Operationalizing Synchrophasor Technology at PG&E

NASPI Workgroup Meeting

September 26th 2017

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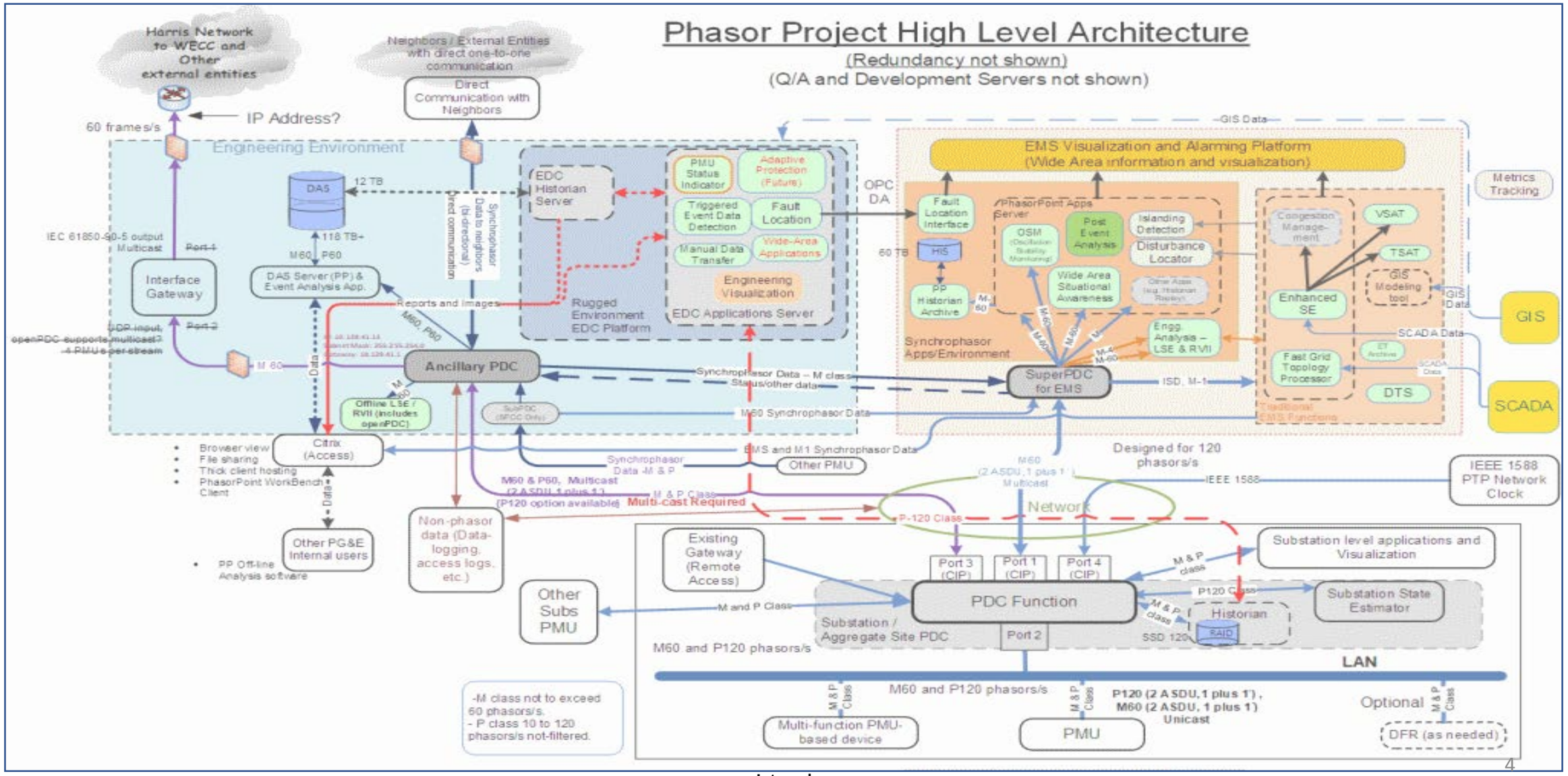
PG&E

- There are approximately 20,000 employees who carry out Pacific Gas and Electric Company's primary business
- The company provides natural gas and electric service to approximately 16 million people throughout a 70,000-square-mile service area in northern and central California
- Service area stretches from Eureka in the north to Bakersfield in the south, and from the Pacific Ocean in the west to the Sierra Nevada in the east.
- 106,681 circuit miles of electric distribution lines and 18,466 circuit miles of interconnected transmission lines.
- 5.4 million electric customer accounts.
- 7,681 MW generation capacity (hydro, nuclear, fossil, and solar)

PG&E Synchrophasor Program History

- PG&E Project Development and Proof-of-Concept (POC)
  - PG&E will participate in WECC wide project meetings and conference calls to coordinate its Synchrophasor project with other WISP participants to leverage areas of expertise and mutual collaborations.
  - PG&E will perform a proof-of concept to validate interoperability, compatibility, and data integrity of various vendors' equipment that PG&E intends to use. Real-time Digital Simulators (RTDS) and test equipment will allow PG&E to test various operator and engineering tools.
  - PG&E will perform comprehensive system studies to determine the locations for PMUs, the phasor data concentrators and super phasor data concentrators based on a series of criteria including availability of PG&E's network.
- PMU and PDC Deployment
  - PG&E will design, procure, install and test phasor measurement units and phasor data concentrators at existing electric transmission substations within their service territory.
  - PG&E will use a combination of existing equipment and new equipment.
  - PG&E will upgrade its existing telecom infrastructure to handle the added traffic of transmitting phasor data from substations to its control centers.
- Data Storage and User Applications
  - PG&E will store phasor data for both real time (or near real time) operational use and for operational basis, training, system planning, engineering and post disturbance analyses.
  - Storage capacity will be installed at PG&E control centers.
  - PG&E's existing energy management system will be enhanced to include phasor data into the state estimator and situational awareness systems.
  - PG&E will develop new engineering tools taking advantage of the new phasor data.
  - PG&E synchrophasor system shall be designed to allow applications and functions to be added in the future.
- Data Sharing
  - PG&E will collaborate with its neighboring utilities, the CAISO and WECC to gather any additional phasor data to support the operation of the PG&E transmission system. Specifically, the project includes integration of the synchrophasor data from neighboring systems such as BPA, SDG&E, SCE, APS and IPC to engineer solutions for grid monitoring and training tools for PG&E's system operation and engineering. The footprint for PG&E's project covers the Pacific AC and DC systems surrounding PG&E and includes monitoring of critical 60kV,115kV, 230kV, 345kV, and 500kV systems.
  - PG&E will provide an interface for WECC to make use of the phasor data. PG&E is assisting WECC in evaluating alternative solutions that would support data format provided by PG&E. However, WECC is responsible for any data format conversions if data conversion becomes necessary.

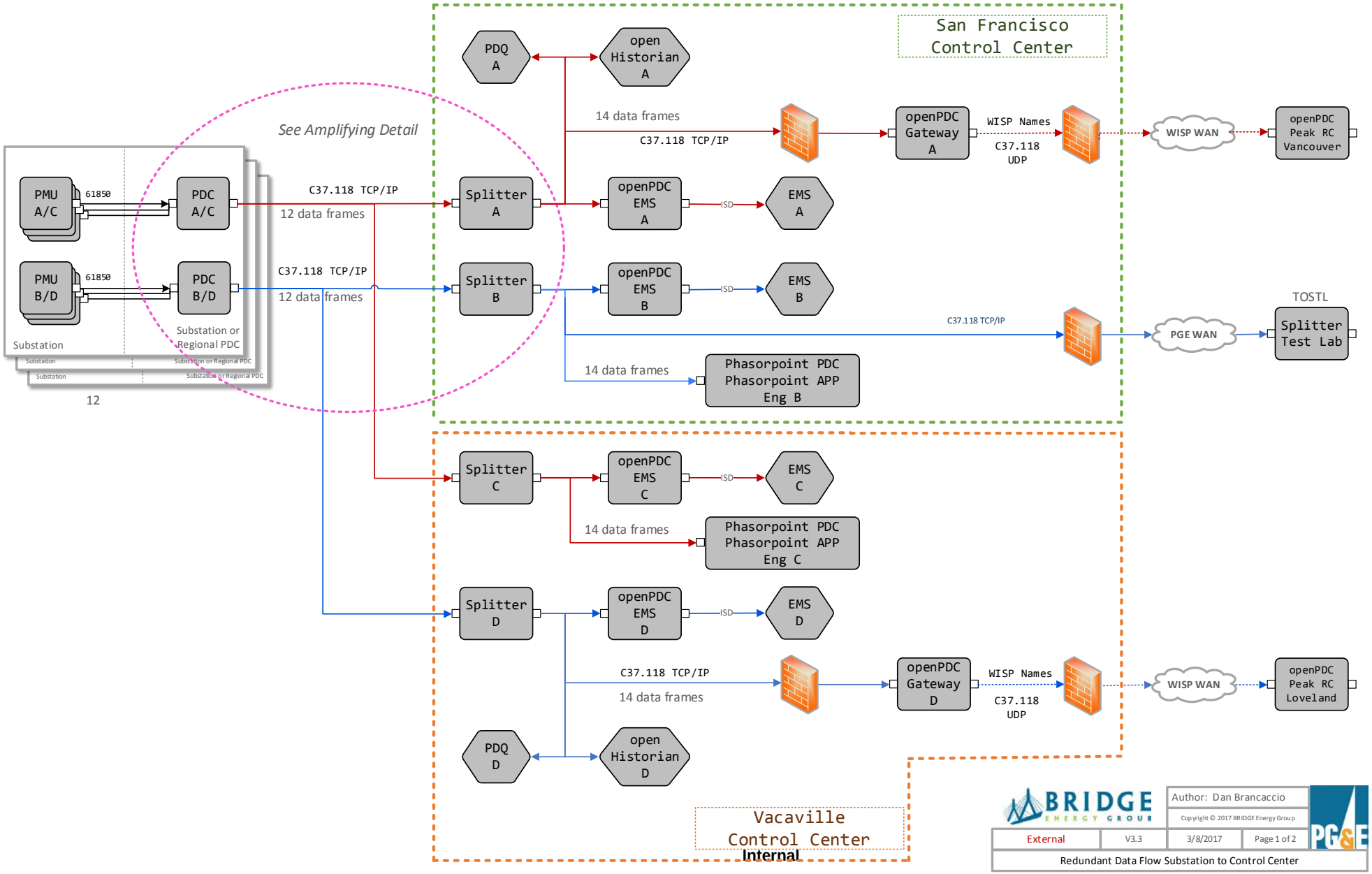
PG&E Synchrophasor Program History



PG&E Synchrophasor Deployment Today

- Transmission
  - PMUs in 21 substations
  - 202 PMUs, 101 redundant measurement locations
  - 24 Substation PDCs, 12 redundant locations
  - 4 control center PDCs, 2 redundant locations
  - 4 redundant Archives
    - openHistorian, PhasorPoint archive – Hitachi Direct Connect SAN 60 TB (2) 120 TB (2)
- Generation
  - 3 PMUs, one each generator at combined cycle plant
  - 1 PDC
  - Archive OSIsoft PI, openHistorian, SEL SynchroWAVe
  - Visualization, SEL SynchroWAVe, open source Grafana
- Transmission Operations Synchrophasor Test Lab (TOSTL)

