Utilizing RTDS Simulation Scenarios for PHASOR System Performance Testing at Southern California Edison

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Introduction

Southern California Edison (SCE) is deploying the first phase of its new synchrophasor data management and exchange system, which is referred to as the PHASOR System, as part of its smart grid development program. The PHASOR System is comprised of General Electric's (GE) XA/21 [1] system as the core, Electric Power Group's (EPG) Enhanced Phasor Data Concentrator (ePDC™) and ISG synchrophasor applications for data synchronization and external data transfer, and Instep's eDNA data historian for long-term data archival. SCE's PHASOR System is designed to support a maximum of 2,000 phasor data quantities sourced from up to 100 unique phasor measurement units (PMUs).

Phase 1 of the PHASOR project successfully laid the foundational infrastructure for a synchrophasor data management system that supports four primary functions: collect, store, share, and verify. The SCE system is designed to:

1. Collect phasor measurement data acquired from PMUs paired with digital fault recorders (DFRs) using software-based phasor data concentrators (PDCs).
2. Store both PMU and DFR event records in a corporate data historian for long-term archival and retrieval.
3. Share SCE's PMU data with the Western Electricity Coordinating Council (WECC) and other authorized external entities in a secure manner utilizing phasor gateways.
4. Verify the occurrence of abnormal grid conditions with WECC reliability coordinators through the use of a basic alarming and visualization software interface.

SCE specified a series of required performance tests as part of the formal system acceptance testing phase to ensure the PHASOR system performs as expected using a battery of operational scenarios. This included structured performance tests in addition to a 100-hour stability test. To effectively test the system's performance under full load, it was necessary for SCE to develop a unique synchrophasor data simulation capability. For this purpose, SCE employed the use of its Real-Time Digital Simulator (RTDS®). The RTDS is an advanced computer simulator based on

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[1] GE and XA/21 are trademarks of General Electric Company.

parallel processing technology where multiple computer processors are coordinated to work on the same solution in a synchronized manner. In SCE's integrated Advanced Technology laboratory environment located in Westminster, California, engineers utilized RTDS in conjunction with an additional installation of EPG's ePDC to successfully generate 2,000 phasor data quantities and then transmit the data to the PHASOR system located at a control center more than 30 miles away.

This white paper provides an overview of the RTDS modeling work needed to generate a large quantity of simulated PMUs and signals, the lab configuration employed to interface the RTDS to the physical PHASOR System across a large distance, the performance and stability test scenarios performed on the PHASOR System, and lessons learned throughout the process.

RTDS

Real-time digital simulators are used in the electric power industry by utilities, equipment manufacturers and research organizations. Electric power utilities use them as a tool to study their network and to formulate different strategies for their protection and control systems. Real-time simulators provide equipment manufacturers with the most comprehensive means available for testing their products during design and manufacturing. Research organizations commonly use real-time simulations to explore new approaches to power system design, control and protection.

In real-time digital simulations, devices connected to the simulator operate as if connected to the physical power system. The outcome of the simulation is directly coupled to the performance of the devices under test. Real-time digital simulators operating in a closed-loop fashion allow actual physical devices to fully interact with the power system. The RTDS used at SCE's lab has the capacity to simulate a large number of PMUs and associated phasor data quantities for closed-loop system testing. A typical lab configuration is shown in Figure 1.

