Department of Energy
National Energy Technology Laboratory
Award DE-OE0000702
Final Report
Phasor Simulator for Operator Training Project

Project Period - September 15, 2014 to September 14, 2016

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626-685-2015

Final Scientific/Technical Report
Report Period – September 15, 2014 to September 14, 2016
Date Submitted – September 22, 2016

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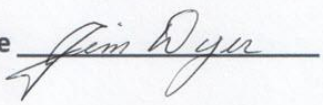
Signature 

DOE Disclaimer

Acknowledgment: This material is based upon work supported by the Department of Energy under Award Number DE-OE0000702.

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List of Acronyms

BPA: Bonneville Power Administration

COI: California-Oregon Interconnection

CSV: Comma Separated Value

DOE: Department of Energy

EMS/SCADA: Energy Management System/Supervisory Control and Data Acquisition

EPG: Electric Power Group

*e*PDC: *e*nhanced Phasor Data Concentrator

ePHASORSim: OPAL-RT's Real-Time Transient Stability Simulator

ePMU: Emulator of Phasor Measurements Units (Add-on module to TSAT)

ERCOT: Electric Reliability Council of Texas

ESM: Event Streamer & Manager

FACTS: Flexible Alternating Current Transmission System

GUI: Graphic User Interface

ISO: International Organization for Standardization, Independent System Operator

NASPI: North America Synchrophasor Initiative

OPAL: OPAL-RT Technologies

OTS: Operator Training Simulator

PDC: Phasor Data Concentrator

PMU: Phasor Measurement Unit

PSLF: Positive Sequence Load Flow

PSM: Power System Model

PSOT: Phasor Simulator for Operator Training

PSS/e: Power System Simulator for Engineers

PWDS: Power World Dynamics Studio

RAS: Remedial Action Scheme

RT: Real-Time

RTCA: Real-Time Contingency Analysis

RTDCP: Real-Time Dynamics Case Preparation

RTDMS: Real Time Dynamics Monitoring System

RTDS: Real Time Digital Simulator

RTNET: Real-Time Network (State Estimator (SE))

RTO: Regional Transmission Organization

SCE: Southern California Edison

SE: State Estimator

TSAT: PowerTech Labs Transient Security Assessment Tool

WECC: Western Electricity Coordinating Council

Phasor Simulator for Operator Training Project (PSOT)

Project Details:

DOE Award Number: DE-OE0000702
Name of Recipient: Electric Power Group, LLC
Project Title: Phasor Simulator for Operator Training (PSOT) Project
Name of Project Director/Principal Investigator: Jim Dyer
Consortium/Teaming Members:

1. Electric Reliability Council of Texas (ERCOT) – Cost Share Participant
    a. Project Manager – Bill Blevins
    b. Training Manager - Mark Spinner
2. Southern California Edison (SCE) - Cost Share Participant
    a. Project Manager – Armando Salazar
    b. Training Manager – Brad Ambrose
3. Electric Power Group – Project Manager and Cost Share Participant
    a. Key Project Personnel - Simon Mo, Iknoor Singh, Neeraj Nayak & Prashant Palayam

Executive Summary:

Synchrophasor systems are being deployed in power systems throughout the North American Power Grid and there are plans to integrate this technology and its associated tools into Independent System Operator (ISO)/utility control room operations. A pre-requisite to using synchrophasor technologies in control rooms is for operators to obtain training and understand how to use this technology in real-time situations. The Phasor Simulator for Operator Training (PSOT) project objective was to develop, deploy and demonstrate a pre-commercial training simulator for operators on the use of this technology and to promote acceptance of the technology in utility and ISO/Regional Transmission Owner (RTO) control centers.

The original proposal to DOE and participants' input enabled the PSOT project to develop two different approaches for an operator training simulator -- Event Library Approach and On-the-fly real-time simulations Approach.

1. **Event Library Approach** - Events simulations are performed off-line and are stored in an event library prior to the training session. PSOT is used to stream simulated or recorded data in real-time (C37.118 data stream) for visualization during operator training. Event library is also populated with mitigation actions for events, and operators can be trained on the effectiveness of different mitigation actions.
2. **On-the-fly real-time simulations Approach** – This requires integration with real-time simulators using C37.118 data stream. This was successfully demonstrated by integration with TSAT/ePMU for ERCOT. SCE elected to use PowerWorld Dynamic Studio for on-the fly real-time simulation approach, they feel it had several advantages over other tools, such as the ability to

read the files from PSLF and it is simple to use. EPG has also tested PSOT Phasors streams generated by PowerWorld Dynamics Studio as well as OPAL-RT's ePHASORSim. Using On-the-fly RT simulation approach for training, the instructor and the students can run different events with the ability to interact with the simulations (e.g., evaluating different mitigation scenarios) and students get to immediately observe the system impact of events and event mitigation.

ERCOT and SCE provided the necessary data and information for EPG to effectively run the necessary power system simulations and build the utility specific library of simulated events. This exercise helped to identify the preferred event simulations and associated corrective actions. The PSOT project provided ERCOT and SCE a library of both utility specific and generic simulated events and software for training operators. PSOT software included a streamer to replay simulated events, and EPG's Real Time Dynamics Monitoring System (RTDMS) application to calculate power system grid metrics and visualization for detection, diagnosis, corrective action and restoration. PSOT is designed to integrate with any analytic and visualization engine.

ERCOT utilizes TSAT for load flows and dynamic simulations and indicated a preference to perform event simulations On-the-fly for operator training as part of the PSOT project. EPG and ERCOT collaborated with PowerTech Labs who introduced a new simulation tool in 1Q 2015 with the ability to perform high-speed "on-the-fly" dynamic event simulations and stream out data in real-time with ePMU. TSAT/ePMU was used as a real-time simulator for ERCOT. The ability to perform real-time simulations was a significant advancement and allowed EPG to meet ERCOT's training needs. Similarly, EPG and SCE evaluated both Real Time Digital Simulator (RTDS) and Power World real-time simulators in an effort to meet SCE's plans to also perform on-the-fly dynamic event simulations.

EPG completed deployment and demonstration of PSOT Event Library Approach at SCE and ERCOT. EPG also evaluated, tested and integrated On-the-fly approach with PSOT. EPG provided training to project participants for event library approach. The objective of the training session was to train the trainer and have the trainers train their operators.

EPG also developed an Event Library Approach using generic power system events for the purpose of commercialization and introduction to other ISOs and utilities. EPG accomplished pre-commercial activities by demonstration at NASPI, WECC JSIS, EPG and PowerTech Users Group Meetings. The target market for the PSOT product are Training Departments at utilities/ ISOs who have or are planning to bring synchrophasor technology into the control center and have a need to train their Power System Operators and Operating Engineers.

Both ERCOT and SCE plan to utilize PSOT for operator training and are planning integration of PSOT system with their Operator Training Simulator (OTS) system. The purpose of integration will be to train operators by showing side-by-side comparison, in both SCADA OTS and PSOT system. As part of the project, EPG, ERCOT & PowerTech Labs developed a detailed design document for post project activity and budgeting. Similarly, SCE plans to integrate PSOT with Bulk Reliability in a Compact Kit (B.R.I.C.K) system used as OTS system as part of post project commercial activity.

PSOT project addresses the critical need for a commercial product for operator training that will make synchrophasor technology used and useful by operators in utility and ISO/RTO control centers.

Statement of Problem:

The electric power industry, including both SCE and the ERCOT regions, has invested in excess of $200,000,000 in phasor technology infrastructure. ISOs and utilities want to integrate this technology into real-time operations at their control centers. A necessary step for integrating new technology for mission critical control center operations is training power system operators on synchrophasor technology and making it part of their training methods. The current training approach on synchrophasor technology using recorded events is inadequate for several reasons, including:

- Significant events don't happen frequently.
- Recorded events do not cover some of the critical N-n contingencies that cause cascades.
- Recorded data is often of bad quality making use of events for training unsatisfactory.
- Event data is proprietary, inhibits knowledge sharing and ability to get a wide-area view.
- Traditional simulations do not provide high-resolution to learn about event signatures, wide-area situational awareness, or dynamic metrics.

PSOT fills these gaps and enables utilities and ISO/RTOs to use either an event library or on-the-fly approach for operator training; a complement to existing Energy Management System/Supervisory Control and Data Acquisition EMS/SCADA based training using OTS. Successful demonstration of PSOT will go a long way for subsequent wide-spread adoption by the industry and addresses the critical need for commercial grade applications in the control room operations.

Project Objective:

Project objectives were to conduct pre-commercial research, design, develop, and demonstrate for commercial use a phasor-based simulator for use in utility and ISO/RTO control centers to train operators on the use of synchrophasor technology in real-time operations to:

- use advanced synchrophasor technology metrics such as phase angles, sensitivities and oscillations/damping to monitor, diagnose, and take timely corrective actions in real-time
- understand the early warning indications for events over a wide-area such as the entire Interconnection that have the potential to cascade
- manage what-if scenarios
- test alternate operator actions and consequences in a training environment
- understand and prepare to act on outages of critical system components or series of components.

PSOT is designed to promote acceptance of synchrophasor technologies in control rooms by providing operators needed training on use of synchrophasor technology. Use of technologies and tools in control rooms enable operators to learn about the technology and how to make use of it in a variety of real life situations.

PSOT Technical Approach:

The development, testing, deployment and training on PSOT required multiple steps to complete. The following describes EPG's approach to this project, in conjunction with its utility partners:

1. EPG developed a functional specification document with the intent of clearly defining the application's capabilities and any limitations. After receiving the project participants' feedback and making any necessary adjustments, the EPG Team developed the design specifications for the application. The design specifications included mock-ups for the PSOT application.
2. EPG, in conjunction with the project partners, performed the necessary research to determine which dynamic power system simulation models would best fit the needs of this project, both for the generic events and client specific events.
3. EPG in conjunction with the project partners identified the suitable power system events (generic and utility specific).
4. EPG selected a suitable generic power system case, along with its dynamic data. The utility partners provided their respective utility specific power flow and dynamic file cases to EPG.
5. Once the appropriate models were selected, power system events were identified and the base cases were available, the EPG Team first ran the utility specific dynamic simulations and later the generic event dynamic simulations. In addition to each event simulation there were event mitigation actions simulated. EPG simulated both generic and client specific event and mitigation scenarios for training, using existing simulation technologies e.g., Positive Sequence Load Flow (PSLF) and PowerTech Labs Transient Security Assessment Tool e-PMU (TSAT-ePMU) and PowerWorld Dynamics Studio.
6. EPG developed the necessary converter module to convert event simulation output from CSV file format to IEEE C37.118 data format, which is used for playing the events/mitigations on RTDMS.
7. EPG developed an instructor's tool Event Streamer & Manager (ESM) for:
    a. Building event library, allowing grouping of events and its associated mitigations scenarios.
    b. Playing events for operator training in standard IEEE C37.118 data stream.
8. EPG built an event library that contains both generic and client specific events for training. The event library includes event scenarios with mitigation options, and associated configuration files.
9. EPG ran utility specific event simulations for both SCE and ERCOT and shared the results with both.
10. EPG provided documentation for each simulated event and their associated mitigation scenarios.
11. EPG used RTDMS server application to configure simulated PMU and its measurements, calculate advanced metrics such as system frequency, angle difference, voltage sensitivity, detect power system events, oscillations and generate alarms to indicate emerging system events.
12. EPG used RTDMS Visualization for training operators on control room displays for detection, diagnosis, corrective action and restoration.
13. EPG setup demonstration and provided training to the utility partners.

14. At ERCOT's request, EPG investigated and developed the capability of performing On-the-Fly simulations, using PowerTech's TSAT-ePMU simulation tool for the ERCOT events.
15. At SCE's request, EPG and SCE evaluated the capability of performing On-the-Fly simulations, using RTDS and PWDS simulation tool for SCE events.
16. At ERCOT's request, EPG investigated and documented design details for integrating the PSOT system with their OTS system, post project.

PSOT Training Approaches:

Simulation of possible power system events is a good way to understand the limitations of a power grid and prepare operational guidelines, in case such events should happen. Power system operators make sure that generation and load balance at all times, all consumers are served, and all power system metrics are within limits; even under severe contingency conditions, such as major line faults and generation trips. If the operator knows before-hand how an event will unfold in real life, they will be better prepared to handle that event, minimizing its impact on the system. Simulation of such events is a good way to understand their impact on the power grid. Additionally, different corrective actions can also be simulated and their effectiveness can be validated. Based upon an event and its best possible corrective action(s) as provided by simulation results, operational guidelines can be prepared to deal with such an event in real life.

PSOT uses simulated power system events, along with their mitigation actions; converts the output results to an IEEE C37.118 synchrophasor format; and provide an easy to use Event Streamer and Manager (ESM) module to easily play an event/mitigation on RTDMS screen for training the operators.

The event simulations are performed using industry standard power system simulation tools PSLF and PSS/E for power flow and dynamic data. At the project beginning, it was believed that using a dynamic power system simulation tool to generate the high-resolution data (replicating PMU data at 30 samples per second) would require a significant amount of time to run (5 to 15 minutes). The time-delay between operator action and running the event to get the results would introduce a wait time that is not suitable for training operators. To overcome this limitation, the original project design was to have all event simulations performed off-line and the output results and mitigation scenarios will be saved and retained in an Event Library. Using the Event Library Approach, during a training session, the instructor will select, using the administrative ESM, an event from the event library and initiate it. Once the event is running on the RTDMS visualization, the trainee can observe the various metrics associated with the event and has the ability to re-play the event. Figure 1 shows the components of and data flow for the Event Library Approach at both SCE and ERCOT.

In November of 2014, EPG and ERCOT met to review and discuss the project functional specifications. During the meeting the ERCOT trainers mentioned that operators do not always follow the same path into and out of the events. Part of training on the simulator is to allow for the operators to make good or bad decisions and to understand the consequences of those actions. During training scenarios crews with more experience may get to an event later because the crew has taken measures to limit or mitigate events. Other crews may get to scenarios sooner because they were slower in recognizing needed actions or might miss necessary actions. In these training scenarios the operators may see several options to resolve an event and the ERCOT training staff encourages the student to test the various options, using the on-the-fly simulation approach, and evaluate the results. Therefore, the ERCOT trainers would like the ability to modify an event on-the-fly based on training needs. An example of this might be adding a generator trip,

line trip or load shedding if actions were not promptly taken. ERCOT has this capability in its existing simulator and would like to have it in the PSOT project as well. EPG agreed to explore the capability of and identify requirements to performing on-the-fly simulations.

In December of 2015, EPG was made aware of PowerTech Labs new product TSAT-ePMU, which had the capability of running high-speed dynamic power system simulations on networks with 10,000 buses or less. In January of 2015, EPG, ERCOT and PowerTech formed a collaboration to integrate TSAT-ePMU instead of PSS/E into PSOT at ERCOT. Using TSAT-ePMU, the instructor, during training session, runs an on-the-fly event simulation and students get to immediately observe the system impact of events and event mitigation.

The ability to perform on-the-fly simulations is a significant advancement and allowed EPG to meet ERCOT's training needs. Similarly, EPG and SCE evaluated both RTDS and PowerWorld in an effort to meet SCE's plans to also perform on-the-fly dynamic event simulations. Figure 2 below shows the components of and data flow for the On-the-Fly Library Approach at ERCOT and SCE.

