FY12 DOE/NETL Transmission Reliability R&D Internal Program Review

Automated Reliability Reports (ARR)
Grid Performance Metrics Using Model-less Algorithms
Prototype Development and Field Test at MISO

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Presentation Outline

- Project objectives
- Accomplishments this year
- Deliverables and schedule
- Risk factors affecting timely completion
- Possible follow-on funding in FY 13
- Model-less algorithm description
- Real data example
- Issues
- Post-contingency analysis

Project objectives

- Provide automated reliability measures of closeness to operations limits with minimal model data
- Verify adequacy and accuracy of voltage, thermal and stability transmission reliability metrics and model-less algorithms for automated reports
- Investigate MISO phasor data adequacy, data quality and completeness to use for estimating metrics
- Investigate algorithms for predicting post-contingency reliability measures

Accomplishments this year

- **COMPLETED** – Define, create and deliver the prototype functional specification including model-less algorithms, monitoring visualization and tracking reports
- **COMPLETED** – Identify and define with MISO the Grid phasor data adequate for testing and validating model-less algorithms
- **COMPLETED** – Off-line test and validation of grid reliability performance metrics using model-less algorithms and MISO Grid phasor data for agreed normal and disturbance days
- **COMPLETED –** Functional specification revision to include MISO feedback on monitoring visualization and tracking reports
- **IN PROGRESS** – Validating model-less algorithm results
- **IN PROGRESS** – Tracking phasor data for evaluating sources of data error
- **IN PROGRESS** – Evaluating post-contingency algorithms
- **IN PROGRESS** – Tune performance metrics algorithms and thresholds using results from MISO validations

Deliverables and schedule

- Validation of model-less algorithm results using MISO data – initial evaluation by September 2012
- Tracking phasor data for evaluating sources of data error – initial plan by September 2012
- Evaluating post-contingency algorithms – initial feasibility analysis by September 2012

Risk factors affecting timely completion

- **Grid Phasor Data Availability:** Waiting for Host PMU installations and readiness
- **Grid Phasor Data Quality:** Experience using phasor measurements is demonstrating the need for better phasor data quality filters and estimation of grid performance metrics uncertainties
- **Completion of Prototype Deployment at MISO:** MISO personnel and IT Contractors availability
- **Validity of stability margin concept:** MISO data and computations will be important validation results

Possible follow on funding for FY 13

- Continue and complete the Field Demonstration with MISO for improving models, performance metrics, monitoring visualization, and tracking automatic reports
- Assess grid phasor data quality and availability using field demonstration results and research more effective phasor data quality filters and estimation of grid performance metrics uncertainties
- Research identification and definition of a grid reliability composite index using this project grid performance metrics and MISO reliability coordinators experience during the Field Demonstration
- Validate the post-contingency algorithms and field test results

Model-less algorithm description

- Thermal – short term and long term – typically measured in Amps or power (MW or MVA) – this one is fairly easy to find from measurements.
- Voltage – plus or minus 5% of nominal – this one is fairly easy to find from measurements.
- Stability – voltage collapse, SS stability, transient stability, bifurcations – margins to each critical point – this one is hard to find.
- Other
  - Control limits - Ramp constraints, under/over excitation, taps
  - Short circuit current capability

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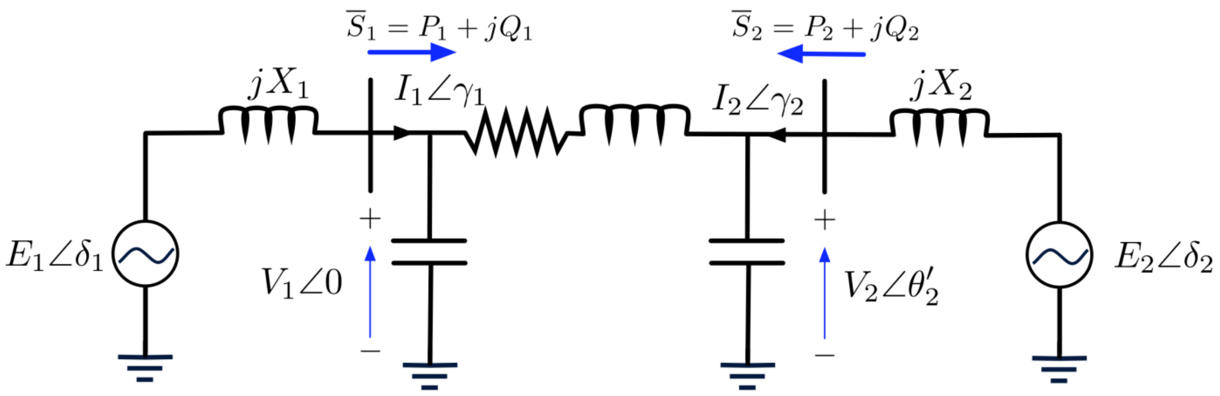
Conjecture

