DOE/OE Transmission Reliability Program

Real Time Applications Using Linear State Estimation Technology (RTA/LSE)

DOE Grant Award #DE-OE0000849

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Electric Power Group

NASPI
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Acknowledgement and Disclaimer

- Acknowledgment: This material is based upon work supported by the Department of Energy under Award Number DE-OE0000849.

Presentation

- Introduction & participants
- Project objective & approach
- Overview of application developments
- Status & schedule
- Planned activities

Introduction

- Project: Real Time Applications Using Linear State Estimation Technology
  - DOE Grant Award DE-OE0000849
- Primary recipient: Electric Power Group, LLC
  - Principal Investigators: Ken Martin & Lin Zhang
- Project Partners (host site & cost share):
  - Bonneville Power Administration
    - Project lead – Tony Faris/Thong Trinh
  - New York Power Authority
    - Project lead – Atena Darvishi/Alan Ettlinger
- Project host site - Duke Energy
    - Project lead – Megan Vutsinas, Tim Bradbury, Evan Phillips

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Advisors & observers

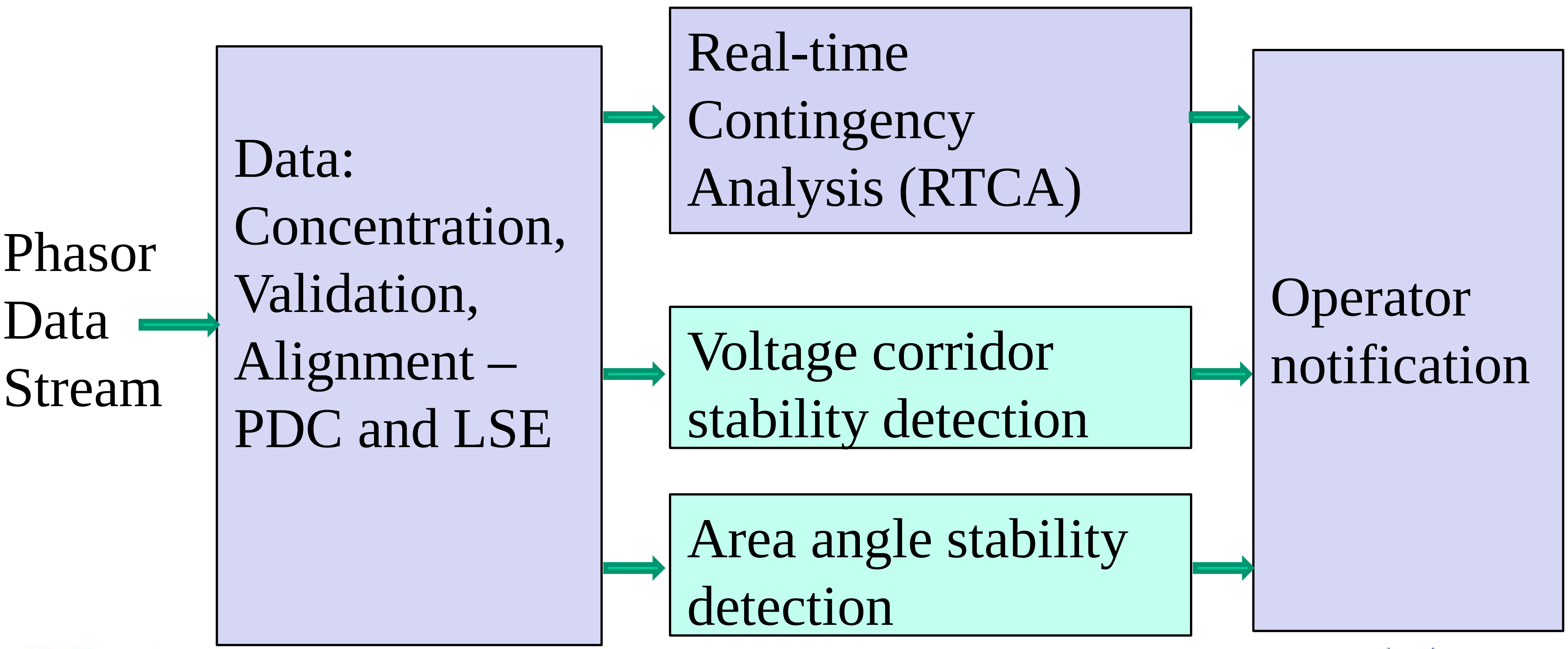
- Project Advisors
  - Anjan Bose – Washington State University
  - Ian Dobson – Iowa State University
  - Dejan Sobajic – Grid Engineering
  - Anurag Srivastava – Washington State University
- Project Observers
  - Dominion Virginia Power (Dominion) - Kyle Thomas
  - Peak Reliability - Hongming Zhang
  - PJM - Emanuel Bernabeu, Ryan Nice

Project Objective

- Develop Real Time Applications Using Phasor Data and Linear State Estimator Technology
  - Provide operators with actionable intelligence on contingencies, voltage margins, & phase angle limits
- Applications include
  - Real Time Contingency Analysis
  - Voltage Stability Monitoring
  - Area Angle Limit Monitoring