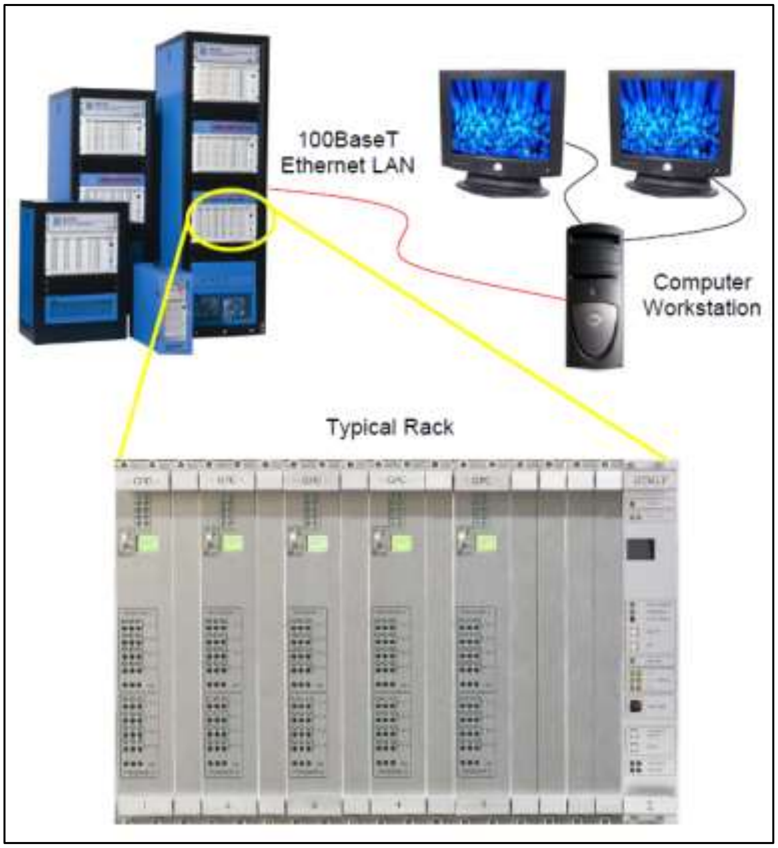

Figure 1 – Typical RTDS Lab Configuration

RTDS Technical Overview

The RTDS is an advanced computer simulator based on parallel processing technology where multiple computer processors are coordinated to work on the same solution in a synchronized manner. This parallel processing technique makes it possible to conduct simulations of large networks in real time with a high degree of accuracy. The RTDS also includes dedicated user-friendly simulation interface software called RSCAD making it possible to generate a model of the entire power system. The modeling algorithm used is based on the widely accepted Electromagnetic Transient algorithm [1].

The RSCAD software consists of several modules that allow engineers to develop power system network models, transmission line models, customized power system components, and scripts to automate simulations. It also facilitates using a graphical user interface (GUI) to drive hardware simulations.

The model of the power system network is developed using the Draft module in the RTDS software. RSCAD/Draft has an extensive library that includes component models of the most common power system components such as transformers, transmission lines, generators, busses, controllers, hardware interfaces, capacitors, exciters, reactors, governors, power system stabilizers, loads, and solid-state devices.

Once the desired component is selected and dragged onto the Draft page, specific system data is entered giving electrical characteristics to the generic elements, which creates a model representing the actual SCE network that will be used in the simulation. RSCAD/Draft is also used to solve system load flow (initial system conditions) and to compile the model creating the code, which is then transferred to the RTDS hardware to conduct simulations.

With the model successfully constructed and compiled in Draft, the case is ready to be downloaded to the hardware and begin simulation. The simulation is controlled by a graphical user interface module called RSCAD/Runtime. Runtime allows the user to control the status of different devices in the simulation and conduct data acquisition from the simulation to capture the simulation results and the status of the different external devices connected to the RTDS.

The RTDS provides multiple analog signal outputs (voltages, currents, etc.) that can be connected to external hardware. It also has the ability to take multiple signals generated from external devices and provide them as input to the RTDS thus allowing the RTDS to respond to various scenarios, and to control the simulation response. In cases where higher currents and voltages are required, the RTDS can be connected to amplifiers to boost the voltage and current outputs from the RTDS to the level required by the external device.

Large-Scale Power System Model Development in RTDS

Real-time digital simulator testing of the PMU system requires an RTDS model of the large SCE power system. SCE engineers developed a base case model of the utility’s bulk power system and its main interconnections allowing them to analyze a variety of issues facing electric utilities (i.e., integration of renewable resources, energy storage, controls, protection, stability, operations). This large RTDS model required 12 RTDS racks or subsystems. The model included all SCE 500 kV and 230 kV transmission lines, busses and in some cases 115 kV systems. It also included all tie lines and equivalent models for neighboring utilities. This large power system model with integrated protocol converter hardware GTNET-PMU components can simulate the PMU signals required to test the SCE PHASOR System. The completed model can generate and transmit 2,000 analog phasor data quantities.

RTDS Model of the Large Bulk Power System

Development of a large bulk power system model in the RTDS simulator for PMU system testing requires three steps: (1) build and initialize the model, (2) validate the model and (3) add phasor measurement units.

Building and initializing a large power system model in the RTDS can be achieved by utilizing two different approaches; engineers could build the model from ground-up [2] or simply use the

RTDS’s data conversion program [3]. The large network model used for SCE’s PMU testing was developed by implementing the first approach.