If you compute a Thevenin Equivalent as seen by both ends of a transmission line, the angle across the system will indicate a level of loading in the system – and this angle should approach 90 degrees at the critical line/equivalent combination. At 45 degrees there would be a 30% margin.



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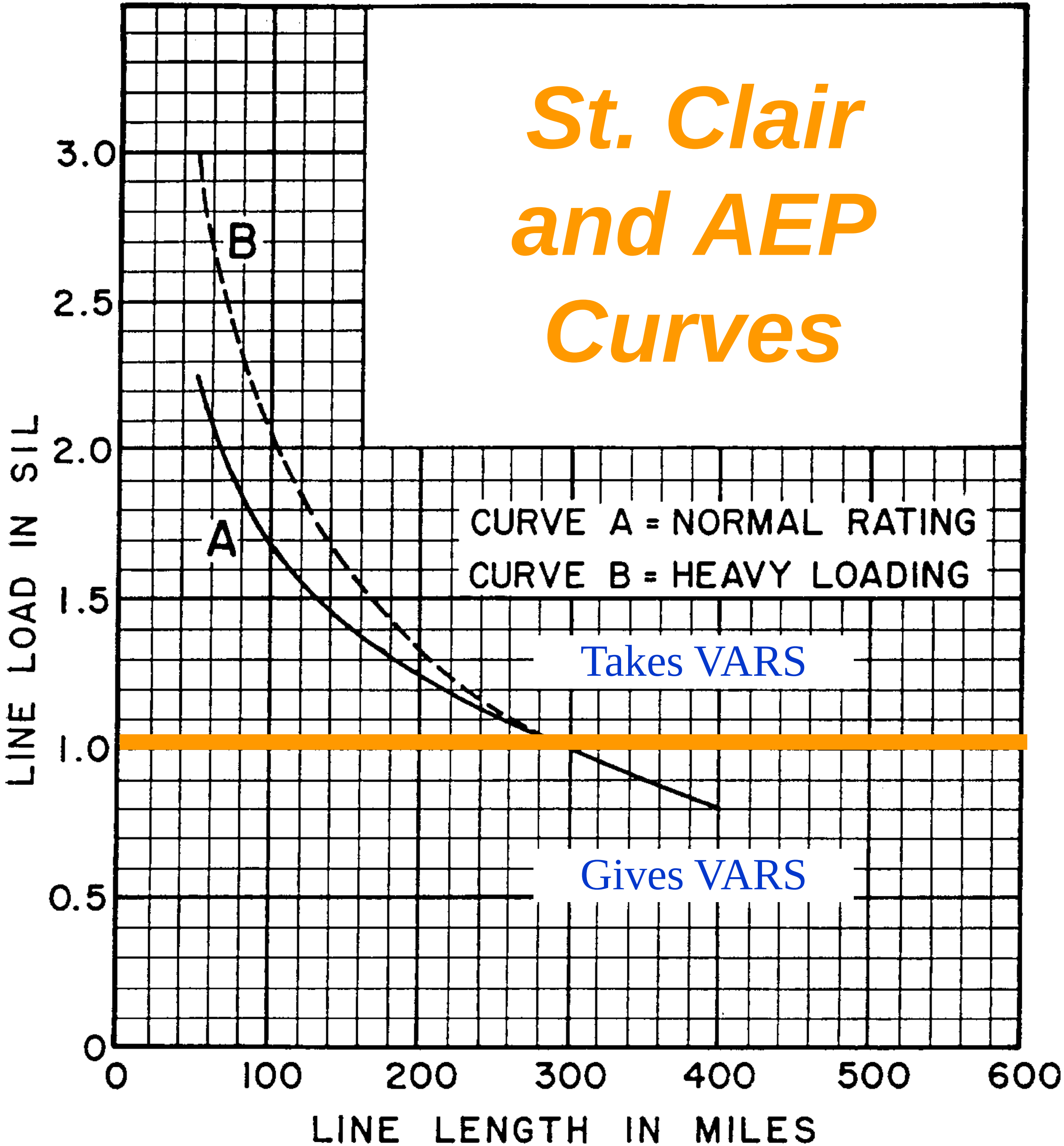
Others

