RTDS Domain Space

In

Large Scale Wide-area Applications

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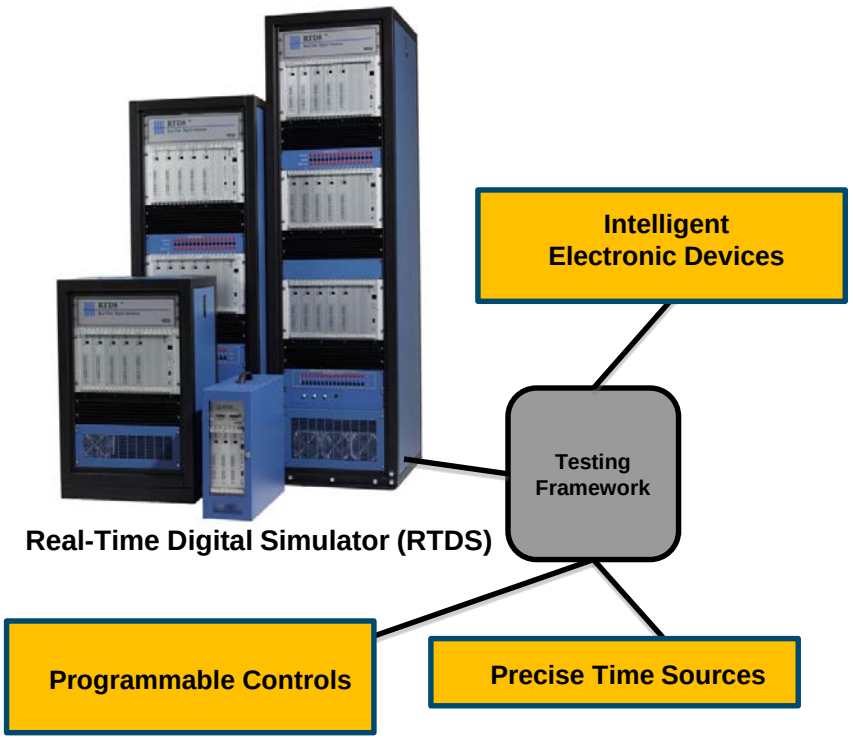
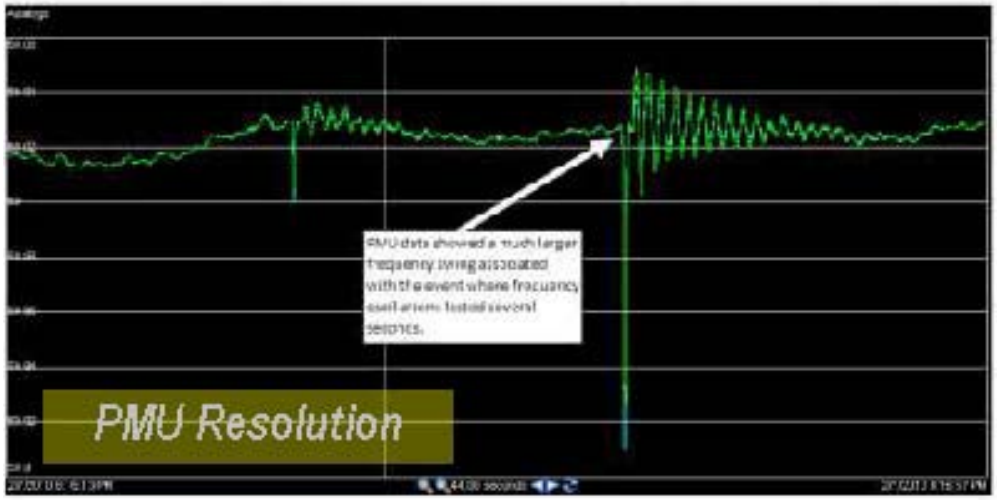
Background

- Interconnected complex power systems require system simulations tools to examine dynamic behavior, model validation, and analytic tools
- Device performance is part of the overall system performance measure
- Need for an environment to create system dynamics without impacting grid reliability for performance evaluation of power system



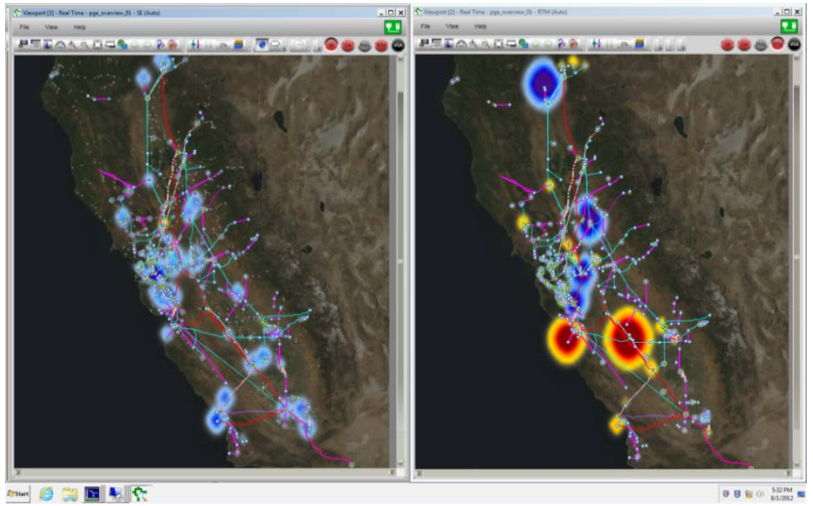
What is Synchrophasor Technology?

- Next generation measurement technology.
  - (voltages, currents, frequency, frequency rate-of-change, etc.)
  - Higher resolution scans (e.g. 30-120 samples/second)
  - Improved visibility into dynamic grid conditions.
  - Early warning detection alerts.
- Precise GPS time stamping.
  - Wide-area Situational Awareness.
  - More accurate Post-Event Analysis



High Level Applications and Functions in PG&E Project

1. Situational Awareness, Visualization and Alarming for Operators
2. Enhanced Energy Management Systems and State Estimation (EMS)
3. Post-Disturbance Event Analysis for Planners and Engineers
4. Operator and Engineering Training Enhanced Dispatch Training Simulator
5. Cognitive Tasks and Human Performance Analysis
6. Data Exchange with Neighboring Systems
7. Fault Location



Applications and Functions in PG&E Project

1. Situational Awareness, Visualization and Alarming for Operators
   - –Unbalance power applications
   - –Abnormal angles and voltages
   - –Line overloads,
   - –Dynamics oscillations (small signal oscillation) monitoring and
   - –System restoration
2. Enhanced Energy Management Systems and State Estimation (EMS)
   - –Adding synchrophasor measurements to existing SE measurements
   - –Track dynamic state changes of a system during disturbances
   - –EMS measurement support Volt-VAR Optimization
3. Post-Disturbance Event Analysis for Planners and Engineers
   - –Substation-level data analysis
   - –System-level event analysis
4. Operator and Engineering Training
   - –PMU Based Dispatch Training Simulator (DTS)
5. Cognitive Tasks and Human Performance Analysis
6. Provide interfaces with EMS and with third parties
7. Distributed and / or Linear State Estimation
8. Data Exchange with Neighboring Systems
9. Fault Location