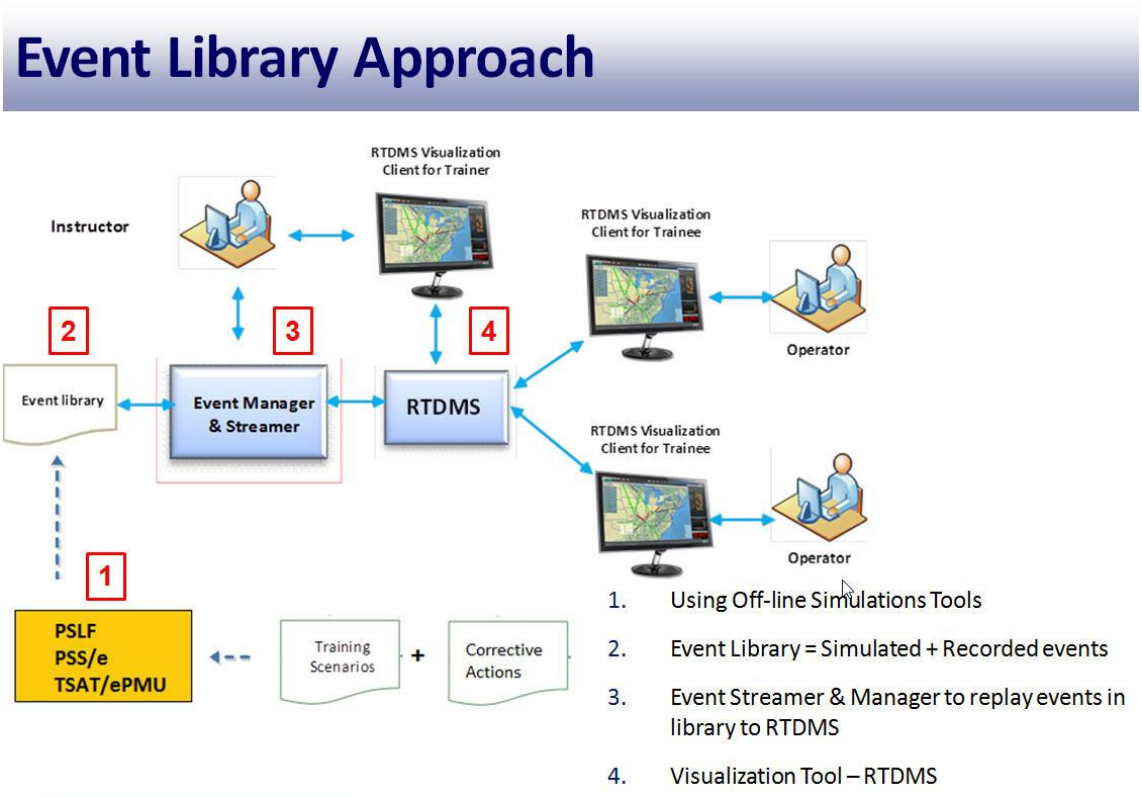


Figure 1 - Components of and Data Flow Diagram for the Event Library Approach at SCE and ERCOT

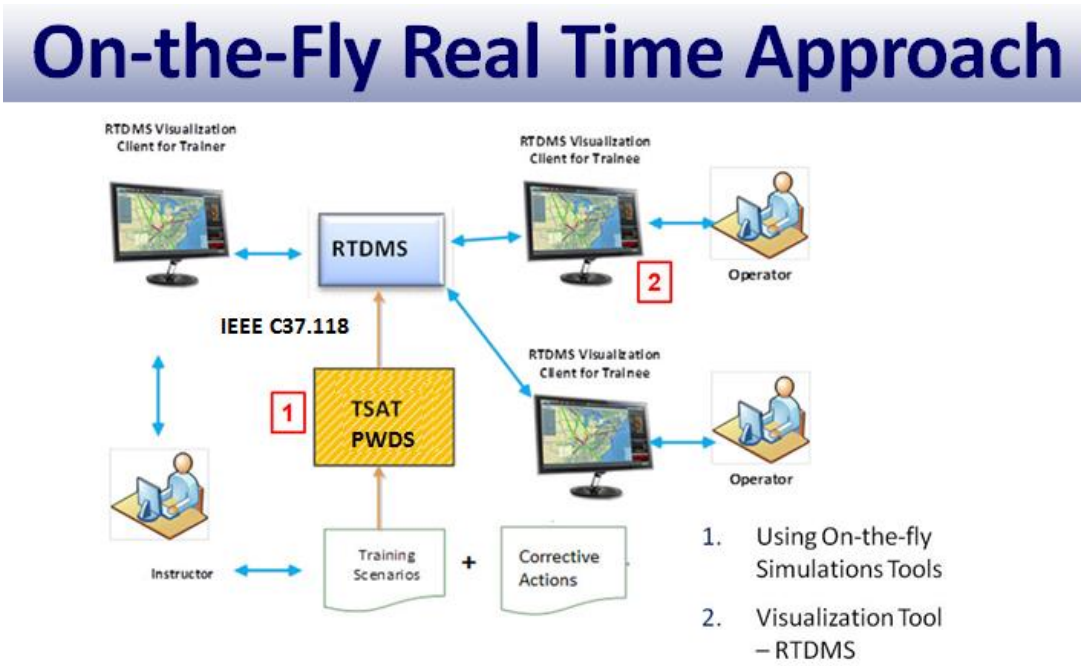


Figure 2 - Components of and Data Flow Diagram for the On-the-Fly Approach at ERCOT and SCE

Utility Specific Event Simulations:

Southern California Edison
Criteria for selecting SCE specific model – The Western Electricity Coordinating Council (WECC) and operating entities in the Western region use the PSLF power system model and therefore, EPG utilized that model for the SCE and WECC event cases. The power system model for SCE consisted of a power flow file for HS2020 (Heavy Summer 2020) and a corresponding dynamic data file from WECC, representing the complete Western Interconnection power system model. EPG coordinated with SCE to get the necessary base cases from the WECC in PSLF format. EPG has commercial licenses for PSLF at its premises, which was used to conduct the event simulations.

Utility Specific Events for SCE - Utilizing the PSLF power system model and WECC's HS2020 dynamic power flow case, EPG ran nine (9) utility specific events and one actual recorded event for SCE.

1. Magunden Separation
2. South of Lugo N-2 RAS
    a. Mira Loma – Vincent 500 kV line in service
3. South of Lugo N-2 RAS
    a. Mira Loma – Vincent 500 kV line out of service
4. Mira Loma Low Voltage Load Shedding Scheme
    a. Mira Loma – Vincent 500 kV line in service
    b. Mira Loma – Vincent 500 kV line out of service
5. Devers RAS – Loss of the two Devers-Valley 500 kV lines
6. Lugo 1 AA bank trip, with RAS

7. Lugo 2 AA banks trip, with RAS
8. Loss of 2 Palo Verde Units
9. Loss of two COI lines and Insertion of the Chief Joseph Breaking Resistor
10. Solar Plant Oscillations

The output of the SCE specific event simulations was labeled as to the event name and stored in the Event Library for future use in training sessions. In addition to the events being stored in the Event Library, SCE was also provided a PowerPoint presentation that contained full event documentation. The documentation can be utilized as an event refresher for the instructor or as a self-teaching aide for students.

Electric Reliability Council of Texas
Criteria for selecting ERCOT specific model - As mentioned earlier, ERCOT expressed the need to have "on-the-fly" event simulations as part of the PSOT project. As a result of their identified need for on-the-fly event simulations, there was no other alternative but to utilize TSAT/ePMU simulation tool and take advantage of its ability to perform high-speed "on-the-fly" dynamic event simulations. ERCOT Operating Engineer staff provided the necessary historical state estimator cases and dynamic files necessary for EPG to effectively build a library of eight (8) ERCOT specific simulated events and three (3) actual recorded events.

Utility Specific Events for ERCOT - Utilizing the TSAT-ePMU simulation tool and stressed state estimator and planning cases, EPG ran the following eight (8) utility specific events and three (3) actual recorded events.

1. Loss of 3 units at North Edinburg
2. Loss of 2-345 kV lines in Rio Grande Valley Region
3. Loss of 2-345 kV lines out of North Edinburg
4. Valley Compound Event
5. Laredo Event
6. Loss of 3 units at Martin Lake
7. Loss of 2-345 kV lines and nearby unit north of Houston
8. Loss of 2-345 kV CREZ lines
9. Matador Wind Farm Oscillations
10. Hamilton Road Oscillations
11. Valley Wind Ramp Event

The output of the ERCOT specific event simulations were labeled as to the event name and stored in the Event Library for future use in training sessions. In addition to the events being stored in the Event Library, ERCOT was also provided a PowerPoint presentation that contained full event documentation. The documentation can be utilized as an event refresher for the instructor or as a self-teaching aide for students.

Generic Power System Models:

The EPG team developed two generic power system models utilizing the ERCOT and WECC (SCE portion of the grid) models as a template. The names of all substations and power plants were changed within the model so as not to disclose any confidential information. Utilizing the two models, the EPG team completed performing five event simulations on each model and also completed drafting the full event

documentation. The generic events were added to the Event Library of ERCOT and SCE. Below are the one-line diagrams (Figures 3 and 4) of the two generic power systems used for the generic event simulations.

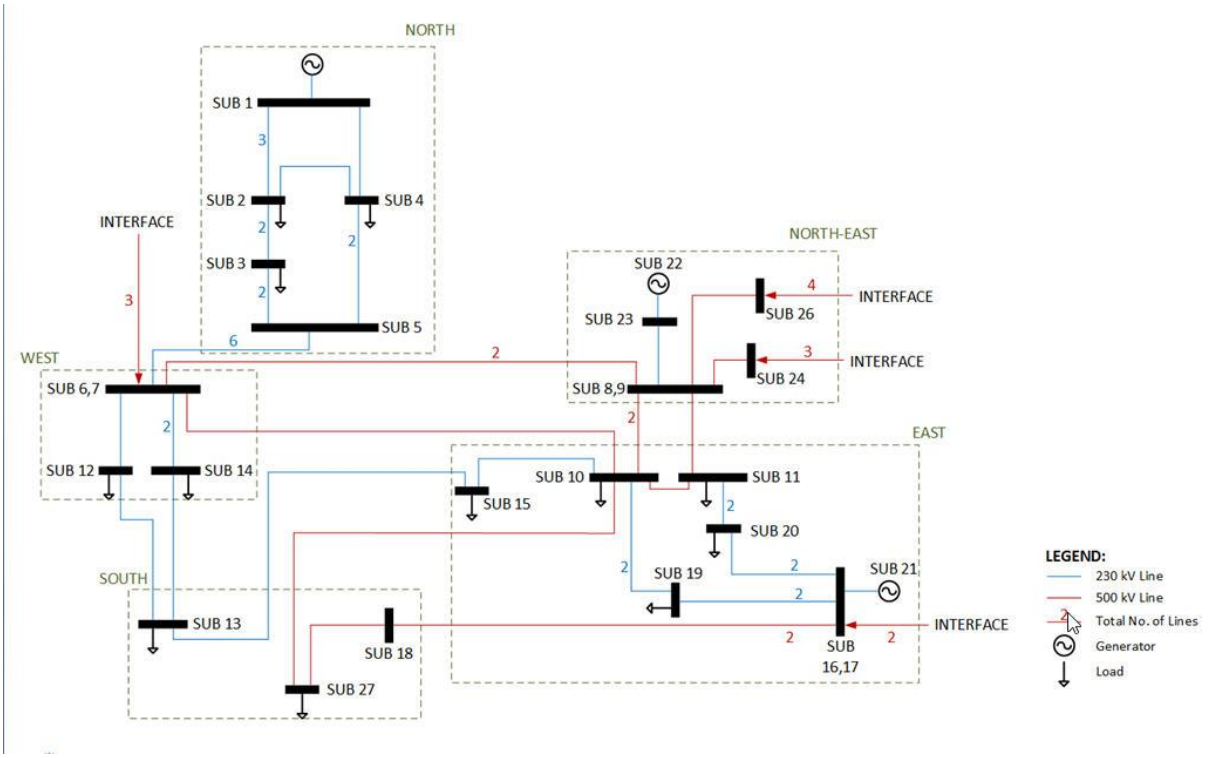


Figure 3 - Generic Power System West

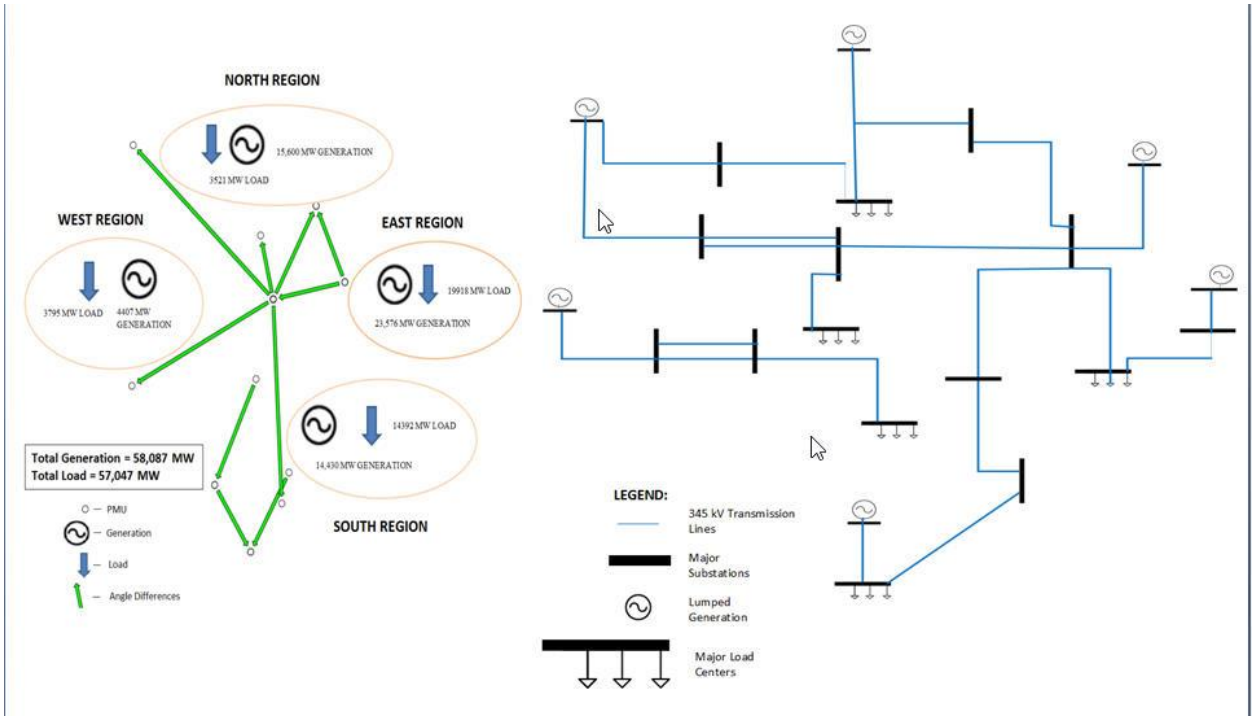


Figure 4 - Generic Power System South

Below is a list of the event simulation performed on the Generic Power System West

- Event Case 1 – Northern Region Islanding Event
- Event Case 2 – Double Line Trip South of SUB 9
- Event Case 3 – Triple Line Trip South of SUB 9
- Event Case 4 – Double Line Trip West of SUB 17
- Event Case 5 – Double Transformer Bank Trip at SUB 9

Below is a list of the event simulation performed on the Generic Power System South

- Event Case 1 – Loss of two 345 kV Lines in the South
- Event Case 2 – Loss of a 345 kV Line and two 138 kV Lines
- Event Case 3 – SUB 47 Wind Farm Oscillations
- Event Case 4 – Loss of 3 units and two 345 kV Lines
- Event Case 5 – Wind Ramp Event in the South

As was the case with the utility specific events, EPG provided both SCE and ERCOT full event documentation for both the Generic Power System West and South events.