Architecture Transmission



BRIDGE ENERGY GROUP		Author: Dan Brancaccio	PG&E
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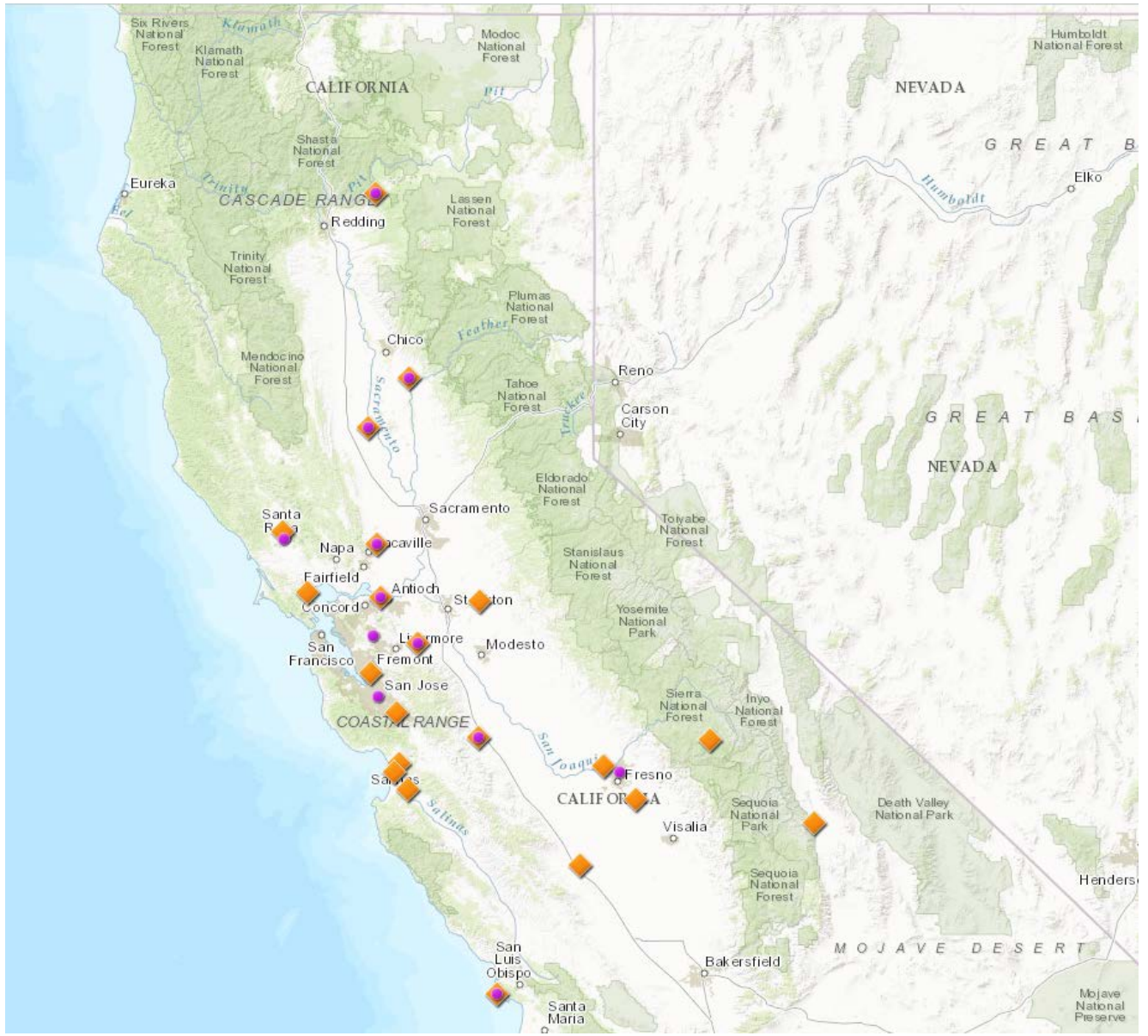
External	V3.3	3/8/2017	Page 1 of 2
Redundant Data Flow Substation to Control Center			

Transmission PMUs and PDCs



Legend

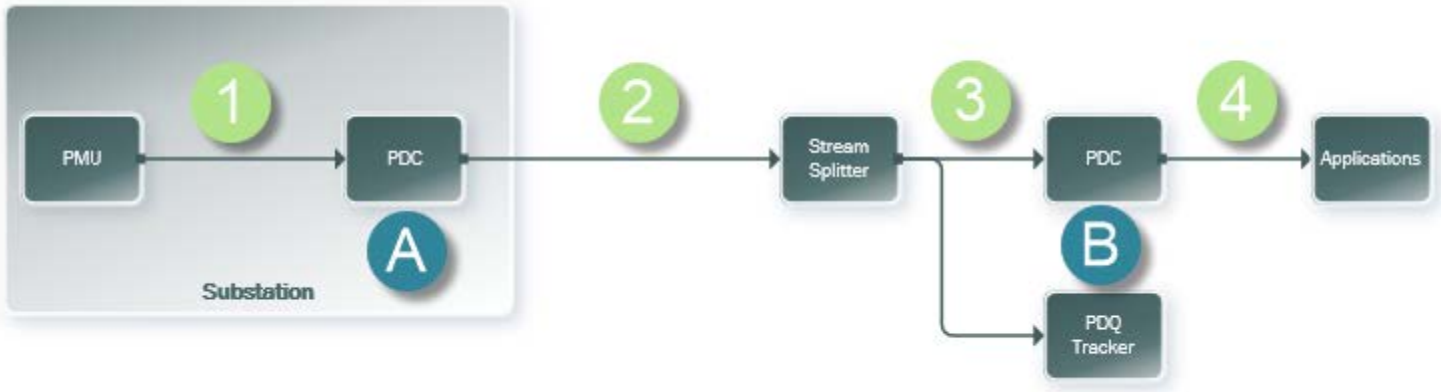
PG&E substations with PDC

PG&E substations with PMU

Data Availability effort

- Simplify data path
  - Identify all data paths
  - Move point to point paths inside control center where possible using GPA Synchrophasor Stream Splitter
- Switch protocol
  - Switch from IEC 61850-90-5 to IEEE C37.118-2005 Substation PDC to Control Center
  - Switch from UDP Multicast to TCP/IP Unicast
- Review naming convention
  - Internal naming convention consistent and usable
  - Comply with WISP naming convention for sharing data with Peak RC and other entities
- Deploy data availability measurement tools
- Regular interaction with network communication group
- Attend Monthly Peak RC SPDQ meeting

Understand how your architecture effects your availability statistics

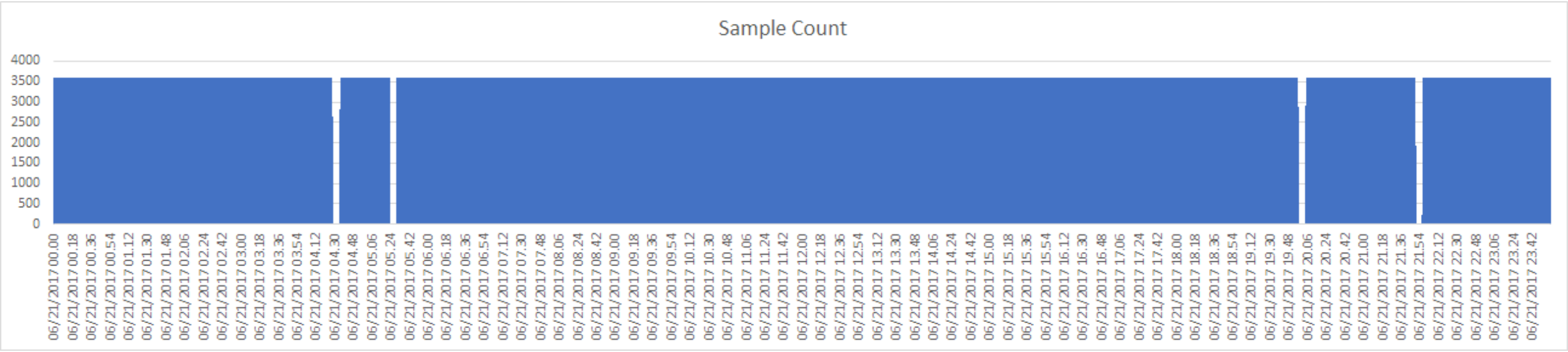


The PDC “hides” data availability problems
Availability issues at location 1 appear as data errors at location 2
Availability issues at location 2 are unchanged at location 3 but appear as data errors at location 4
Availability issues at location 2 cause all the PMUs reporting to PDC A to have the same availability issues as seen by PDC B or the PDQTracker

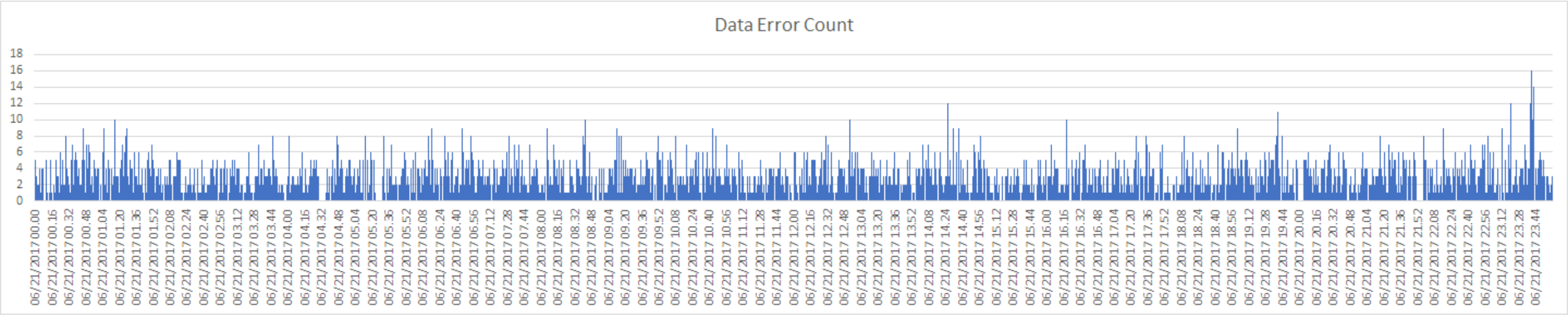
Data Availability 98.21% what does it mean?

