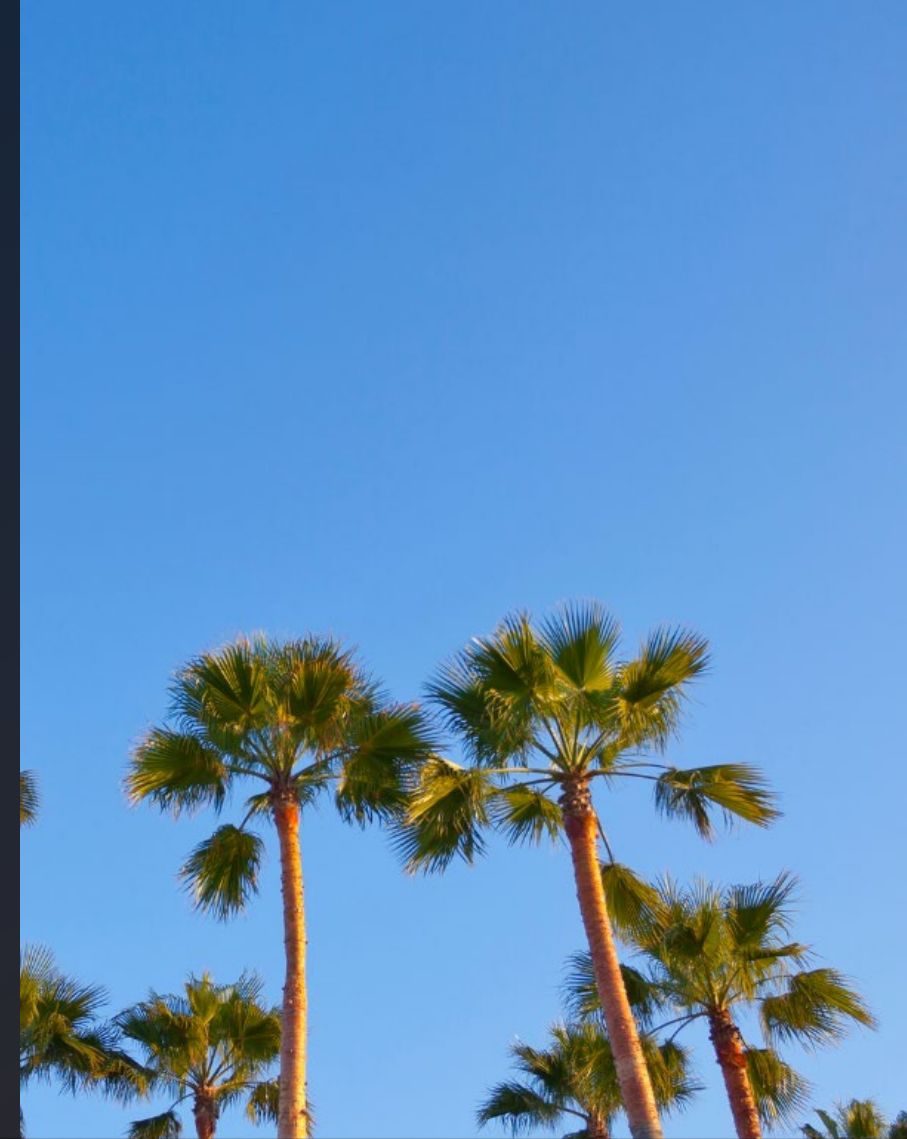


Testing Virtualized PAC Systems: Bridging the Gap Between Simulation and Field Deployment

