21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

CIGRE US National Committee
2014 Grid of the Future Symposium

Use of the Power System Outlook (PSO) and SMART®[1] Programs to View PSLF Dynamic Simulation Data Files

B. BHARGAVA — Electric Power Group
A. SALAZAR — Southern California Edison
P. MACKIN — USE Consulting
F. SMALL — Bridge Energy Grp.
United States of America

SUMMARY

Power system operations are becoming increasingly complex as operations extend over a large geographical regions. There has been an increasing growth of independent renewable generation adding to this complexity. An Interconnection can have multiple control areas which are not always coordinated. Although Reliability Control Centers for the entire interconnected system are being established, they are still using old monitoring tools that may not provide adequate wide area dynamic visibility of the system. Lack of such visibility has recently resulted in major grid disturbances and blackouts in south western US and India. With the development of the Synchronized Phasor Measurement Systems (SPMS), the high speed data that is required for monitoring large interconnected systems is now available. Some tools are also being developed to analyze the data. This paper presents the SCE experience with a couple of those tools, one for visualization and one for post disturbance analysis, integrated with the functional capability of dynamic simulated data to assess "what if" scenarios under power system specific conditions. The tools described here have the ability to visualize wide area phasor measurement system data and the ability of the tools to view simulated in the same format provides engineers and operators to compare and benchmark simulations for additional analysis.

KEYWORDS

Synchrophasor – Power System visualization – Dynamic simulation – Model Validation

1. ***S.M.A.R.T. stands for Synchronized Measurement and Analysis in Real Time***

bhargava@electricpowergroup.com

1. INTRODUCTION

The WECC system in Western US extends over 14 states and part of Canada (British Columbia and Alberta) and Baja Mexico. Analysis of several past disturbances has shown that events occurring in one region can impact the entire system, and if not attended properly, can result in major disturbances. Fortunately, new technology known as Synchro-Phasor technology is now available which can enable the operator to visualize the entire inter-connected power system and monitor it just like a closed circuit TV system enables the store manager to keep an eye on his/her entire store operations.

It is important to have both tools and training so that the operators can see what is happening in the entire grid. However, the analysis of the data requires high level of skills which generally cannot be expected from the operators who are accustomed to looking at their own system. It is too much to expect that they be able to comprehend quickly enough the complex inter-area dynamics and be able to take timely preventive action. It is important to provide tools that quickly take the enormous amount of data, screen it, process it and provide the operators with valuable information and training required for reliable operation of the system.

2. PROGRAM DEVELOPMENT AT SOUTHERN CALIFORNIA EDISON CO

Southern California Edison realized the potential of the SPMS technology in the mid-nineties and started its development aggressively. SCE installed 20 Phasor Measurement Units (PMUs), the Phasor Data Concentrators and developed two programs to view the Synchro-Phasor system data by 2007. The two programs developed by SCE are:

1. Power System Outlook (PSO) program and
2. SMART – stands for ***Synchronized Measurement and Analysis in Real Time*** [6].

The programs have been very useful to SCE and others with whom SCE shared them. The PSO program is able to take a recorded *.dst file (IEEE 1344 phasor file format)[1-5], extract information, plot various system parameters such as frequency, power flow, voltage and oscillations. The reports of system events captured by SCE's SPMS system were regularly sent out and shared with the operations and planning personnel in WECC and its members. The SMART program has been in use in the SCE Control Room by SCE operators since 2007. Although, the technology application at SCE was primarily limited to the SCE area initially, it has now being extended to other areas. The California ISO has taken a lead role in collecting Synchro-phasor system data from SCE, BPA, PG&E, etc. Likewise Peak Reliability (formerly the WECC Reliability Center) is able to collect data from various TOs in their region and bring data into the Reliability Control Center.

To effectively deploy this technology, it is very important that the operators learn and use it. Since the technology can show the dynamics of the system, the operators are able to see much more than what they can see using SCADA systems. In order to familiarize the operators with this technology, SCE has installed the SMART program in the Control room. Figures 1 and 2 show the installation of the SMART program displays. Further, training programs were also developed for imparting training to the operators.

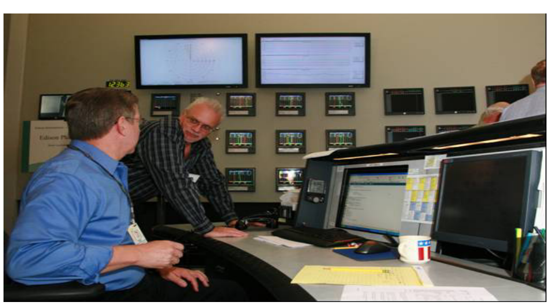


Figure 1: SMART screens in SCE control room.