- 60 Hz sample rate delivers 5,184,000 samples per day
- An availability 0f 98.21% means 92,793 samples did not get delivered
- To address the dropped data frames you need to know how they are distributed

Discrete time slices



Spread out over entire day (4407 data errors)



Data to Peak RC

Improvements

Availability Today

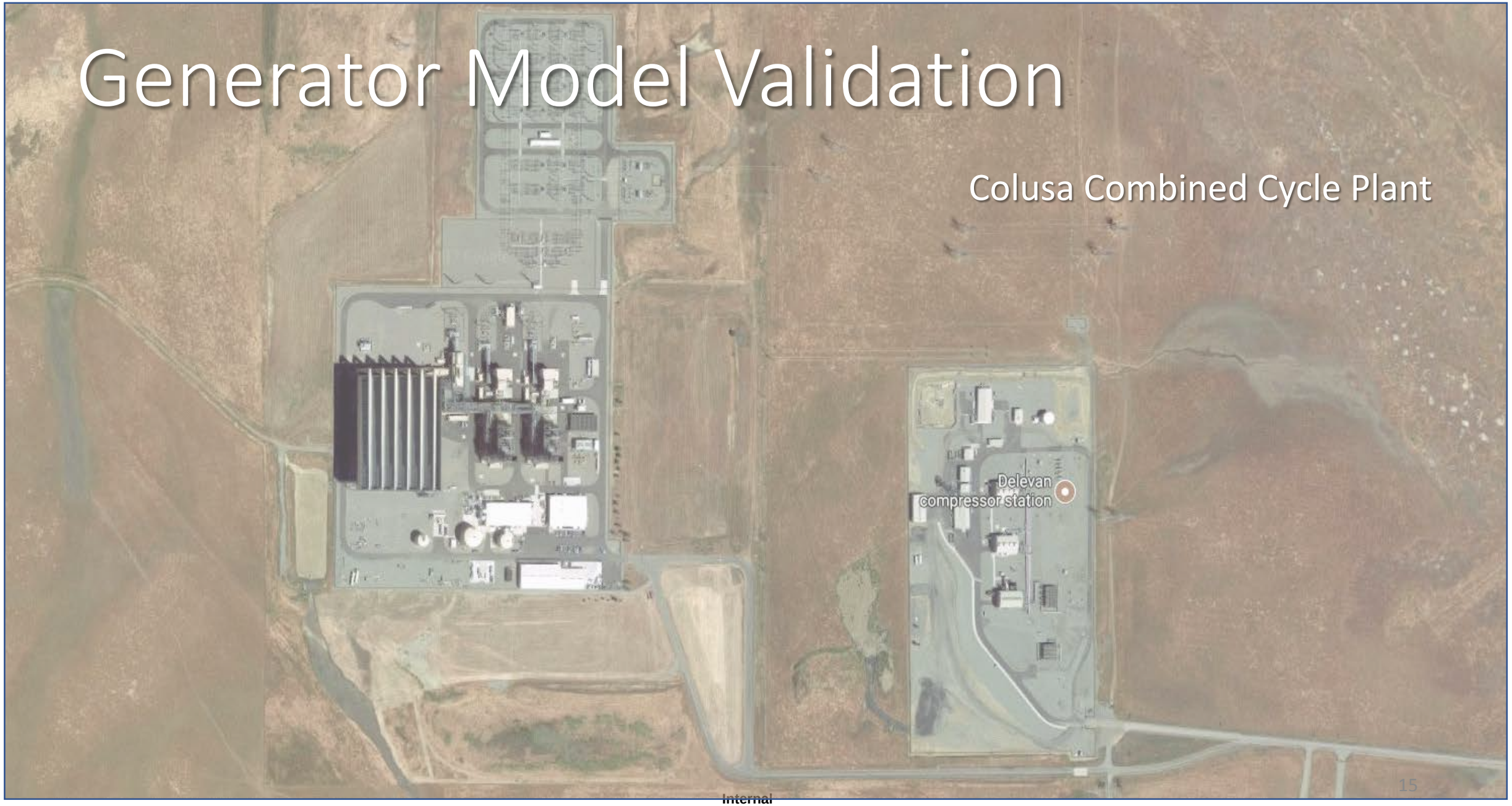
W080BELOTA____01				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.01	0.01	0.01	0.01
Time Errors %	0.00	0.00	0.00	0.00
W080BELOTA____02				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.01	0.01	0.01	0.01
Time Errors %	0.00	0.00	0.00	0.00
W080BELOTA____03				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.01	0.01	0.01	0.01
Time Errors %	0.00	0.00	0.00	0.00
W080BELOTA____04				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.01	0.01	0.01	0.01
Time Errors %	0.00	0.00	0.00	0.00
W080GATES_____01				
Availability %	99.10	99.10	100.00	99.10
Data Errors %	0.90	0.90	0.00	0.90
Time Errors %	0.00	0.00	0.00	0.00
W080GATES_____02				
Availability %	99.10	99.10	100.00	99.10
Data Errors %	0.90	0.90	0.00	0.90
Time Errors %	0.00	0.00	0.00	0.00
W080GATES_____03				
Availability %	99.10	99.10	100.00	99.10
Data Errors %	0.90	0.90	0.00	0.90
Time Errors %	0.00	0.00	0.00	0.00
W080GATES_____04				
Availability %	99.10	99.10	100.00	99.10
Data Errors %	0.90	0.90	0.00	0.90
Time Errors %	0.00	0.00	0.00	0.00
W080GREGG_____01				
Availability %	99.10	99.10	100.00	99.10
Data Errors %	0.90	0.91	0.01	0.90
Time Errors %	0.00	0.00	0.00	0.00
W080GREGG_____02				
Availability %	99.10	99.10	100.00	99.10
Data Errors %	0.90	0.91	0.01	0.90
Time Errors %	0.00	0.00	0.00	0.00
W080GREGG_____03				
Availability %	99.10	99.10	100.00	99.10
Data Errors %	0.90	0.91	0.01	0.90
Time Errors %	0.00	0.00	0.00	0.00
W080GREGG_____04				
Availability %	99.10	99.10	100.00	99.10
Data Errors %	0.90	0.91	0.01	0.90
Time Errors %	0.00	0.00	0.00	0.00
W080GREGG_____05				
Availability %	99.10	99.10	100.00	99.10
Data Errors %	0.90	0.91	0.01	0.90
Time Errors %	0.00	0.00	0.00	0.00
W080GREGG_____06				
Availability %	99.10	99.10	100.00	99.10
Data Errors %	0.90	0.91	0.01	0.90
Time Errors %	0.00	0.00	0.00	0.00
W080HELMPG____01				
Availability %	99.10	99.10	100.00	99.10
Data Errors %	0.92	0.92	0.02	0.92
Time Errors %	0.00	0.00	0.00	0.00

W080TBLMTN____04				
Availability %	99.58	99.91	99.91	100.00
Data Errors %	0.42	0.09	0.09	0.00
Time Errors %	0.00	0.00	0.00	0.00
W080TBLMTN____05				
Availability %	99.58	99.91	99.91	100.00
Data Errors %	0.42	0.09	0.09	0.00
Time Errors %	0.00	0.00	0.00	0.00
W080TBLMTN____06				
Availability %	99.58	99.91	99.91	100.00
Data Errors %	0.42	0.09	0.09	0.00
Time Errors %	0.00	0.00	0.00	0.00
W080TBLMTN____07				
Availability %	99.58	99.91	99.91	100.00
Data Errors %	0.42	0.09	0.09	0.00
Time Errors %	0.00	0.00	0.00	0.00
W080TESLA_____01				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.00	0.00	0.00	0.00
Time Errors %	0.00	0.00	0.00	0.00
W080TESLA_____02				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.00	0.00	0.00	0.00
Time Errors %	0.00	0.00	0.00	0.00
W080TESLA_____03				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.00	0.00	0.00	0.00
Time Errors %	0.00	0.00	0.00	0.00
W080TESLA_____04				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.00	0.00	0.00	0.00
Time Errors %	0.00	0.00	0.00	0.00
W080TESLA_____05				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.00	0.00	0.00	0.00
Time Errors %	0.00	0.00	0.00	0.00
W080VACADX____01				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.00	0.00	0.00	0.00
Time Errors %	0.00	0.00	0.00	0.00
W080VACADX____02				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.00	0.00	0.00	0.00
Time Errors %	0.00	0.00	0.00	0.00
W080VACADX____03				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.00	0.00	0.00	0.00
Time Errors %	0.00	0.00	0.00	0.00
W080VACADX____04				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.00	0.00	0.00	0.00
Time Errors %	0.00	0.00	0.00	0.00
W080VACADX____05				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.00	0.00	0.00	0.00
Time Errors %	0.00	0.00	0.00	0.00
W080VACADX____06				
Availability %	100.00	100.00	100.00	100.00
Data Errors %	0.00	0.00	0.00	0.00
Time Errors %	0.00	0.00	0.00	0.00

