PMU-based EMS and Power Network Analysis Applications

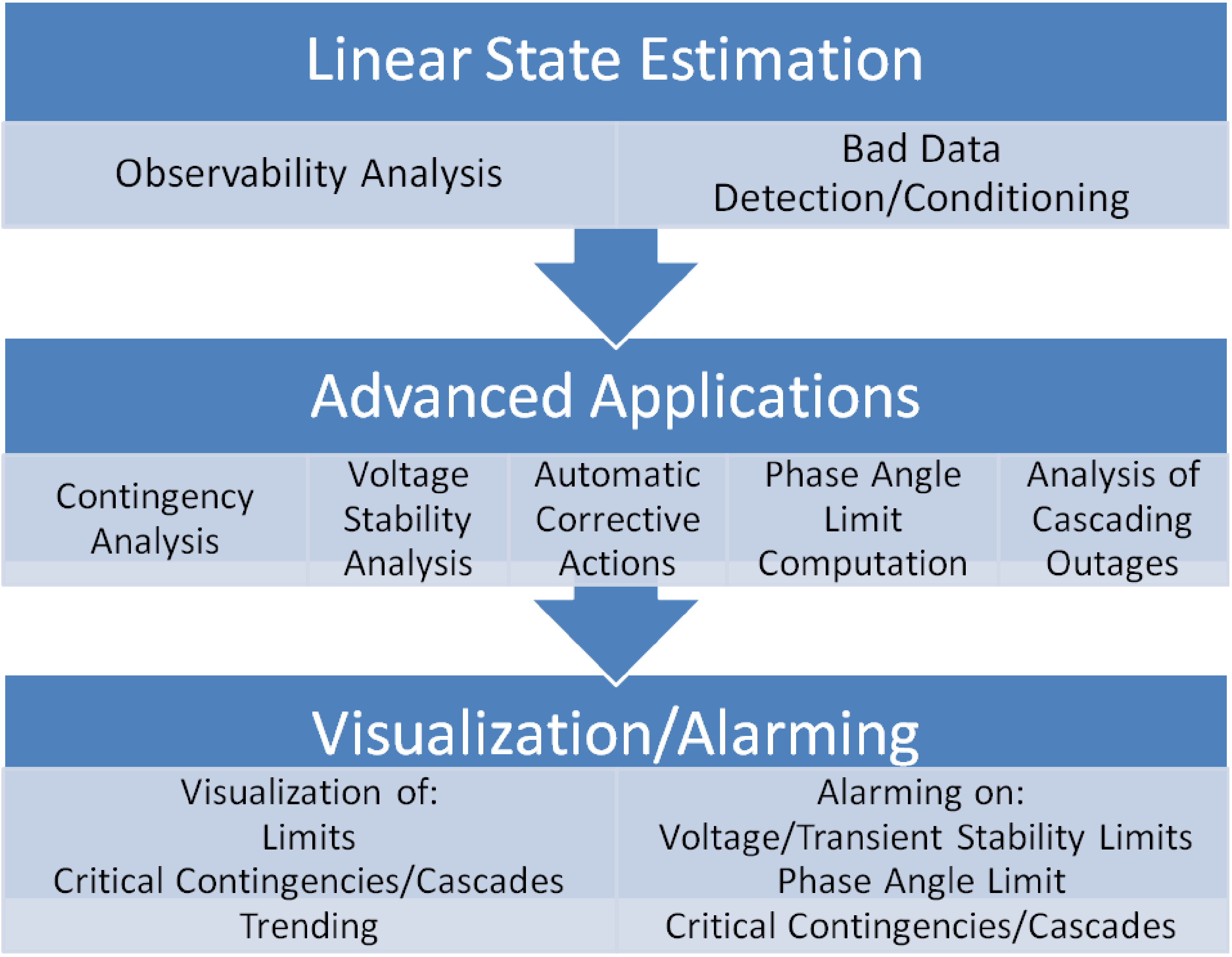
Robin Manuguid, SDG&E and Marianna Vaiman, V&R Energy

NASPI Work Group Meeting

Charlotte, NC • September 26 - 27, 2023

Linear State Estimation: Foundation for Measurement-Based Advanced Applications

- The framework was pioneered by V&R Energy during NASPI Voltage Stability Workshop on October 22, 2014:
  - Introduced the concept of a “PMU-based State Estimator Case” or “LSE Case”
  - Prior to this, “standard” output of LSE was conditioned and expanded PMU stream
- Only the use of LSE produced accurate results



SDGE
ENERGY

2014 NASPI Voltage Stability Case 1

- Correct results announced by NASPI at the Workshop

NASPI North American SynchroPhasor Initiative

Voltage Stability Case 1

First Time of Unacceptable Operating Conditions	303.4 sec
Shunt Cap Switching Time	247.8 sec
Pre-Switching Real Power Margin	343.75 MW
Post-Switching Real Power Margin	400.00 MW
Real Power Margin @ 0 sec	618.75 MW
Real Power Margin @ 150 sec	506.25 MW
Real Power Margin @ 305 sec	112.50 MW
Real Power Margin @ 445 sec	400.00 MW
Description of Method	PV Analysis

- Results submitted by vendors one week before the Work-shop

NASPI North American SynchroPhasor Initiative

VOLTAGE STABILITY CASE 1
RESULTS AND COMMENT SHEET

	Electric Power Group	RPI	V&R	Alstom Grid	ABB
First Time of Unacceptable Operating Conditions	170	None	303.5	None	None
Shunt Cap Switching Time	247	247.8	245	247.8	248
Pre-Switching Real Power Margin	23.53 kV/100 MW	411	335	29	92
Post-Switching Real Power Margin	7.5 kV/100 MW	461	391	86	92
Real Power Margin @ 0 sec	0.38 kV/100 MW	645	617	Not Available	196
Real Power Margin @ 150 sec	3.1 kV/100 MW	520	515	76	193
Real Power Margin @ 305 sec	6 kV/100 MW	190	111	46	32
Real Power Margin @ 445 sec	2.9 kV/100 MW	388	385	69	107
Description of Method	Voltage Sensitivity to Change in Real Power	AQ Bus Method	Linear State Estimation, PV/QV Analysis	RVII – local voltage instability detector	Equivalencing, PV analysis

VR ENERGY

2014 NASPI Voltage Stability Case 2

- Correct results announced by NASPI at the Workshop

NASPI North American SynchroPhasor Initiative

Voltage Stability Case 2

First Time of Insecure (N-1) Operating Condition	1312 seconds
Reason(s) for Insecurity	Voltage Violation in Zone 10 – N-1 Outages
First Time of Unacceptable N-0 Operating Condition	None
Reason for Unacceptable Condition	N/A
Time of Instability	4012 seconds
Security Margin (Transfer into Zone 10) @ 1500 sec	50.0 MW
Stability Margin (Transfer into Zone 10) @ 1500 sec	250.0 MW
Security Margin (Transfer into Zone 10) @ 4000 sec	0.0 (-) – Insecure
Stability Margin (Transfer into Zone 10) @ 4000 sec	0.0 (-) – N-1 Unstable
Assumptions Used	50/50 Pickup
Noticeable System Changes	1. Line 115-130 Trips 2. Line 115-130 Returned to Service 3. Bus 122 STATCOM Trips 4. Bus 122 STATCOM Switched Back In 5. Bus 112 Shunt Cap Switches In 6. Line 116-120 Trips - Unstable
Description of Method	PV, Contingency Analysis

NASPI North American SynchroPhasor Initiative

VOLTAGE STABILITY CASE 2
RESULTS AND COMMENT SHEET

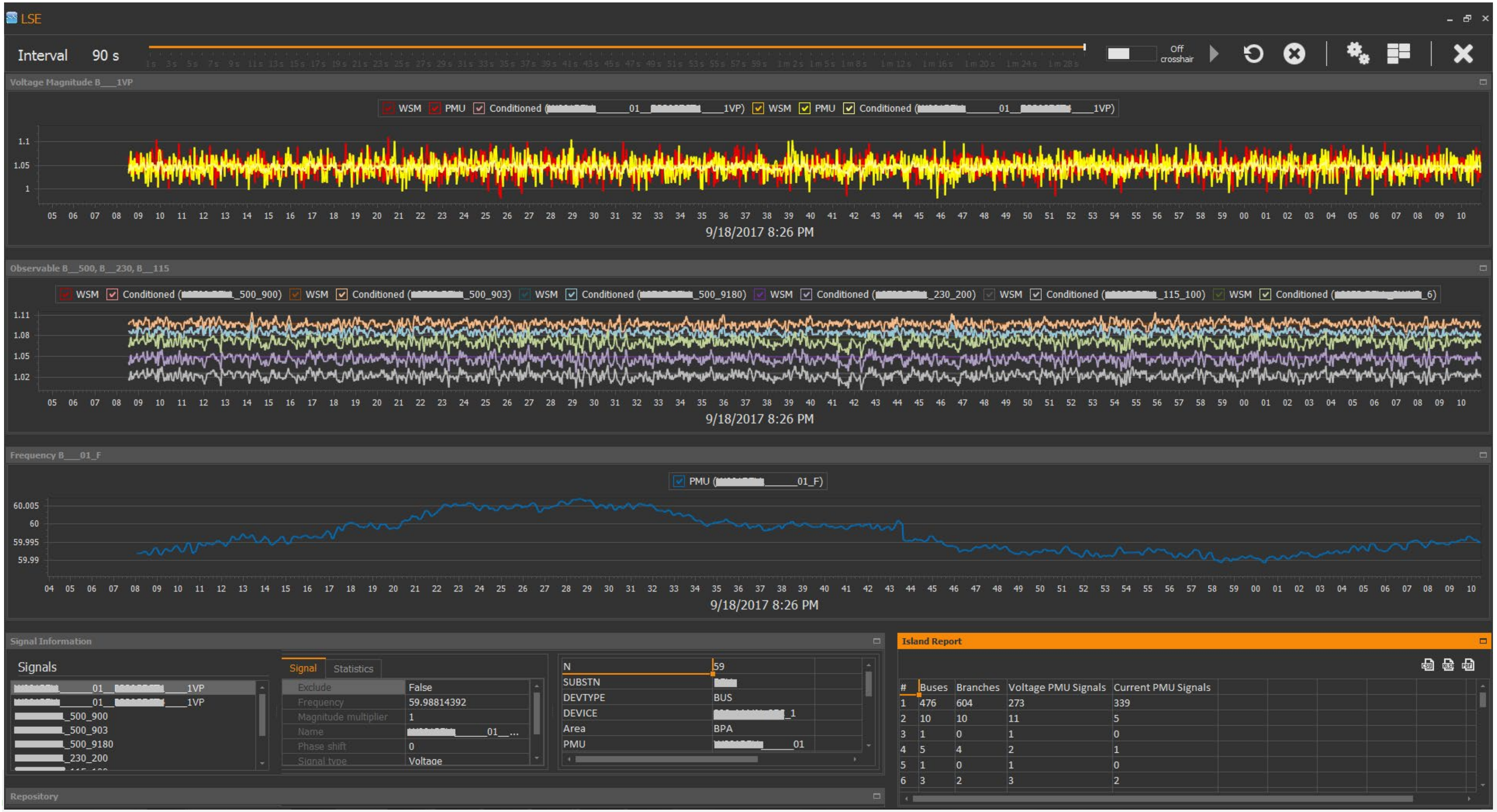
	Alstom Grid	V&R Energy
First Time of Insecure (N-1) Operating Condition	2410	1312
Reason(s) for Insecurity	Line L02	Contingency L02 Contingency L11
First Time of Unacceptable N-0 Operating Condition	4064	None
Reason for Unacceptable Condition	Voltage Violation @ Bus 113	N/A
Time of Instability	4070	4012
Security Margin (Transfer into Zone 10) @ 1500 sec	730	40
Stability Margin (Transfer into Zone 10) @ 1500 sec	760	250
Security Margin (Transfer into Zone 10) @ 4000 sec	170	Negative
Stability Margin (Transfer into Zone 10) @ 4000 sec	200	Negative
Assumptions Used	-Total generation is the sum of three branches: • Bus 151 to Bus 156 CKT 1 • Bus 151 to Bus 156 CKT 2 • Bus 136 to Bus 130 CKT 1 -Upper bound voltage limit criteria was relaxed -Bus 136 generator Pmax increased from 1000MW to 1070MW for transfer analysis	Ignored 500kV equivalents & their voltages
Noticeable System Changes	At t=502s, line 130-115 circuit 1 tripped and reconnected at t=800s At t=2246s, first shunt cap (100 MVAR at bus 112) gets switched in at load in zone 10=912MW At t=2868s, Second shunt cap (125 MVAR at bus 120) gets switched in at load in zone 10=1152MW	Event 1 - 502 s. Switching off line 130-115 “1”. Event 2 - 802 s. Line 130-115 “1” switched back. Event 3 - 1302 s. Switching off FACTS at bus 122. Event 4 - 1602 s. Switching in FACTS at bus 122. Event 5 - 2462 s. Shunt cap switching at bus 112. Event 6 - 2868 s. ("non-switching"). Increase in transformer 116-117 flow. FACTS reaches reactive limit, loses control of bus 116 voltage. Event 7 - 4012 s. Contingency 116-120 which causes system collapse at 4012 s. There is no State Estimator solution after this N-1 contingency occurs.
Description of Method	PV Analysis	Linear State Estimation, AC Contingency Analysis, VS assessment (PV/QV, Sensitivity)