Project approach

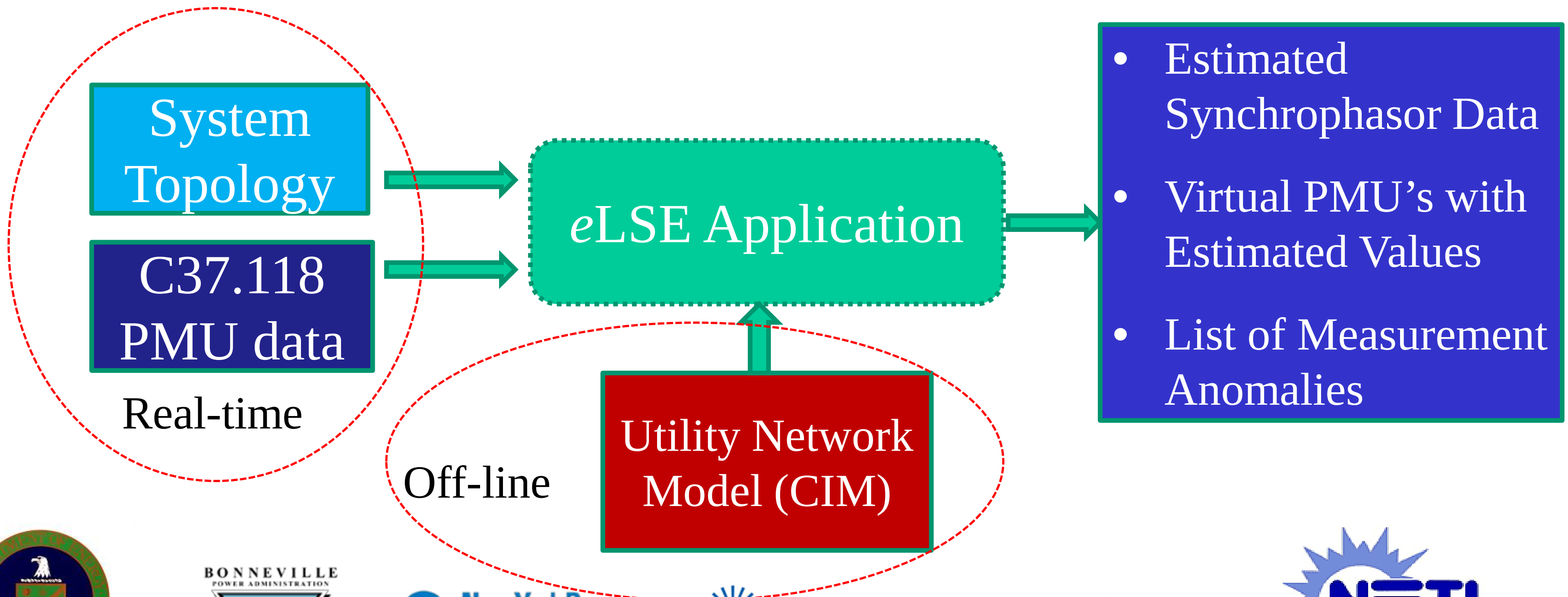
- Implement 3 applications to monitor power system
- Test with simulated and recorded data
- Demonstrate at host utilities



ENHANCED LINEAR STATE ESTIMATOR (*e*LSE)

