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Linear State Estimator in Next Generation EMS

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Out-line

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Motivation

Concurrent work

LSE in PG&E SGIG Project

Test Results

Q & A

Motivation

Traditional SE – Background

PG&E EMS network model – 4,000+ buses

Typical periodicity: 2 minutes

Typical Execution time – under 30 seconds

Next Generation EMS Applications using SynchroPhasor data

Long-term direction:

- State Measurement

Today:

- Hybrid State Estimator
- Linear State Estimator (LSE)

Linear State Estimator – Benefits

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LSE runs at **subsecond** cycles using phasor measurements –
Much faster than State Estimator

Validation of PMU data,
including topology error detection at substation level

Output of LSE can be used for RAS, SE –
Estimated values (as opposed to raw inputs)

Useful in case of man-in-the-middle (Cyber) attacks also?

Concurrent Work in LSE Area

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Virginia Tech [Dominion & Quanta]

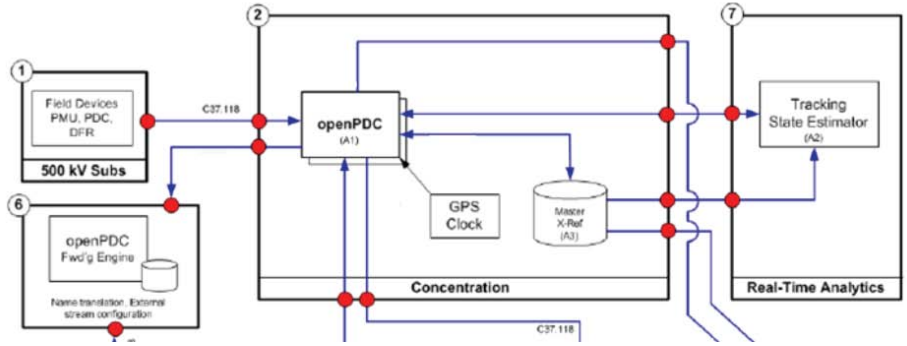
Georgia Tech [also with PG&E]

RPI

WSU [also with PG&E/Alstom]

Others??

SOC Synchrophasor Architecture



Summary

- The SuperCalibrator Concept was Introduced to Solve the Limitations of Traditional State Estimators:
  1. System Asymmetries,
  2. Voltage Imbalance,
  3. Instrumentation Channel Error.
- The SuperCalibrator Concept has Been Successfully Demonstrated on Several Systems Including a Small Five-Substation Power System
- State Estimation rates of FOUR PER SECOND has been achieved
- The SuperCalibrator Approach is Scalable to Any Size System

PSERC Seminar, June 17, 2008 52

Rensselaer Polytechnic Institute Electrical, Computer, and Systems Engineering

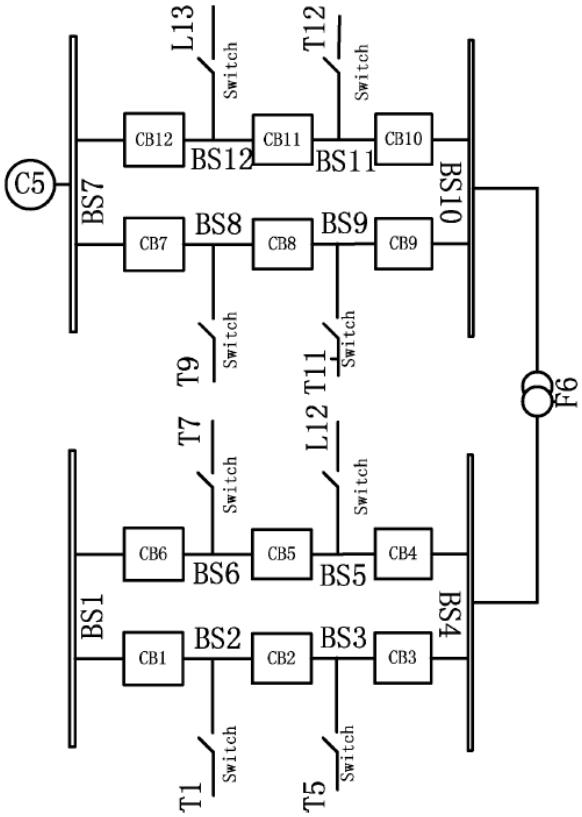
Phasor Data Only State Estimation (PSE)

- PSRC project
- State estimation using synchrophasor data from phasor measurement units (PMUs) only
  - Siting of PMUs to achieve observability and redundancy
  - Method to correct angle bias
- Dynamic state estimation – use the measured synchrophasor data to compute voltage and current phasors across a power network

11/09/2011 JHC 8

Two level Linear State Estimator

Substation



$$z = \begin{pmatrix} z_{inj} \\ z_{cb} \end{pmatrix} = \begin{pmatrix} A_{KCL} \\ I \end{pmatrix} \mathrm{x} + \begin{pmatrix} r_{inj} \\ r_{cb} \end{pmatrix} = Hx + r$$

Control Center

State Estimation

- **States**

  Complex Bus Voltages

- **Measurements (Phasor)**

  Bus Voltages: V_{bus}

  Two Direction Branch Currents: I_{b1}, I_{b2}

  Injection Currents: I_{inj}

- **Measurement Functions**

$$z = \begin{pmatrix} V_{bus} \\ I_{b1} \\ I_{b2} \\ I_{inj} \end{pmatrix} = Hx + r = \begin{pmatrix} I \\ Y_{b1} \\ Y_{b2} \\ Y \end{pmatrix} x + r$$

LSE in PG&E SGIG Project

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Phases:

Preliminary Observability Analysis

Phase 1: Stand-alone LSE Application Integration

Phase 2: LSE integration and Testing at POC

Phase 3: Deployment in Production (2013)