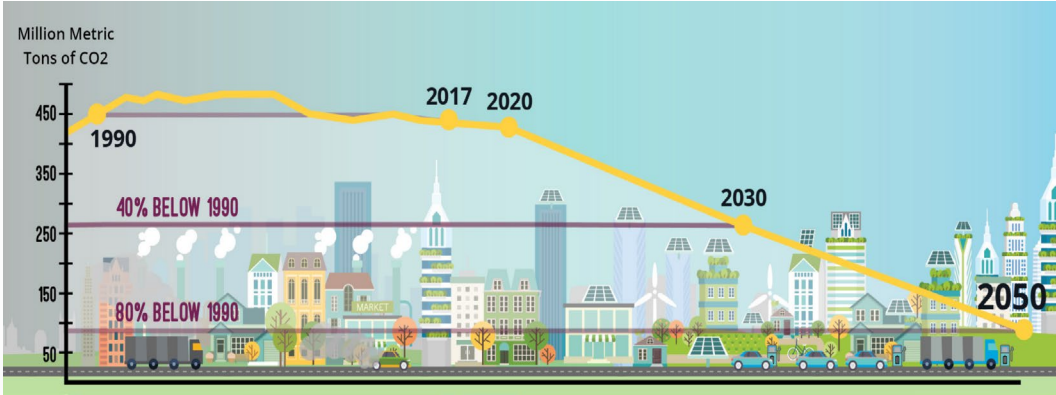
- ▶ Zeus Xioco: Tesco Automation
- ▶ Nicole Rexwinkel: Southern California Edison



Overview

- Background
- Use Cases for digitalization & virtualization
- Test Environment – lab set up for FDS and VPR
- GOOSE/SV simulation for Protection Testing
- SV simulation for Network Testing
- Future Development
- Conclusions

SCE vision for Decarbonization



California’s climate-change goals include a 40% reduction in absolute greenhouse gas (GHG) emissions from 1990 levels by 2030, and 80% by 2050, as well as net-zero GHG emissions economy-wide by 2045

SCE is required by law to meet the following retail sales requirements for the power it delivers to customers:

- ✓ By 2020 – **33%** of power from Renewables Portfolio Standard (RPS)-eligible resources (*requirement met*)
- ❑ By 2030 – **60%** of power from RPS-eligible resources
- ❑ By 2045 – **100%** carbon-free power

SCE has published several whitepapers outlining the cross-sector collaboration required for achieving carbon neutrality:

Pathway 2045 (2019)

SCE’s 2019 data-driven analysis of the steps that California must take to meet the 2045 goals to clean our electric grid and reach carbon neutrality

Reimagining the Grid (2020)

An assessment of the grid changes needed to support GHG reduction goals, while adapting to evolving customer (EV, DERs) and climate-change driven needs

Mind the Gap (2021)

An assessment of policy changes and additions needed to ensure California meets its GHG emissions reductions targets by 2030 in anticipation of its goal to decarbonize by 2045

Countdown to 2045 (2023)

A data-driven analysis of the steps that California must take to meet 2045 goals, which identified 5 key actions for affordably achieving carbon neutrality

Reaching Net Zero (2024)

Details company’s plan to reach net zero and support California’s interdependent climate goals through a safe, reliable, and affordable clean energy transition