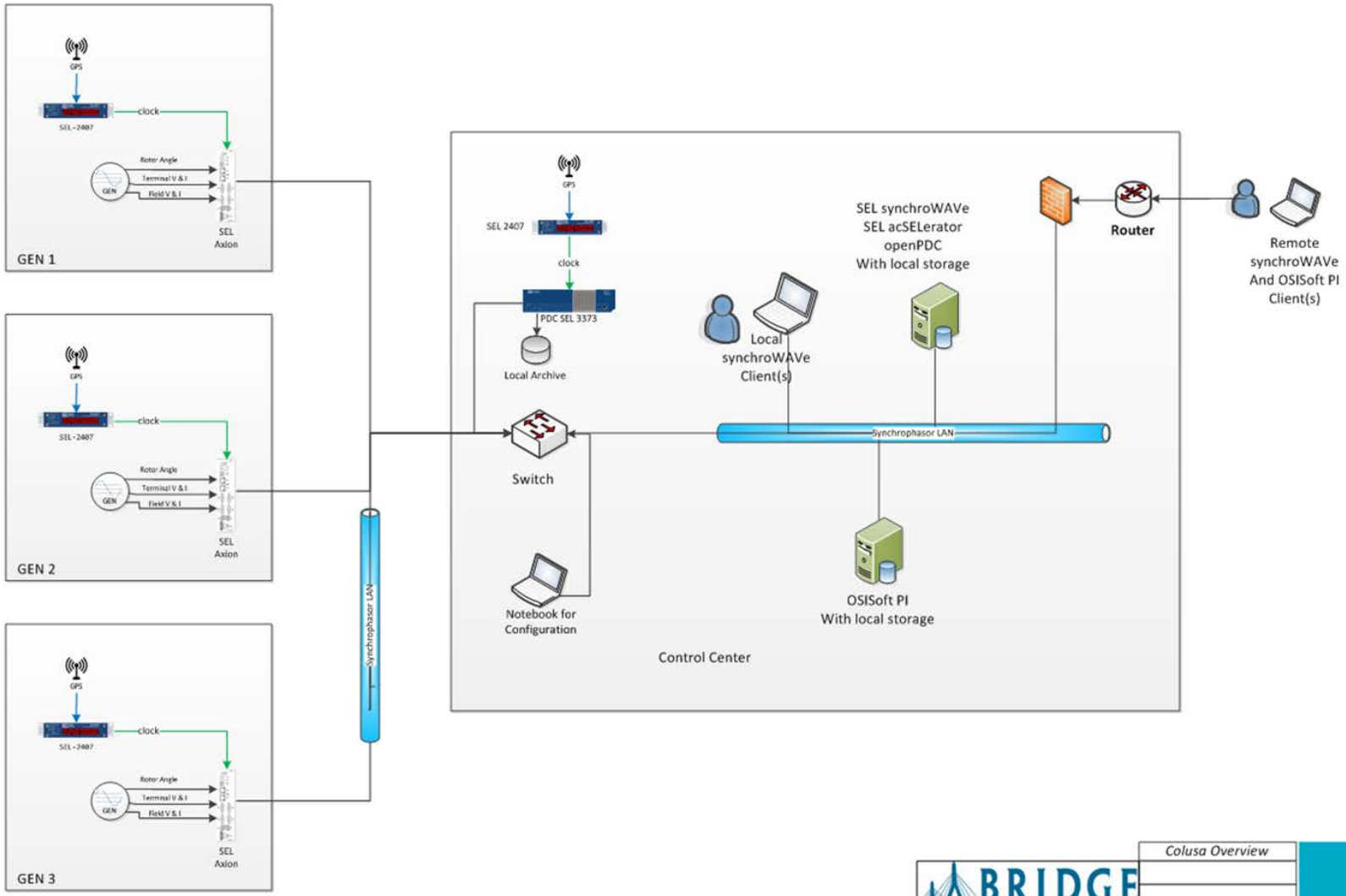
Previously only 2 PMUs were being sent to Peak RC with availability around 60% and a latency of almost 20 seconds

Generator Model Validation

Colusa Combined Cycle Plant

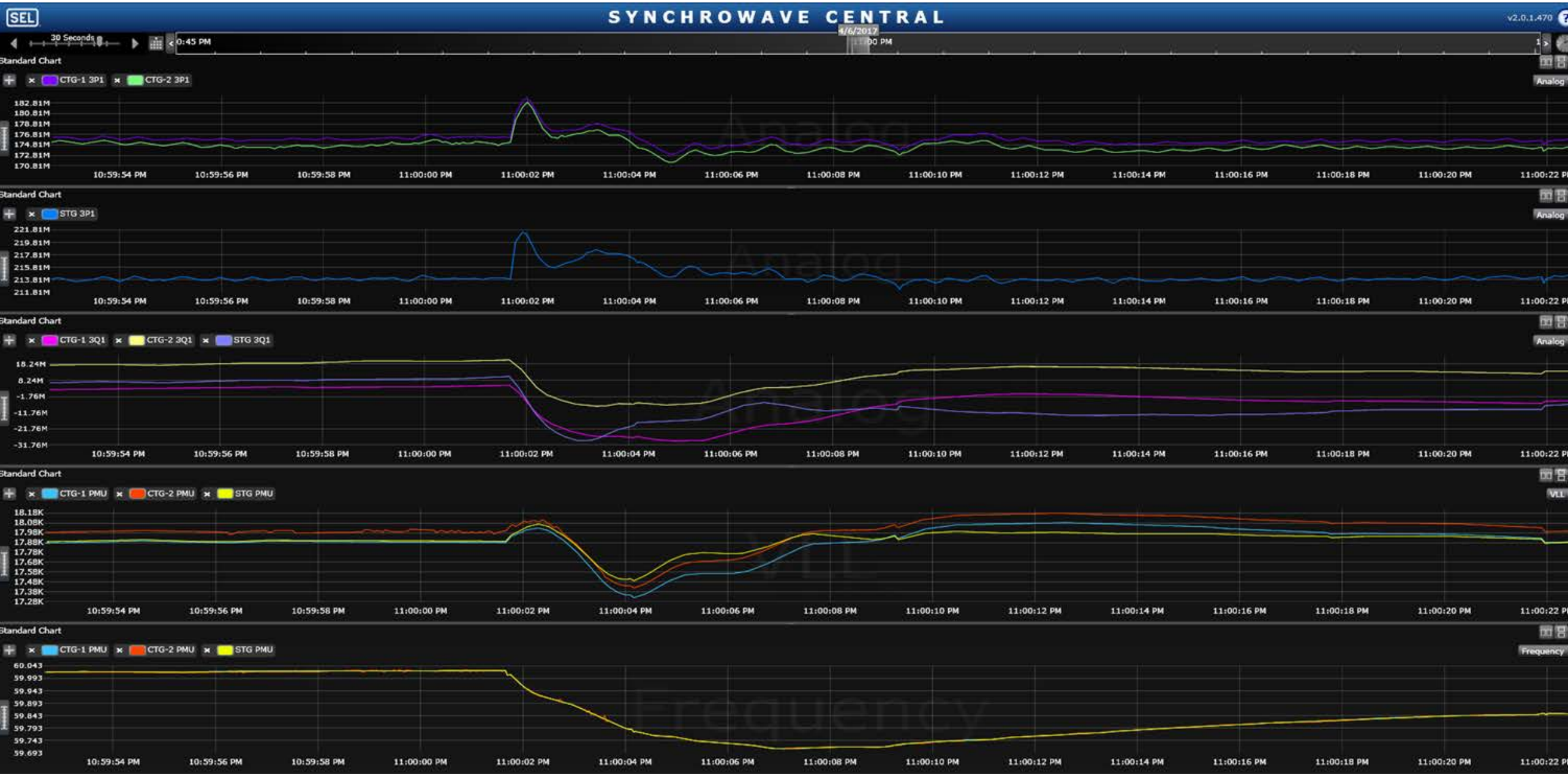


Architecture Generation

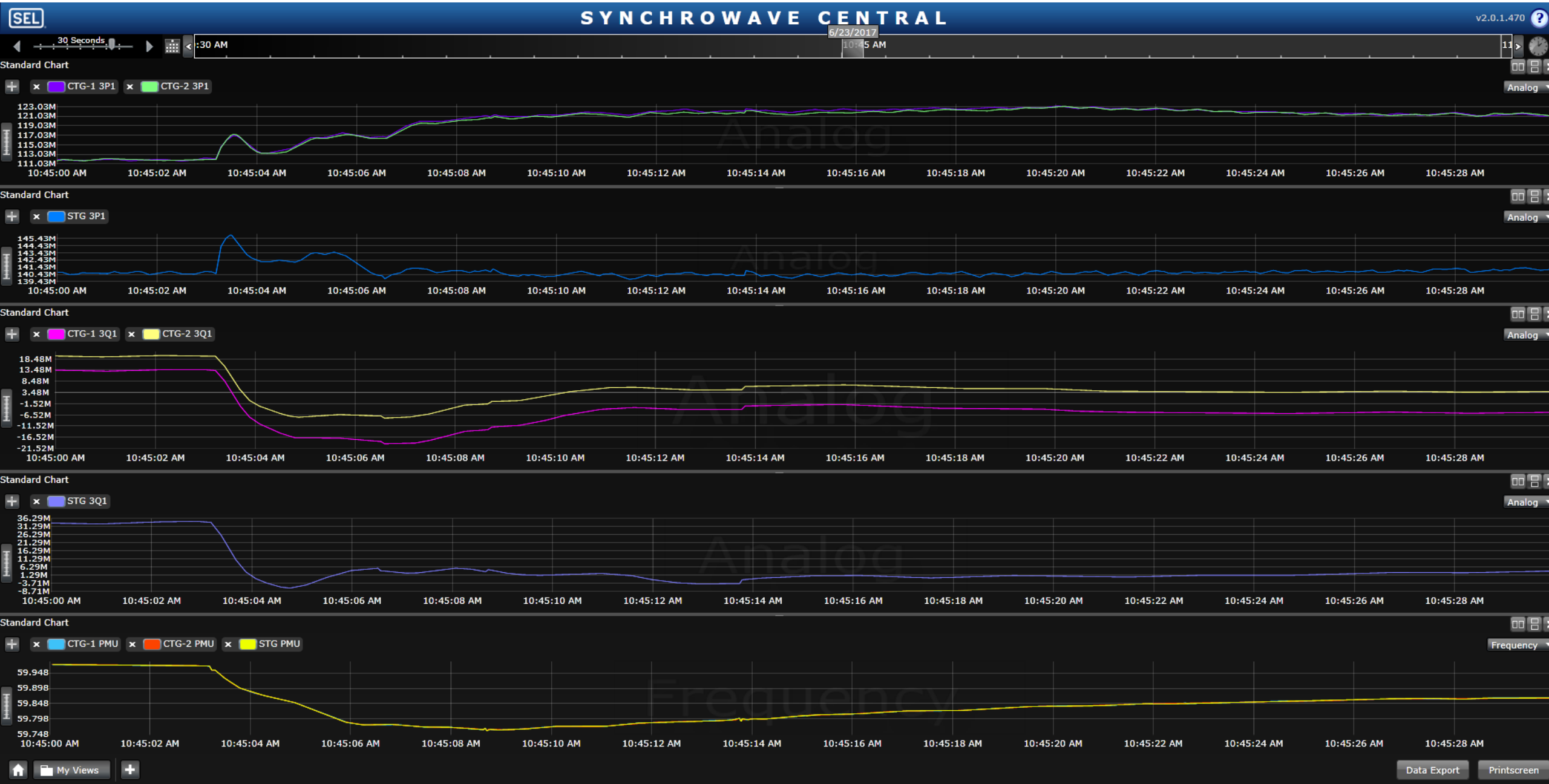



Colusa Generation
Zoom Out
Last 24 hours
Rotor to Voltage Phase Angle offset
Degrees
55
50
45
40
35
14:00
16:00
18:00
20:00
22:00
00:00
02:00
06:00
08:00
10:00
12:00
CTG-1
CTG-2
STG
2017-09-13 01:52:00
CTG-1: 49
CTG-2: 46
STG: 46
Rotor Angle
Metric
Current
STG 48.03
CTG-2 48.48
CTG-1 51.21
Colusa MW
MW
300
250
200
150
Colusa MW Total
565.9 MW
Colusa MVAR
MVAR
100
50
0
-50
Colusa MVAR
-26.5 Mvar
Colusa Generator voltage
Voltage
STG 17.93 K
CTG-2 17.93 K
CTG-1 17.88 K
Colusa Generator Current
Current
STG 7823
CTG-2 5191
CTG-1 5239

