Measurement-Based Sensitivity Estimation for Online Power System Monitoring and Control

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CERTS
Consortium for Electric Reliability Technology Solutions

Outline

Motivation

- To maintain operational reliability, operators rely on online studies conducted on a model of the system obtained from
  1. A mix of a priori information, including
     - Historical electricity demand patterns
     - Equipment maintenance schedules
     - Up-to-date network topology
  2. Observations in the form of measurement data

- When SCADA systems provide only low-bandwidth, unsynchronized measurement data to a control center:
  - A priori information and observations contributed similarly in, e.g., topology error identification and contingency analysis

- The availability of high-bandwidth, time-synchronized PMU data shifts this balance, creating a larger role for observations
  - This reduces the need for full model information, thereby opening the door to much faster and more accurate online monitoring and control tools

Overall Project Objective

- Linear sensitivities, e.g., Injection Shift Factors, Loss Factors, are used in many online analysis and market tools:
  - Contingency analysis, real-time security-constrained economic dispatch, generation re-dispatch, congestion relief
- Existing approaches to computing such sensitivities typically employ an AC or DC **model**; this is not ideal because
  1. Accurate model containing up-to-date topology is required
  2. Results may not be applicable if actual system evolution does not match predicted operating points
- Phasor Measurement Units (PMUs) provide high-speed voltage and current measurements that are time-synchronized
- Objectives:
  1. Estimate linear sensitivities by exploiting measurements obtained from PMUs without the use of a power flow model
  2. Utilize measurement-based sensitivities to improve the performance of online tools for monitoring and control

Looking Back

- Developed measurement-based estimation methods for
  - Power flow Jacobian [Submitted to TSG]
  - Injection shift factors [NAPS 2014, Submitted to TPWRS]
  - Loss factors [Submitted to TPWRS]
  - Line outage angle factors [Submitted to NAPS 2015]
- Demonstrated key advantages of proposed measurement-based methods:
  - Eliminate reliance on system models and corresponding accuracy
  - Resilient to undetected system topology, incorrect model data, and operating point changes
- Demonstrated effectiveness of proposed methods for improving the performance of online tools for monitoring and control:
  - Real-time security-constrained economic dispatch [GM 2015]
  - Locational marginal price formation [Submitted to TPWRS]

Outline

Power System Sensitivities

- Power flow Jacobian (J)
- Injection shift factors (ISFs)
- Power transfer distribution factors (PTDFs)
- Line outage distribution factors (LODFs)
- Outage transfer distribution factors (OTDFs)
- Loss factors (LFs)
- Line outage angle factors (LOAFs)

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PMU-Based Approach to ISF Estimation

- Proposed measurement-based approach relies on inherent fluctuations in net injections
- Collect PMU measurements of active power flow and injections
- Cast ISFs as an overdetermined linear relationship between measured quantities
- Overdetermined linear system can be solved using, e.g., least-squares error estimation (LSE)
- Other assumptions:
  - The ISFs are approximately constant across the measurements used in the estimation
  - The regressor matrix has full column rank
- Other sensitivities can be estimated in a similar fashion

Outline

Online Tools Relying on Linear Sensitivities

- Contingency analysis
- Generation re-dispatch
- Congestion relief
- Real-time security-constrained economic dispatch (SCED)

Security-Constrained Economic Dispatch

SCED problem formulation:

$\max$ {social surplus}

($\min$ {generator costs})

subject to:

$$\begin{cases} \text{power balance} \rightarrow \text{requires LFs} \\ \text{equipment limits} \\ \text{network flow constraints} \rightarrow \text{requires ISFs} \\ \text{reliability constraints} \rightarrow \text{requires ISFs, LODFs and LOAFs} \end{cases}$$

Objective:

- Solve the SCED problem using measurement-based sensitivities in place of model based sensitivities

118-Bus System (Balance Constraint Only)

- Compare SCED outcomes obtained with (i) nonlinear power flow model LFs [actual], (ii) model-based LFs, and (iii) measurement-based LFs
  - Scenario 1: two undetected transmission line outages
  - Scenario 2: incorrect line impedance data

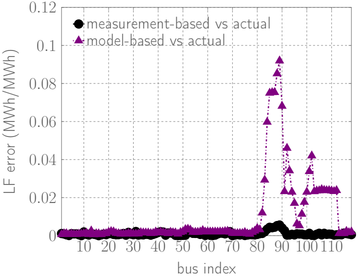

Figure: Errors in LF estimates with respect to full power flow LFs for Scenario 1

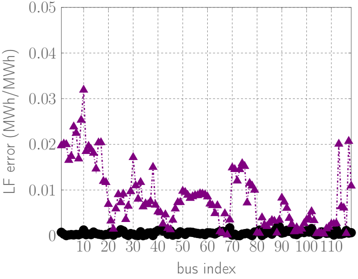

Figure: Errors in LF estimates with respect to full power flow LFs for Scenario 2