Proof of Concept Testing - Architecture

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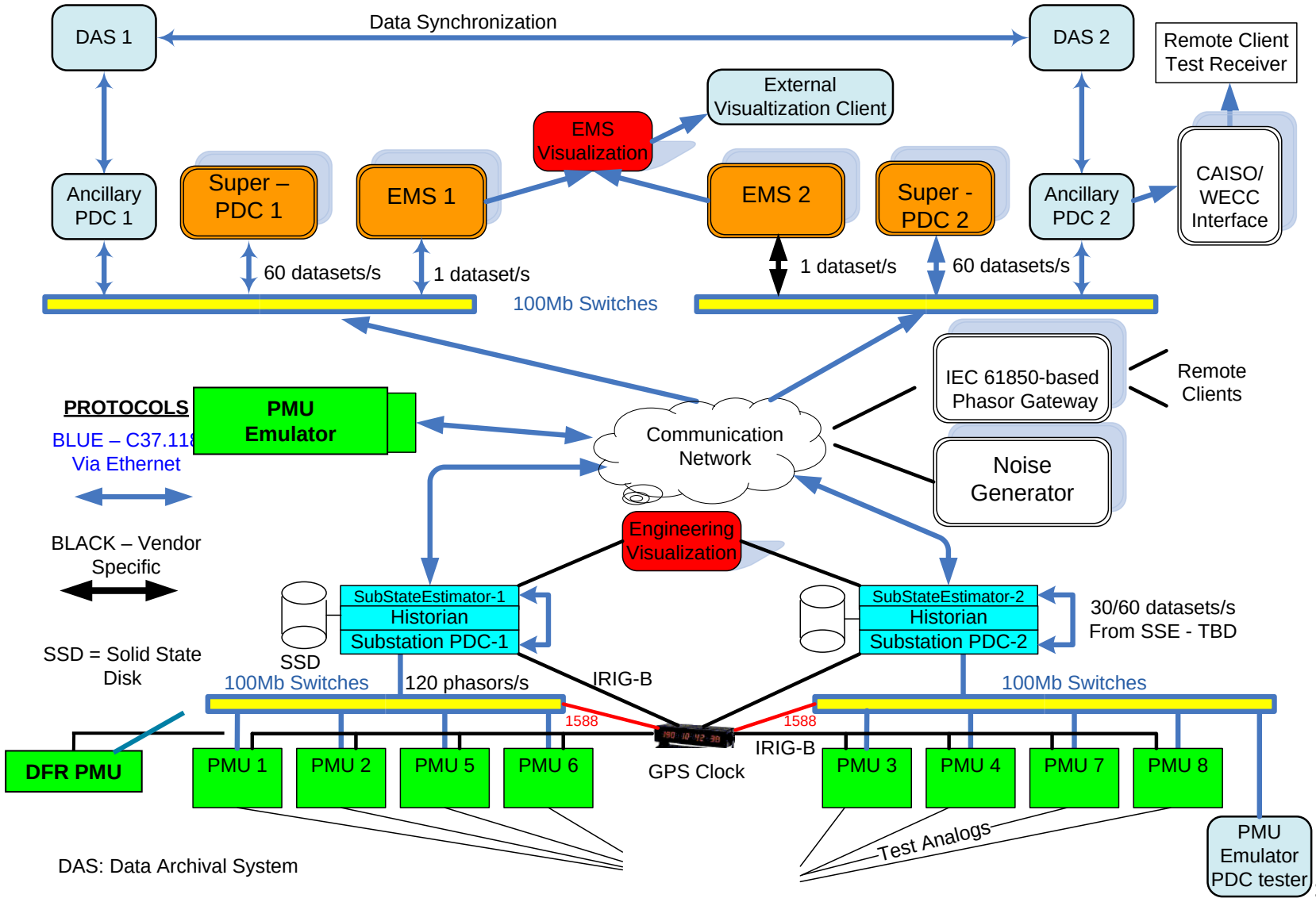
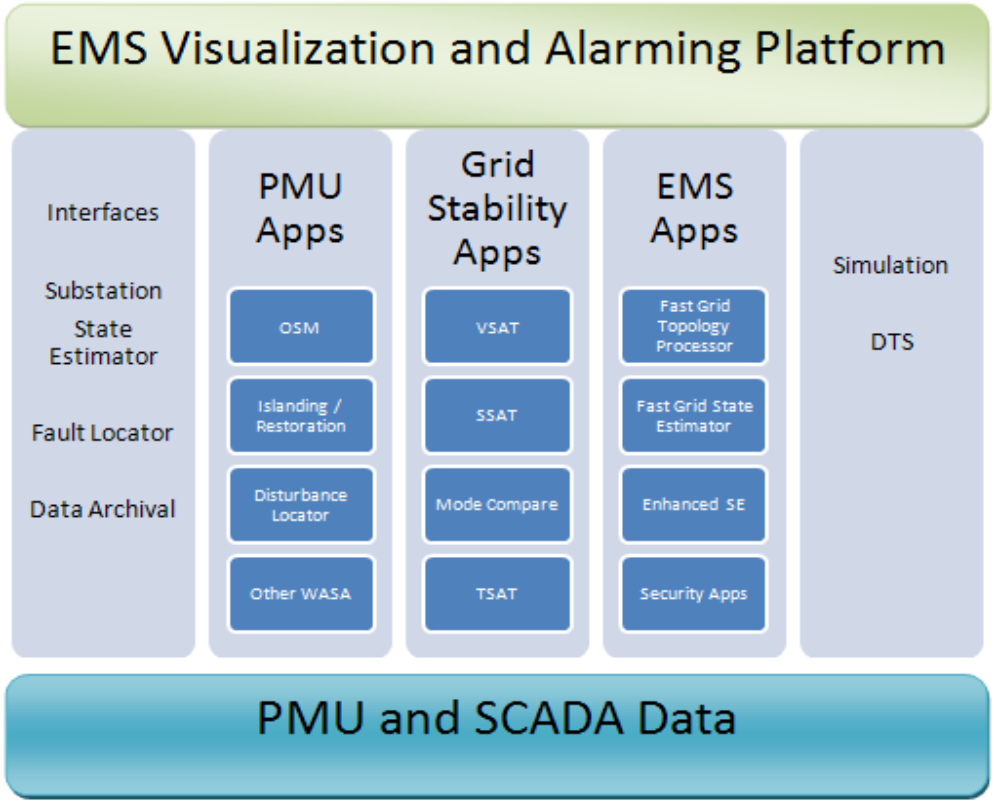
PG&E Synchrophasor Project – Proof of Concept Architecture