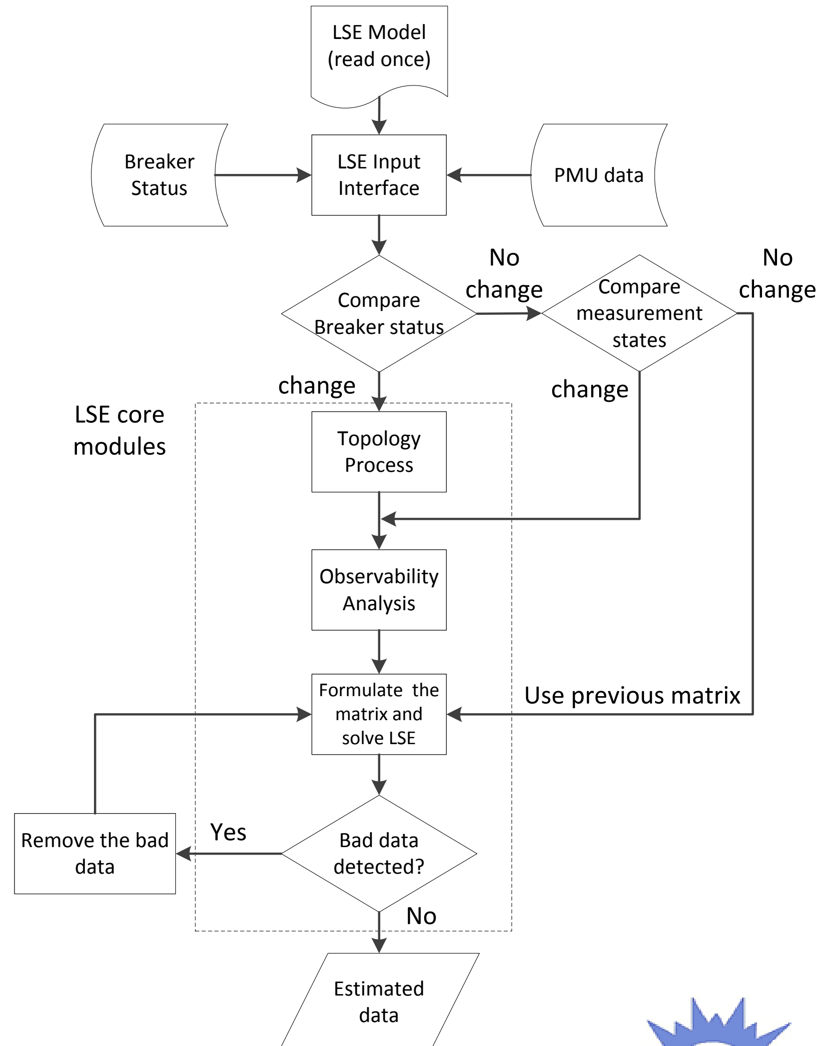
*e*LSE Inputs

- Network Model (CIM format)
  - Converted into eLSE format model
- PMU Data (C37.118)
  - Real-time or recorded
- Topology Info (Breaker status)
  - From EMS or recorded



Flow Chart of *e*LSE Engine

- *e*LSE input interface processes inputs and send them to *e*LSE core modules
- *e*LSE core modules include:
  - Topology Process
  - Observability Analysis
  - Linear State Estimation
  - Bad Data Detection & Identification



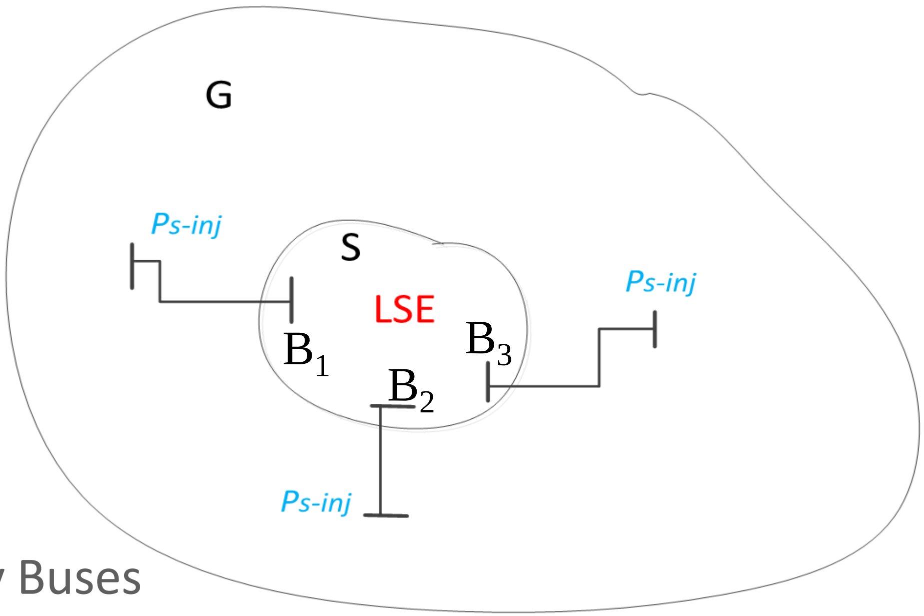
REAL-TIME CONTINGENCY ANALYSIS (RTCA)

RTCA operation

- Tests what can happen next based on the current system
  - Uses a pre-made list of contingencies such as line outages, transformer failure, RAS actions, etc.
  - Checks for low voltage or excessive power flow caused by the outage
- Uses a solved case from the LSE
- Applies each contingency, checks for violations
  - Check power flow and bus voltage limits
  - Rank and list violations
  - Send alerts based on violation level
- Manual operation allows testing user specified cases
  - Special conditions, pre-study before switching

RTCA Challenge – getting good results with small number of measurements (observability)

- Entire Network = G
- LSE observable subnetwork = S



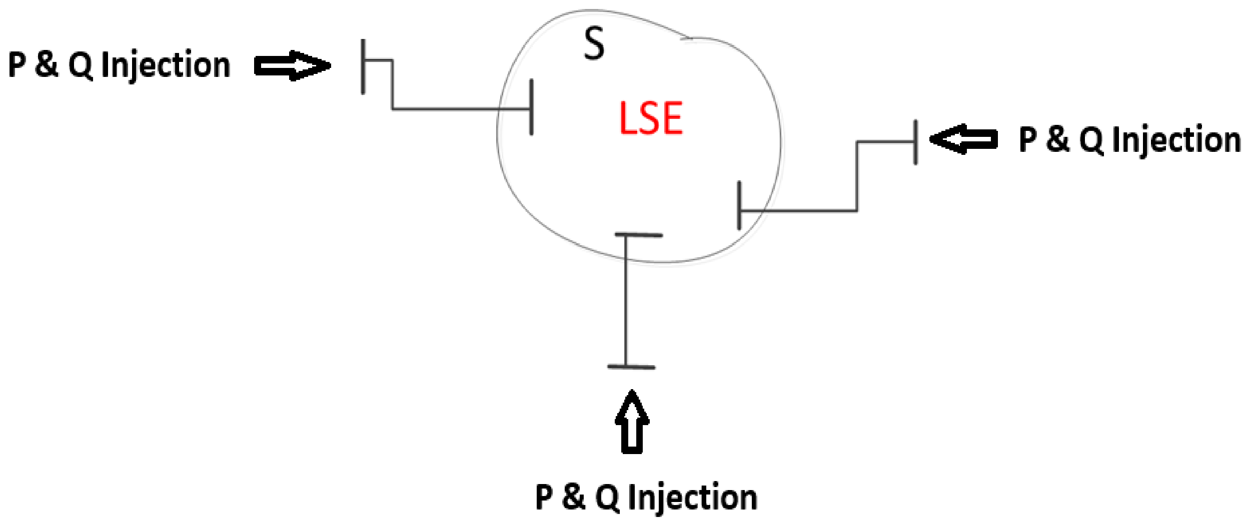
- Systems connected by lines on
  boundary busses B_i
- Ps-inj = Power Injection at Boundary Buses

