IEEE PES ISGT NA 2019

Panel Session

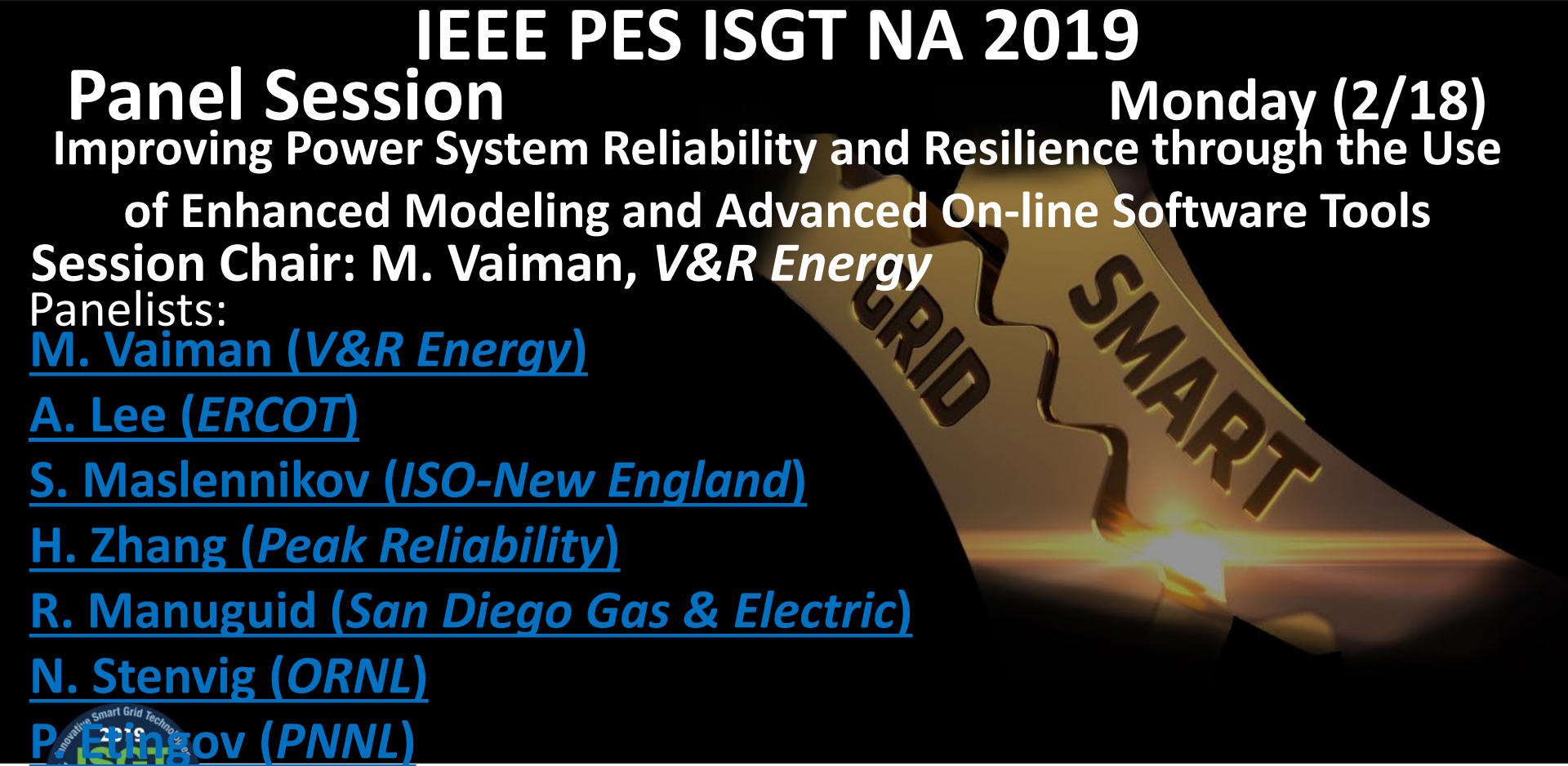
Monday (2/18)

Improving Power System Reliability and Resilience through the Use of Enhanced Modeling and Advanced On-line Software Tools

Session Chair: M. Vaiman, *V&R Energy*

Panelists:

- M. Vaiman (*V&R Energy*)
- A. Lee (*ERCOT*)
- S. Maslennikov (*ISO-New England*)
- H. Zhang (*Peak Reliability*)
- R. Manuguid (*San Diego Gas & Electric*)
- N. Stenvig (*ORNL*)
- P. Etingov (*PNNL*)



Improving Power System Reliability and Resilience through the Use of Enhanced Modeling and Advanced On-line Software Tools

Chair: Marianna Vaiman, V&R Energy

IEEE ISGT 2019

Washington, D.C. • February 18, 2019

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IEEE

- “The average amount of remotely conscious decisions an adult makes each day equals about 35,000”
  - Multiple internet sources
- The main goal of advanced on-line software tools is to improve situational awareness and help the operators to make the right decisions, especially in critical situations

Reliability, according to the U.S. Department of Energy (DOE), is the ability of the system or its components to withstand instability, uncontrolled events, cascading failures, or unanticipated loss of system components. Resilience, as defined by DOE, is the ability of a system or its components to adapt to changing conditions and withstand and rapidly recover from disruptions.

ISO new england

CALENDAR

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About Us > What We Do > In Depth

What We Do

- Our Three Critical Roles
- Our History
- In Depth

What Is Reliability?

The Electricity You Need, When You Need It

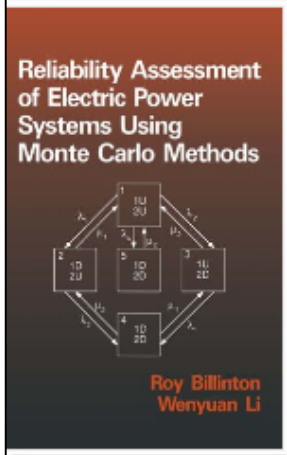
Across the six states of New England, the dependable flow of electricity drives daily life, business, and critical services. When you start the coffeemaker and turn on the television each morning, the coffee flows and the sound of the day's news fills the room. You can depend on our morning routine to unfold with comfortable predictability in large part because the wholesale side of the power system is making sure that the right amount of electricity is there when it's needed—instantly. (Learn more about how electricity is generated, transported, and delivered in New England.)

The Ability to Withstand Disturbances on the System

Events on the distribution system, such as a car hitting a utility pole or a tree falling on distribution lines during a storm, are the most frequent cause of disruptions to customers' electric service. Failures on the distribution system typically cause **power outages**.

Failures of the transmission system over a broader area are referred to as **blackouts**. The impact of a blackout can be widespread and severe

Springer Link



Reliability Assessment of Electric Power Systems Using Monte Carlo Methods

Authors (view affiliations)
Roy Billinton, Wenyuan Li

Abstract

The term *reliability* has a very wide range of meaning and cannot be associated with a single specific definition such as that often used in the missionoriented sense.[1] It is therefore necessary to recognize this fact and to use the term to indicate, in a general rather than a specific sense, the overall ability of the system to perform its function.

Power reliability can be **defined** as the degree to which the performance of the elements in a bulk. **system** results in **electricity** being delivered to customers within accepted standards and in the amount. desired.

Reliability - Definition and Discussion - INFO - Oak Ridge National ...
https://info.ornl.gov/sites/publications/Files/Pub57467.pdf

How do Enhanced Modeling and Advanced On-line Tools contribute to improving reliability and resilience of a power system?

Panel Session Overview

No.	Summary of Topics	Presenter
1	Wide Area Monitoring at ERCOT	Alex Lee, ERCOT
2	PNNL Tools for Advanced Synchrophasor Analysis	Pavel Etingov, PNNL
3	Ensuring Western Interconnection Reliability and Resilience by Advanced Modeling and Real-Time Analytical Tools	Hongming Zhang, Peak Reliability
4	Online Cascading Analysis at ISO New England	Slava Maslennikov, ISO NE
5	ORNL Advanced Power System Modeling Updates	Nils Stenvig, ORNL
6	Real-time Voltage Stability Assessment at SDG&E	Robin Manuguid, SDG&E
7	Q&A	All

Question 1. What are the main challenges when bringing new on-line/real-time advanced applications to the Control Center?

Question 2. Considering the impact of recent fires in California, how does your organization addresses wildfire resilience?

Question 3. Are there any modeling aspects that we are currently not considering that potentially could improve power system reliability?

Question 4. In some situations, it is not easy to identify whether an issue is due to an error in the model, or an error (a bug) in the tool. Do you have any practices to separate those? If Yes, can you share them?

Wide Area Monitoring at ERCOT

Alex Lee

ercot Lead Operations Planning Engineer

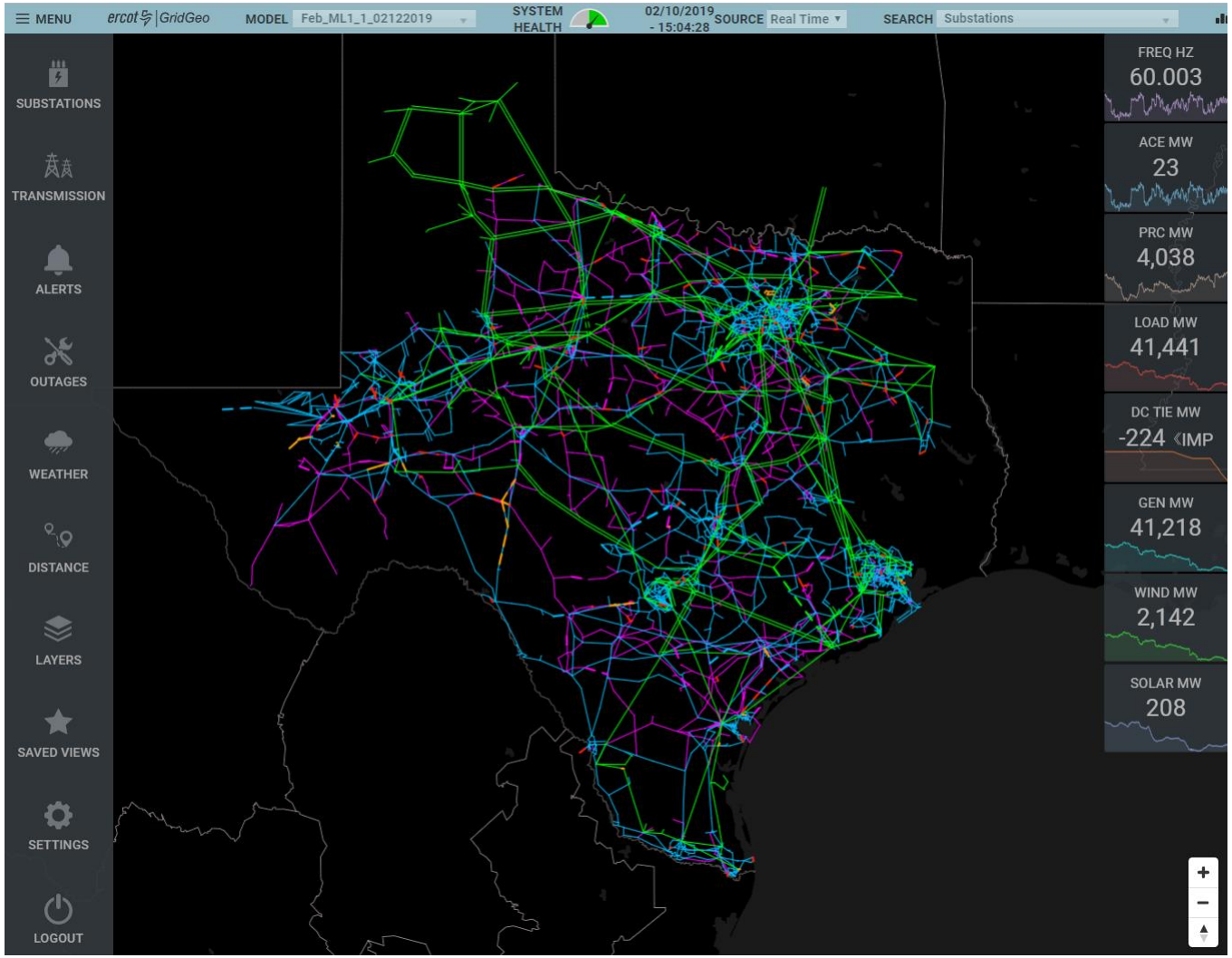
February 18, 2019

Overview

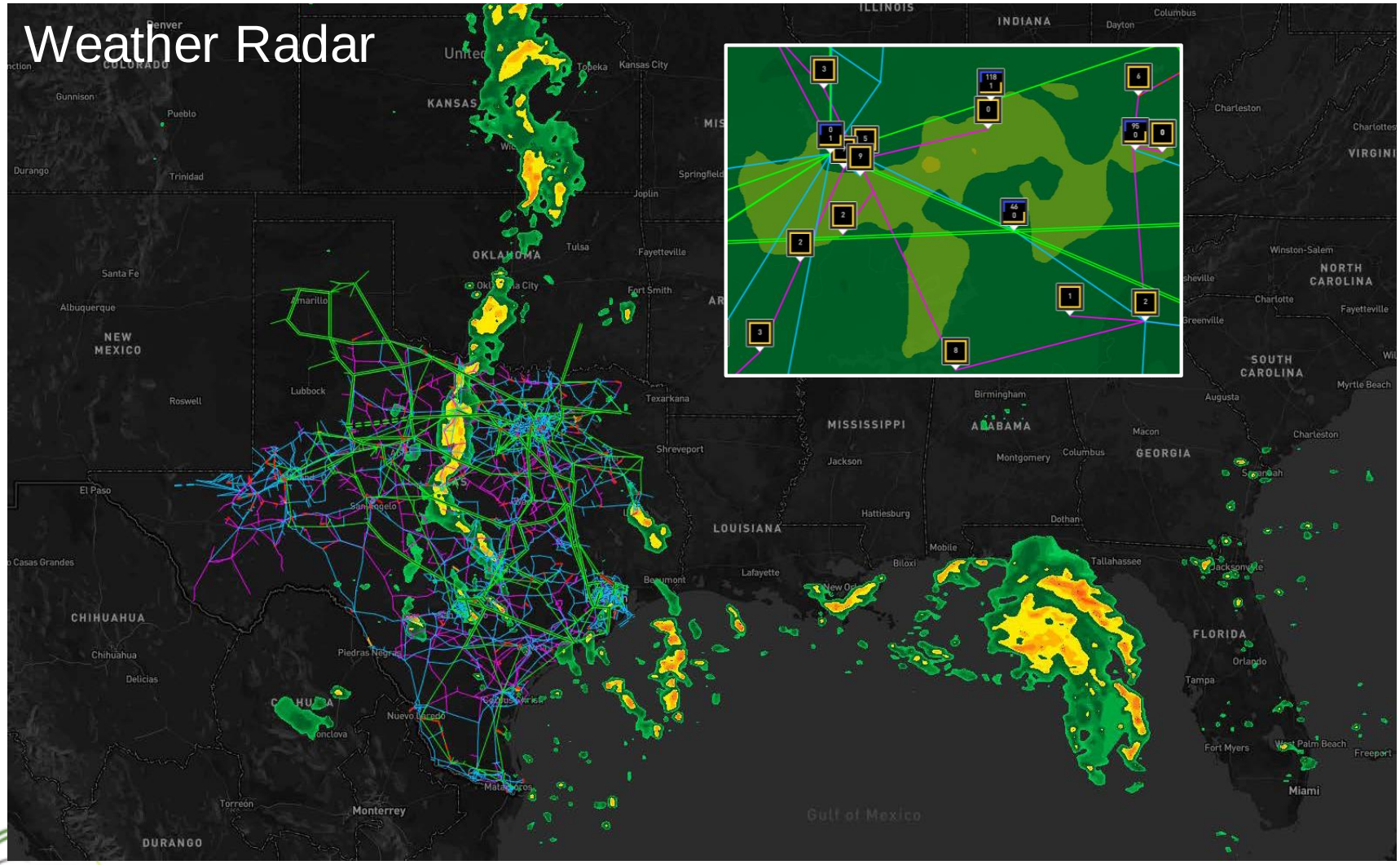
- Wide area monitoring and situational awareness using the browser-based application, Grid Geo.

- Rising penetration of renewable generators pushes for reactive power coordination and inertia monitoring.

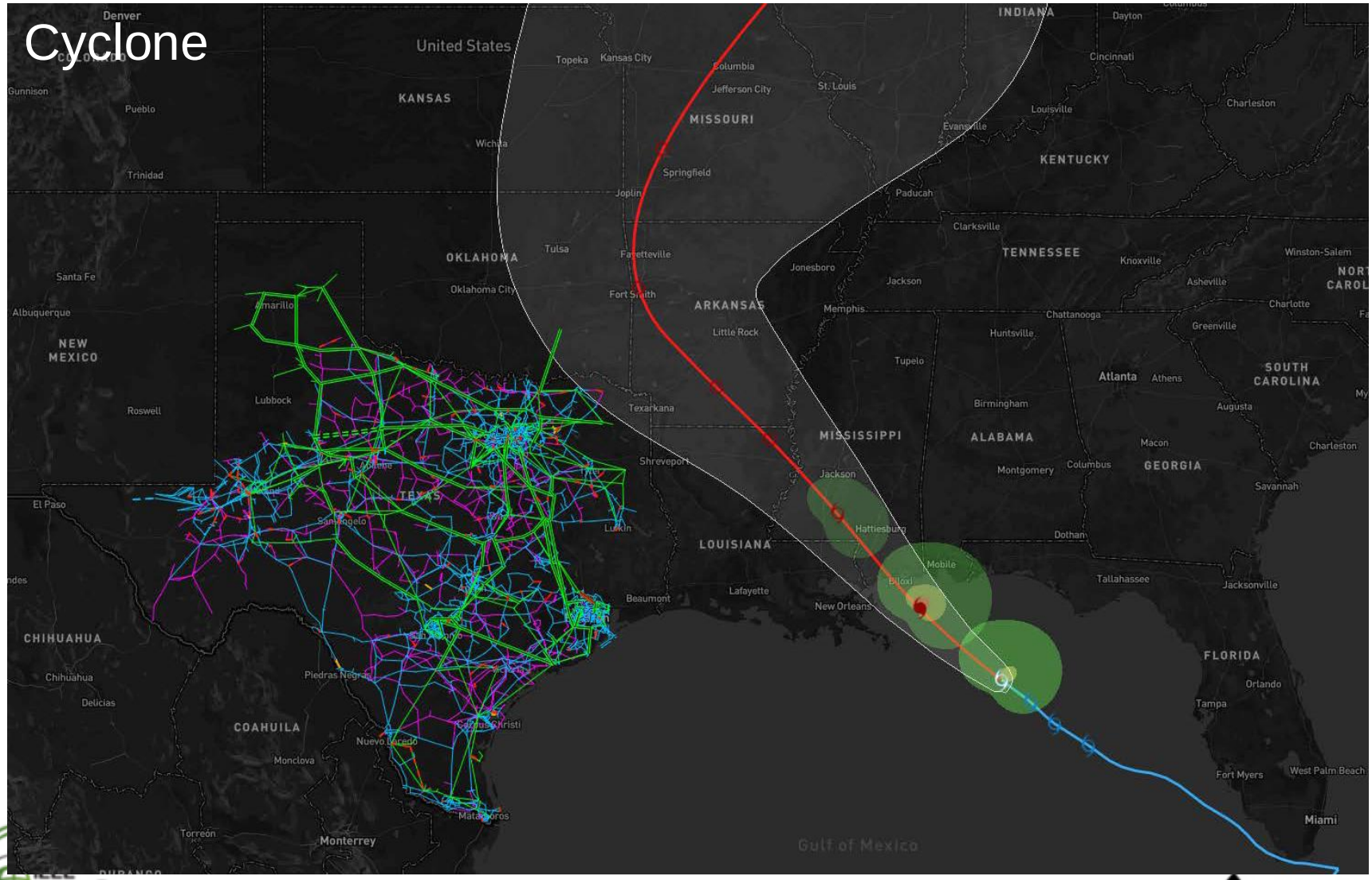
Grid Geo: Wide Area Monitoring



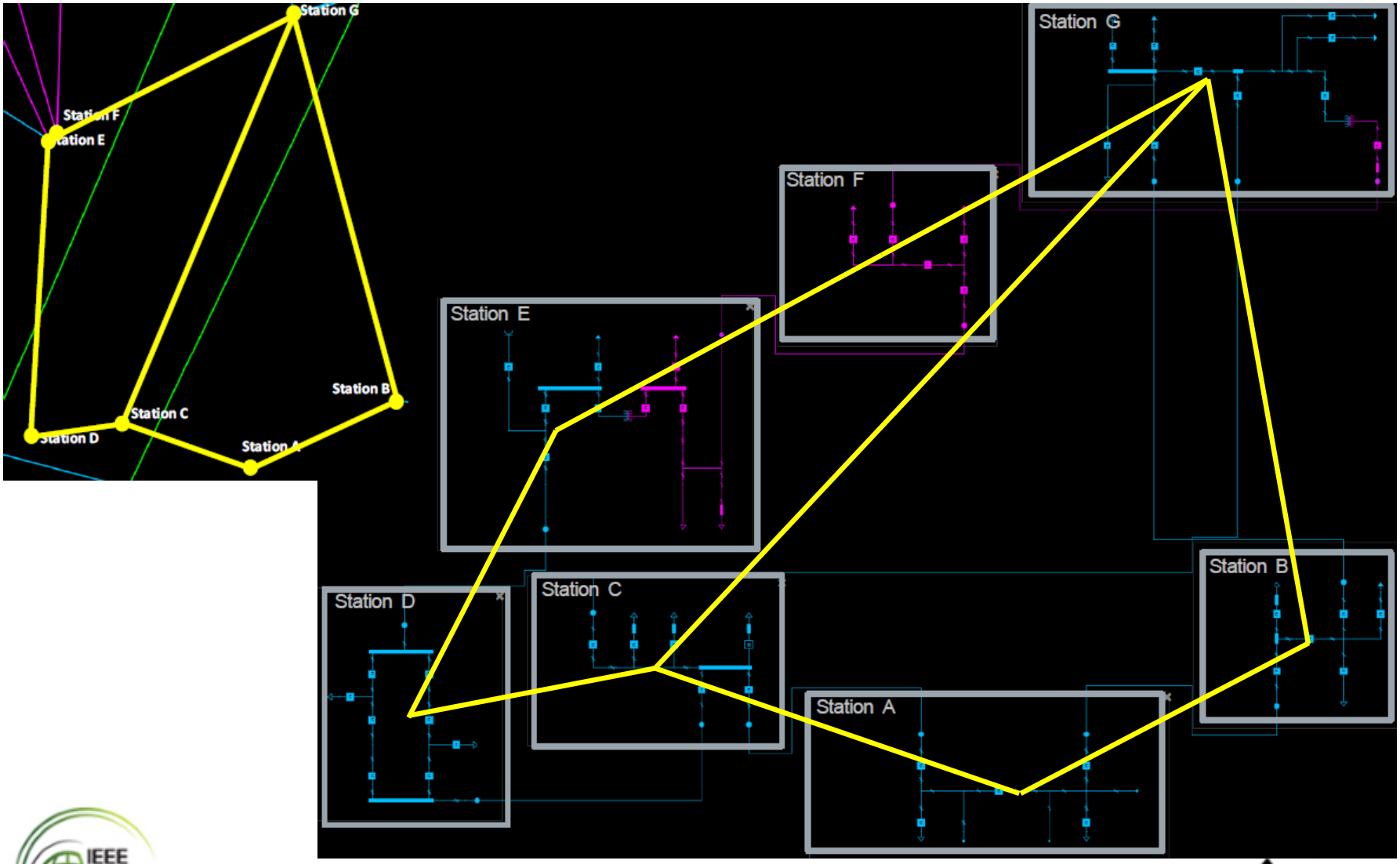
Grid Geo: Situational Awareness



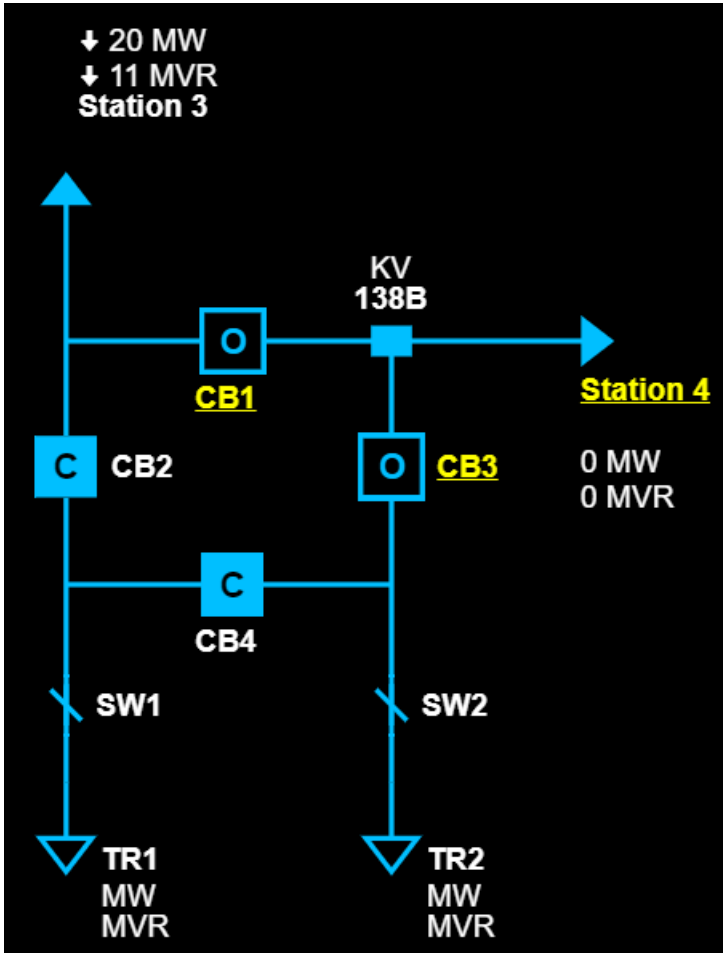
Grid Geo: Situational Awareness

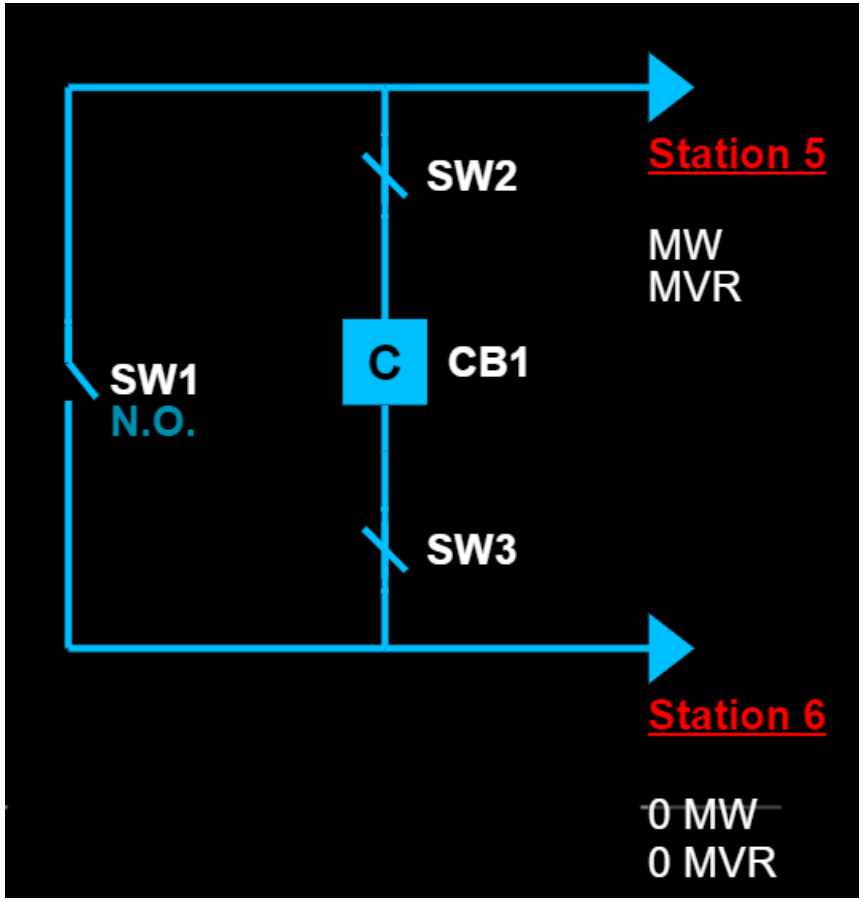


Grid Geo: Multi-Station One-lines

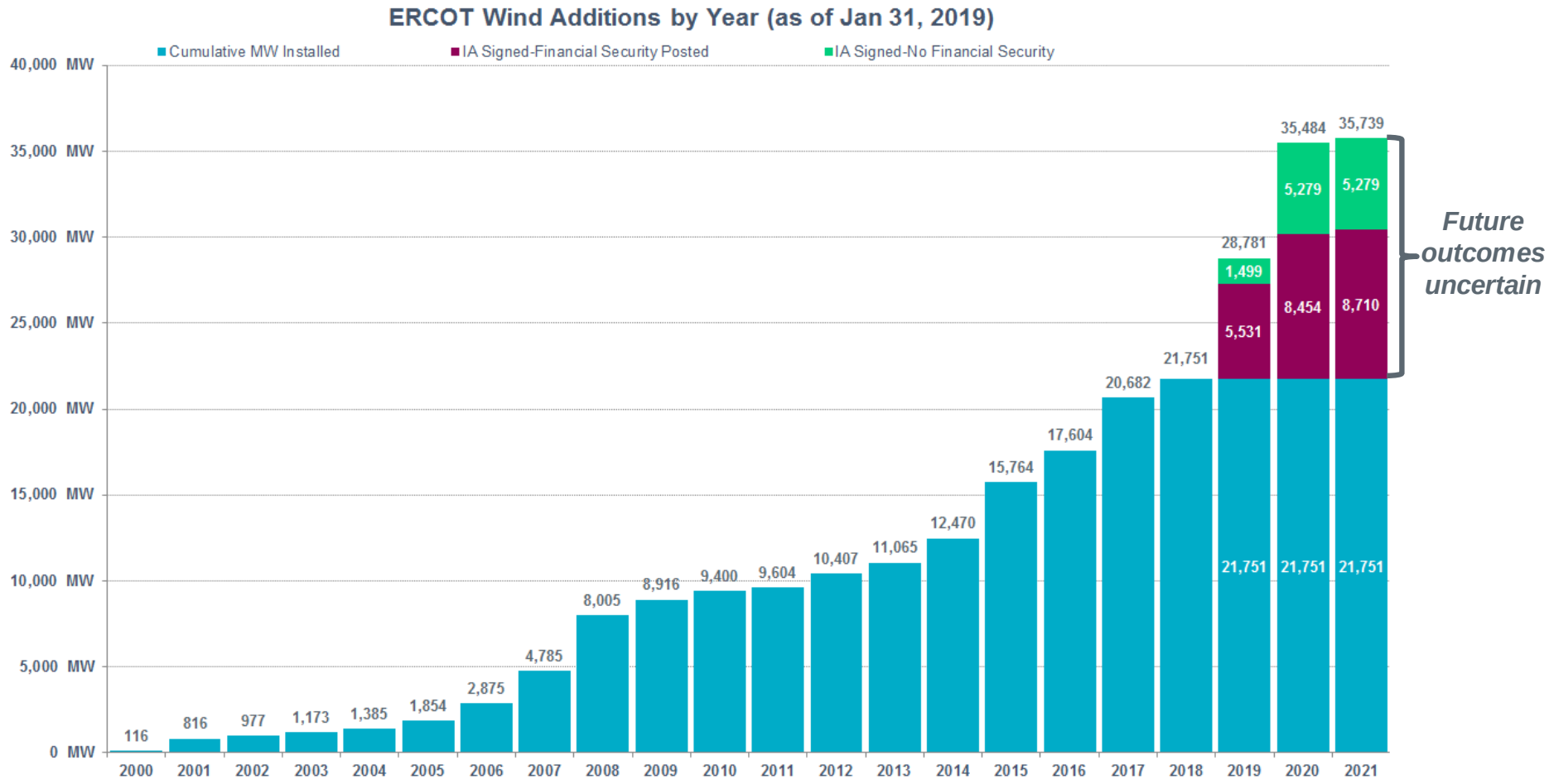


Grid Geo: Substation Highlighting

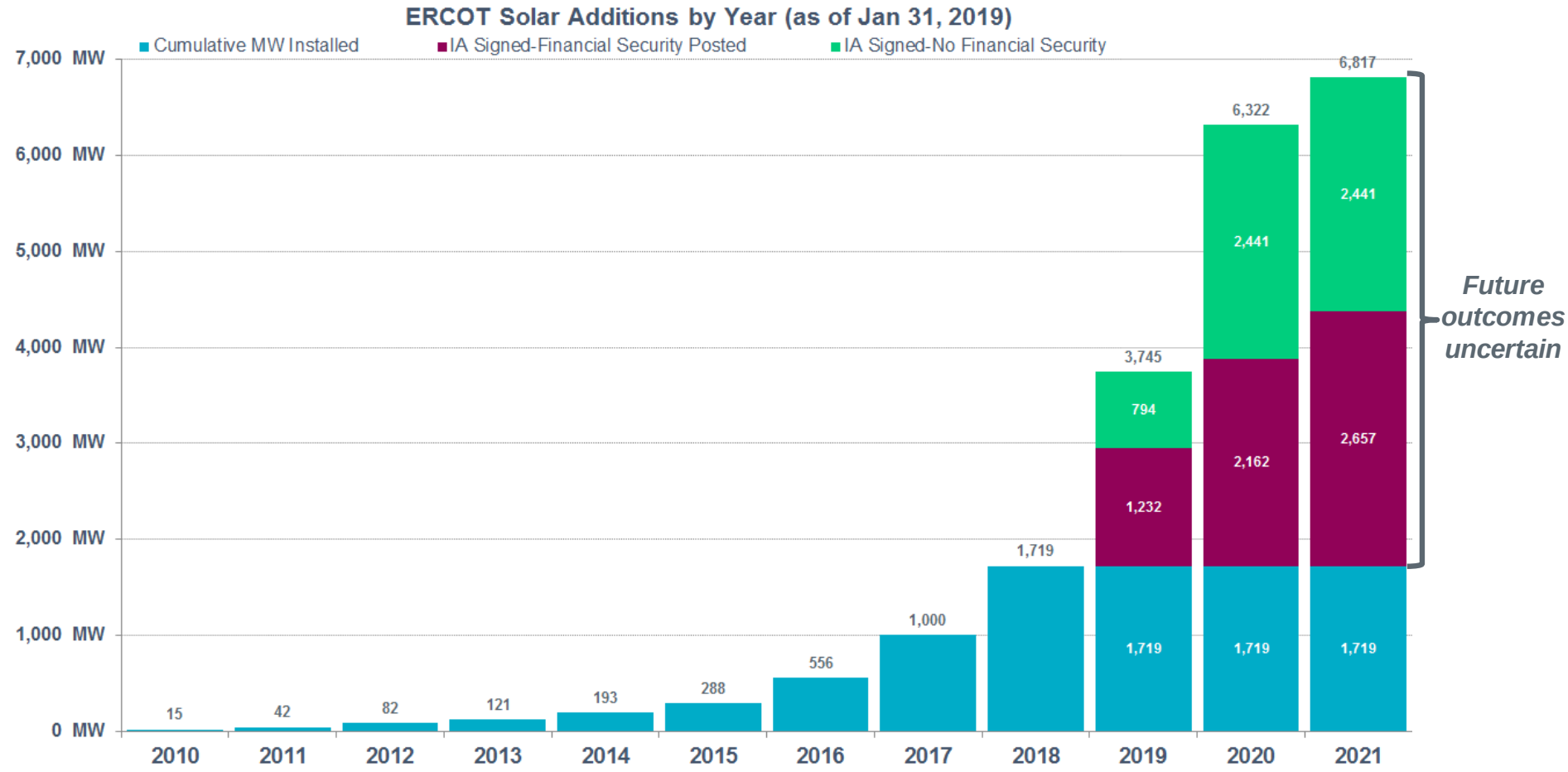




Wind Generation Growth

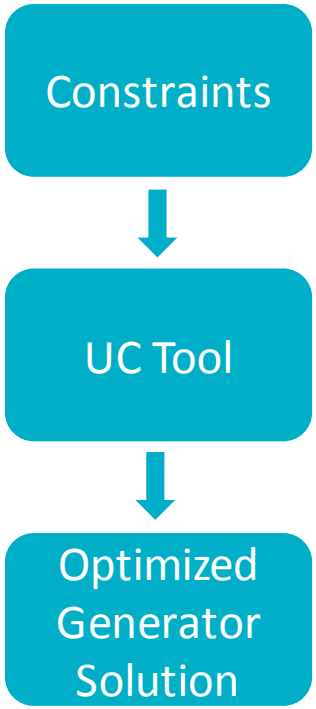


Solar Generation Growth

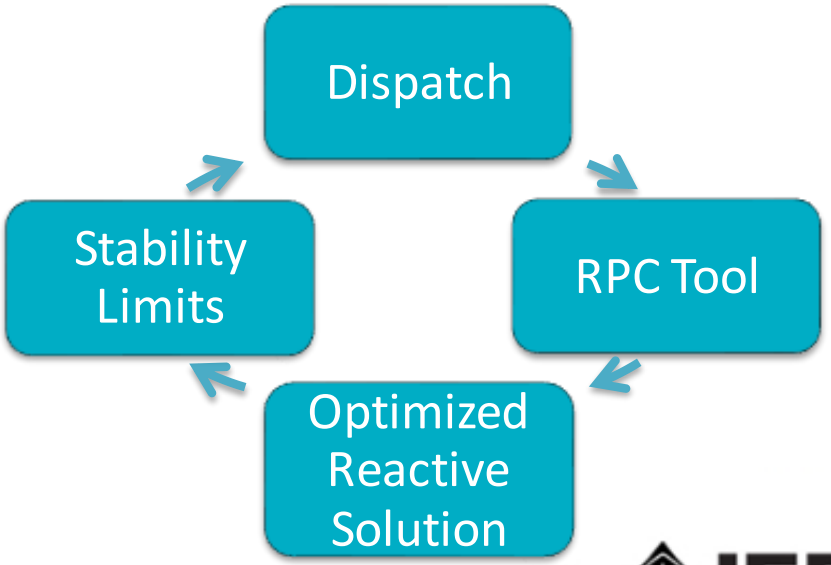


Reactive Power Coordination (RPC)