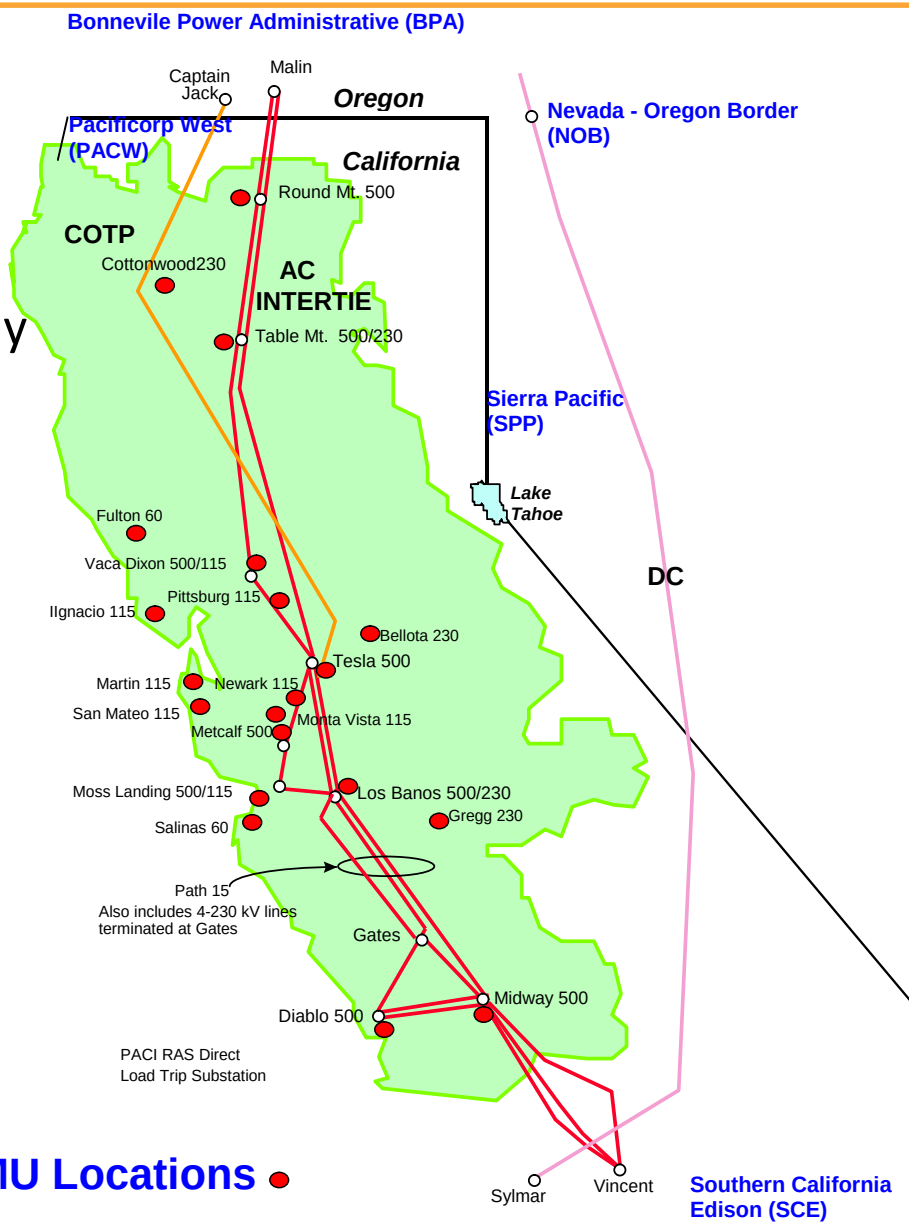
Activities to Mature at PG&E POC

1. Expand PG&E System Model and Hardware (e.g., RTDS & Associated Equipment)
2. Synchrophasor Data Quality Validation
   - Enhanced Intrusion Detection
   - Wider data access
   - Enhanced Visualization
   - On-line Data Mining to Support System Engineering and Planning
   - Data Exchange for Advanced Applications
3. Automated Dynamic Set-points for Angle Alarms
4. Restoration Process Enhancement Tools - Blackstart
5. Post-Event Analysis and Offline Analytics
6. Fault Location on Series Compensated Lines
7. Enhanced Reactive Margin Detection - RVII
8. Training
   - Training Course (s)
   - PMU capable DTS

Background at PG&E

As part of the System Deployment:

- Proof-of-Concept (POC) Facility
- PMU and PDC field installations
  - Over 160 PMUs networked from nearly 30 switchyards, 60-500 kV
    - 60 and/or 120 measurements-per-second
    - M and P class data.
  - Fully Redundant Substation PDCs
  - Fully Redundant Super PDCs at Two Control Centers
  - Engineered to Support Disaster-Recovery Control Centers
- Control Center Applications
- Engineering Applications



POC Facility Update

- RTDS Upgrade
  - Hardware upgrade – new cards and additional racks
  - Ability to model
    - PG&E's Bulk transmission system, Part of neighboring systems
    - Key generators and loads
  - Excess of 130 virtual PMUs
  - Significant model update and extension – Transmission, Generation, Load
- Additional Real PMUs and Aggregate PDCs (46 physical PMUs, 6 PDCs)
  - PMU, PDC, OpenPDC – Multi-vendor
- Additional Clocks
- New Servers and Applications
  - 8 new high-power servers - Each with 5 times more capability than previous servers
  - Running over 30 applications, including 3 Super PDCs
  - Architecture reflecting Control Center and redundancy requirements
- Additional network switches and routing capability
- Upgraded data storage capacity

Integrating Lessons Learned
FERC Report, Situational Awareness

Angular Separation

- Ability to determine, in real time, the standing angles that would result following major transmission line outages
- Placing PMUs in locations such that standing angles can be seen directly by system operators in SCADA/EMS systems

Real-Time External Visibility

- Lack of adequate awareness of external contingencies that could impact one's system

Real-Time Tools

- E.g., Without having tools in place to determine the phase angle difference between the two terminals of a line after the line tripped, one should not / cannot commit to restore the line quickly.
- Need seasonal and next-day contingency analyses that address the angular differences across opened system elements
- Having, but not using, the real-time tools to monitor system conditions
- Real-Time Contingency Analysis (RTCA) tools need to be functional and operating

Metrics and Valuation Measures

SE Differences

- Compare SE executions
  - Use better model based on model comparisons
    - Base case is with PMU data turned off
    - Change case is with PMU data turned on
  - Capture
    - Performance index differences
    - Largest voltage differences
    - Largest flow differences
    - Observability
    - Bad data detection

Volt / VAR Optimization Measurement

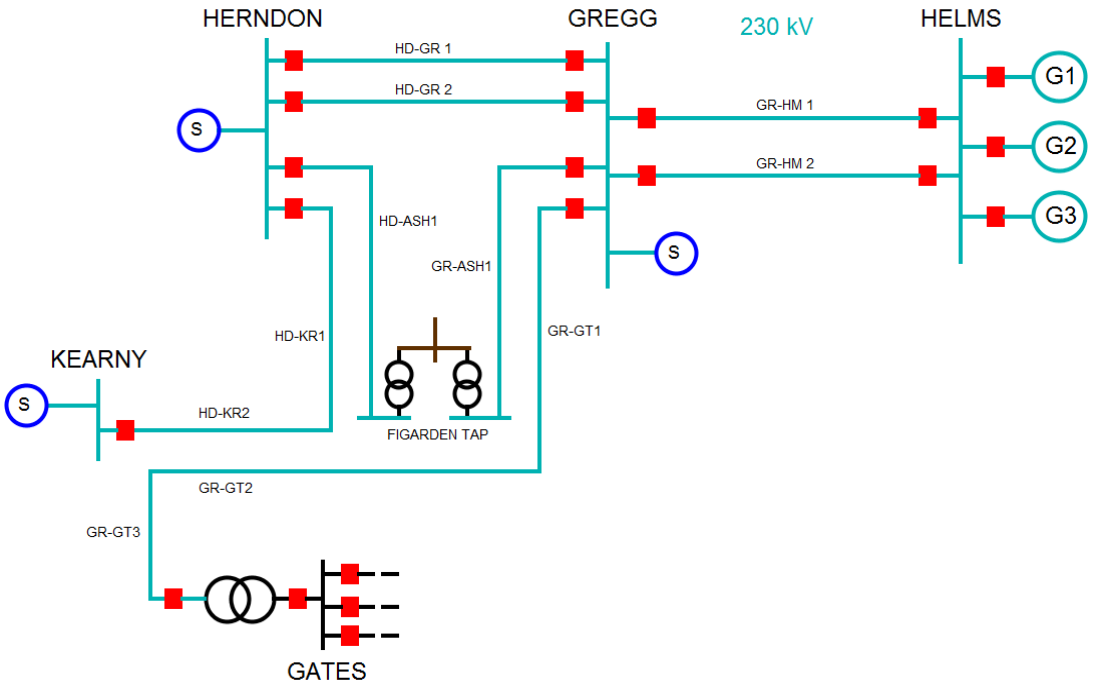
- For differences between SE with and without PMU data, capture
  - Differences in Voltage margins due to optimization
  - Differences in Var requirements due to optimization

Congestion Management

- Based on SE results
- Compare on critical stability limited and voltage limited critical paths
  - Nominal Transfer Capability (NTC)
  - Real-time Transfer Capability (RTC)
  - Changes to LMPs and/or flowgates
  - Changes to Congestion
- Capture change in cost based on LMP or Flowgate

PG&E's Advanced Technology Deployment Process

1. Scope and Specifications
2. Proof of Concept (POC)
   - A smaller scale engineered synchrophasor system including all elements of the production system for device, function, and interoperability validation
   - Multi-vendor concept (PMU and PDCC) to validate interoperability and performance
3. Deployment and Commissioning
   - Includes standardization, trainings, and life cycle management



How do we manage a small scale system to help validate:

- **Standards**
- **Create environment for security testing**
- **Support training across multiple lines of business**
- **Manage stranded asset**
- **Life cycle management**
- **Validate Analytics and Tools**