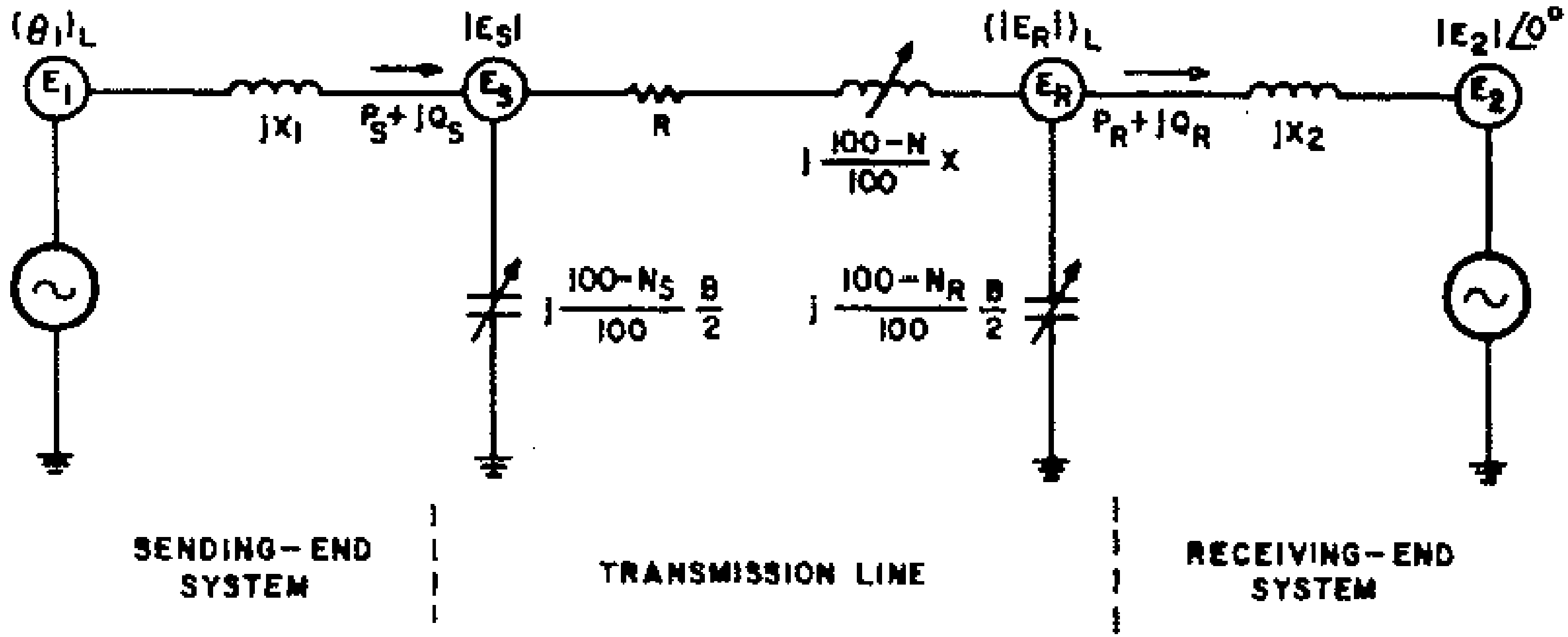
- St. Clair and AEP curves

- T. He, S. Kolluri, S. Mandal, F. Galvan, P. Rastgoufard, "Identification of Weak Locations using Voltage Stability Margin Index", APPLIED MATHEMATICS FOR RESTRUCTURED ELECTRIC POWER SYSTEMS – Optimization, Control, and Computational Intelligence, Edited by Joe H. Chow, Felix F. Wu, James A. Momoh, Springer, 2005, p. 25 -37. This was done for Entergy.