C37.118 is used for interim testing while harmonization with IEC 61850 is demonstrated

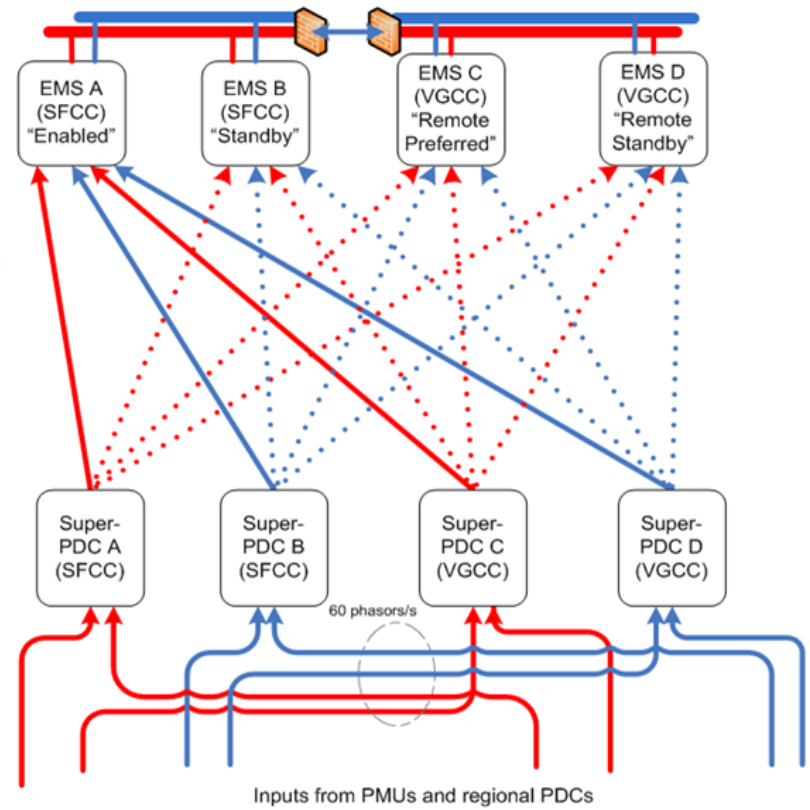


POC Applications

Strategic Team: ***PG&E, ALSTOM, GE, Mississippi State University, Quanta***
Academic & Testing ***GeorgiaTech, OMICRON / RTDS / Virginia Tech., Washington State Univ.***