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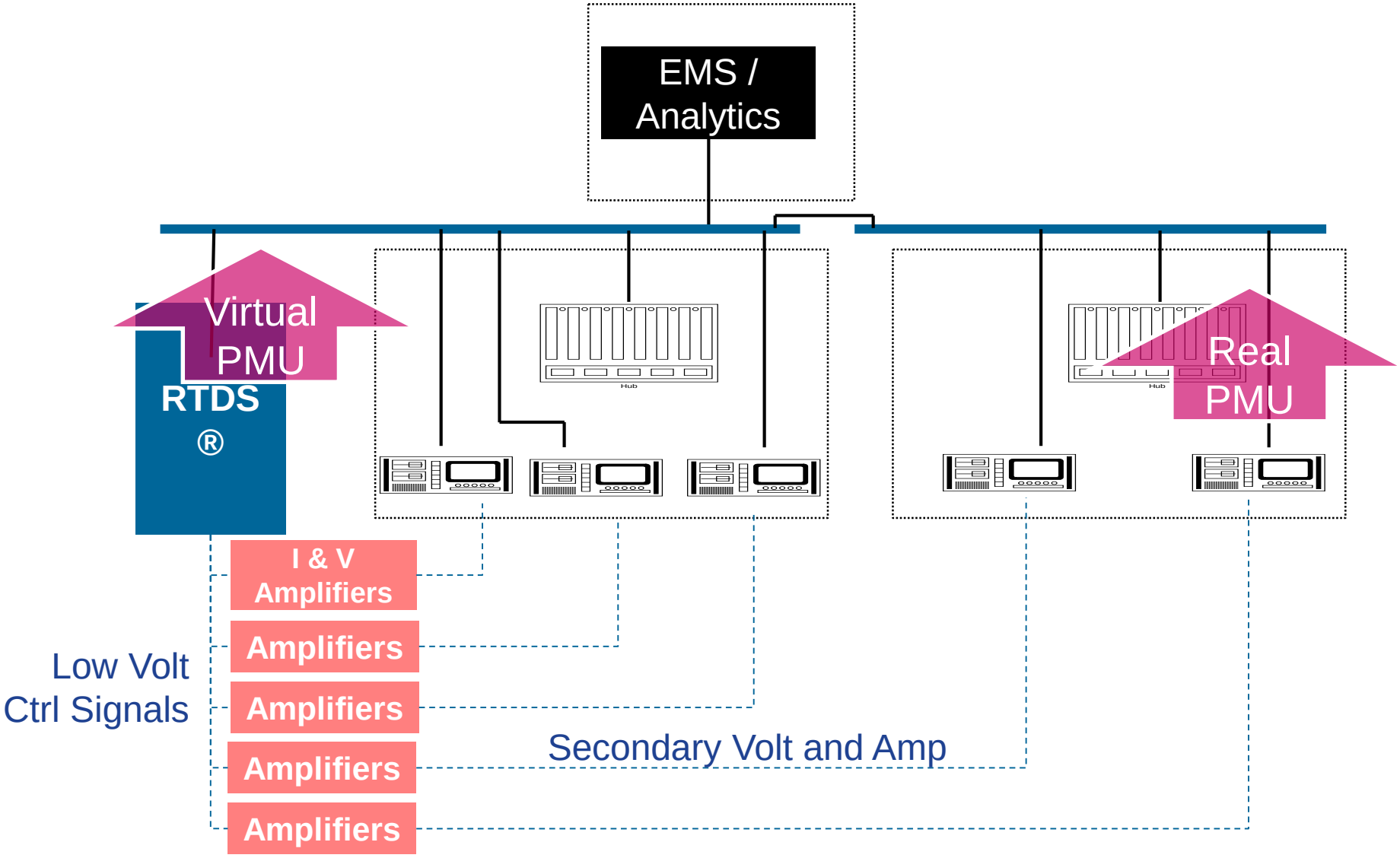
Background: PG&E POC

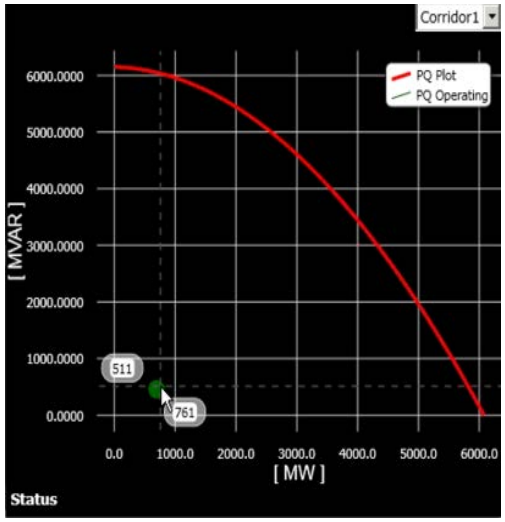
- Proof-of-Concept Facility
  - Validating Every Device and Function: PMU, PDC, Clocks, Switches, Routers, etc.
  - Validating and Improving Industry Standards (e.g.: IEEE, IEC)
  - RTDS and Various Test Equipment to Validate Functions
  - Training and Troubleshooting Ground
  - System Integration and End-to-End Testing
  - Commissioning Process Development

Virtual PMUs and Physical PMUs Testing

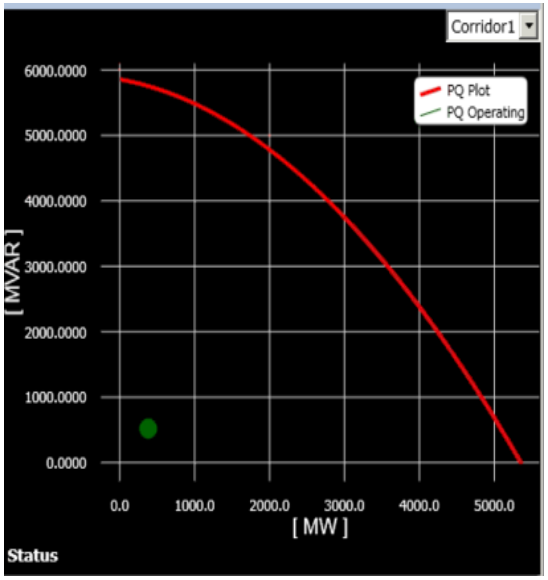


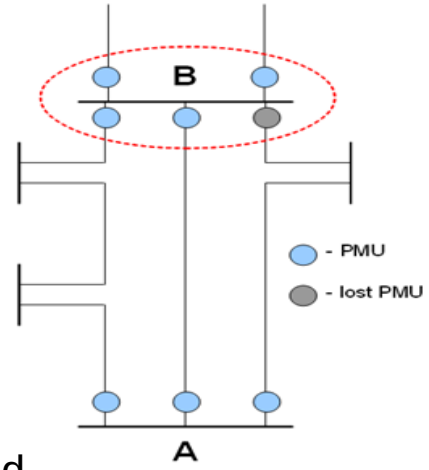
Reactive Margin and Operational Boundary for a Corridor Using RTDS Simulations (Normal system, No planned clearances, No system adjustments, Flexible to support a variety of system contingencies)