Approach with 2 methods:

Method 1 – consider only the observable subsystem S

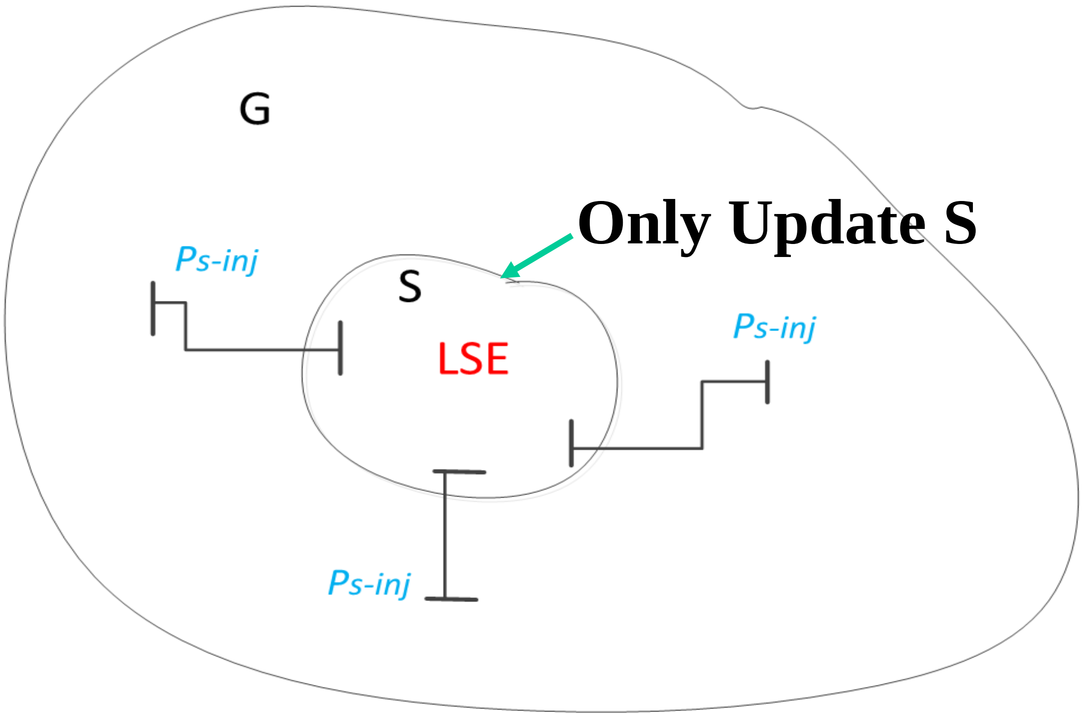
Method 2 – consider the whole system but update observable portion S

Method 1



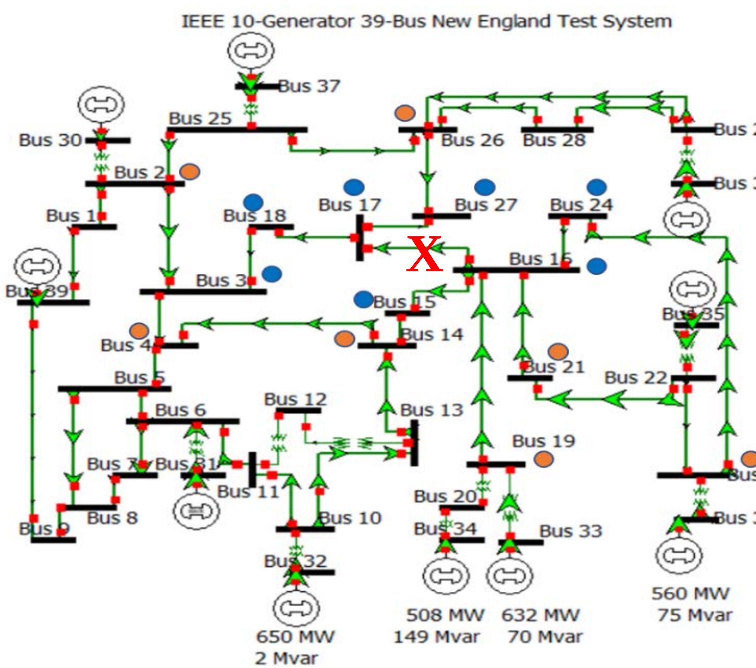
- Use only the subsystem that is covered by PMU measurements (this portion is called ‘observable’)
- External System is removed and its effect is represented by constant Power Injections (P & Q)
- Apply contingencies only to subsystem S