Anticipated Benefits Vs. Actual Accomplishments:

Anticipated Benefits	Actual Accomplishments
1. Build both generic and client specific event library for training, using existing simulation technologies e.g., Positive Sequence Load Flow (PSLF), Power System Simulation for Engineers (PSS/E) and Transient Security Assessment Tool (TSAT)	SCE - Utilizing PSLF, developed nine (9) agreed upon utility specific event simulations and one (1) developed from actual recorded events. ERCOT - Utilizing TSAT-ePMU, developed eight (8) agreed upon utility specific event simulations and three (3) developed from actual recorded events. Generic System Events - Developed a total of ten (10) generic power system event simulations using both PSLF and TSAT-ePMU
2. Provide event library which includes event scenarios with mitigation options, and event documentation.	SCE - the ten (10) utility specific and ten (10) generic power system events were provided to SCE and stored in the Event Library for future use. SCE was provided full event documentation for both their utility specific and generic power system events. ERCOT - the eleven (11) utility specific and ten (10) generic power system events were provided to ERCOT and stored in the Event Library for future use. ERCOT was provided full event documentation for both their utility specific and generic power system events.
3. Convert simulation outputs to an Institute of Electrical and Electronics Engineers IEEE C37.118 data stream.	In PSOT, the event simulations were performed using industry standard power system simulation tools PSLF and TSAT-ePMU using power flow and dynamic data. The output of the simulated power system events is converted to an IEEE C37.118

	synchrophasor format; and PSOT provides an easy to use Event Streamer and Manager module to easily play an event on RTDMS visualization for training the operators.
4. Build PSOT administration module for case selection and human machine interface HMI module for visualization. 5. Stream simulation output to HMI module and provide replay function for training.	Event Streamer and Manager (ESM) is the instructors interface for utilizing the following functions: a) Ability to read .CSV file from Event Library b) Ability to manage event & its associated mitigation files c) Ability to replay PMU data from .CSV file to RTDMS visualization in IEEE C37.118 data format during training d) Ability to Pause and Stop replaying data e) Ability to select all or some of available PMUs for a specific event f) Provides settings for communicating with RTDMS
6. Provide interface to run multiple scenarios and evaluate event mitigation methods that can be incorporated in operating procedures and guidelines for use in control rooms.	The ESM is the interface in the Event Library Approach to manage simulated events and several event mitigation methods for each event. Due to time delay between operation action and running the event, the simulations are performed offline and stored in the event library. During training, trainers can use the ESM to run multiple scenarios from event library and evaluate event mitigation methods that can be incorporated in the operating procedures and guidelines for use in control rooms. TSAT-ePMU and PWDS has an interface in the On-the-fly approach to simulate events and several event mitigation methods for each event. During the training, trainers can use the TSAT-ePMU and PWDS interface to run multiple scenarios on-the-fly and evaluate event mitigation methods that can be incorporated in the operating procedures and guidelines for use in control rooms.
7. Extensible design for subsequent extension to work with other simulators used by industry.	During the project research, EPG demonstrated the following simulation tools could be integrated with PSOT: ➢ PSLF ➢ PSS/E ➢ TSAT-ePMU

	➢ PowerWorld Dynamic Studio ➢ RTDS ➢ OPAL-RT ePHASORSim

Benefit Analysis:

Operational Benefit – PSOT is designed to train operators so they can be proficient in the following areas and more effectively manage the grid:

1. Use of the advanced metrics e.g., phase angles, sensitivities, oscillations.
2. Early detection of wide-area cascading events such as islanding and blackouts, instability issues using advanced metrics and alarming.
3. Event Diagnostics in preparation for corrective action and restoration.
4. Alternate corrective actions and observe consequences in a training environment.

In addition, ERCOT uses an EMS Simulator for training their operators on different event and contingency cases. To leverage the existing EMS simulator, ERCOT and EPG explored the capability and feasibility of running some specific event cases in parallel on both the PSOT and their EMS Simulator, with events time-synchronized. This would allow the operators to do a side-by-side comparison and to observe different metrics on the two tools simultaneously. It was agreed that integration of PSOT, TSAT-ePMU and ERCOT's EMS Simulator would be completed under a Phase II post PSOT Project. This will also benefit the trainers to have a single source for triggering simulation events and their mitigation methods. On-the-fly RT simulation approach is a standalone system which requires a manual process to use the same base case and same event simulation sequence used in the EMS simulator. The Phase II will enable trainers to use the existing EMS simulator and PSOT system simultaneously without manual process and with complete automation of using the same base case and same event simulation sequence and correction action used by the instructor.

Cost Benefit - EPG was awarded the PSOT project by DOE under the Grant Award DE-E0000702. The Project started on September 15, 2014 and ended September 14, 2016. SCE & ERCOT are cost share partners along with EPG. SCE and ERCOT are also demonstration hosts for the PSOT project. PowerTech Labs Inc. joined the project in early 2015 to provide TSAT/ePMU software to accommodate ERCOT's plans for integration with their real-time simulation tools to enable on-the-fly simulations.

Commercial Benefit – As part of the American Recovery and Reinvestment Act of 2009, the Department of Energy provided the electric industry with funds to further expand the use of synchrophasor technology, including at ISO/RTO/utility control centers. The requirements for effective implementation of synchrophasor technology in real-time operations are twofold; including 1) Operator Training, and 2) Policies and Procedures on this advanced technology.

PSOT addresses the critical need for a commercial product for operator training that will make synchrophasor technology used and useful by operators in control rooms.

Project Activities:

As PSOT Project Manager, EPG submitted six (6) quarterly reports to DOE on the project status and participants' activities for each quarter. These reports served the purpose of keeping the DOE staff informed on the projects progress vs. schedule and to identify any potential issues.

Project Products:

PSOT Functional Specifications - On February 2, 2015, after getting SCE's and ERCOT's comments on the draft functional specification, EPG completed the drafting of the final functional specification and draft design specification.

PSOT Design Specifications - On May 18, 2016, EPG completed the Final Functional and Design Specification document. See embedded copy below.

DOE_PSOT_Function
al_and_Design_Spec_

PSOT Components - PSOT is a phasor-based training simulator to train power system operators on the use of synchrophasor technology.

PSOT uses of the following components:

1. Industry standard Power System Simulation Tools to perform event simulations using dynamic models and build a library of system events
    a. Off-line Simulation Tools including PSS/E, PSLF, TSAT/ePMU.
    b. On-the-fly Simulation Tools including TSAT/ePMU, RTDS, PWDS.

2. RTDMS is used for Analytics and Visualization to train operators on:
    a. Event Detection & Alarming.
    b. Event Diagnostics.
    c. Event Corrective Action & Restoration.

3. ESM (Event Streamer & Manager)
    a. Instructor's user interface.
    b. Retrieve, stream and play system events from the event library.
    c. Converts event files that are in a CSV format to IEEE C37.118 data format.

    On-the-fly simulation tools have the capability to stream dynamic event simulation directly to RTDMS and are independent of the Event Streamer and Manager.

4. *e*PDC (*enhanced* Phasor Data Concentrator)
    a. Gathers multiple data streams from On-the-fly real-time simulations tools.
    b. Outputs time-synchronized dynamic event simulation directly to RTDMS as a single data stream.

RTDS is hardware-based digital simulator that is used by SCE for on-the-fly simulations for sending multiple data streams and requires *e*PDC for synchronization of these streams. TSAT/ePMU & PWDS is software-based on-the-fly simulation tool with a single time-synchronized output data stream fed directly to RTDMS.

PSOT Event Library Approach - Simulations for SCE & ERCOT

Utility Specific Events for SCE - Utilizing the PSLF power system model and WECC's HS2020 dynamic power flow case EPG ran nine (9) utility specific events and one actual recorded event for SCE.

Utility Specific Events for ERCOT - Utilizing the TSAT-ePMU power system model and stressed state estimator and planning cases, EPG ran eight (8) utility specific events and three (3) actual recorded events.

Full documentation of the SCE and ERCOT event simulations can be found under Utility Specific Event Simulations," sections of this report.

PSOT Generic Library of Simulations

The EPG team developed two generic power system models utilizing the ERCOT and WECC (SCE portion of the grid) models as a template. The names of all substations and power plants were changed within the model so as not to disclose any confidential information. Utilizing the two models, the EPG team completed performing five event simulations on each model and also completed drafting the full event documentation. The generic events were added to the Event Library of ERCOT and SCE.

Full documentation of the ten (10) generic event simulations can be found under Generic Power System Models section of this report.

PSOT NASPI Presentations

As PSOT Project Manager, EPG made project presentations at the North American Synchrophasor Initiative (NASPI) Work Group meetings on:

- October 22, 2014
- March 24, 2015
- October 15, 2015
- On March 22, 2016, due to an extremely full agenda, EPG was requested to submit an update on the project status

The copies of the presentations were included in the corresponding quarterly report.

PSOT Commercialization Plan

As part of the project, EPG performed market research in an effort to develop a project commercialization plan. The research identified the target market is Training Directors at utilities and ISO/RTO's who:

- Have already deployed and are expanding the use of synchrophasor technology for better PMU placements.
- Are planning to bring synchrophasor technology into the control center in an effort to support real-time operations, improving grid reliability and increase wide-area situational awareness.

Below is a copy of EPG's commercialization plan

PSOT_Commercializa
tion_Plan_121115-F.(

PSOT Project Training

As part of the project, EPG was to provide training, training documentation (PowerPoint briefings), user's manual and other appropriate training material. The following describes how EPG, working with the project participants, met the requirement.

ERCOT Training

The primary focus of EPG's training at ERCOT was to train the trainer and allow the trainer to train the system operators as their training cycle comes up. On May 10 and 11, 2016, EPG held a training session for the ERCOT training staff and approximately 10 operating staff members. Day one of the training consisted of an overview of the project, the process of developing the simulated events and some hands-on practice of running a simulated event utilizing the Event Library approach. Day two of training was limited to a smaller group with the focus of providing more detailed hands-on training and navigation of the RTDMS visualization. In addition to the training, EPG provided ERCOT's training staff with training aids, which included PSOT application user's guide and detailed event simulation documentation. The copies of the presentations were included in the quarterly report.

SCE Training

On February 11, 2016, EPG provided the three members of SCE's GCC training staff with a four-hour familiarization of the PSOT application. The familiarization session consisted of an overview of the project, the process of developing the simulated events, navigation of the RTDMS visualization and some hands-on practice of running a simulated event utilizing the Event Library approach. The GCC training staff informed EPG that due to an aggressive operator training schedule they would not be available for PSOT training until 4Q 2016. EPG agreed to work with SCE and provide the training at a mutually agreeable date. The training to be provided will focus on training the trainer and allow the trainer to train the system operators as their training cycle comes up. The copies of the presentations were included in the quarterly report.

PSOT Phase II Final Design Concept for Post Project Implementation at ERCOT

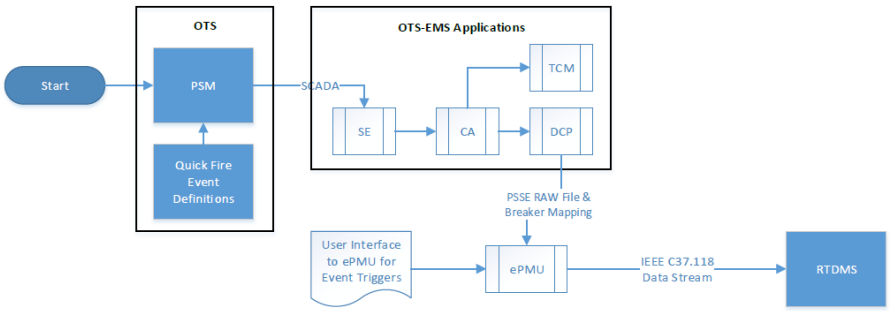
As a result of this DOE project, ERCOT has been able to define a scope of work which will be needed to realize additional training scenarios. Specifically, ERCOT trainers have indicated their plans to run on-the-fly event simulations. In order to perform on-the-fly event simulations requires integration between the Powertech TSAT-ePMU tool and the Alstom EMS simulator. The Phase II scope of work is as follows:

1. To integrate the interface of the Alstom EMS simulator with that of the TSAT-ePMU simulator. The goal would be to define all events in a common interface which would inject events to the

dynamic simulation tools and then to the existing simulator. In this way the dynamic simulator would stream the PMU data slightly before the EMS simulator. This is realistic and would be the expected way the control room will see events. Typically, PMU data is read 30-times per second and SCADA data is read once every 10-seconds. Therefore, it would be the goal to integrate the interfaces in such a way that the simulators will train operators which alarms they will be getting and in which sequence they will be received. The PMU alarms will be received faster than the normal EMS alarms are received historically. This will reinforce the benefits of having synchrophasor technology and alerting operators when events occur.

2. The following diagram includes a conceptual view of this design.

DATA FLOW DESIGN CONCEPT FOR THE PSOT PROJECT



Proposed requirements for interface to ePMU/RTDMS (to be discussed)

The goal is to provide an interface to the user/trainer that will allow for entry of on-the-fly events into ePMU and also for choosing pre-defined events from a prepared file(s).

The pre-defined events should be triggered using a unique event ID.

On-the-fly events shall be entered separately into Quickfire and ePMU by the trainer.

Pre-defined events can be prepared in two ways –

1. Coded directly in TSAT switching file format, or,
2. Other custom format translated into switching file format at the time of execution.

a. PSM generates SCADA points every 4-seconds (including generator MW/MVARs, line flows and breaker status).
b. The generated SCADA points become the input for the EMS within the OTS Framework.
c. State Estimator (SE/RTNET), RTCA and RTDCP are configured to operate in a similar manner as real-time.
    i. RTNET/RTCA runs every 5 minutes in sequence.
    ii. RTDCP runs every 10 minutes.
d. Quick Fire events are entered into the data flow stream at the PSM. The proposal is to have Powertech's ePMU simulate a rolling EMS case similar to RTDCP, with the case being refreshed every 3-5 minutes.
    i. Quick Fire events should be transmitted to ePMU and implemented automatically.
    ii. Interface should be provided for the trainer to implement events on the fly (either ad-hoc events or pre-planned events not included in Quick Fire)
e. RTDMS should show flat values equal to last known simulation values, during the transition from one EMS case to the next.

f. The justification for Phase II is that it will allow the trainers to devote more attention on the operators than on running the simulation tools. Current Phase I is able to support dynamic simulations and existing simulations to occur in the same training session. Since the two systems have separate interfaces which are not fully integrated Phase I will require more support staff in order to run this in an integrated fashion. Reducing the number of required trainers running simulations while allowing for improved one-on-one training is considered to be the key benefits of Phase II.

Project Summary:

Problem - The electric power industry has made a significant investment in synchrophasor technology infrastructure, with plans to integrate this technology into real-time operations at utility and ISO/RTO control centers, but first there is the unmet need of training power system operators on this technology and PSOT was designed to fill that gap.

Project Objective and Approach - The PSOT project objectives were to conduct pre-commercial research, design, develop, and demonstrate for commercial use of a phasor-based simulator to train power system operators on the use of synchrophasor technology in real-time operations. The development, testing, deployment and training of users on the PSOT required a fifteen (15) step process.

Event Simulations Tools - PSOT uses simulated power system events, along with their mitigation actions; converts the outputs results to an IEEE C37.118 synchrophasor format; and provide an easy to use Event Streamer and Manager (ESM) module to easily play an event/mitigation on RTDMS screen for training the operators. At the project start, the event simulations were performed using industry standard power system simulation tools PSLF and PSS/E using power flow and dynamic data. The PSS/E simulation tool was later replaced with PowerTech Lab's new product TSAT-ePMU, which had the capability of running high-speed dynamic power system simulations on networks with 10,000 buses or less.