Using the RTDS to build a model from scratch allows engineers to construct, run and analyze power system simulation cases. The SCE power system model is built by selecting, adding and interconnecting the necessary components from the model libraries. First individual subsystems similar to the one shown in Figure 2 are constructed by combining components. As each subsystem is fully developed, a new subsystem is added and the two subsystems are interconnected by a transmission line whose minimum length is defined by the selected simulation time step. This is a challenging part of model development, finding the appropriate interconnection and break-up points from one subsystem to another one. Knowing where to merge or break-up a subsystem requires a detailed transmission network map and a thorough understanding of the power system network. RTDS is an excellent tool for engineers as its simulation time-step function specifies the time between two solutions and it determines the voltage and branch current for each solution node. For this project, a simulation time-step of 50 microseconds was chosen, which determined that each break-up point required a transmission line with a minimum length of about 10 miles.

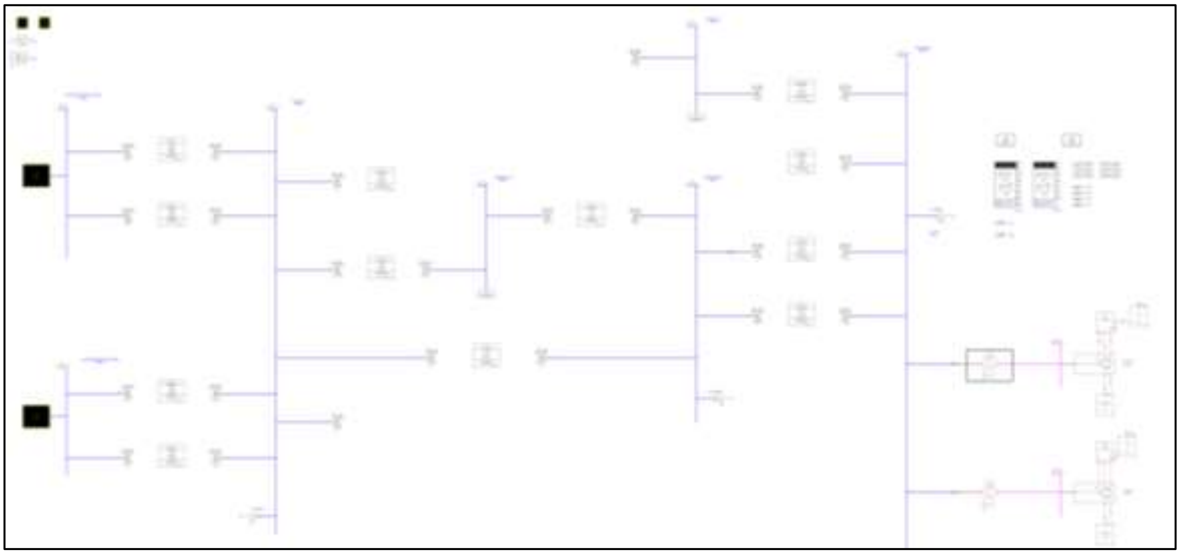

Figure 2 – Single Line Diagram for One Subsystem

Most of the parameter data associated with each of the components of the SCE power system model came from a short-circuit network model developed by SCE Protection Engineering using Computer Aided Protection Engineering (CAPE) software. The generator, generator controls and load flow data came from WECC positive sequence load flow (PSLF) steady-state and dynamic models. Model development using this approach required a substantial amount of time and dedicated resources; however, once the model building process was defined, model development progressed without major issues.

The RSCAD/Draft module is also used to initialize the load flow with initial system conditions. Initial conditions for generators, busses and loads are derived from WECC PSLF steady-state and dynamic cases. The model was built incrementally, and at each incremental step load flow initialization followed to ensure there were no issues during the process. If load flow initialization is not performed properly, the case may become unstable or it could take longer to reach a stable operating state during simulation time. Once the load flow is initialized the model is compiled to create the code, which is then transferred to RTDS hardware to conduct real-time simulations.

Each RTDS rack in the SCE lab consisted of at least two PB5 processor cards. This RTDS rack configuration allows for modeling up to 144 nodes within each RTDS subsystem. Each subsystem had at least some nodes left unused for future use and the final network model grew to 12 subsystems. The final network model included all SCE 500 kV and 230 kV busses, some 115kV busses, and equivalent network models for all neighboring utilities. The model included generators with their corresponding inertia and control components as well as transformers, loads, shunt and series capacitors, shunt reactors, and equivalent sources [Figure 2]. The final 12-rack power system model contained 191 three-phase busses, 181 transmission lines, 77 generators, and 64 equivalent sources as illustrated in the RSCAD Runtime model for the large bulk power system depicted in Figure 3.