Method 2



- Use the entire system G
- Update the observable subset S with measurements from the LSE
- Use the load flow program to adjust the whole system to the observable system
- Apply contingencies to any part of the system (primarily subsystem S)

Method 2 Results – Contingency Line 16-17



Highlighted – Buses/Lines in Subnetwork S

Vmag (pu) | Power (MW)

		Contingency 16_17							
	Bus Results						Branch Results		
Bus No	Scaled System	Full System	% Error		From Bus	To Bus	Scaled System	Full System	% Error
1	1.04923587	1.052979209	-0.355499848		1	2	-90.78242352	-85.25989106	6.477292423
2	1.05218021	1.06171797	-0.898332755		1	39	90.78242352	85.25989106	6.477292423
3	1.041905853	1.058670871	-1.583591123		2	3	423.115656	352.9883521	19.86674729
4	1.035508921	1.0571593	-2.04797698		2	25	-203.3053485	-188.4837451	7.863597665
5	1.05470734	1.071598385	-1.576247728		2	30	-275	-250	10
6	1.056629554	1.072330031	-1.464146002		3	4	-118.7364212	-96.37446678	23.20319392
7	1.042342825	1.059207037	-1.592154449		3	18	153.323605	125.9258513	21.75705261
8	1.03981934	1.056665055	-1.594234154		4	5	-256.5929558	-189.7680978	35.21395786
9	1.046141916	1.053120786	-0.662684656		4	14	-485.4783458	-406.7164714	19.36530237
10	1.044515506	1.058894016	-1.357879958		5	6	-619.6029206	-522.2469011	18.64176107
11	1.047033338	1.062112774	-1.419758511		5	8	362.3814279	332.1413506	9.104580701
12	1.028982864	1.046919127	-1.713242536		6	7	495.5005047	444.8030266	11.39773678
13	1.039967646	1.056147984	-1.532014239		6	11	-437.4537944	-403.7312554	8.35271941
14	1.032597618	1.052484955	-1.889560147		31	6	678.3410623	563.7939983	20.317184
15	1.014522239	1.034296619	-1.911867393		7	8	236.8932233	209.8802234	12.87067425
16	1.025213515	1.041943999	-1.605698914		8	9	23.81361083	18.98225286	25.45197352
17	1.038753736	1.057691257	-1.790458289		9	39	23.79344621	18.97309836	25.40622385
18	1.038264852	1.056873646	-1.760739702		10	11	435.7747427	401.5335529	8.527603615
19	1.044659973	1.053572273	-0.845912495		10	13	279.2252573	248.466447	12.37946233
20	0.986500768	0.992901562	-0.644655527		10	32	-715	-650	10
21	1.022396001	1.038918058	-1.590313749		12	11	3.838258963	4.035430282	-4.886004842
22	1.043347599	1.053627441	-0.975661877		12	13	-12.08825896	-11.53543028	4.79244092
23	1.037240403	1.048755516	-1.097978715		13	14	266.7976101	236.6816178	12.72426331
24	1.030867715	1.046580913	-1.501383967		14	15	-201.1559048	-171.7125885	17.1468595
25	1.057086774	1.065654822	-0.804017179		15	16	-586.0332429	-492.3732826	19.02214512
26	1.047644273	1.064021159	-1.539150419		16	17	0	0	
27	1.035675979	1.055233488	-1.853382129		16	19	-539.5111385	-451.4357074	19.51007189
28	1.045186671	1.056303402	-1.052418357		16	21	-394.2090448	-329.6866614	19.57082008
29	1.046000606	1.054182869	-0.776171096		16	24	-50.61302554	-42.69641942	18.54161597
30	1.0475	1.0475	0		17	18	36.52633923	32.23689631	13.30600466
31	0.982	0.982	0		17	27	-36.52633922	-32.23689631	13.30600461
32	0.9831	0.9831	0		19	20	192.5420128	174.6968819	10.21491094
33	0.9972	0.9972	0		19	33	-691.6457851	-629.1367816	9.935677788
34	1.0123	1.0123	0		20	34	-555.7265963	-505.5193695	9.931810703
35	1.0493	1.0493	0		21	22	-698.1478253	-604.5058795	15.49065923
36	1.0635	1.0635	0		22	23	13.07103266	42.76601306	-69.43593354
37	1.0278	1.0278	0		22	35	-715	-650	10
38	1.0265	1.0265	0		23	24	424.6637154	353.8234394	20.02136324