- Results submitted by vendors one week before the Workshop

V&R ENERGY

PMU-ROSE LSE at Peak RC

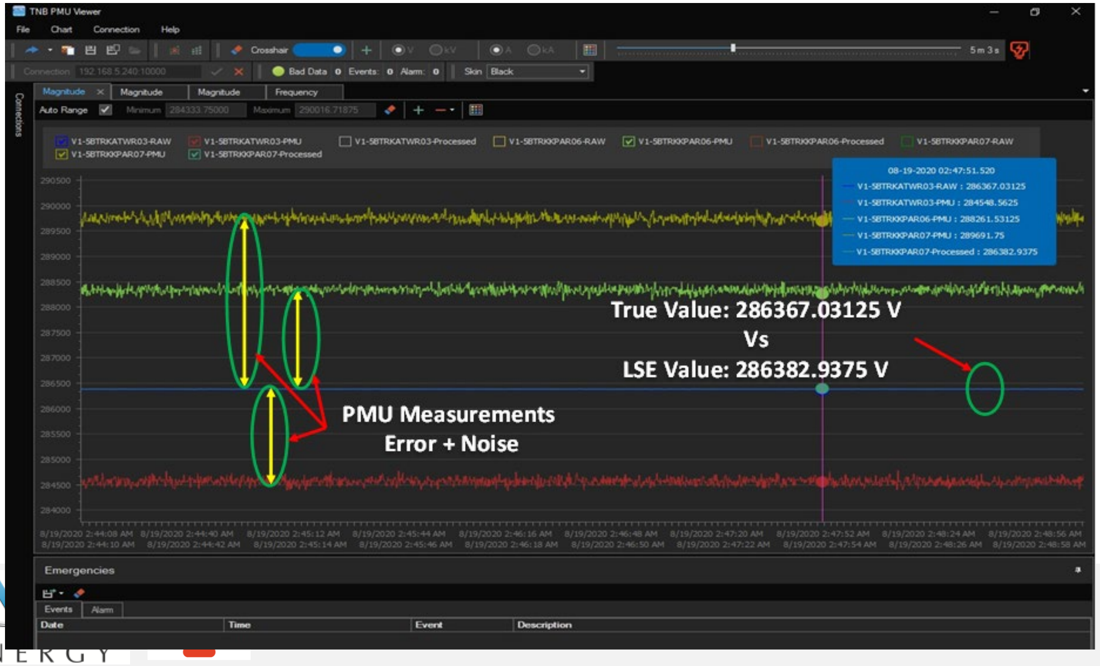
- Provides the mechanism for selecting, viewing, and analyzing the input data and LSE result

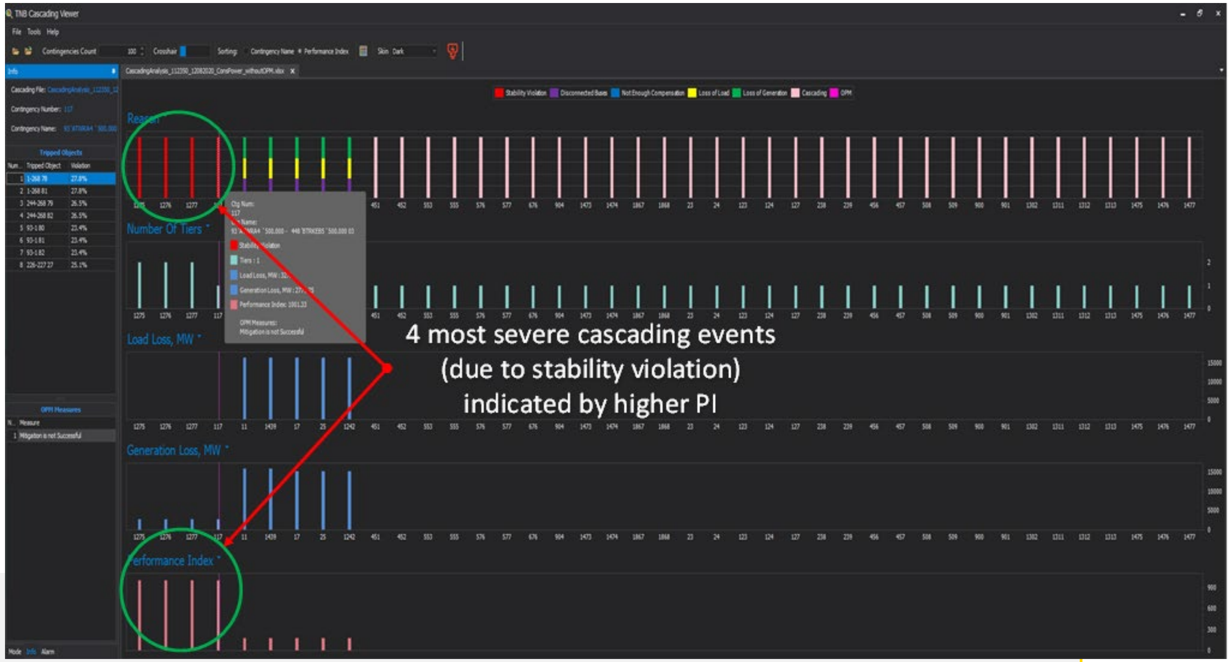


PMU ROSE at TNB: Estimating Values Using LSE and Cascading Analysis

- LSE results:
  - LSE (dark green line) successfully suppresses the error and estimates voltage with a difference of less than 0.01% compared to the true value
  - Substation with multiple PMU measurements with random errors and noise denoted by yellow, light green and red lines
  - The true value is blue line

- Cascading results:
  - Cascading Viewer visualizes results of online cascading analysis
  - 1877 N-1 initiating events are analyzed in one run
  - 41 critical cascading events were identified and ranked based on severity measured using the Performance Index (PI)