Training Approaches - At the encouragement of the project participants, the project evolved into two different approaches for event simulation training. Approach 1 - Event Library Approach, during a training session, the instructor will select an event from the event library and initiate it. Once the event is running on the RTDMS visualization, the trainee can observe the various metrics associated with the event and has the ability to re-play the event. Approach 2 - On-the-Fly Approach, using TSAT-ePMU & PWDS, the instructor, during a training session, runs an on-the-fly event simulation and students get to immediately observe the system impact of events and event mitigation.

Utility Specific Events - SCE, utilizing the PSLF power system model and WECC's HS2020 dynamic power flow case EPG ran nine (9) utility specific events and one actual recorded event for SCE. ERCOT, utilizing the TSAT-ePMU simulation tool and stressed state estimator and planning cases, EPG ran eight (8) utility specific events and three (3) actual recorded events. Both SCE and ERCOT were provided full event documentation.

Generic Events - EPG developed two generic power system models utilizing the ERCOT and WECC (SCE part of the grid) models as a template. Utilizing the two models, EPG completed performing five event simulations on each model and also completed drafting the full event documentation. The generic events were added to the Event Library of ERCOT and SCE.

Operational Benefit – PSOT is designed to train operators so they can be proficient in the following areas and more effectively manage the grid:

1. Use of the advanced metrics e.g., phase angles, sensitivities, oscillations.
2. Early detection of wide-area cascading events such as islanding and blackouts, instability issues using advanced metrics and alarming.
3. Event Diagnostics in preparation for corrective action and restoration.
4. Alternate corrective actions and observe consequences in a training environment.

Cost Benefit - The Project started in September 2014 and ended September 14, 2016. SCE & ERCOT are cost share partners along with EPG. SCE and ERCOT are also demonstration hosts for the PSOT project.

NASPI Presentations - As PSOT Project Manager, EPG made project presentations at four of the North American Synchrophasor Initiative (NASPI) Work Group meetings.

Commercialization Plan - As part of the project, EPG performed market research in an effort to develop a project commercialization plan. The research identified the target market are Training Directors at utilities and ISO/RTOs who have already deployed or are planning to bring synchrophasor technology into the control center in an effort improving grid reliability.

In conclusion, the PSOT project addresses the critical need for a commercial product for operator training that will make synchrophasor technology used and useful by operators in utility and ISO/RTO control centers.

Phasor Simulator for Operator Training

(PSOT)

Report on

Final Functional and Design Specifications

Prepared for the
Office of Electricity Delivery and Energy Reliability,
Transmission Reliability Program of the U.S. Department of Energy
Under Contract No. DE-OE0000702

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May 18, 2016

Acknowledgement

The work described in this report was conducted collaboratively by Southern California Edison (SCE), Electric Reliability Council of Texas (ERCOT), Dominion Virginia Power, and funded by the Office of Electricity Delivery and Energy Reliability, Transmission Reliability Program of the U.S. Department of Energy.

Preface

Synchrophasor systems are being deployed in power systems throughout the world. As operations and system controls become reliant on synchrophasors, it is essential that operators are trained on the use of synchrophasor technology. Use of technologies and tools in the control rooms enables operators to learn about the technology and how to make use of in a variety of real life real-time situations. The Department of Energy (DOE) has funded this project to conduct pre-commercial research, design, development, and demonstration for Phasor Simulator for Operator Training (PSOT) to train operators on the use of synchrophasor technology in real-time operations (DE-OE0000702). PSOT shall promote acceptance of synchrophasor technologies in ISO/utility control rooms by providing system operators needed training on use of synchrophasor technology.

This Report documents the functional requirements and design specifications of PSOT.

Acronyms

BPA: Bonneville Power Administration

CSV: Comma Separated Value

DOE: Department of Energy

EPG: Electric Power Group

ERCOT: Electric Reliability Council of Texas

FACTS: Flexible Alternating Current Transmission System

GUI: Graphic User Interface

ISO: International Organization for Standardization, Independent System Operator

PDC: Phasor Data Concentrator

PMU: Phasor Measurement Unit

PSLF: Positive Sequence Load Flow

PSOT: Phasor Simulator for Operator Training

PSS/e: Power System Simulator for Engineers

RTDMS: Real Time Dynamics Monitoring System

RTDS: Real Time Digital Simulator

SCADA: Supervisory Control and Data Acquisition

WECC: Western Electricity Coordinating Council

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PSOT Functional Requirements and Design Specifications

1. Introduction

Project objectives are to conduct pre-commercial research, design, development, and demonstration for commercial use of a Phasor Simulator for Operator Training (PSOT) for use in ISO/utility control centers to train operators on the use of synchrophasor technology in real-time operations.

PSOT shall promote acceptance of synchrophasor technologies in control rooms by providing operators needed training on use of synchrophasor technology. Use of technologies and tools in control rooms enable operators to learn about the technology and how to make use of it in a variety of real life real-time situations.

Training approach using recorded events is inadequate for several reasons:

1) Significant events don't happen very frequently.
2) Recorded events do not cover some of the critical N-n contingencies that cause cascades.
3) Recorded data is often of bad quality making use of events for training unsatisfactory.
4) Event data is proprietary, inhibits knowledge sharing and ability to get a wide area view.
5) Traditional simulations do not provide high resolution to learn about event signatures, wide-area situational awareness, or dynamic metrics.
6) Different event mitigation strategies cannot be compared side by side.

The PSOT shall utilize investments in synchrophasor technology and build upon existing ISO/RTO/utility practices of power flow/dynamic simulation practices and operating practices. The PSOT shall be designed to train operators on:

1) Use of the advanced power system metrics e.g., phase angles, sensitivities, oscillations.
2) Understand the early warning indicators for events over a wide-area such as the entire Interconnection that have the potential to cascade, e.g., wide-area phase angle differences.
3) Test alternate operator actions and consequences in a training environment.

EPG will utilize the Positive Sequence Load Flow (PSLF) for SCE and PowerTech Lab's Transient Security Assessment Tool (TSAT/ePMU) for ERCOT to run the dynamic events, convert the model output into a usable format, build a library to store the events, develop graphic user interface (GUI) to access and manage the library files that are to be streamed through the RTDMS visualization application. In addition, the project will:

1) Integrate PSOT application with Power World & RTDS for SCE for On-the-fly simulations
2) Integrate PSOT with Powertech Lab's TSAT/ePMU for ERCOT for On-the-fly simulations
3) Develop a library of events and event mitigation options utilizing a generic model
4) Discuss and Document Integration efforts between PSOT and ERCOT's EMS simulator

2. Functional Requirements Overview

Simulation of possible power system events is a good way to understand the limitations of a power grid and prepare operational guidelines, in case such events should happen. Power system operators make sure that generation and load balance at all times, all consumers are served, and all power system metrics are within limits; even under severe contingency conditions, such as major line faults and generation trips. If the operator know before- hand how an event will unfold in real life, they will be better prepared to handle that event, minimizing its impact on the system. Simulation of such events is a good way to understand their impact on the power grid. Additionally, different corrective actions can also be simulated and their effectiveness can be validated. Based upon an event and its best possible corrective action(s) as provided by simulation results, operational guidelines can be prepared to deal with such an event in real life.

PSOT is required to simulate the power system events, along with their mitigation actions; convert the outputs results to an IEEE C37.118 synchrophasor format; and provide an easy to use GUI module to easily play and replay an event/mitigation on RTDMS screen for training the operators.

The event simulations is required to be performed using industry standard power system simulation tools PSLF, PSS/E and TSAT using power flow and dynamic data. Using a dynamic power system simulation tool to generate the high resolution data (replicating PMU data at 30 samples per second) requires a significant amount of time to run (5 to 15 minutes). Therefore, the time-delay to run the event and get the results would be a considerable source of frustration for the system operator in training. To avoid the source of frustration, the PSOT event simulations is required to be performed off-line and the output results and mitigation scenarios will be canned and retained in an event library. During a training session, the instructor will select, using the administrative GUI, an event from the event library and initiate it. Once the event is running on the RTDMS visualization, the trainee can observe the various metrics associated with the event and has the ability to replay the event. After the trainee has observed the event and has a wide area situational awareness, he/she can request the instructor to run any associated event mitigation scenario.

PSOT is required to help train the operators on using phasor technology to help diagnose an event. Such trainings shall include the use of advanced power system metrics provided by phasor technology, such as wide-area visualization, angle differences, oscillation detection etc., in addition to the metrics available in EMS SCADA technology.

Section 3 describes the case simulation requirements.

Section 4 describes the PSOT application requirements for event library and On-the-fly simulation approach.

Section 5 describes the design for event streamer and manager

3. Case Simulation Requirements – Event Library

3.1 Overview

PSOT is required to train operators on the use of the advanced metrics e.g., phase angles, sensitivities, oscillations; and understanding the early warning indicators for events over a wide-area such as the entire Interconnection that have the potential to cascade, e.g., wide-area phase angle differences. It is required to generate a library of events and event mitigation options utilizing a generic model. Positive Sequence Load Flow (PSLF) and PowerTech Lab's Transient Security Assessment Tool (TSAT) simulation tools will be used to run the dynamic events, convert the model output into a usable format, and build the event library. Once the event files are generated, they will be managed by PSOT and application.

This section describes the requirements for generating event files based on generic model and specific model of SCE and ERCOT.

3.2 Requirements for Selecting Generic Model

A generic example power system model is required for performing a set of event simulations and their remedial actions. The generic model will serve as an academic example model for basic understanding of event signatures and can be used as an introductory trainer module at SCE. The generic model will be an open-domain freely available power system model with both power flow and dynamic data files. It will be a power system model representing a typical small power system, e.g. IEEE 30 bus, 39-bus, 118-bus or others. The criteria for selection of such a system will be:

1) The model should be in public domain with no proprietary issues.
2) The model should have an easily importable dynamic data file into PSLF, PSS/E or TSAT simulation programs; or, there should be suitable dynamic data for the model which can be used to create a dynamic file.
3) The model should have all the basic power system components such as, generators, loads, transformers and transmission lines.
4) The model should be easily expandable to include other components such as, series capacitors, shunt devices, Flexible Alternating Current Transmission System (FACTS) devices, wind generators etc.

3.4 Requirements of Event Scenarios for SCE Specific Model

The Western Electricity Coordinating Council (WECC) and operating entities in the Western region use the PSLF power system model and therefore, EPG will utilize that model for the SCE and WECC event cases. The power system model for SCE will consist of a power flow file and a corresponding dynamic data file from WECC, representing the complete Western Interconnection power system model. WECC has a library of power system models, representing different years and different seasons for peak and off-peak loading conditions. It is required that EPG coordinates with SCE to get the necessary base cases

from the WECC in PSLF format. SCE suggested we use a HS 2015 or 2020 power flow and dynamic case files. Since the project will not be completed until late 2015 or early 2016, a HS2020 case will be selected. HS 2015 case is optional.

List of events, both internal and external of SCE's footprint, to be simulated,

1. Magunden Separation
2. South of Lugo N-2 RAS
    a) Mira Loma – Vincent 500 kV line in service
    b) Mira Loma – Vincent 500 kV line out of service
3. Mira Loma Low Voltage Load Shedding Scheme
    a) Mira Loma – Vincent 500 kV line in service
    b) Mira Loma – Vincent 500 kV line out of service
4. Devers RAS – Loss of the two Devers-Valley 500 kV lines
5. Loss of 3 Palo Verde Units
6. Lugo 1 AA bank trip
7. Lugo 2 AA banks trip
    a) With RAS
    b) Without RAS
8. Loss of two COI lines and Insertion of the Chief Joseph Breaking Resistor
9. Solar Oscillations – Recorded Event

3.5 Requirements of Event Scenarios for ERCOT Specific Model

It is required to handle more than one seasonal study (e.g. Peak Summer, Peak Winter, and Blackout). The dynamic simulations will be performed on different seasonal conditions. ERCOT will need to provide those base power flow cases and dynamic files compatible with TSAT. Based on those base cases, events will be simulated. The event library is required to include 8 simulated events and 3 recorded events.

The list of 8 simulated events includes following

Simulated Events	What happened?	Phase Angle Difference Indicating Grid Stress
Loss of 3 units at North Edinburg	Loss of 650 MW & Imports increased	Airline – Railroad
Loss of 2 345kV lines in Rio Grande Valley Region	Ajo-Rio Hondo & North Edinburg-Lon Hill 345kV lines relayed	Airline – Railroad
Loss of 2 345kV lines out of North Edinburg	North Edinburg – Lon Hill & North Edinburg – Rio Hondo 345kV lines relayed	Airline – Railroad
Valley Compound Event	Loss of 3 Units at North Edinburg & Loss of 2 345kV lines out of North Edinburg	Airline – Railroad
Laredo Event	Lobo-San Miguel 345kV line & 2 138kV lines relayed	Cedro Hill – Marion
Loss of 3 units at Martin Lake	Loss of 2200 MW & Imports increased	Martin Lake - Jewett
Loss of 2 345kV lines and nearby unit north of Houston	Singleton – Zenith & Singleton – Tomball 345kV lines relayed, Loss of 700 MW	Jewett – Zenith
Loss of 2 345kV CREZ lines	High Wind Generation & Big Hill – Kendall 2 345kV lines relayed	Big Hill – Kendall

The list of 3 recorded events includes following

Simulated Events	What happened?	Phase Angle Difference Indicating Oscillations & Grid Stress
Matador Wind Farm Oscillations	Poorly damped oscillations at 3.3Hz	Matador – Killen Switch
Hamilton Road Oscillations	Poorly damped oscillations at 1.7Hz	Hamilton Road – Killen Switch
Valley Wind Ramp Event	Cascading Outages	Penascal – Killen Switch

4. PSOT Software Application Requirements – Event Library

4.1 Overview

PSOT application is required to manage event files generated by power engineers through an Event Streamer & Manager (ESM). PSOT application is also required to provide ESM for trainer to select and replay event files in IEEE C37.118 standard to RTDMS as the front end for operator training on the use of synchrophasor technologies. The PSOT system work flow is shown in Figure 1.

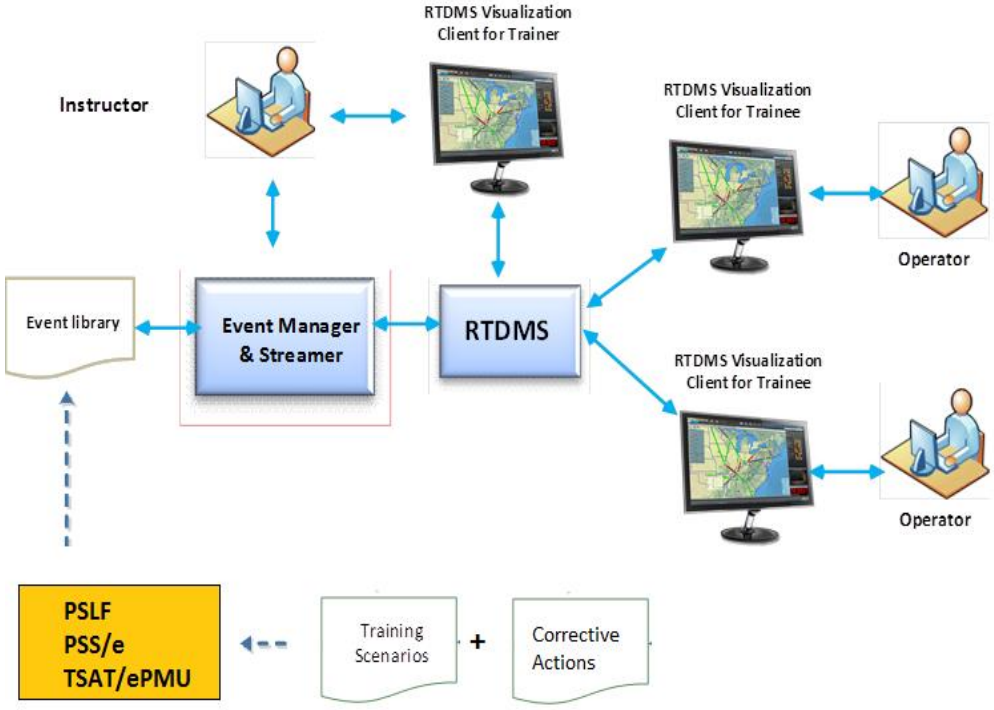

Figure 1. PSOT Work Flow Diagram

In addition to event library requirements, SCE requires PSOT integration with their RTDS and Power World where RTDS & Power World will be used for event simulation and RTDMS for visualization and operator training.