DECARBONIZE ELECTRICITY

100% RETAIL SALES
100%*

ELECTRIFY TRANSPORTATION

90% OF VEHICLES
75%*

ELECTRIFY BUILDINGS

95% OF BUILDINGS
70%*

USE LOW-CARBON FUELS

48% NON-ELECTRIC ENERGY
43%*

SINK REMAINING CARBON

75 MMT CARBON SINK
108 MMT*

=
CARBON NEUTRALITY BY 2045

Challenges Today



CYBERSECURITY



ASSET
MANAGEMENT



CONSTRUCTION
& LOAD GROWTH



CHANGING GRID

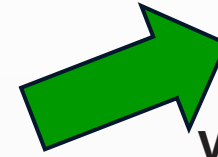
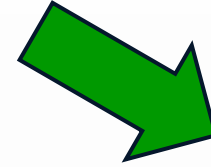
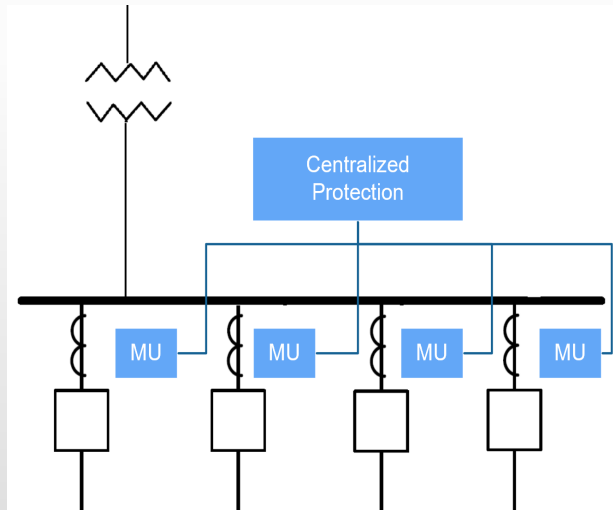
Today's Substation



Future Substation



Centralized Protection

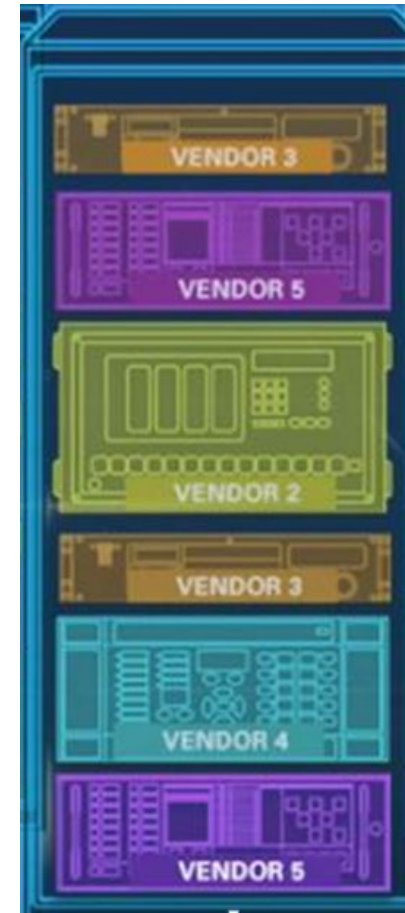


Virtualization Protection Relay (VPR)

- Reducing substation control room footprint
- Reducing construction time
- Simplifying device management and maintenance
- Improving event data analysis
- Improving redundancy
- Improving testing and deployment

Vision: Testing for Digital Substations & vPAC

- Full digital twin enabling lab-based commissioning of protection & control
- Test new schemes, firmware, and logic without outages or field risk
- Replay real faults to improve settings and validate new functions
- Accelerates adoption of advanced protection technologies
- Creates a repeatable, scalable environment for utility-wide standardization



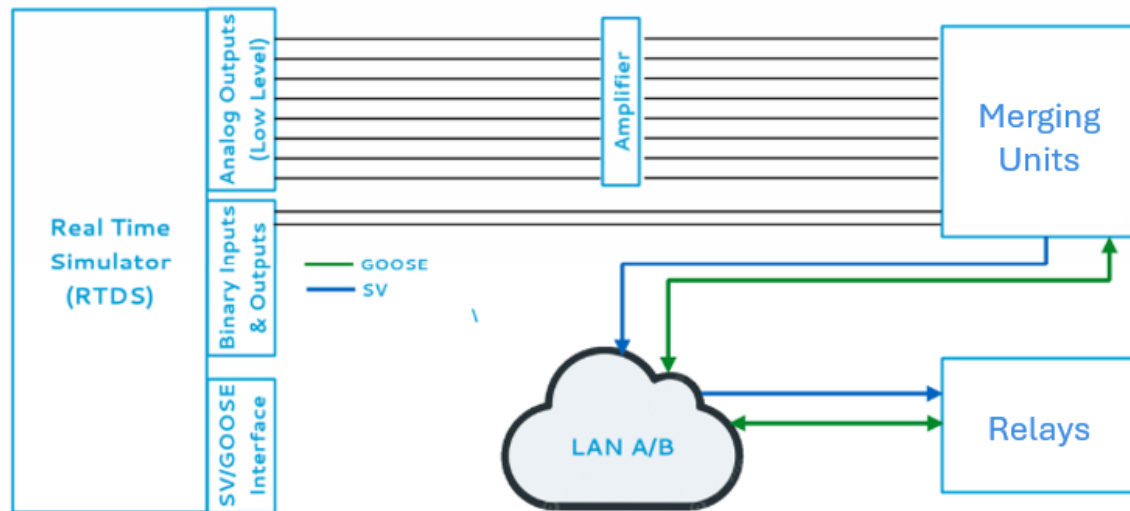
HIL Testing for Digital Substations & vPAC