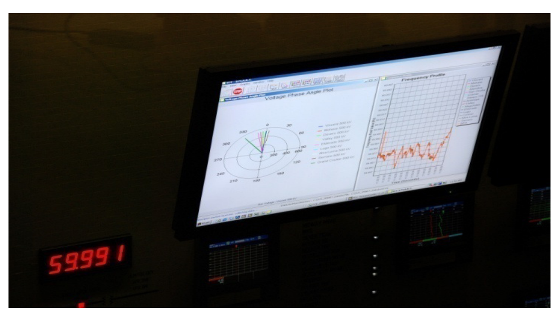


Figure 2: Volt phase angle display and frequency plot

2.1 Power System Outlook Program:

The Power System Outlook is an off-line analysis program that was developed by SCE during 1997-2005. The program was developed to view the Synchro-phasor system data being collected by SCE PMUs. The program reads the IEEE 1344 file format commonly known as the *.dst format. The program enables the user to see the entire recorded *.dst file which is 3 minutes long for SCE, and 5 minutes long for BPA, Cal ISO and others. Although, several other formats such as C37.118, Comtrade etc. have been develop, this format still allows more flexibility for storing, replaying or viewing files. The PSO program can display and can be used for:

- Monitoring system stress (Phase angle separations),
- Monitoring voltage support at critical locations,
- Monitoring modal oscillations and modal damping,
- Monitoring dynamic power swings,
- Post disturbance analysis (what operated correctly or incorrectly),
- Model validation for off-line analysis tools,
- Monitoring machine excitation and governor systems,
- System voltage and reactive power management,
- Pattern identification/recognition for quick event analysis and
- System load response to voltage and frequency variations

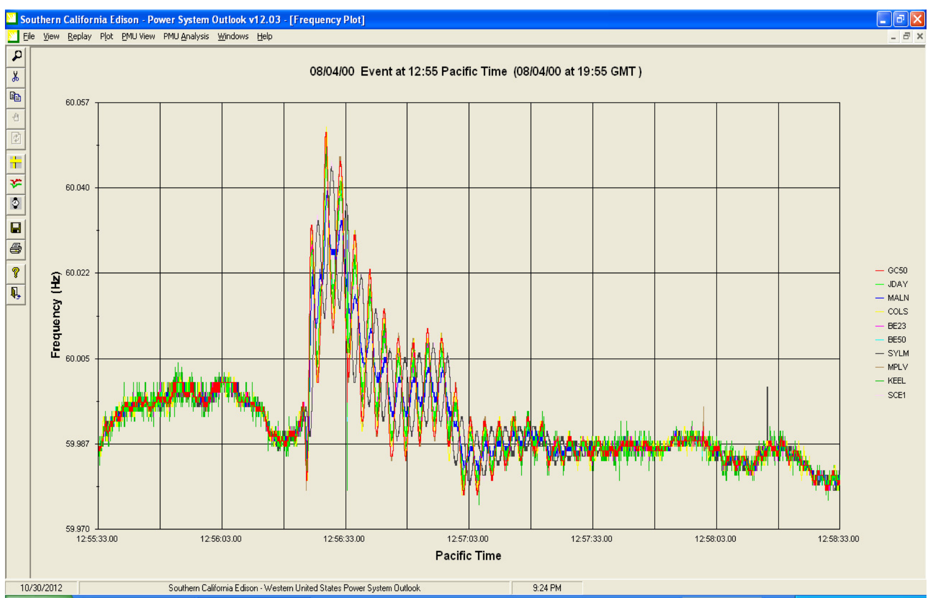


Figure 3: Frequency plot using PSO program

Figure 3 shows the frequency plot from PSO for a WECC system event. Since the measurements taken by Phasor Measurement Units are at a high resolution of 30 samples per second and time synchronized, the user can plots frequency measurements from all the PMUs and identify inter-area oscillations in the system using PSO and identify the location of the event. The figure above shows bus frequencies from busses in the North and South and the inter-area oscillations can been clearly.