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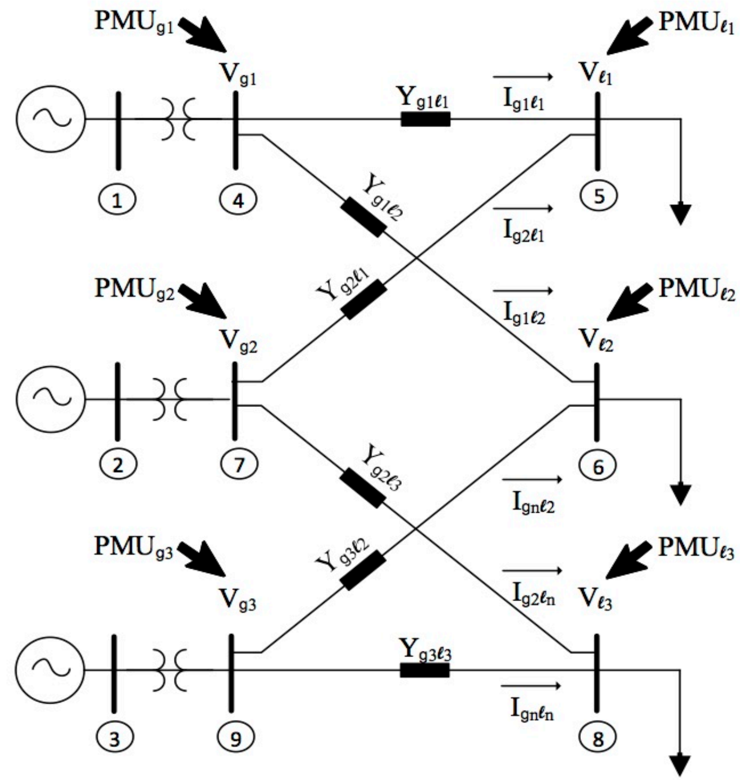
Decision & next steps

- Method 2 selected
  - Both methods produced high errors at boundary due to limited observability
  - Method 2 gave better results and also allows testing contingencies near boundary and externally; drawback is longer computation time
  - Testing with IEEE 300 bus test system confirmed improvement on a bigger system and advantages of Method 2
- Testing for deployment at BPA
  - WECC Planning Case 2020 HS (~ 20,000 Buses)
  - Subnetwork – 500 kV BPA System
    - Buses – 162 and Branches – 196

VOLTAGE CORRIDOR STABILITY LIMIT MONITORING

Methodology: Single Line Equivalent for a Transmission Corridor

- The PMU measurements at both ends of a transmission corridor are required
- Complex power is computed from the complex V & I measurements
- Using the complex power through the system and current flow in and out of the corridor, the voltage across the corridor can be computed
- The index is simply the voltage across the system divided by the load voltage
- Reactive support has to be considered



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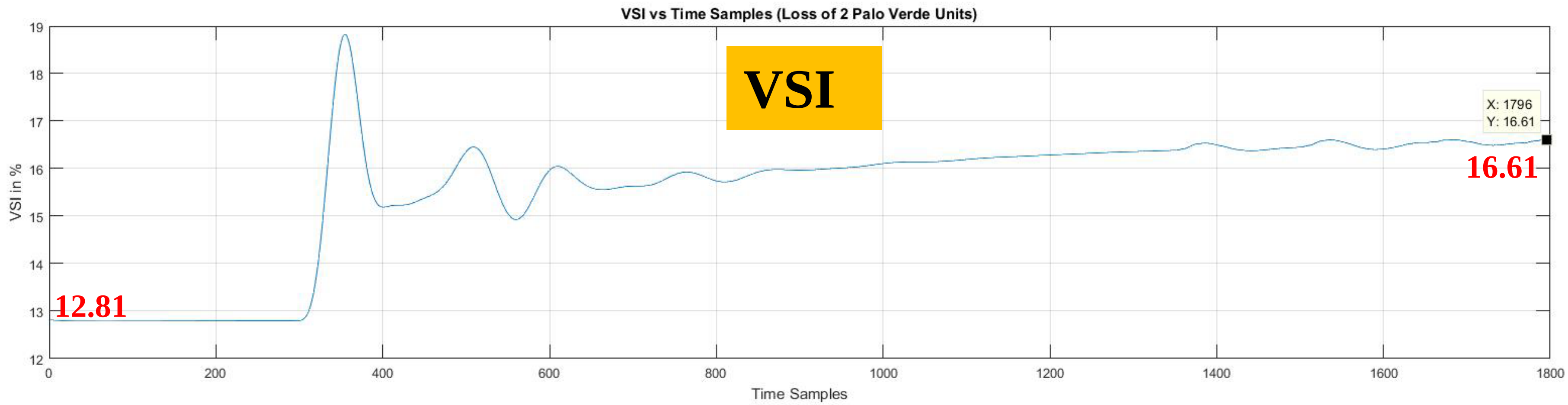
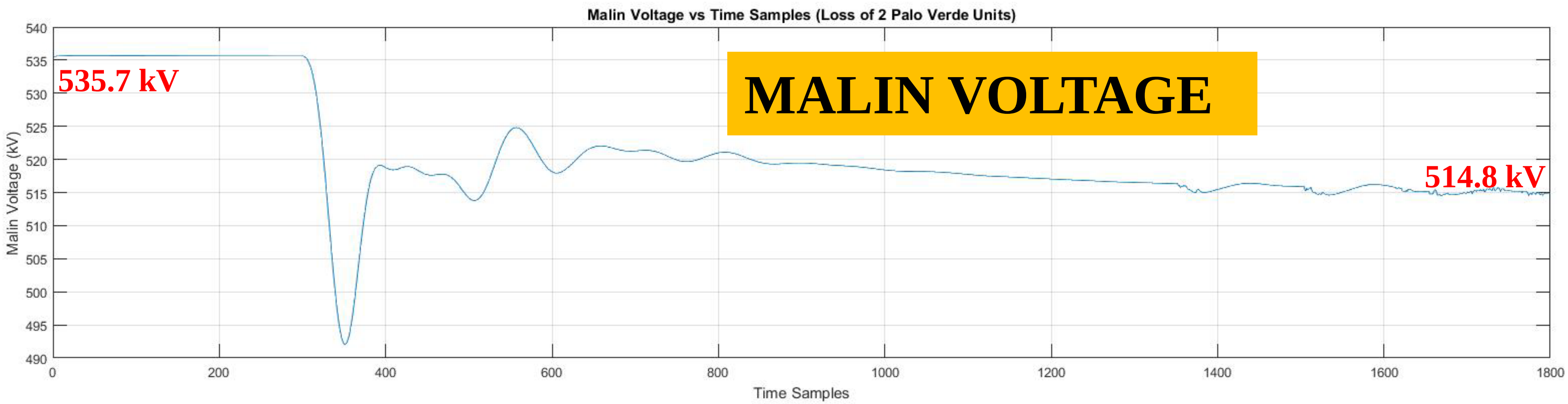
VSI reaction to loss of 2 Palo Verde Units