- Validate protection and control logic against real-time power system
- Enables safe testing of edge cases
- Reduces commissioning time by debugging logic and settings in the lab
- RTDS
 - Industry-standard
 - Proven accuracy for protection relay testing.
 - Native support for IEC 61850 GOOSE, SV, and MMS messaging
 - Scales easily for large substation or multi-terminal systems

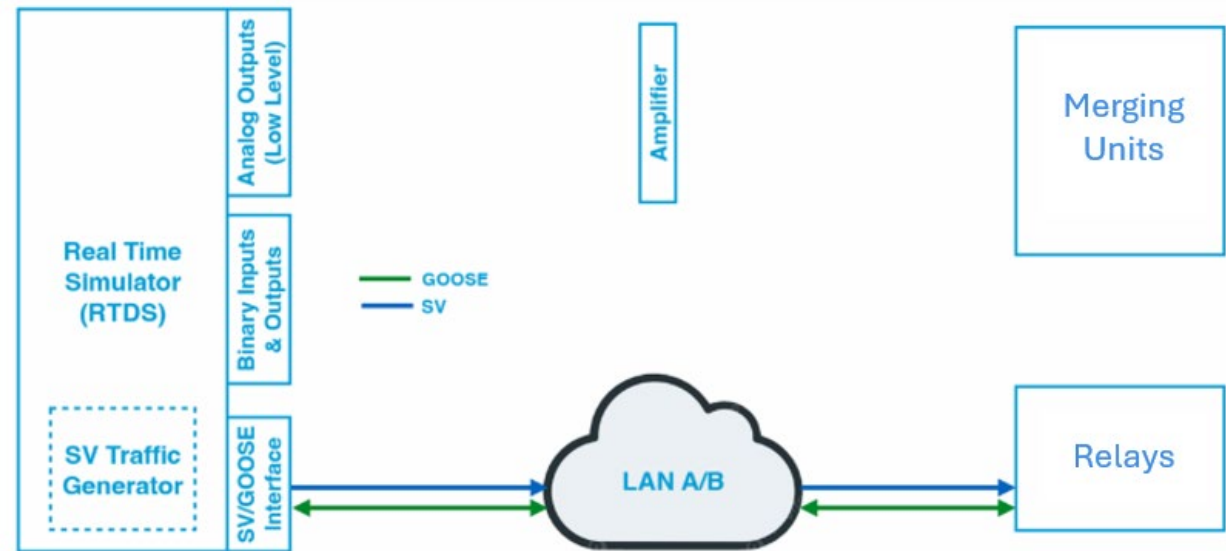


Test Environment – Fully Digital Substation

HIL with Analog Outputs & HIL Amplifier

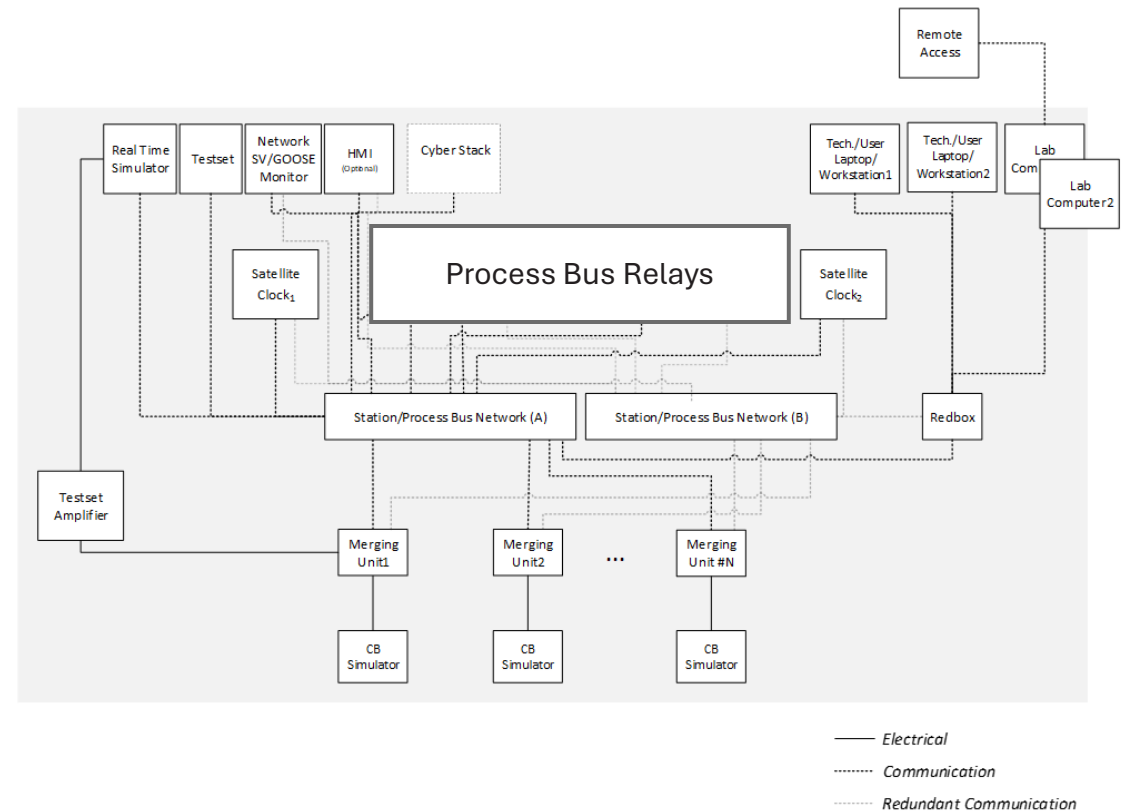


HIL with GOOSE and SV Simulation



Protection Testing Approach – SV/GOOSE Simulation

- Utilize GTNET to mirror real-world digital substation designs where SV and GOOSE share the same physical network
- Ensures accurate testing of network congestion, VLAN tagging, and priority handling
- Allows evaluation of protection scheme performance under realistic traffic mixes
- Supports validation of time-critical interactions (e.g., SV input to GOOSE trip output) on the same LAN
- PRP is essential for high-availability protection systems where packet loss is unacceptable.



SV Simulation & Network Testing

- GTFPGA modules for SV simulation evaluated network architecture design & performance
- Helps identify gaps in design:
 - vLAN and port assignment
 - Ability of system to recover from abnormal network conditions



Network Testing Approach – SV Simulation

- Establish Baseline Performance
- Stress Testing: RTDS Model with up to 96 SV Streams plus 21 merging unit SV Streams.
- Processing Limits:
 - Network monitoring equipment reached capacity limits and needed to be replaced with a higher-capacity device.
 - Some devices began alarming at high GOOSE rates (~4,500 packets/sec), indicating processing constraints at the application level.
 - SV Traffic Overload Effects Exceeding link capacity caused packet loss resulting in SV communication alarms (LSVS failures) across relays.
- Traffic Shaping Effectiveness VLANs and traffic shaping successfully prevented issues during normal and most abnormal conditions.