Most of the limits that are used in system operation are based on analysis of the system using power flow and stability programs. For accurate results it is important that the elements and system simulated have good models. Since, the PSO program can read any *.dst file, it can be used to visualize and analyze simulation data from the PSLF program. This capability was developed by SCE and Navigant consulting engineers in 2005 and 2006, and it has been particularly useful when a simulation is done to duplicate and compare a significant real system event.

Use of the PSO Program to view PSLF dynamic data:

- Is a significant development.

- ❖ Enhanced engineers' capability to compare real events with simulation results.
- ❖ Provided the capability to view Frequency domain analysis of PSLF dynamic simulations.

This paper will review three significant events and compare simulations with the recorded data:

- ❖ August 4, 2000 (stressed system conditions).
- ❖ Oct. 8, 2002 (Major power generation drop and frequency excursions), and
- ❖ November 29, 2005 WECC system oscillations.

2.1.1 WECC System Oscillations under stressed -conditions – August 4, 2000

Event description:

- ❖ System was operating fairly stressed.
- ❖ Phase angle separation between Devers and Grand Coulee was above 90 degrees.
- ❖ Lost ties between British Columbia and Alberta, which was exporting about 460 MW to Alberta.

Loss of Alberta export over stressed the already stressed north-south system. System oscillated for several seconds indicating low damping. Oscillations damped when capacitor voltage support was provided at Keeler substation in Seattle area.

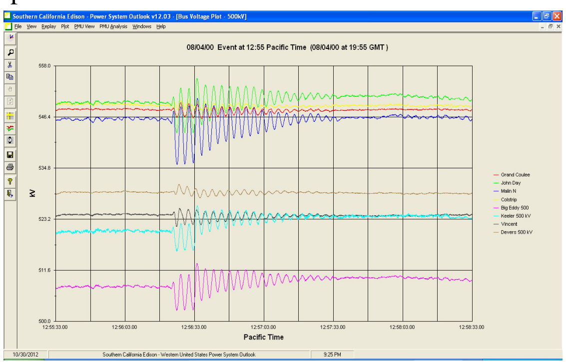


Figure 4: Voltage oscillations plot for 500 kV system August 4, 2000 – Real event.

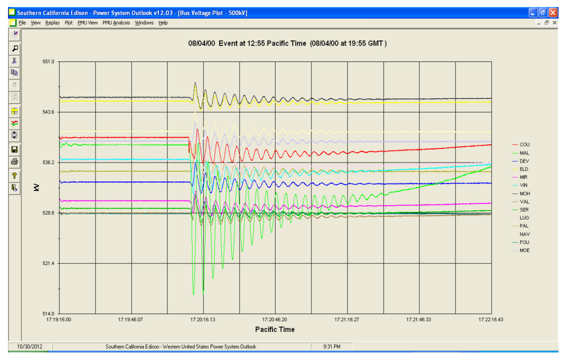


Figure 5: Voltage oscillations plot for 500 kV System on August 4, 2000 – Simulation

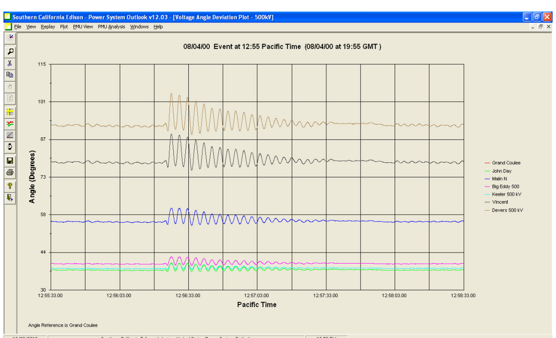


Figure 6: Angle oscillations plot for 500 kV system on August 4, 2000 – Real event.

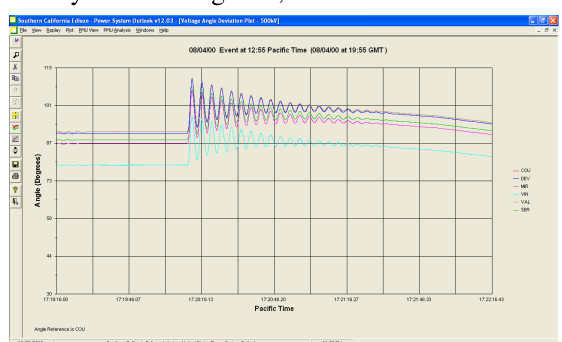


Figure 7: Angle oscillations plot for 500 kV system August 4, 2000 – Simulation

Side by side comparison of the real recorded event and the simulated event shows a close resemblance indicating that the simulation is a good representation of the event. The PSO program also compares the oscillation frequency and the damping shown in figures 10, 11, 12 and 13. The oscillation frequencies are very close, but the damping is a little different. The user could change the system constants to get better comparison, if desired, however, these results are close and can be accepted. Comparing the results in frequency domain provides additional capability to the user to correct / modfy the models.