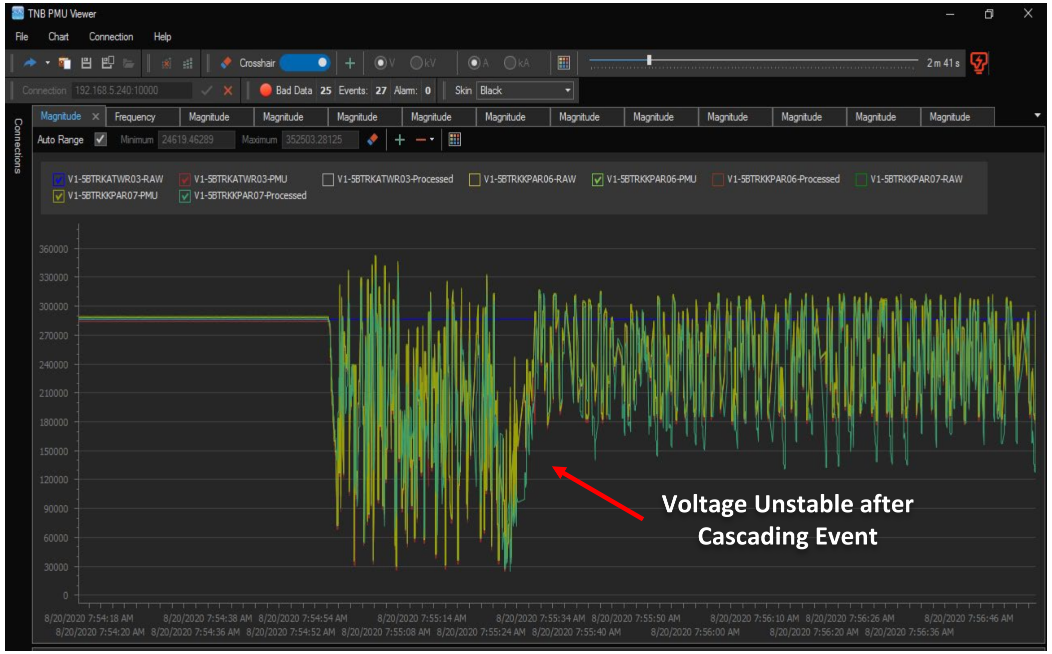


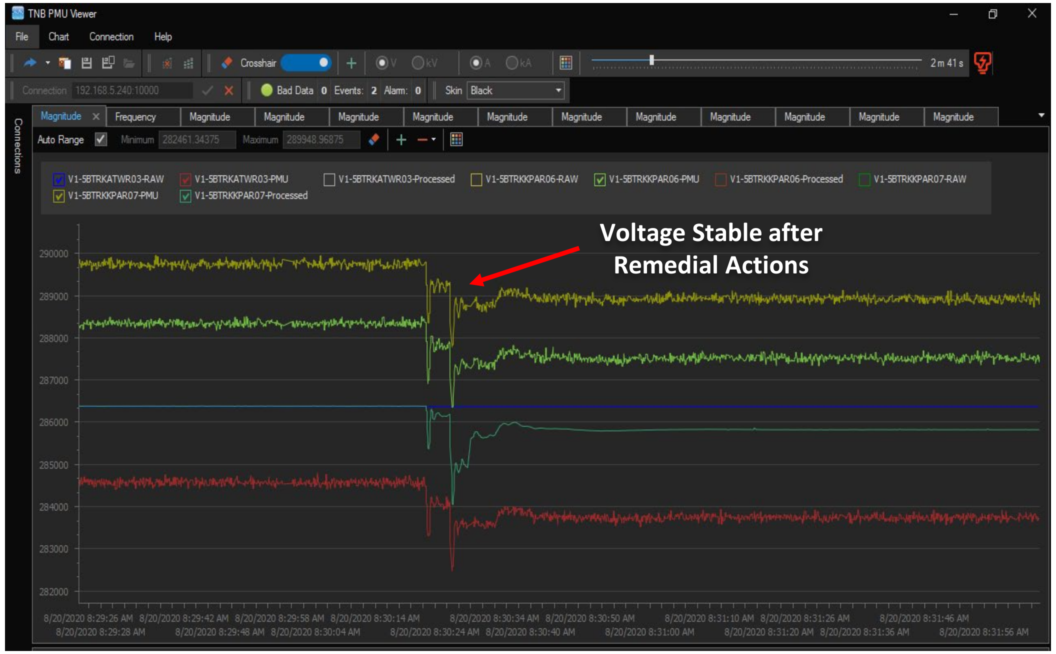


PMU ROSE at TNB: Effect of Remedial Actions

- A critical Initiating event results in stability violation
- The initiating event was tripping a transformer which leads to overload on other branches

- Optimal mitigation measures are identified to alleviate this stability violation
- The effect of these measures can be seen in the PMU Viewer





- LSE calculation accurately represents transient event

PMU-Based Linear State Estimator at SDG&E®:

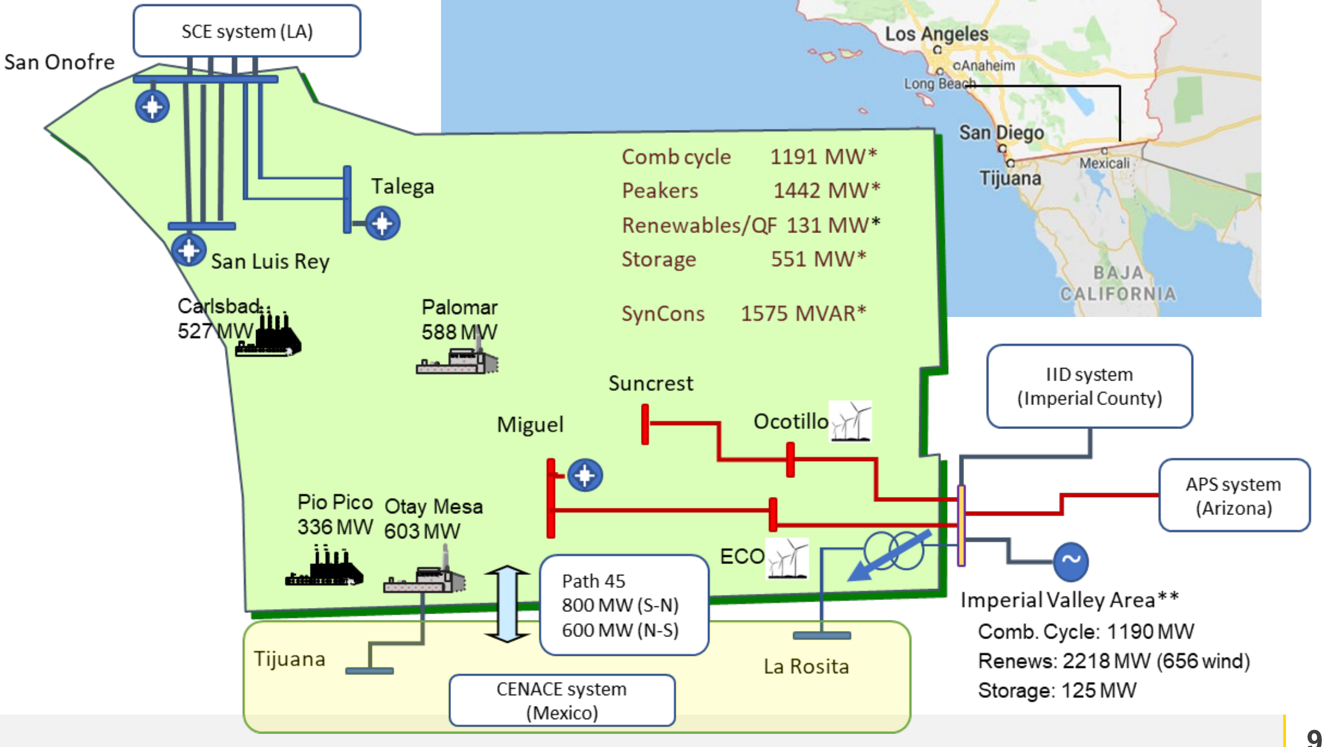
Implementation and Drivers

Robin Manuguid

September 26-27, 2023

About SDG&E®

- SDG&E is a regulated public utility in southern California, U.S.A.
- Serves San Diego & Southern Orange Counties: 1.46 million electric and 892,000 gas meters
- System Peak = 4,890 MW (9/16/14)
- Service area span 4,100 square miles.
- NERC-Registered: TO/P, GO/P, TP, LSE
- Within the CAISO BA area boundary in the RC West footprint; Coordinated Functional Registration (CFR) with the CAISO for TOP Reliability Standards

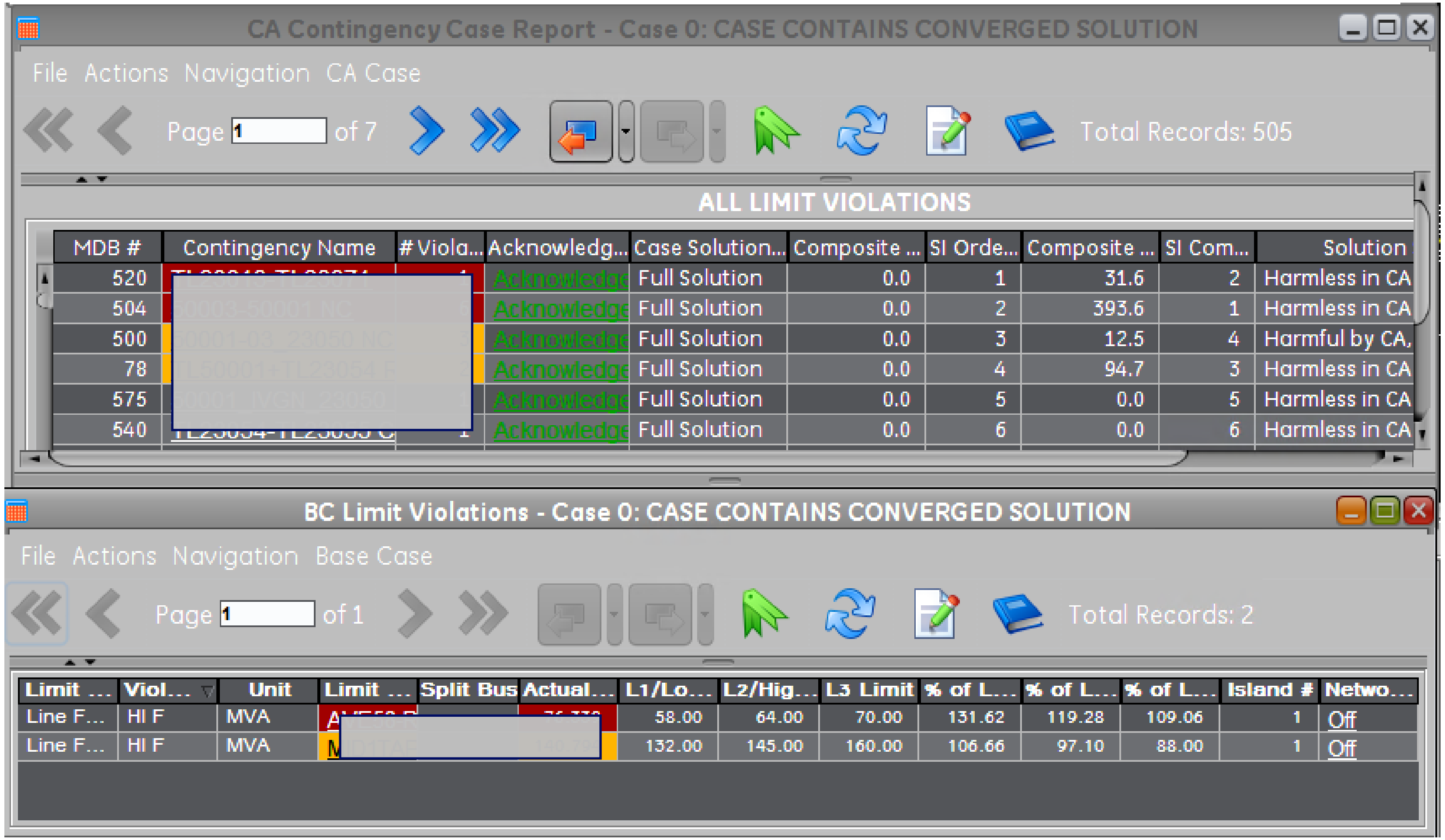


Importance of Linear State Estimator

- **Linear State Estimator (LSE) is based on PMU measurements of voltage and current:**
  - Voltage and current vectors are considered as the state variable
- **Advantages of LSE:**
  - Improves real-time resilience:
    - A backup to the conventional SE solution if it fails to solve or SCADA data is not available
  - Improves real-time reliability:
    - A check/validation for the quality of conventional state estimator
  - High speed of state estimation due to using a direct non-iterative solution
    - Solves at PMU sample rate (30 times/sec)