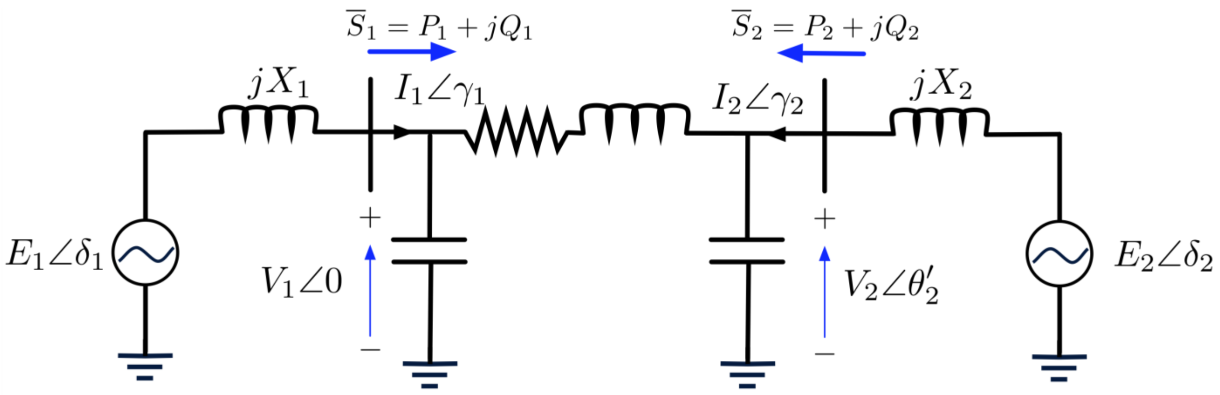
St. Clair and AEP Curves



R.D. Dunlop, R. Gutman, P.Marchenko, "Analytical Development of Loadability Characteristics for EHV and UHV Transmission Lines," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-98, No.2 March/April 1979. Gutman was/is with AEP.



PMU Data



- In the above line plus equivalents, PMU measurements at both ends will provide voltages V_1, V_2, (magnitude and angle) and currents I_1 and I_2 (magnitude and angle)

- From these measurements, we only need to compute the angle difference $\delta_1 - \delta_2$ (we really don't care about E or X)

Real data example

- The set of measured quantities include
  - Line-to-line voltages at both ends of the line
  - 3-phase complex power flowing into both ends of the line
- Measured quantities are sampled ten times per second
- Pseudo-measurements of line currents are obtained from the relation between complex power, voltage, and current
- Least Squares Errors (LSE) estimation is used to obtain per-second estimates of measurements and pseudo-measurements
- Since the system is at off-nominal frequency, phasor measurements rotate at a speed equal to the difference between the actual system frequency and the nominal frequency
  - To compensate for this effect, voltage estimates are redefined by defining the angle on one of the line ends to be zero and adjusting all other angles accordingly

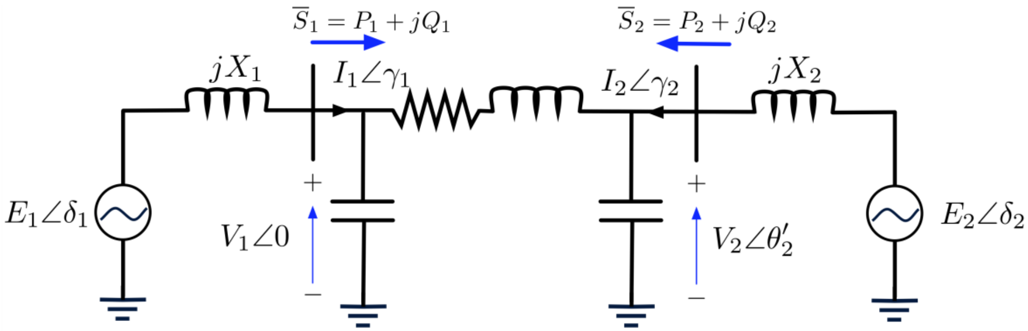
Real Data
(note that data quality is a problem)