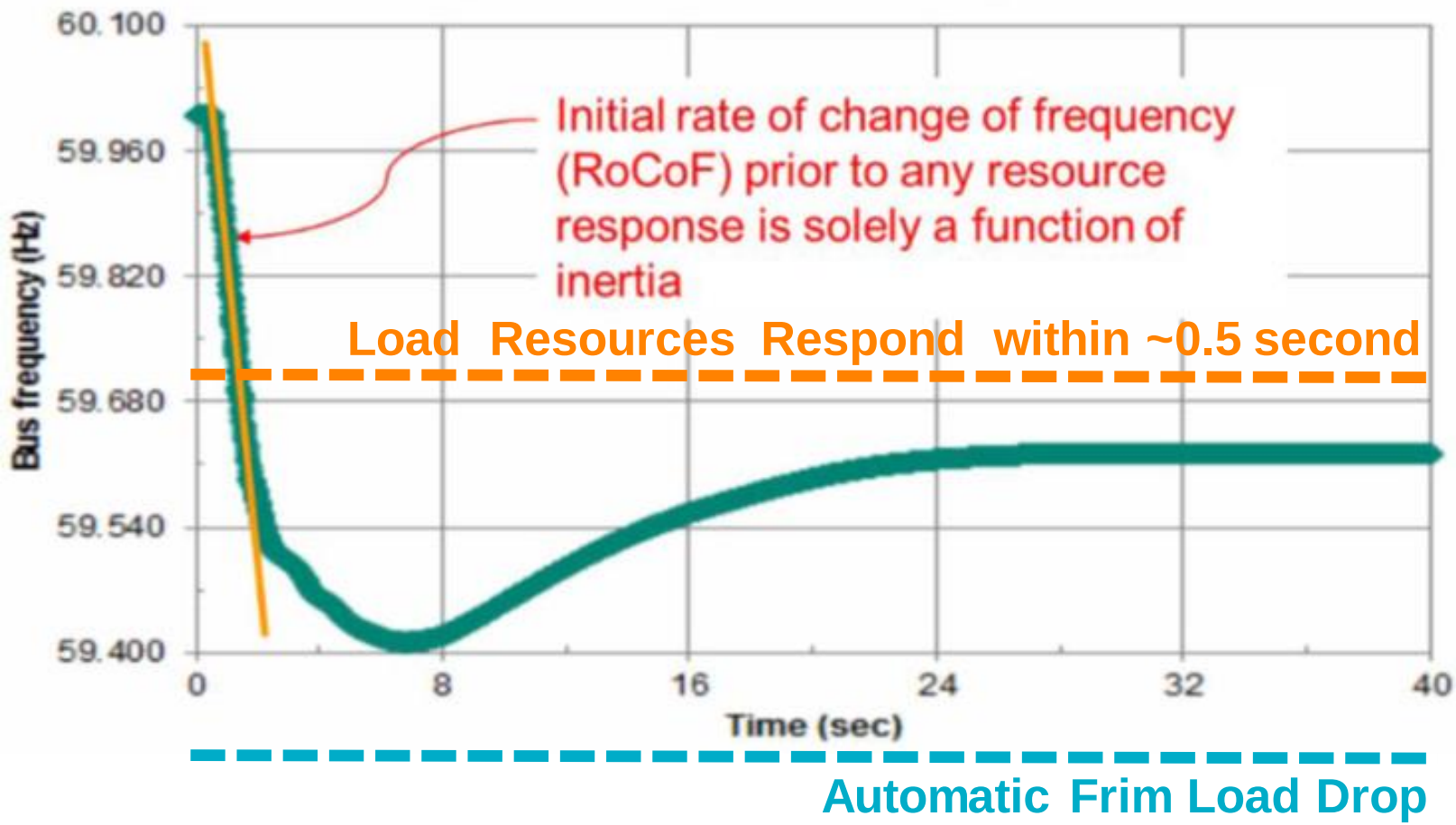
- Unit Commitment
  - Optimized Generators Schedule
  - Focuses on MW



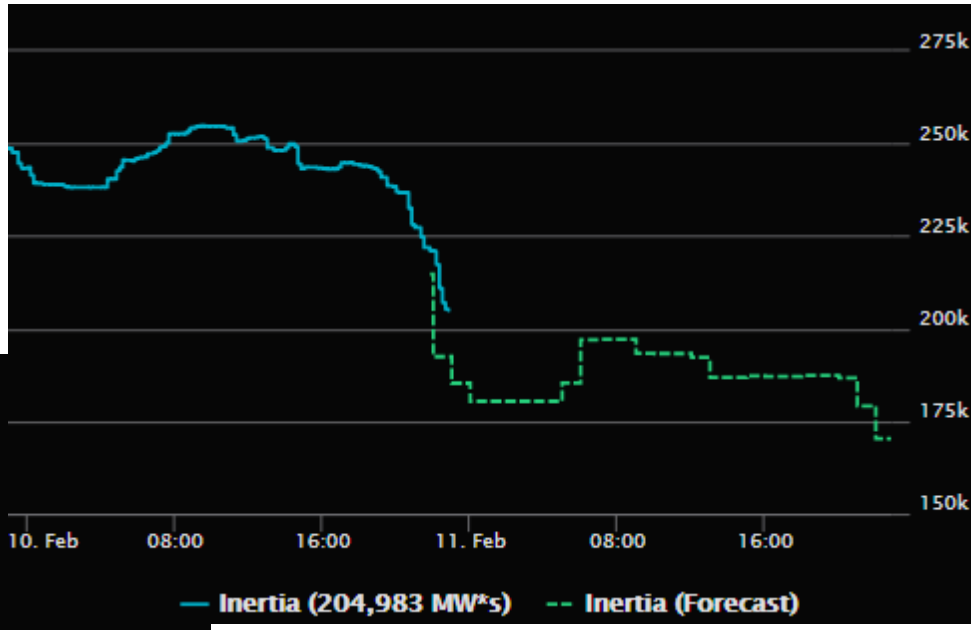
- RPC
  - Optimized Generators and Reactive Devices Schedule and Voltage Set Points
  - Focuses on MVAR

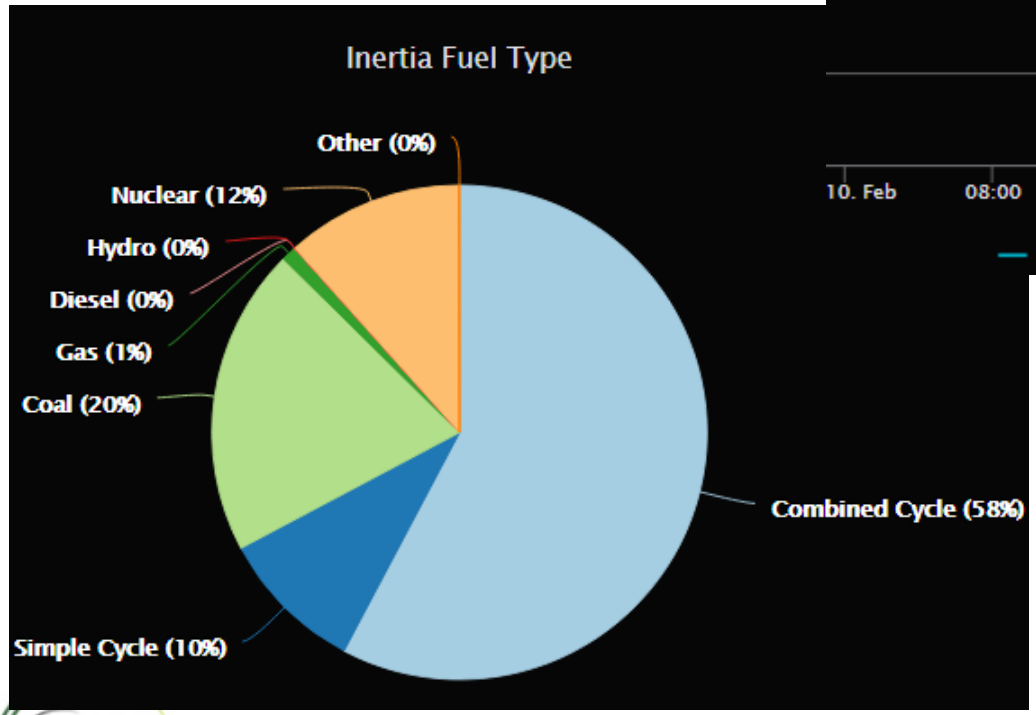


Critical Inertia



Inertia Monitoring





Alex Lee is a Lead Operations Planning Engineer at ERCOT.

Alex has 10 years of experience at ERCOT. In this role, he captures the trend in the utility sector, integrates new technologies, and actively engages with stakeholders to achieve excellence in reliability and economics.

He is enthusiastic about clean technology, data science, and human engineering.

He has a master's degree in Electrical and Computer Engineering from Georgia Institute of Technology and expects to complete the Executive MBA from the University of Texas at Austin in 2020.

PNNL-SA-141135

Pacific Northwest
NATIONAL LABORATORY

PNNL Tools for Advanced Synchrophasor Analysis

Pavel Etingov

Pacific Northwest National Laboratory

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Synchrophasor Projects

1. Open source suite of synchrophasor tools
   - The project objective is to develop and advance applications of phasor measurement units (PMUs) and synchrophasor data for power system planning, modeling, and analysis.
2. Machine Learning for synchrophasor technology
   - The project objective is to develop a framework for PMU big data analysis.

Ongoing projects are supported by the DOE through GMLC program. Some previous work was also funded by BPA through TI program.

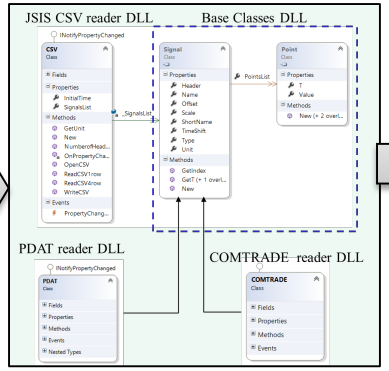
- Project Team
  - Jim Follum
  - Frank Tuffner
  - Heng Wang
  - Xinya Li
  - Jason Hou
  - Urmila Agrawal
  - Huiying Ren
  - Eric Andersen (PM)
  - Pavel Etingov

Open Source Platform for Synchrophasor Analysis

Data Sources

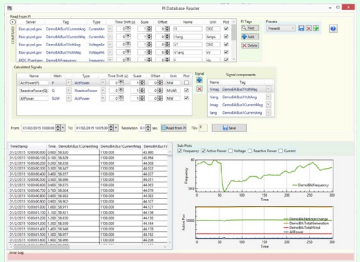
- PI
- Open Historian
- PDAT
- COMTRADE
- CSV

Data Readers

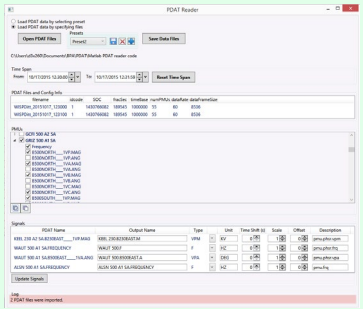


Data Processing

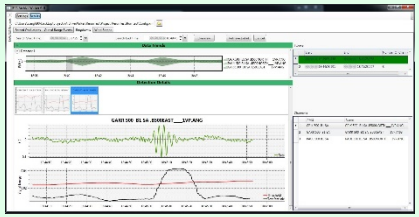
PI Reader



PDAT Reader

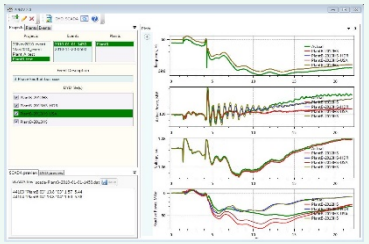


Archive Walker

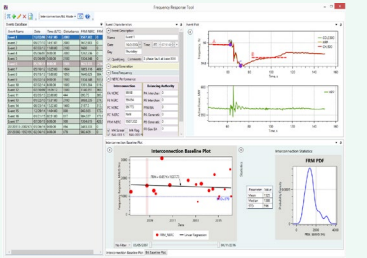


Applications

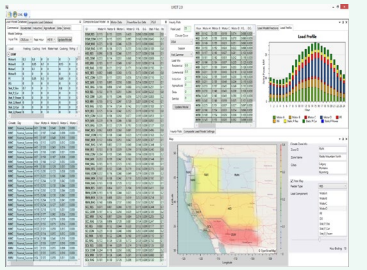
PPMV



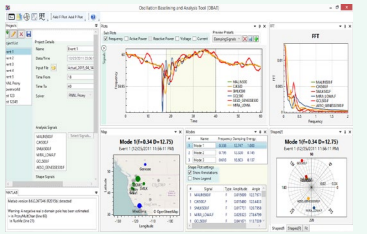
FRAT



LMDT

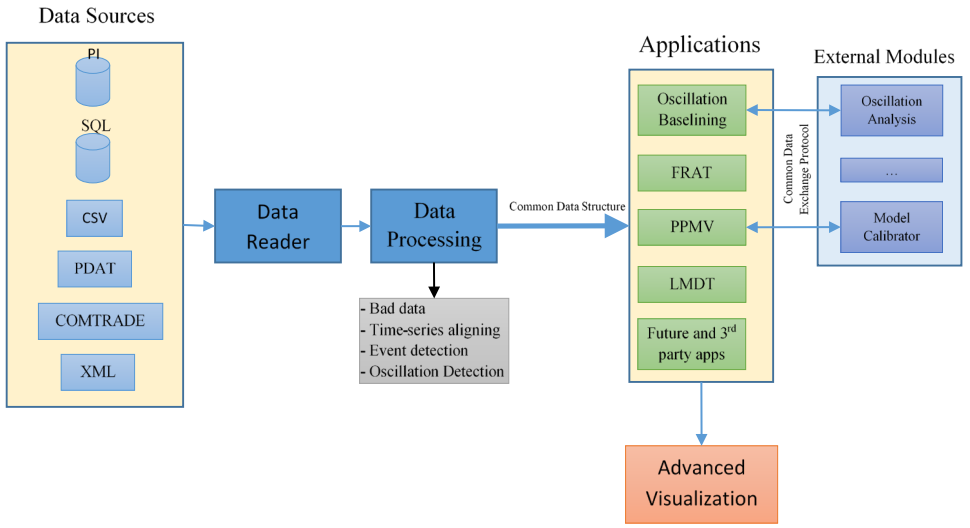


OBAT



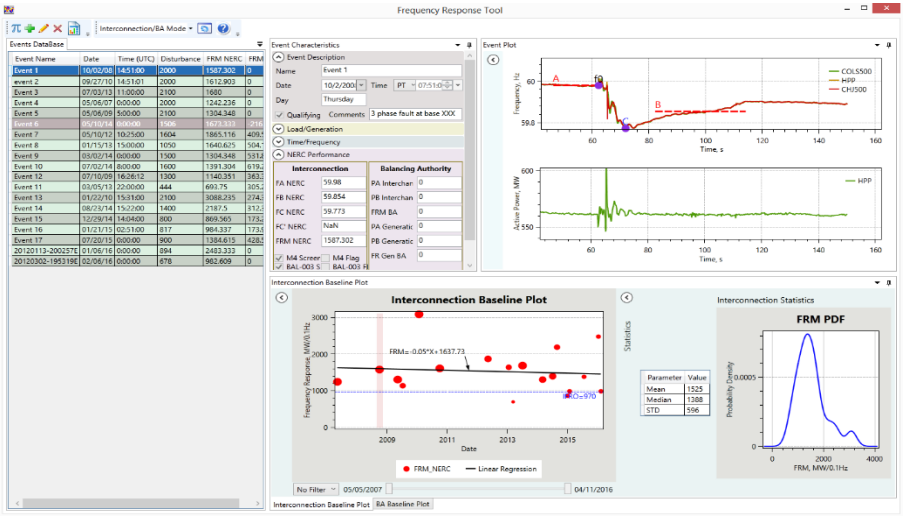
Open Platform for Synchrophasor Applications

- Based on Open Source Components:
  - Extended WPF Toolkit™
  - OxyPlot
  - Math.NET
- Building blocks for future and 3rd party applications.
- Common data structure and data exchange protocols.
- Support external modules/solvers:
  - Oscillation Analysis
  - Model Calibration

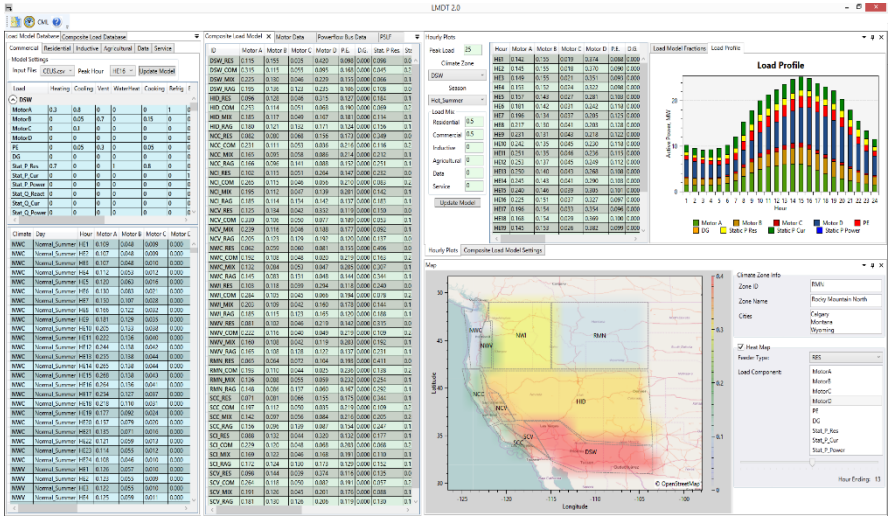


PNNL Tools based on the Open Platform for Engineering Applications

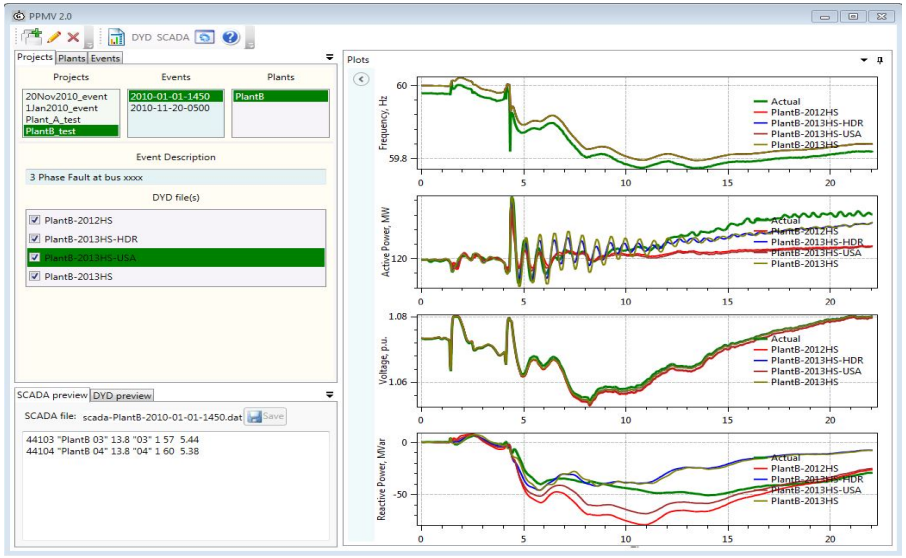
Frequency Response Analysis Tool (FRAT 2.0)



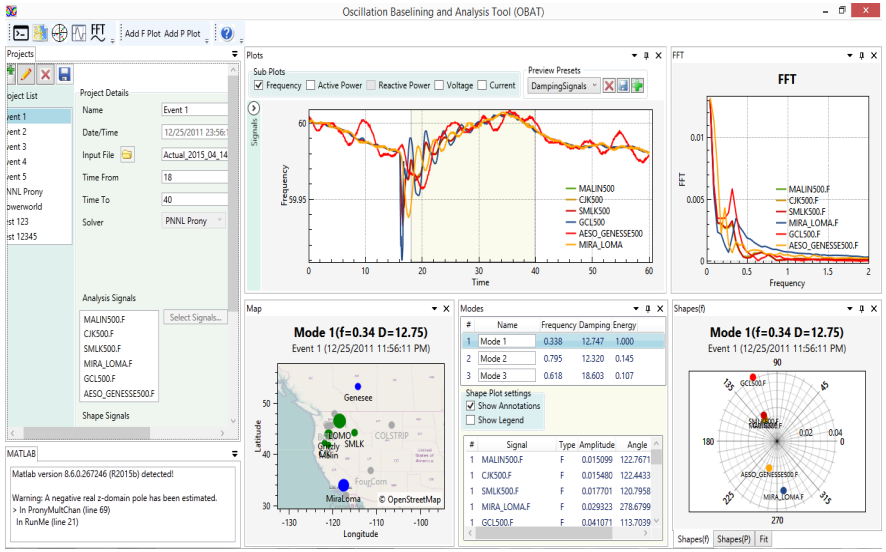
Load model Data Tool (LMDT 2.0)



Power Plant Model Validation Tool (PPMV 2.0)

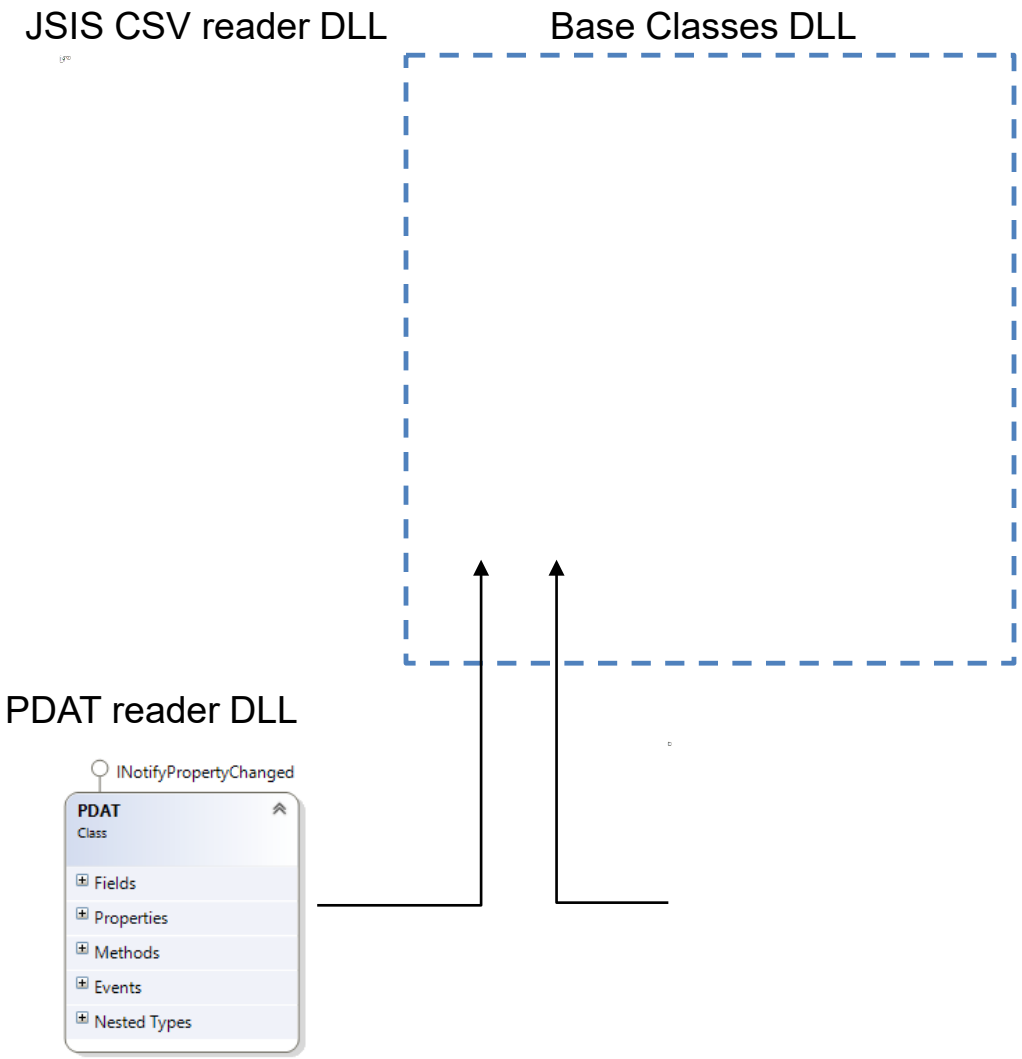


Oscillation Baselining and Analysis Tool (OBAT)



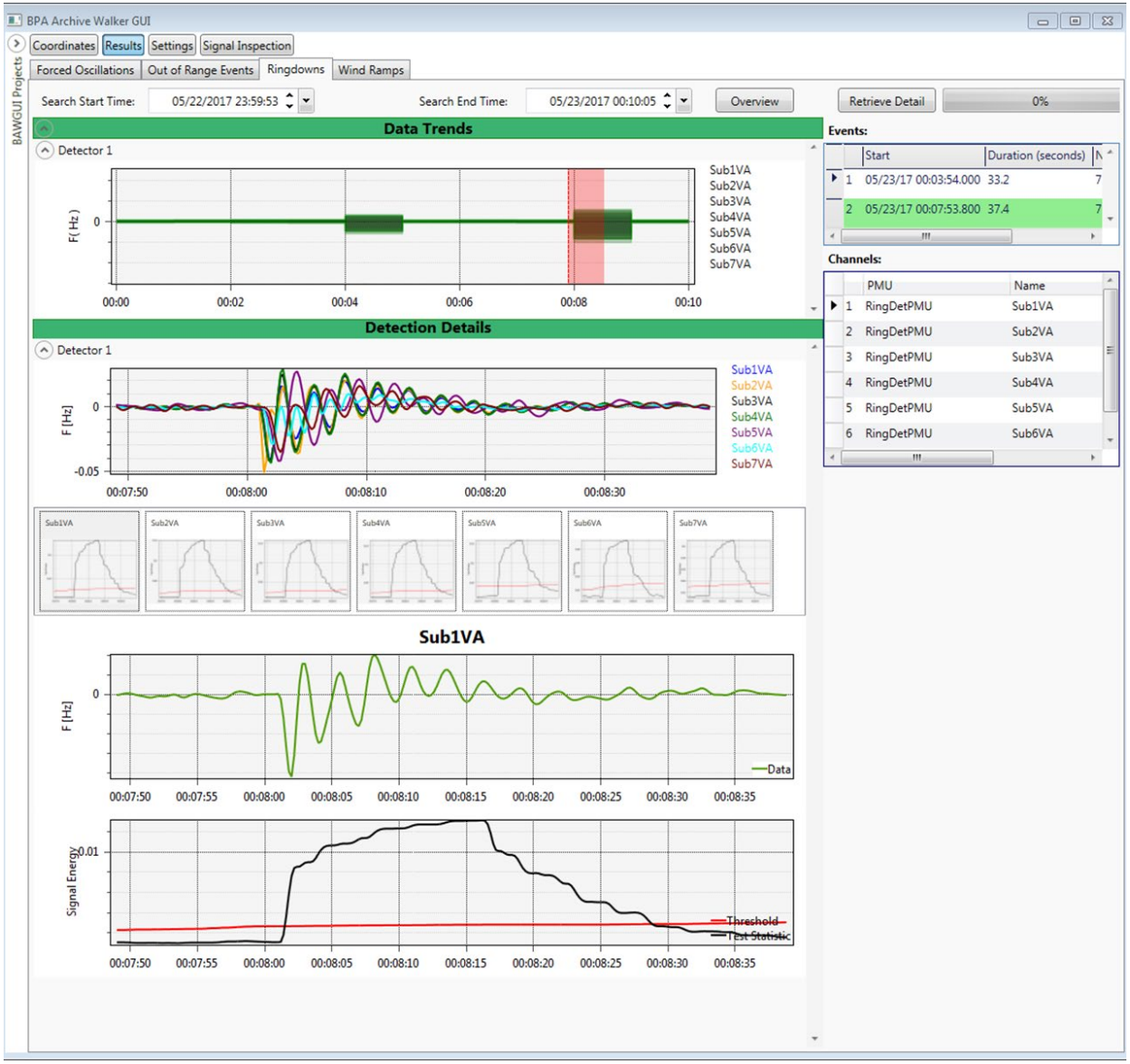
Data readers

- PI database reader
- Open Historian
- JSIS CSV reader
- PDAT reader
- COMTRADE reader
- Archive Walker
  - Open-source tool designed to detect events and identify periods of interest in synchronized power system measurements