Next steps: determine threshold & determine reactive support

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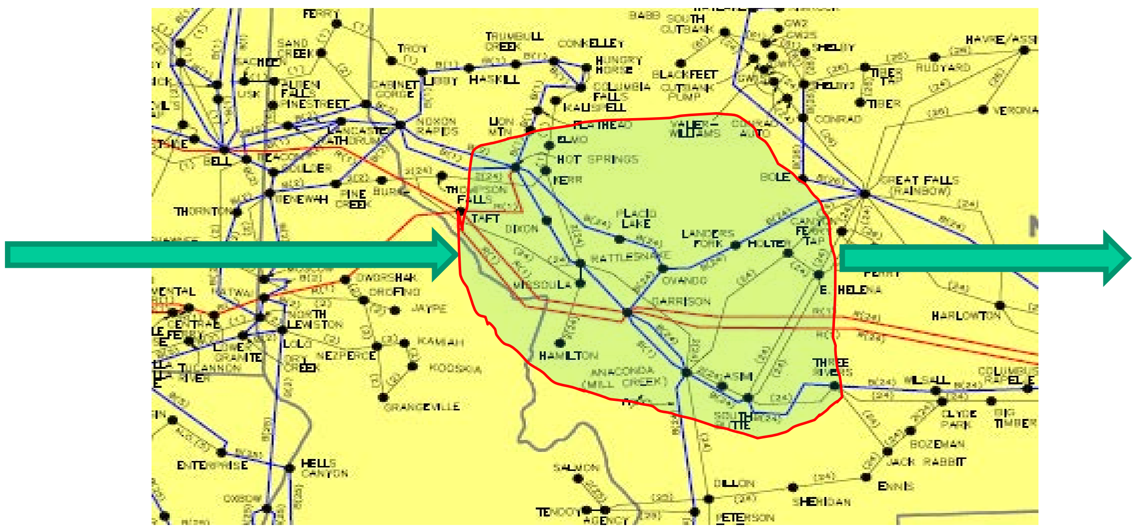
AREA ANGLE LIMIT MONITORING

Area-angle application

- Power flow creates a phase angle
- Higher angles result from
  - Higher power flow
  - Higher impedance (fewer lines carrying flow)
- Angle can indicate excessive stress or a lost transmission line
- Area angle indicates transmission failure or overloads

Power flow into area



Power flow out of area

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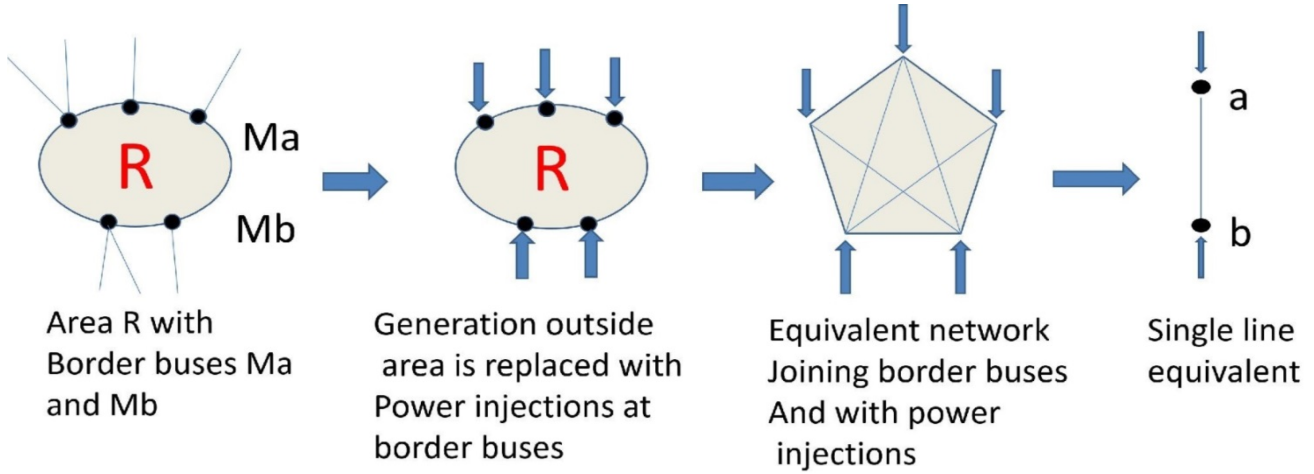
Methodology: reduce area & relate to angle