In addition to event library requirements, ERCOT requires that PSOT integrate with TSAT/ePMU for on-the-fly simulation and also with their existing SCADA Simulator to provide side-by-side comparison of synchrophasor technology and EMS system.

4.2 PSOT Application Requirements – Event Library

As PSOT work flow shown in Figure 1, the following functional blocks are required:

1) Training Scenarios: This is a list of event scenarios and their mitigation actions, from utility

specific models in ERCOT & SCE footprint, and from generic model for other users.

2) Power flow, dynamic files and simulation scripts: Suitable power flow and dynamic file cases will be required for SCE and ERCOT event cases. EPG will obtain the sequence of events, and their associated mitigation actions to prepare simulation scripts to run dynamic simulations.
3) Dynamic Simulation Program: Using the case files and the program scripts, EPG will run simulations for the events and their mitigation actions. PSLF will be used to run simulations for SCE case files, while TSAT/ePMU will be used to run simulations on the ERCOT case files.
4) Event Library: Each event case and its corresponding mitigation actions will be simulated, converted to a CSV format file and placed together in a folder, with each folder corresponding to each event. This event folder is termed as an "Event Library" for that particular event.
5) Event Streamer & Manager (ESM): The ESM is required to read the CSV file and stream event/mitigation simulated data to RTDMS during training. The instructor will enable the replay of CSV file through the front-end GUI. The ESM is required to use an IEEE standard communication protocol such as C37.118 data stream to stream simulated data to RTDMS during training.
6) RTDMS: Real Time Dynamics Monitoring System (RTDMS) is the synchrophasor based analytics and visualization tool. The analytics in RTDMS calculates phase angle differences, detects oscillations and alarms based on synchrophasor metric violation. The RTDMS Visualization Client is the front end visualization where the instructor and the trainees can observe the power system metrics from the simulation file and generated alarms to obtain training on event detection, diagnosis and corrective action.

4.3 PSOT Application Requirements – On-the-fly simulations

ERCOT & SCE expressed desire to do on-the-fly simulations and integrate with PSOT system using standard IEEE C37.118 data stream. For SCE, PSOT is required to integrate with RTDS and Power World. RTDS and Power World are capable of performing dynamic simulations and streaming simulated data in IEEE C37.118 data stream to downstream applications. For ERCOT, PSOT is required to integrate with TSAT/ePMU. TSAT/ePMU is also capable of performing dynamic simulations and streaming simulated data in IEEE C37.118 data stream to downstream applications.

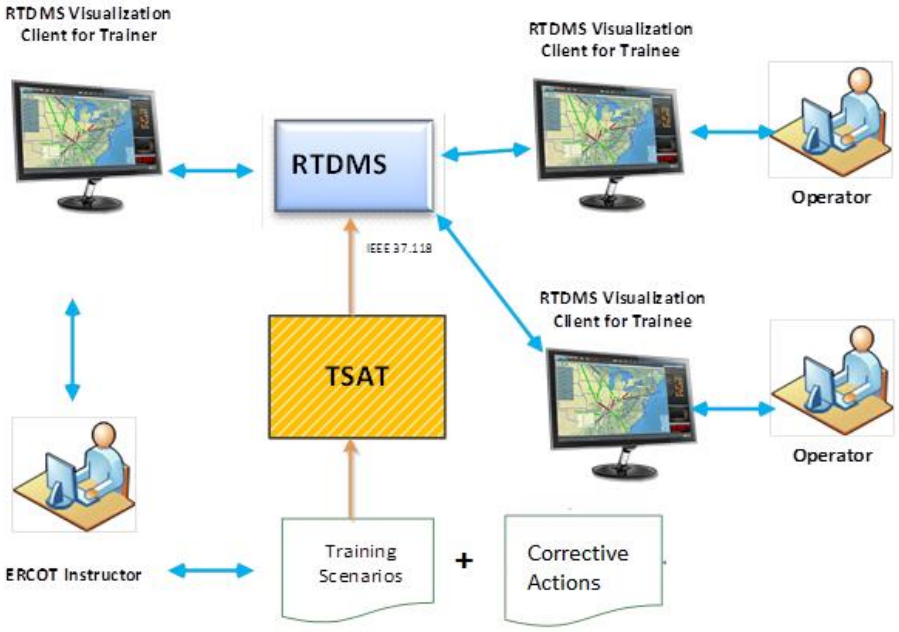

Figure 2. TSAT/ePMU-PSOT Work Flow Diagram

Figure 2 shows a typical example to perform on-the-fly simulations for ERCOT. TSAT/ePMU has a GUI to input base case, dynamic file, event sequence and PMU locations. The instructor can use the TSAT/ePMU to start the simulation during the training. The simulated data is streamed directly to RTDMS in IEEE C37.118 data format. The operator and instructor observe the simulated data in RTDMS Visualization Client immediately.

Similar setup is required for RTDS and Power World for On-the-fly simulations. Figure 3 shows the integration of RTDS with PSOT. ePDC is required to gather multiple output streams from RTDS and send a single stream to RTDMS in IEEE C37.118 data stream.

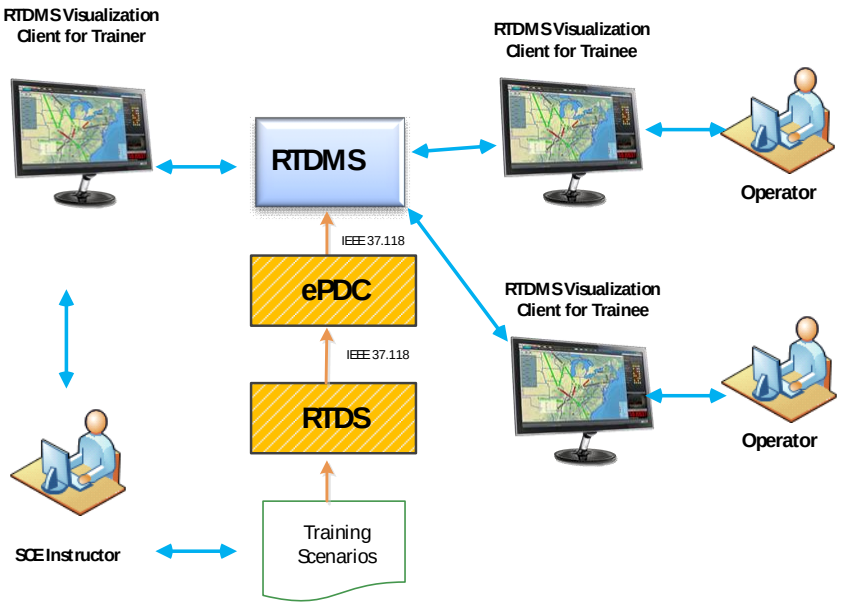

Figure 3. RTDS-PSOT Work Flow Diagram

4.4 PSOT Application Requirements – Integration with ERCOT EMS Simulator

ERCOT also expressed a desire to integrate on-the-fly simulation approach with their existing EMS simulator to address the following requirements

a) Provide operator training on side-by-side comparison in both SCADA OTS and PSOT system
b) Provide interface between EMS simulator and TSAT/ePMU

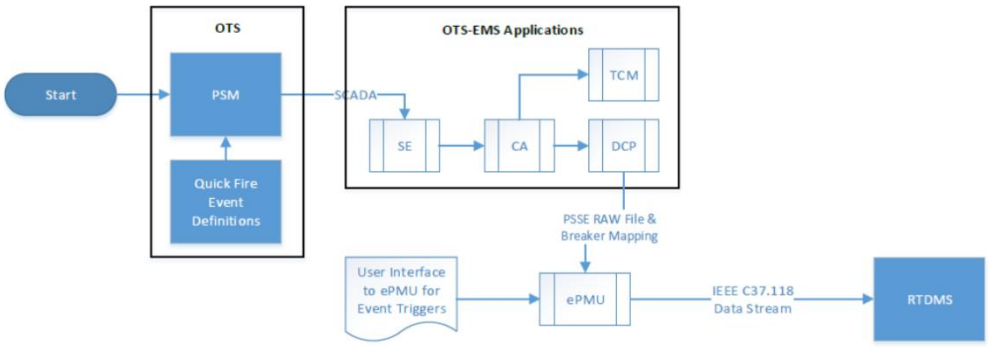

Figure 3. PSOT Work Flow Diagram

Figure 3 shows high level architecture diagram of PSOT integration with ERCOT's EMS OTS simulator. User interface is required to be built to bridge the communication between Quick Fire toolbox inside

OTS system and TSAT/ePMU. TSAT/ePMU will receive the base case used in OTS, event sequence initiated by instructor to simulate same event used for training using EMS simulator. The design of integration between ERCOT's EMS simulator and PSOT system is required to be documented as part of the PSOT project. The implementation is planned for post PSOT project.

5. PSOT Application Design

5.1 PSOT Application Design

PSOT Software System is designed to have two main components:

1) Event file management and streamer (Event Manager and Streamer): manage event library, start/pause/stop event file playing
2) RTDMS: commercial available application
    a. bad data detection
    b. alarm detection
    c. advanced calculation of angle difference, power, mode, sensitivity, oscillation
    d. data storage
    e. feature rich visualization front end for real-time simulation and scenario replay

Since RTDMS is commercially available, this section focuses on the design of Event Manager and Streamer as shown in Figure 4.

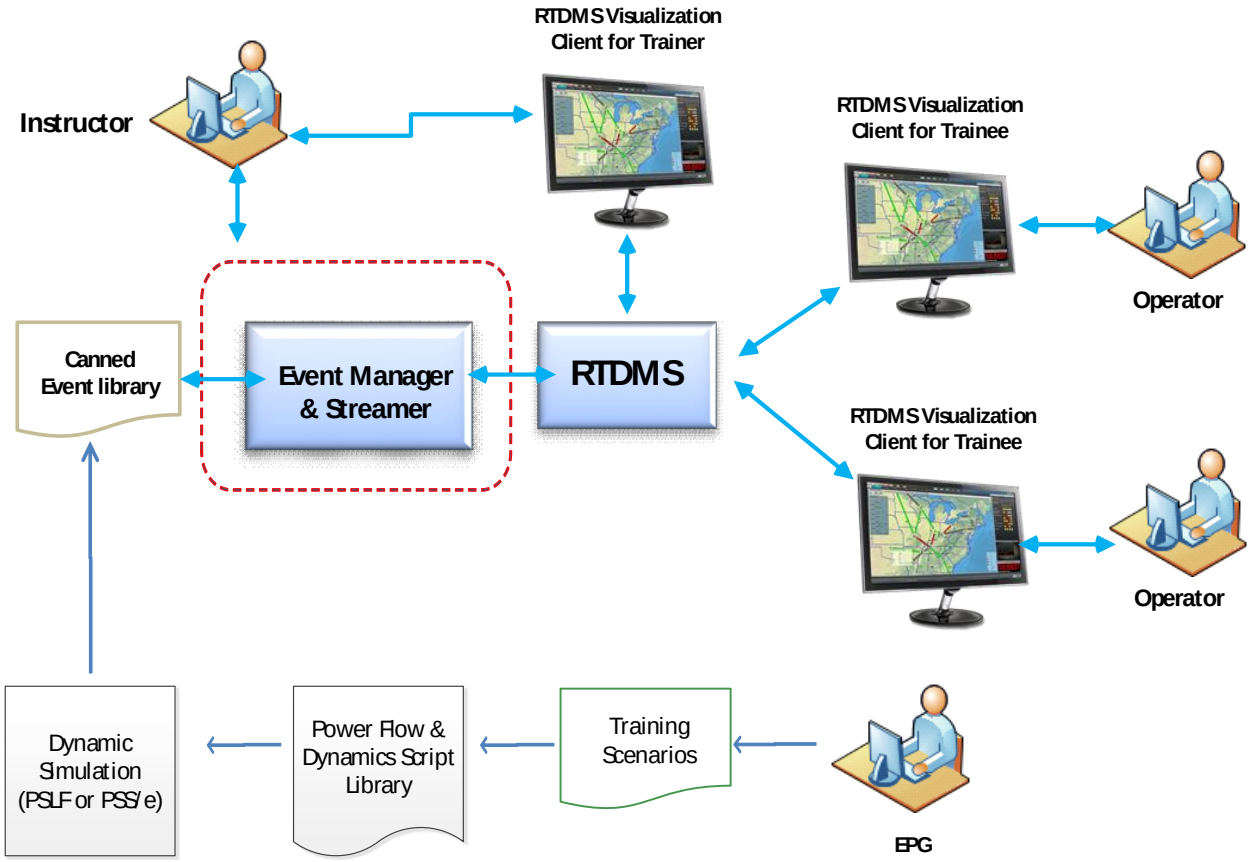

Figure 4. Event Manager and Streamer in PSOT

5.1.1 Event Manager and Streamer Layout Design

Event Manager and Streamer is designed to be a standalone application with a Graphical User Interface. The layout is shown in Figure 2.