Two Generators Connected

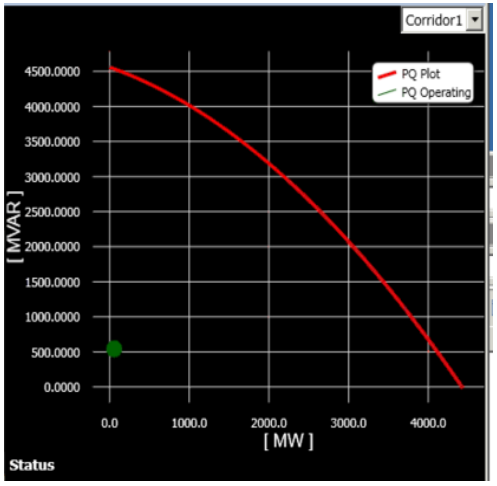


One Generator Disconnected

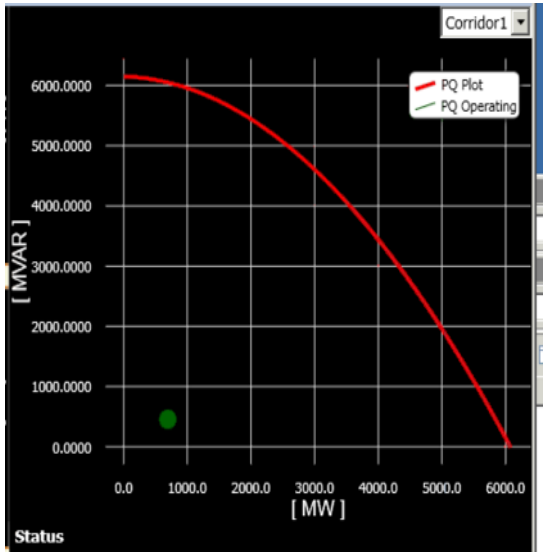




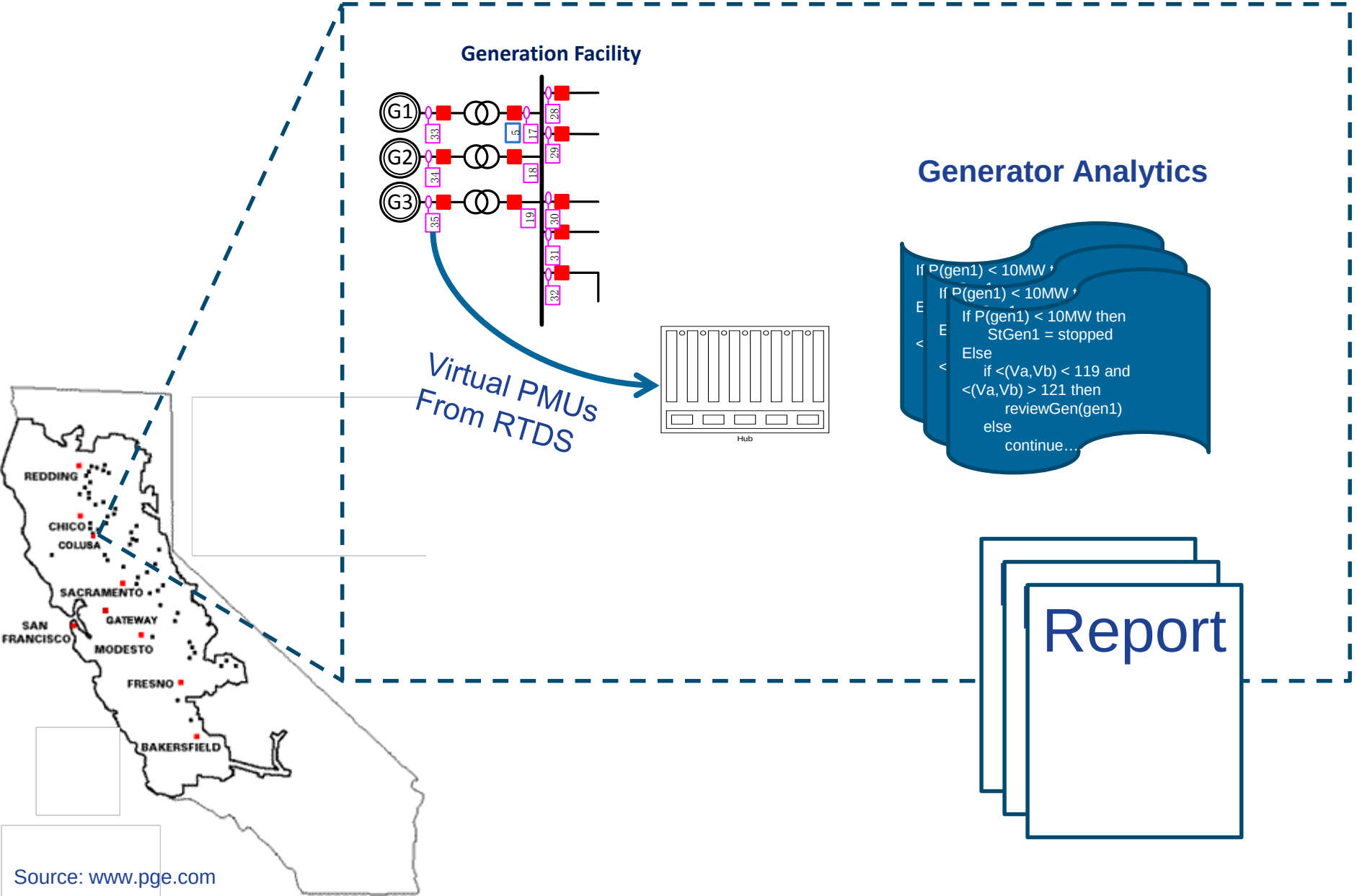
Both Generators Removed



Both Generators Re-connected



Localized Benefits



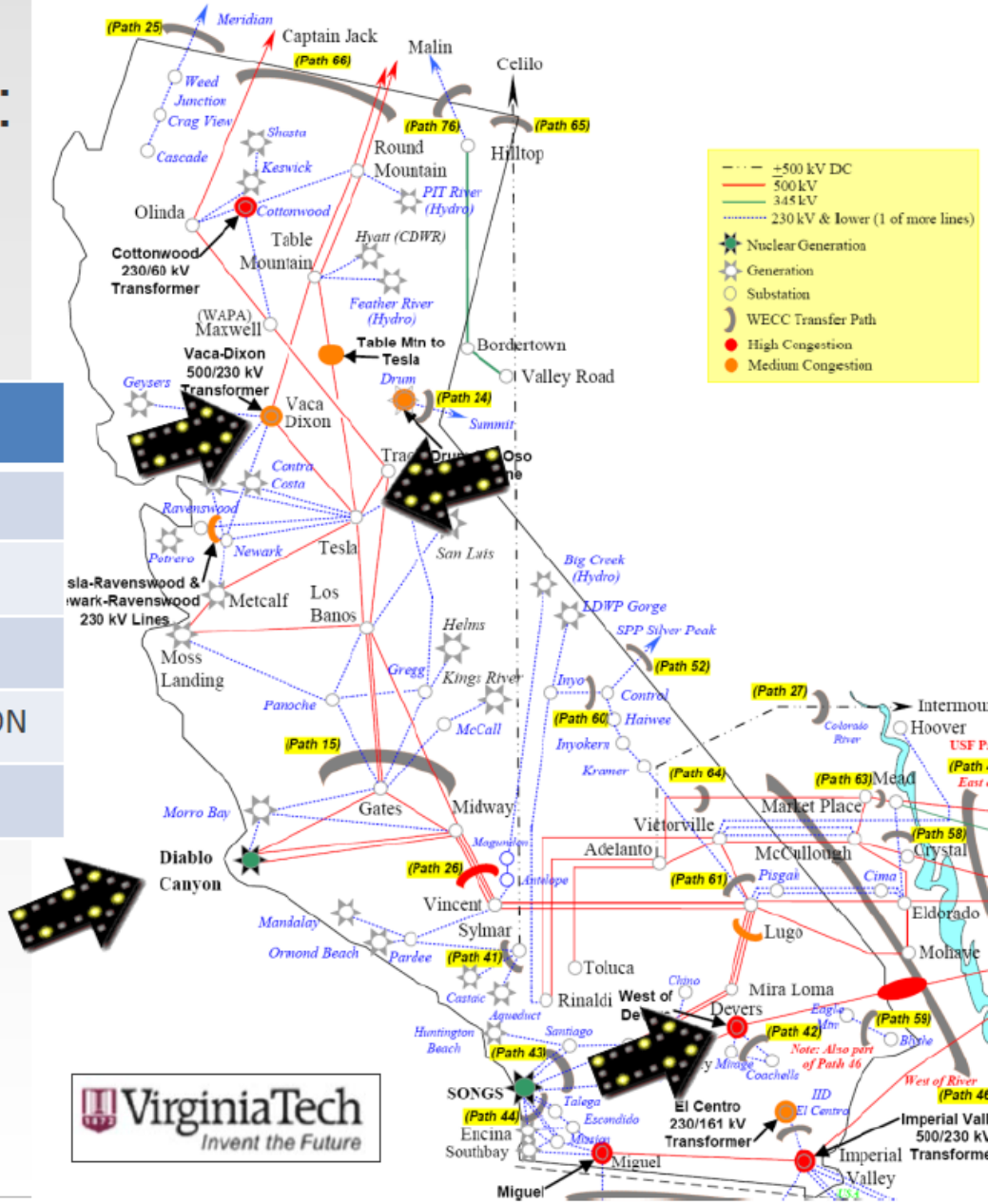
Source: www.pge.com

Adaptive Voting Scheme: PMU Placement

Line Current	
DEVERS	VALLEYSC
DEVERS	PALO VERDE
DIABLO	MIDWAY