- Select an area with a distinct power flow through it, that has PMU measurements at all busses on border of area
- Determine a weighting for each boundary bus based on the network admittances; this uses the Kron reduction on the base case to determine the weighting. This effectively reduces the area to a single line equivalent
- The maximum allowed power flow is determined by studying single line outages; the area angle threshold is given by the worst case outage



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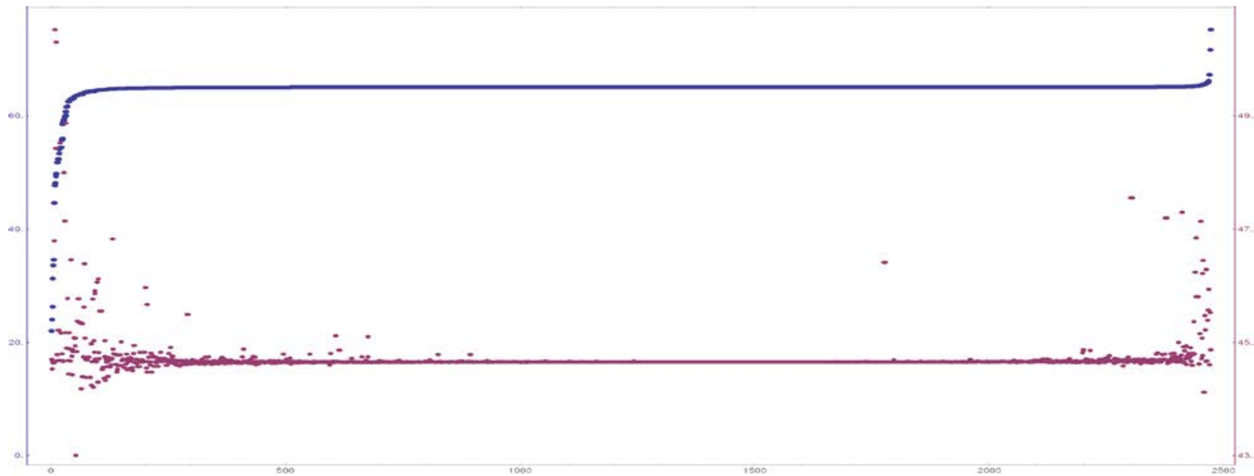
Challenges

- With limited PMU coverage, it is difficult to find an area where the boundary is completely monitored by PMUs
- The area needs to have a distinct power flow through it to cause angle changes reflected by power flow
- With a large meshed grid, there may be many exceptional outages (ie, outages where line limits are exceeded but the angle change doesn’t exceed a threshold)



Project status

- Presented paper on RTCA development at the NAPS conference in September 2018
- Project extended 1 year to March 14, 2020
- RTCA and voltage corridor applications have been turned over to the EPG development team
  - User interfaces will also be developed
- We continue to resolve issues in Area angle app

Extended Project Timeline

Task	Deliverable	Completion Date	Documentation & notes
1	**Project Management Plan**	4/12/2017	Project management plan document
2	**Research, Design & Development of Prototype**		
2.3	*Real time applications prototype, and development and testing*	10/1/2018	Test cases and test results
2.3A	*Completion and testing of deployable applications*	1/31/19	Documented test results
2.4	*Prototype Demonstration for DoE and all the participants*	3/16/2019	Demonstration at EPG
3	**Deployment, Testing & Acceptance**		
3.1	*Factory Acceptance Test*	5/4/2019	Test cases and test results
3.2	*Site Acceptance Test*	8/31/2019	Test cases and test results
4	**Demonstration at utility host site, training and a report**	11/7/2019	Demonstration, training and report
5	**Marketing and Outreach**		
5.1	*Marketing Plan*	2/1/2020	Marketing plan
5.2	*Outreach*	3/14/2020	Industry presentations & briefing documents

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Looking Forward

- Planned next steps
  - Application Implementation in operational code
    - Operational code testing in December 2018
  - Develop area angle application
  - Adapt applications for test site deployment
    - NYPA – November-December 2018
    - Duke – January-February 2019
- Project roadmap
  - FY 2019: Complete application development & deploy at host sites
  - FY 2020: Host site demonstrations with real-time operation & produce commercialization plan

Questions?