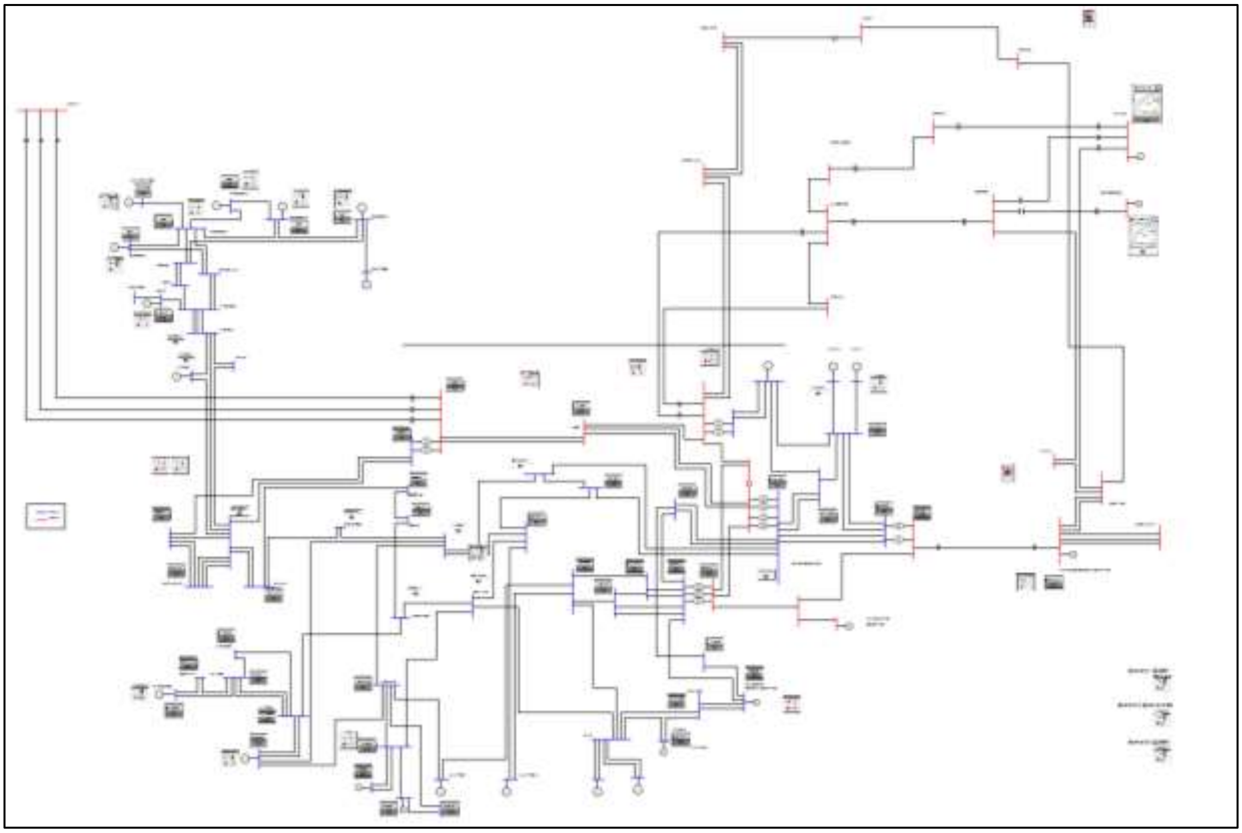

Figure 3 – RSCAD Runtime Model for Large Bulk Power System

Once the model is built and initialized, the second step is to validate the network model. Any large RTDS network model requires a validation process to ensure the accuracy of the model and to impart confidence in any study using the model. Validation should be performed for both short-circuit and load flow data. Short-circuit validation is performed against the CAPE model and load flow validation against the WECC PSLF model. Due to time constraints before the actual system test, the team was only able to perform short circuit validation testing for this study. Because the primary intent of the RTDS network model was to provide 2000 phasor quantities needed for PMU system site acceptance testing (SAT), it was concluded that short-circuit validation was sufficient for this project. In addition, because the system model was built one subsystem at a time, the short-circuit fault comparison between RTDS and CAPE models at each subsystem provided the necessary model validation. These short-circuit validation results reveal that the RSCAD network model closely matches the CAPE model.