Key Takeaways

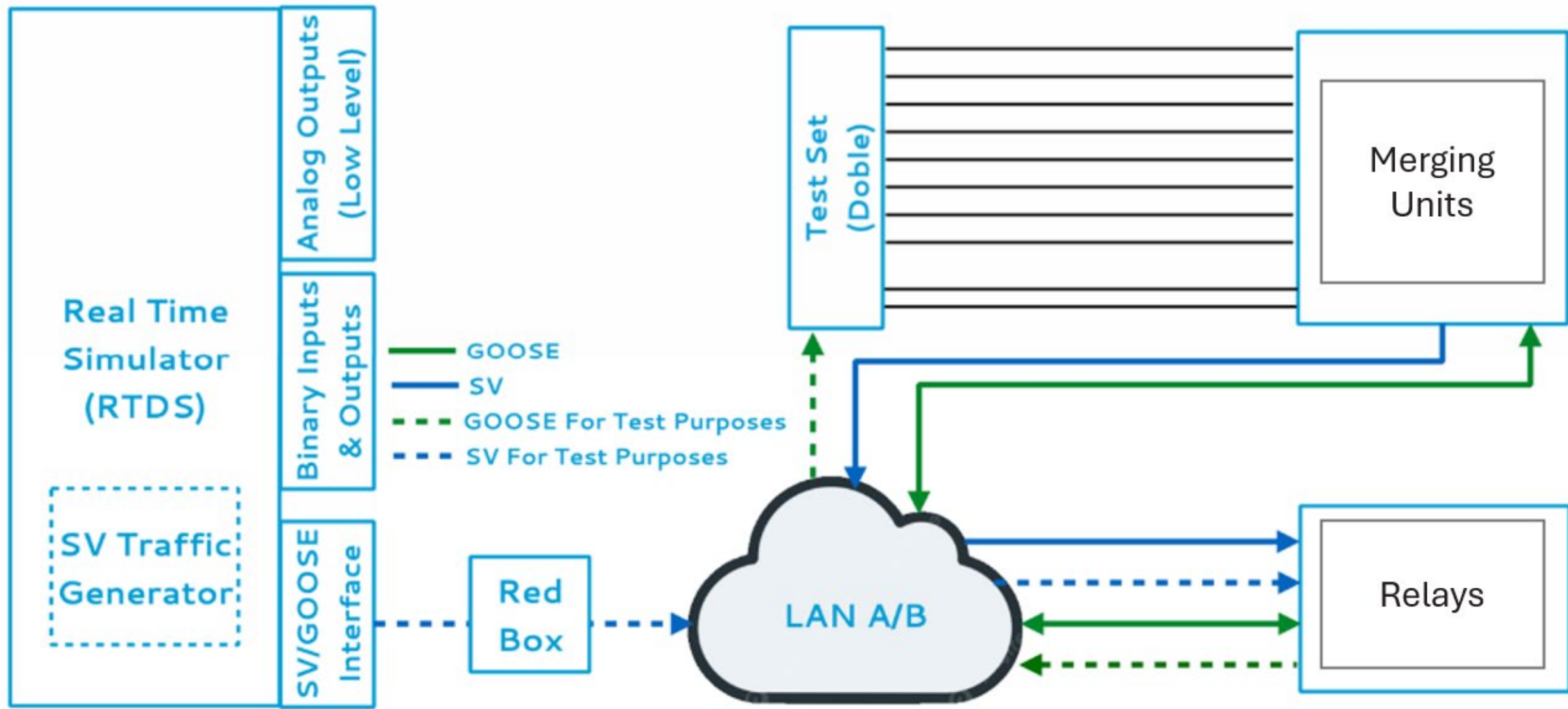
- HIL testing for process bus and virtual protection can be accomplished with fewer IEDs and external hardware through GOOSE/SV simulation
 - RTDS HIL testing expedites readiness for deployment
 - Model development remains biggest challenge
- Network architecture and designing for resiliency is critical for substation digitalization
 - Dedicated network test tools are needed to precisely measure network performance
- Performance testing – proof of concept testing approach differs from pre-commissioning