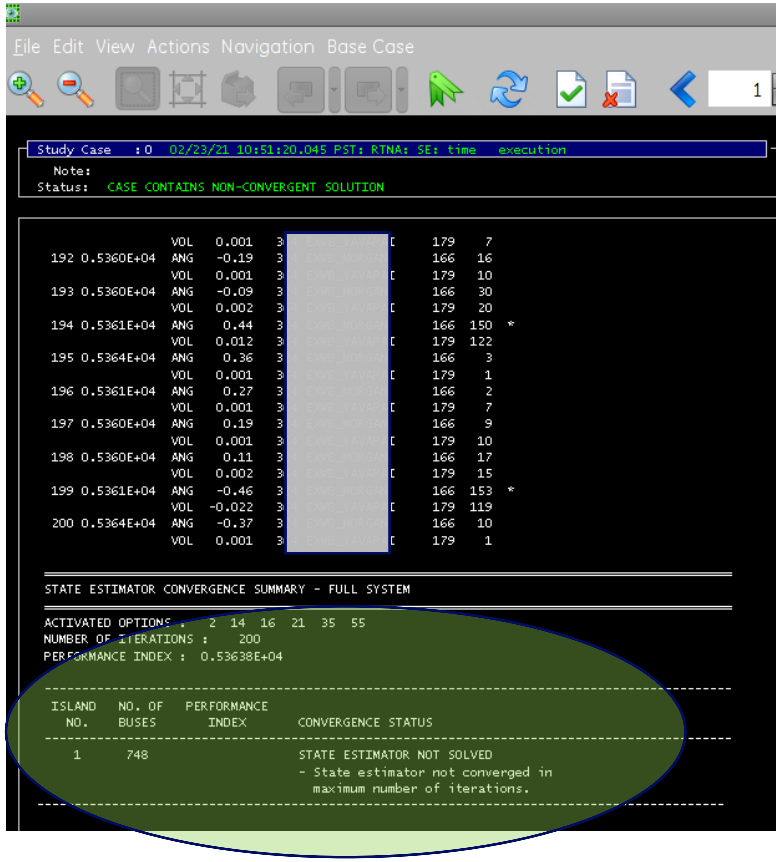
SDG&E Real-Time Operations Tools

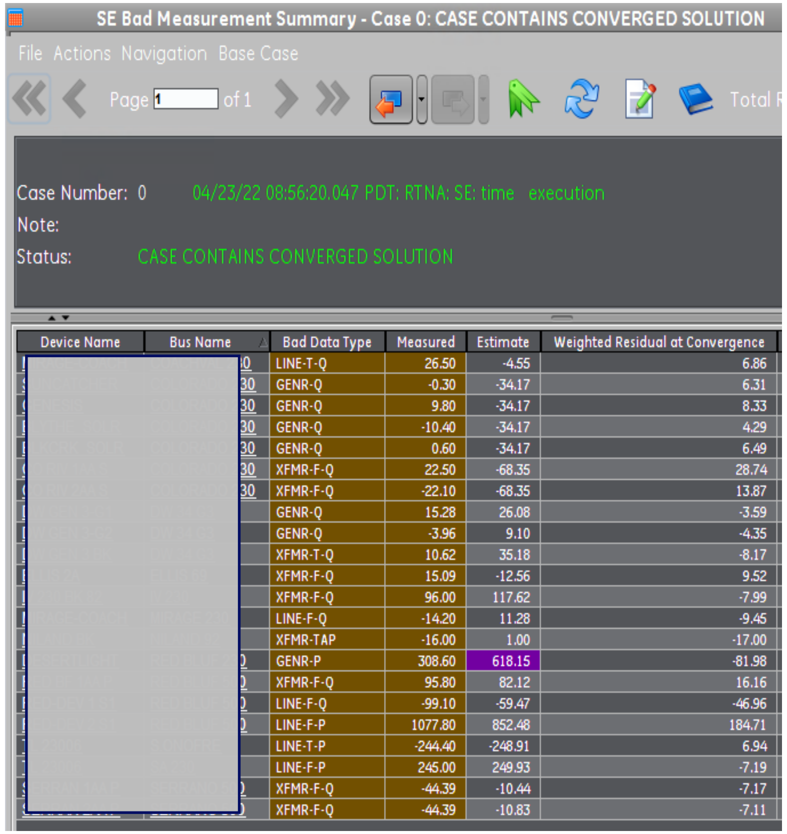
- **Conventional SE/RTCA - EMS (GE) network model**



SDG&E Real-Time Operations Tools

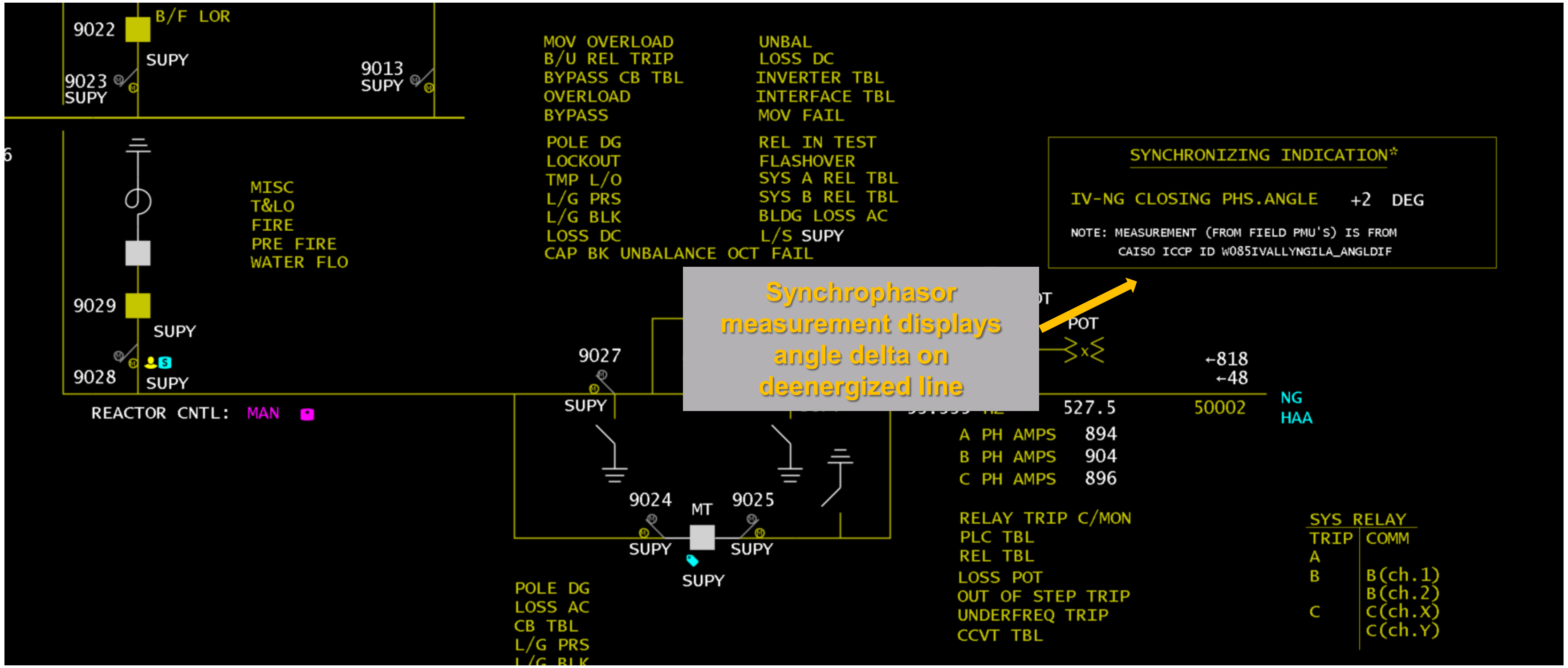
- **Conventional SE/RTCA - EMS (GE) network model**