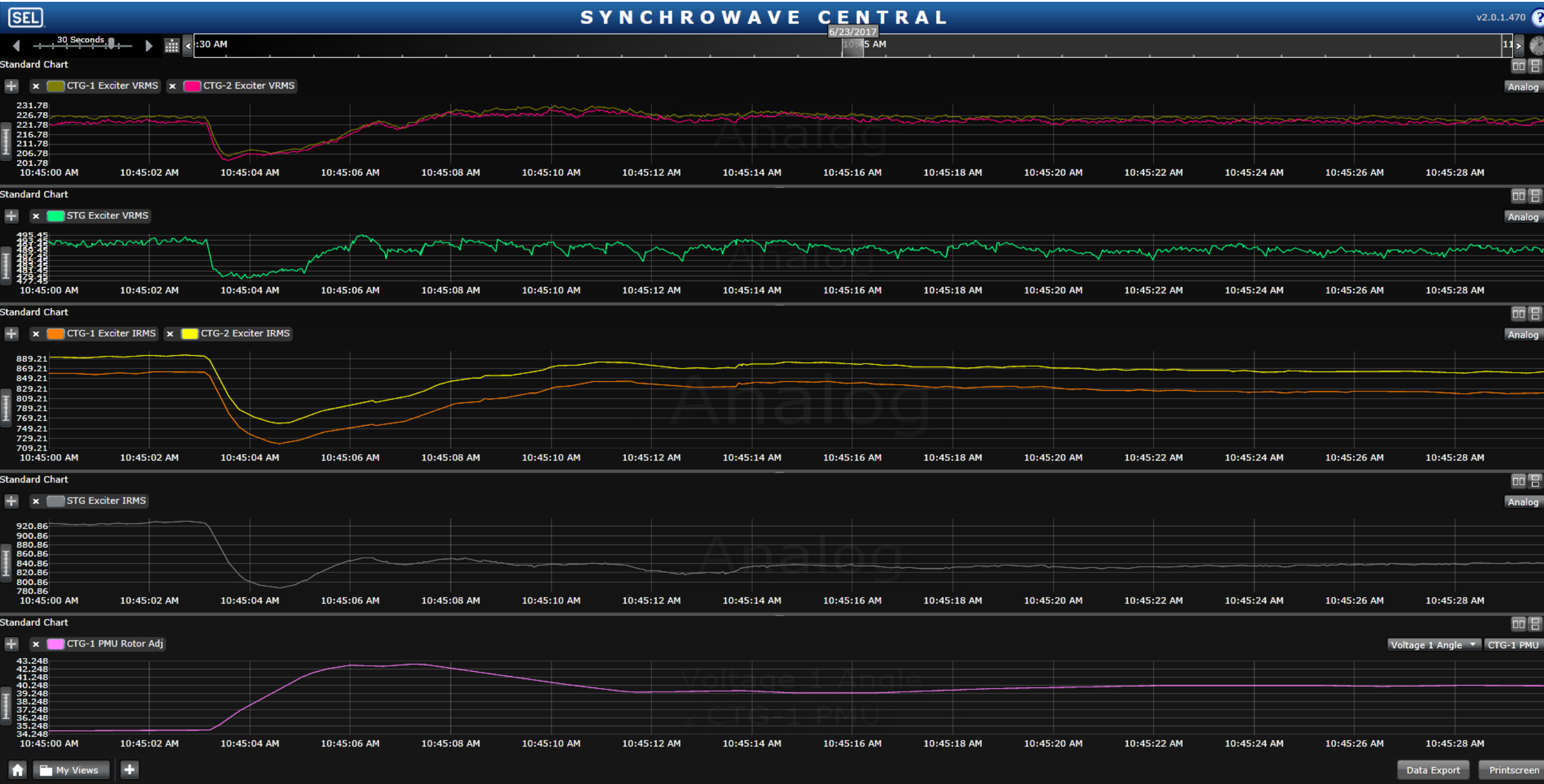
RAS Event 4-6-2017 (Colusa P, Q, V, and F)



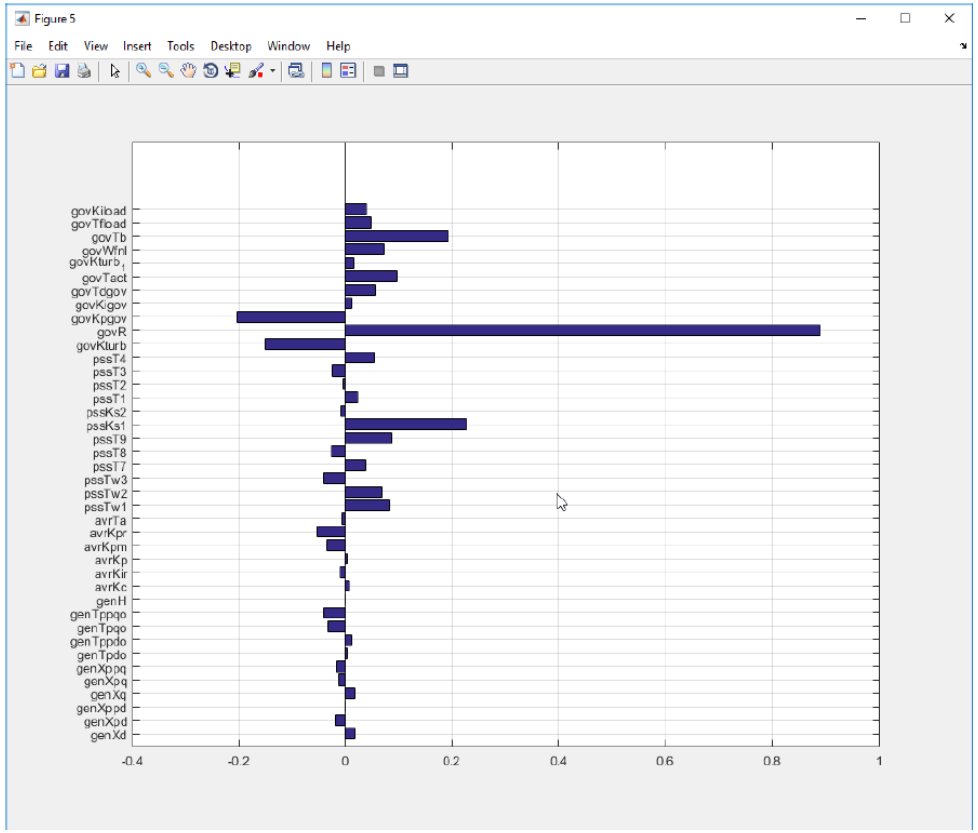
RAS Event 6-23-2017 (Colusa P, Q, V, and F)

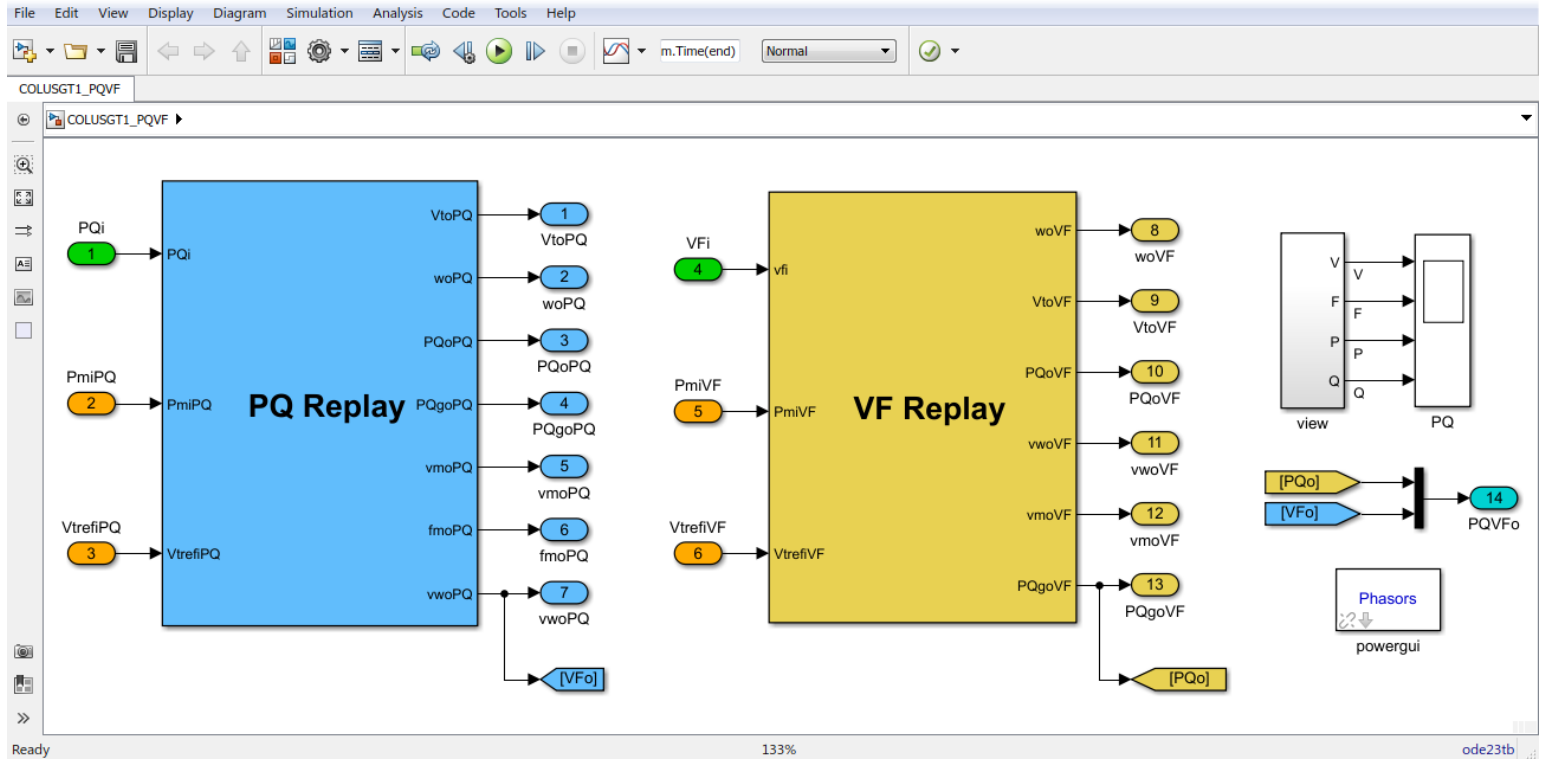


RAS Event 6-23-2017 (Colusa Exciter Voltage & Current and Rotor Angle)