TESLA	LOS BANOS
Refere	
Su	CA-DIXON
	ESLA

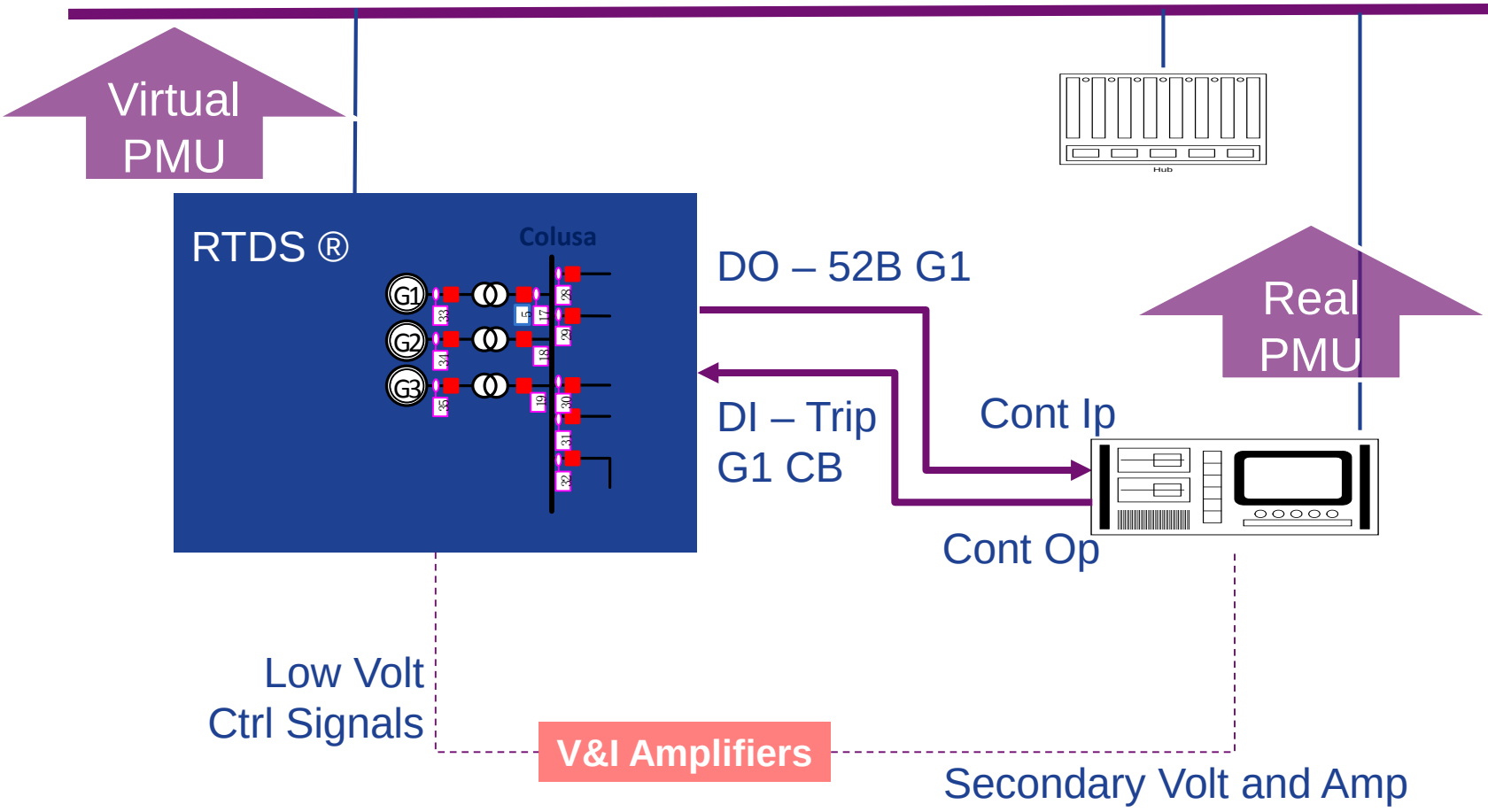
PMU
DEVERS
TESLA
DIABLO
VACA-DIXON

Do you have the original of this slide?



VirginiaTech
Invent the Future

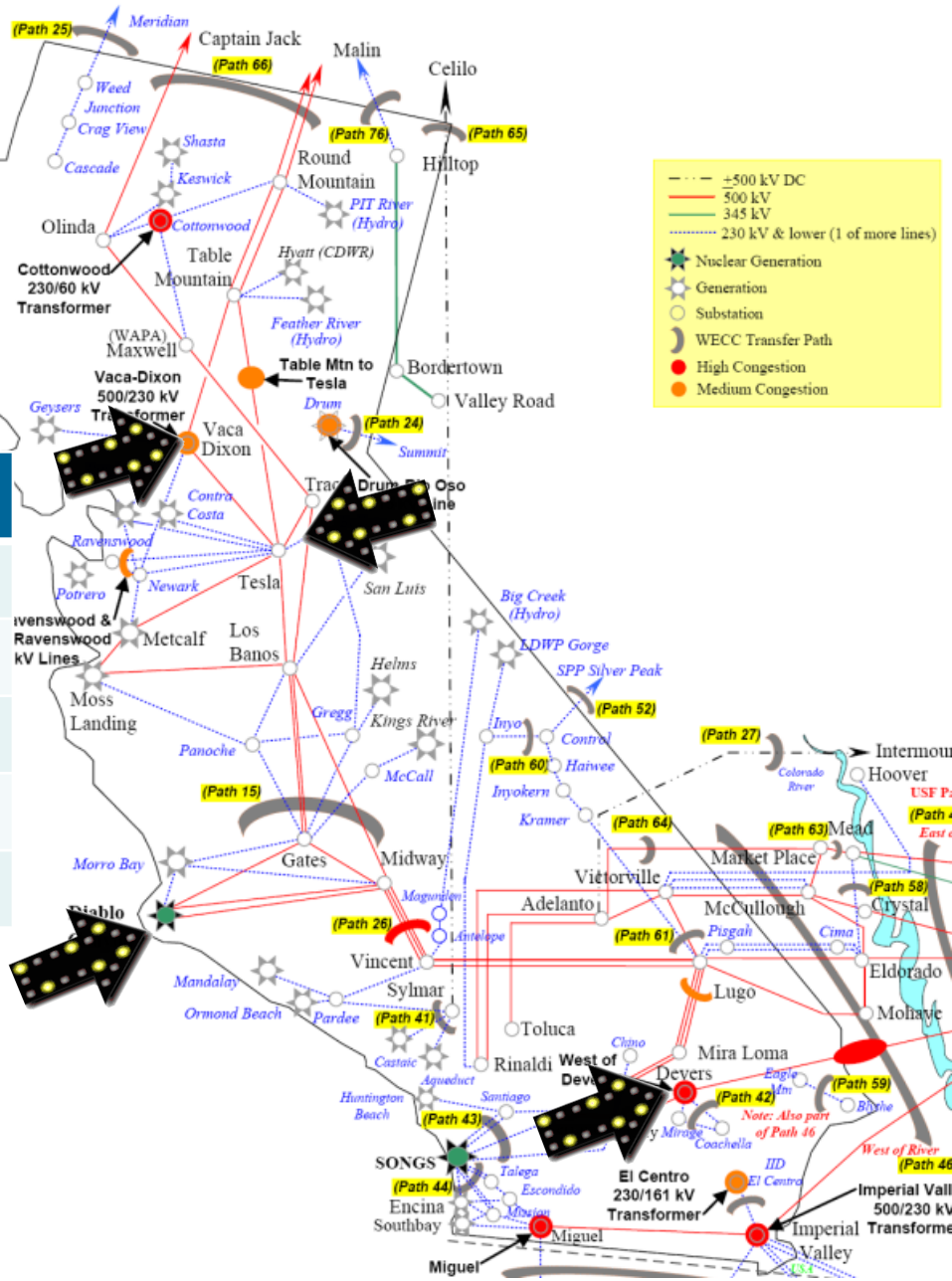
Closed-Loop Testing



Adaptive Protection PMU Placement

Line Current	
DEVERS	VALLEYSC
DEVERS	PALO VERDE
DIABLO	MIDWAY
TESLA	LOS BANOS
References	
Summer	VACADIXON
Winter	TESLA