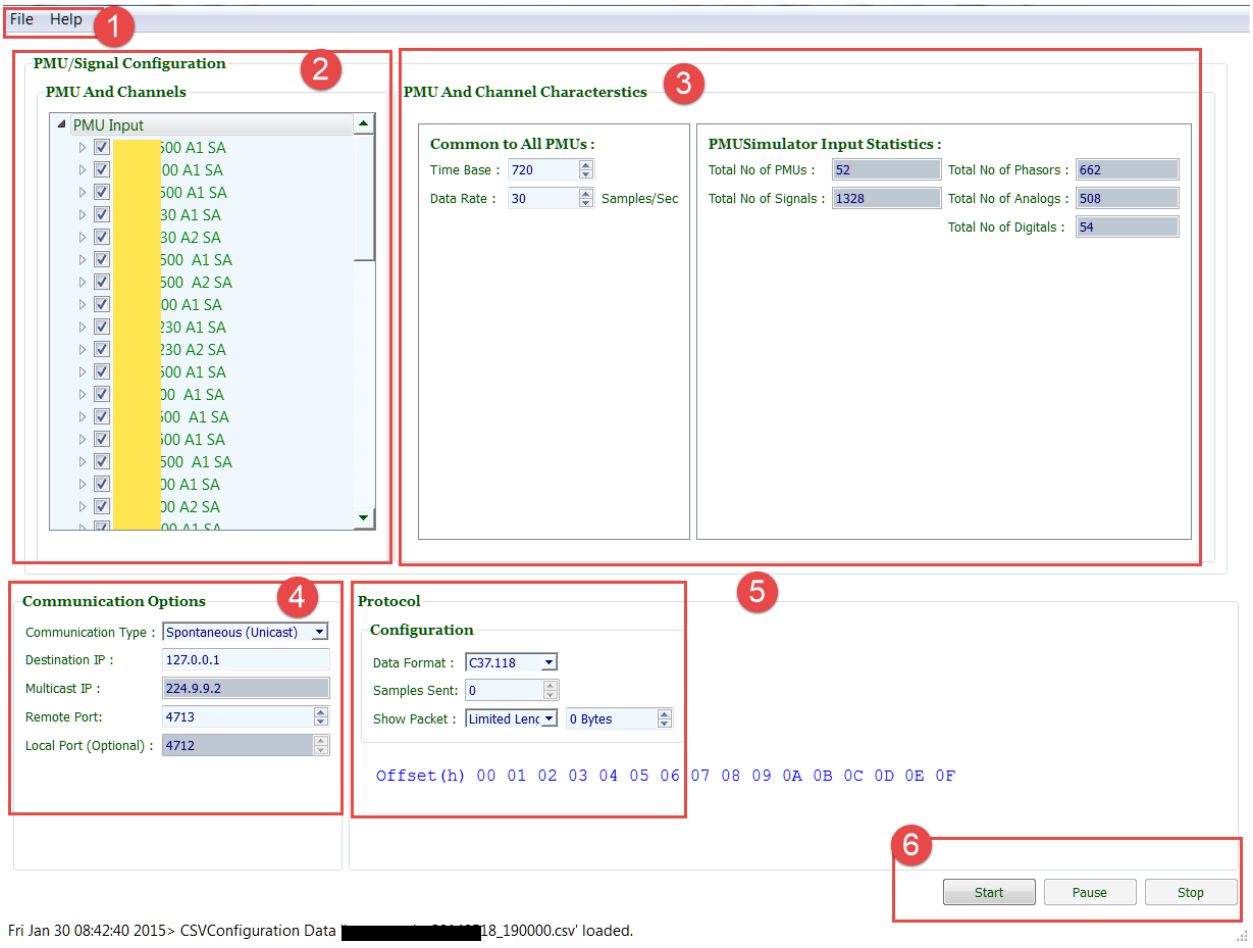

Figure 2 Event Manager and Streamer GUI Layout

Event Manager and Streamer layout is divided into following areas:

1) Menu – open recorded data file, manage event library & select event file
2) PMU/Signal Management – add/remove PMU/Signal for simulation
3) Sample rate and time base configuration and overall PMU reporting
4) Communication Management – TCP or UDP
5) Protocol Management – C37.118 or C37.118.2
6) Start/Pause/Stop event/mitigation replay

The menu items of File is shown in the following Figure 3 where

1) Replay Event – open a dialog window for user to select an event or mitigation data file to replay
2) Event Library Management – open a dialog window for user to manage event library

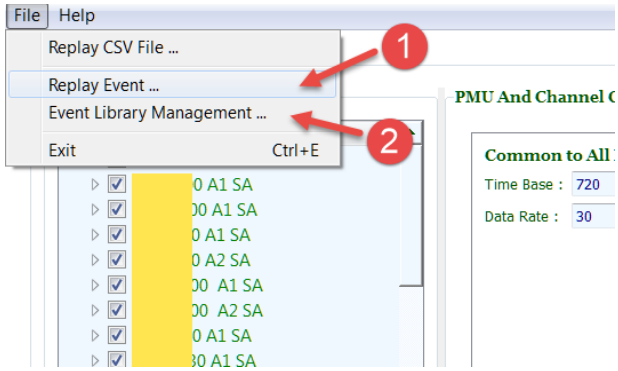

Figure 3 Menu Items for File Menu

5.1.2 Event Manager Design

When "File - Event Library Management " menu item is selected, the following event library management dialog window as shown in Figure 4 will be displayed allowing user to add/delete/edit event library.

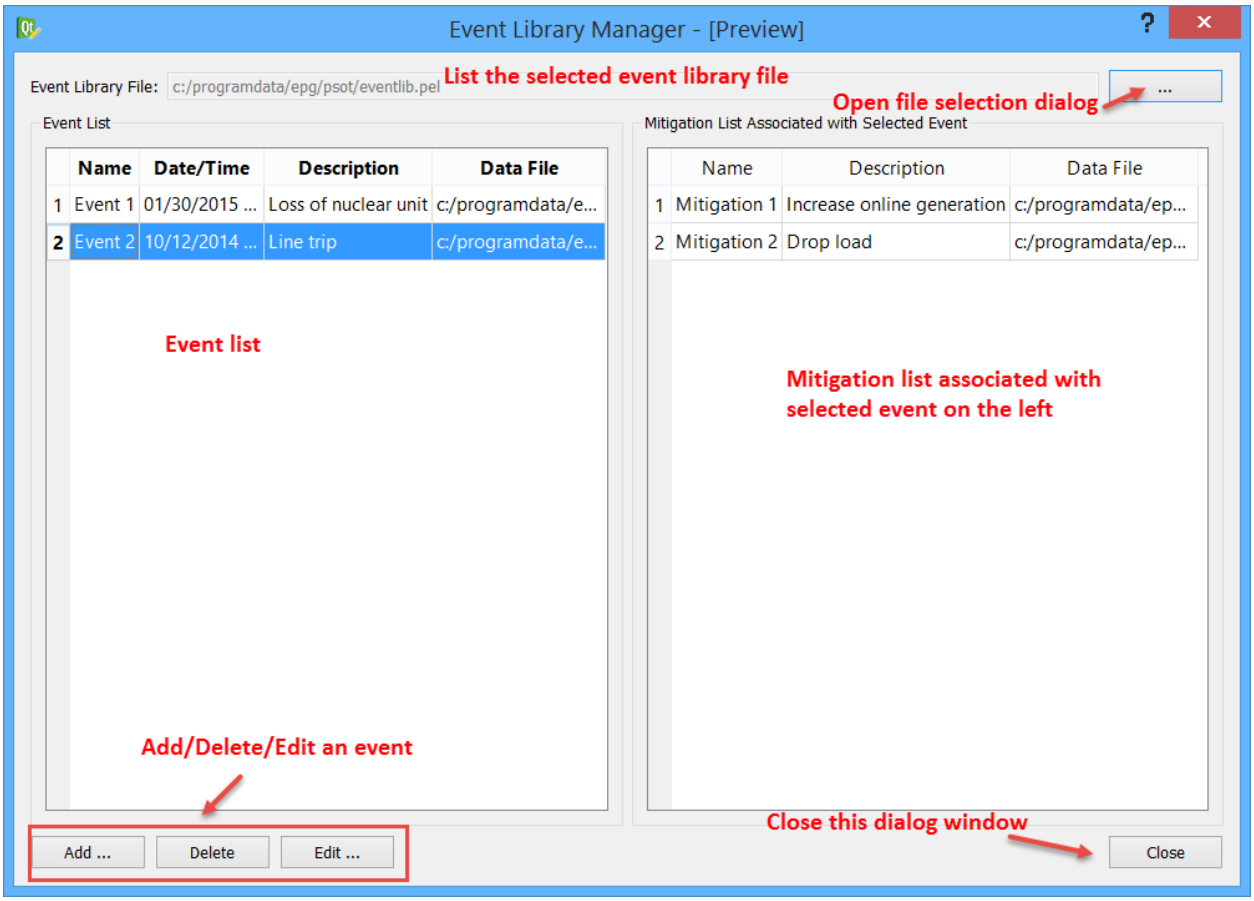

Figure 4 Event Library Manager GUI

When PSOT is installed, an empty event library file named “eventlib.pel” will be provided in the PSOT data folder. The default data folder will be c:/programdata/epg/psot. The event file name will listed in the line edit widget. To change the event library file, click the Open file selection button to choose a new event library file. Save the event library file in another name is not recommended but allowed through copying “eventlib.pel” to another name.

When the Event Library Manager dialog is launched, it will read the event information from the event file selected. The event list widget will list all events by their name, date/time of the event, description of the event and the event data file path. The mitigation list will list all mitigations associated with the selected event on the event list by their name, description, and mitigation data file path.

The Event Library Manager dialog allows user to add a new event, delete an existing event, or edit an existing event. Any accepted updates will be saved into the selected event library file.

Event Library Manager will remember status within a session or from previous session.

1. Add a New Event to Event Library

Click “Add ” button to launch the Add New Event dialog as shown in Figure 5.

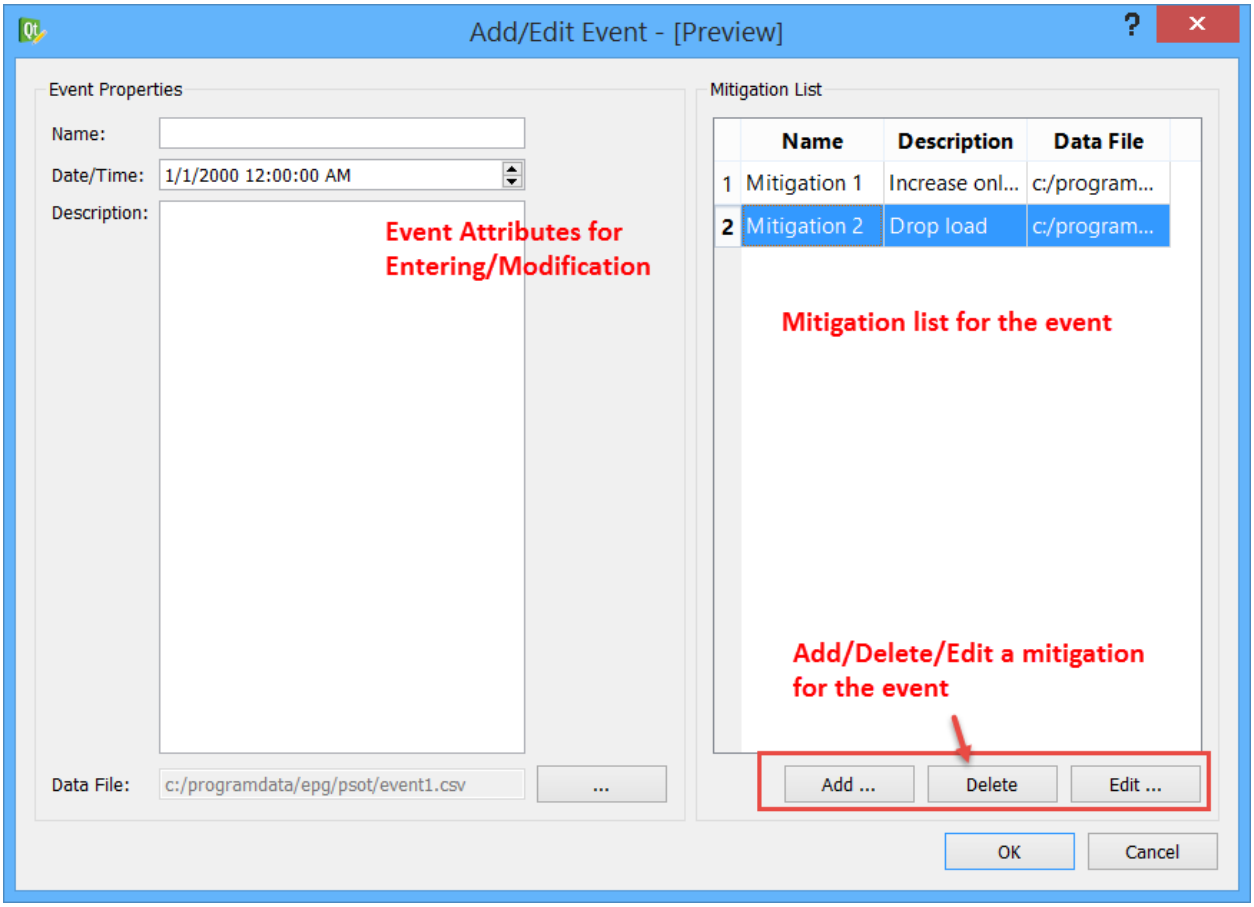

Figure 5 Add/Edit an Event Dialog

Mitigation(s) associated with the event can be added, deleted, or changed:

1) To add a mitigation action to the event, click "Add " button. A popup dialog will be displayed for user to enter mitigation name, mitigation description, and select a mitigation file path.
2) To delete a mitigation, select an existing mitigation and click "Delete" button. Confirmation dialog box will be displayed.
3) To edit a mitigation, select an existing mitigation and click "Edit ", the process is similar to add a new mitigation except that existing mitigation properties are populated for editing instead of blank requiring user to enter.

Once event properties are set or modified and mitigation(s) are set or modification, click "OK" button will save the changes to the event library file. The newly added event will automatically be selected in the event list of Event Library Manager GUI.

By clicking "Cancel" button, no new event will be added.

2. Delete an Existing Event from Event Library

First select an event in the event list, then click “Delete” button. A confirmation window will be displayed. Once confirmed by user, the event will be delete from the event list and the event library file will be get updated. The event list will automatically select the next event if available or select the previous event if next event is not available. The mitigation list will automatically adjust according to the event list current selection update.

3. Edit an Existing Event in Event Library

Click “Edit ” button to launch the Edit Event dialog. It is the same process as add a new event except that event information will be populated for editing.

5.1.3 Event Streamer Design

1. Select Event and Mitigation for Replaying

To replay an event file or a mitigation action file, user needs to load the event/mitigation data file through menu “File - Replay Event ” which will launch the “Load Event or Mitigation Data” dialog box as shown in Figure 6.

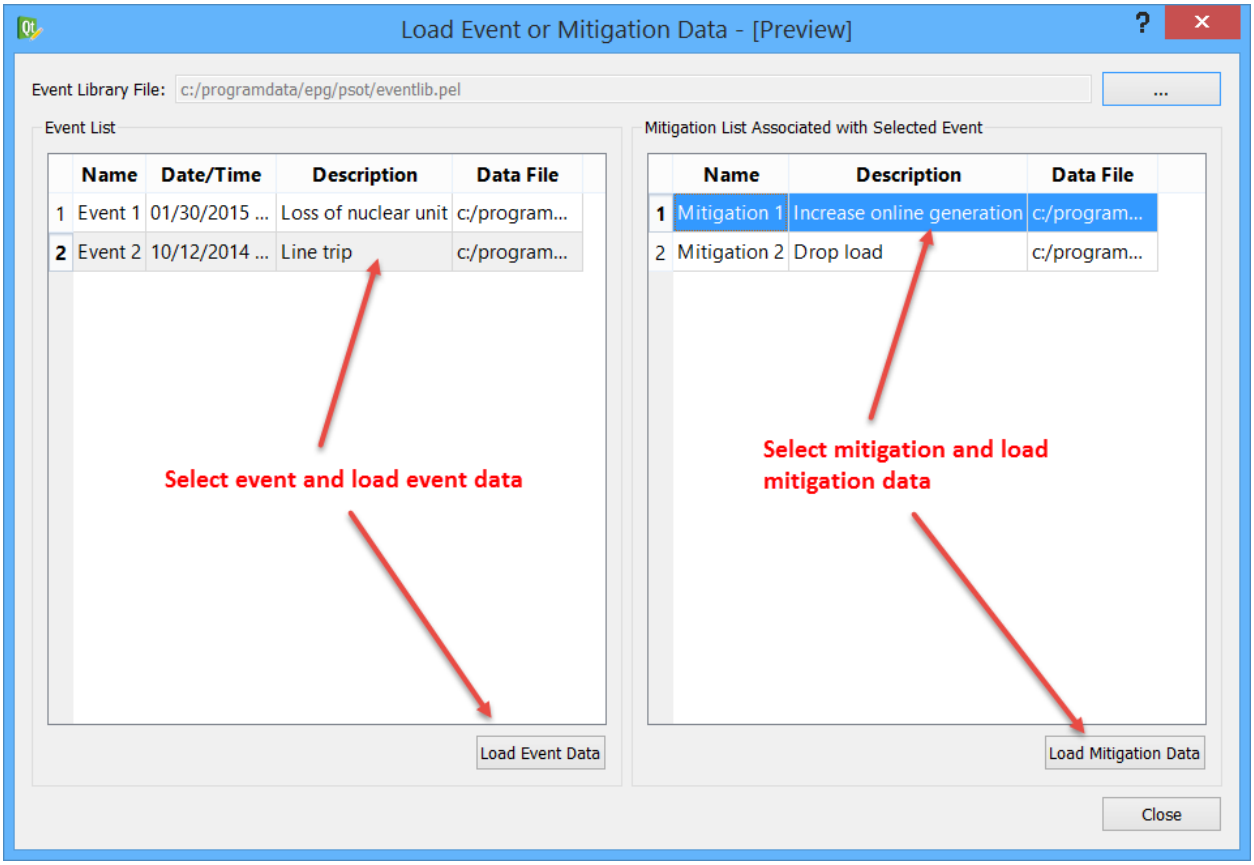

Figure 6 Event or Mitigation Data Loading GUI

The popup dialog will allow user to select event library file, list events and mitigations associated with the selected event.