Phasor Model Development using RTDS GTNET Hardware

RTDS has special hardware interface cards that allow its simulator to generate PMU signals per the IEEE C37.118 standard. GTNet and GTSynch hardware interface cards provide for PMU signals of up to 240 samples per second and support time synchronization using an external timing source typically provided by global positioning systems (GPS). The GTNet network interface card is similar to a protocol converter that can send and receive data packets between RTDS hardware and external devices. The GTNet card can be configured to work on different protocols such as GSE, SV, DNP3 or PMU. A GTSynch synchronization card is used to ensure the RTDS time-step clock remains locked to the time reference signal provided as input to the GTSynch card.

Twenty-two GTNet cards were required to simulate the 2,000 analog phasor quantities. Each GTNet-PMU card is capable of simulating eight PMUs and each PMU can generate up to 12 different analog phasor quantities. PMU components were added to the model one at a time and compiled, and then the simulation was run to ensure no errors were introduced. Selected numbers of major transmission line currents and bus voltages provided the phasor signals required for the test. Most subsystems included two GTNet cards and could generate up to 192 phasor quantities.

Once the power system model was built and verified with all PMUs and compiled successfully in RSCAD/Draft the model was ready for the final step, downloading to the hardware and the start of simulation. The simulation is controlled by a graphical user interface called Runtime. The RSCAD/Runtime allows the user to control the status of different devices in the simulation, perform data acquisition, and to display data. It also has the capability to capture the status of devices connected to the RTDS. For example, during the simulation, the user can monitor specified system quantities using graphical icons of meters and plots. It is also possible to dynamically interact with the simulation as it runs by creating push buttons, set-point sliders, switches etc.

PHASOR System Test Environment

SCE's Power Systems Lab PHASOR System testing environment is illustrated in Figure 4. The primary components of the entire test setup included: (1) the RTDS System, (2) the satellite clock, (3) the ePDC, and (4) a communication network connection to SCE's Grid Control Center.

