or may be computed based on a PMU measurement at another node
    - The optimal PMU placement problem for complete system observability is solved by the binary linear programming approach

Optimal PMU Placement and Observability Analysis

- Two types of observability-related computations can be performed:
  - Identification of optimal PMU locations such that voltage vector may be computed at each node in the network:
    - Already installed PMUs may be considered during the analysis
    - Certain locations, based on the field needs, can be excluded from the analysis
  - Observability analysis based on existing PMU locations

Observability Analysis for Existing PMU Locations

- Observability analysis is performed is real-time for the current network topology:
  -  - Installed PMUs
  - Observable/non-observable locations are shown in different colors, for example blue for observable, grey for non-observable



Observability Analysis after Switching Events

- Observable portion(s) of the BCM network may change when network topology changes
- The number of PMUs needed to provide full system observability may increase for certain network configurations (e.g., after some switching events occur)
- The number and locations of PMUs in BCM network were selected such that the system remained fully observable considering most frequently observed network configurations

Conclusion

- A PMU-based platform, including observability analysis for normal conditions and after various switching events, has been tested at ComEd's GriT Lab
- Optimal PMU placement for BCM network was performed such that:
  - Existing PMU locations were considered
  - Locations that were not practically viable, were excluded
  - System observability was maintained after switching events