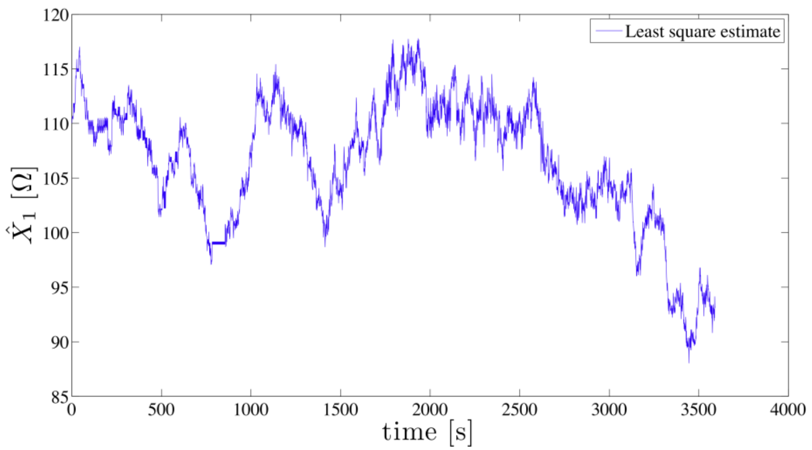
19:08:01	761.27	-110.86	59.995
19:08:02	761.33	-111.03	59.996
19:08:02	761.27	-111.19	59.996
19:08:02	761.28	-111.34	59.996
19:08:02	761.16	-111.49	59.996
19:08:02	761.13	-111.64	59.996
19:08:02	NaN	NaN	NaN
19:08:02	NaN	NaN	NaN
19:08:02	761.09	-112.06	59.996
19:08:02	760.99	-112.19	59.996
19:08:02	760.92	-112.33	59.996
19:08:03	760.86	-112.48	59.996
19:08:03	760.9	-112.62	59.996
19:08:03	760.91	-112.77	59.996
19:08:03	761.03	-112.89	59.997
19:08:03	760.94	-113.02	59.997
19:08:03	760.89	-113.12	59.997
19:08:03	760.9	-113.22	59.997
19:08:03	760.98	-113.32	59.997
19:08:03	760.99	-113.43	59.997
19:08:03	761.09	-113.54	59.997
19:08:04	761.16	-113.66	59.997

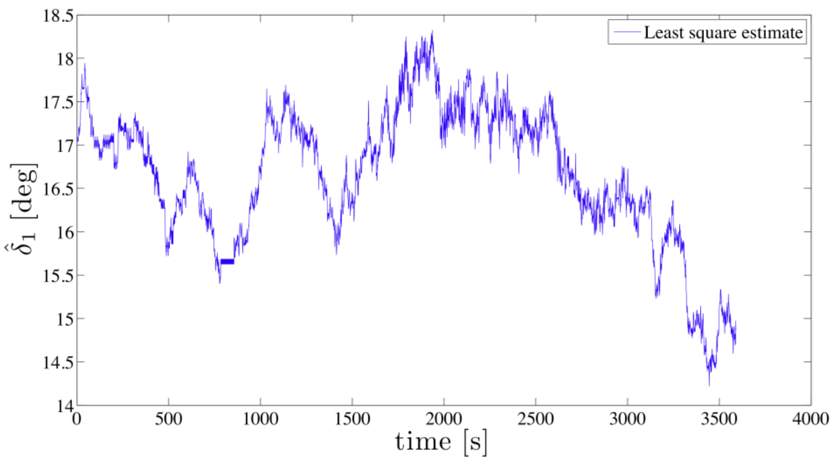
19:08:20	760.63	-122.96	60
19:08:20	760.63	-122.96	60
19:08:20	760.74	-122.96	60
19:08:20	760.78	-122.95	60
19:08:20	760.78	-122.95	60
19:08:20	760.9	-122.93	60
19:08:20	760.83	-122.93	60
19:08:20	760.92	-122.9	60
19:08:20	760.97	-122.89	60
19:08:20	760.97	-122.87	60
19:08:21	761.02	-122.86	60.001
19:08:21	760.93	-122.85	60
19:08:21	760.96	-122.82	60.001
19:08:21	761.03	-122.77	60.001
19:08:21	761.02	-122.71	60.002
19:08:21	761.03	-122.63	60.002
19:08:21	760.92	-122.53	60.002
19:08:21	760.83	-122.42	60.003
19:08:21	760.75	-122.31	60.003
19:08:22	760.73	-122.19	60.003
19:08:22	760.68	-122.08	60.003
19:08:22	760.69	-121.99	60.003

765 kV *Line Case Study*

- Stability margin analysis
- Date:
  - 09/03/10
- Time horizon:
  - 18:07:12EDT-19:07:12EDT
- E_1=E_2=765 kV (assumed)