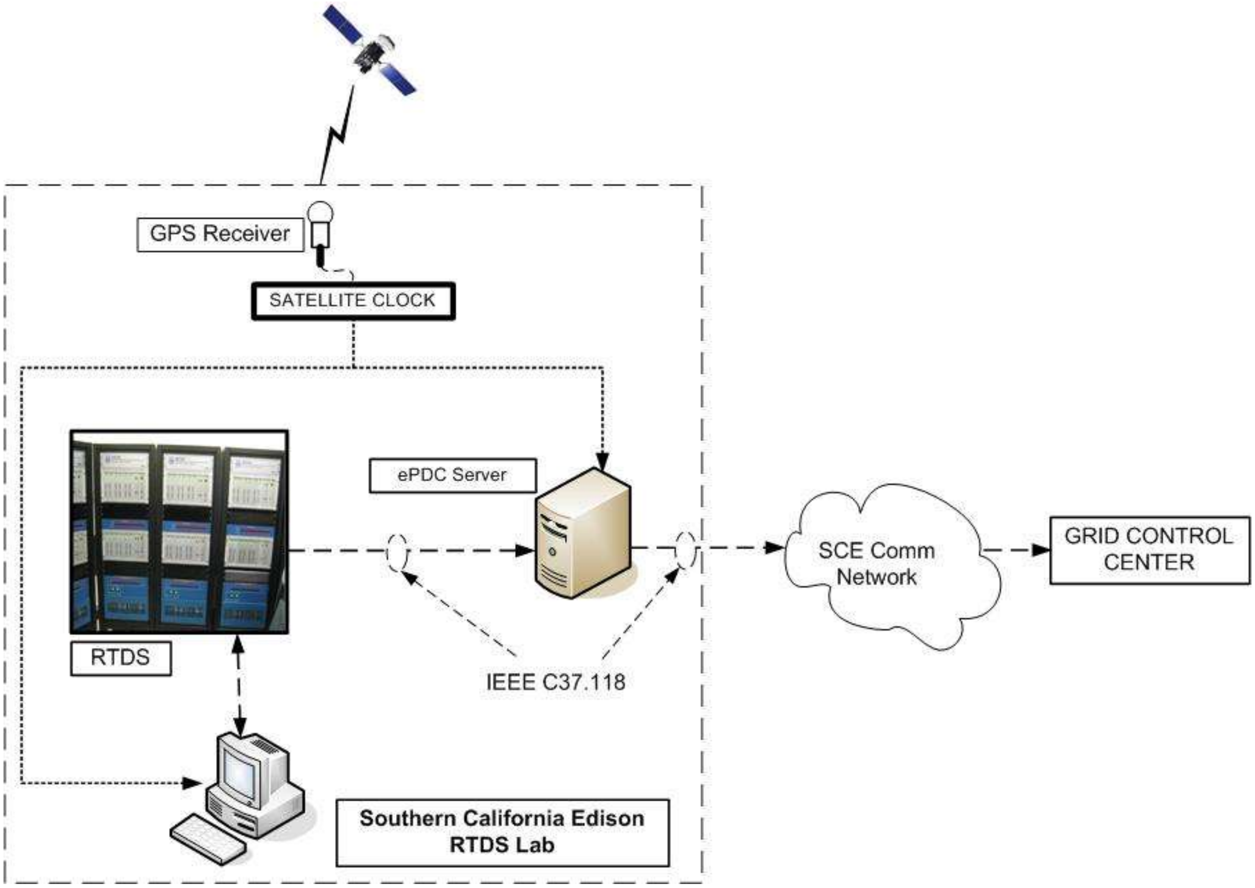

Figure 4 – Phasor System Test RTDS Lab Environment

SCE's Power Systems Lab is comprised of a multi-rack RTDS system. The RTDS racks are fully integrated with the latest processors, network protocol converters, special I/O cards that can be used to interface analog and digital signals between the RTDS and external devices, and time synchronization hardware. The fiber-optic communication backbone links all the lab's racks to facilitate high-speed transfer of data.

A rooftop mounted satellite receiver provided precision time signals to a satellite clock housed inside the lab. The satellite clock is also used to time synchronize the PC workstation, RTDS simulator and the ePDC server.

The ePDC aggregated and time synchronized (aligned) the phasor quantities generated by PMUs during the RTDS simulation. The ePDC sent these phasor quantities to the grid control center 30 miles from the lab via a dedicated communication network.

PHASOR Test Environment Configuration

The PHASOR System incorporates both production and non-production environments. The production environment is limited to the primary and hot backup operations (OP) systems. The non-production environment contains three separate systems: (1) primary product test (PT), (2) training (TRN) and (3) development (DEV). Figure 5 illustrates the PHASOR production environment where the primary and hot backup operations systems are redundant systems that interface with each other as well as the energy management system (EMS) and SCE data historians.

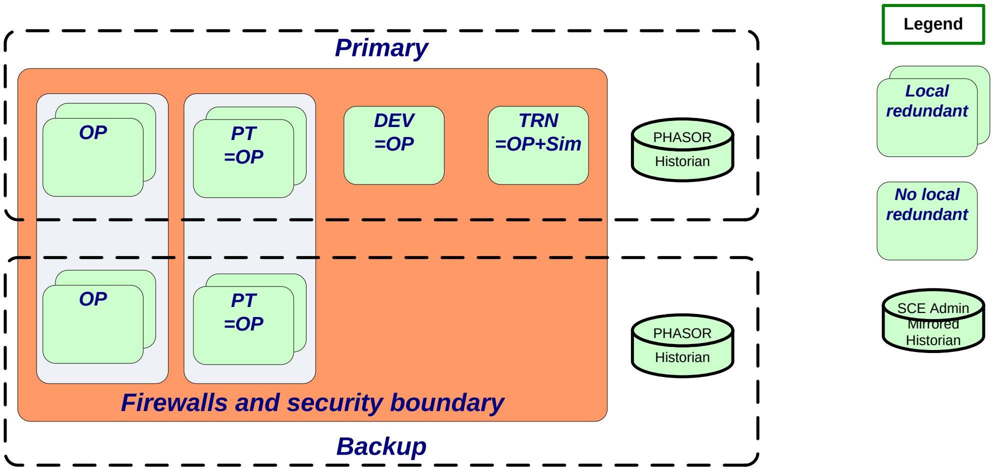

Figure 5 – PHASOR System Environments

The PHASOR product test systems are also redundant systems. They are used to test and validate changes prior to their promotion to the production environment. In addition to interfacing with one another, the product test systems interface with the RTDS Technologies power system simulator. The PHASOR System's DEV is utilized for the development and preliminary testing of database/display/software changes. The PHASOR System's TRN is utilized to familiarize PHASOR operators with the system's user interface.