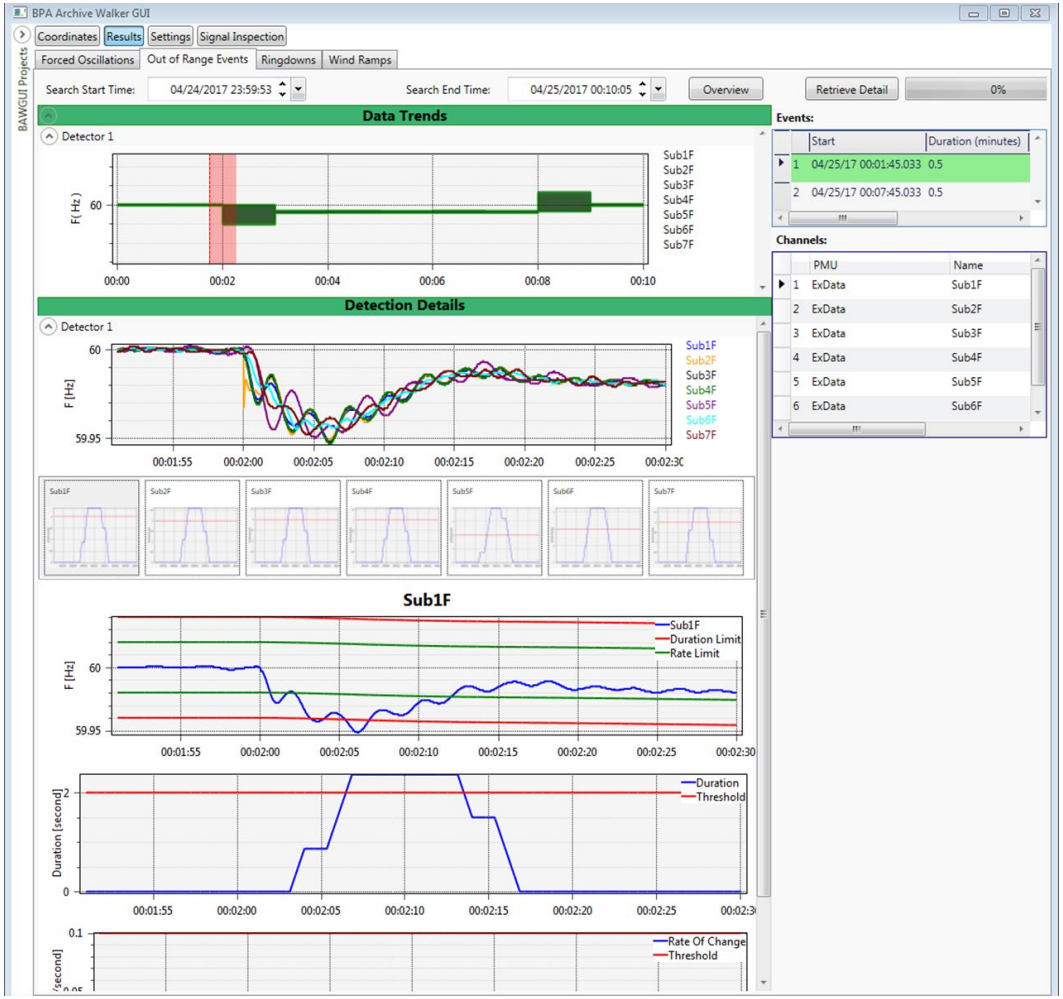
Archive Walker Overview

- New open source tool released in 2018
- PMU data processing
- Event detection
  - Out of range
  - Transient oscillations
  - Forced oscillations
  - Mode meter
  - Wind ramps
- End-users notification via alarms and visualizations



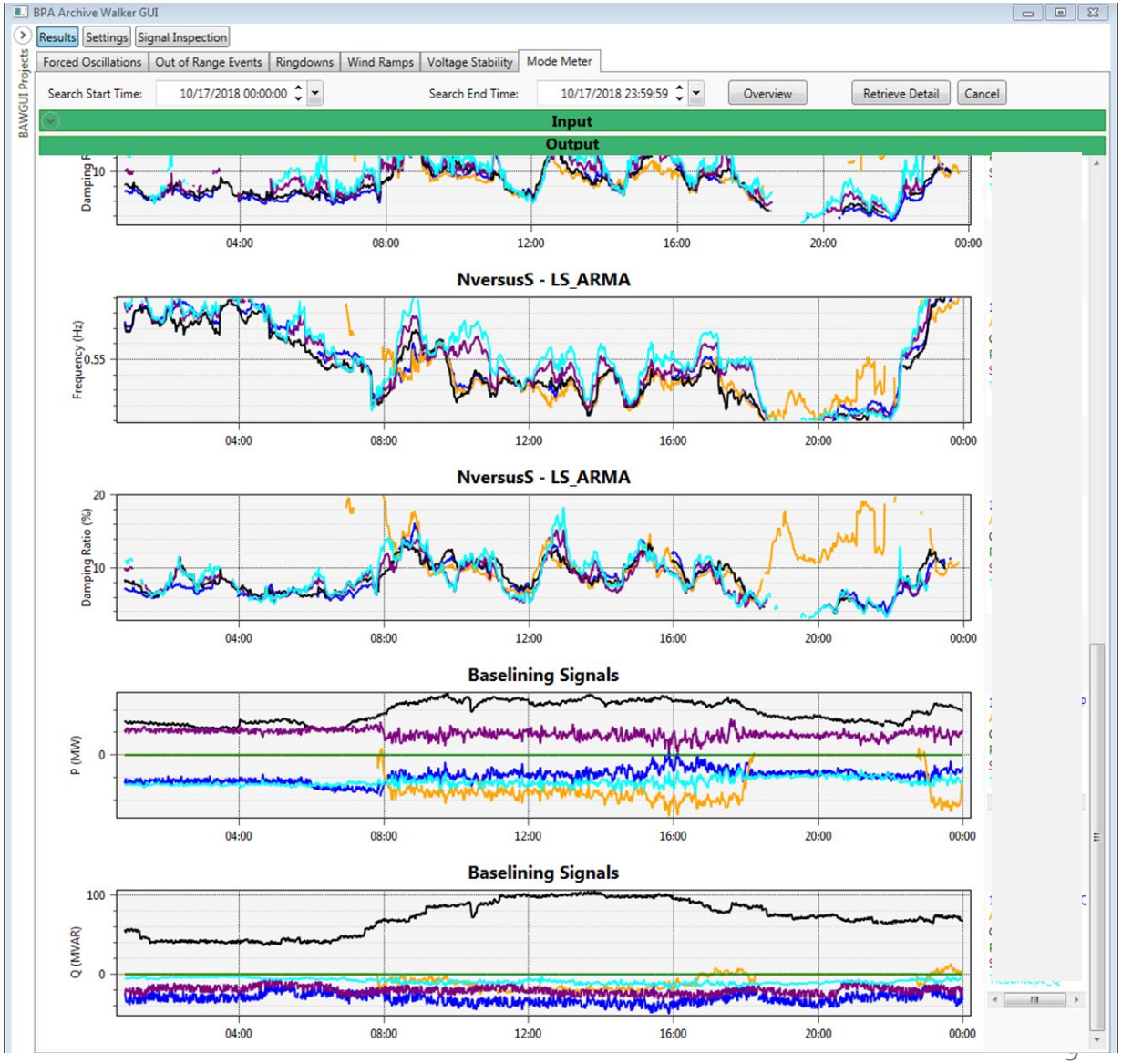
AW Detectors: Out-of-Range

- General detector for sudden changes in frequency, voltage, etc.
- Flexible design captures:
  - Large disturbances over short time scales
  - Small, persistent deviations



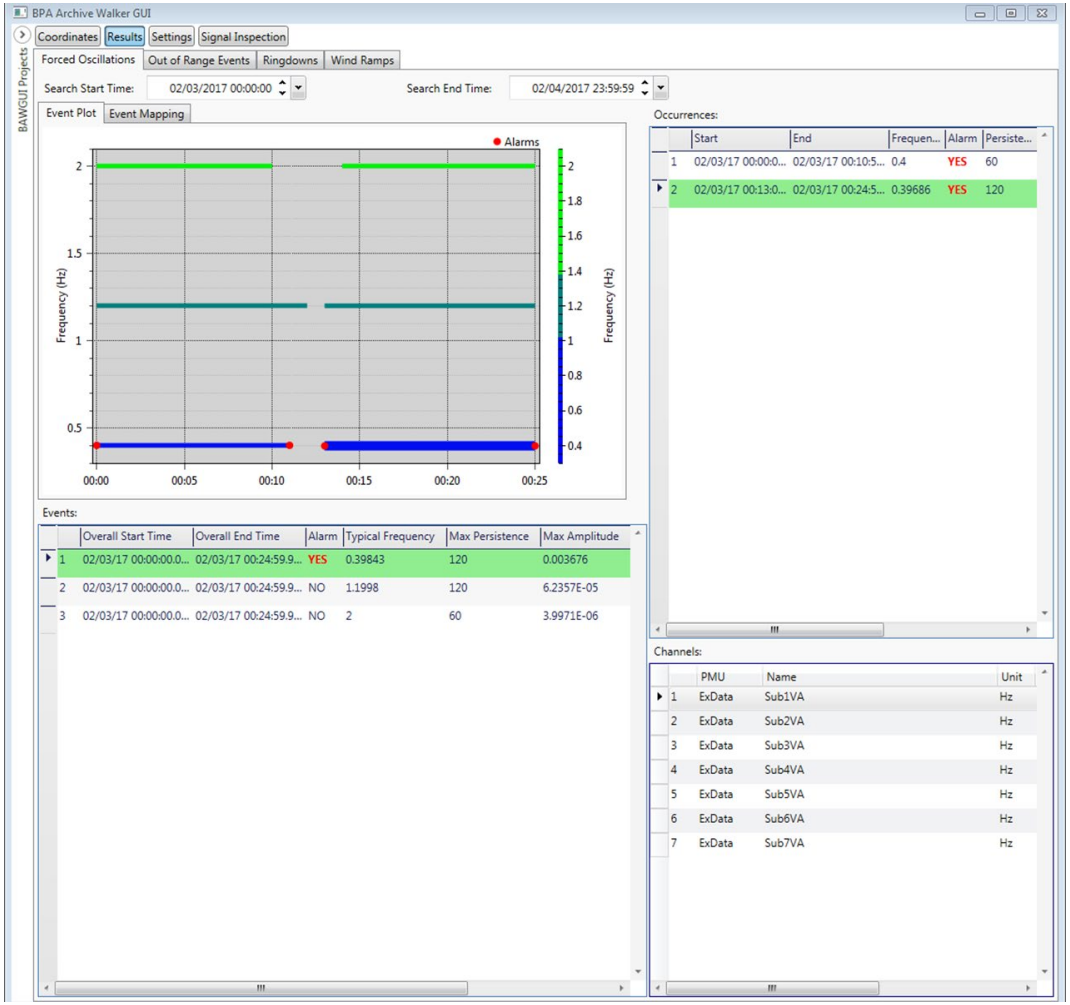
AW Detectors: Mode Meter

- Monitor system's dynamic stability
- Extract signals for baselining
- Advanced algorithms: mitigate bias from forced oscillations and grid disturbances



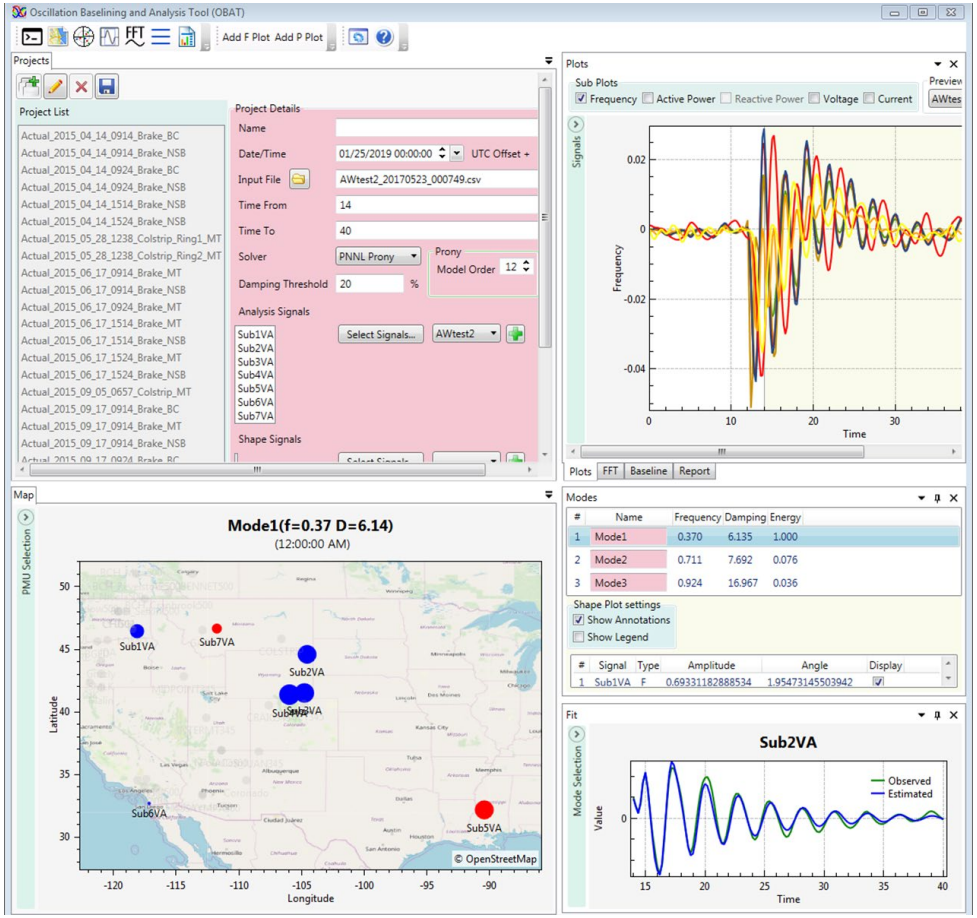
AW Detectors: Forced Oscillations

- Forced oscillations
  - Can be symptomatic of malfunctioning equipment
  - May create large oscillations across grid
- Employs two complimentary detection algorithms
  - periodogram-based
  - spectral coherence



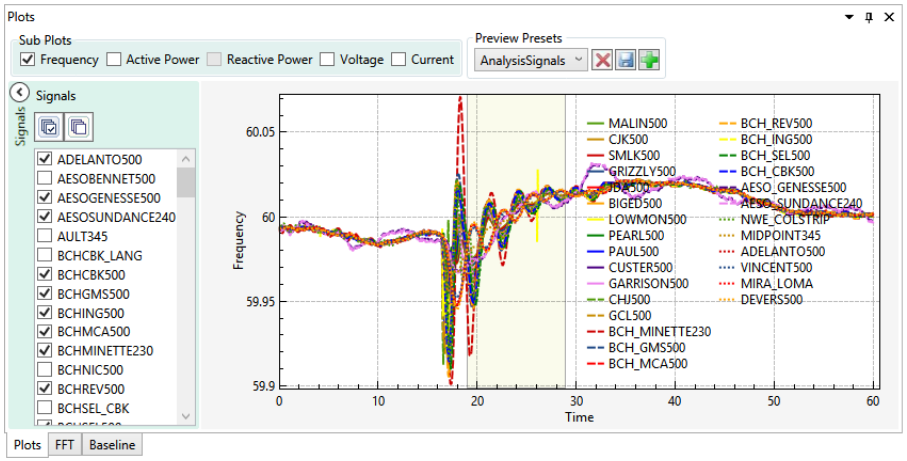
AW Detectors: Transient Oscillations & Integration with OBAT

- Detects oscillations occurring after large disturbances
- OBAT is used for Post-event analysis
- Implemented oscillation analysis methods:
  - Prony
  - VARPRO
  - Matrix Pencil
- Database of events
- Event baselining
- Advanced visualization
- Automatic reporting

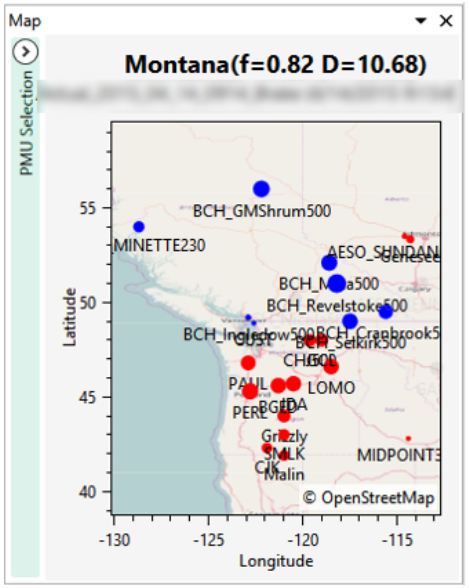


OBAT - Visualization

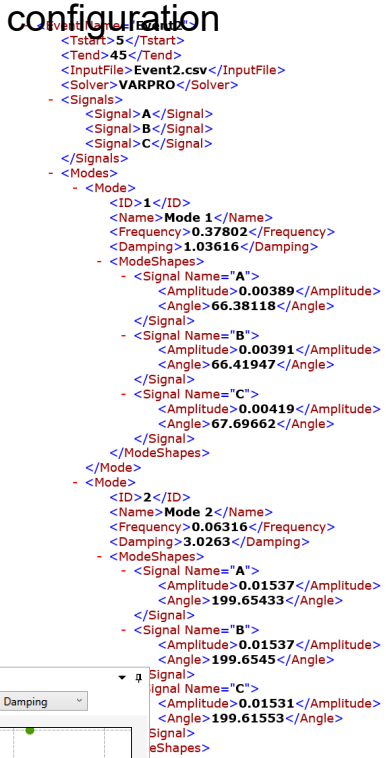
Event plot



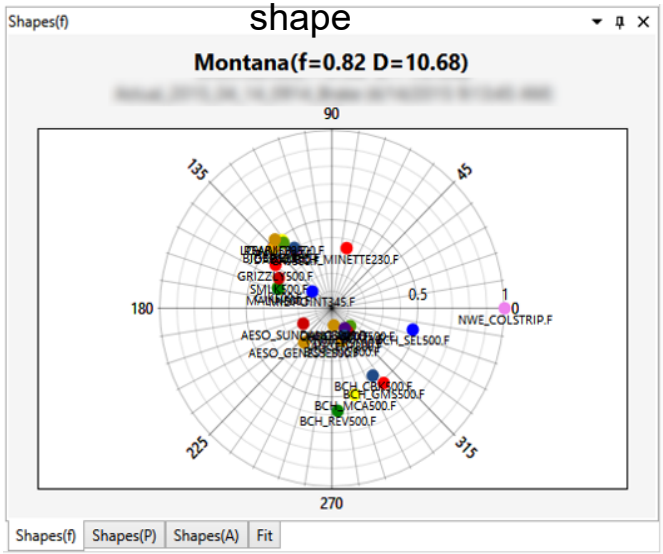
Map



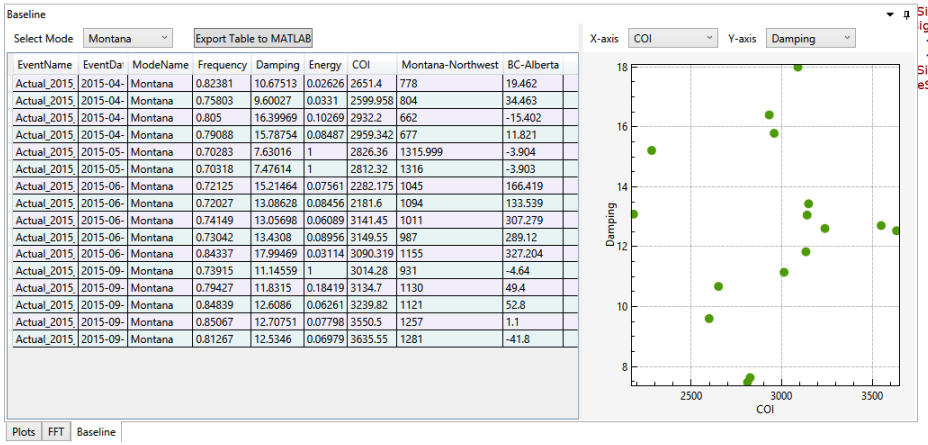
XML-based configuration



Mode shape



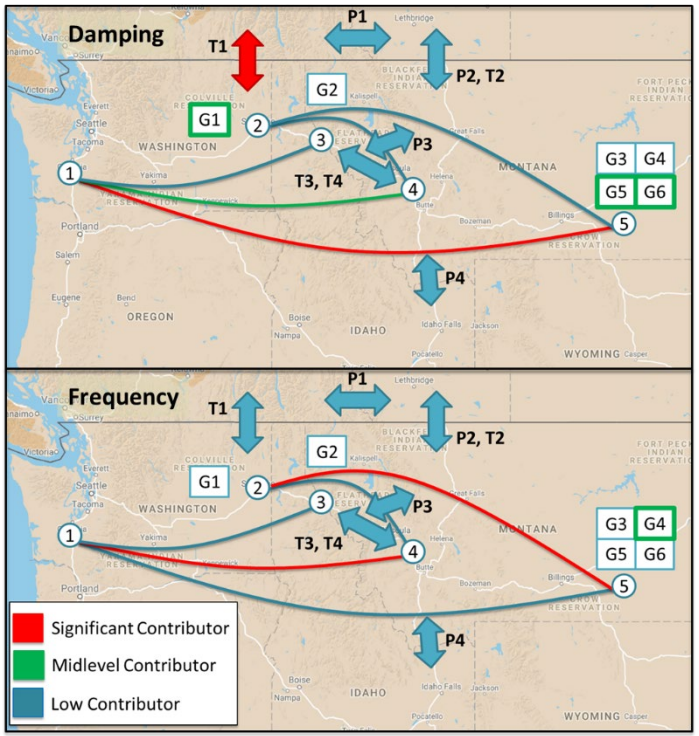
Baselining

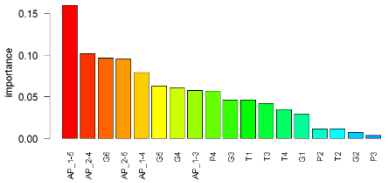


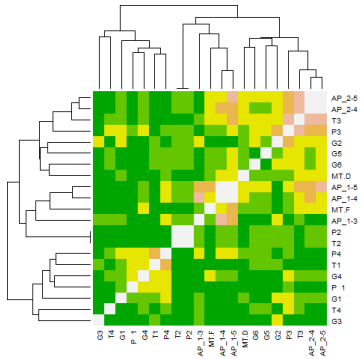
EventName	EventDa	ModeName	Frequency	Damping	Energy	COI	Montana-Northwest	BC-Alberta
Actual_2015_	2015-04-	Montana	0.82381	10.67513	0.02626	2651.4	778	19.462
Actual_2015_	2015-04-	Montana	0.75803	9.60027	0.0331	2599.958	804	34.463
Actual_2015_	2015-04-	Montana	0.805	16.39969	0.10269	2932.2	662	-15.402
Actual_2015_	2015-04-	Montana	0.79088	15.78754	0.08487	2959.342	677	11.821
Actual_2015_	2015-05-	Montana	0.70283	7.63016	1	2826.36	1315.999	-3.904
Actual_2015_	2015-05-	Montana	0.70318	7.47614	1	2812.32	1316	-3.903
Actual_2015_	2015-06-	Montana	0.72125	15.21464	0.07561	2282.175	1045	166.419
Actual_2015_	2015-06-	Montana	0.72027	13.08628	0.08456	2181.6	1094	133.539
Actual_2015_	2015-06-	Montana	0.74149	13.05698	0.06089	3141.45	1011	307.279
Actual_2015_	2015-06-	Montana	0.73042	13.4308	0.08956	3149.55	987	289.12
Actual_2015_	2015-06-	Montana	0.84337	17.99469	0.03114	3090.319	1155	327.204
Actual_2015_	2015-09-	Montana	0.73915	11.14559	1	3014.28	931	-4.64
Actual_2015_	2015-09-	Montana	0.79427	11.8315	0.18419	3134.7	1130	49.4
Actual_2015_	2015-09-	Montana	0.84839	12.6086	0.06261	3239.82	1121	52.8
Actual_2015_	2015-09-	Montana	0.85067	12.70751	0.07798	3550.5	1257	1.1
Actual_2015_	2015-09-	Montana	0.81267	12.5346	0.06979	3635.55	1281	-41.8

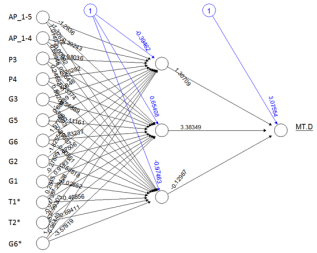
Oscillation Baselining Concept

- Identify factors driving system oscillation modes
- Utilizes System Conditions (power flows, generation, angle pairs)
- Applies a comprehensive set of statistical analysis approaches:
  - Cross-Correlation Analysis
  - Principal Component Analysis (PCA)
  - Analysis of Variance (ANOVA)
  - Classification and Regression Tree (CART)
  - Support Vector Machine (SVM)
  - Artificial Neural Network (ANN)
- Classifies the dominant, secondary, and trivial system condition and control factors



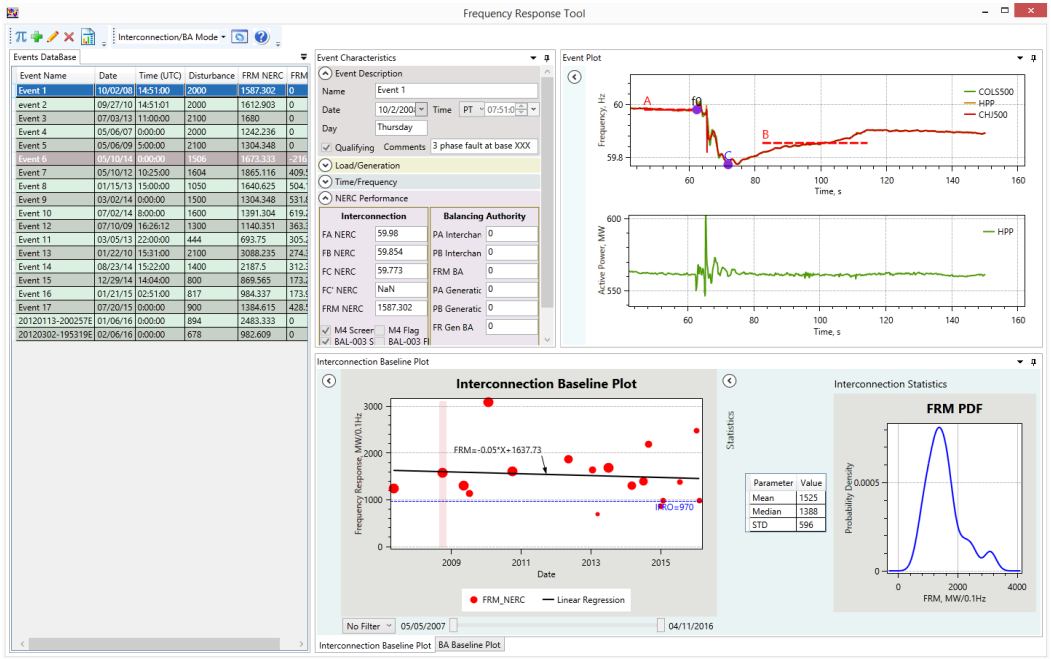




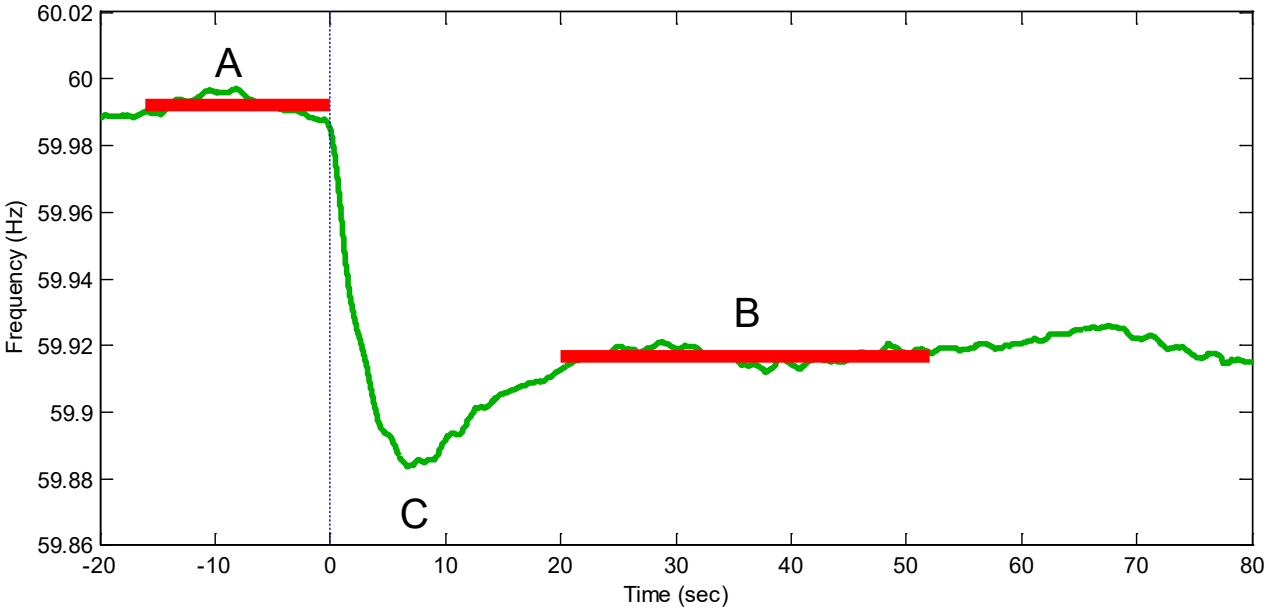


Frequency Response Analysis Tool (FRAT)

- Developed under NERC and BPA guidance.
- Frequency response monitoring:
  - Interconnection
    - Balancing Authority
      - Power Plant
- Calculates NERC FRM using PMU and SCADA measurements according to BAL-003 standard.
- Compliance reporting.
- Baselining frequency response for interconnection and BA.
- Statistical Analysis.
- Advanced visualization.



NERC-BAL-003-1 Reliability Standard

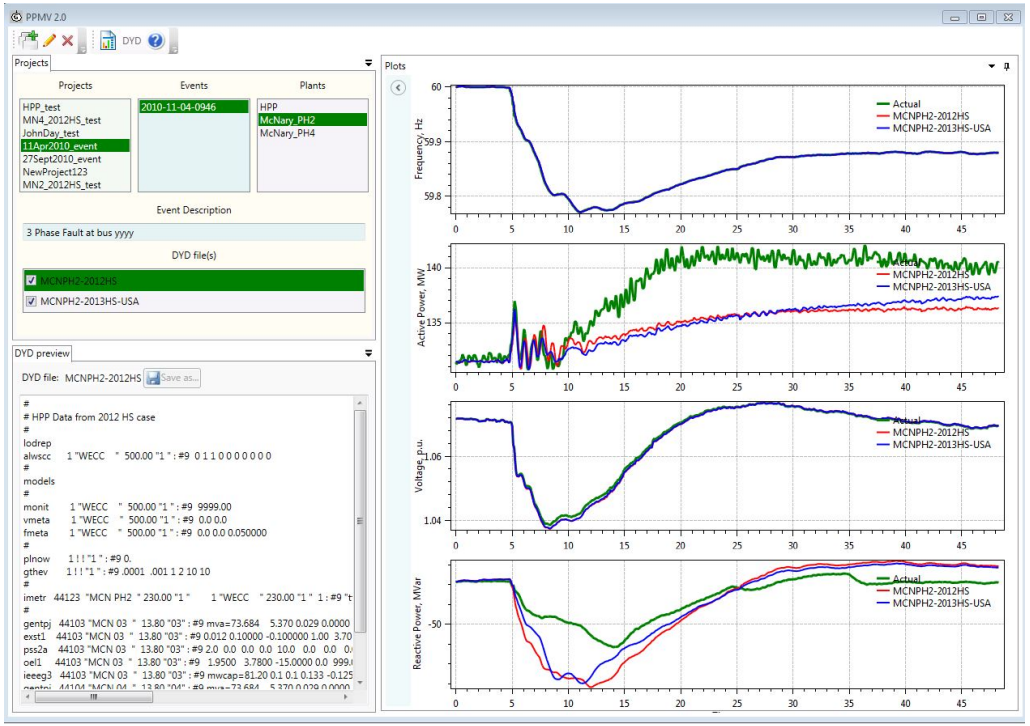


F_A = pre-disturbance frequency (average from -16 to 0 sec)
F_B = settling frequency (average from 20 to 52 sec)
F_C = minimum (nadir) frequency

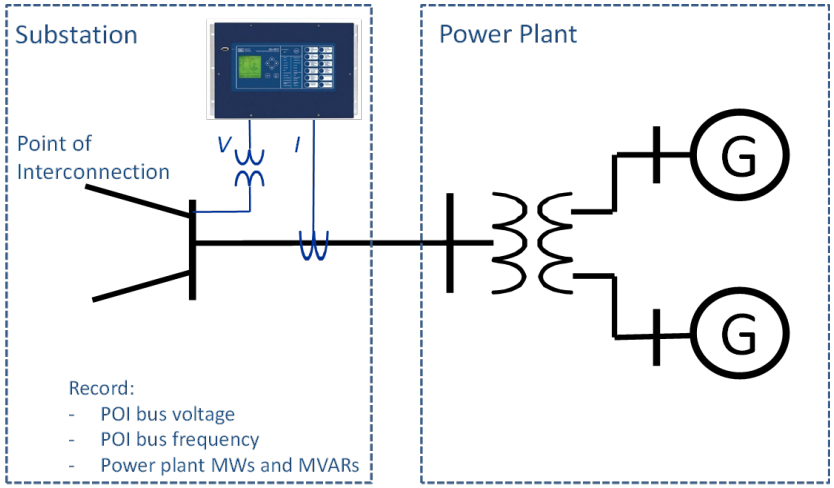
NERC FRM: Frequency difference between Point A and Point B

Power Plant Model Validation Tool (PPMV)

- Supports GE PSLF and Siemens/PTI PSS®E Play-In function for generator model validation.
- Maintains the database of model validation studies (projects).
- Maintains the database of the historic events.
- Maintains the database of the power plants.
- Advanced visualization capabilities.
- Automatically generates reports.
- Performs sensitivity analysis
- Supports interface to external model calibration modules.

