Event Detection and Localization in Distribution Grids with Phasor Measurement Units

Omid Ardakanian¹, Ye Yuan¹, Roel Dobbe², Alexandra von Meier², Steven Low³, and Claire Tomlin⁴

¹University of Alberta, ²Huazhong University of Science and Technology, ³University of California, Berkeley, ⁴California Institute of Technology

Introduction

Real-time monitoring & automatic control proactive, distributed and participative.

Central operator reactive, conservative w/ ad-hoc interventions

Challenge:

- time slots 1…K for successive switching operations, tap changes, and faults

- Ohm’s Law

- Synchrophasor data provide unprecedented insights into the operating state of the system which can be used to uniquely determine the system model (i.e. the admittance matrix) and quickly identify the critical events, e.g. switching operations, tap changes, and faults.

Goal:

given time-synchronized voltage and current phasor measurements in a polyphase distribution network, recover the admittance matrix Y and detect any changes due to events (faults, reconfiguration, etc)

- Y must be sparse and symmetric

Ohm’s Law for successive time slots 1…K:

\[ \begin{bmatrix} I_1(t) & I_2(t) & \cdots & I_K(t) \\ V_1(t) & V_2(t) & \cdots & V_K(t) \end{bmatrix} = Y_{bus} \begin{bmatrix} I_1(t) \\ I_2(t) \\ \vdots \\ I_K(t) \end{bmatrix} \]

Challenges:

1. \( Y_{bus} \) is low rank => standard least square does not work, it has infinite number of solutions;
2. Measurement error;
3. Limited deployment of sensors.

Identification Algorithm

Step 1: Use similarity transformation to re-arrange data matrices:

\[ T Y_{bus} = \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}, \quad T I_{bus} = \begin{bmatrix} I_1 \end{bmatrix}. \]

Step 2: Compute \( X = V_1 V_2^T \)

Step 3: Rewrite Ohm’s law as

\[ \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} V_1 & V_2 \\ V_2 & V_2 \end{bmatrix} X \quad Y_1 X + Y_2 V_2 \]

- Compute \( Y_1 X = \arg \min_{Y \in \mathbb{C}^{K \times K}} \| I_1 - Y_2 V_2 \|_2 \)

Step 4: Obtain \( Y_{11}, Y_{22} \)

- \( I_1 = (Y_{11} X + Y_{12}) V_2 \)
- \( I_2 = (Y_{12} X + Y_{22}) V_2 \)

- \( C = I_2 V_2^T - (V_2^T I_1^T) X \)
- \( C = -X^T Y_{11} + X + Y_{22} \)

- \( \min \left\{ \frac{\| \text{vec}(Y_{11}) \|}{\text{vec}(Y_{22})} \right\} \)
  \text{s.t.:} \ [X^T \otimes X^T] \frac{\| \text{vec}(Y_{11}) \|}{\text{vec}(Y_{22})} = \text{vec}(C),

- \( Y_{11} \in \mathbb{S}^{(d - K) \times (d - K)}, Y_{22} \in \mathbb{S}^{d \times d} \)

Step 5: Obtain \( Y_{12} \)

- \( Y_{12} = \arg \min_{Y \in \mathbb{C}^{(d-K) \times d}} \| (Y_{11} X + Y_{12}) V_2 - I_1 \|_2 \)

Event Detection and Localization Algorithm

Detection Algorithm

- \( e(k) = I_{bus}(t) - I_{bus}(k) \)
- \( Y_{bus}(t) - Y_{bus}(k) \)

- Check if \( \text{error} \) is white noise

- If yes, continue;
- Otherwise, detect the event.

Event Localization Algorithm

(requires a small no. of samples)

- \( \min \| \Delta Y_{bus}, \Delta Y \| \quad \text{s.t.:} \left\{ \begin{array}{l} I_{bus}(t + K) - Y_{bus}(t) = \Delta Y_{bus} \\ I_{bus}(t) - Y_{bus}(t) = \Delta Y \end{array} \right\} \)

Experimental Setup

1. Compute real and reactive powers consumed at each node in every time slot
2. Simulate events at the specified times and update the admittance matrix
3. Perform power flow analysis for every time slot in OpenDSS
4. Add Gaussian white noise to the results to simulate phasor measurements
5. Solve the convex problems using the CVX toolbox to update the admittance matrix

Example Results

- Performed extensive simulations on IEEE 13, 34, 37, and 123 test feeders
- Identified various events and pinpointed them to a small geographical area
- Studied sensitivity of the proposed techniques to the synchrophasor measurement error

Further Information


For correspondence, yye@hust.edu.cn