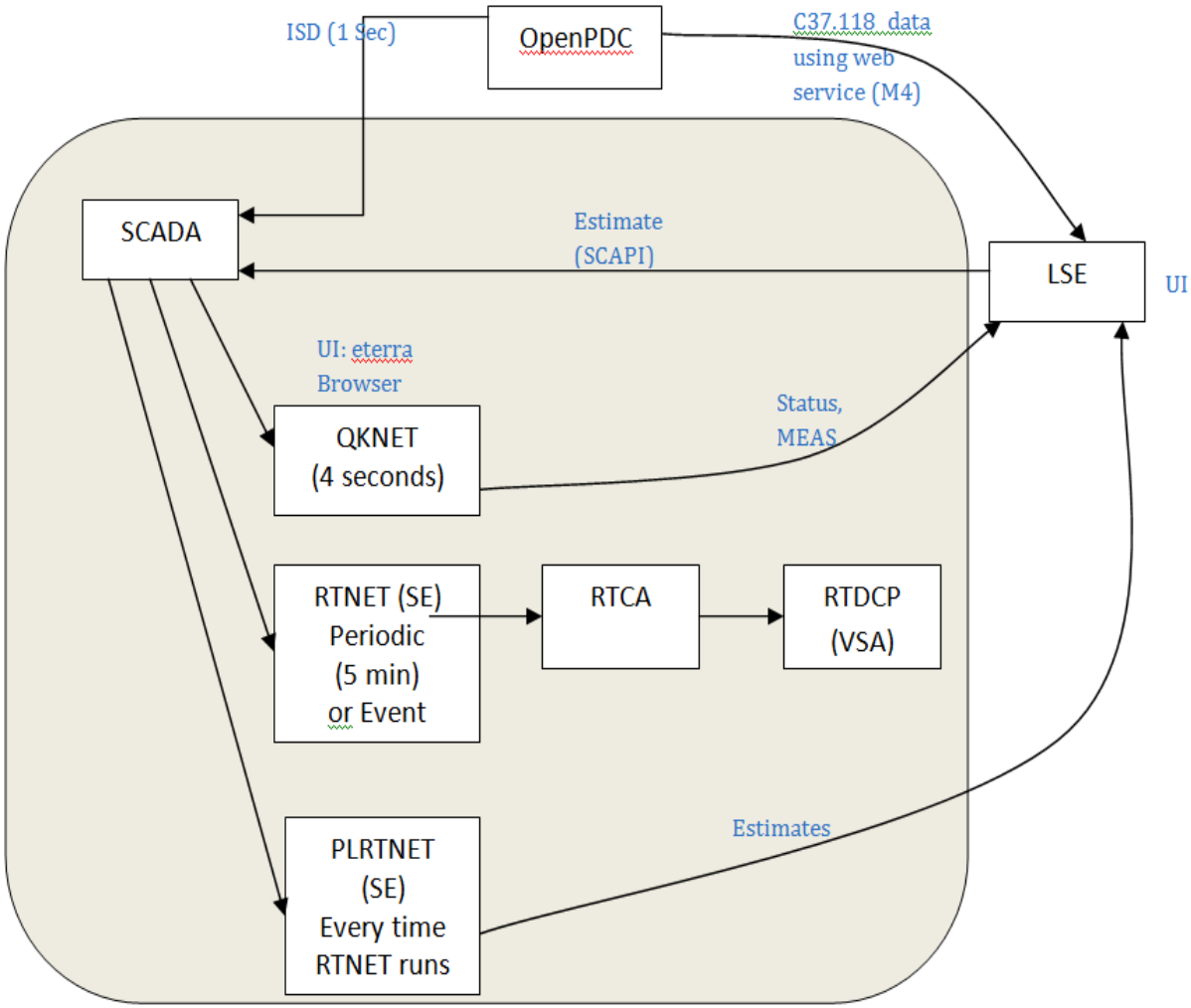


SynchroPhasor Applications for the Control Center

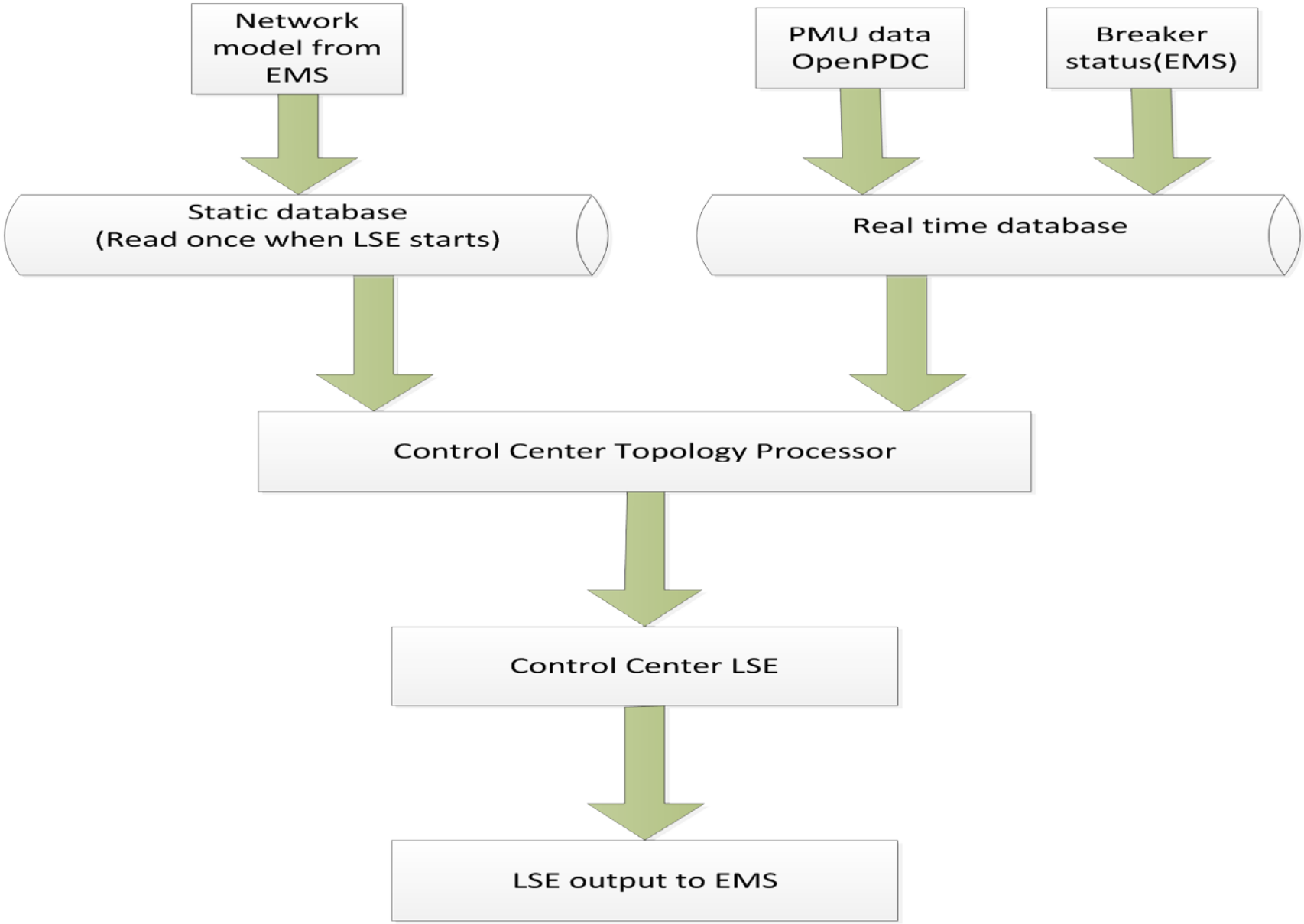


Multi-host Redundancy (ISD Link)