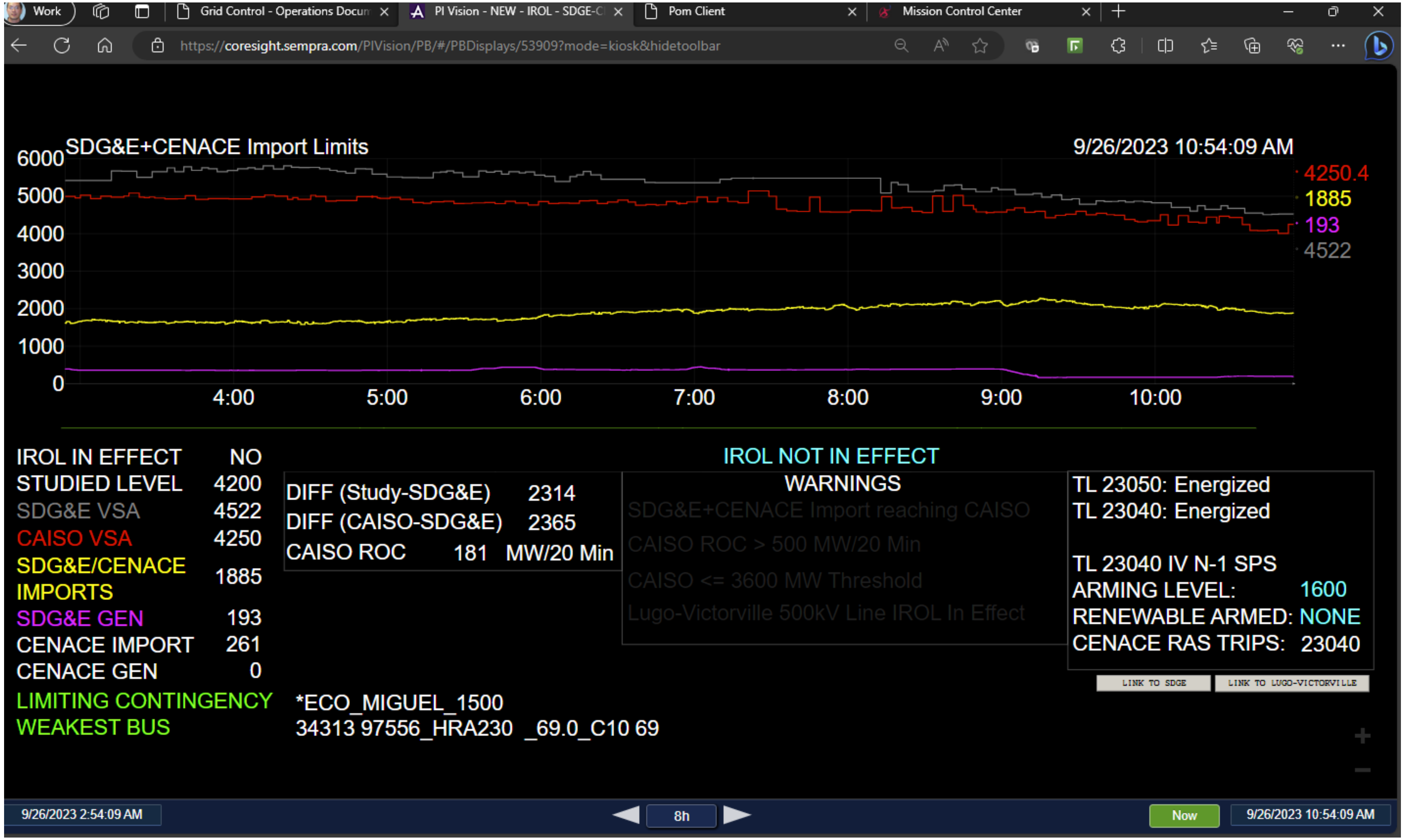
SDG&E Real-Time Operations Tools

- **EMS Display with PMU data**



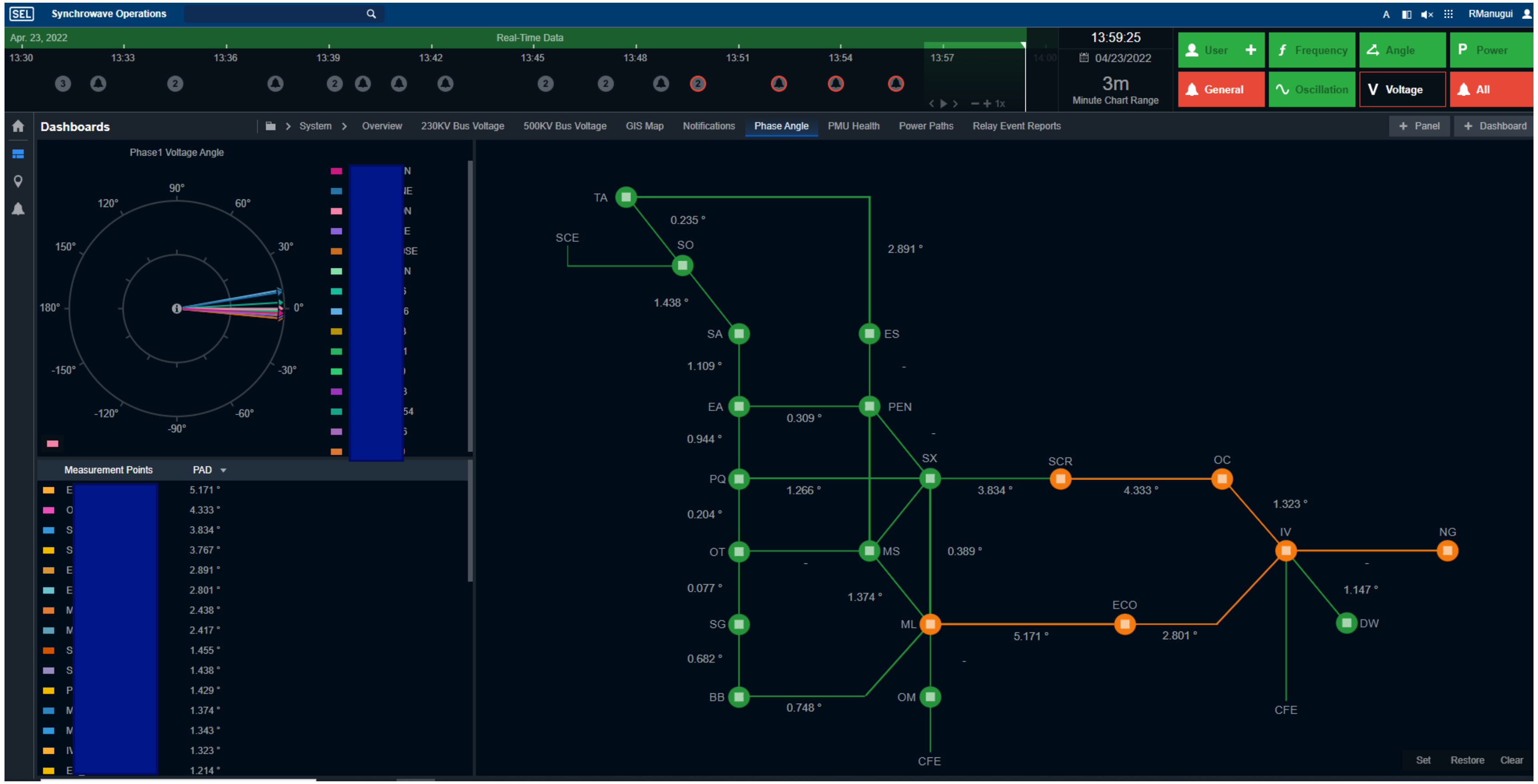
SDG&E Real-Time Operations Tools

- **Voltage Stability – use RC West's EMS model export in CIM15 loaded in V&R's ROSE**



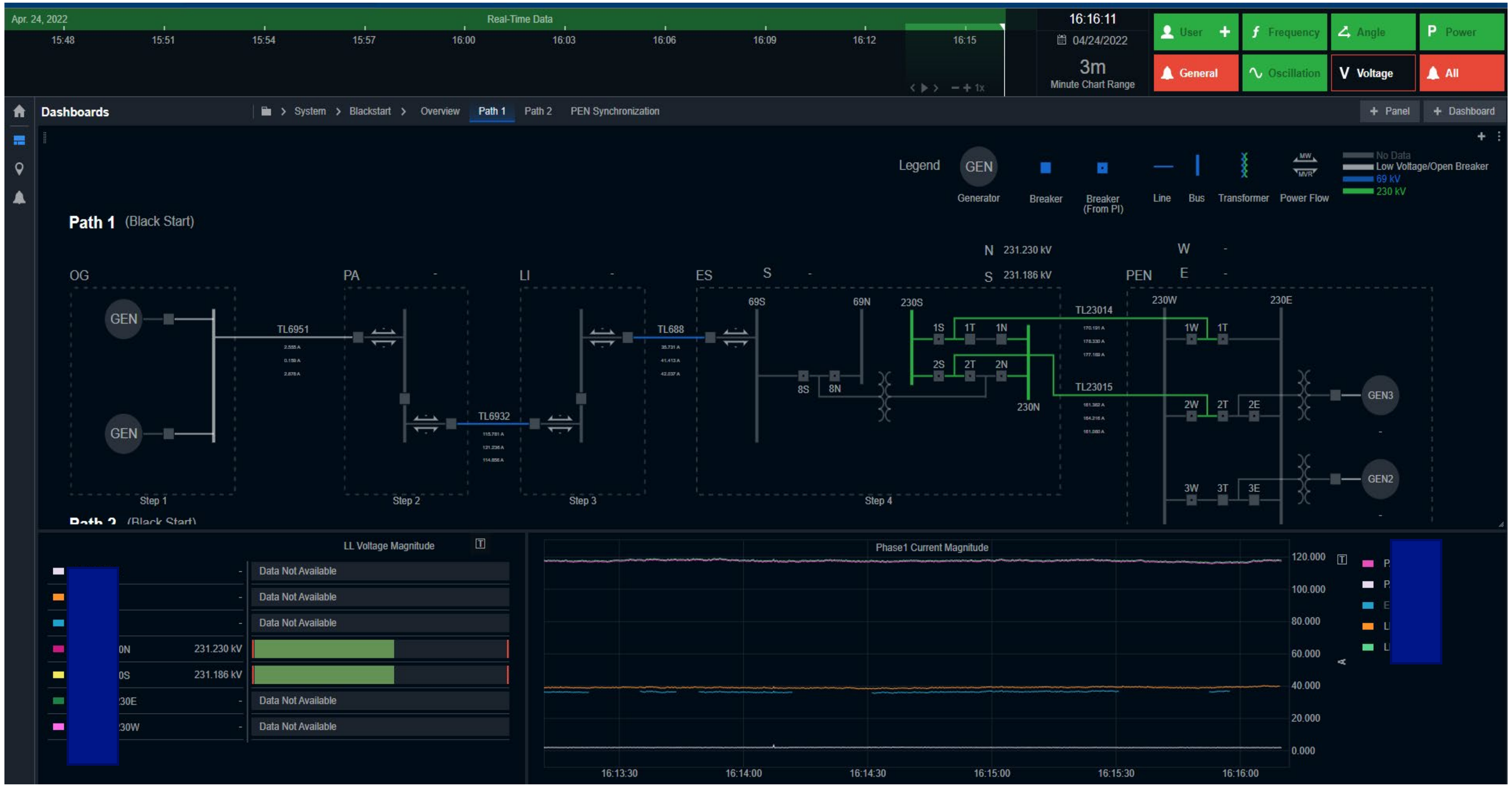
SDG&E Real-Time Operations Tools

- **Synchrowave Operations System – (SEL) power system monitoring and visualization, oscillation detection, notification**



SDG&E Real-Time Operations Tools

- **Synchrowave Operations System – (SEL) power system detection, notification, visualization**

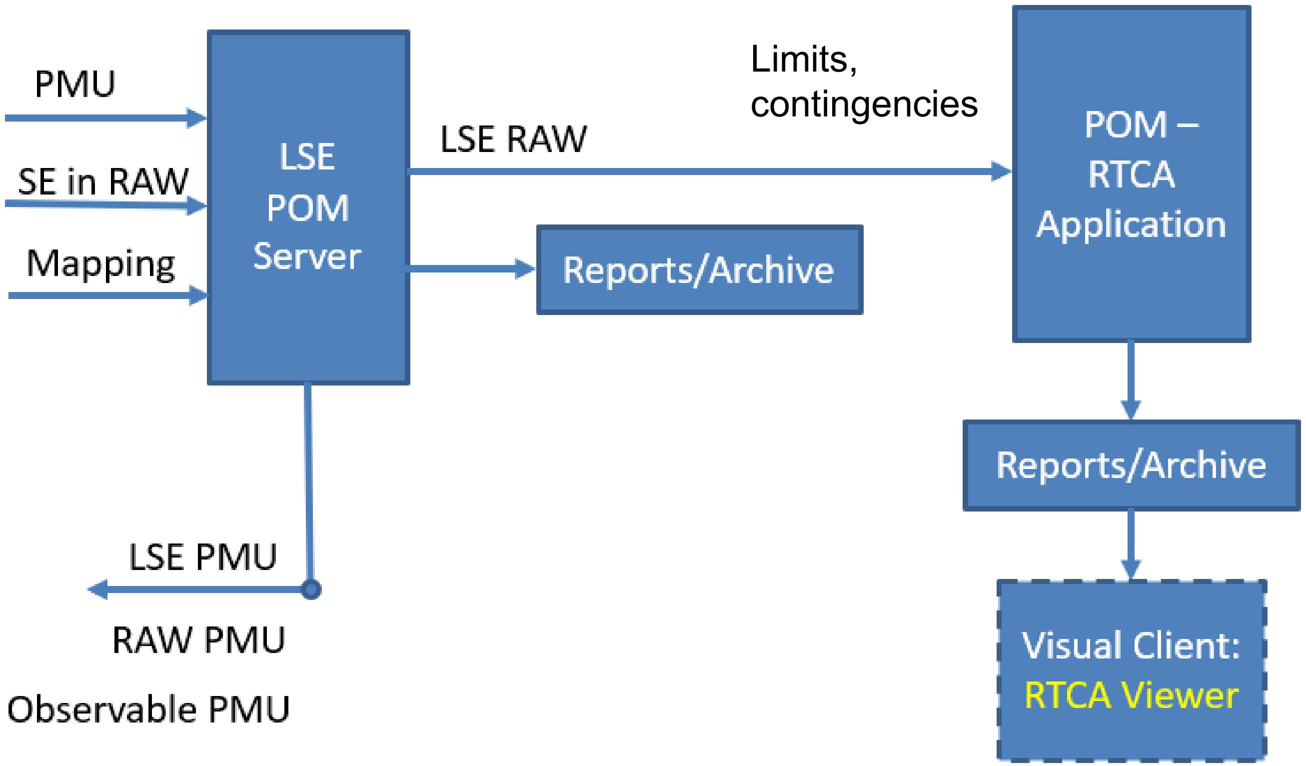


SDG&E PMU ROSE Architecture

Abbreviations:

- LSE PMU - LSE result at PMU locations
- LSE RAW - PMU-based State Estimator cases in Siemens PSS/E .raw data format
- Observable PMU - LSE result at locations observable with existing PMUs
- RAW PMU - Voltage magnitude and phase and current amplitude and phase from conventional State Estimator cases, converted to IEEE standard C37.118
- RTCA - Real-Time Contingency Analysis
- SE in RAW - Power flow cases (e.g., conventional State Estimator cases) in Siemens PSS/E .raw data format
- POM - Physical and Operational Margins applications (POM Core)

3 apps: LSE POM Server, POM-RTCA, RTCA Viewer



SDG&E PMU-Based LSE

LSE is performed 30 fps and includes:

- Bad data detection and conditioning
- Observability analysis
- Creation of conditioned and expanded PMU data streams
- Creation of PMU-based state estimator case (e.g., LSE Case) for the use by RTCA

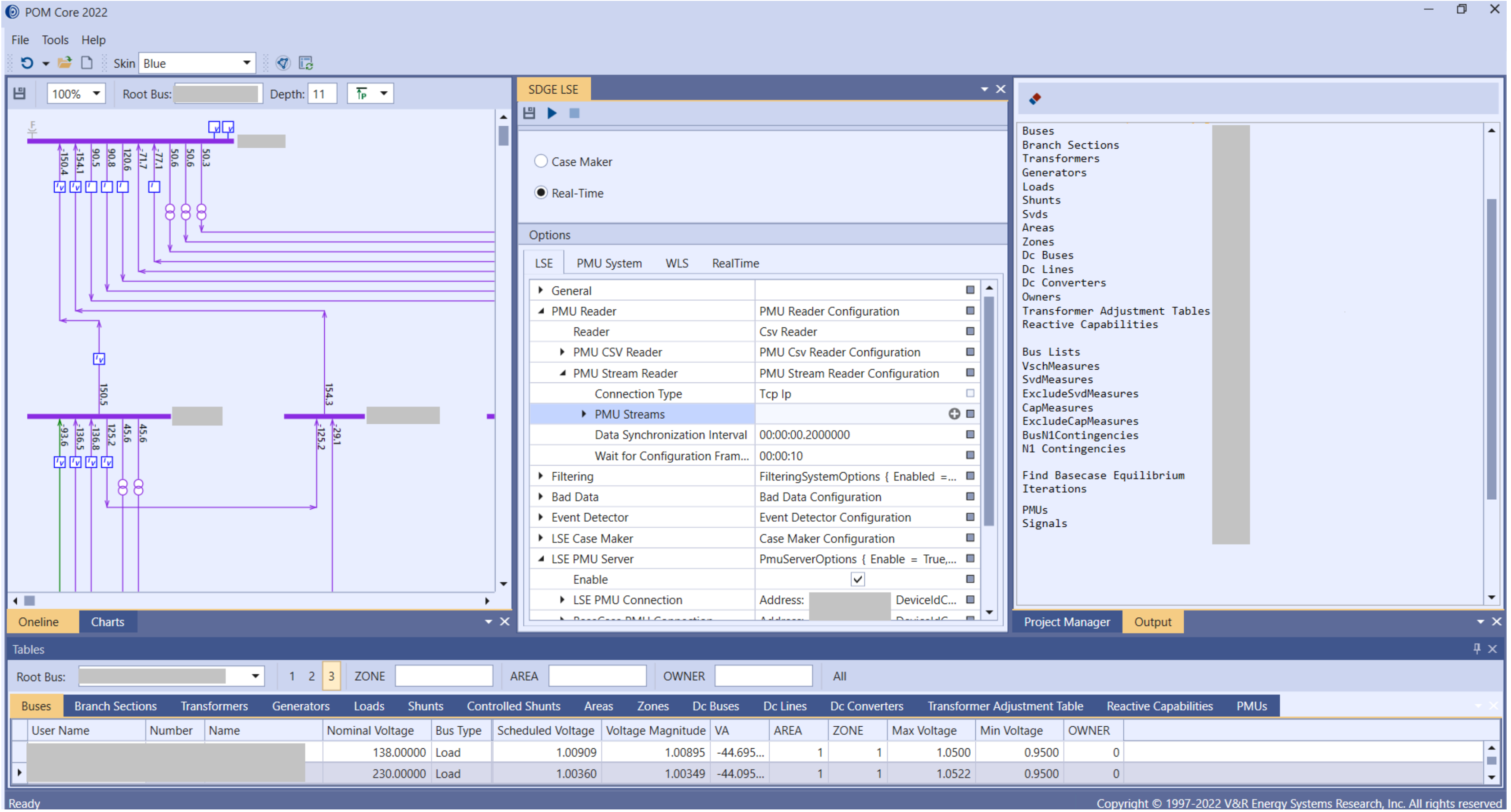
Scalable System

- More PMU measurements available
- More distributed PMUs across the system
- More accurate LSE/Base Case

Drivers:

- Backup of conventional SE
- Faster analysis
- Improve PMU data quality
- Increase system observability

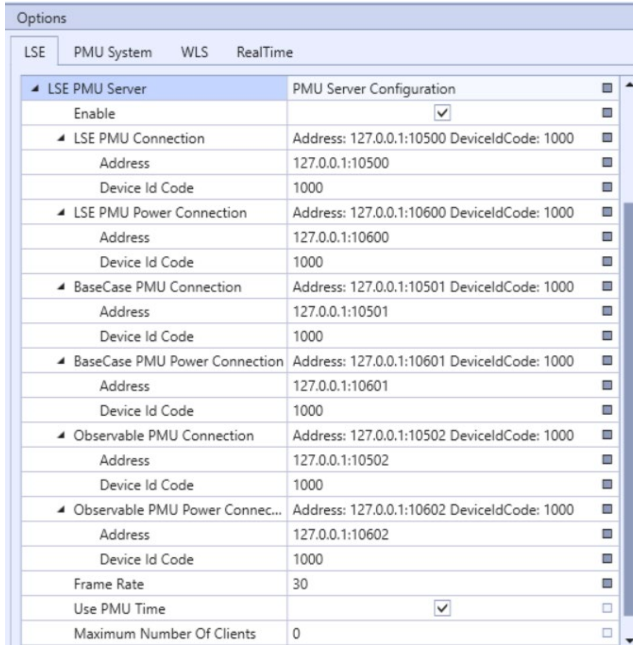
SDGE PMU ROSE: LSE



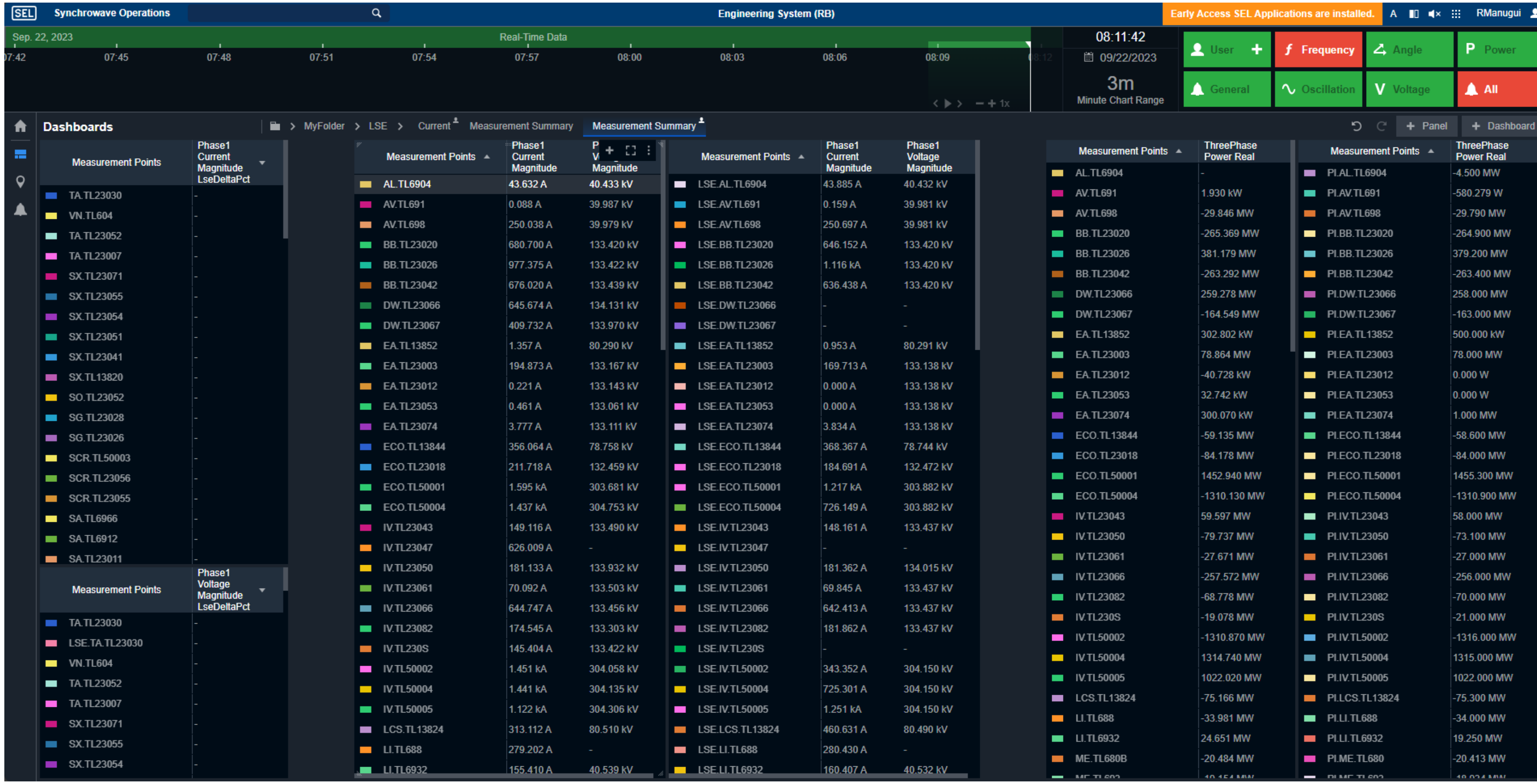
SDG&E PMU-Based LSE: Conditioned streams