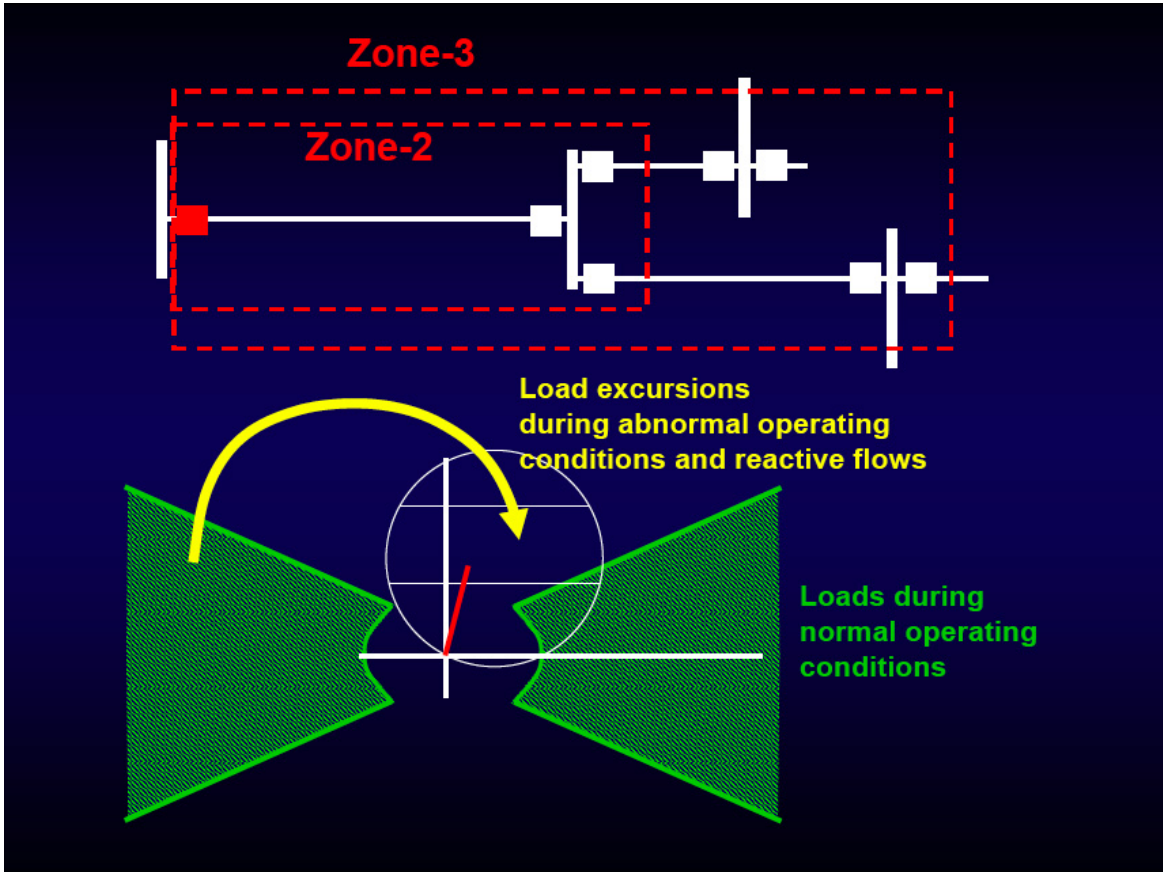
PMU
DEVERS
TESLA
DIABLO
VACADIXON



Adaptive Protection
Advantages of RTDS

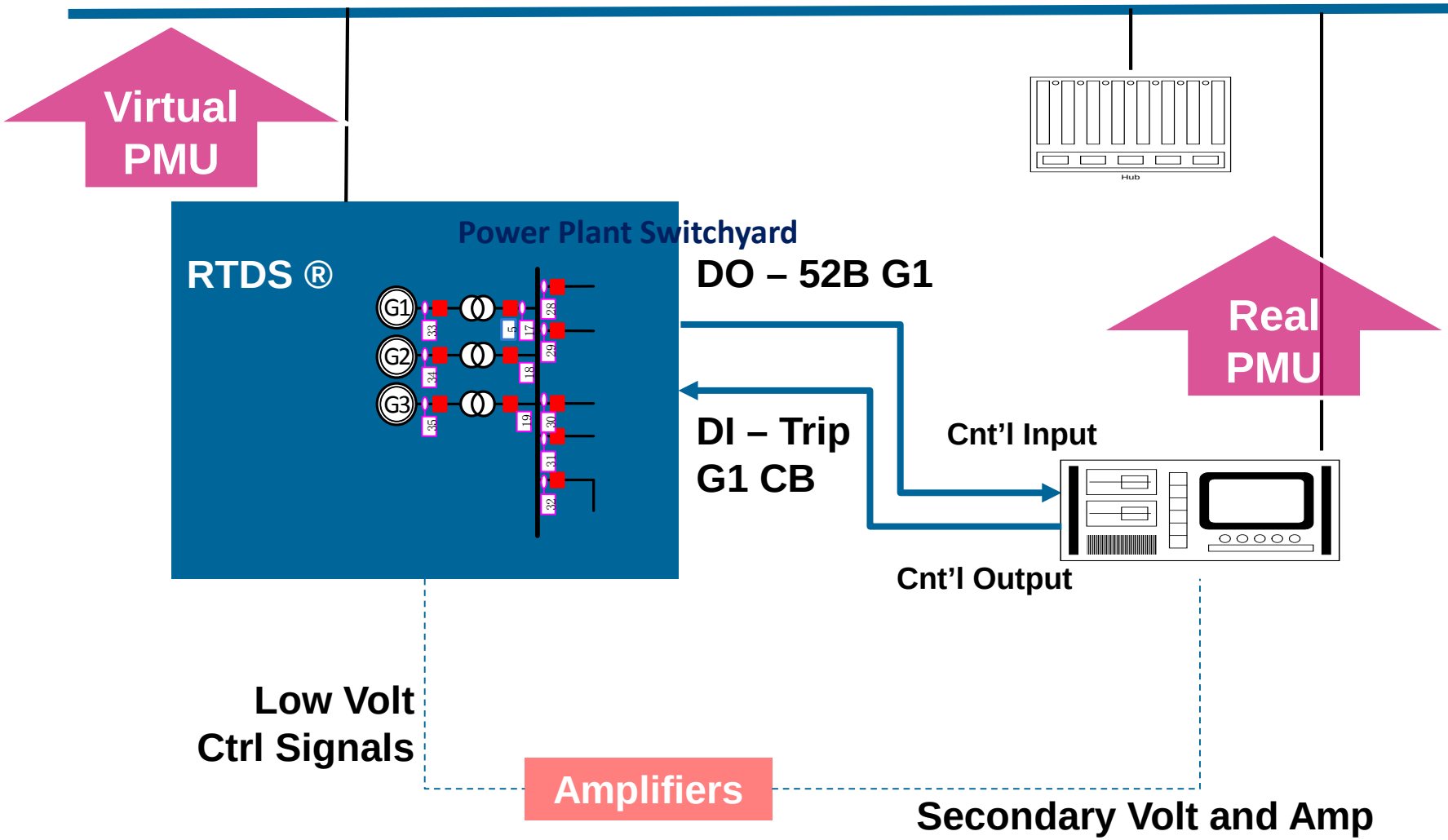
- Test variety of Power System conditions without having to wait for special condition, specific season, ….
- Validating analytics and concepts before implementation, engaging neighbors for data exchange, field deployment, …

RTDS – Virtual PMU based Impedance Relay Encroachment Alarm



Picture courtesy of Virginia Polytechnic Institute

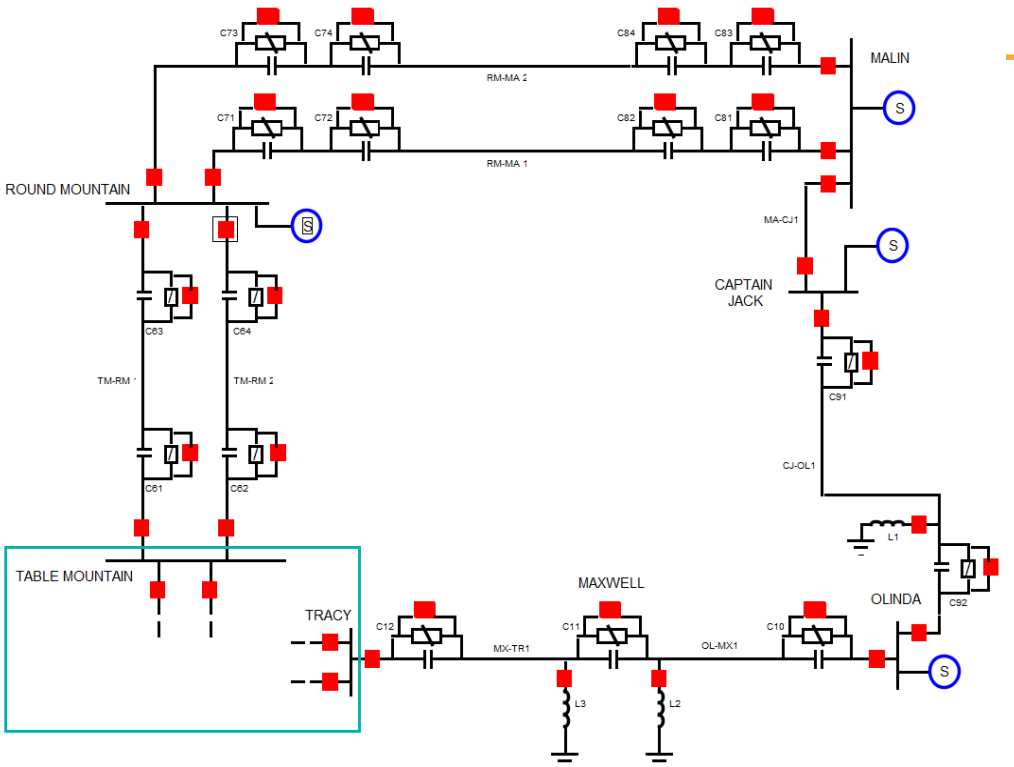
Closed-Loop Testing



Next Steps

Applications and Functions

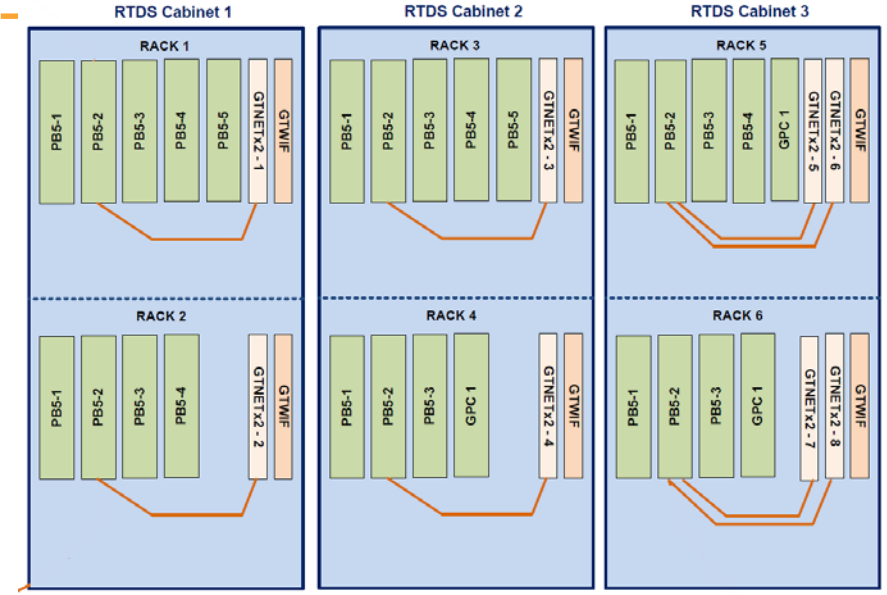
- Synchrophasor Data Quality and Security Validation
- Automated Dynamic Set-point Determination for Angle-based Alarms
- Enhanced Fault Location
- Real-time Voltage Instability Indication (RVII)
- Efficient System Restoration (Blackstart)
- Post-Event Analysis
- PMU-enabled Dispatcher/Operator Training Simulator



