Study Committee C2

Power System Operation and Control

Paper ID_10228

Approach to Distribution PMU Placement and Observability Analysis

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Motivation

- The increasing penetration of large amounts of inverter-based resources (IBR) and distributed energy resources (DER) at medium-voltage levels is driving an interest in various tools to help manage bidirectional power flow and dynamics in the fast-changing distribution grid
- Interest in using synchrophasor-based technology and other time-synchronized solutions from bulk power systems in active distribution networks and microgrids

Method/Approach

- Using a synchrophasor-based application platform including a distribution linear state estimator (DLSE) application to provide real-time situational awareness
- The platform can provide a multitude of advanced applications with real-time validated sensor data to reliably control bi-directional power flow along the feeders, but requires:
  1. A reliable circuit model
  2. Optimal sensor placement for observability
- Approach:
  1. Developed a tool to automate model reduction and validation, leveraging existing industry software
  2. Implemented an optimal PMU placement process using a binary linear programming algorithm

Devices	Power (kW)
Photovoltaic System	10
Electronically Coupled Generator	10

Part of the tool's user interface showing threshold levels for electronically coupled sources; devices with power below a threshold are reduced

References

1. N. Gurung et al., "Use of PMU-Based Software Platform to Provide Real-Time Situational Awareness for Bronzeville Community Microgrid," (*2020 IEEE PES T&D Conf. & Expo*, Oct. 12 - 15, 2020, Chicago, IL, USA).
2. A. Abur, "Optimal Placement of Phasor Measurements Units for State Estimation", PSERC Publication 06-58, October 2005.
3. F. Aminifar, A. Khodaei, M. Fotuhi-Firuzabad and M. Shahidehpour, "Contingency-Constrained PMU Placement in Power Networks," in *IEEE Transactions on Power Systems*, vol. 25, no. 1, pp. 516- 523, Feb. 2010.
4. O. Ciniglio, M. Papic, M.Y. Vaiman, M.M. Vaiman, "Optimal PMU Placement to Achieve Complete Observability of Idaho Power Co. System", (*2017 IEEE ISGT Conf., 2017ISGT0226.*)

Model reduction, formatting, and model validation automation

- Using distribution feeder model data from Geographical Information Systems (GIS) with interface to CYME software
- Using an Excel interface and Python scripts to leverage CYME's model reduction automation feature to develop a tool. Key features:
  1. Automated CYME network model reduction while
     a) Protecting (not allowing the reduction of) certain devices , certain specific nodes, and/or certain loads in the original model
     b) Protecting photovoltaic systems and IBR based on a threshold (e.g., reducing all those generators which have a power under 10 kW)
  2. Automated power flow analysis based on different scenarios:
     a) Global parameters or user-defined parameters for generators, loads and topology;
     b) Easy-to-define scenarios based on ranges for parameters (specifying the minimum, the maximum, and step size (increments) in the range.
  3. Standardized reduced model and power flow solution output formats

Devices	To Reduce
Breakers	No
Cables	Yes
Distributed Loads	Yes
Fuses	Yes
LVCBs	Yes
Overhead Lines (Balanced)	Yes
Overhead Lines (by phase)	Yes
Overhead Lines (Double-circuit)	Yes
Overhead Lines (Unbalanced)	Yes
Reclosers	No
Sectionalizers	Yes
Spot Loads	Yes
Switches	No
Fixed Shunt Capacitors	Yes
Non-energized devices	Yes

Part of the tool's user interface showing which devices can be protected (are not allowed to be reduced)

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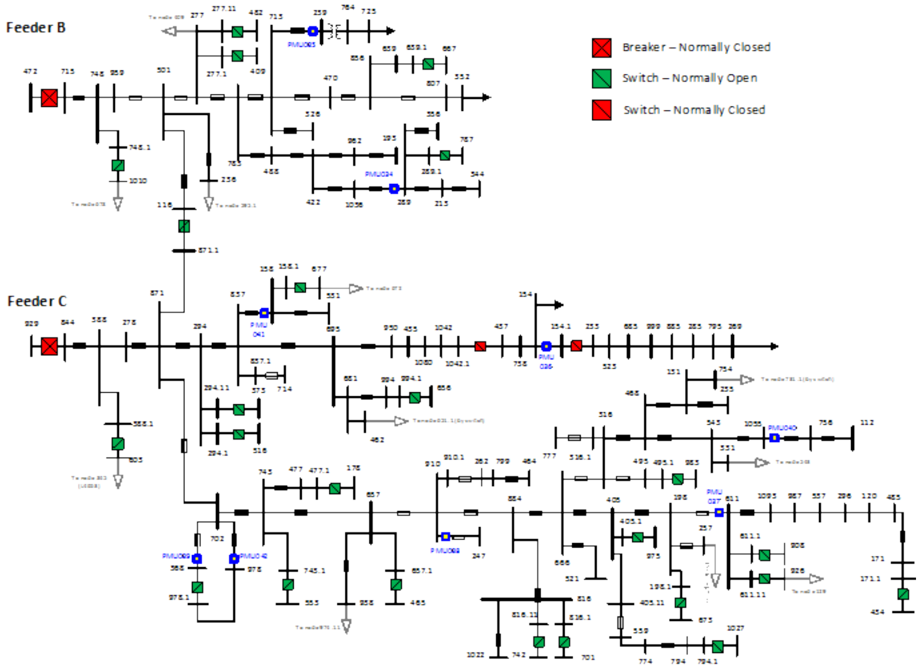
Observability analysis and PMU placement

- Python script for optimal PMU placement for full network observability
- Binary linear programming approach

Results

- Used the tool on 25 feeders at ComEd
- Models reduced by an order of magnitude: to about 2,000 nodes, with 170 PMUs providing full observability of these 25 feeders (average of 7 PMUs per feeder)
- Effort level: 2 engineers for 1 week



A sample reduced distribution circuit model schematic for inter-connected feeders B and C, needing 9 PMUs to achieve full observability. The locations of PMUs are shown by blue squares

- Iterative process, taking into account:
  1. Practical/physical limitations in PMU placement (forbidden locations)
  2. PMUs already existing in the field (committed locations)
  3. Most common/probable topologies in the field
  4. Practical redundancy needs

Conclusions

- Distribution linear state estimation (DLSE) enables high-resolution (per cycle) visibility into the status of the active distribution grid and real-time data quality validation and control
- Developed tools to streamline model reduction
- Improving model reduction time by two orders of magnitude
- Improving consistency and standardization, leading to cost-efficient deployment of technology