In the PHASOR site acceptance test (SAT) configuration shown in Figure 6, the 2,000 RTDS-generated synthetic phasor data quantities were transmitted via the ePDC located in the lab to the PHASOR development system's ePDC located at the control center. The PHASOR development system's ePDC subsequently distributed all 2,000 phasor data quantities to the primary operations system, hot backup operations system, product test system, and the development system. Each system would receive the full complement of simulated phasor measurements in order to support the structured performance and stability tests.

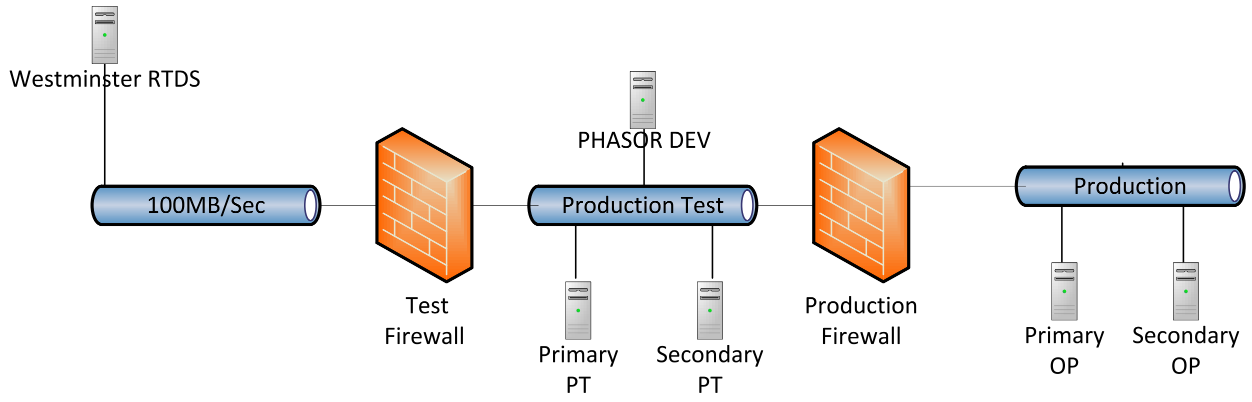

Figure 6 – SAT Test Setup

PHASOR Performance Testing

Structured performance testing is a critical component of a well-planned acceptance testing strategy for major utility management and control systems. The main objective of performance testing is to ensure the system-under-test continues to operate as designed while undergoing a variety of stress tests. In the case of SCE's PHASOR System, the utility's engineers defined several performance tests, which included:

A. Normal Scenario
B. Emergency Scenario
C. Catastrophic Scenario
D. 100-Hour Stability Test

Each scenario is intended to exercise the PHASOR System's ability to process synchrophasor data, trend high-speed synchrophasor data using GE's XA/21 Enternet Suite visualization application, generate operator alarms, and simulate a specified number of display call-ups. The expectation for these scenarios is that all PHASOR systems and subsystems remain functional and that each PHASOR system, subsystem and device operates with sufficient spare capacity should a PHASOR component fail, and then the system, subsystem or device under test would pick up the additional load resulting from the failure. SCE requires that the system meet **all** performance requirements in the event of any single component failure. The system functions and test conditions required for the first three tests are provided Tables 1, 2 and 3.

Table 1 – Normal Scenario

NORMAL SCENARIO – Test Duration: 1 hour	
System Function	**Test Condition**

PMU Real-Time Data Processing	2,000 phasor data quantities
High-Speed Trending	5 operator consoles
	10 tracks each
	30 samples per second rate
Alarming	5 alarms/minute
Display Call-Ups	10 call-ups/minute

Table 2 – Emergency Scenario

EMERGENCY SCENARIO – Test Duration: 1 hour	
System Function	**Test Condition**
PMU Real-Time Data Processing	2,000 phasor data quantities
High Speed Trending	5 operator consoles
	10 tracks each
	30 samples per second rate
Alarming	200 alarms/minute
Display Call-Ups	20 call-ups/minute

Table 3 – Catastrophic Scenario

CATASTROPHIC SCENARIO – Test Duration: 10 minutes	
System Function	**Test Condition**
PMU Real-Time Data Processing	2,000 phasor data quantities
High Speed Trending	5 operator consoles
	10 tracks each
	30 samples per second rate
Alarming	2,000 alarms/minute
Display Call-Ups	40 call-ups/minute

<u>100-Hour Stability Test</u>:

The fourth test demonstrates the stability of the system for a 100-hour period of continuous operation. The stability test is considered successful if no critical function ceases to perform for any period of time, no major hardware failure occurs, no failover occurs, and no restarts occur within the test period. Major hardware failure is defined for the purpose of this test as the loss of network, hardware such as server, disk, user workstation, etc. Table 4 provides the system functions and test conditions used for testing system stability.