LSE Application Context



LSE Application



Migrating new application to familiar UI

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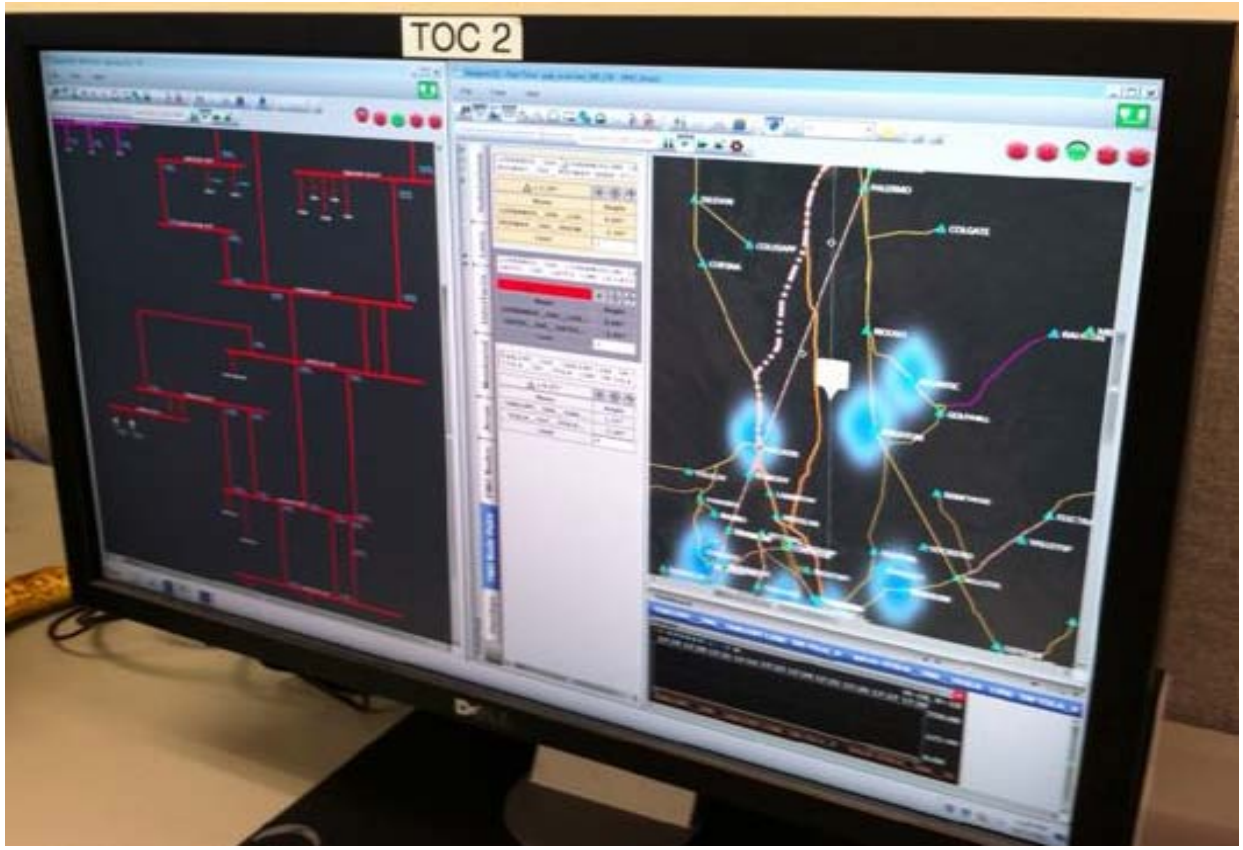
```
BUS <2,-1> 0.9794751 -0.4566735 0 0
BUS <3,-1> 0.9774434 -0.2958587 0 0
BUS <4,-1> 1.040004 -0.3429523 0 0

LOD <2,-5> 0.9794751 -0.4566735 17.50009 -0.5600058
LOD <4,-5> 1.040004 -0.3429523 1.000004 0

BCH <2,3> 0.9794751 -0.4566735 10.76673 2.77821
BCH <3,2> 0.9774434 -0.2958587 10.76673 -0.3633826
BCH <2,4> 0.9794751 -0.4566735 7.1599 2.624655
BCH <4,2> 1.040004 -0.3429523 6.834125 -0.5169379

GEN <4,0> 1.040004 -0.3429523 1.23037 8.000219
GEN <6,0> 0.9499998 0.4112037 -1.329083 10.47996
```

Text UI of LSE

To e-terra*Vision*



"The ultimate goal is to ensure new applications are accepted and used by operators."

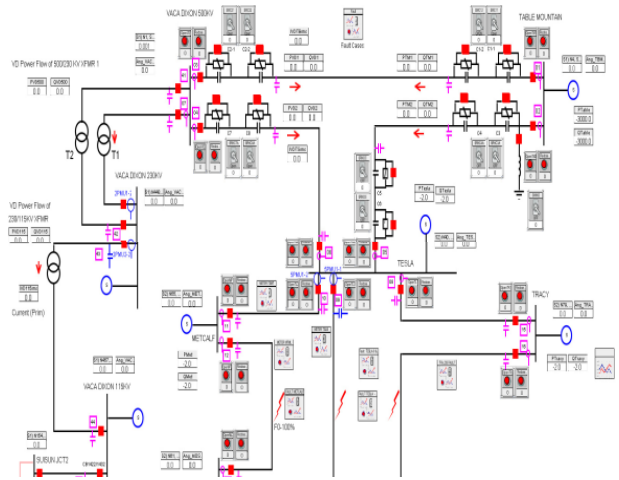
Modeling

EMS model – 4,000+ buses and evolving

Load Flow Program – < 15,000 busses

RTDS model - ~ 250 buses

One more model for LSE?