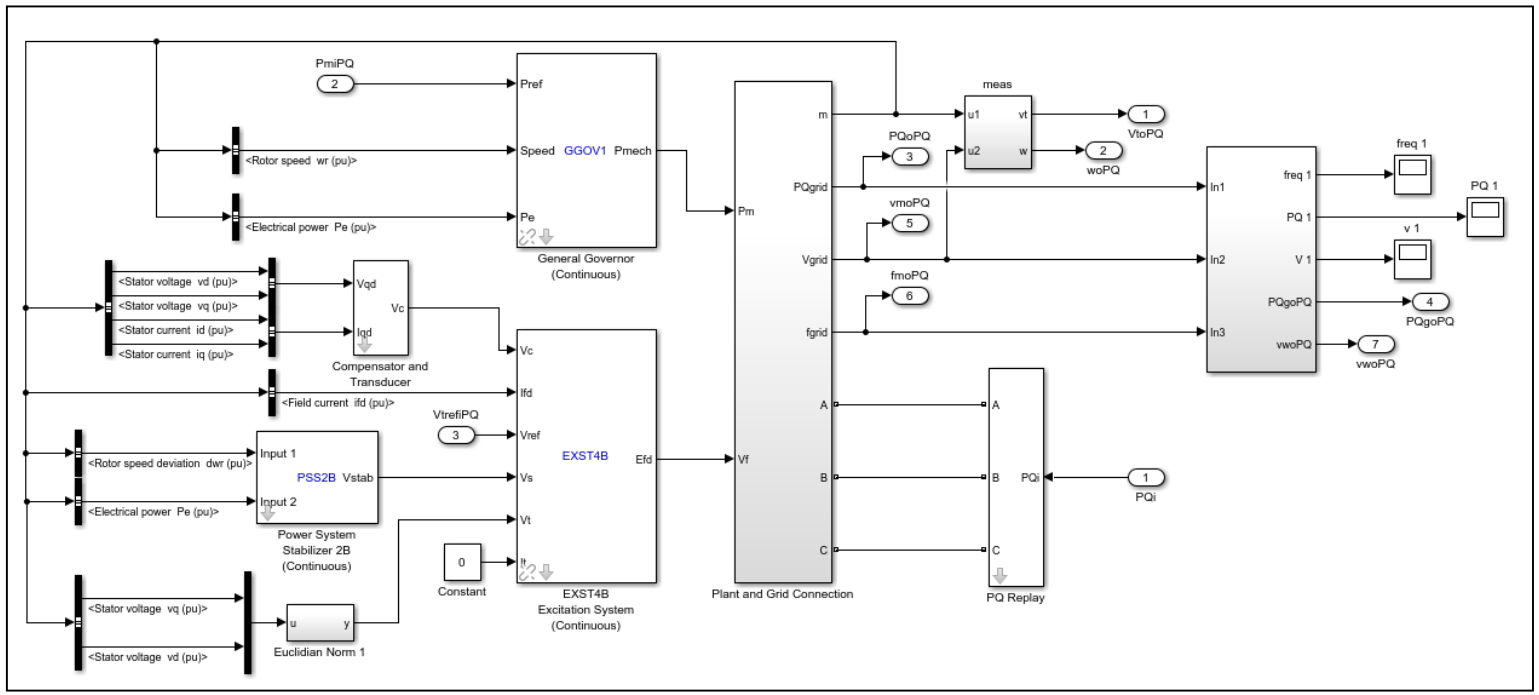


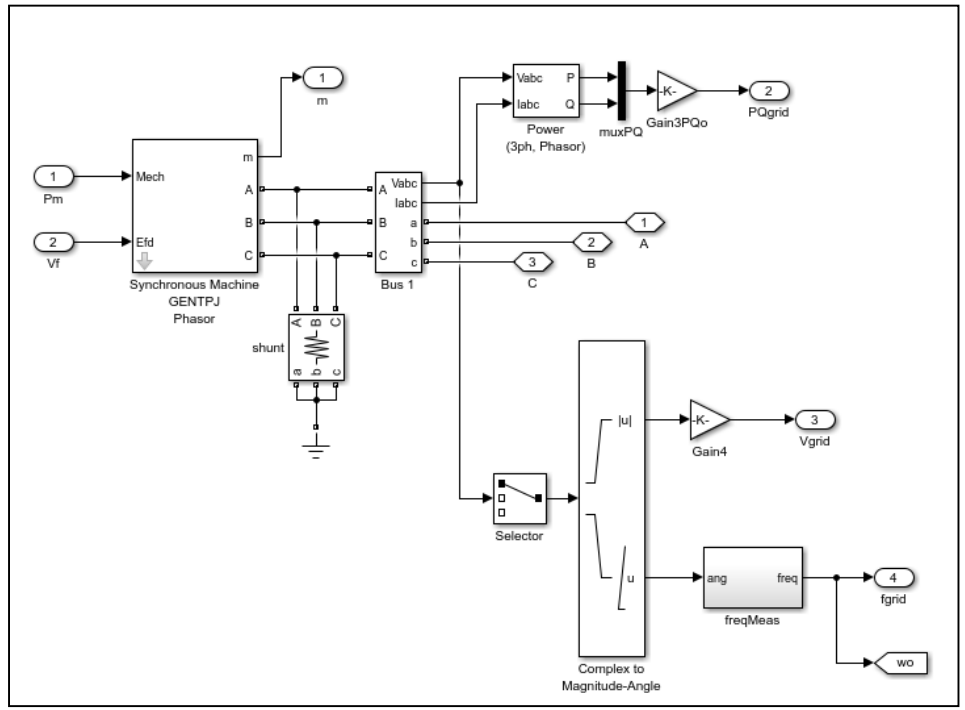
MathWorks Simulink Modeling and Parameter Estimation Tool