118-Bus System (Balance Constraint Only)

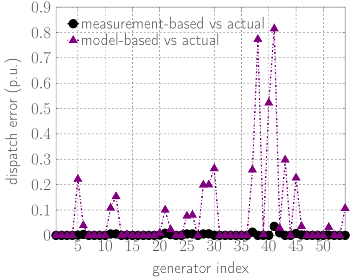

Figure: Errors in P_i^g with respect to ED solution with full power flow LFs for Scenario 1

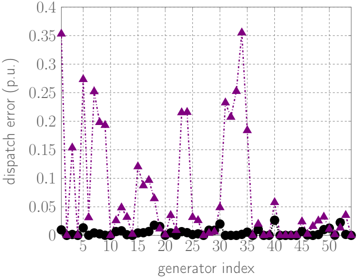

Figure: Errors in P_i^g with respect to ED solution with full power flow LFs for Scenario 2

118-Bus System (Balance Constraint Only)

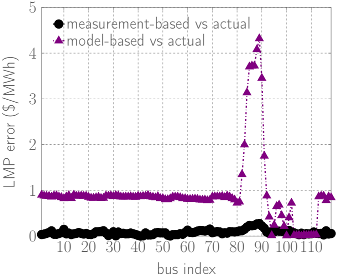

Figure: Errors in prices with respect to ED solution with full power flow LFs for Scenario 1

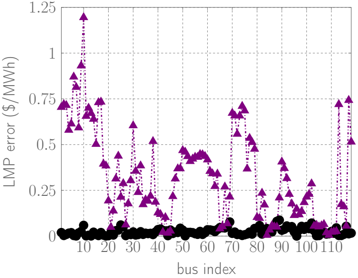

Figure: Errors in prices with respect to ED solution with full power flow LFs for Scenario 2

118-Bus System (All Constraints)

- Compare SCED outcomes obtained with (i) nonlinear power flow model LFs, DFs, (ii) model-based LFs, DFs, and (iii) measurement-based LFs, DFs
  - Scenario 3: incorrect line impedance data

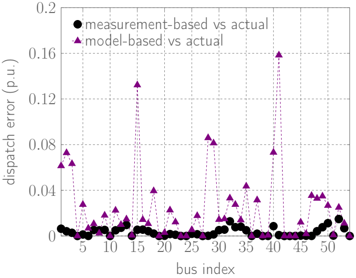

Figure: Errors in P_i^g with respect to SCED solution with full power flow LFs, DFs for Scenario 3

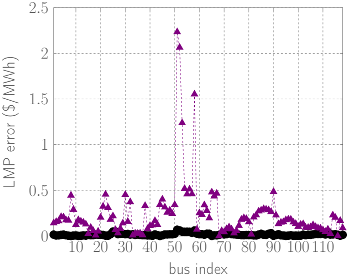

Figure: Errors in prices with respect to SCED solution with full power flow LFs, DFs for Scenario 3

118-Bus System (All Constraints)

- SCED dispatch impacts the base and outage case line flows
- Dispatch based on erroneous data can result in overloads and failure to achieve "N-1" reliability

Table: base and outage case line flows on limited lines Scenario 3

		line flow (p.u.)								
		no outages			line 13-17 outage			line 38-65 outage		
line	thermal limit (p.u.)	linear. ac	model-based	meas.-based	linear. ac	model-based	meas.-based	linear. ac	model-based	meas.-based
8-5	2.0	1.61	1.74	1.60	2.00	**2.16**	2.00	1.58	1.71	1.58
23-25	0.5	0.194	0.197	0.193	0.330	0.342	0.331	0.008	0.017	0.006
49-51	0.6	0.381	0.379	0.380	0.379	0.377	0.379	0.340	0.332	0.340
49-66	1.4	1.00	1.06	1.00	1.015	1.07	1.01	1.43	**1.55**	1.43
89-90	1.4	1.40	**1.52**	1.40	1.40	1.52	1.40	1.40	1.52	1.40

Outline

Looking Forward

- Technical accomplishments to be completed in FY15:
  - A1 Develop measurement-based LOAF estimation approach
  - A2 Test LOAF estimation approach on large-scale test systems
  - A3 Test the effectiveness of the sensitivity estimation algorithms using real PMU and SCADA data provided by MISO
- Deliverables to be completed under FY15 funding
  - D1 Technical report [Due at the end of FY15 Q2]
  - D2 Conference submission to GM [Submitted FY15 Q1]
  - D3 Conference submission to NAPS [Submitted FY15 Q3]
  - D4 Journal submissions to TPWRS [Submitted FY15 Q2 & Q3]
- Risk factors affecting timely completion of planned activities as well as movement through RD&D cycle
  - R1 Failure to obtain appropriate data from MISO
- Thoughts on follow-on work for FY16
  - T1 Develop and test comprehensive measurement-based SCED
  - T2 Develop measurement-based techniques for ATC computation