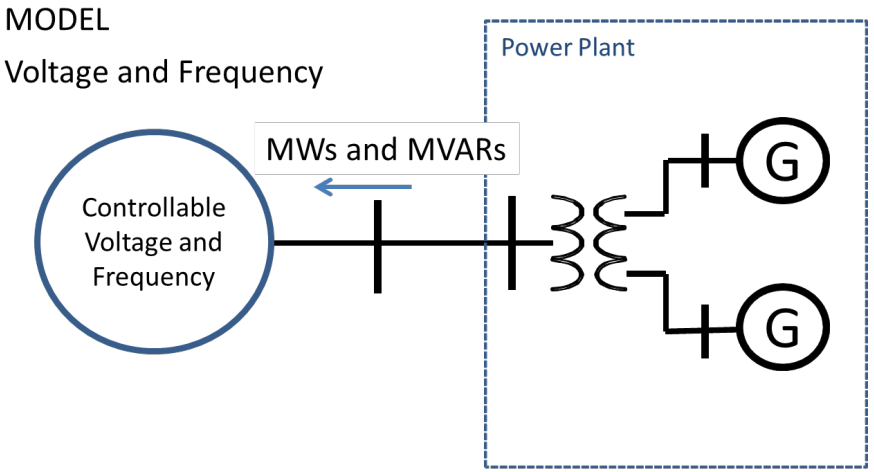


Disturbance-Based Model Validation



PMU needs to be placed at Power Plant POI

Disturbance play-in capabilities available through all major power system analysis packages (e.g., PSLF, PSSE, PowerWorld, TSAT)



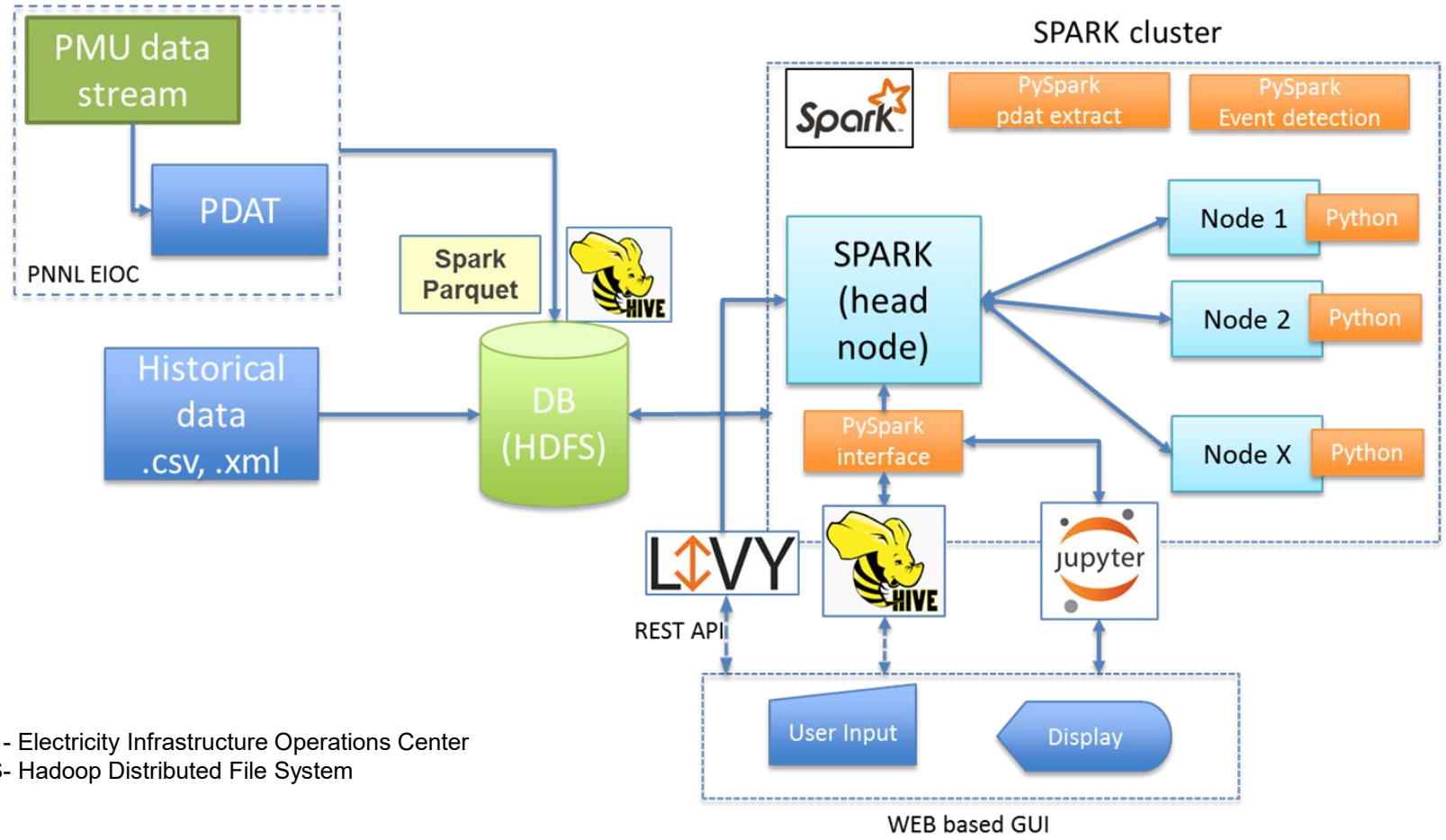
PNNL cloud infrastructure

- PNNL cloud is based on OpenStack (a free and open-source software platform for cloud computing)
- Cloudera Apache Hadoop Distribution:
- Apache Spark (an open source cluster computing framework)
- Apache Hive (a data warehouse infrastructure built on top of Hadoop for providing data summarization, query, and analysis)
- HBase (an open source, non-relational, distributed database)

Apache Spark

- Large scale parallel data processing framework
- Extremely powerful (up to 100x faster than Hadoop)
- Large datasets distributed across multiple nodes within a computer cluster
- Support real time data stream
- Built-in Machine Learning library
- Support different languages (Scala, Java, Python, R)
- Support different data sources (SQL, Hive, HBase, Cassandra, Oracle, etc.)
- Open source and free
- Available through public cloud services (Amazon AWS, Microsoft Azure, IBM, etc.) and through new PNNL institutional cloud system.

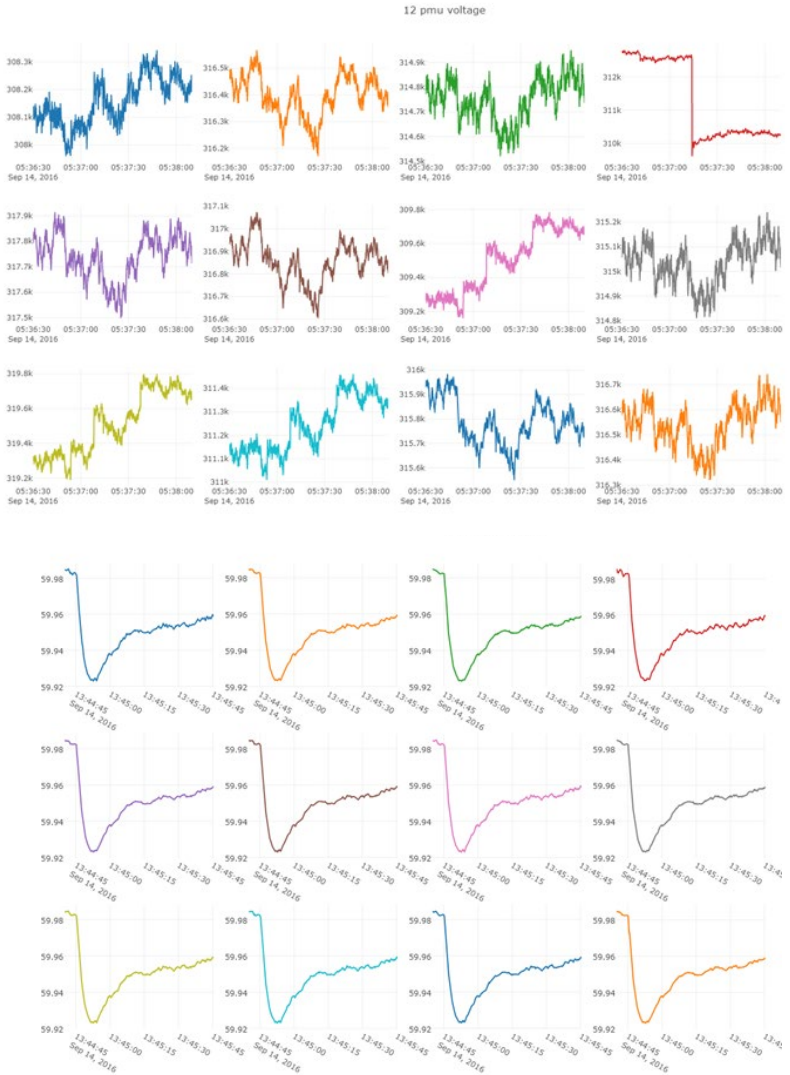
Cloud based ML-PMU Framework



EIOC - Electricity Infrastructure Operations Center
HDFS- Hadoop Distributed File System

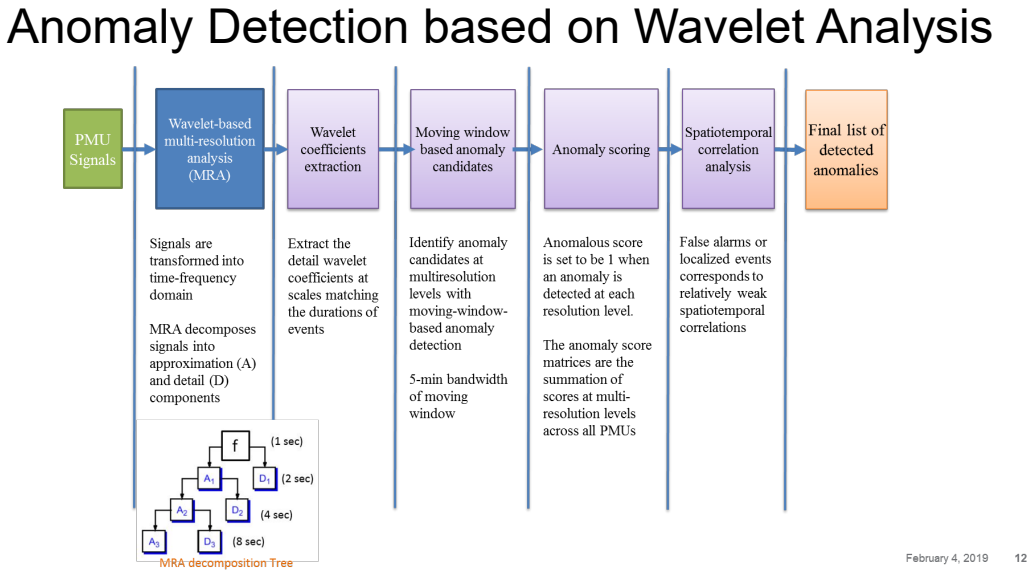
Event detection

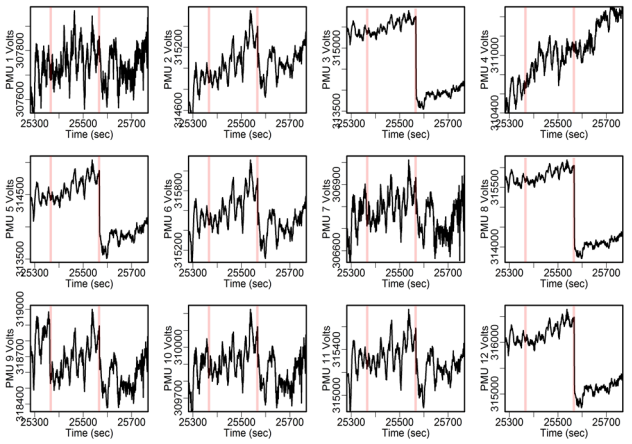
- User specified
  - Delta frequency
  - Event duration
- Cross validation signal checks to avoid false alarms
- Spark usage significantly increases the computational throughput of the application
- Processing of 1 day takes about 5-7 minutes (processing the same dataset using a PC takes about 1 hour)



ML methods under development

- Methodologies for both online and offline anomaly detection have been developed
- Python (PySpark) modules are under development
  - PDAT data extraction
  - Event detection (based on thresholds)
  - Wavelet anomaly detection
  - Angle pairs baselining
  - Dynamic nonlinear model and Kalman filter based online detection framework





Conclusions and Future Plans

- Industry-grade, open-source power system analytical tools and software modules have been developed.
- Developed tools have been used by many organizations and electrical utilities including: NERC, WECC, BPA, PG&E, SCE, SPP, BC Hydro, PacifiCorp, CAISO, SDG&E, and many more.
- Spark cluster for ML and PMU (big data) analysis was deployed. It is based on the PNNL institution cloud system.
- Continue enhancement of the open source tools and developing new software tools and modules.
- New DOE TCF project to intergrade PNNL tools into V&R real-time platform started in 2019.

Additional information

Online Resources

- FRAT: https://svn.pnl.gov/FRTool
- PPMV: https://svn.pnl.gov/PPMV
- LMDT: https://svn.pnl.gov/LoadTool
- OBAT: https://svn.pnl.gov/OBAT
- Archive Walker: https://github.com/pnnl/archive_walker

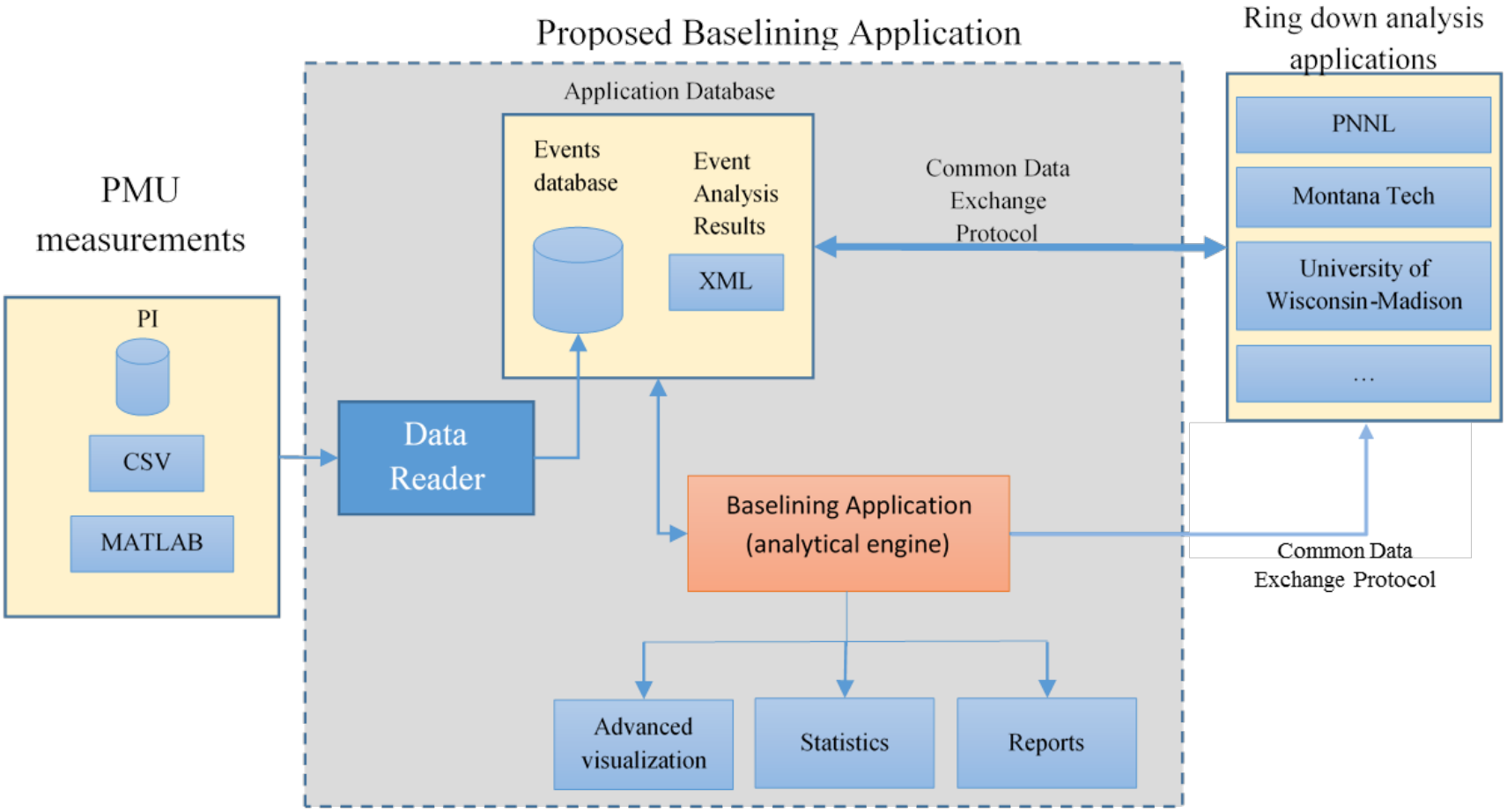
- Pavel.Etingov@pnnl.gov
- James.Follum@pnnl.gov
- Francis.Tuffner@pnnl.gov

Selected publications

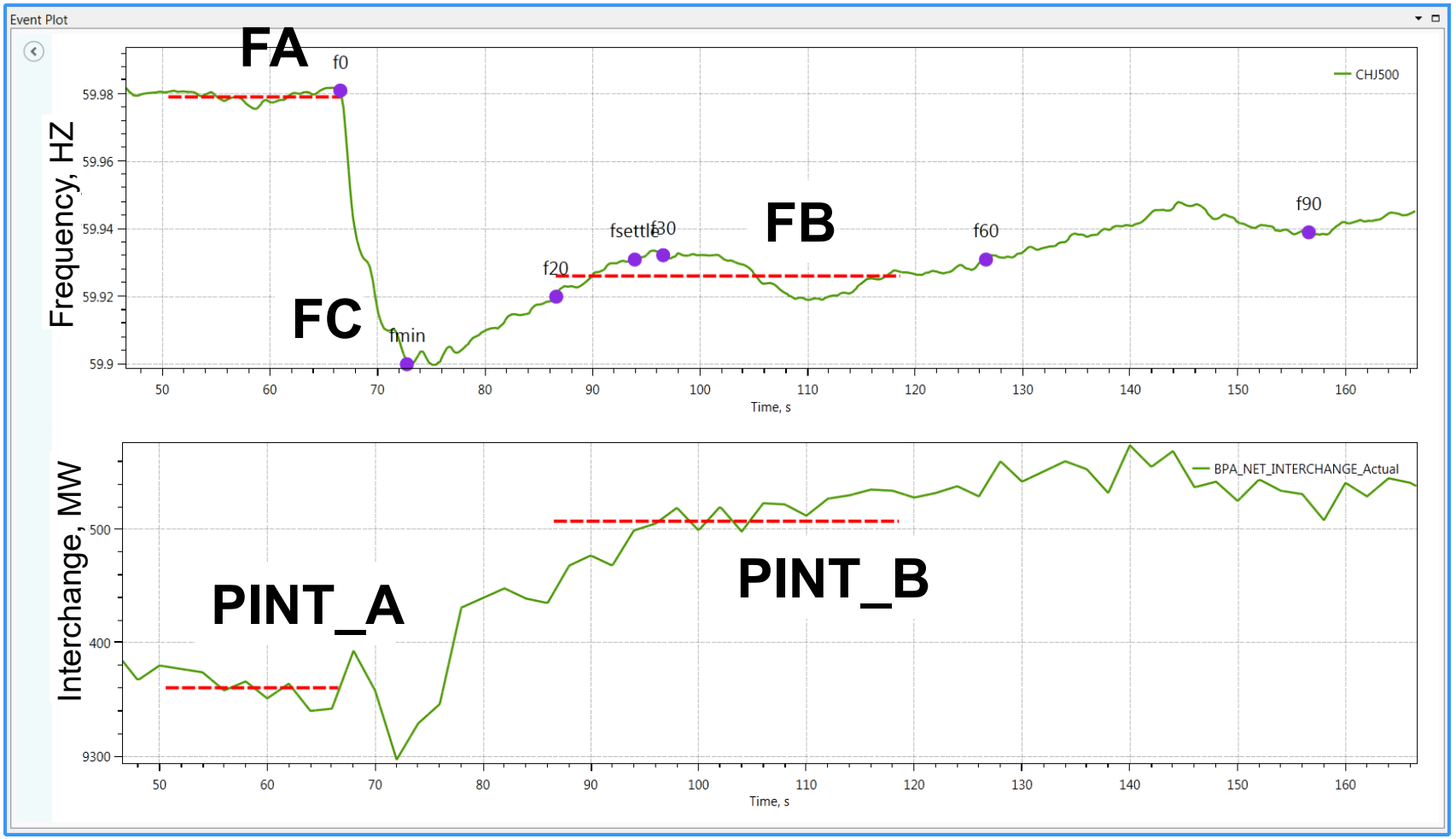
- Etingov P V, Tuffner F K, Follum J D, Li X, Wang H, Diao R, Zhang Y, Hou Z, Liu Y, Kosterev D, Yang S, Matthews G. "Open-Source Suite for Advanced Synchrophasor Analysis", IEEE PES Transmission and Distribution Conference & Exposition, April 15-19, 2018, Denver, CO.
- Hou Z ,Follum J D, Etingov P V,Tuffner F K,Kosterev D ,Matthews G H, "Machine Learning of Factors Influencing Damping and Frequency of Dominant Inter-area Modes in the WECC Interconnect", PMAPS conference, Boise, ID, June 24-26
- H. Ren, Z. Hou and P. Etingov, "Online Anomaly Detection Using Machine Learning and HPC for Power System Synchrophasor Measurements," 2018 IEEE International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), Boise, ID, 2018.
- R. Huang, R Diao, Y Li, J Sanchez-Gasca, Z. Huang, B. Thomas, P. Etingov, S. Kincic, S. Wang, R. Fan, G. Matthews, D. Kosterev, S. Yang. "Calibrating Parameters of Power System Stability Models using Advanced Ensemble Kalman Filter," in IEEE Transactions on Power Systems, vol. PP, no. 99, pp. 1-6., 2017
- Etingov PV, Z Hou, H Wang, H Ren, DV Zarzhitsky, JA De Chalendar, D Kosterev, AJ Faris, and S Yang. 2017. "Cloud Based Analytical Framework for Synchrophasor Data Analysis." In CIGRE US National Committee 2017 Grid of the Future Symposium, Cleveland, Ohio, October 22-25, 2017

Backup slides

OBAT Conceptual Design

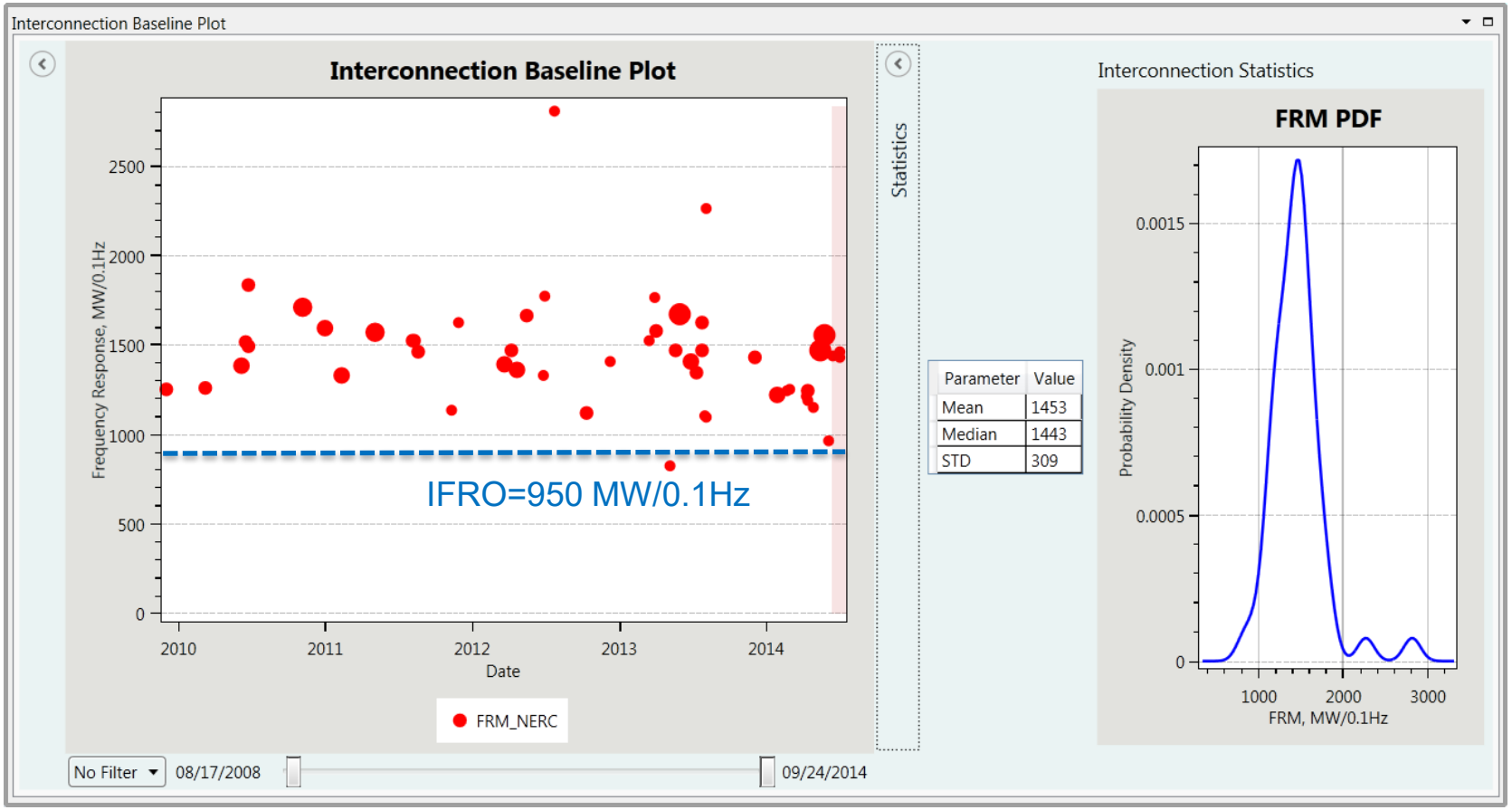


BA Frequency Response Measure Calculation

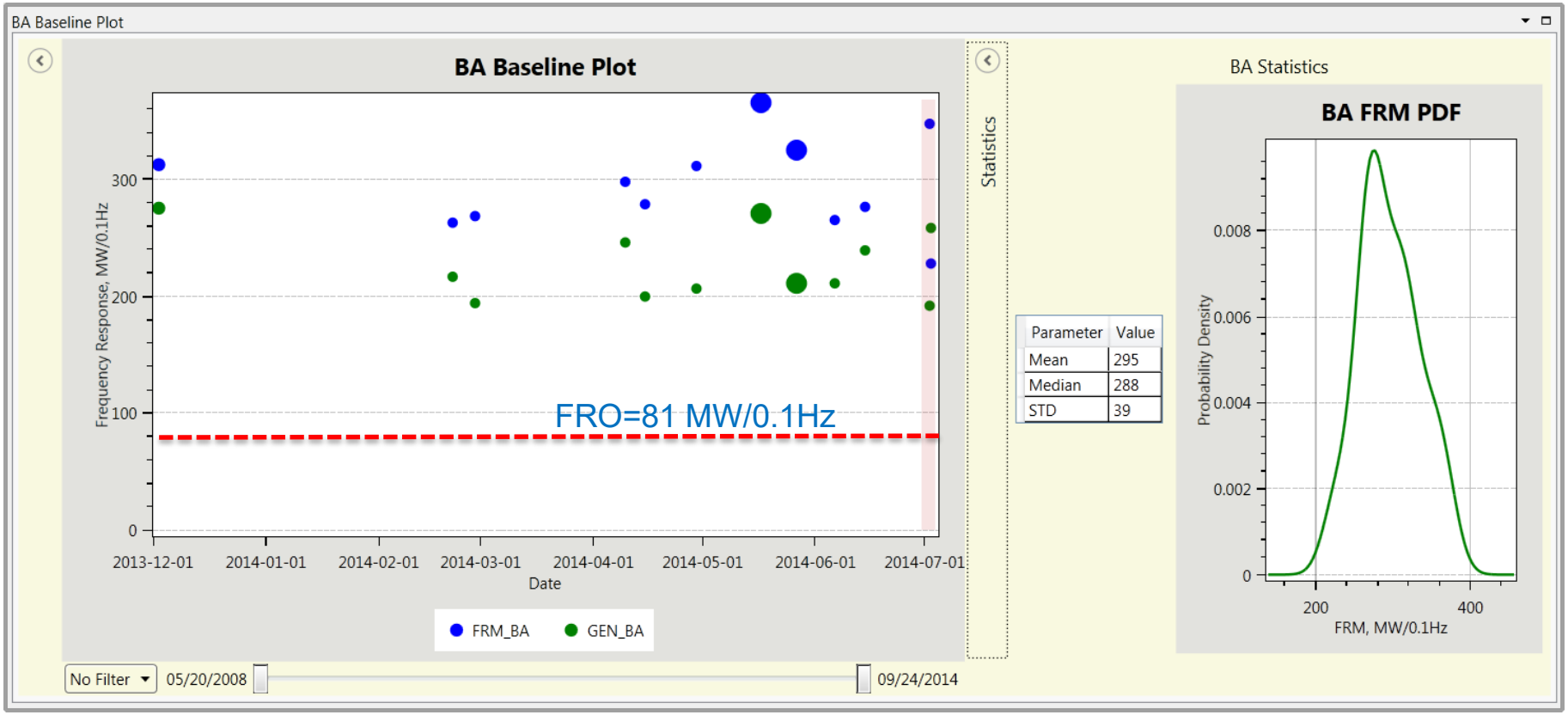


BA FRM = (PINT_B – PINT_A + BA GEN LOSS) / (FA – FB)

Western Interconnection Performance



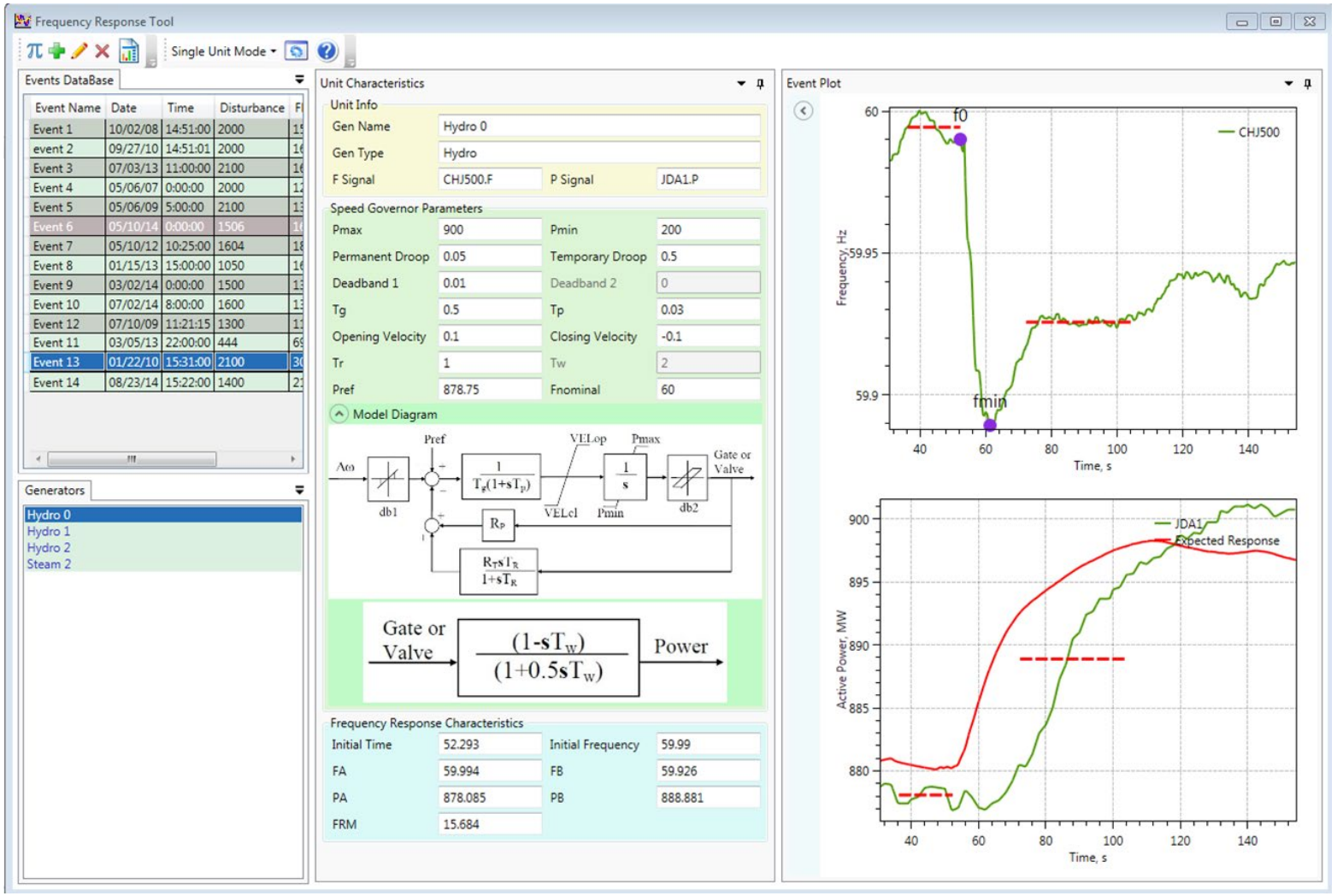
Balancing Authority Performance



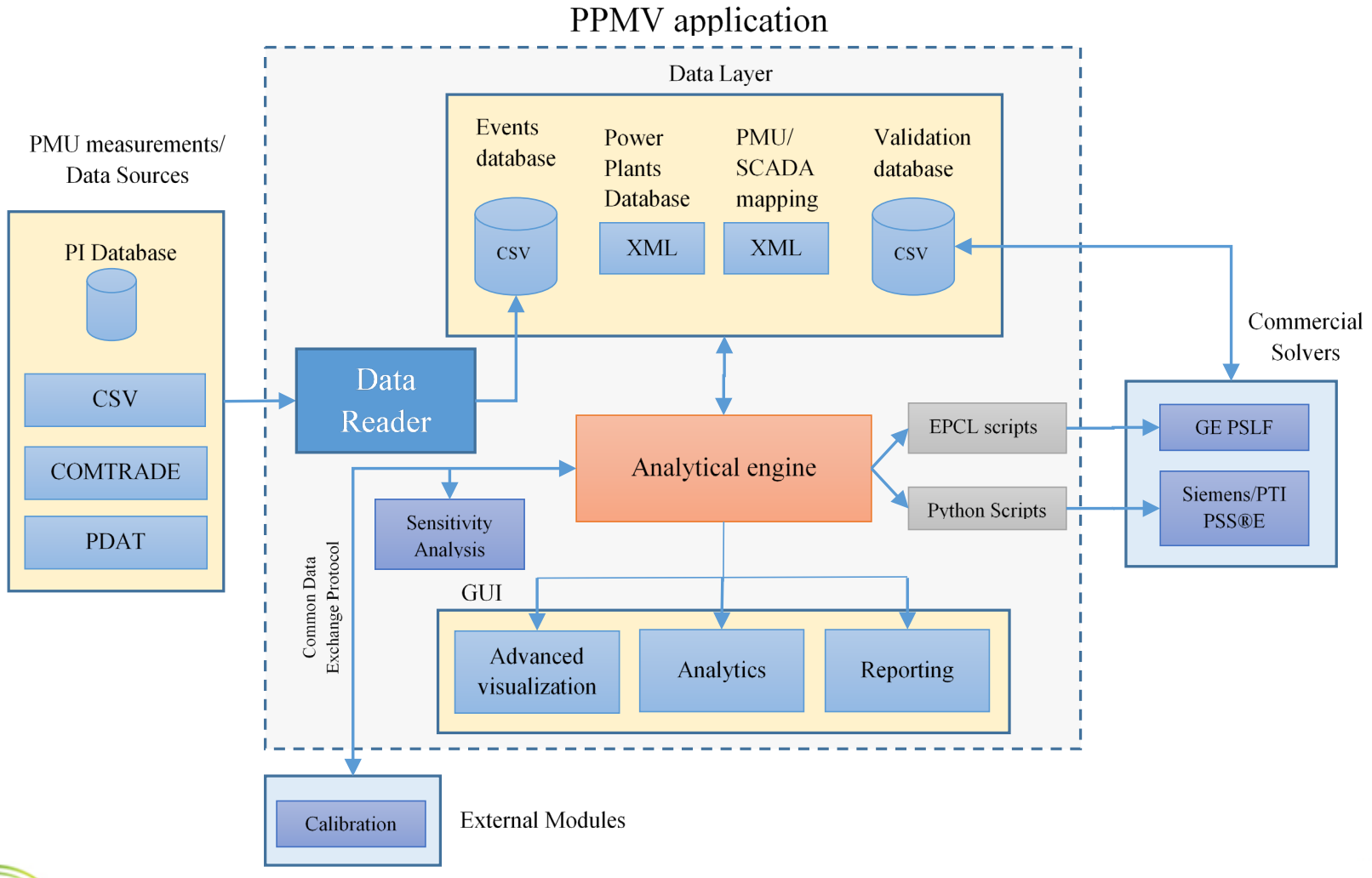
Interchange response is measured for compliance with NERC BAL-003-1