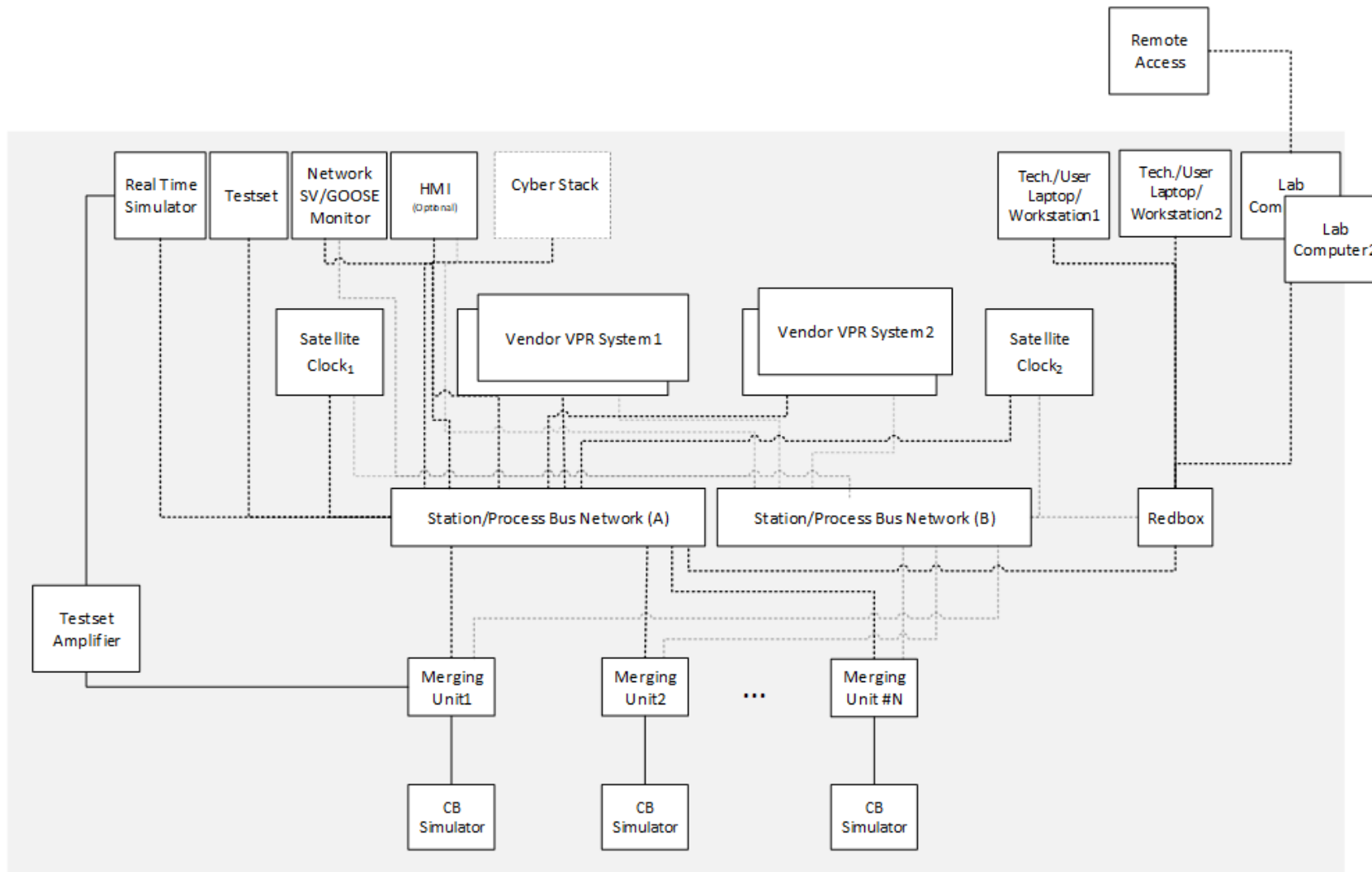
Future Work

- SCE's Virtual Substation Relay Proof of Concept Demonstration completed in 2025
- VPR Field Demonstration planning (2026)
- VPR Line Differential Protection Scheme Lab Demonstration Planning (2026/2027)
- Process Bus Substations in service (2026/2027)
- VPR Field Demonstration (2028)

Q&A

Appendix





——— Electrical
 Communication
 - - - - - Redundant Communication