Naming Conventions: SCADA Analog vs. PMU Signal

TABLEMT	LINE	TM-VD_4	PVAA	V5PMU01_1_1N7-PA1
TABLEMT	LINE	TM-VD_4	PVAM	V5PMU01_1_1N7-PM1
TABLEMT	LINE	TM-VD_4	PIAA	V5PMU01_1_1N7-PA7
TABLEMT	LINE	TM-VD_4	PIAM	V5PMU01_1_1N7-PM7

LSE Model (cont)

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Subset of EMS model

Need for Breaker Status

Substation SE – limited by PMU information

Line side PMUs

Use of Pseudo Measurements

Migrating new applications to a production EMS

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- The Development Environment
- The User Interface
- Where should the application reside?
- Inputs and Outputs
- Application Program Interface (API)
- Security and Administration
- Redundant configuration
- Study version of application
- Training
- Re-inventing the wheel
- Product Life Cycle Maintenance
- Algorithm

LSE Testing

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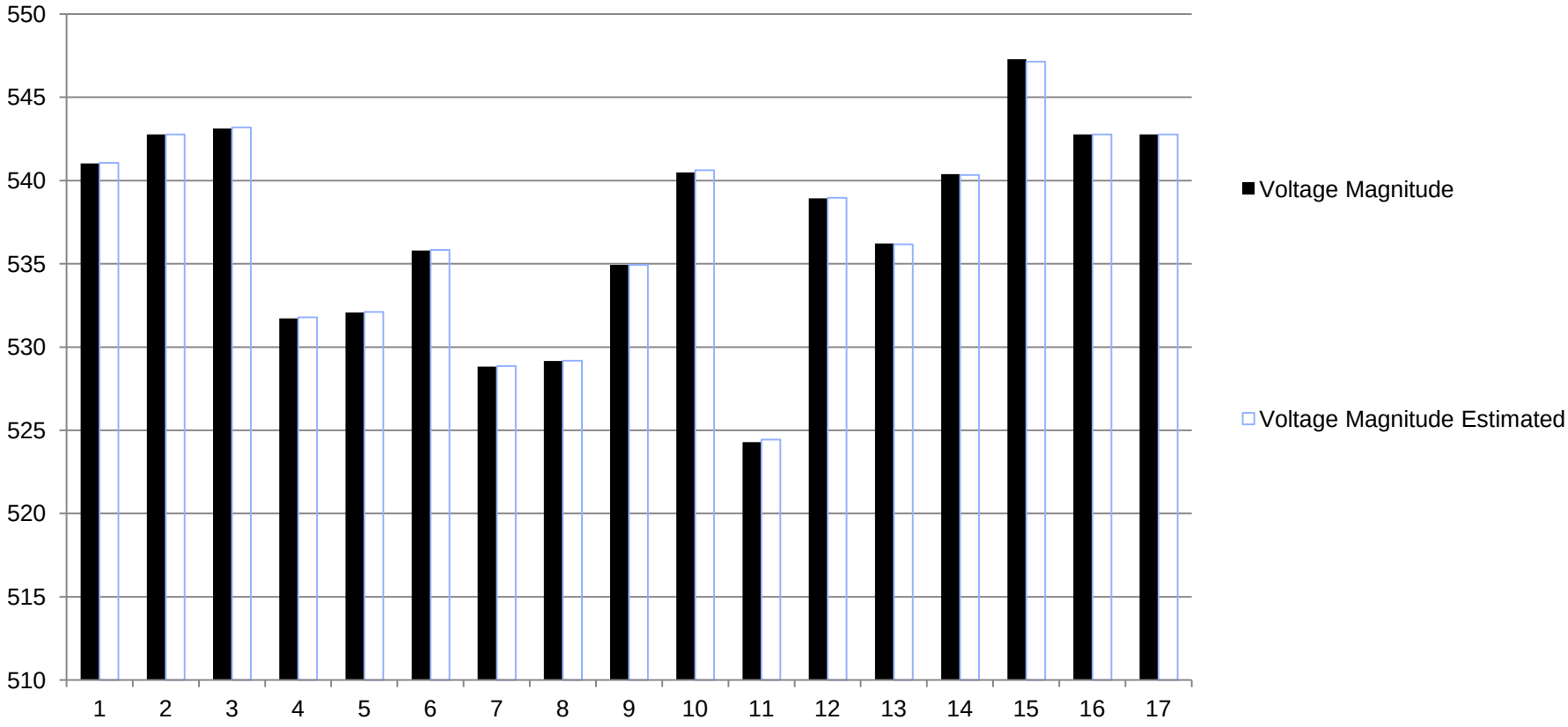
Standalone Testing