Generation response is calculated to determine how much frequency response to acquire

Power Plant Performance

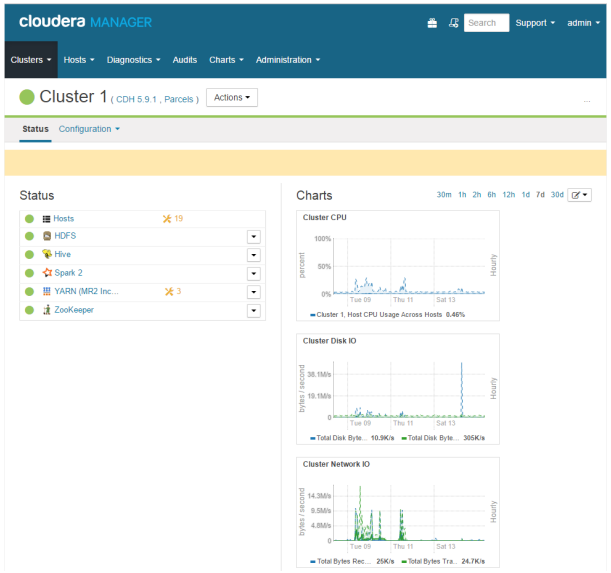


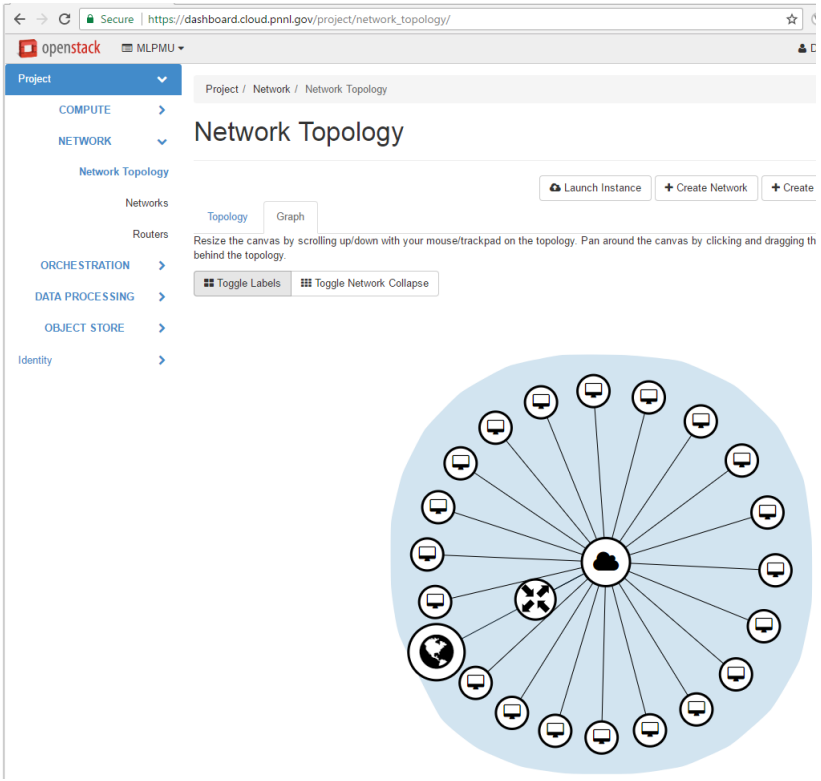
PPMV Tool Conceptual Design



Spark research cluster based on PNNL cloud

- Current configuration
  - 20 nodes
  - RAM 512 Gb
- Spark 2.2





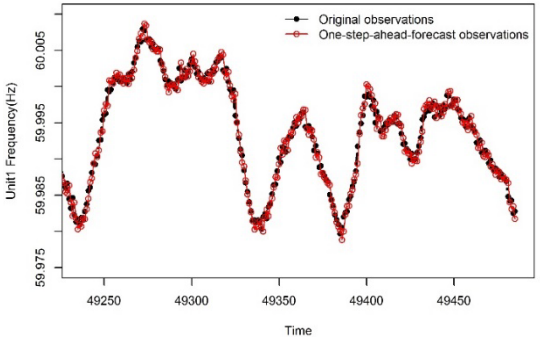
Online Detection using Dynamic Linear Model

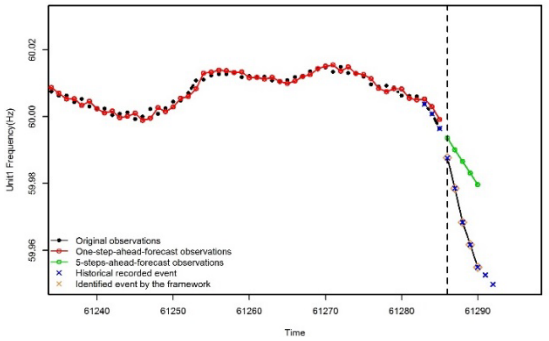
- Pure data-driven dynamic linear model training using Kalman filter with PMU measurements
- Predict ‘normal’ system behaviors
- The contrasts between non-normal observations and ‘normal’ predictions provide the basis for system anomaly detection
- Assign anomalous score based on exceedance probabilities

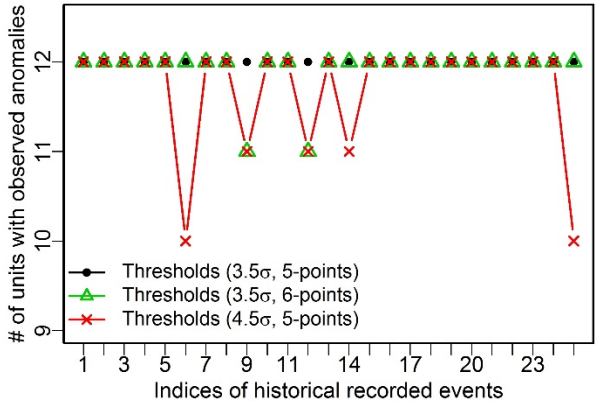
$$y_t = F_t\theta_t + \vartheta_t, \qquad \vartheta_t \sim N(0, V_t)$$

$$\theta_t = G_t\theta_{t-1} + w_t, w_t \sim N(0, W_t)$$

$$F(x) = P(X \le x) = \sum_{t \le x} f(t)$$







Pavel V. Etingov is a staff research engineer at the US Department of Energy's Pacific Northwest National Laboratory (PNNL).

He joined PNNL in 2008 where he serves as a Project Manager, Principal Investigator (PI)/co-PI and key technical contributor in multiple projects, funded by the U.S. DOE, BPA, California Energy Commission, California ISO, ISO New England, and some others electrical utilities.

Dr. Etingov's research interests include stability analysis of electric power systems, power system operation, modeling and control, PMU applications, wind and solar power generation, application of artificial intelligence to power systems, and software development.

He is a member of the IEEE PES, CIGRE, WECC JSIS, WECC MVWG, and NASPI.

He graduated with honors from Irkutsk State Technical University specializing in electrical engineering in 1997. He was a fellow at the Swiss Federal Institute of Technology in 2000-2001. Pavel received his Ph.D. degree in 2003 from the Energy Systems Institute of the Russian Academy of Sciences, Irkutsk, Russia.

Ensuring Western Interconnection Reliability and Resilience by Advanced Modeling and Real-Time Analytical Tools

Hongming Zhang, Ph.D.

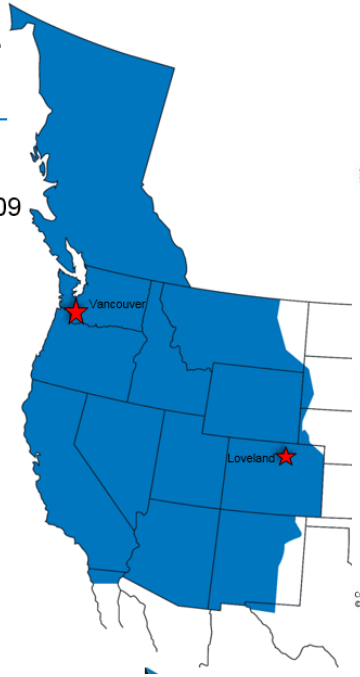
EMS Manager, Peak Reliability

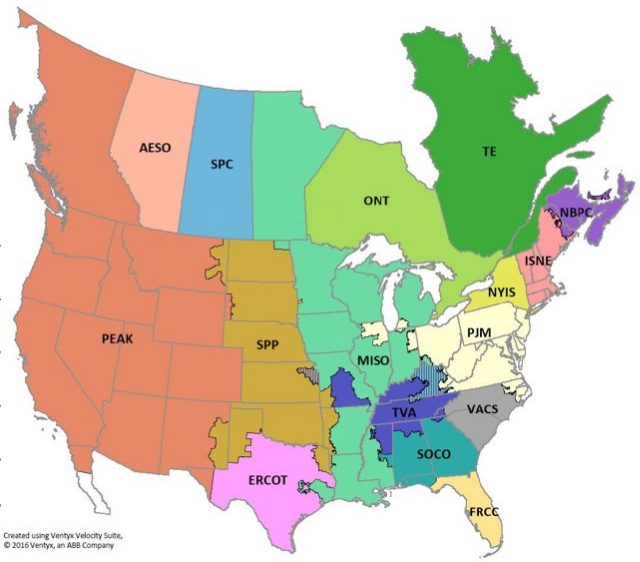
Agenda

- Introduction: Peak RC's Facts and Objectives
- Overview and Use Cases of RC Real-time Control Room Tools:
  - RTCA for Predictive Operation Analysis
  - RTVSA for IROL Real-time Assessment
  - TSAT for Transient RAS Modeling/Monitoring
  - Online System Oscillation Monitoring Tools
- Conclusion

Peak Reliability Facts

- **Founded: Jan 1, 2014**
  - Preceded by WECC RC est. Jan 1, 2009
- **System Load: ~ 150,000 MW**
- **Offices:**
  - Vancouver, WA – HQ
  - Loveland, CO
- **Registered Functions:**
  - Reliability Coordinator
- **RC Area:**
  - 37 Balancing Authorities
  - 55 Transmission Operators





NERC Reliability Coordinators
As of June 1, 2015

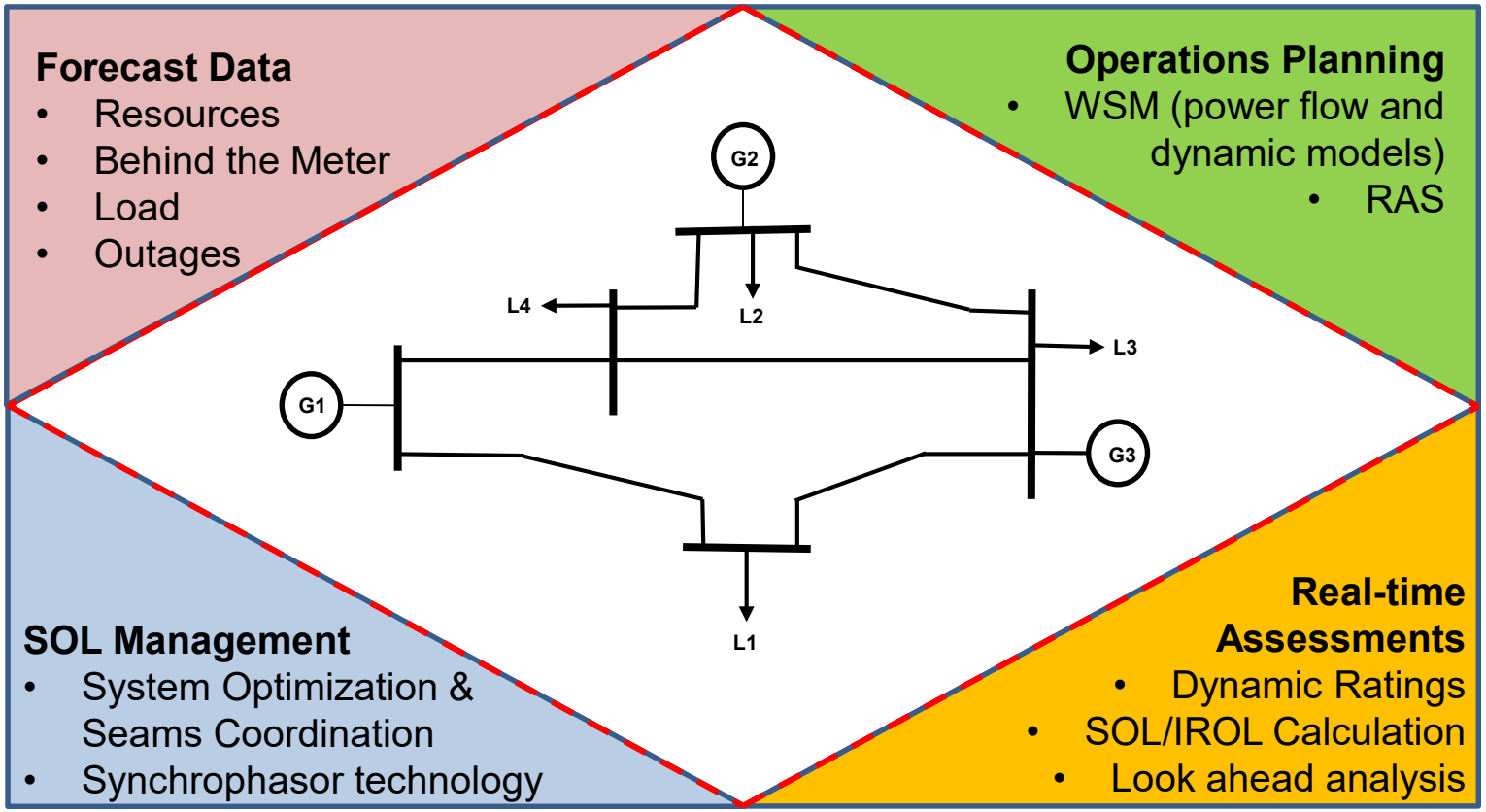
Alberta Electric System Operator
Electric Reliability Council of Texas
Florida Reliability Coordinating Council
Hydro Quebec TransEnergie
ISO New England, Inc.
Midcontinent ISO
New Brunswick Power Corporation
New York Independent System Operator
Ontario Independent Electricity System Operator
Peak Reliability
PJM Interconnection
Saskatchewan Power Corporation
Southern Company Services, Inc.
Southwest Power Pool
BAs receive RC services from SPP or TVA
Tennessee Valley Authority
BAs receive RC services from TVA or MISO
VACAR South

WECC footprint will have four RCs: CAISO, SPP, BC Hydro and AESO by 12/2019

- FERC/NERC Requirements:
  - Highest level of authority responsible for the reliable operation of the Bulk Electric System (BES)
  - Authority to prevent or mitigate generation and transmission emergencies in day-ahead and real-time
  - Wide Area view of BES (situational awareness)
  - Pre- and post-Contingency BES monitoring, analysis, and direction

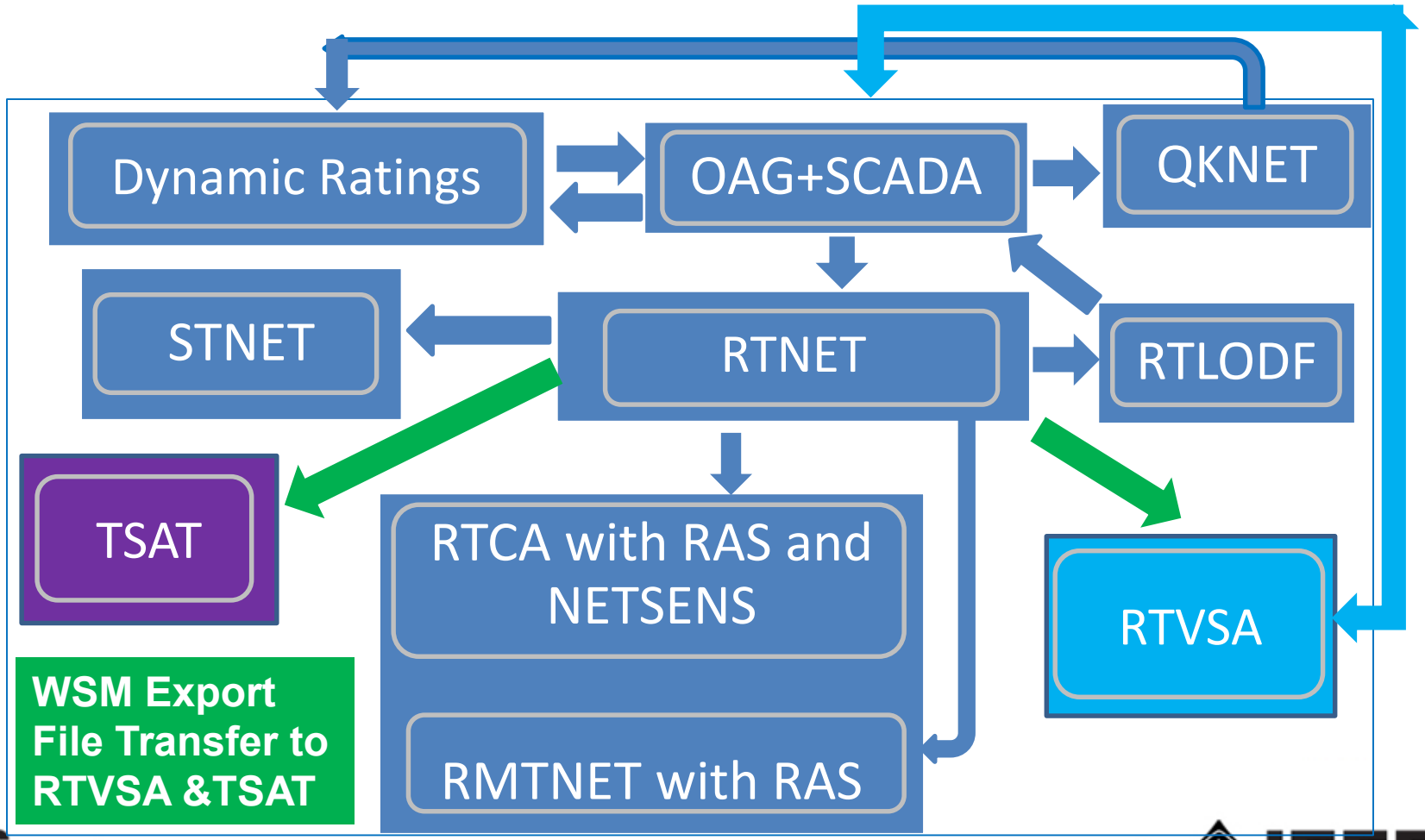
Main Objectives of Reliable Operation

- **Maximize** transmission utilization. **Optimize** generation dispatch. **Prevent** blackouts or uncontrolled cascading



Monitoring WECC System by RT-Tools

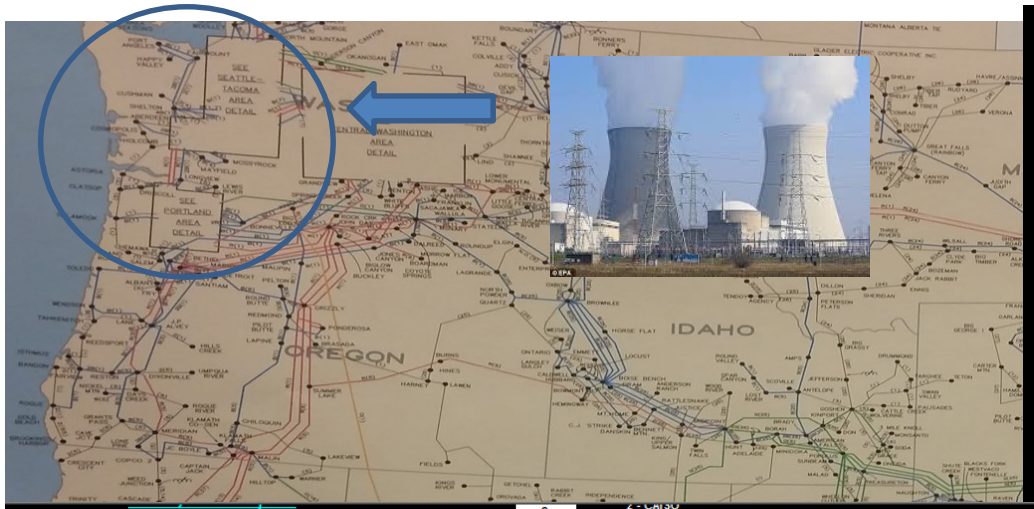
Vendors: GE V&R PowerTech

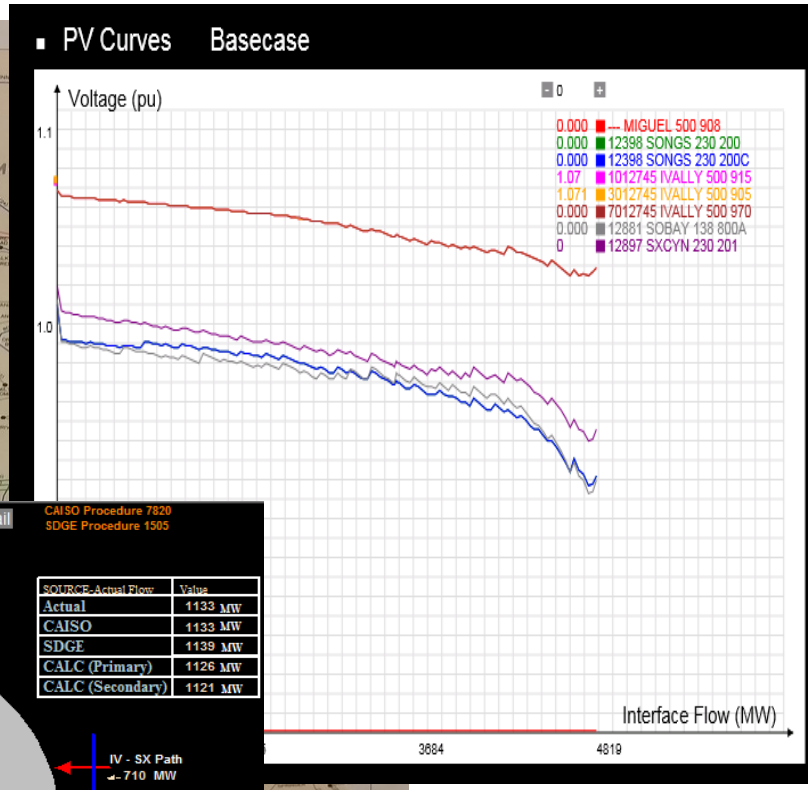


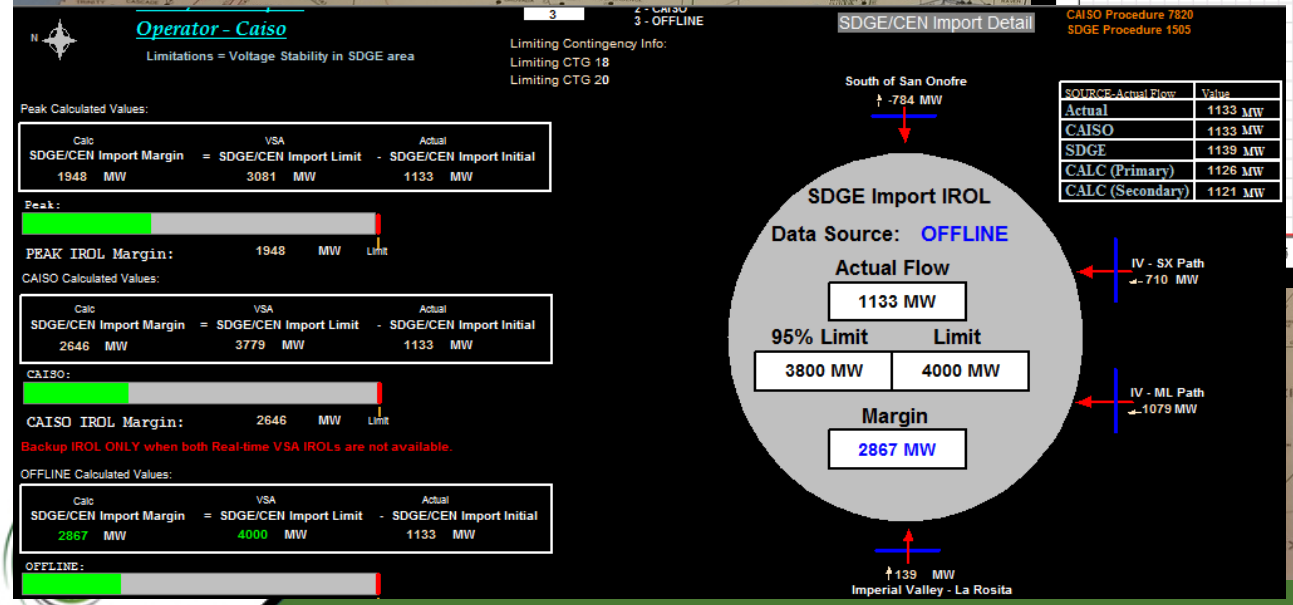
Real Time Contingency Analysis (RTCA)

- RTCA runs for 5-min with input SE basecase
  - **~8,000** contingencies for screening various violations e.g. branch, voltage, interface, node pair, islanding and unsolved/partially unsolved
  - **515** RAS records are modeled active in RTCA to mimic **272** physical RAS and special relays
  - Over **1230** CTGs are enabled for RAS screening.
- Sensitivity analysis tools are available for RTCA backup and overload mitigation study
- Look ahead RTCA is implemented in RMTNET

Voltage Stability vs IROL Monitoring

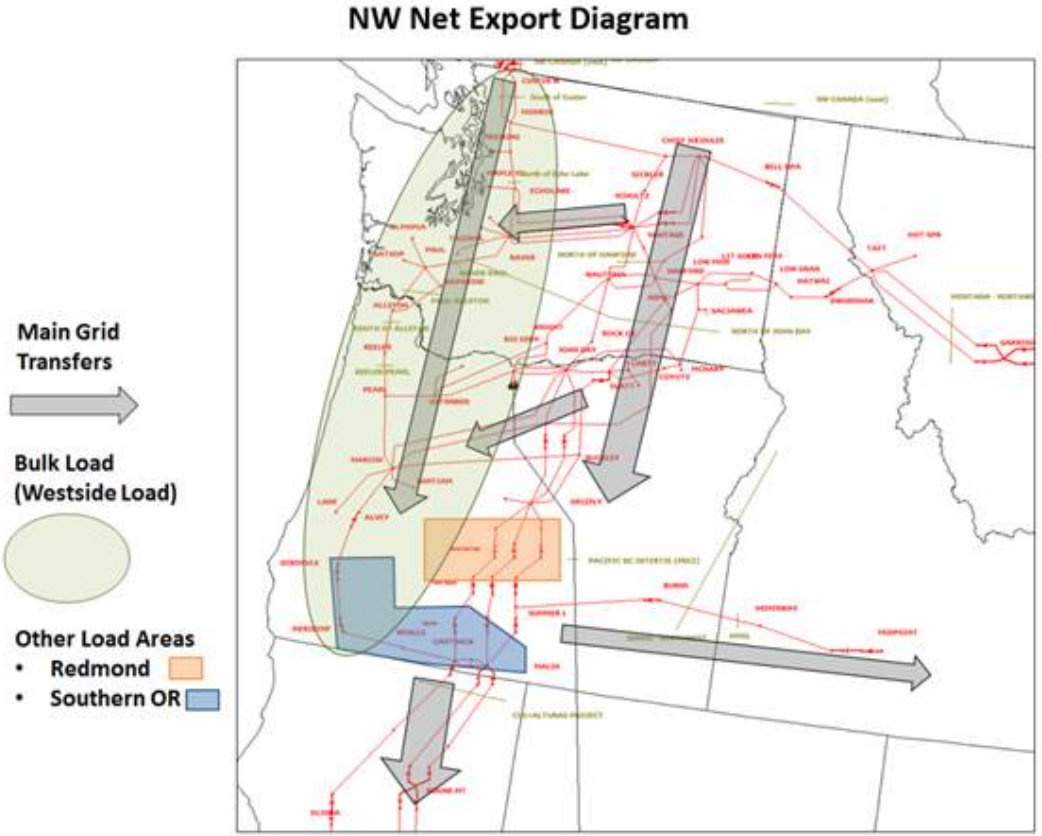






Is Transmission Capability Limiting?