Synchrophasor Technology Realization
Usage Domain

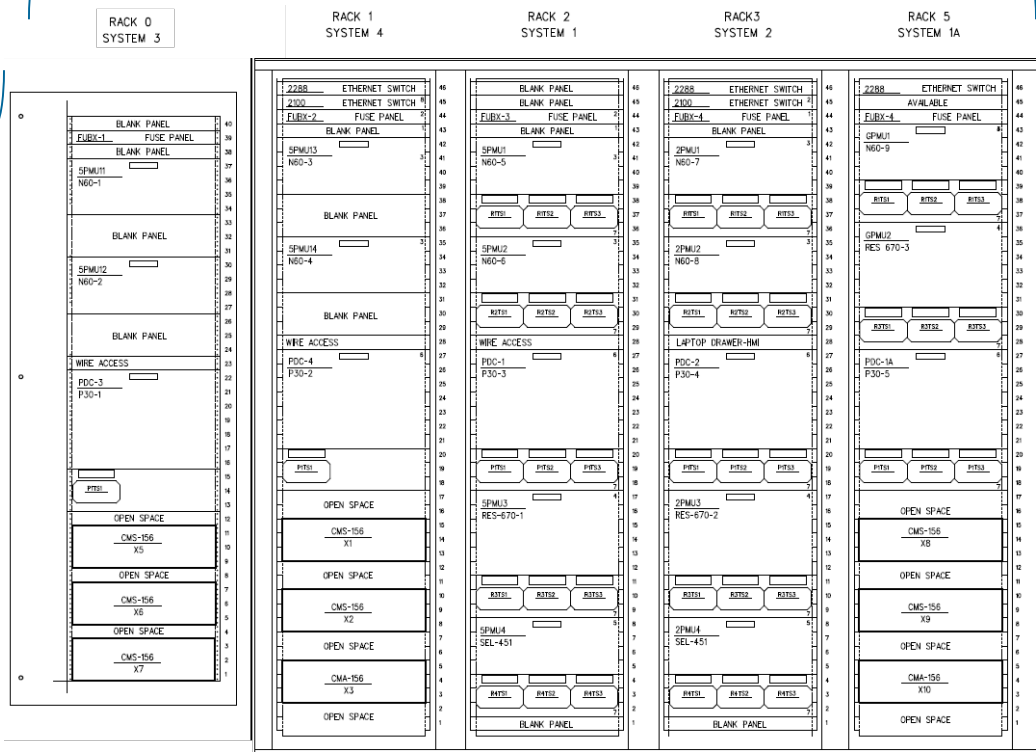
Application Tool/Function	Recipient Usage Domain
Enhanced Tool for Validating Synchrophasor Data Quality and Security Linear State Estimation Model validation	Real-time Operations (Control Center)
Enhanced Tool with Set-Point limits for Automated/Dynamic Angle-Based Wide-Area Alarms	Real-time Operation (Control Center)
Enhanced Fault Location	Engineering Application for Systems Operations & Planning
Real-Time Voltage Instability Indicator	Real-time Operations (Control Center)
Faster and More Efficient System Restoration	For Dispatcher Training Simulator (DTS) – Training Domain
Improved Post-Event Analysis	Engineering Application for Systems Operations & Planning
Dispatcher/Operator Training Simulator (DTS)	Real-time Operations Training