To load event data, click “Load Event Data” button, the data file associated with the event will be loaded into memory and ready to be replayed. If data file cannot be found and there is any error reading the file, error message will be displayed.

To load mitigation action data for a particular event, click “Load Mitigation Data” button, the mitigation data file associated with the event will be loaded into memory and ready to be replayed. If data file cannot be found and there is any error reading the file, error message will be displayed.

When data is loaded into memory, the “Load Event or Mitigation Data” dialog box will disappear.

“Load Event or Mitigation Data” dialog box will remember status within a session or from previous session.

2. Communication and Protocol Configuration

TCP/IP communication options to stream synchrophasor data IEEE 37.118 format is shown in Figure 7.

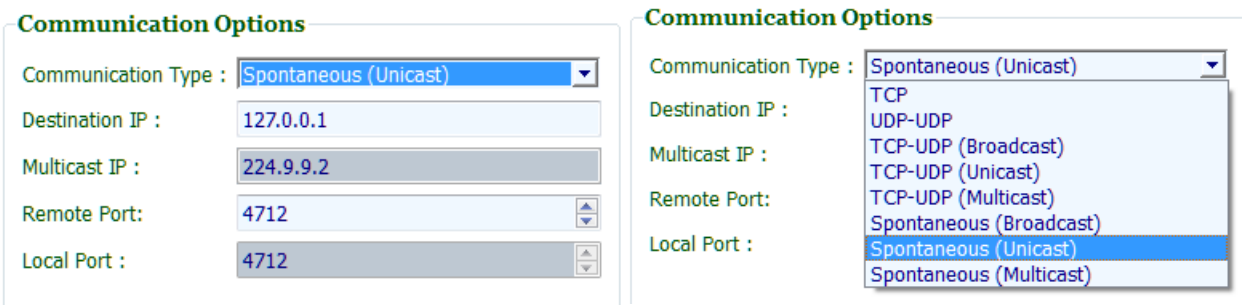

Figure 7 Communication Configuration GUI

Event Streamer is designed to support IEEE 37.118 or IEEE 37.118.2 standards. The configuration GUI is shown in Figure 8.

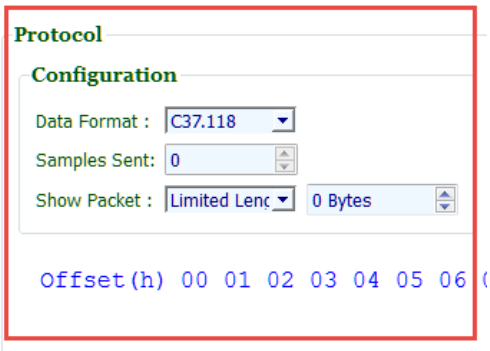

Figure 8 Protocol Configuration GUI

3. Set Sample Rate and Start/Pause/Stop Event/Mitigation Replay

The user interface is shown in Figure 2.

5.1.4 Event Library File Format

Event library file will be saved as in XML file format with extension of ".pel" – PSOT Event Library in short. The file format is shown below:

```
<?xml version="1.0" ?>

<Events>

      <Event Name="Event1" DateTime="01/30/2015 01:23:00 PM"
Description="Nuclear unit x tripped"
DataFile="c:/programdata/epg/psot/event1.csv">

            <Mitigation Name="Mitigation 1" Description="Increase online
generation" DataFile=" c:/programdata/epg/psot/event1_m1.csv">

            <Mitigation Name="Mitigation 2" Description="Reduce Load"
      DataFile=" c:/programdata/epg/psot/event1_m2.csv">

      </Event>

</Events>
```

5.1.5 Event Data File Format

EPG Synchrophasor CSV file format as described in Appendix: EPG Synchrophasor Data File Format (.CSV) will be used to store event data. PSLF simulation output format will be supported also.

Appendix: EPG Synchrophasor Data File Format (.CSV)

Version 3, 2012

1. Introduction

Synchrophasor data is used both in real-time from direct transmission and after the fact as recorded data. The SYNCHROPHASOR standard, C37.118, describes a real-time data transmission format but does not define a format for recorded data storage or exchange. Several formats have been used for synchrophasor data, most notably the Phasor File (also known as dst') data format pioneered in the WECC and supported by Bonneville Power Administration users.

The IEEE COMTRADE standard is a file format designed for time series data that is established worldwide and is supported by standards making bodies. It has a significant number of recording parameters that have been adapted for phasor data. COMTRADE file format is getting adopted quickly.

Phasor File and COMTRADE formats are binary files. It is not human friendly and hard to manipulate their content. It's desirable to have a human readable and easy to manipulate file format for data exchange. The CSV (comma separated values) file format is a widely accepted format to store data in ASCII files in which data is stored in rows and columns. The data in rows are and delimited by comma (,). These files are human readable, and can be easily recognized by spreadsheet applications and other applications to perform data analysis and manipulation. This document proposes a format to store Synchrophasor data in CSV files, which is adopted by Electric Power Group's synchrophasor applications, including PGDA, RTDMS, ePDC, and PMU Simulator. All EPG applications shall support importing/exporting synchrophasor data in this format.

Section 2 describes the CSV file naming convention. It is highly recommended for event data, though not required in many cases. Section 3 describes the header and data arrangement in the CSV file.

2. CSV File Naming Convention

The file name follows the convention defined in **IEEE PC37.232** standard. This file name convention defines a readable, comma delimited filename format. The "required fields" for the filename shall be as follows and in order as shown here:

Start Date, Start Time, Time Code, Station ID, Device ID, Company Name,

Additional fields may be added as needed and are called "user fields" are shown here:

User 1, User 2, User3, and so on .Extension

2.1 Start Date Field Format

This field is a fixed numeric format of (yymmdd). The start date is the date at which the first sample was recorded or the date at which the first trigger occurred. This is determined in the Time Code field.

2.2 Start Time Field Format

This field is a non-fixed numeric format and can be specified to the required precision (hhMMssmmmuuu). The start time is the time at which the first sample was recorded or the time at which the first trigger occurred, also determined in the Time Code field.

2.3Time Code Field Format

This field is limited to a maximum of seven characters. The first character is the sign and is followed by up to five characters indicating the time difference between the time system used for the Start Date and Start Time fields (collectively, the Time Tag) and Universal Coordinated Time (UTC) without offset. The format for the five characters is as follows and in order: up to two digits for the hours followed by the letter "h" followed by two digits for the minutes. The last three characters are required only when fractional hours are in use. In addition, one final character, the letter "t", should be concatenated at the end to the Time Code Field if the filename's Time Tag is referencing the date and time of the first trigger. The calculation for the time difference should also consider whether standard time or daylight time was in affect at the time of the recording. The following examples provide a number of valid descriptions for the Time Code Field:

-4 *Time Tag is 4 hours behind UTC*

+5t *Time Tag is 5 hours ahead of UTC and references trigger time*

-7h15 *Time Tag is 7 hours and 15 minutes behind UTC*

0t *Time Tag is UTC and references trigger time*

2.4 Station Identifier, Device Identifier, and Company Name Fields Formats

Users may formulate their own codes for these fields.

The following fields are optionally recommended for packing meaningful information in the filename:

Duration Field Format:

The duration is equal to the time difference between the first and last samples in the file. The fields should be in the same format as the Start Date and Start Time Fields. For example a file with 2 years, 1 day, and 99 seconds of data will have a duration code of "020001,000139".

Type Field Format:

This field may be used to describe the type of originating event and users may formulate their own codes. For example, the code "AG" may be used for a record created from a phase A to ground fault event.

Geographic Position Coordinates Field Format:

Two user fields are required in order to support position information. The first field is an expression of latitude and the second field is an expression of longitude.

2.5 Examples of File Names

- `120831,175215183,-4t,sta80,ben717,epg.csv`
  Note: The Start Time field is given in millisecond resolution and refers to when the first trigger in the record occurred with a COMTRADE configuration file extension.

- `120831,175215183,-4t,sta80,ben717,epg,000000,001359,uf,critical-frequency.csv`
  Note: This is a same example as above but with two user fields added and file duration fields added. "uf" added to represent that the file was created by a under frequency trigger and "critical-frequency" trigger also occurred in the record.

3. CSV file column header information

The first row contains column header information. The data block starts from the second row and continues to end of file.

3.1 The column header information format

The first row is the header and must start with Date Time and contain at least one signal column and ended with cartridge return and line feed character:

DateTime(ISO Format),SignalName1,SignalName2,SignalName3, *CR/LF*

3.2 Signal Name format

A signal name is comprised of PMU Name, Channel Name, and signal type which are separated by dots (.).

PMU Name . Signal Channel Name . Signal Type

Examples:

```
Bull Run.Frequency.FR

Bull Run.Frequency.DF

Bull Run.500 kV Bus +SV.VM
```

```
Bull Run.500 kV Bus +SV.VA

Bull Run.Watts Bar +SI.IM

Bull Run.Watts Bar +SI.IA

Bull
Run.B16;B15;B14;B13;B12;B11;B10;B09;B08;B07;B06;B05;B04;B03;B02;B01.DG
```

Note: A Digital signal has 16 bits in C37.118 standard. There are 16 channel names for a Digital signal to present every bit. These 16 channel names will be separated by semi column where the first channel represents the highest bit (bit 15) and last channel represents the lowest bit (bit 0). For example:

```
Bull Run.B16;B15;B14;B13;B12;B11;B10;B09;B08;B07;B06;B05;B04;B03;B02;B01.DG
```

Note: There is no name for Status flags in C37.118. `Status` should be used as the ***Signal Channel Name***. For example:

```
Callaway.Status.ST
```

Note: There is no name for frequency in C37.118. `Frequency` should be used as the ***Signal Channel Name***. For example:

```
Callaway.Frequency.FR
```

3.3 Signal Type format

The following code describes each signal type along with its unit:

Label	Description	Engineering Unit
FR	Frequency	Hz
DF	DF/DT	Hz/s
VM	Voltage magnitude (line to line voltage)	kV
VA	Voltage angle wrapped to (-180 180] degrees	Degree
IM	Current magnitude (line current)	A
IA	Current angle wrapped to (-180 180] degrees	Degree
PP	Active power	MW
PQ	Reactive power	MVar

DG	Digital	N/A
ST	Status flag, a 16-bit unsigned integer mapped to C37.118 STAT word.	N/A
AN	Analog	Depending on the signal
ZZ	Generic type other than specified above, such as for derived/calculated values	depending on the signal
UN	Unknown or missing information	depending on the signal

3.4 Column Header Row Example

```
Date Time,Callaway.Status.ST,Callaway.Frequency.FR,Collinsville.500 kV
Line.VA,Cordova.Line1.IM
```

4. Data information

4.1 Date Time Data in ISO 8601 Format

The first column is the Date Time information in human readable format following ISO 8601 standard. Exactly the components shown here must be present, with exactly this punctuation. Note that the T appears literally in the string, to indicate the beginning of the time element.

```
Year:

   YYYY (eg 1997)

Year and month:

   YYYY-MM (eg 1997-07)

Complete date:

   YYYY-MM-DD (eg 1997-07-16)

Complete date plus hours and minutes:

   YYYY-MM-DDThh:mmTZD (eg 1997-07-16T19:20+01:00)

Complete date plus hours, minutes and seconds:

   YYYY-MM-DDThh:mm:ssTZD (eg 1997-07-16T19:20:30+01:00)

Complete date plus hours, minutes, seconds and a decimal fraction of a
```

second

YYYY-MM-DDThh:mm:ss.sTZD (eg 1997-07-16T19:20:30.45+01:00)

where:

YYYY = four-digit year

MM = two-digit month (01=January, etc.)

DD = two-digit day of month (01 through 31)

hh = two digits of hour (00 through 23) (am/pm NOT allowed)

mm = two digits of minute (00 through 59)

ss = two digits of second (00 through 59)

s = three or four digits representing a decimal fraction of a second

TZD = time zone designator (Z or +hh:mm or -hh:mm)

There are two ways to handle time zone offsets:

1. Times are expressed in UTC (Coordinated Universal Time), with or without a special UTC designator (Z).
2. Times are expressed in local time, together with a time zone offset in hours and minutes. A time zone offset of +hh:mm indicates that the date/time uses a local time zone which is hh hours and mm minutes ahead of UTC. A time zone offset of -hh:mm indicates that the date/time uses a local time zone which is hh hours and mm minutes behind UTC.

Note: to preserve high enough resolution, three or four digits are used to represent the decimal fraction of a second.

4.2 Signal Data

Signal data starts at the second column and continues till (n+1) column where n is the number of signals. For Status and Digital signals, data should be saved as 16 bits unsigned integer. For phasors, analogs, frequency, and MW/MVAR signals, values are in floating point. The signal data is required to be evenly spaced ordered by increasing date/time. If the data is unavailable for any signal for a particular time, that value should be set to -9999.

Example of data for frequencies:

2010-10-08T04:50:00.0000,59.994,59.994,59.994

2010-10-08T04:50:00.0333,59.995,59.992,60.003

2010-10-08T04:50:00.0667,59.994,59.995,59.991

```
2010-10-08T04:50:00.1000,59.993,59.992,59.975

2010-10-08T04:50:00.1333,59.995,59.992,60.006

2010-10-08T04:50:00.1667,59.994,59.991,59.993
```

PSOT

Phasor Simulator for Operator Training Project

Commercialization Plan
December 2015

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626-685-2015

Submitted to DOE

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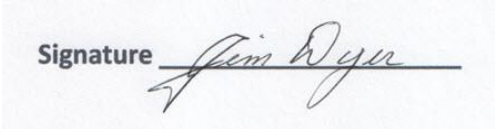
Signature 

Acknowledgment: This material is based upon work supported by the Department of Energy National Energy Technology Laboratory under Award Number DE-OE0000702.