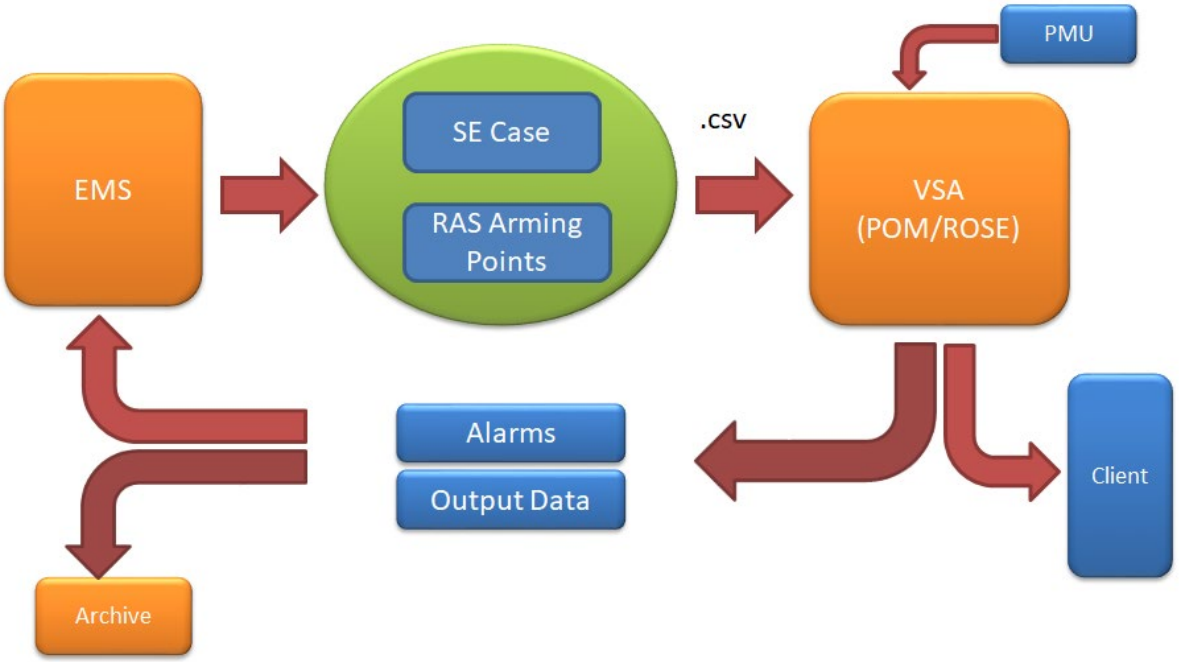
- Oregon Net Export IROL consists of three competing WECC paths limited by stability



- Power flows on multi-paths could be competing or interacting negatively

Monitoring IROL by Real-time Tool-RTVSA

- Peak implemented V&R POM for RTVSA
- Presently RTVSA tool performs real-time (5-min interval) assessment of multi-IROLs

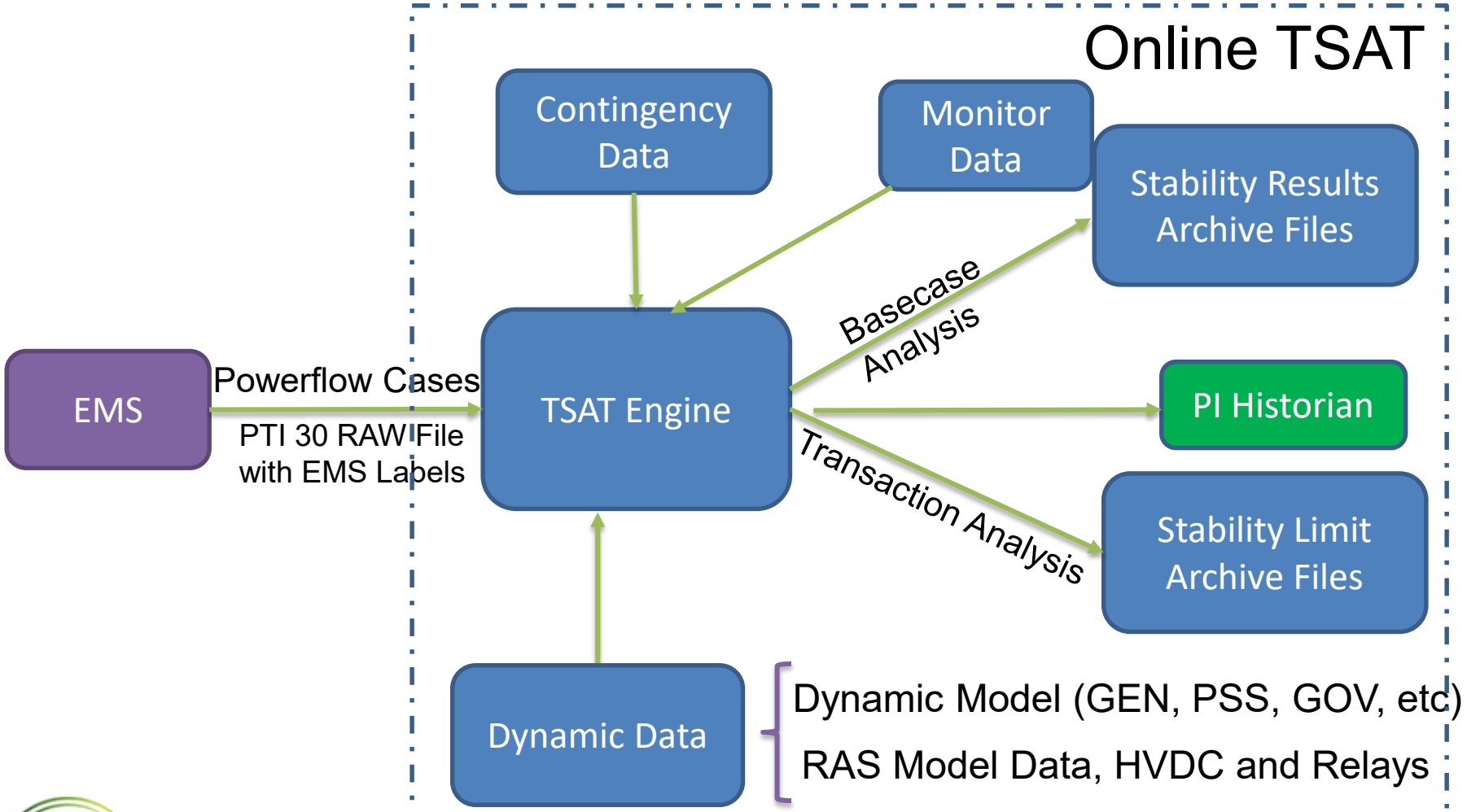


RTVSA Application Architecture

RTVSA Tool Highlights

- Solve multiple IROL scenarios in parallel using multi-threads computation
- Apply RTCA contingencies and relevant RAS models by user defined VB scripts
- Capable for both PV and QV analysis
- Allow for minimal load shedding analysis
- Model auto shunts switching schemes
- Integrated with EMS for operation views

Peak Online Transient Analysis Tool

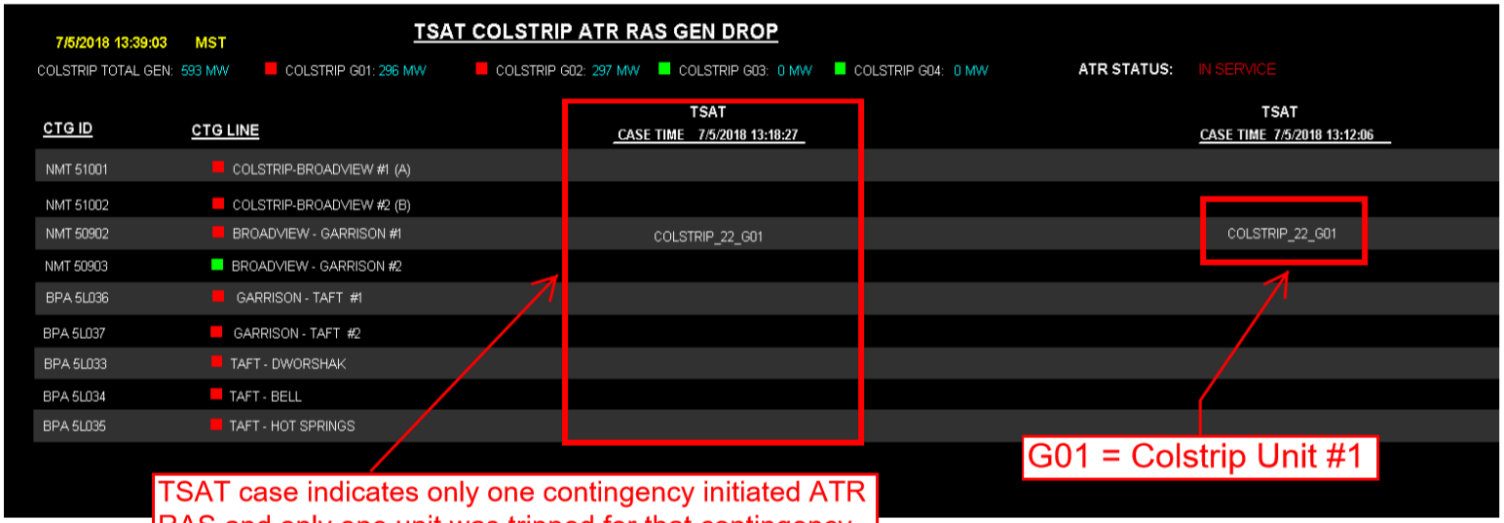


Peak TSAT Operational Use Cases

- Monitor a subset of RTCA contingencies that require dynamic or transient RAS models to mimic post-contingency conditions accurately. Otherwise, RTCA may report false CTG violations e.g.
  - False SOL exceedances
  - Falsely unsolved [N-2] or [N-1-1] CTGs
  - False unsolved islanding cases
- TSAT is used to resolve the RTCA issues

Monitoring Transient RAS in Real-time

- Nine CTGs associated with ATR RAS are modeled in TSAT. The RAS gen drop unit IDs are identified by TSAT and exported to PI
- RC can trip the units to verify a CA violation

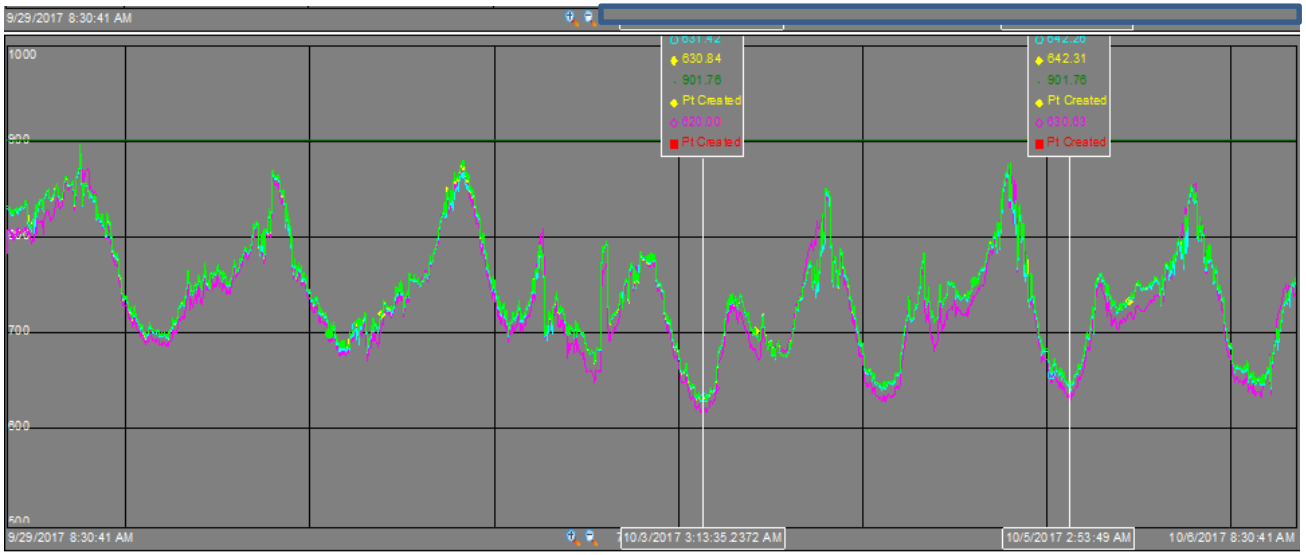


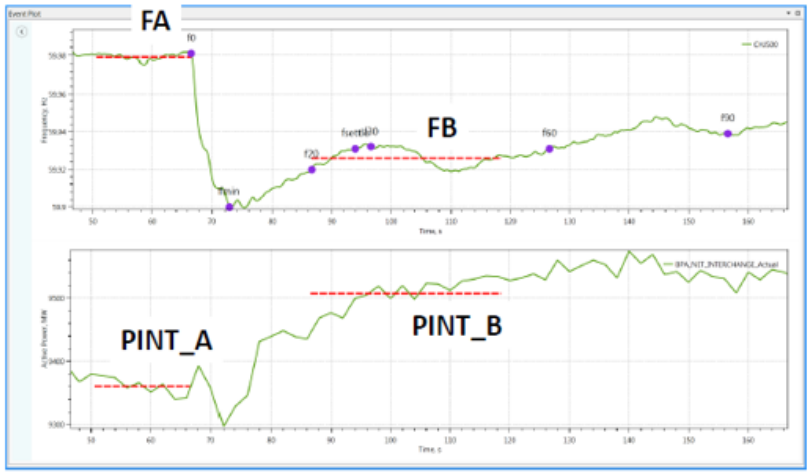
Other TSAT Use Cases in Analysis

- Frequency Responsive Measure (Frequency Bias) can be calculated in real-time on a system and a single BA level.
- Inter-area power transfer limit assessment
  - SDGE and SDGE/CEN IROL Calc. (collecting data)
  - COI/NW Net Export Limit Study (in progress)
- PV momentary cession impact study and RAS gen drop level/effectiveness assessment
- MOD-033 and ePMU data streams for baselining study and PMU oriented training

Monitoring System Frequency Response

R-T Freq. A-C Measure in 7 day





BA Frequency Response Measure

BA FRM = (PINT_B – PINT_A + POUT_BA) / (FA – FB)

By NERC ERSTF Measure 4, TSAT calculates WECC A-B measure, A-C measure, C-B measure against pre-defined system disturbances

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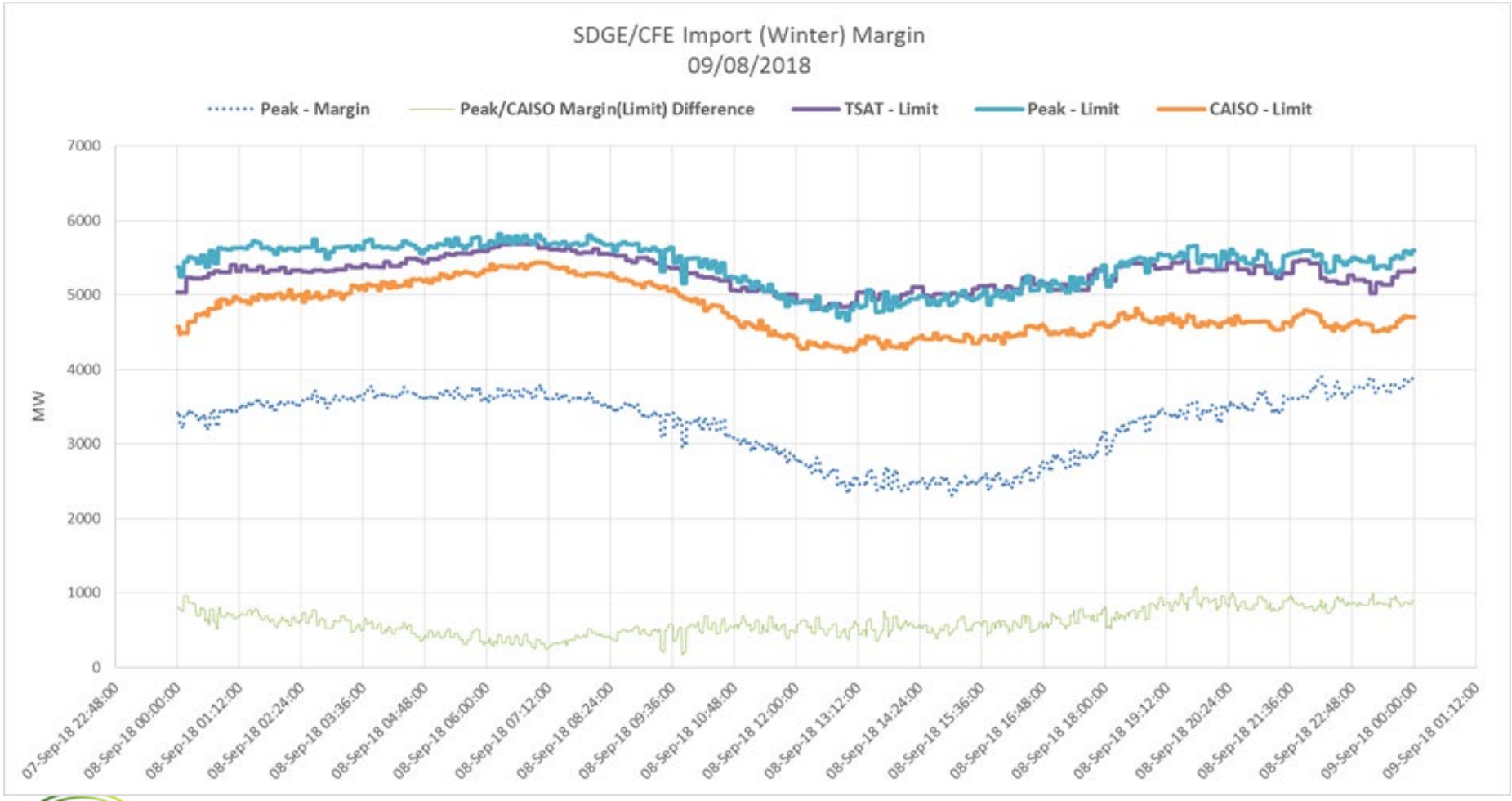
IROL Calculation and Benchmarking



2017 US-Canada Separation Event

PMU playback:

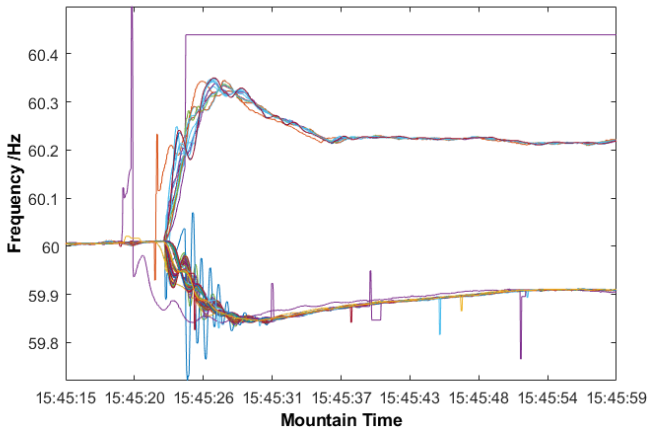
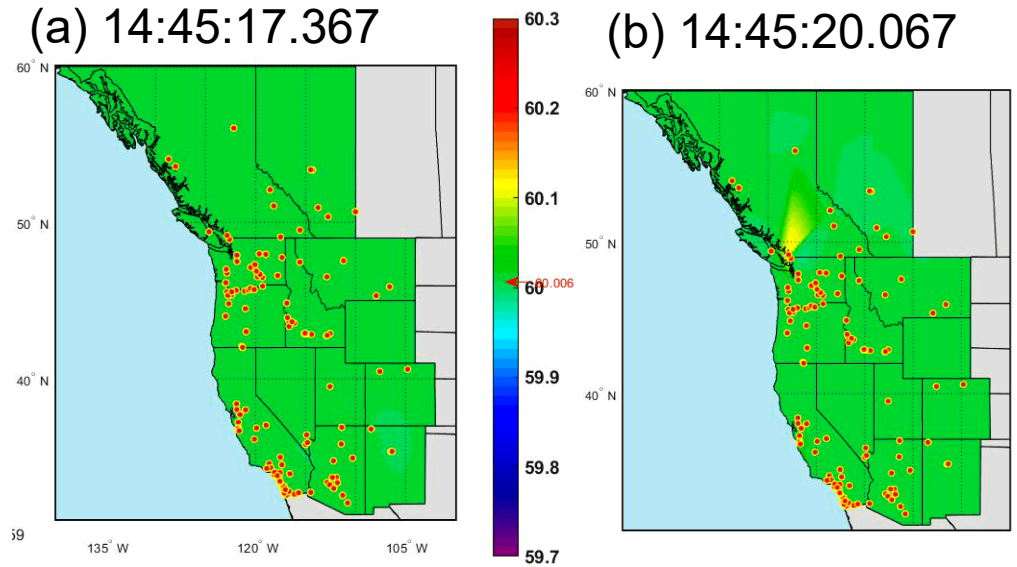
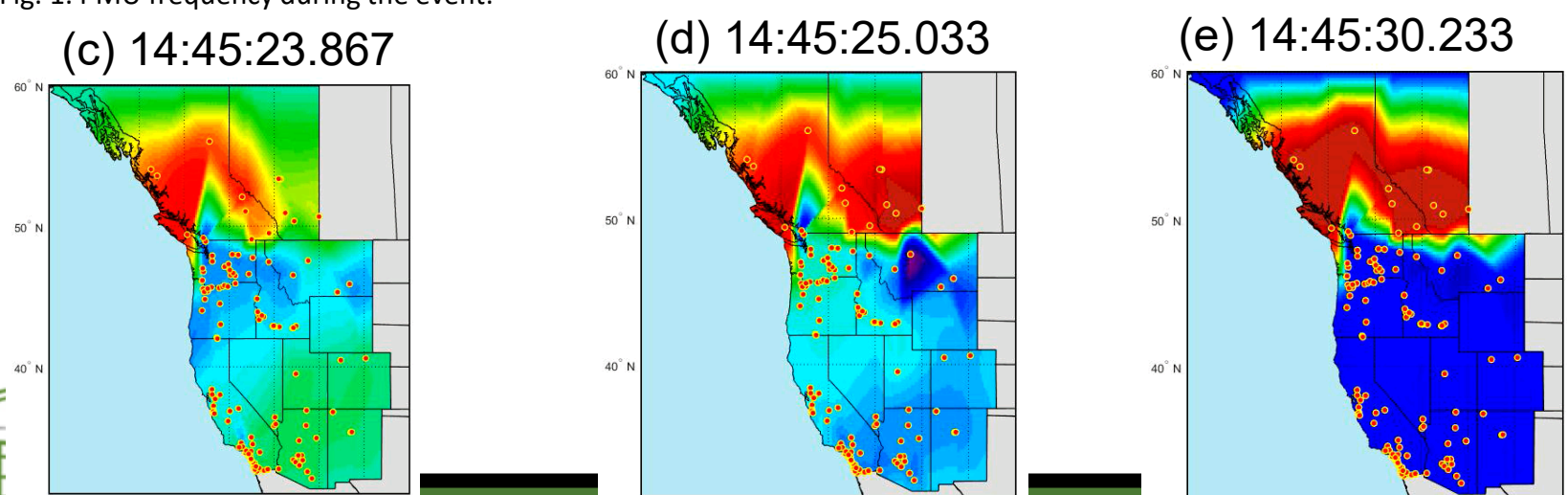


Fig. 1. PMU frequency during the event.


(a) 14:45:17.367
(b) 14:45:20.067


(c) 14:45:23.867
(d) 14:45:25.033
(e) 14:45:30.233

Real-time TSAT Simulation Results

- EMS RTCA showed unsolved for this contingency due to lack of capability of modeling the Out Of Step RAS
- TSAT predicted the separation with stable islands correctly

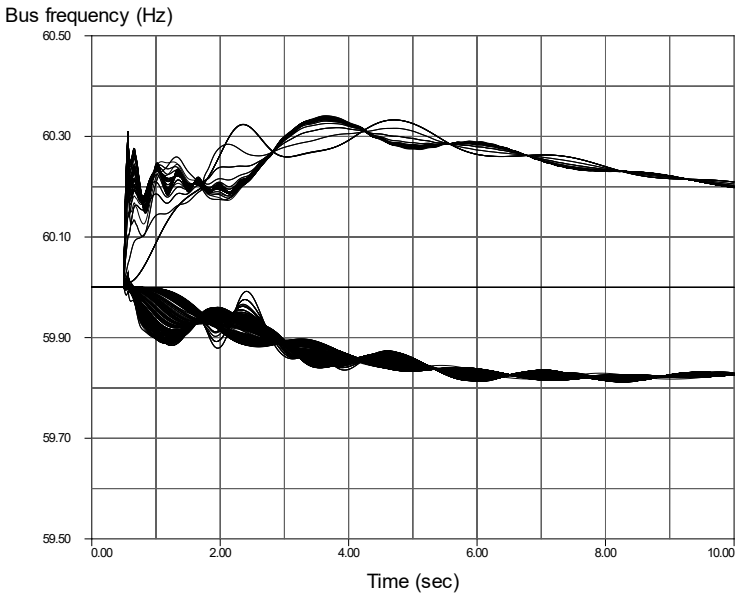


Fig. 1. Online TSAT real-time result for this contingency.

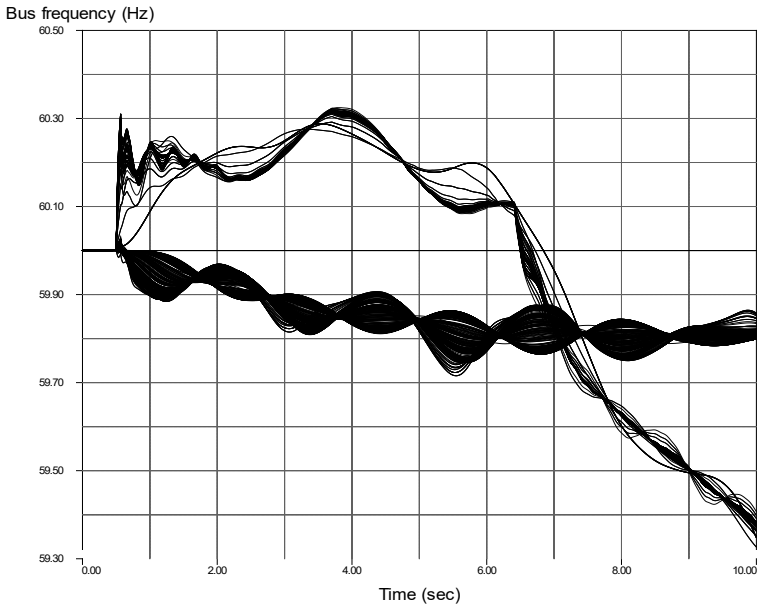


Fig. 2. TSAT results without the OOS RAS.

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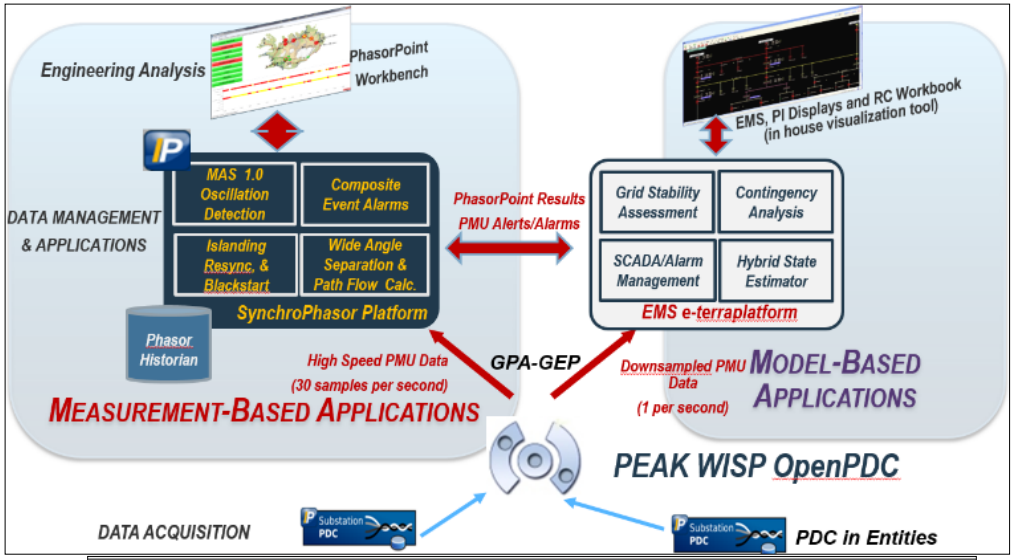
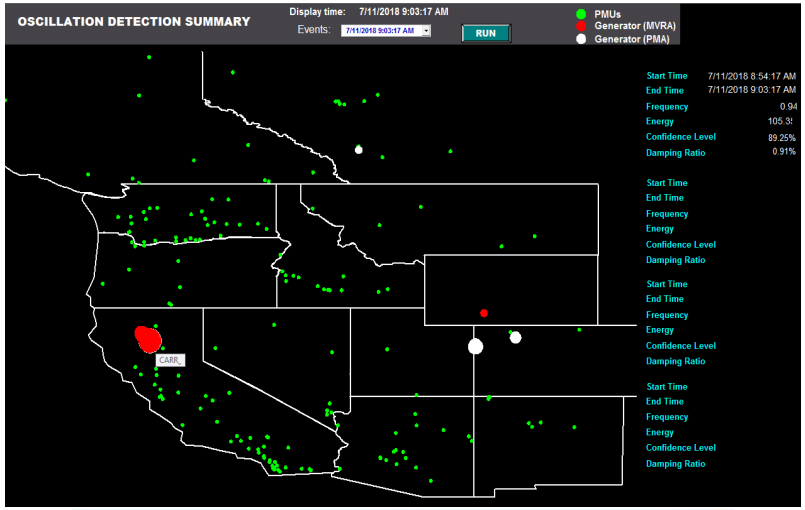
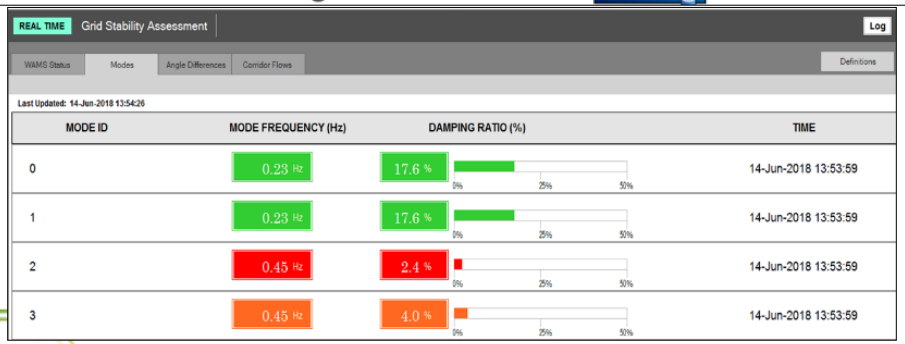
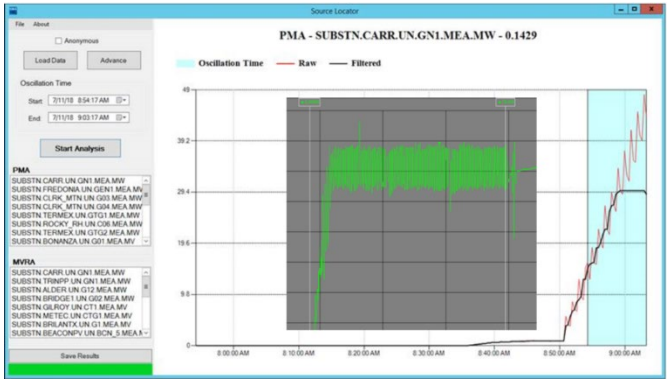
Monitoring System Oscillation in R-T

Peak implemented GE-Phasor Point and WSU online Oscillation Monitoring Tool



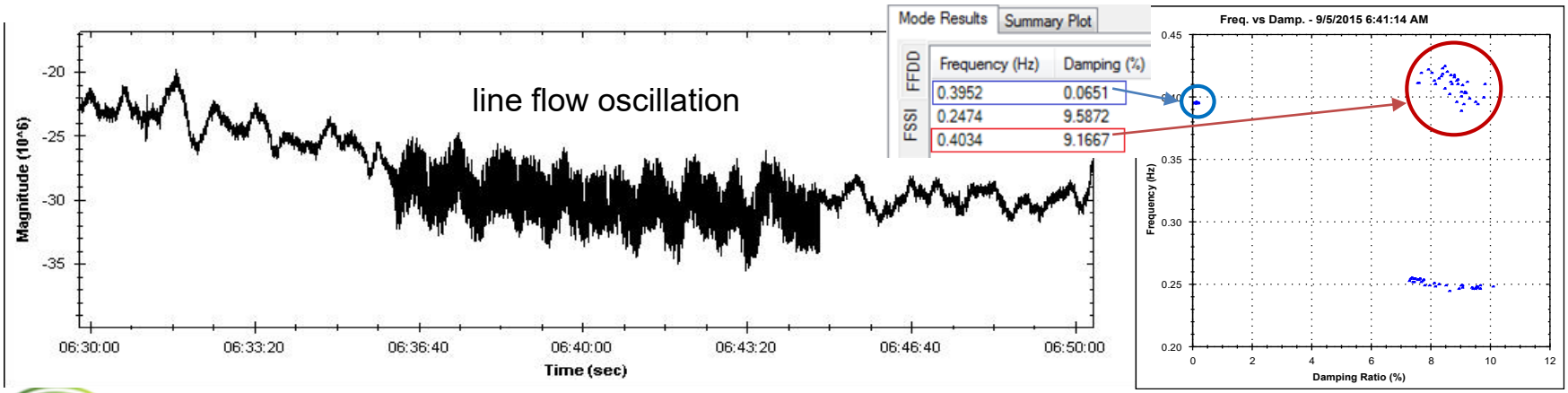






Forced Oscillation vs. Inter-area Modes

- A nearly 0.4 Hz forced oscillation triggered by a unit operating with faulty combustion turbine MW transducer excited N-S mode B on Sept xx 2015.
- The resonant excitation of this 0.4 Hz mode can be seen through the ~6 MW oscillations at Hxxx and resulted in ~40 MW oscillations on the COI.



Conclusion

- Peak RC implemented advanced online tools with a full West wide System Model (WSM) for reliability coordination function
- Advanced modeling and real-time tools were proven critical for enhancing system security across the West Interconnection that is evolving to “Green Grid”
- Peak’s experience will be useful to new RCs

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Hongming J. Zhang is EMS Network Applications Manager at Peak Reliability.

Dr. Zhang (M'01–SM'10) has been with Peak Reliability (formerly WECC Reliability Coordinator) since January 2008. In his current position, he is mainly responsible for Advanced Network Applications (e.g. State Estimator, Real-Time Contingency Analysis, Online Voltage Stability and Transient Security Analysis Tools etc.) and Dispatcher Training System (DTS). He also led new Synchrophasor applications implementation for control room solution under WISP and PRSP projects jointly funded by DOE and WECC/PEAK member entities. Dr. Zhang previously worked in ERCOT and ABB Automation Inc., Texas.

Hongming received his Ph.D. degree in Electrical Engineering from Texas A&M University at College Station in 2001. He received MSEE and BSEE degrees from Shanghai Jiao Tong University (China), in 1993 and 1988, respectively.