Use of Virtual PMUs in PG&E SynchroPhasor Test Facility

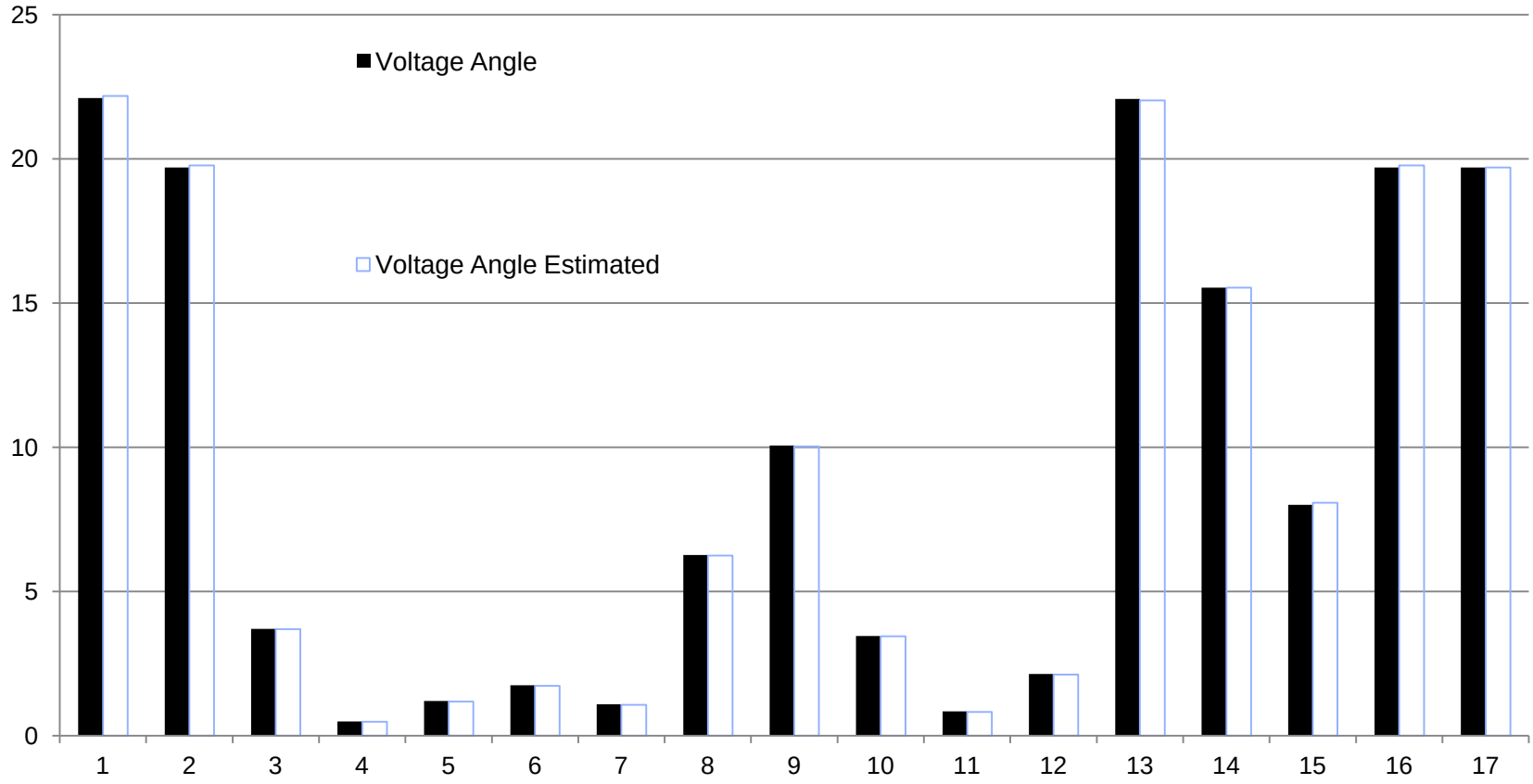
Nearly 100 Test scenario

Validation with the EMS State Estimator

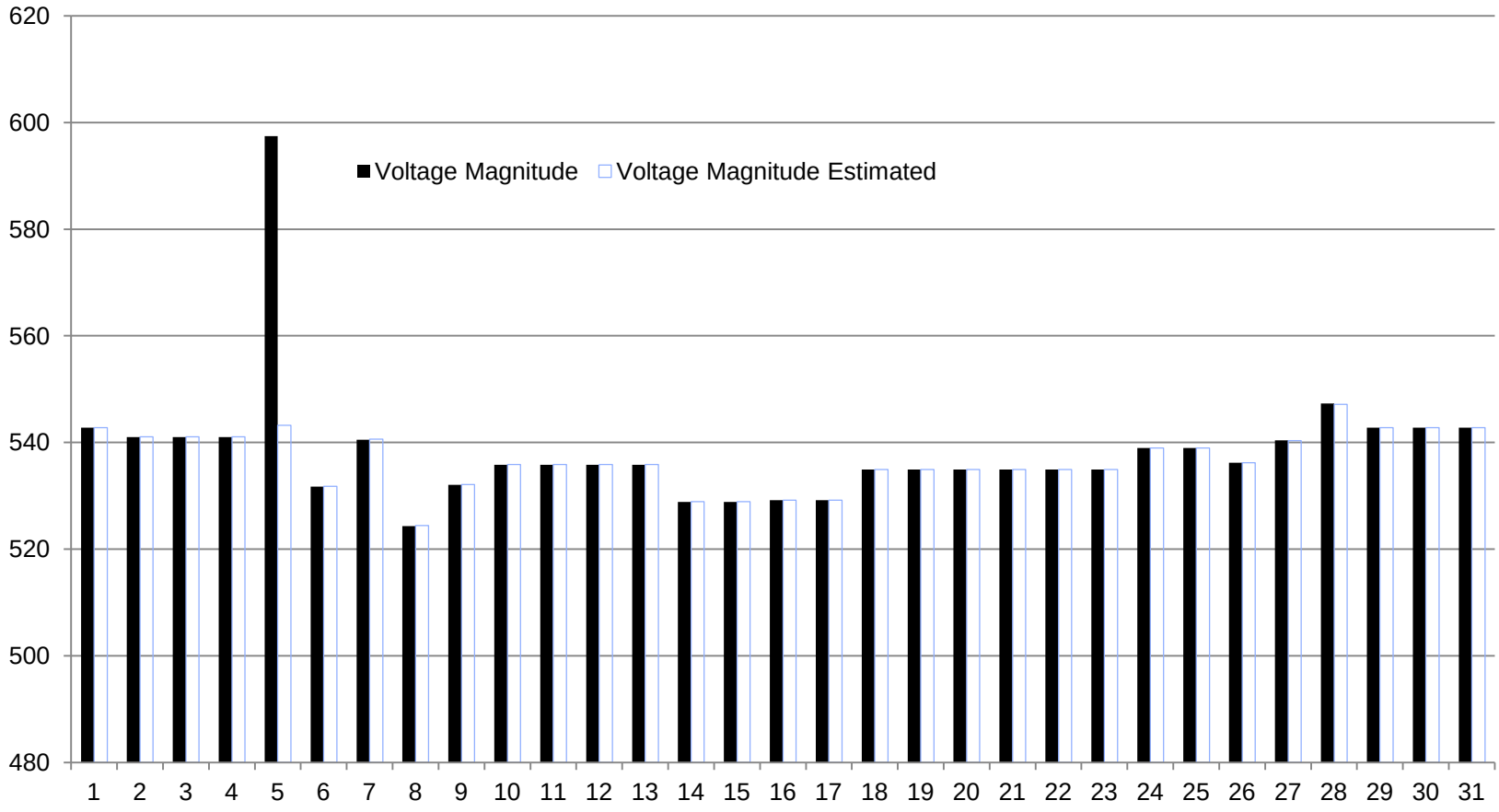
LSE Test – Scenario 1 – Basecase – Voltage Magnitude