Phasor Simulator for Operator Training Project

Commercialization Plan

Purpose of document:

This document provides the following:

1. **PSOT Project Background**
    a. Statement of Problem
    b. PSOT Project Objectives
    c. DOE Funding
    d. PSOT Components
        i. Power System Simulations Tools
        ii. Real Time Dynamics Monitoring System (RTDMS)
        iii. Event Streamer & Manager (ESM)
        iv. enhanced Phasor Data Concentrator (ePDC)
    e. PSOT Approaches
        i. Event Library Approach
        ii. On-the-fly Approach
        iii. Integration with SCADA Operator Training Simulator (OTS)
    f. PSOT Event Simulations
        i. Utility Specific
        ii. Generic
    g. PSOT Benefits

2. **Commercialization Activities Accomplished**
    a. Target Market
    b. Presentation at Industry Forums and User Group Meetings
    c. Presentation to ISOs, TOs & RTOs

3. **Commercialization Activities Planned for Post Project**
    a. Product Announcement and Rollout

4. **Commercial Licensing Strategy**
    a. Product License Value
    b. Support & Maintenance Contract Agreement
    c. Professional Technical Service Agreement
    d. On-site Training and Support
    e. Support Integration of PSOT with EMS Training Simulator

5. **EPG Team for Commercialization**

PSOT Project Background:

Statement of Problem

After the 2003 Northeast blackout investigation, NERC and other reliability entities identified the need for using time-synchronized high-resolution data for wide-area real-time situational awareness and dynamics monitoring of grid metrics in an effort to improve grid reliability and reduce the likelihood of cascading outages. The value of utilizing synchrophasor data in operations are threefold, it can provide 1) wide area perspective, 2) early warning indication of grid stress, approaching areas of instability and oscillation detection, and 3) situational awareness of the interconnected grid. As part of the American Recovery and Reinvestment Act of 2009, the Department of Energy provided the electric industry with funds to further expand the use of synchrophasor technology, including at ISO/RTO/utility control centers. The requirements for effective implementation of synchrophasor technology in real-time operations are twofold; it includes 1) Operator Training and 2) Policies and Procedures on this advanced technology.

PSOT Project Objectives

The Phasor Simulator for Operator Training (PSOT) project is designed to address the need for operator training using simulated events, historical events and real time simulations. The objectives of PSOT are:

- Develop and demonstrate a synchrophasor based training platform for use in training control center operating personnel.
- Enable training using historical events, simulated events and real-time simulations.
- Enable operators to test alternative actions after events to gain firsthand experience with actions that are most effective for different types of grid events.
- Help operators understand event signatures and event pre-cursors that indicate stressed conditions.
- Help in the development of policies and procedures for use in real-time operations.
- Integrate with existing utility and ISO simulators and tools.

DOE Funding

EPG was awarded the PSOT project by DOE under the Grant Award DE-E0000702. The Project started in September 2014 and is scheduled for completion in 1Q 2016. SCE & ERCOT are cost share partners along with EPG. SCE and ERCOT are also demonstration hosts for the PSOT project. Dominion is an observer and industry advisor. Powertech Labs Inc. joined the project in early 2015 to provide TSAT/ePMU software to accommodate ERCOT's desire for integration with their real-time simulation tools to enable on-the-fly simulations. PSOT is integrated with TSAT/ePMU at ERCOT and with RTDS simulator at SCE.

PSOT Components

PSOT is a phasor-based training simulator to train power system operators on the use of synchrophasor technology.

PSOT makes use of the following

1. Industry standard Power System Simulation Tools to perform event simulations using dynamic models and build a library of system events

    a. Off-line Simulation Tools including PSS/E, PSLF, TSAT/ePMU.
    b. On-the-fly Simulation Tools including TSAT/ePMU, RTDS.

2. RTDMS is used for Visualization to train operators on
    a. Event Detection & Alarming.
    b. Event Diagnostics.
    c. Event Corrective Action & Restoration.

3. ESM (Event Streamer & Manager)
    a. Instructor's user interface.
    b. Retrieve, stream and play system events from the event library.

    On-the-fly simulation tools have the capability to stream dynamic event simulation directly to RTDMS and are independent of the Event Streamer and Manager.

4. ePDC (enhanced Phasor Data Concentrator)
    a. Gathers multiple data streams from On-the-fly simulations tools.
    b. Outputs time-synchronized dynamic event simulation directly to RTDMS as a single data stream.

    RTDS is hardware based digital simulator that is used by SCE and Dominion for on-the-fly simulations for sending multiple data streams and requires ePDC for synchronization of these streams. TSAT/ePMU is software based on-the-fly simulation tool with a single time-synchronized output data stream fed directly to RTDMS.

PSOT Approaches

The EPG Team, working with the SCE and ERCOT, have designed and demonstrated three methods for using PSOT, namely:

1. Event Library Method:
    Events are archived in a library for use in operator training. Events may be simulated contingencies, extreme events or historical events. The library also includes event mitigation strategies and operators can select from the library to understand the effectiveness of alternative mitigation strategies.

2. On-the-fly Method:
   Real-time simulators such as RTDS and TSAT are used to simulate events in real-time and enable operators to take actions in real-time to understand effectiveness of actions.

3. Integration with Supervisory Control Data Acquisition (SCADA) Operator Training Simulator (OTS):
   The instructor uses existing OTS and PSOT system simultaneously to simulate events in real-time and enable operators to observe system impact in both traditional SCADA and PSOT Visualization. This method also enables the instructor to train operators on alternative mitigation strategies in real-time to understand the effectiveness of actions and provide side-by-side comparison of EMS using SCADA Visualization and Phasor technology using PSOT Visualization.

The PSOT methods for operator training are described in detail in the following sections:

1. Event Library Method – Implemented at SCE & ERCOT:

   a. The output from off-line simulation tool is labeled and stored in an event library prior to the training session (see below diagram).
   b. The event library may be simulated events from off-line simulation tools or actual events recorded using synchrophasor data.
   c. The event library approach can be utilized in either a training class session or as a self-teaching aid for operators and shift engineers.

   For the Event Library method, the PSOT components and data flow is presented in the following figure.

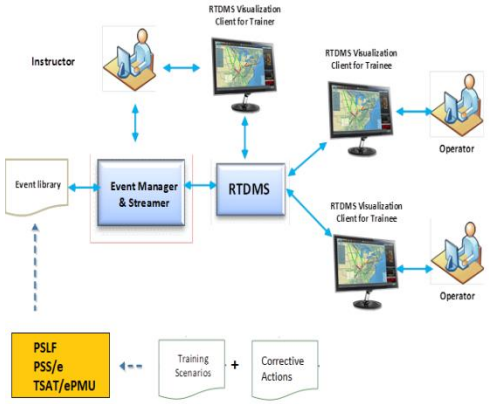


Figure 1. Event Library Approach

Step1: ***PSLF, PSS/e & TSAT/ePMU*** are off-line simulations tools used to simulate different events and corrective actions necessary for operator training.

Step2: ***Event Library*** archives all the event simulations, alternative mitigation actions and recorded synchrophasor data.

Step3: ***Event Streamer and Manager*** enables the ***instructor*** to manage, select and replay events archived in the event library.

Step4: ***RTDMS and Visualization Client*** enables the ***operators*** to detect, diagnose an event, inform instructor on a corrective action to mitigate detected event.

Step5: ***Instructor*** uses ***Step3*** to replay corrective action from ***Event Library.***

2. **On-the-fly Method - Implemented at ERCOT:**

    a. During a training session for operators, instructor sets up an event scenario and runs an on-the-fly event simulation and students get to observe the system impact (see below diagram).
    b. The event sequence can be defined in advance or defined on-the-fly.

For the on- the-fly method, the PSOT components and data flow is presented in the following figure.

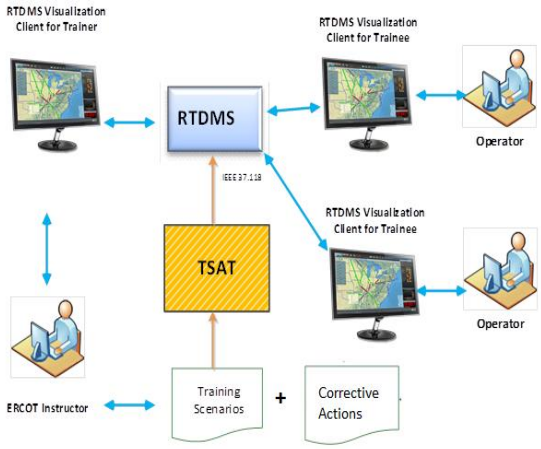


Figure 2. On-the-fly Approach

Step1: ***TSAT/ePMU*** is also used to simulate different events and corrective actions on-the-fly that are necessary for operator training. The training scenarios and corrective actions are either defined in advance or during the training by the ***Instructor***.

Step2: ***RTDMS and Visualization Client*** enables the ***operators*** to detect, diagnose an event, inform instructor on a corrective action to mitigate detected event.

Step3: ***Instructor*** *can* use ***Step1*** to simulate alternative corrective action.

3. Integration with SCADA OTS at ERCOT:

a. During training session for operators, instructor runs the OTS & PSOT in parallel to output event simulation and students get to observe the system impact in both traditional SCADA and PSOT Visualization.
b. The event sequence prepared for the training is triggered by the instructor to both OTS and PSOT.

c. PSOT will utilize on-the-fly simulation tool TSAT/ePMU to process SCADA case and receive commands on the event sequence.
d. The operators identify the desired action in response to training event scenario.
e. The corrective action is triggered by the instructor to both OTS and PSOT and allows the operators to observe the system impact as well as evaluate alternate corrective actions.

PSOT Event Simulations

During the project, the EPG team produced two types of event library simulations for each project cost share participant. SCE & ERCOT were provided with ten utility specific events, utilizing the WECC model for SCE and utilizing stressed state estimator and planning case for ERCOT and ten events using a generic model. The utility specific events were developed based on input from both SCE and ERCOT.

PSOT Benefits

PSOT is designed to train operators on:

a. Use of the advanced metrics e.g., phase angles, sensitivities, oscillations.
b. Early detection of wide-area cascading events such as islanding and blackouts, instability issues using advanced metrics and alarming.
c. Event Diagnostics in preparation for corrective action and restoration.
d. Alternate corrective actions and observe consequences in a training environment.

Commercialization Activities Accomplished:

PSOT addresses a critical need for a commercial product for operator training that will make synchrophasor technology used and useful by operators in control rooms. This section provides the commercial activities accomplished by EPG team during the course of project.

Target Market

Power System Operators and Operating Shift Engineers at Transmission Owners (TOs), Independent System Operators (ISOs) and Regional Transmission Operators (RTOs) who:

a. Have already deployed and are expanding the use of synchrophasor technology for better PMU placements.
b. Are planning to bring synchrophasor technology into the control center in an effort to support real-time operations, improving grid reliability and increase wide-area situational awareness.

Presentation at Industry Meetings & WebEx:

EPG demonstrated event library approach and on-the-fly approach using PSOT work products at:

a. EPG Users Group WebEx on September 15, 2015.
b. Powertech Labs Inc. Users Group Meeting on September 17, 2015.
c. Western Electricity Coordinating Council (WECC) Joint Synchronized Information Subcommittee (JSIS) Work Group Meeting on September 22, 2015.
d. North American Synchrophasor Initiative (NASPI) Work Group Meetings:
    - October 22, 2014 - Houston, TX
    - March 23, 2015 - Burlingame, CA
    - October 15, 2015 - Chicago, IL

Presentation to ISOs, TOs & RTOs:

EPG demonstrated event library approach and on-the-fly approach using PSOT work products at:

a. PJM Interconnection, LLC Norristown, PA on July 13, 2015.
b. Lower Colorado River Authority (LCRA) Austin, TX on August 17, 2015.
c. Hydro One Incorporated Toronto, Canada in August 2015.
d. American Electric Power (AEP) Columbus, OH in September 2015.

Commercialization Activities Planned for Post Project:

Product Announcement and Rollout:

EPG plans to announce PSOT Product availability and continue to commercialize use of PSOT through the following activities:

1. Presentation at industry meetings, including IEEE, CIGRE, NASPI, WECC as appropriate.
2. Presentation to additional ISOs, TOs & RTOs.
3. Preparation of PSOT Brochures for distribution to interested entities.
4. Preparation of PSOT Website Material for Internet posting on EPG website.
5. PSOT Product Announcement for email notification.
6. PSOT Product updates using EPG Newsletter and/or communications to EPG customers.
7. Establish PSOT Advisory Group for Product Roadmap & Enhancement.

Commercialization Licensing Strategy:

Product License Value

The total license package for the PSOT product includes the functionality of the following components:

a. Power System Simulation Tools.
b. RTDMS Platform & Clients.

c. Event Streamer & Manager.
d. *enhanced* Phasor Data Concentrator.
e. Ten event simulations using Generic Model including configuration of RTDMS Platform & Clients for Generic Model.

The PSOT components required by each customer may vary, depending on which training approach they plan to implement. EPG will prepare and provide PSOT product licenses tailored to specific customer requirements. The requirements could be dependent upon the following:

1. Event Library Approach vs. On-the-fly Approach or a combination of both.
2. Hardware vs. Software based Power System Simulation Tool.
3. Existing Component vs. Required Component.

Support & Maintenance Contract Agreement

EPG will provide full Support & Maintenance for PSOT product under a separate commercial agreement. This has been offered to SCE and ERCOT and will be offered to new licensees of PSOT. The Annual Support & Maintenance includes:

a. All new releases, updates and enhancements at no charge.
b. Fixes for Bugs/programmatic errors.
c. On-call consultation for technical issues.
d. Application help for users and administrators.
e. WebEx for installation and demonstration of new enhancements.
f. All updated documentation for new releases, updates and enhancements at no charge.

Professional Technical Service Agreement

If a customer desires additional event simulations (generic or utility specific), EPG will provide professional technical service under a separate commercial agreement or amended as part of the PSOT product purchase.

On-site Training & Support

EPG will provide on-site training support desired by customers under a separate commercial agreement or amended as part of the PSOT product purchase. EPG will evaluate the customer requirements and estimate the on-site training & support value based on following:

1. Train the Trainers in a classroom session; or
2. Train the Trainees by supporting the Trainers in an operator training room.

Support Integration of PSOT with EMS Training simulator

PSOT product was designed to be a standalone system for operator training. During the project, project participants expressed a desire to integrate PSOT with their SCADA training simulator for effective training and to show a side-by-side comparison of synchrophasor technology and SCADA. The implementation steps and effort for integration of PSOT with SCADA training simulator needs to be estimated based on the scope of work. EPG will support the implementation under a time and material professional service agreement.

EPG Team for Commercialization:

James Dyer - Director

Mr. Dyer was formerly a Manager of System Operation and Energy Control Center at Southern California Edison. Mr. Dyer has been guiding the utilization of phasor technologies and development of phasor applications for use by real time operators, dispatchers and reliability coordinators at CAISO and by NASPI members and has been involved with NASPI since its inception. Mr. Dyer has been EPG's project manager on CEC/CAISO projects including deployment of EPG applications at CAISO. Mr. Dyer brings decades of hands on operating and management experience in utility control centers and training of operators. Mr. Dyer was a key investigator for the 2003 Eastern Interconnection blackout. Mr. Dyer has been working on the present-day DOE funded project, Phasor Simulator for Operator Training (PSOT) in coordination with ERCOT and SCE.

Prashant C. Palayam - Product Manager

Prashant graduated as a power system engineer from Illinois Institute of Technology, Chicago, IL in 2011 and started working in EPG since June 2011. He was promoted as Product Manager for EPG's offline data analysis tool, Phasor Grid Dynamics Analyzer (PGDA). His involvement in DOE funded Discovery Across Texas (DAT) demonstration project included data mining for oscillations, impact of inertial frequency response with wind characteristics, data quality investigation of the ERCOT synchrophasor network including transmission owners and baselining analysis. He has been working on the present-day DOE funded project, Phasor Simulator for Operator Training (PSOT) in coordination with ERCOT & SCE.

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