ISGT 2019: February 18, 2019

ONLINE CASCADING ANALYSIS AT ISO NEW ENGLAND

Slava Maslennikov
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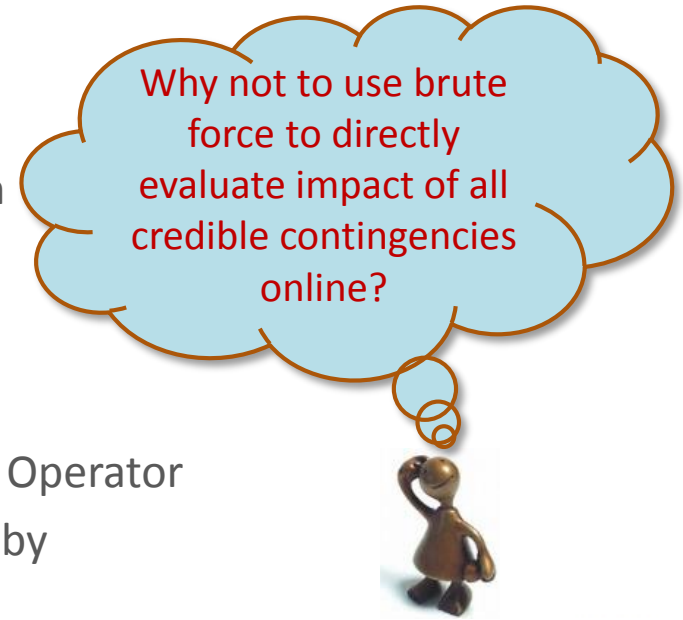
Online Situational Awareness

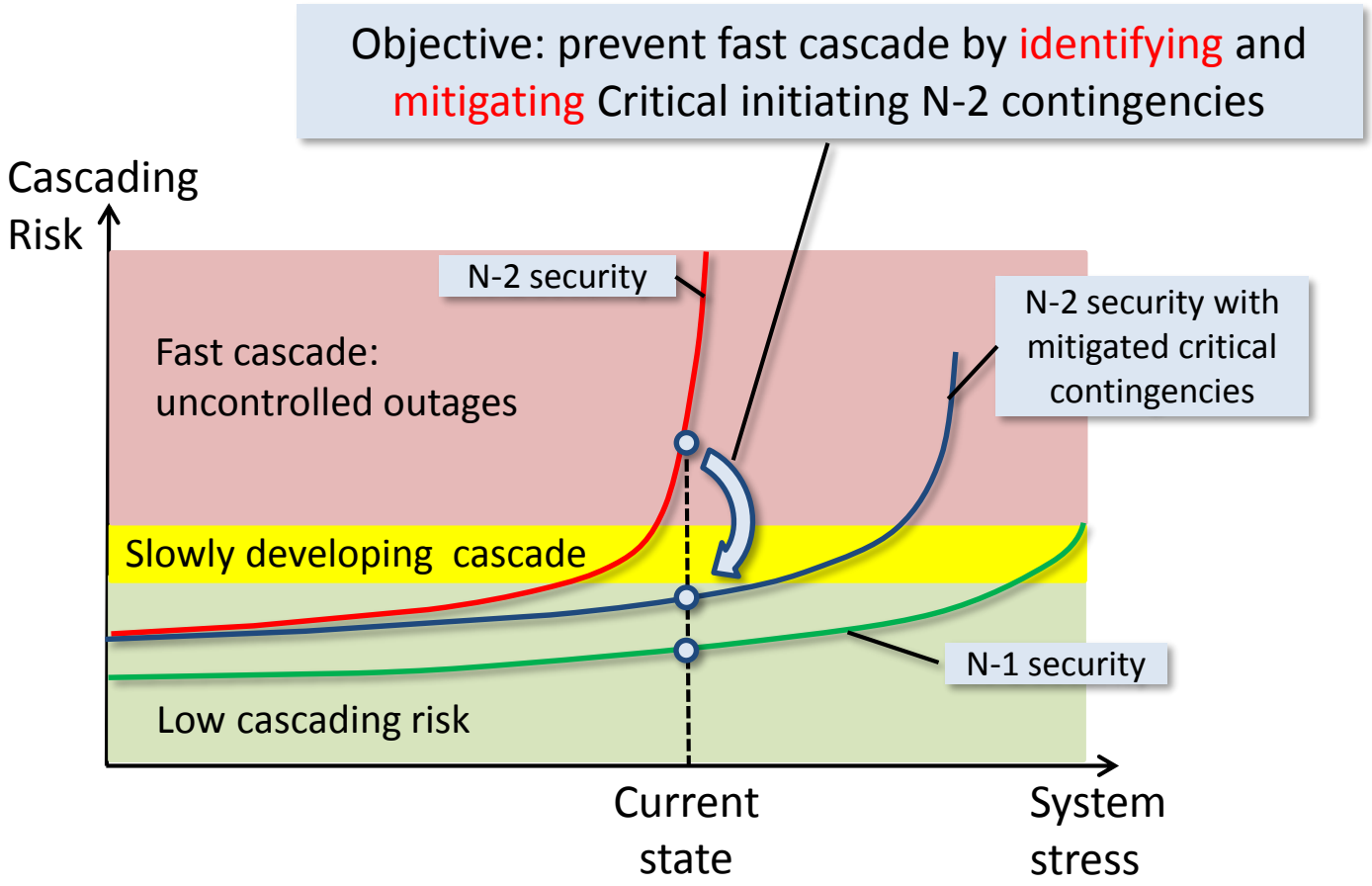
- Traditional Real-Time Security Analysis (SA)
  - ✓ N-1 SA could be insufficient in fast developing situation
  - ✓ N-2 SA could be prohibitively expensive due to too many violations and inability to link violations with actual consequences for the system

- Need for online identification of Initiating Events beyond N-1 representing the threat of severe consequences in terms of
  - ✓ Uncontrolled wide-spread cascading
  - ✓ Unacceptable MW loss of load or generation
  - ✓ Impact on other control areas

- Online Cascading Analysis provides situational awareness for N-k Initiating Events
  - ✓ Actionable information to the Control Room Operator
  - ✓ Practical way to reduce the risk of blackouts by mitigating critical N-k

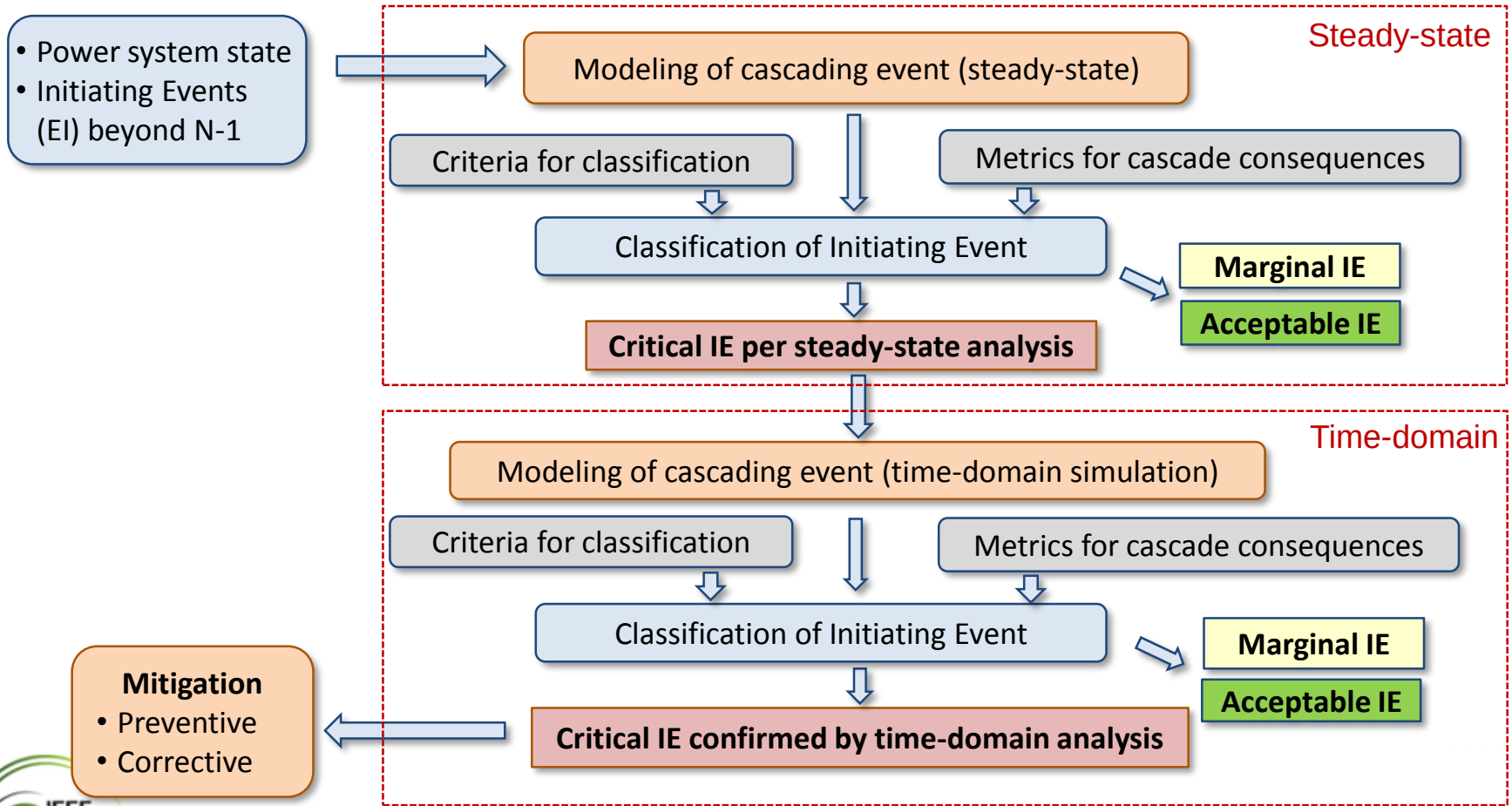


Security Against Uncontrolled Cascading Outages



Practical Approach

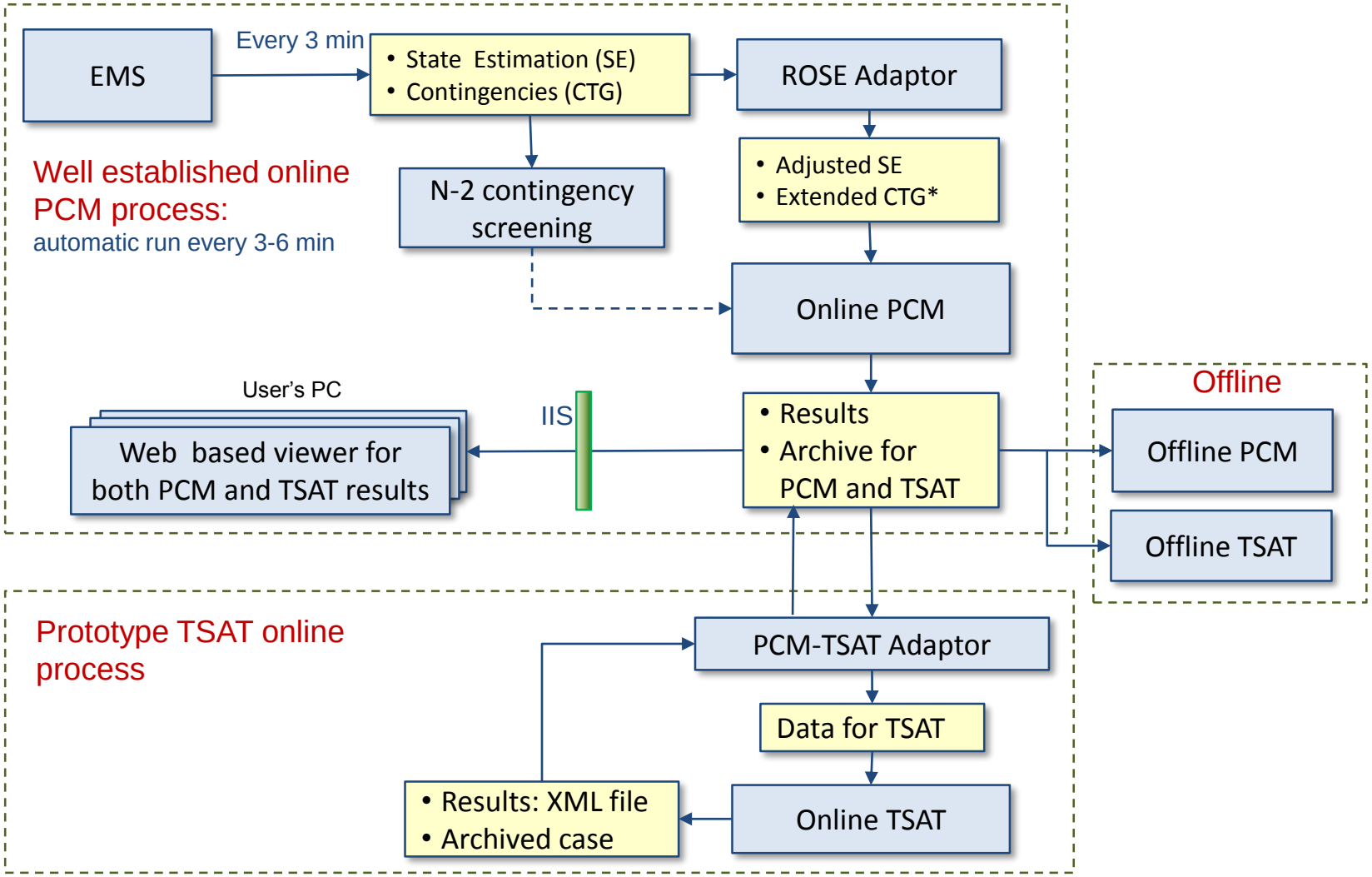
- Identify and mitigate Critical Initiating Events (IE). Criticality is classified based on the consequences of cascade



Framework for Online Cascading Analysis

- Steady-state part is based on V&R's PCM software (2014-2018 work)
  - ✓ Serves as a screening tool for time-domain cascading analysis
- Time-domain part is based on Powertech's TSAT software (2012-2018 work)
- ISO New England:
  - ✓ Guided V&R and Powertech in the PCM and TSAT development
  - ✓ Developed all necessary process components and integration with EMS
- The process intend to model a fast developing cascade. That greatly simplifies the modeling assumptions

Cascading Analysis Process – Data Flow

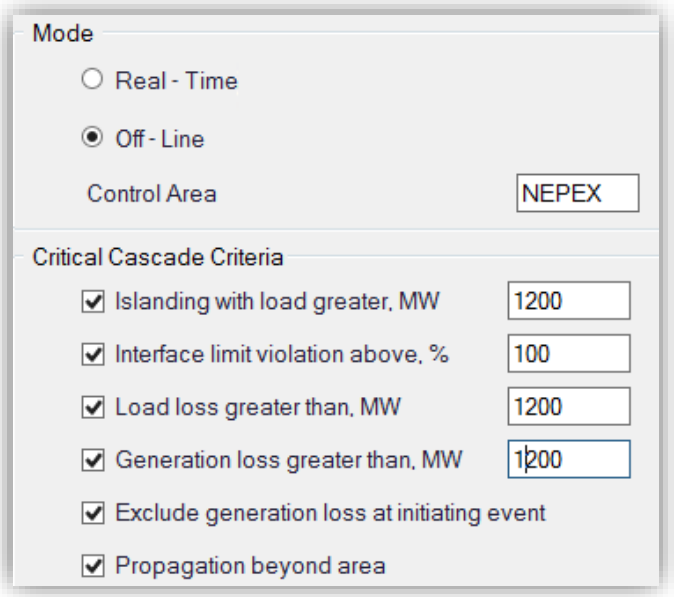


* Extended CTG include selected N-2 used in Day-Ahead processes and all Stuck Breaker. Total ~7,000 x 3 = 21,000 CTGs

Steady-state analysis (PCM tool)

Classification of Critical Cascade in PCM

- Critical contingency triggers fast developing, uncontrolled cascade with severe consequences
- Criteria of Critical cascade:



✓ System wide voltage collapse occurs upon applying initiating contingency or as the result of cascading outages

✓ Islanding with the total MW of load in island greater than pre-defined threshold

✓ Interface MW flow exceeds “stability” interface limit by pre-defined % level

✓ Total MW loss of load exceeds pre-defined threshold

✓ Total MW loss of generation exceeds pre-defined threshold

✓ Cascade propagates beyond Balancing Area footprint

Scenarios in Cascading Analysis

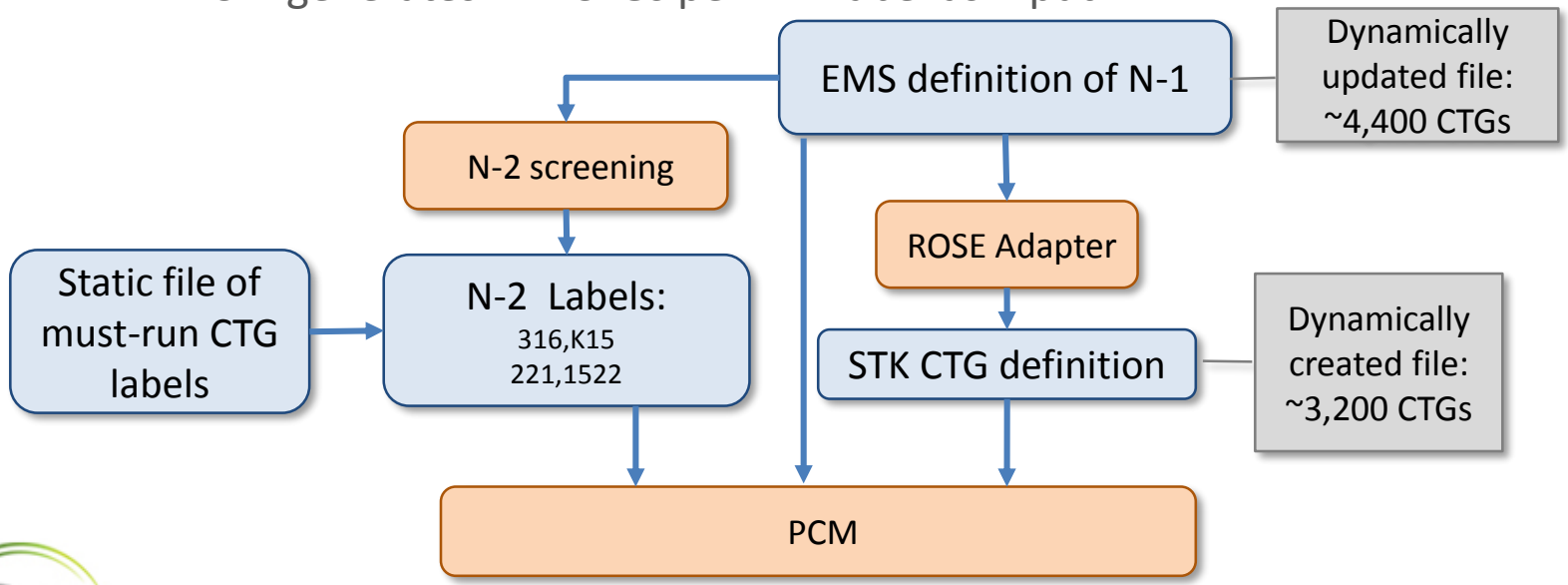
- Cascading study is deterministic per defined tripping criteria
- Tripping criteria can be defined only approximately due to uncertainty of many factors (contingency, protection, operator actions)
- Risk of cascading can be approximately evaluated by running three cascading scenarios for the same initiating contingencies with different tripping criteria

Tripping criteria for scenarios

Scenario	Line % of rate C	Transformer % of rate C	Load voltage p.u.	Load % tripped
HighProbability	130%	130%	0.85	50%
MediumProbability	115%	115%	0.85	40%
LowProbability	101%	101%	0.85	30%

Contingencies for Cascading Analysis

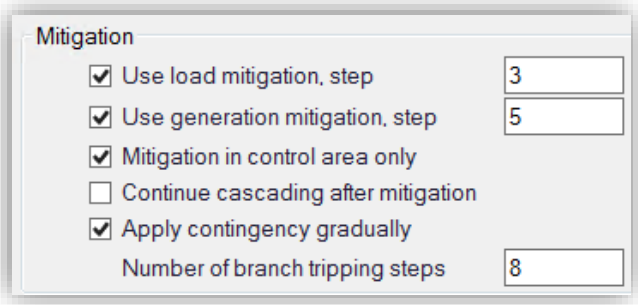
- EMS contains mainly N-1 contingency (CTG) node-breaker definitions. Manual creation of N-k and stuck breaker CTGs for PCM is practically impossible.
- Screening process to select all potentially dangerous N-2
- Cascading analysis process automatically generates N-k and N-1 stuck-breaker (STK) CTGs by using EMS N-1 definition
  - ✓ ROSE Adapter generates all STK CTGs
  - ✓ PCM generates N-2 CTGs per N-2 label as input



Measures for Processing of Infeasible Solution

- Reporting “Stability Violation” only as the result of cascading analysis is insufficient. Results should indicate the impact in measurable quantities to enable the local or system-wide classification

- Measures to minimize AC solution divergence due to numerical issues including “soft” applying CTG
- PCM calculates a reasonable minimal amount of Load and Generation shedding to get feasible AC solution



Voltage collapse is mitigated by load shedding

MW of load shed

Summary Report

I	Initiating contingency	Timer	Tiers	Critical	Stability viol.	Interface limit viol.	Load Loss (MW)	Gen loss (MW)	Propagation	Islands	Islanded load	Mitigation Load (MW)
2350	387 # 398	81	1	Y	M	-	10	0	Y	0	0	182

Time-domain analysis (TSAT tool)

Need for Time-domain Analysis

- Results of steady-state cascading analysis ending in “infeasible solution” are insufficient because cannot answer the question on the scope of the problem – is it local of system-wide collapse.
- Verify results of steady-state analysis when
  - ✓ Cascade “propagates” beyond internal area
  - ✓ Amount of affected by cascade load and generation is larger then a pre-defined threshold
- Process:
  - ✓ Use steady-state analysis as a “screening” tool
  - ✓ Select critical initiating contingencies and run them in TSAT
    - ❖ Contingencies resulting in “infeasible solution”
    - ❖ Contingencies creating a cascade propagating beyond internal area
    - ❖ Contingencies impacting significant amount of MW load/generation
  - ✓ Solution is almost always feasible in time domain with the existing modeling in TSAT-type of software (P,Q=const load is replaced with ZIP model)

Cascading Modeling in TSAT

- Zone 1&2 distance relay for transmission lines
- UFLS and UVLS relay for loads
- Under/over frequency relay for generators
- Added new model (via SPS/UDM functionality): “Sag relay” to model line tripping due to short circuit created by sagged wire
- Automatic extension of integration time due to operation of relay or SPS functions

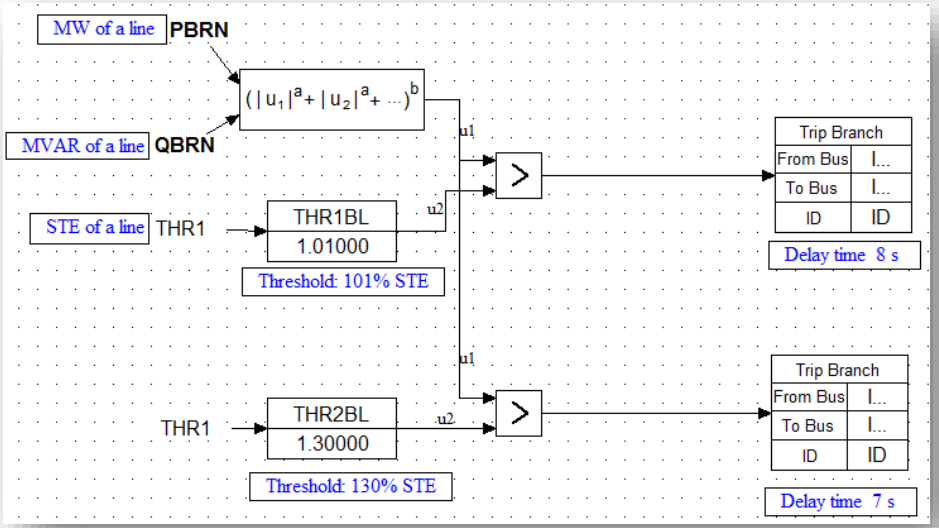
- All model/process parameters are configurable

“Sag Relay”

- Action: Trip a Line
  - ✓ if MVA flow exceeds 130% of STE threshold longer than 7 seconds
  - ✓ if MVA flow exceeds 101% of STE threshold longer than 8 seconds
  - ✓ Time delays are longer than delays of any modeled physical relays to make sure “sag relay” operates only after actions of physical relays

- “Sag relay” is important component to have consistency of cascading analysis in steady-state and dynamic.
  - ✓ Example: a line is overloaded below tripping threshold of the distance relay and sags within 2-10 min, creates short circuit and gets tripped by protection relay.

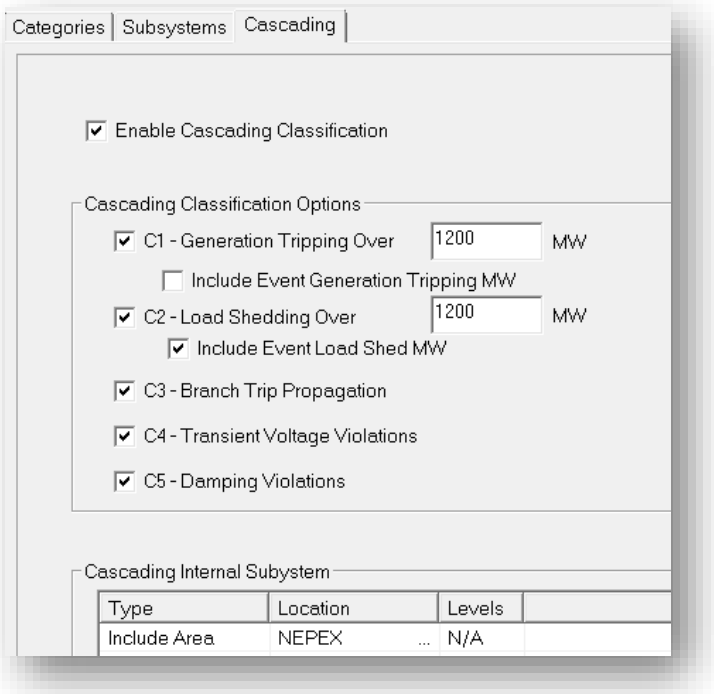
“Sag relay” as User Defined Model in TSAT



Classification of Contingencies in TSAT

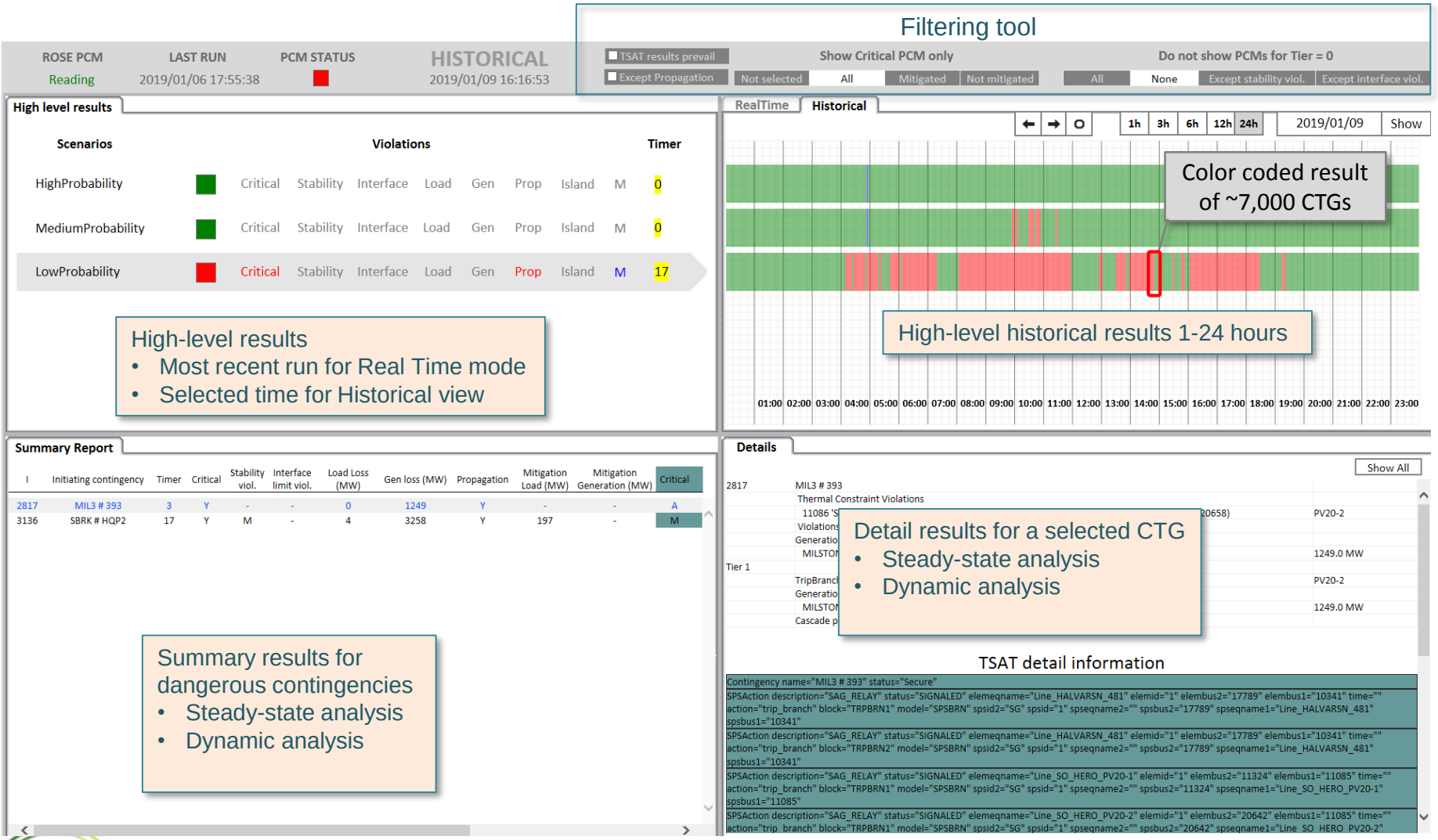
- Critical contingency triggers fast developing, uncontrolled cascade with severe consequences

No	Condition
C1	Tripping MW generation over threshold
C2	Tripping MW load over threshold
C3	Propagation beyond control area
C4	Transient voltage violation. Configurable criteria
C5	Insufficient damping. Configurable criteria



	Triggered conditions				
Classification	C1	C2	C3	C4	C5
Critical	Y	Y	Y	-	-
Marginal	-	-	-	y	y
Acceptable	-	-	-	-	-

Visualization of Cascading Analysis Results



Example: RT run 9:01:51 on 2019/01/10

- PCM: Two CTGs are critical resulting in infeasible solution and both were mitigated by load shedding. Additionally, CTG SBRK#HPQ2 violated "propagation" criterion because of tripping the line ABC

Summary Report

I	Initiating contingency	Timer	Critical	Stability viol.	Interface limit viol.	Load Loss (MW)	Gen loss (MW)	Propagation	Mitigation Load (MW)
1	266_K266-6_stk	0	-	M	-	27	0	-	37
3137	SBRK # HQP2	52	Y	M	-	3	3258	Y	135

- TSAT: Both CTGs were identified as Marginal (M) due to violation of dynamic voltage criteria. Some loads were tripped by UVLS. No tripping of line ABC detected

Summary Report

I	Initiating contingency	Critical	Load Loss (MW)	Gen loss (MW)	Propagation	Transient voltage viol.	Damping viol.
1	266_K266-6_stk	M	43.1	0	-	Y	-
3137	SBRK # HQP2	M	88.38	0	-	Y	-

Computational Efficiency

Steady-state analysis (PCM)

- Parallel processing
- PCM run time is 3-4 min by using 6 threads for ~6.500x3=19,500 CTGs

Time-domain analysis (TSAT)

- Only few contingencies need to be studied in TSAT for every PCM run
- TSAT run is typically shorter than PCM run. Muti-threaded can be used if needed

Full cycle of online cascading analysis takes 4-5 min (for ~6500 contingencies)

Benefits of Cascading Analysis

- Advanced situational awareness. Ability to identify exact Critical complex contingencies (beyond N-1) triggering fast developing uncontrolled cascading
  - ✓ In Real-Time operation
  - ✓ At any stage of Operational Planning horizon
- Practical way to reduce risk of blackouts. Systematic approach to constantly mitigate the risk of contingencies triggering uncontrolled cascading
  - ✓ Timely development of Remedial Actions
  - ✓ Automated mitigation via SCED by adding critical contingencies into dispatch
- Possibility to dramatically improve IROL analysis
  - ✓ Measurable consequences of cascade
  - ✓ Just and objective criteria
  - ✓ Auditable process

Slava Maslennikov is currently a Technical Manager at ISO New England.

Dr. Maslennikov (M'01-SM'10) has joined the ISO New England, Holyoke, MA, USA in 2006 .

His major interests are power system stability, security, operations, smart GRID and PMU-based applications.

He received M.S.(1979), Ph.D. (1984) and Dr. Sc. (1998) degrees all in Power Systems at St. Petersburg Technical University (former Politechnical Institute), St. Petersburg, Russia.

ORNL Advanced Power System Modeling Updates

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OAK RIDGE National Laboratory

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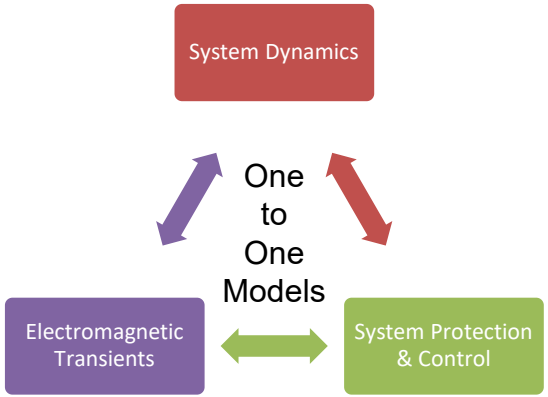
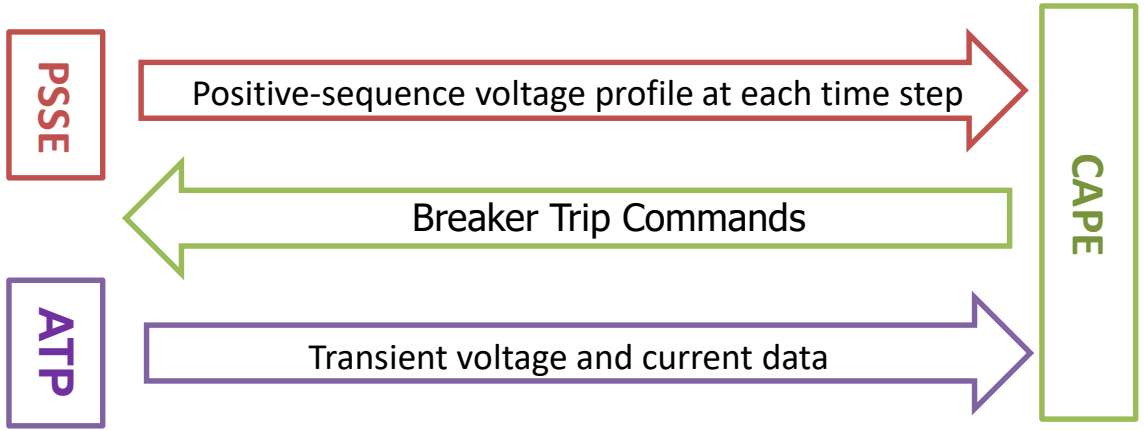
Grid Modeling

One-to-one modeling and simulation across domains

PSSE	Models the electromechanical dynamics of the system
CAPE	Computes unbalanced faults and models the response of the protection system
ATP	Models the electromagnetic dynamics of the system





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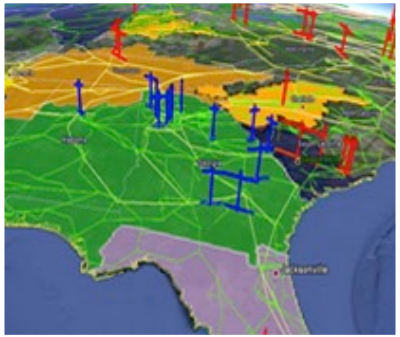
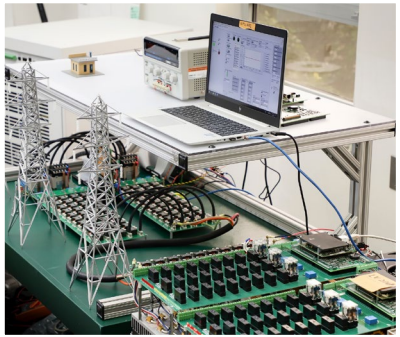
Grid Protection

Increased resiliency through advanced adaptive protection relaying



Protection & Control Modeling

Advanced dynamic protection models used in analysis tools for predictive wide-area imminent fault detection methods and resiliency



Power System Protection Emulation

Power system and protection models implemented in low voltage hardware for testing advanced protection and control schemes

Field Deployment

Develop model driven adaptive protection relay for reliable fault isolation of distribution lateral circuits with varying short circuit contributions and configurations

Adaptive Protection techniques for Network Microgrids

Provide expert analysis based on enhanced models and advanced protection schemes

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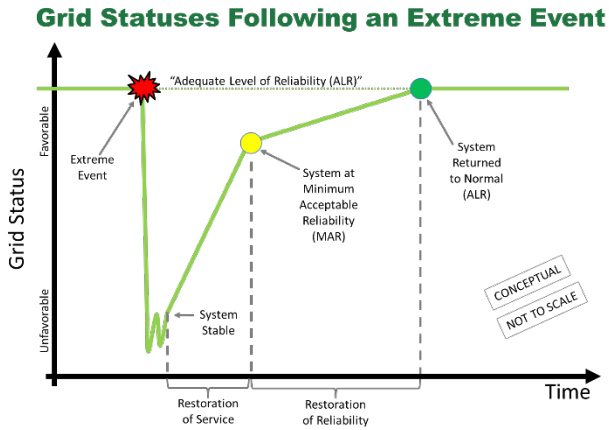
Grid Resilience

Increased resilience through High-Impact Low-Frequency event modeling, restoration, etc…



HILF Modeling

NATF Resilience: Ability of the system and its components to minimize damage and improve recovery from non-routine disruptions, including high impact, low frequency (HILF) events, in a reasonable amount of time.