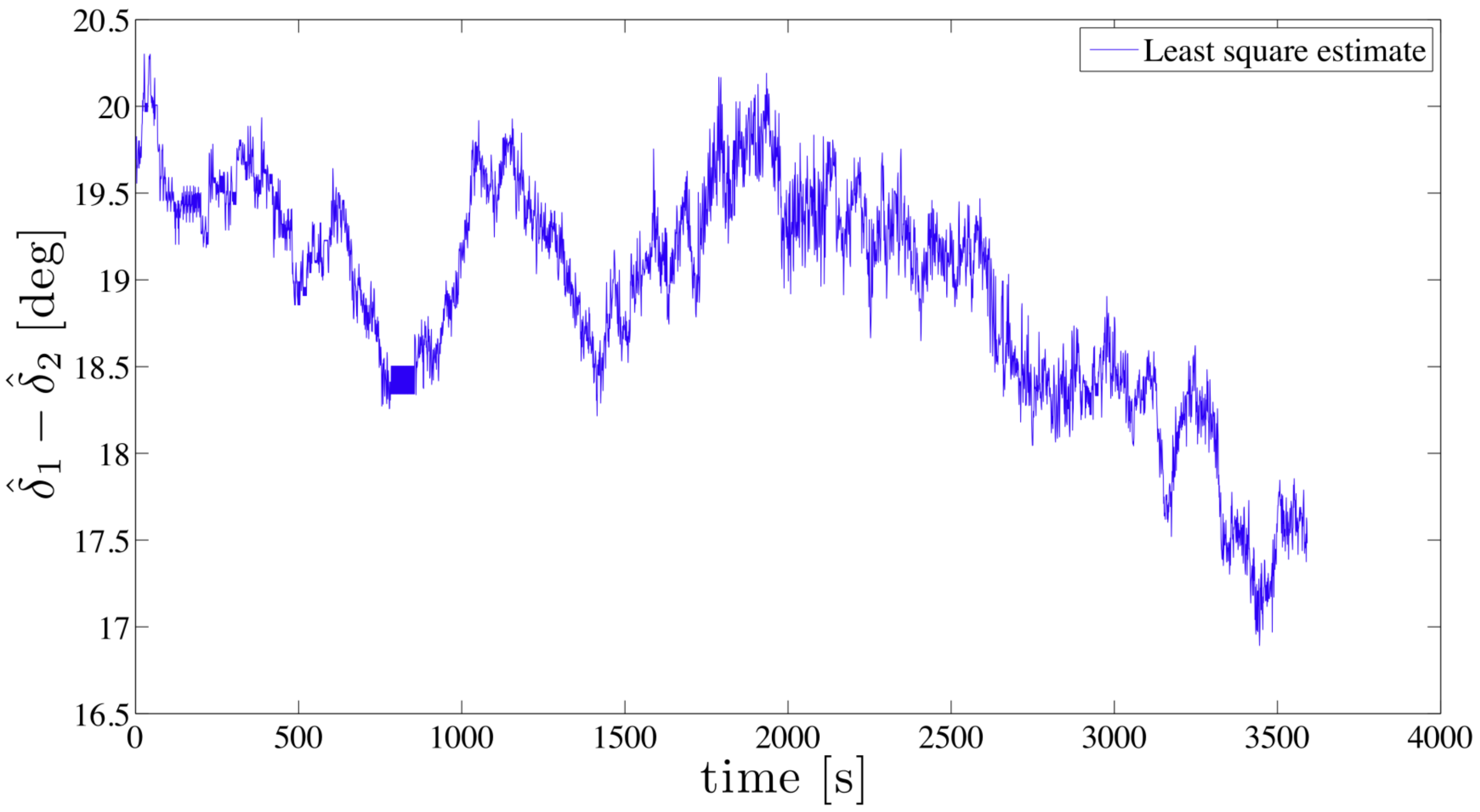






Thevenin parameter estimates for equivalent

Angle Across the System Measure



Issues

- The Thevenin equivalent is not really constant between samples.
- System change (and noise) is actually a good thing.
- Is the 45 degrees criteria correct?
- What is the “path” to the bifurcation?
- Is the “path” to the bifurcation important?
- How many lines need to be monitored?
- How do we verify this is correct?
- PMU data quality
- Can we push the computation down to the substation?
- A lot of this is really hard to prove because we do not know the answers!
- We are working with the MISO to validate the method and provide answers to these issues using real data.

Post Contingency Analysis

- Create the Thevenin equivalents using the pre-contingency key line flow data.
- For a list of contingencies, compute the change in the key line flow data and the corresponding Thevenin equivalent parameters using standard generation shift distribution factors (computed from phasor data across the grid).
- Determine the closeness to operating limits using the same algorithms as for the pre-contingency case.
- Compute the system equivalent inertia from monitored frequency.
- Evaluate transient stability for specified faults on key lines using a single machine vs infinite bus from the pre-contingency Thevenin equivalents and inertia dynamics for the fault-on trajectory.

QUESTIONS

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