LSE is performed 30 fps and includes:

- Bad data detection and conditioning
- Observability analysis
- Creation of conditioned and expanded PMU data streams



WASA Dashboard: LSE PMU, SE SCADA, SCADA



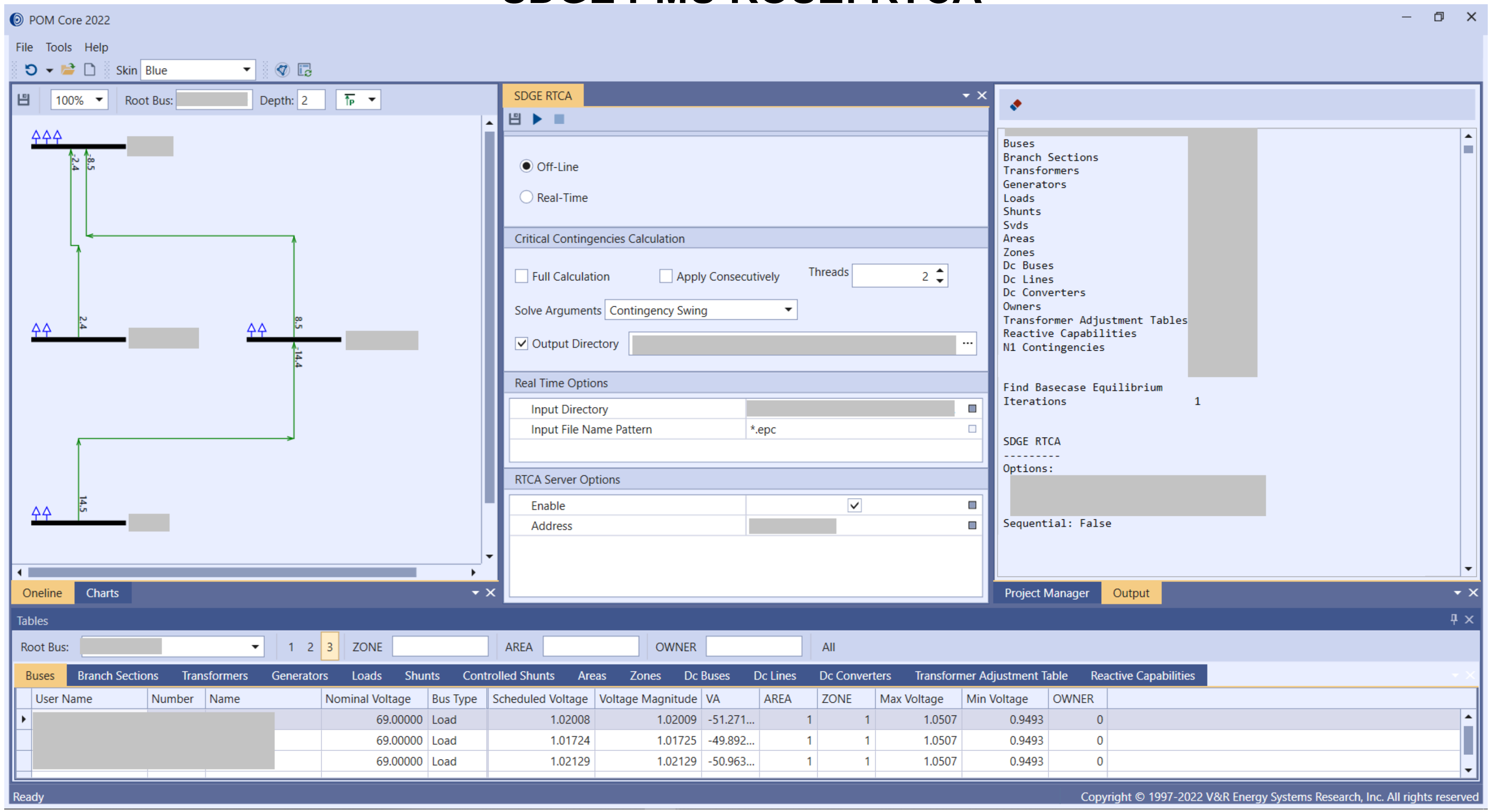
SDG&E PMU-Based LSE: RTCA

- Internal SE model produced by SDGE EMS is used
- LSE (e.g., PMU-based State Estimator) cases are sent by the LSE to RTCA application
- AC contingency analysis is performed using contingency list from EMS
- Output is archived and visualized using RTCA Viewer application
- Can be connected with automated remedial actions program, voltage stability, cascading analysis

Drivers:

Compare SE-based and LSE-based RTCA results

SDGE PMU ROSE: RTCA

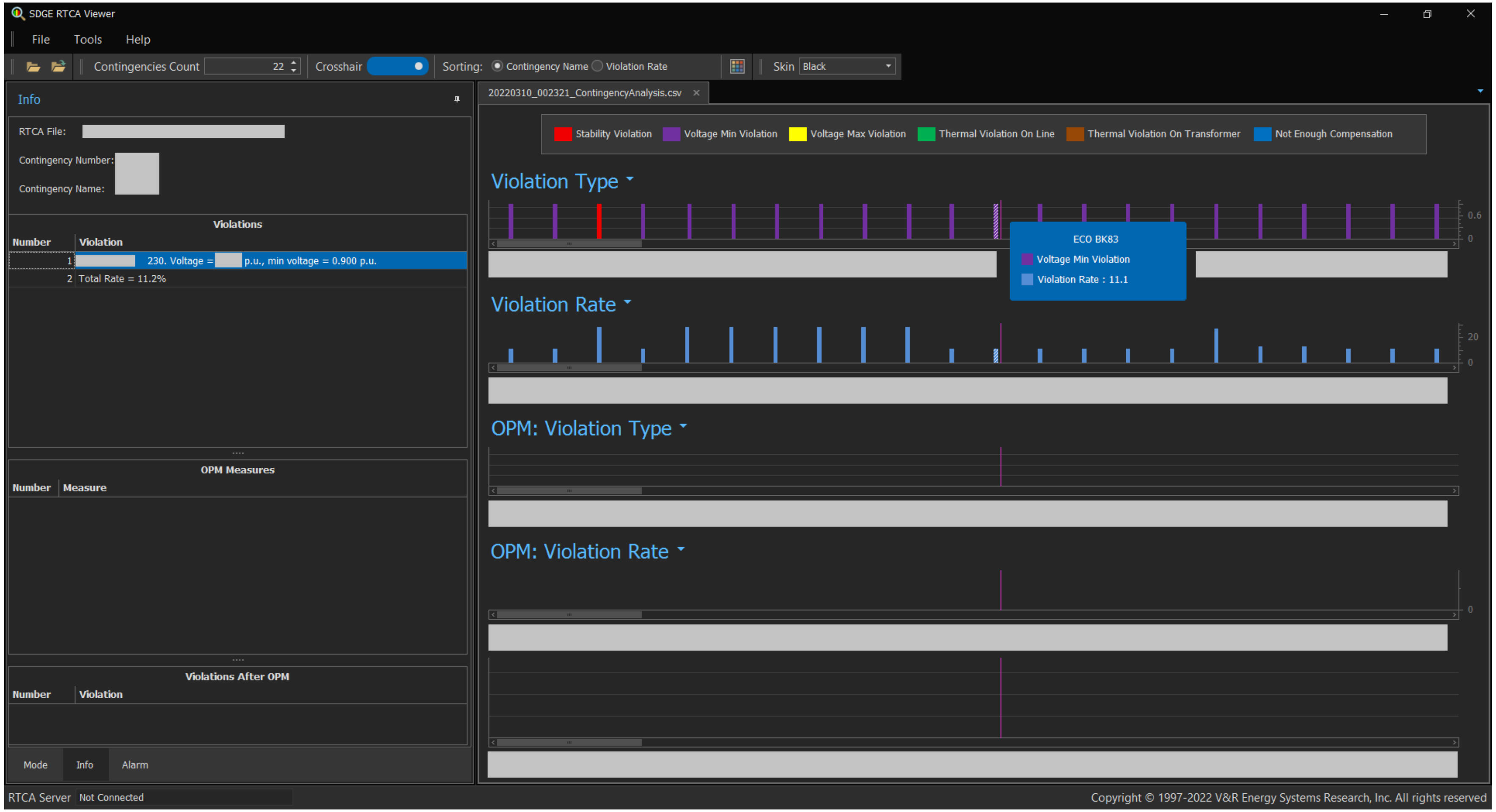


SDG&E PMU-Based LSE: RTCA

- 522 Contingencies in SE/RTCA
- So far 146 valid contingencies

Six Violation types:

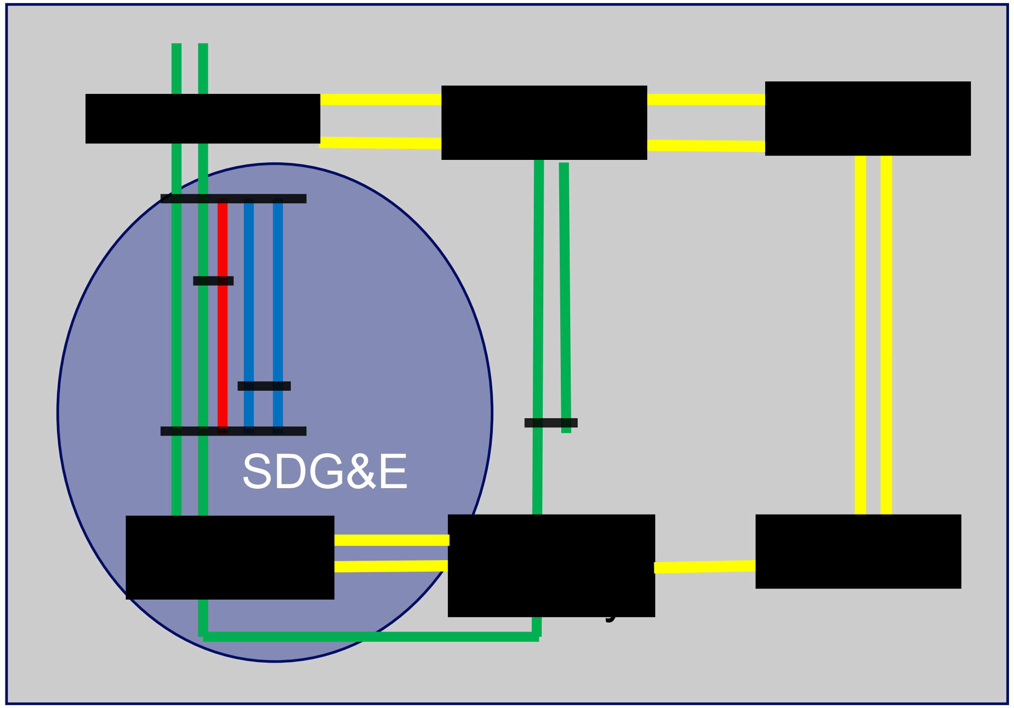
- Stability Violation;
- Voltage Min Violations;
- Voltage Max Violations;
- Thermal Violations on Line;
- Thermal Violations on Transformer;
- Not Enough Compensation.
- Angle diffs (not included)