LSE Test – Scenario 1 – Basecase - Angles



LSE Test – Scenario 2 – Magnitude error detection



LSE Test – Scenario 4 – Measaurements Switched

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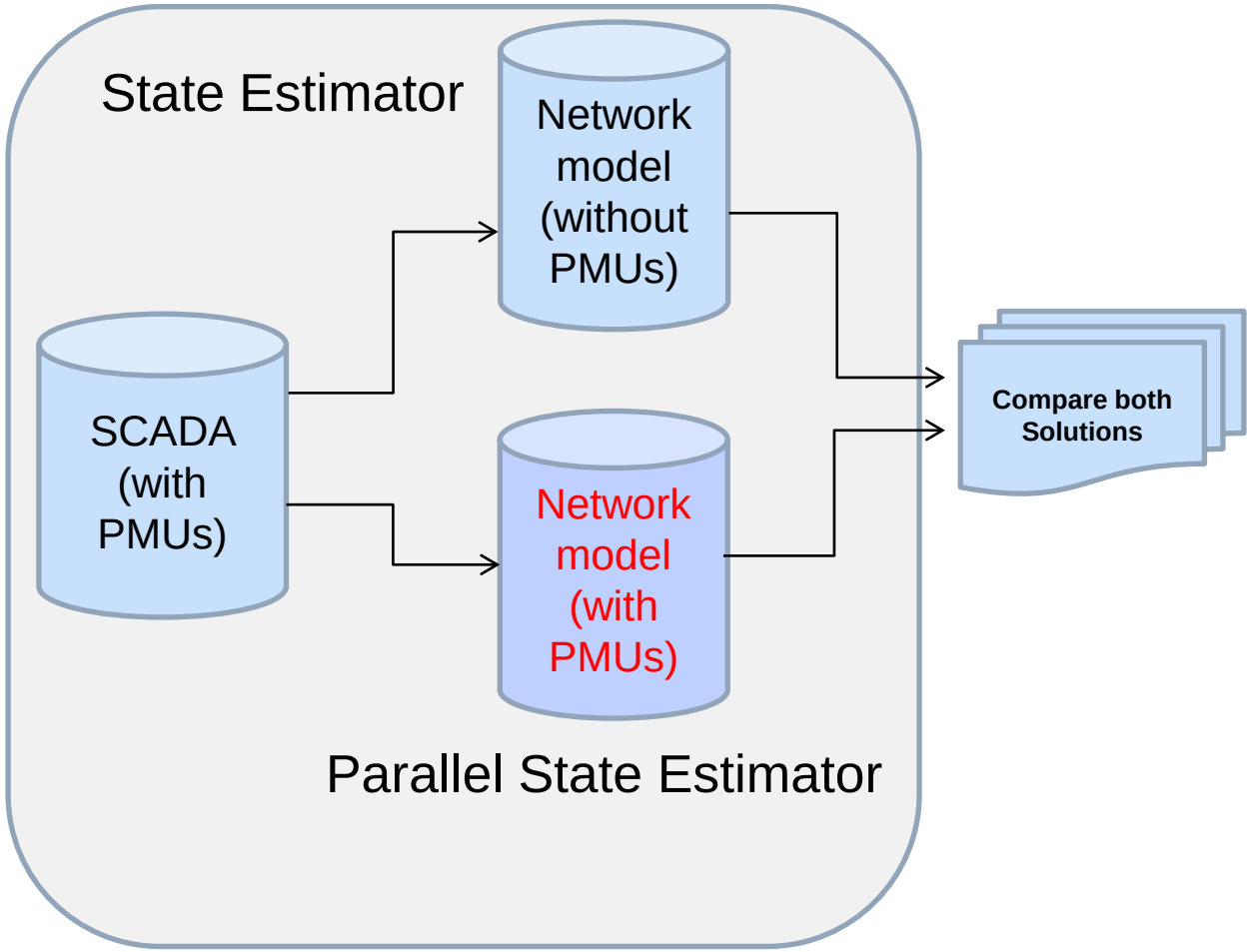
		Current Mag (Meas)	Current Angle (Meas)	Current Mag (Est)	Current Angle (Est)	
PM	TSLA-TRCP1,TESLA5006	119.7161	13.5001	119.3512	13.6014	0.3
PM	TSLA-TRCP1,TRACYPP5015	217.7387	59.862	100.1092	196.4127	54.02
PM	LB-MIDW21,LOSBANOS5006	401.6616	-61.6322	401.6616	-61.6322	0
PM	LB-GATS11,LOSBANOS5015	284.811	-55.1076	282.3152	-56.6063	0.88
PM	LB-GATS11,GATES5106	238.4613	82.9427	235.5999	84.751	1.2
PM	LB-GATS31,GATES5007	473.3989	84.5673	115.7268	80.0987	75.55
PM	TRCP-LB1,TRACYPP5006	105.6367	195.2929	221.4113	57.6276	-109.6

Framework – Parallel State Estimator



Summary

- Review of LSE
- Getting ready for Field testing

The Knee Moment (It Works!)

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