Additional Modeling Activities:

- New Generation Injection Screening Tool for Puerto Rico
- UGA Deployments for frequency & disturbance monitoring
- National-Scale interdependency modeling

Nils Markus Stenvig is an R&D Staff Engineer, Energy and Environmental Sciences Directorate at ORNL.

He currently supports the Electrical and Electronics Systems Research Division within ONRL's Energy and Environmental Sciences Directorate. His ORNL project work is primarily in the areas of transmission security, reliability & resiliency; advanced grid modeling; system protection & control; and microgrids.

Mr. Stenvig was previously employed by American Transmission Company and held engineering positions of Transmission Planning Engineer, Operations Engineer, and Substation Maintenance Engineer over the course of six years. He also has previous experience with International Transmission Company (ITC Transmission), Wolverine Power Supply Cooperative, and was a student scholar at Lawrence Livermore National Laboratory (LLNL).

Mr. Stenvig received the B.S.E.E., MBA, and M.S.E.E. degrees from Michigan Technological University in 2008, 2010, and 2011, respectively.

Real-time Voltage Stability Assessment at SDG&E

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2019 IEEE PES Innovative Smart Grid Technologies Conference

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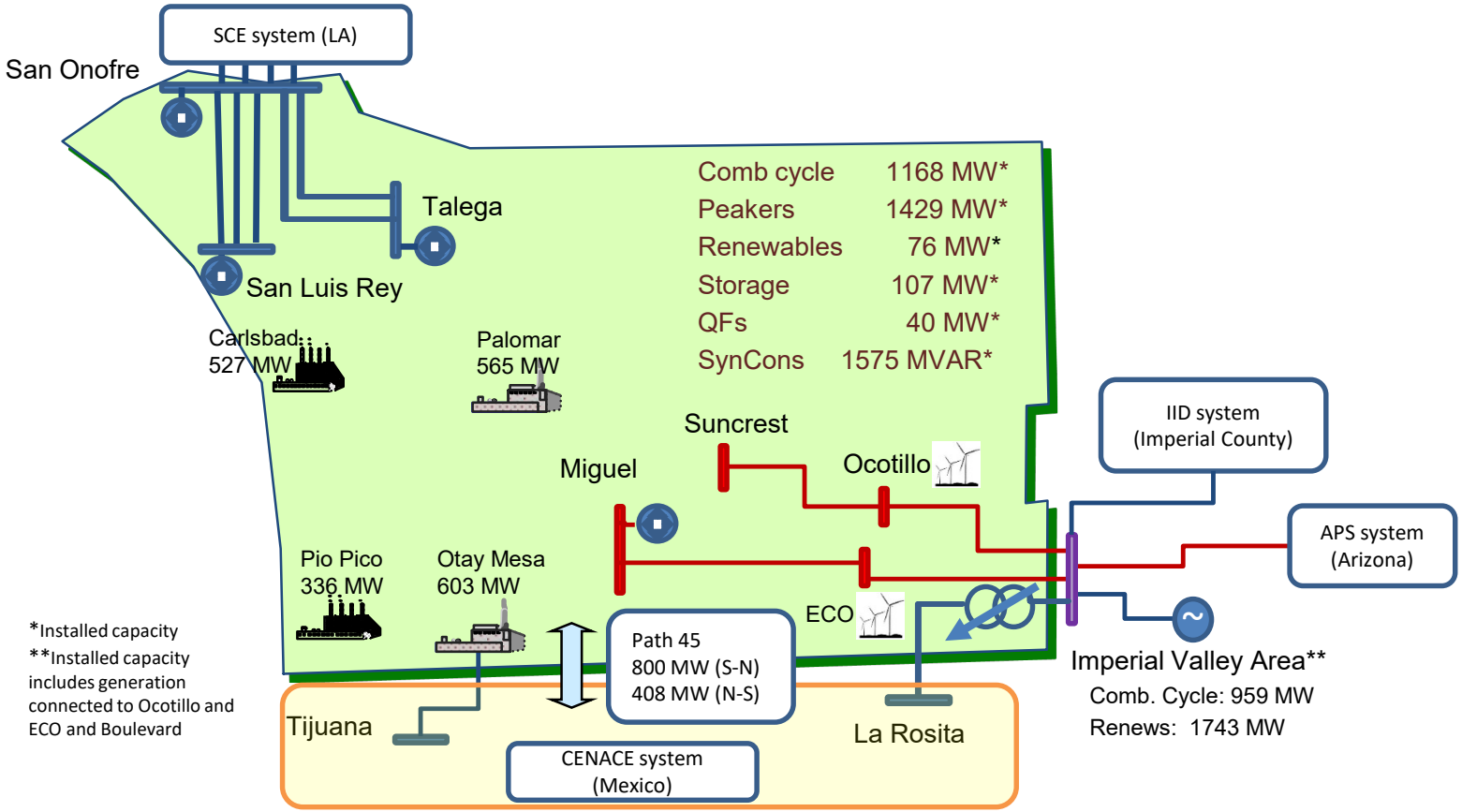
Outline

- San Diego Gas & Electric (SDG&E)
- Real-time Voltage Stability Assessment (VSA) at SDG&E, CISO (California Independent System Operator), and RC (Peak Reliability)
- VSA Transfer Scenarios Monitored
- Lessons Learned
- VSA tool assumption/setup changes in SDG&E
- Concluding Remarks – TOP-010

SDG&E Service Territory

- Serves 3.6 million customers in San Diego & Southern Orange Counties through 1.4 million electric and 873,000 gas meters
- A 4,100 square-mile service area comprised of 500 kV, 230 kV, 138 kV BES transmission facilities; all time-peak of 4,890 MW (9/16/2014)
- NERC-Registered: TO/P, GO/P, TP, LSE
- Within the CISO BA area boundary; Coordinated Functional Registration (CFR) with the CISO for TOP Reliability Standards

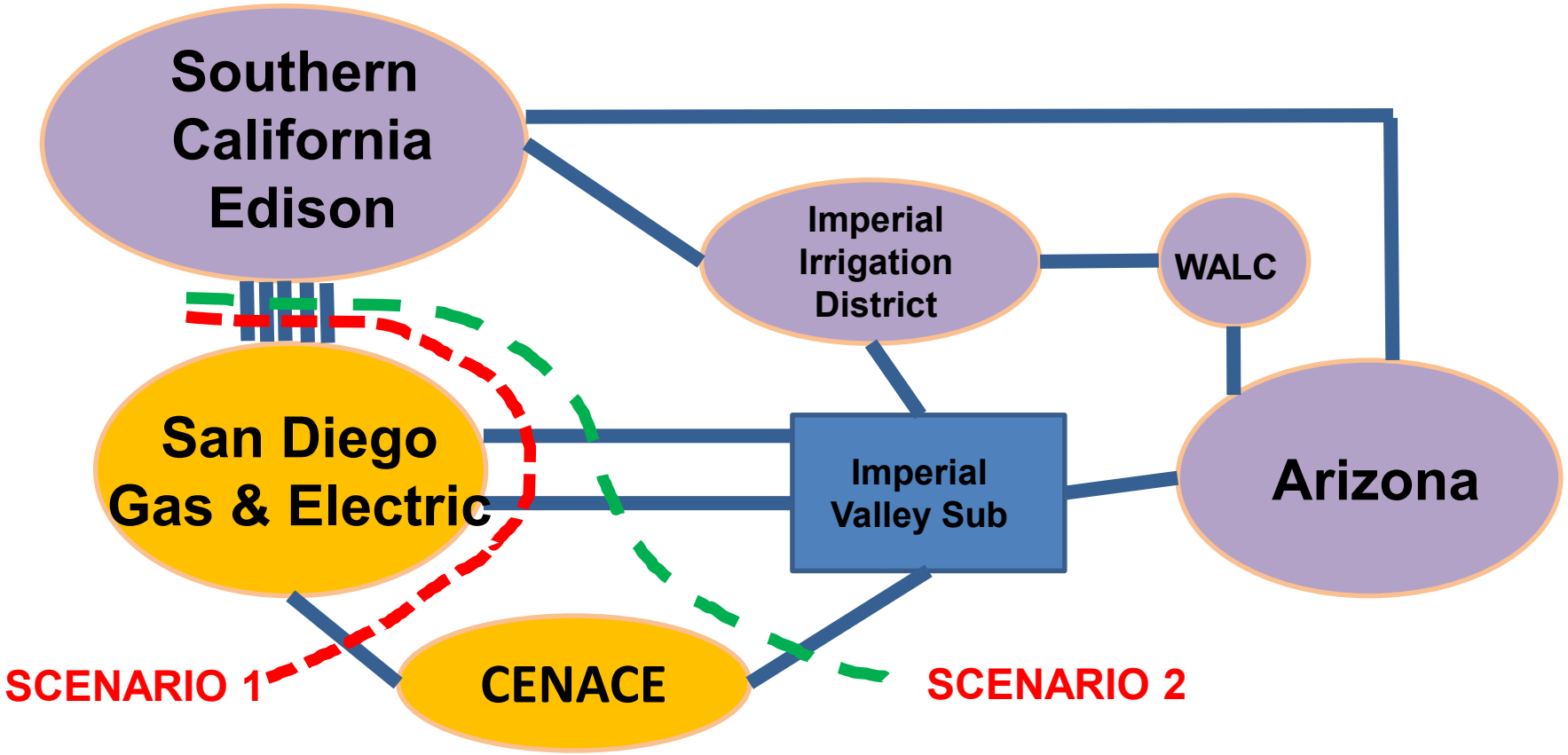
2018 SDG&E System Overview



near Real-Time VSA at SDG&E

- Two VSA tools are running in real-time (as a service); one in synch with the “primary” VSA tool running at Peak Reliability (RC) and the other in synch with the “secondary” tool running at CISO (BA, TOP). Solved SE provided to SDG&E by CISO and Peak at regular interval.
- Two transfer scenarios are running:
    - Import Into SDG&E (Scenario 1)
    - Import Into SDG&E and CENACE combined (Scenario 2)

VSA Transfer Scenarios



Assumptions/Setup

1. interface definition – see lines cut by the green dashed line on the previous slide
2. source - increase generation in APS and SCE bubbles
3. ***sink - increase load in SDG&E and CENACE bubbles (RC and CISO tools)***
   - ***Reduce generation in SDG&E tool***
4. transfer –increase in 100 MW steps up to 5000 MW
5. ***contingencies (include RAS action) – select N-1 (500kV line) and one N-2 (230kV lines)***
6. monitored buses – select buses on path flow expected to increase
7. shunts switching – switch capacitors & reactors on voltage control

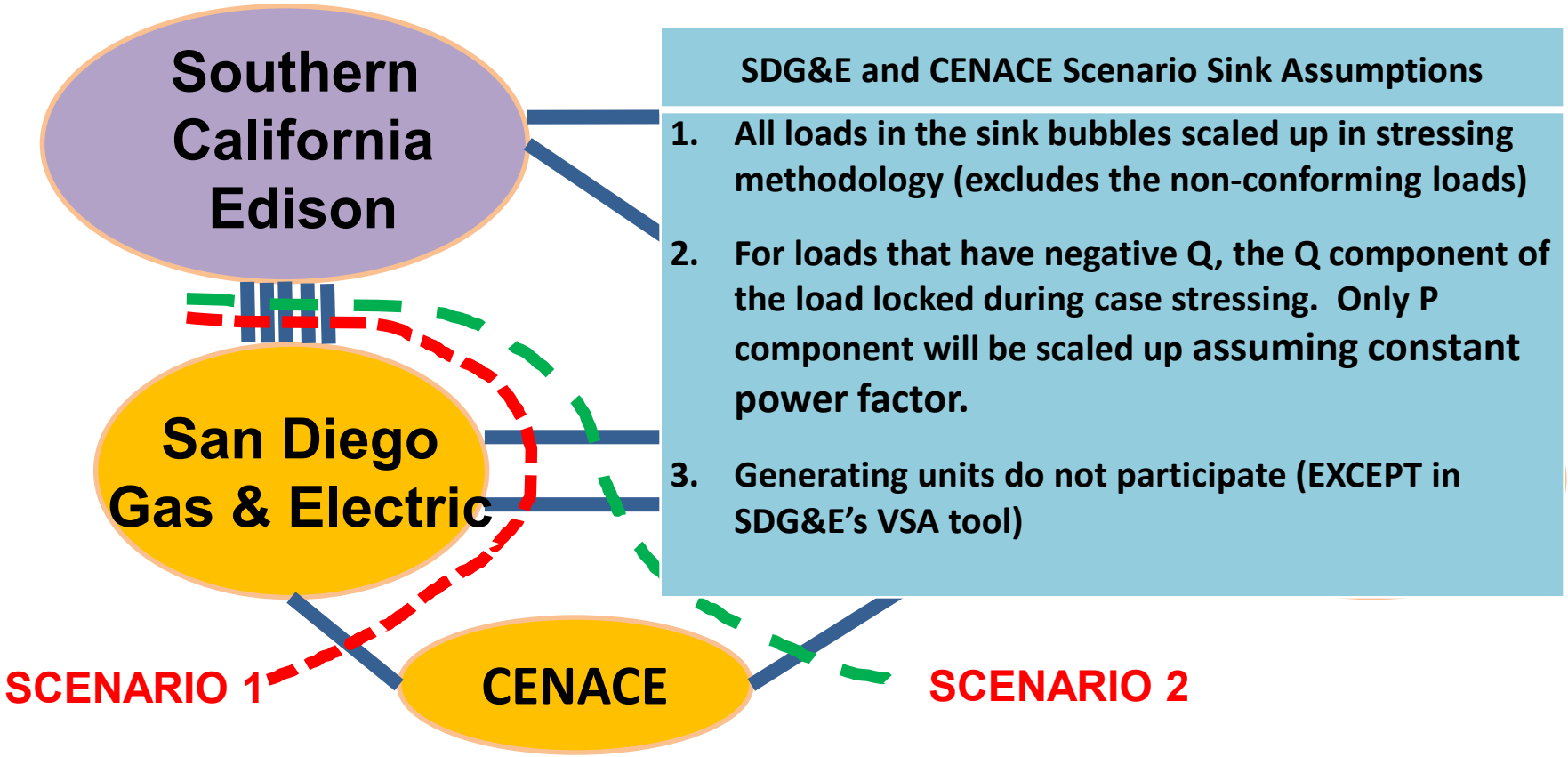
Lessons Learned

1. Network model should be accurate. Ensure periodic reviews due to system additions and retirements.
2. SDG&E (TOP) can update its EMS model more frequently than the CISO & RC can update theirs, so model data sharing in advance is important and notifying the CISO & RC of the status of the work.
3. Be proactive about reviewing vendor patches or program updates to determine which VSA assumptions may be impacted. This includes subscribing to vendor notifications and vendor user group meeting.
4. Engaging vendor and IT support early will help identify and resolve problems faster.
5. Users (OEs), particularly new users, should review and inspect modeling/method assumptions periodically, particularly after a system event occurs.
6. Monitoring of the program output and log file and processes will help diagnose issues sooner.

Lessons Learned

1. Consider running additional scenarios & flexible contingencies (beyond N-1 criteria) during a hot weather alert.
   - Recommendation: add ability to change status of device(s) in a contingency in the scenario file
2. Having two real-time VSA tools (and models), monitoring and investigating significant limit differences and huge limit drops help discover issues in the VSA stressing methodology, VSA assumptions, and the network model.
3. System operators should be trained on the importance of understanding early the resulting limiting bus(ses) and limiting contingencies for situational awareness particularly in infrequent operating condition.
4. Ensure procedures provide clear guidance for analyzing, monitoring, validating and dealing with real-time VSA IROLs.
   - Benchmarking, communicating, coordinating among impacted entities are required.
   - With regular training be able to run offline studies to be able to evaluate the validity of the near real-time result.

Sink Assumption Details

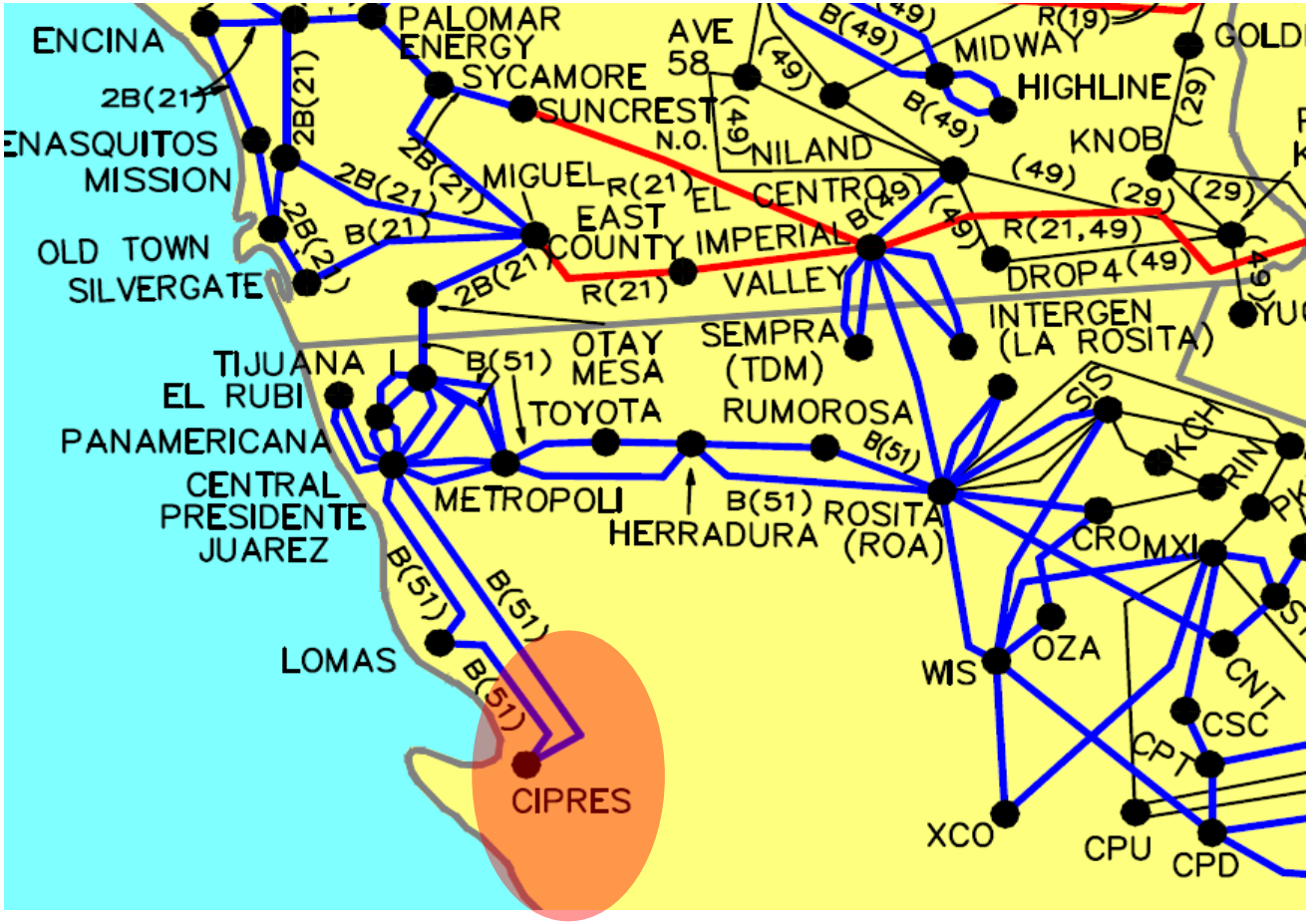


SDG&E and CENACE Scenario Sink Assumptions

1. All loads in the sink bubbles scaled up in stressing methodology (excludes the non-conforming loads)
2. For loads that have negative Q, the Q component of the load locked during case stressing. Only P component will be scaled up assuming constant power factor.
3. Generating units do not participate (EXCEPT in SDG&E's VSA tool)

A 1000 MW drop not expected until later for switching

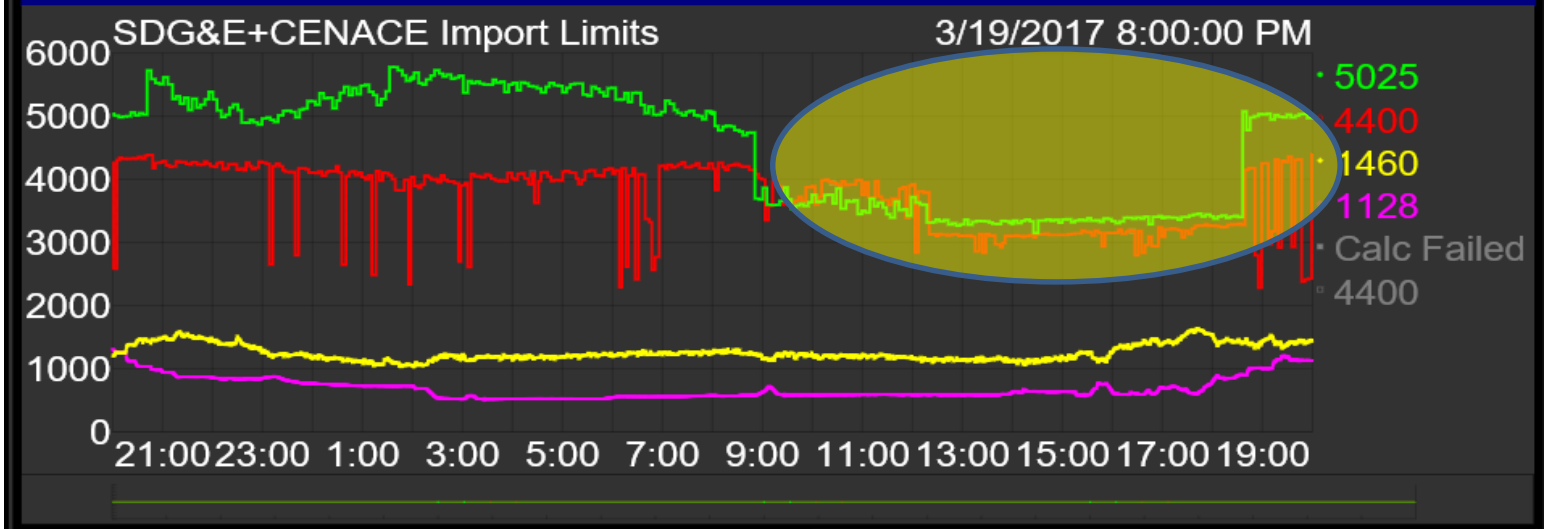
Investigation



Root cause: the CIP-KON 115kV Line was out of service at ~8:45 AM, March 19 2017

Shows a need for realistic MW

CAISO / PEAK RC RTVSA IMPORT LIMITS



IROL NOT IN EFFECT

IROL IN EFFECT	NO	DIFF (RC-CAISO)		TL 23050:	Energized
STUDIED LEVEL	4000	DIFF (Study-SDG&E)	2576	TL 23040:	Energized
PEAK RC TOOL	5025	DIFF (RC-SDG&E)	3562	TL 23040 IV N-1 SPS	
CAISO TOOL	4400	DIFF (CAISO-SDG&E)	2937	ARMING LEVEL:	1100
SDG&E/CENACE IMPORTS	1463	PEAK RC ROC	19 MW/20 Min	RENEWABLE ARMED:	NONE
SDG&E GEN	1128	CAISO ROC	91 MW/20 Min	CENACE RAS TRIPS:	23050
CENACE IMPORT	39				
CENACE GEN	1419				

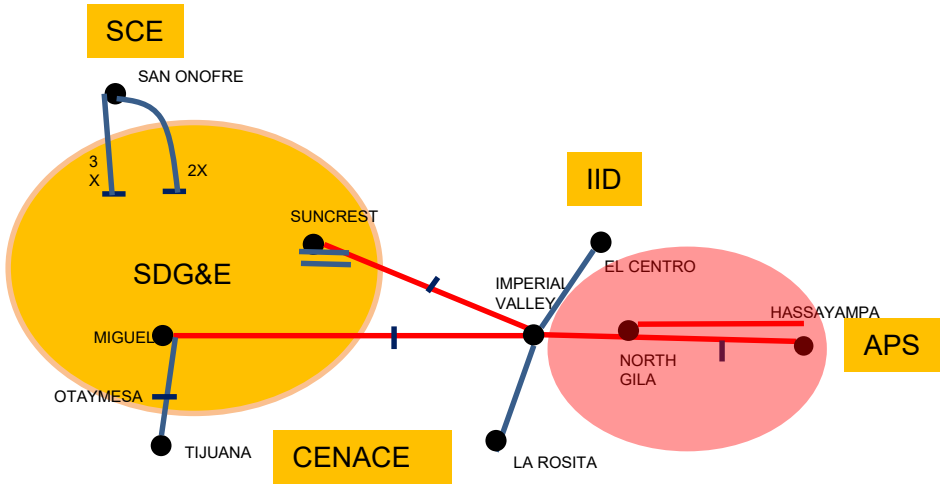
WARNINGS: DIFF (RC-CAISO) > 600 MW

LINK TO SDGE

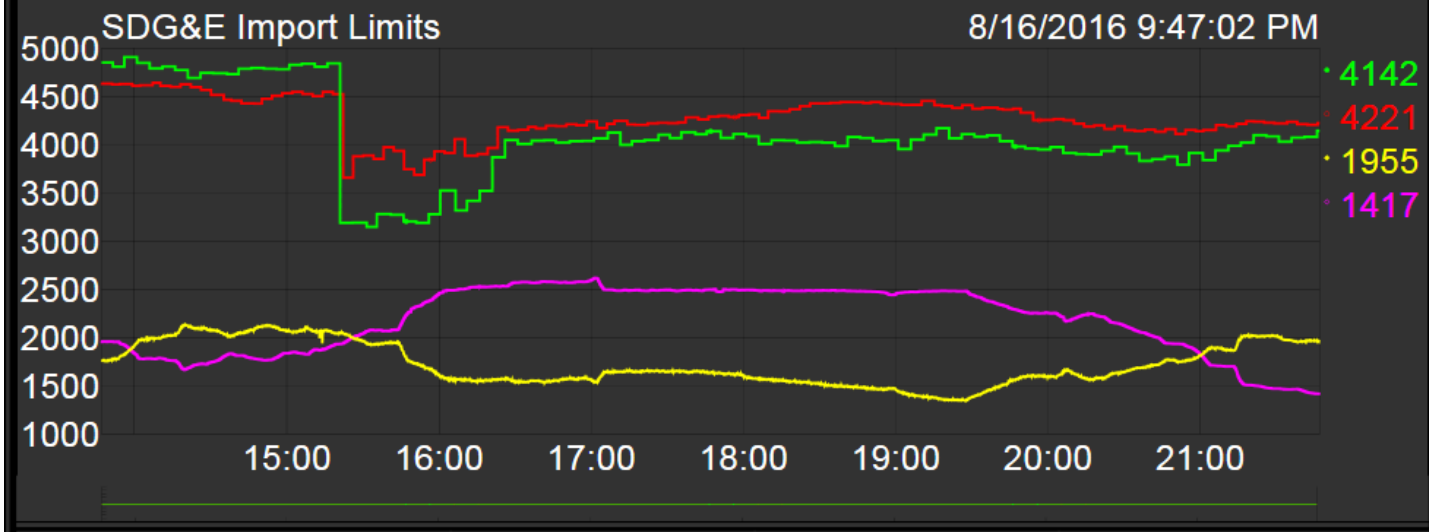
Contingency Assumption Details

- Removed (500kV lines east of Imperial Valley):
  A. Imperial Valley – North Gila 500kV Line
  B. Hoodoo Wash – North Gila 500kV Line
  C. Hassayampa – Hoodoo Wash 500kV Line
  D. Hassayampa – North Gila 500kV Line

- Issues:
  A. These N-1 contingencies have wider area impact
  B. More thermal issue than voltage stability
  C. Could put the focus away



CAISO / PEAK RC RTVSA IMPORT LIMITS



IROL INDEX	3	(1) PEAK RC		(2) CAISO	(3) STUDIED LEVEL
IROL IN EFFECT	YES	DIFF (RC-CAISO)	-79		
STUDIED LEVEL	3000	DIFF (Study-SDG&E)	1045		
PEAK RC TOOL	4142	DIFF (RC-SDG&E)	2187		
CAISO TOOL	4221	DIFF (CAISO-SDG&E)	2266		
SDG&E IMPORTS	1955	PEAK RC ROC	58	MW/20 Min	
SDG&E GEN	1417	CAISO ROC	4	MW/20 Min	

TL 23040: Energized

TL 23040 IV N-1 SPS
ARMING LEVEL: 1100
RENEWABLE ARMED: NONE

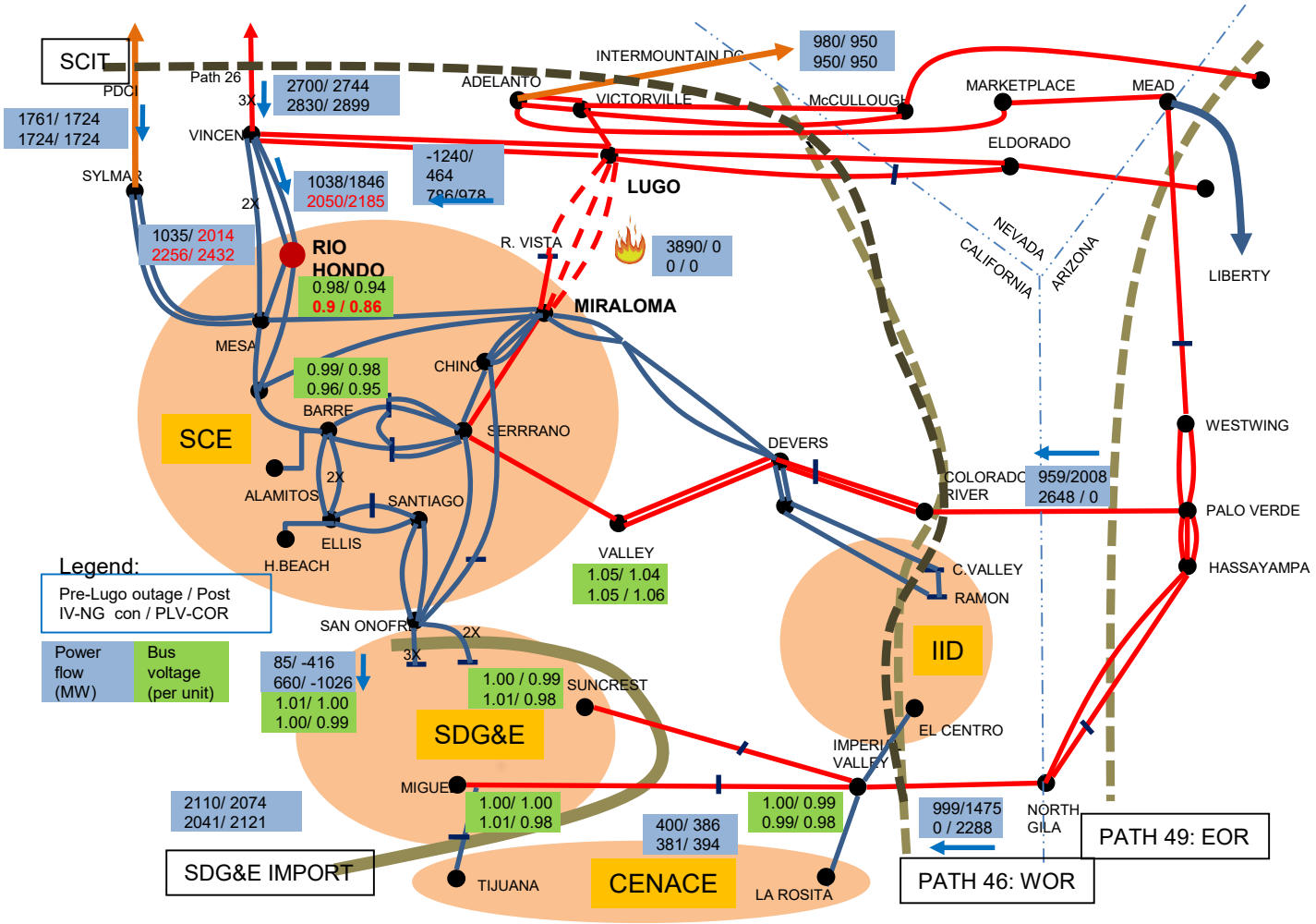
TL 23050: Energized

WARNINGS:

LINK TO SDGE+CENACE IMPORT LIMIT MONITOR

SDGE+CENACE INTERFACE

August 16, 2016 Event (Blue Cut Fire)



Closing

- Per NERC Std. TOP-010-1(i), each TOP (R1) shall address the quality of the Real-time data necessary to perform its Real-time monitoring and Real-time Assessments.
  - Actions to address Real-time data quality issues **… when data quality affects Real-time Assessments.**
- TOP-010-1(i) also requires each TOP (R3) to address the quality of analysis used in its Real-time Assessments.
  - Actions to address analysis quality issues…**when Real-time Assessments affects Operating decision or Instruction.**

Robin Manuguid is a Principal Engineer with San Diego Gas & Electric in the Electric Grid Operations Department.

He held positions in Resource Operations, Power Contracts, Distribution Standards, and Transmission Planning before assuming his current position since 2004.

Robin is an IEEE member and a Registered Professional Engineer in the State of California. He is currently a member of EPAS (Event and Performance Analysis Subcommittee) at WECC.

He received his BSEE degree in Electrical Engineering from California Polytechnic State University at San Luis Obispo in 1992.