SDG&E PMU-Based LSE: RTCA

Bus (SDG&E-owned)	Count	SCADA Coverage	PMU Coverage
500kV	5	5/5	100%
230kV	22	100%	100%
138kV	31	30/31	6/26
69kV	88	85/88	11/88 *

Observability	Initial (before bad data detection)	Stages				LSE Case
		1	2	3	4	
buses	44	106	118	119	119	109
branches	89	192	212	212	213	157

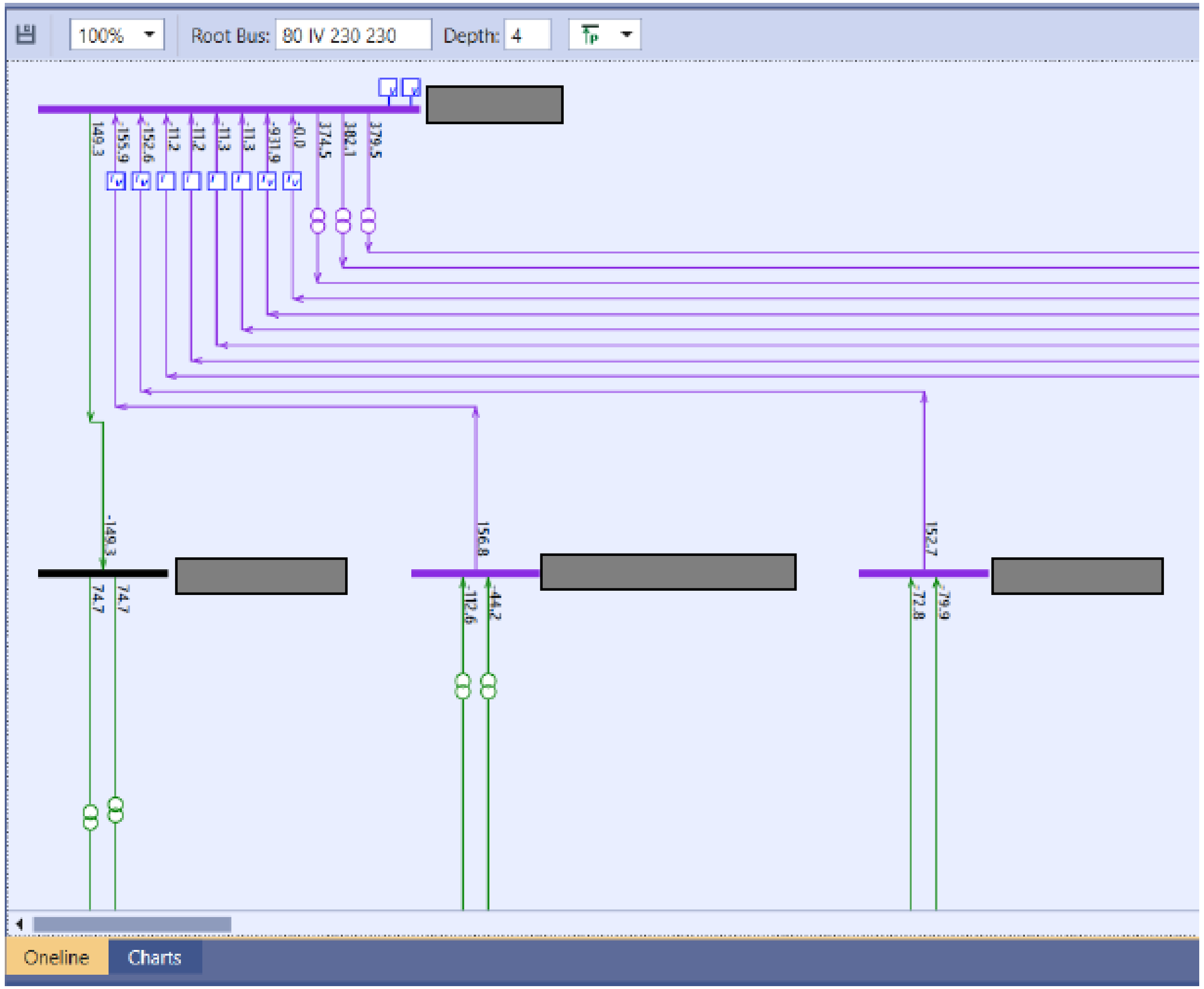


Pacific Southwest Major Corridors (Pacific Southwest Blackout in 2011 took about 11 minutes)

* Optimal PMU placement *to identify additional PMU locations to achieve full SDG&E network observability has been conducted.*

Conclusions

- SDGE PMU ROSE is installed at SDG&E for LSE and RTCA.
- “Bad data” and modelling/mapping errors are being investigated
- Multiple PMUs in one location does not help expand observability.
- Engaging vendor, IT, and EMS support early will help identify and resolve problems faster.
- More PMUs are being installed and existing stand-alone PMUs to be relocated, which will increase system observability, and the size of LSE case (in terms of number of buses, lines, etc.)



Thank you

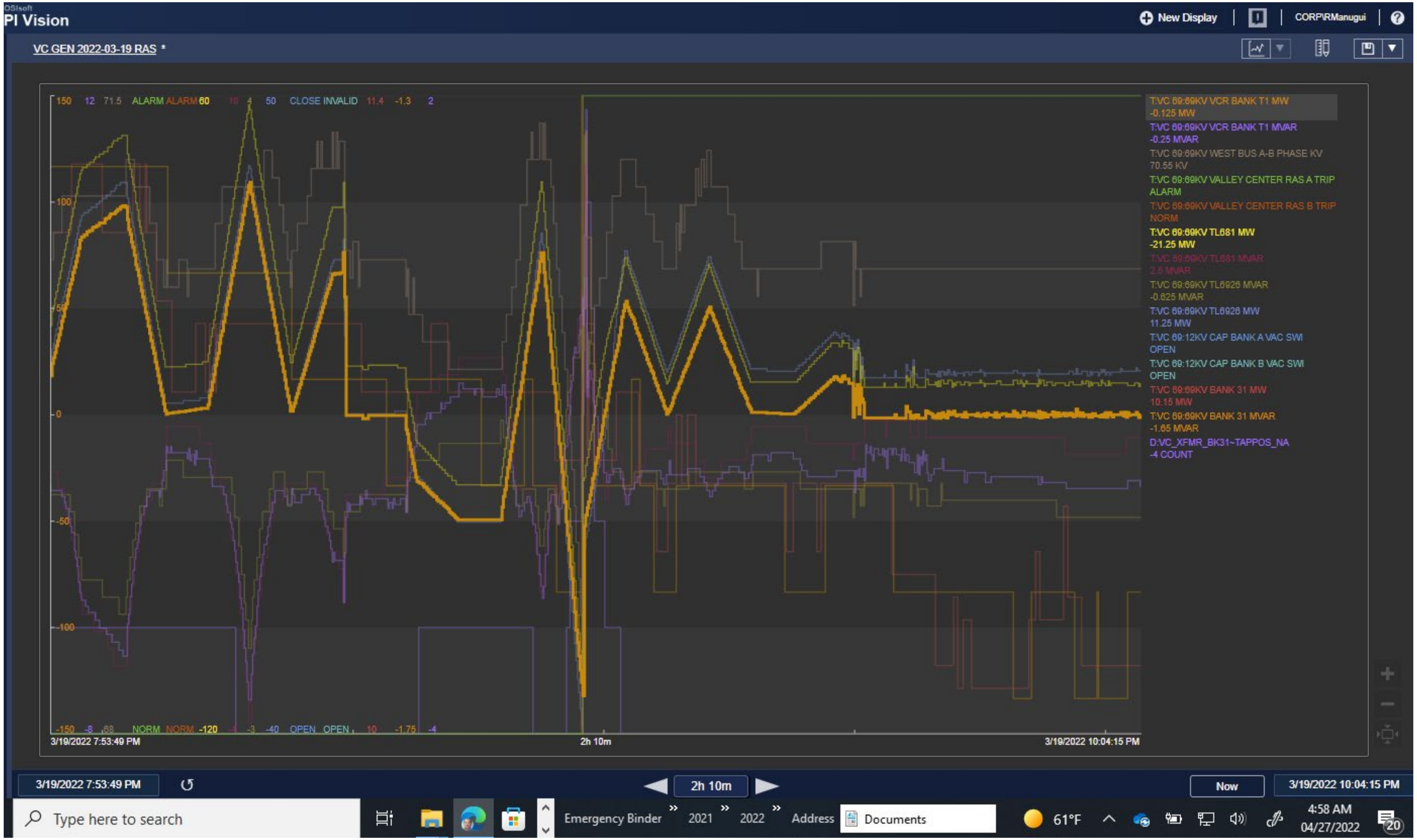
Question?

Robin Manuguid
rmanuguid@sdge.com

Robin Manuguid

Robin is a staff engineer in Grid Operations and leads the long-term outage coordination studies to sequence multi-phase transmission projects and successful completion of major projects. He provides real-time support for real-time tools (i.e., SE, RTCA, and near-RTVSA) and conducts next-day studies. He reviews and updates operating procedures which are often triggered by operating studies. Robin joined SDG&E in 1992 after earning his BSEE from Cal Poly, San Luis Obispo. Since joining the Electric Grid Operations in 2004, he’s been engaging with WECC activities, coordinating with SDG&E SMEs on various NATF programs. He is a Principal Engineer with SDG&E. He is an IEEE member.

Back up slide



LSE Project Alignment with the ERO RRP

The Five Risks:

1. Grid Transformation
   - Batteries on weak grid
2. Security Risks
   - Batteries on weak grid
   - Network model accuracy.
3. Resilience to extreme events
   - Loss of comm paths
4. Critical Infrastructure Interdependecies
   - Polled SCADA data vs streams
5. Energy Policy