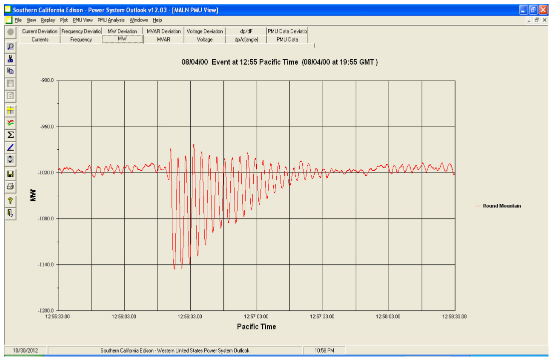


Figure 8: Power oscillations at Malin substation August 4, 2000 – Real event

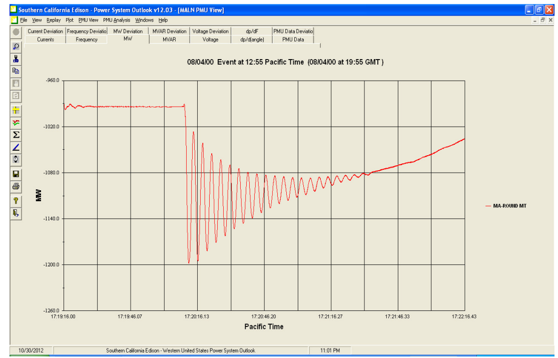


Figure 9: Power oscillations at Malin substation for August 4, 2000 – Simulation

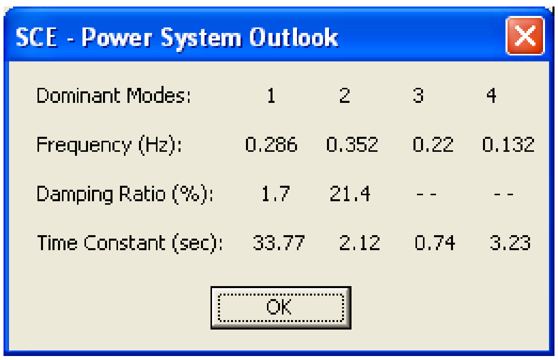


Figure 10: Display of dominant modes and damping for August 4, 2000 – Real event

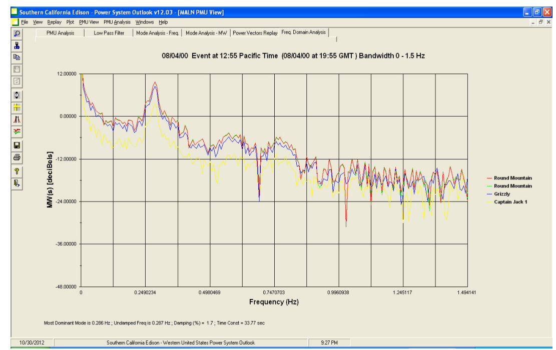


Figure 11: Frequency spectrum in 0-1.5 Hz bandwidth for August 4, 2000 – Real event

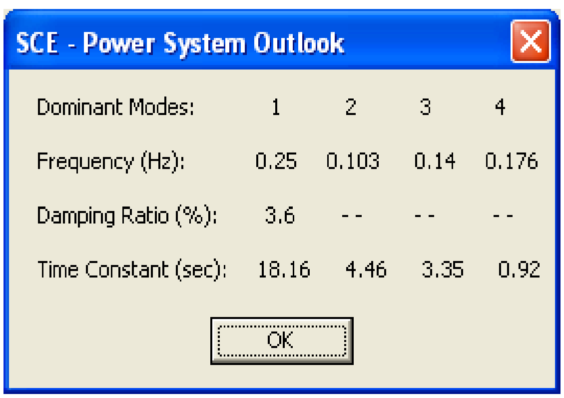


Figure 12: Display of dominant modes and Damping for August 4, 2000 – Simulations. The damping is little higher (3.6 percent).