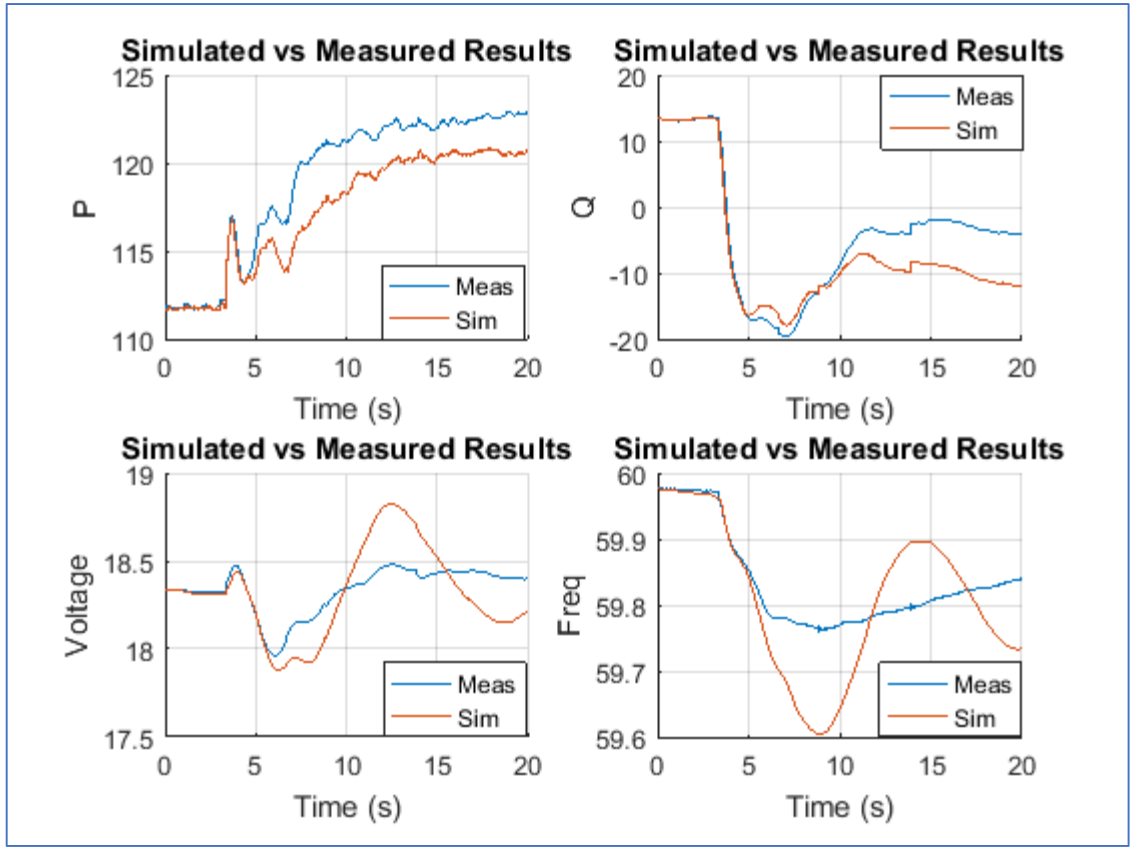


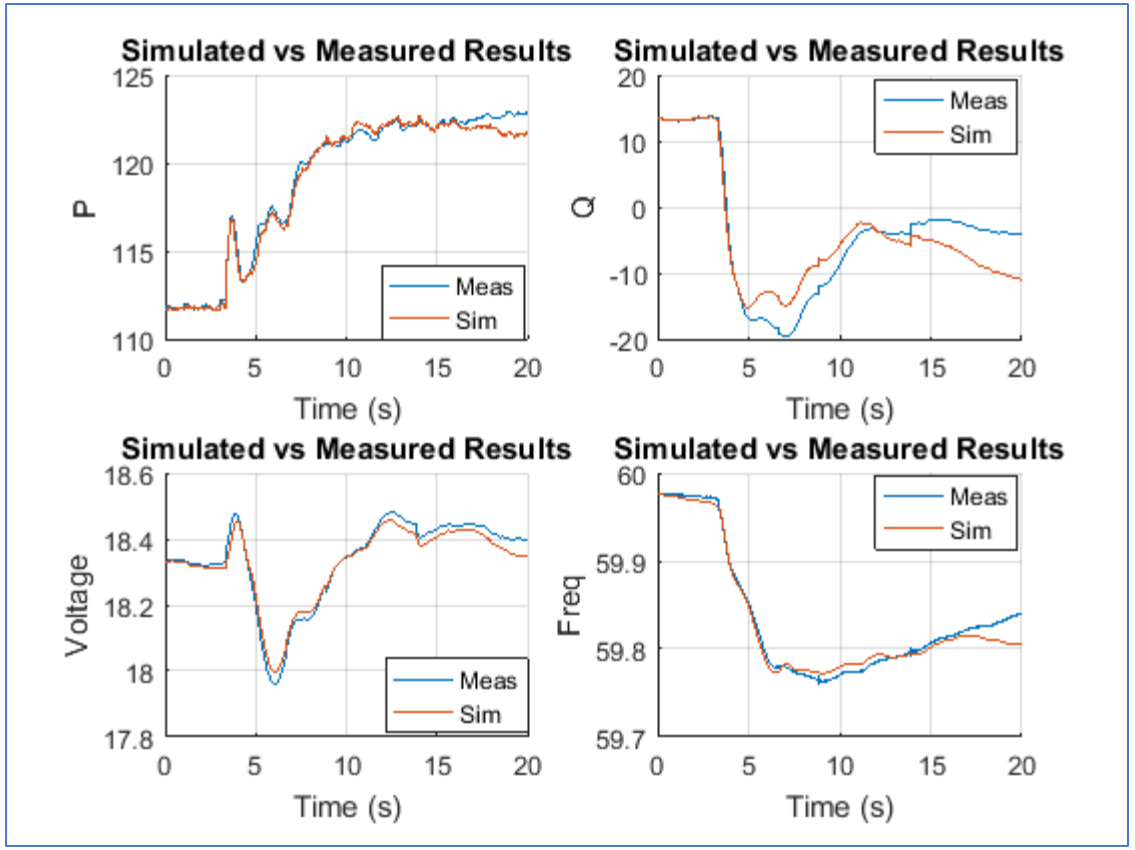
MathWorks Generator Model



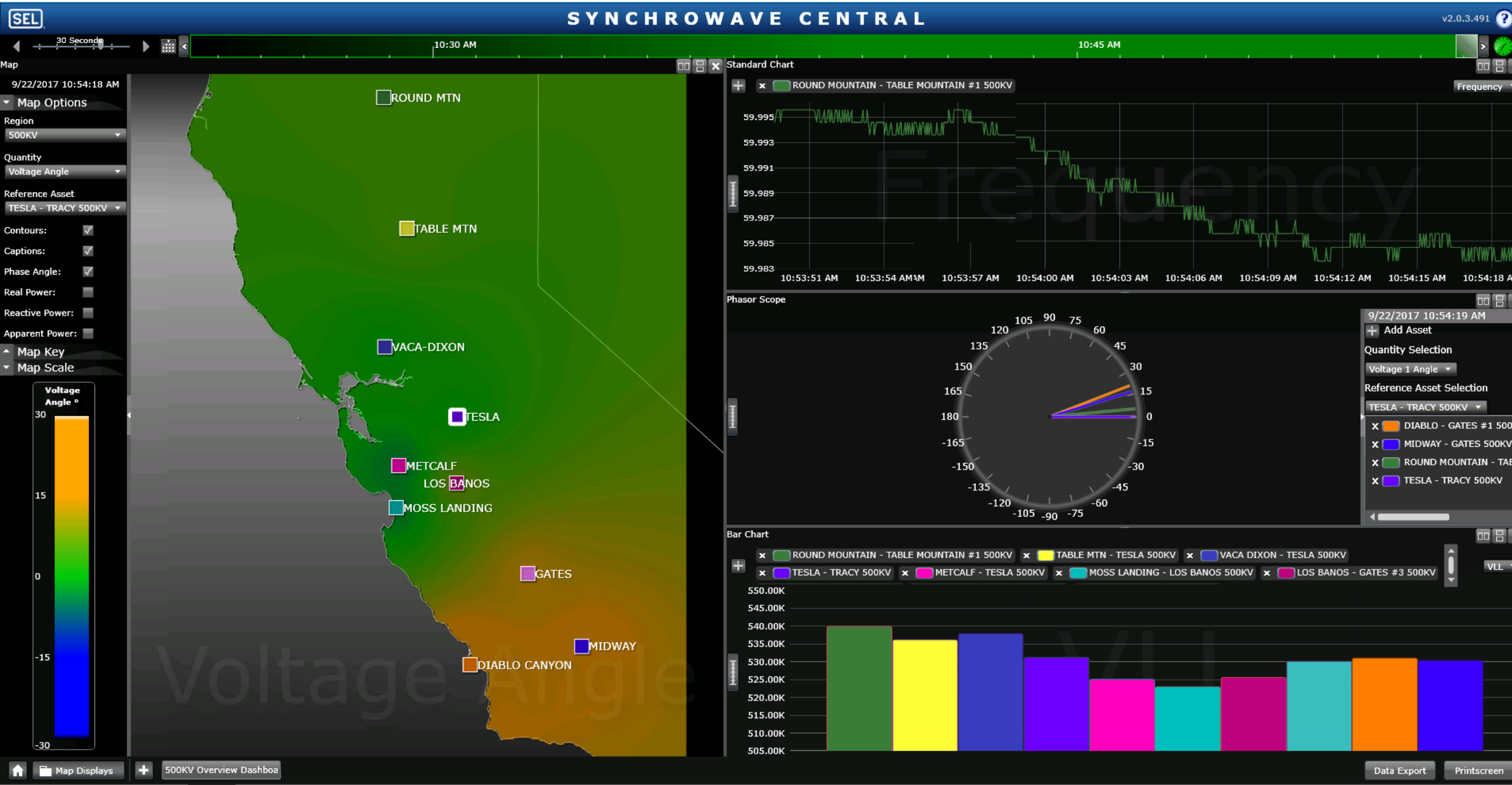


6-23-2017 RAS Event: CTG-1 Original Parameters vs PQVF Optimized Parameters

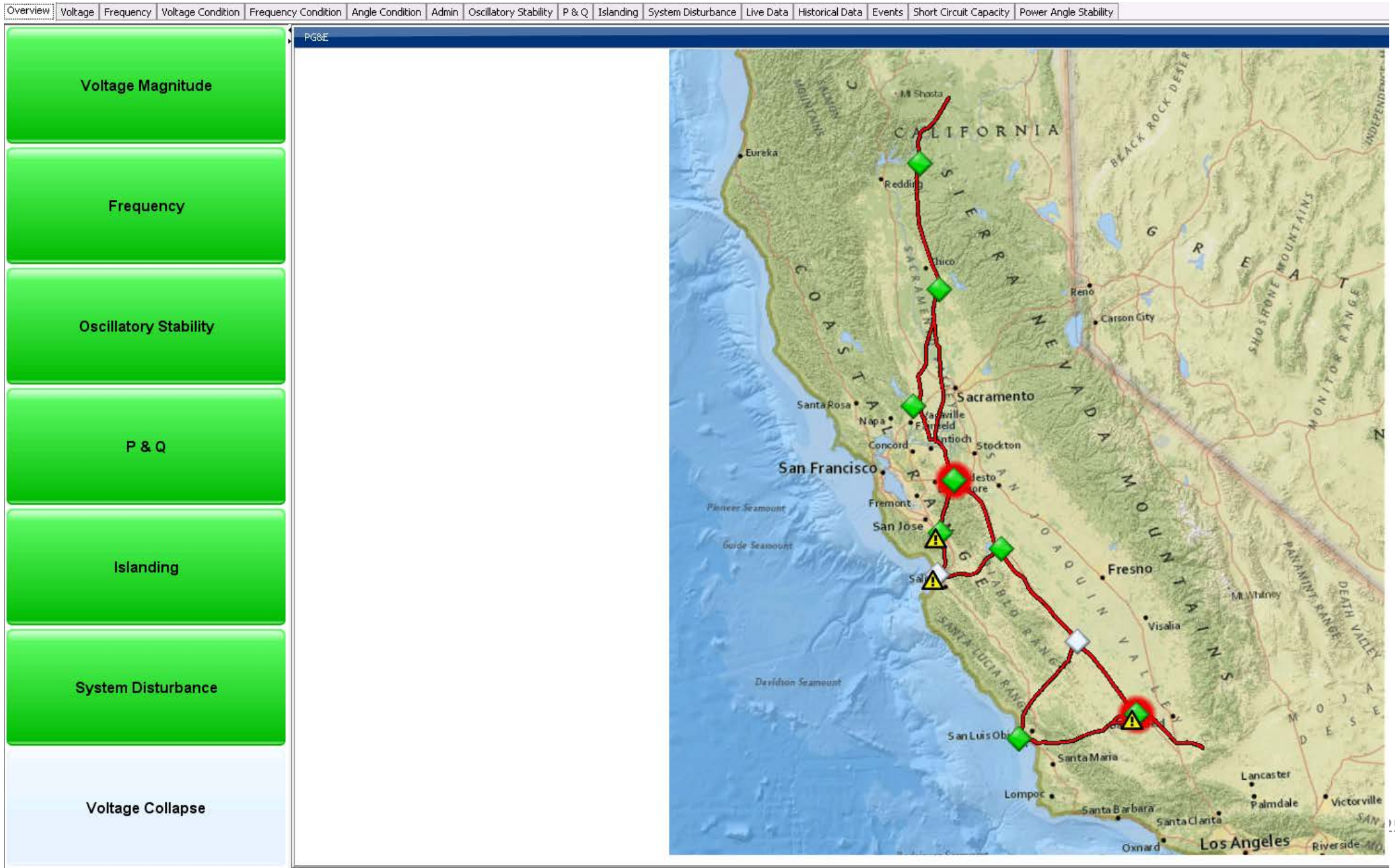




SYNCHROWAVE Central 500 kV Overview

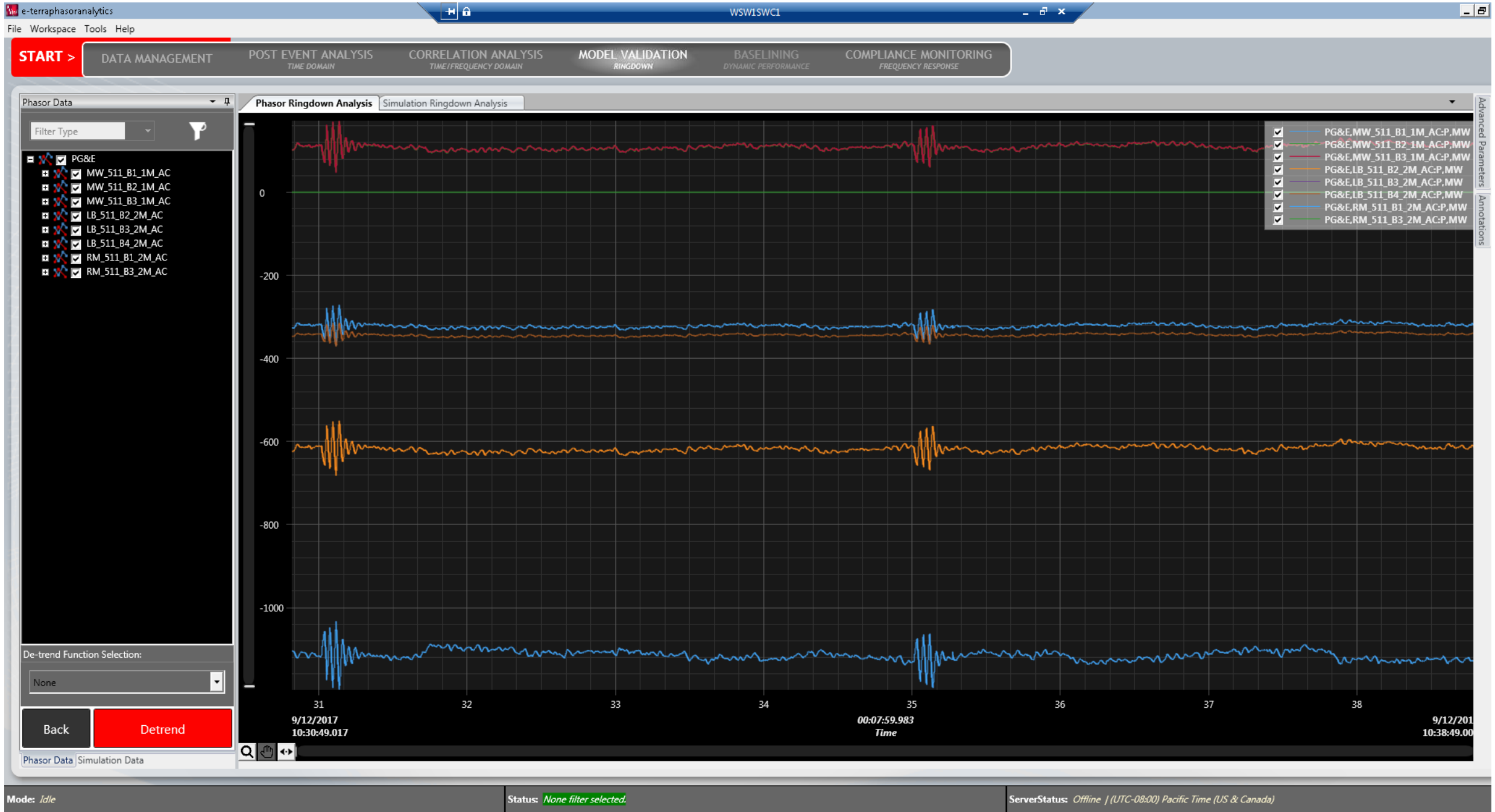


PhasorPoint 500 kV Overview

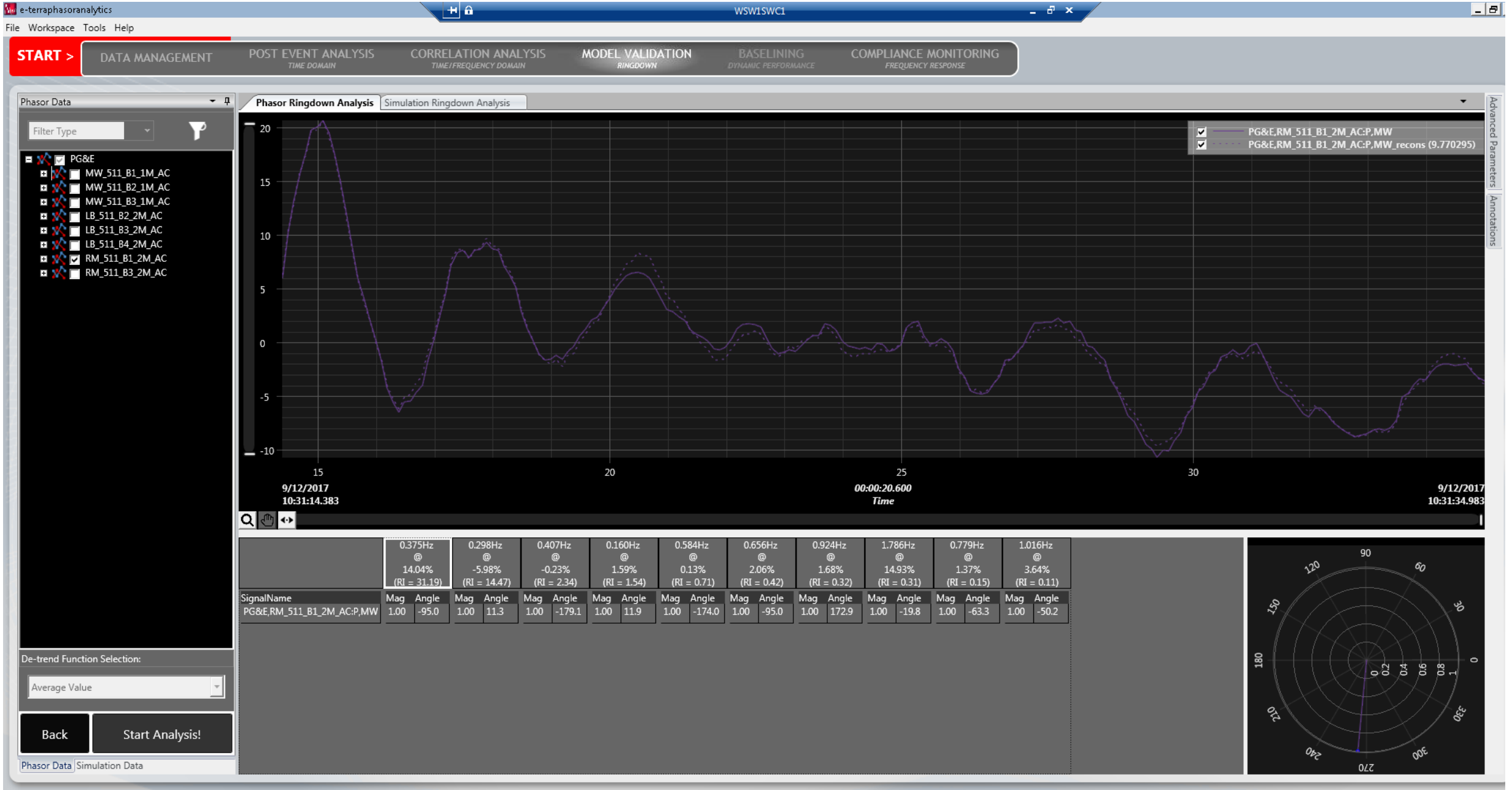


BPA PDCI Modulation Test 6-6-2017

PhasorAnalytics: BPA PDCI Modulation Test 6-6-2017

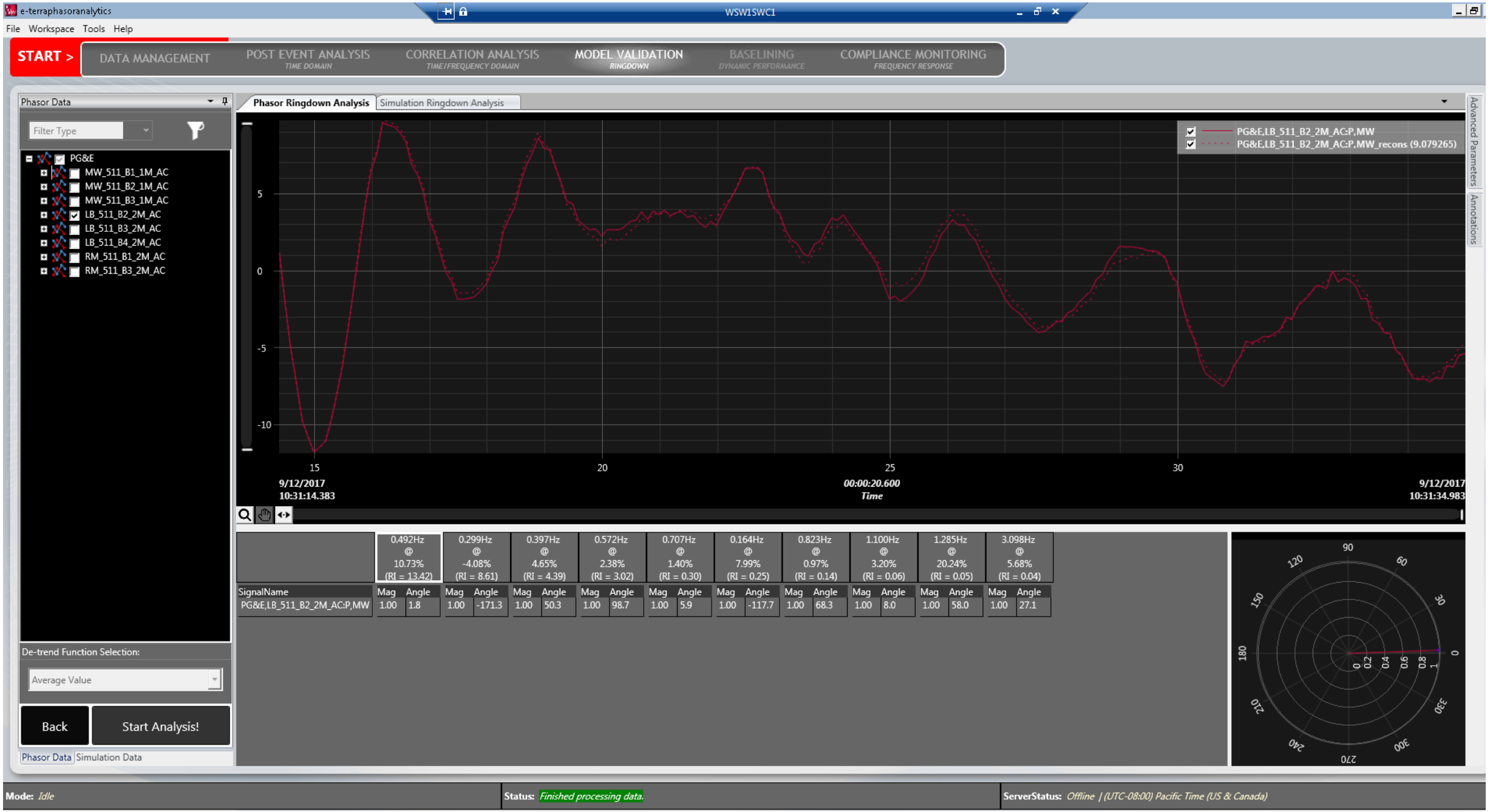


Ringdown: Malin – Round Mountain #1 500 kV Line



	0.375Hz @ 14.04% (RI = 31.19)		0.298Hz @ -5.98% (RI = 14.47)		0.407Hz @ -0.23% (RI = 2.34)		0.160Hz @ 1.59% (RI = 1.54)		0.584Hz @ 0.13% (RI = 0.71)		0.656Hz @ 2.06% (RI = 0.42)		0.924Hz @ 1.68% (RI = 0.32)		1.786Hz @ 14.93% (RI = 0.31)		0.779Hz @ 1.37% (RI = 0.15)		1.016Hz @ 3.64% (RI = 0.11)	
SignalName	Mag	Angle	Mag	Angle	Mag	Angle	Mag	Angle	Mag	Angle	Mag	Angle	Mag	Angle	Mag	Angle	Mag	Angle	Mag	Angle
PG&E,RM_511_B1_2M_AC:P,MW	1.00	-95.0	1.00	11.3	1.00	-179.1	1.00	11.9	1.00	-174.0	1.00	-95.0	1.00	172.9	1.00	-19.8	1.00	-63.3	1.00	-50.2

Ringdown: Los Banos – Midway #2 500 kV Line



PhasorAnalytics: Frequency Response

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