Table 4 – Stability Test

100-HOUR STABILITY TEST	
System Function	**Test Condition**
PMU Real-Time Data Processing	2,000 phasor data quantities
High Speed Trending	5 operator consoles
	10 tracks each
	30 samples per second rate
Alarming	5 alarms/minute
Display Call-Ups	10 call-ups/minute

Lessons Learned

Several issues arose during the setup, configuration and validation of the system testing environment that required SCE engineers' attention prior to initiating formal acceptance testing.

The first of these issues was the incorrect setup of the firewall rules throughout the system. During the initial setup of the test environment SCE encountered communication issues between the Westminster lab PDC and the control center PDC, of which the latter was intended to receive the RTDS simulated PMU data across the network. SCE engineers quickly concluded that the firewall installed on the network between the two site PDCs required additional firewall rules to facilitate proper data flow and avoid any unintended blockages. This validates that it is important that responsible parties are given all the system operation information needed to set up the proper firewall rules, including all required application ports and services.

The second issue was related to the local RTDS communication network setup at the Westminster facility. Initially the local communication network designed for the RTDS C37.118

communication was configured using consumer-grade networking switches in a daisy chain configuration. It was observed early on in the testing phase that this configuration produced unacceptable latency times and loss of packets. The original networking switches were replaced with commercial-grade switches and reconfigured from the daisy chain to an aggregate configuration. As a result of this reconfiguration, latency and packet losses were eliminated. Lastly, the original communication channel between the lab and the PHASOR system was 50 Megabits per second, which also introduced some packet loss. Once increased to 100 Megabits per second the issues related to this channel disappeared.

The third issue encountered involved system time drift on the Westminster lab's PDC. During the initial setup, SCE configured the PDC server to obtain its system time from a GPS-enabled network time protocol (NTP) server. While verifying the test environment configuration, SCE observed that the time of arrival (TOA) latency for the incoming RTDS simulated PMU signals would increase slowly over time. Over the course of a week, the TOA latency grew to more than 1 second, which was deemed unacceptable. As a result of the investigation, SCE determined that additional Windows time synchronization configuration items were required to ensure that the PDC server continuously adjusts its time to synchronize with the GPS NTP server. After completing these adjustments the TOA latency dropped significantly to acceptable levels.

To summarize the lessons learned regarding communications for RTDS testing of the phasor system:

1. Thoroughly document the requirements for firewall rules, including all required application ports and services. Make no assumptions.
2. Fully document bandwidth requirements for the entire system. Have a specialist design the communications architecture.
3. Ensure that all devices and servers under test are time synchronized against the proper GPS network time servers.

Conclusion

The advent of high-capacity synchrophasor data management systems in the electric utility sector requires novel approaches to validating their system performance requirements. Traditional testing methods typically cannot produce the vast quantity of PMU data required by SCE's PHASOR System to support performance and stability testing at full load. Since most utilities do not have access to hundreds of physical PMU devices installed in substations to support these tests, the RTDS provides a cost-effective means to produce the maximum required number of phasor data quantities through simulation. With SCE's advanced real-time simulation facilities the performance of the system was validated using 2,000 RTDS-generated synthetic phasor data quantities transmitted at 30 samples per second to a control center more than 30 miles away. Once several network configuration issues with the test environment were addressed, SCE was able to validate the complete set of PHASOR System performance requirements at full load. All performance tests were passed successfully.

References

[1] Dommel H.W., “Digital computer solution of electromagnetic transients in single and multiphase networks.” IEEE Transactions on Power Apparatus and Systems. Vol. PAS-88, April 1969.

[2] Bi, T. Zhang, Y. Forsyth, P. and Wierckx, R., “Large Scale Power System Simulation and PMU Testing using a Real Time Digital Simulator,” International Conference on Power Systems Transients, 4-7, June 2007.

[3] Ouellette, D., Desjardine, M., Kuffel R., Zhang, Y., Xu, E., “Using a Real Time Digital Simulator with Phasor Measurement Unit Technology,” 2011 The International Conference on Advanced Power System Automation and Protection, pp 2472-2476.