RTDS Virtual PMUs compared to Physical PMUs

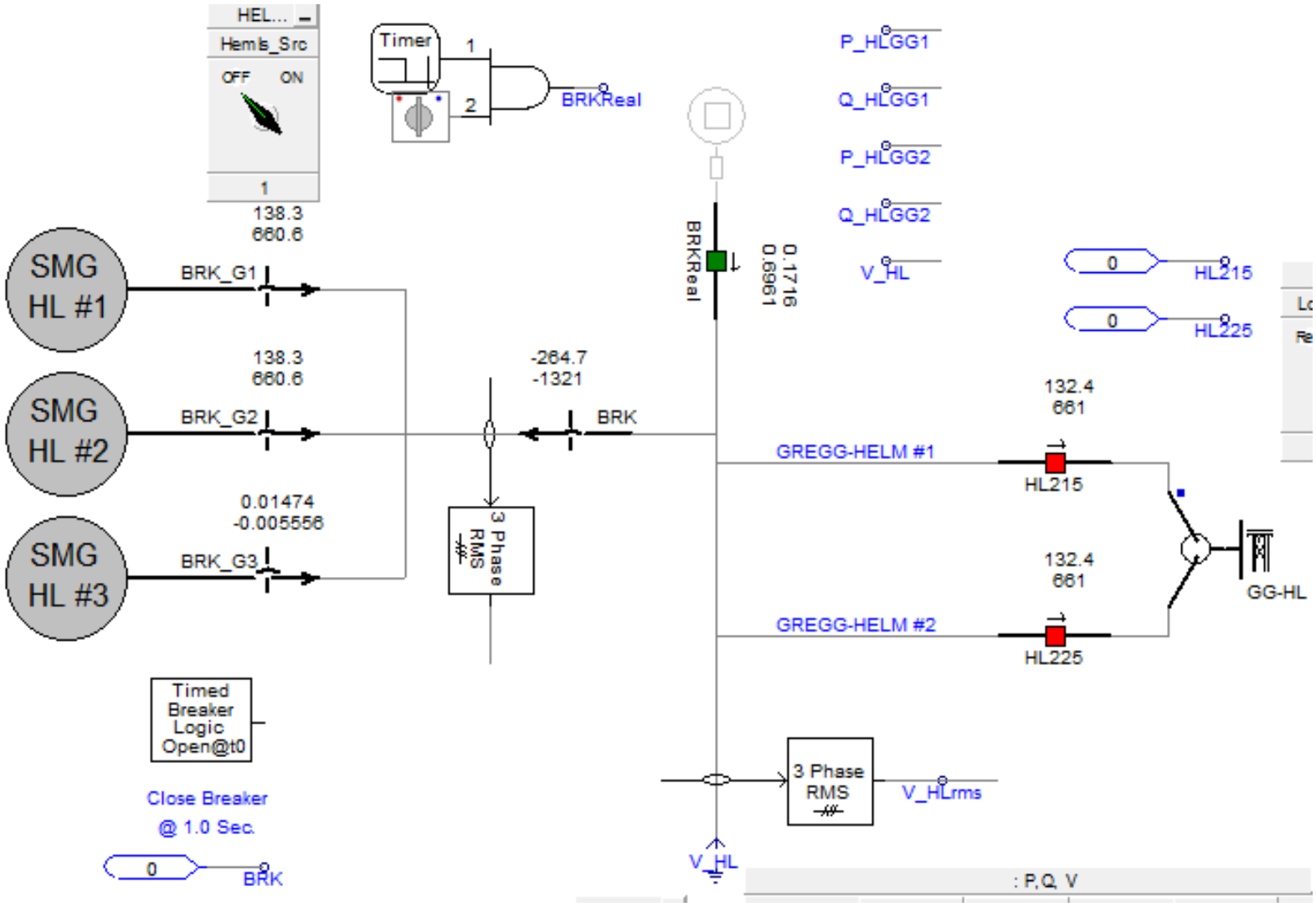


136 Virtual PMUs

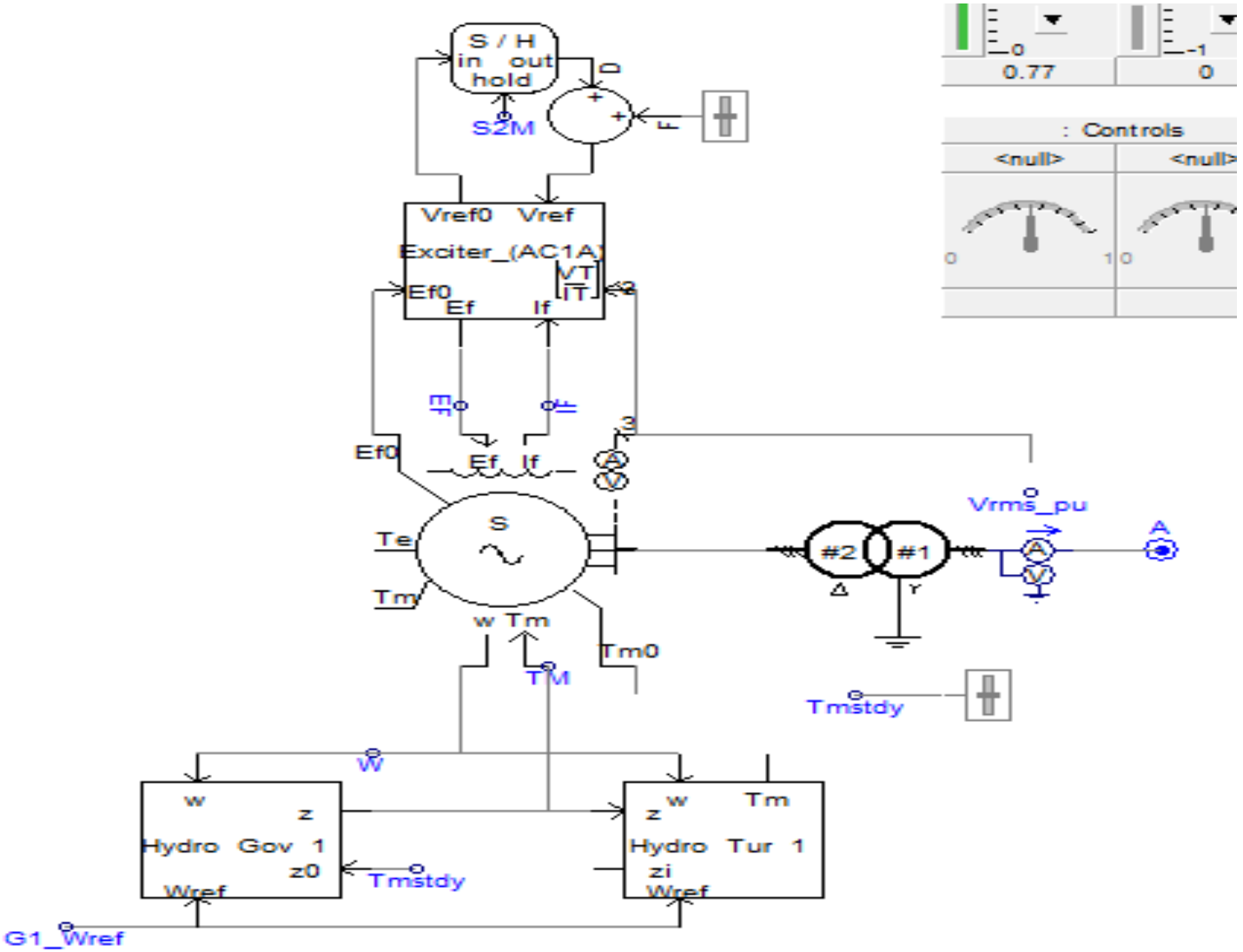
46 Physical PMUs



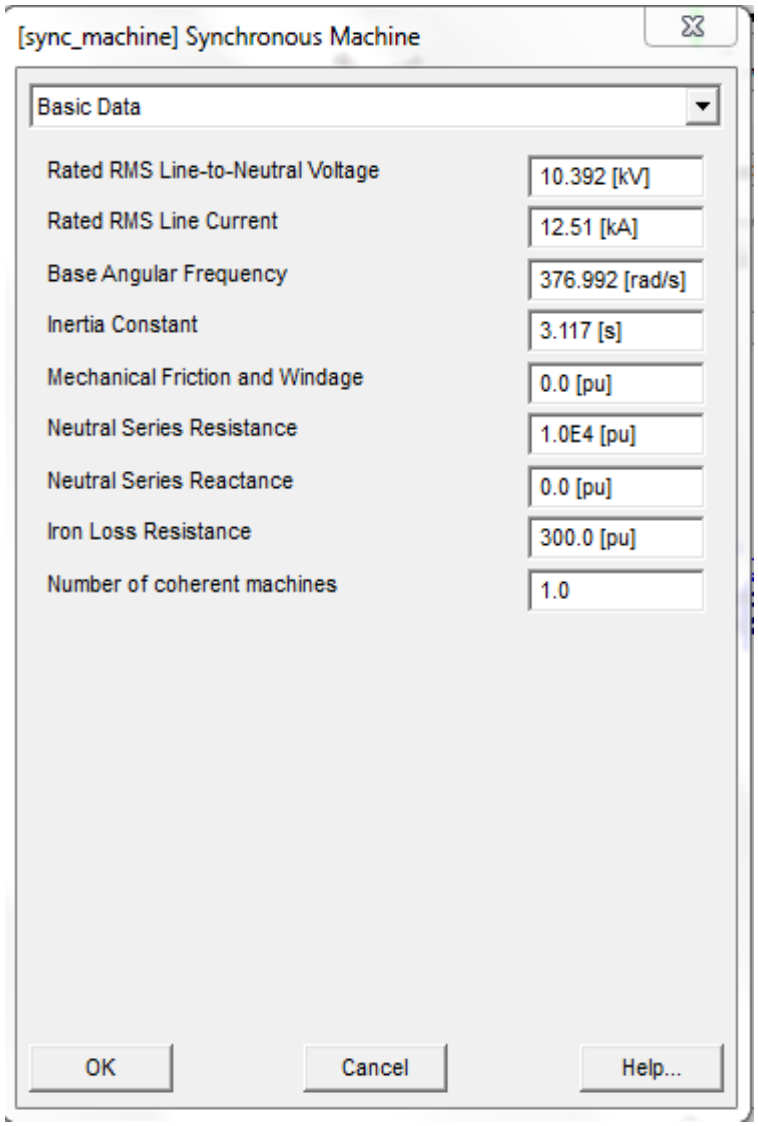
Power House and T-Lines

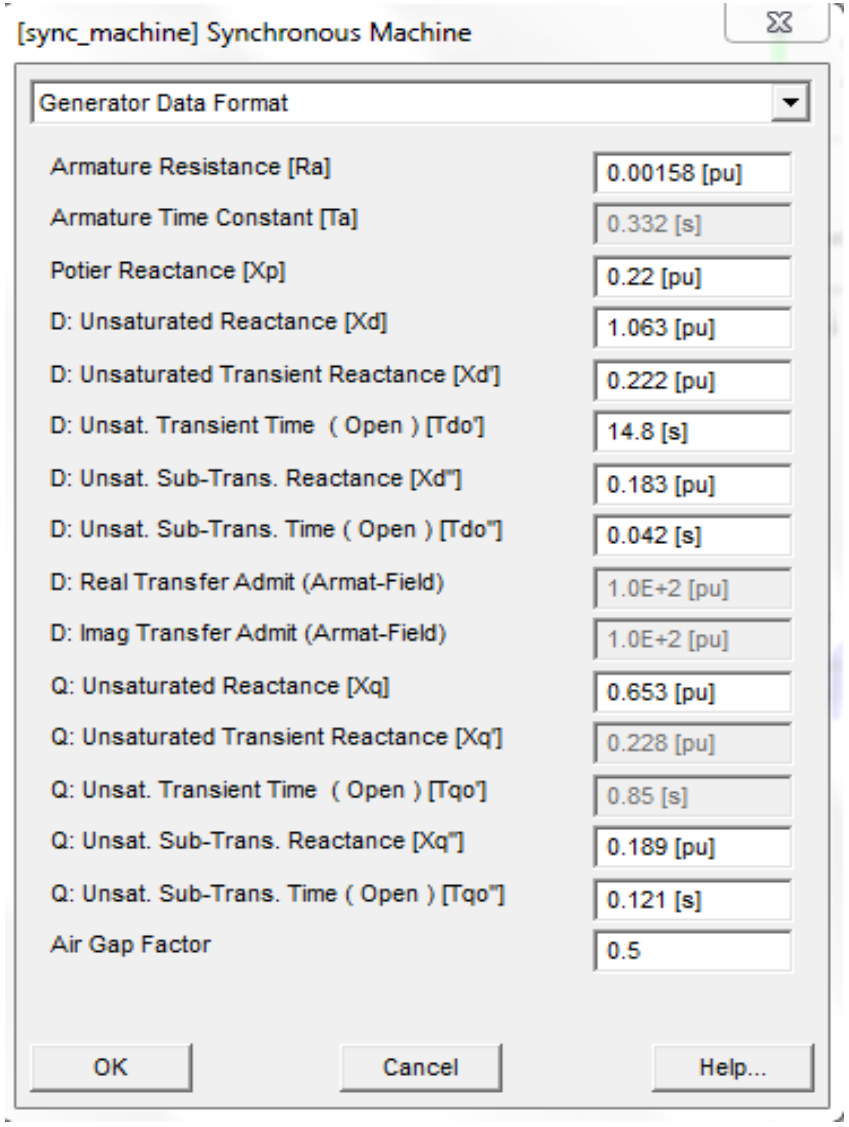


RTDS Gen model, includes: Hydro Governor, Hydro Turbine, Exciter



Synchronous Machine Parameters





Questions