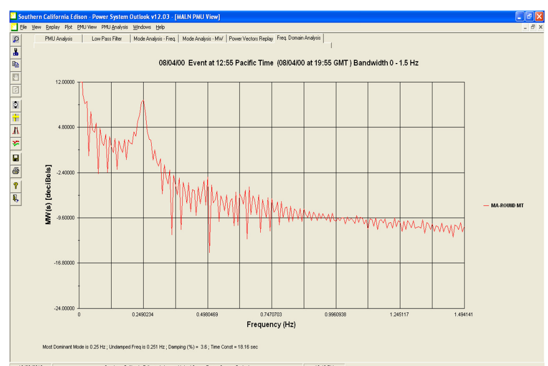


Figure 13: Frequency spectrum in 0-1.5 Hz for August 4, 2000 – Simulations. The frequency is slightly lower (0.25 Hz).

2.1.2 WECC System Event – Major power generation drop and frequency excursions – October 8, 2002

The next event simulated and compared was a generation drop event that occurred on October 2, 2002. About 2900 MW generation was dropped in Northwest US to maintain the stability of the system when a critical 500 kV line tripped. This generation drop resulted in a frequency decline to 59.62 Hz. The plots from the PSO show a close frequency drop characteristics.

Figures 16 and 17 show similar voltage plots, however the voltage at a bus increases but does not drop indicating the switching off of a capacitor bank may not have been simulated. Figures 18 and 19 show that the power oscillations at Malin substation match fairly well.

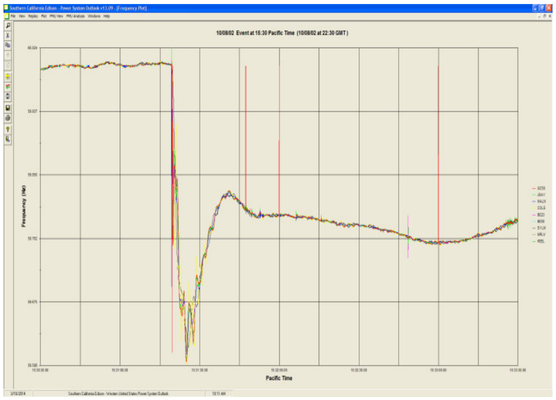


Figure 14: Frequency excursion on October 8, 2002 - Real event

Figure 15: Frequency excursion on October 8, 2002 - Simulation

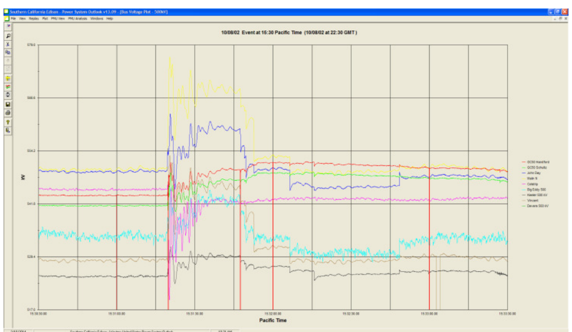


Figure 16: Voltage oscillations plot for 500 kV System. October 8, 2002 – Real event

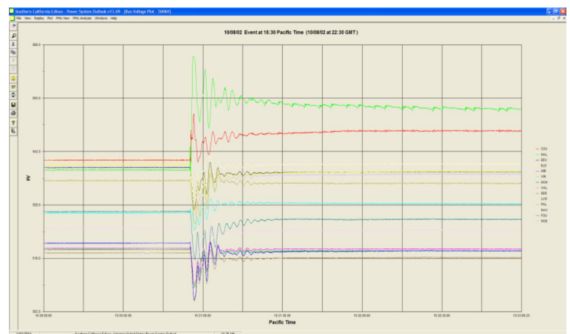


Figure 17: Voltage oscillations plot for 500 kV system October 8, 2002 – Simulation

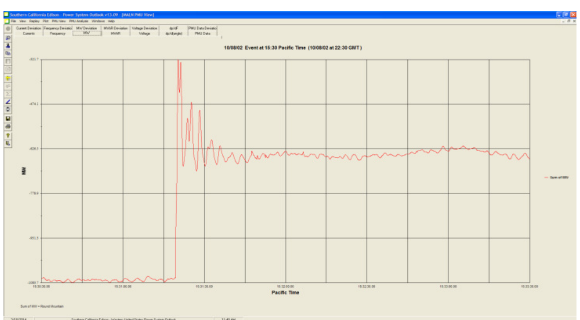


Figure 18: Power oscillations at Malin substation October 8, 2002 – Real event

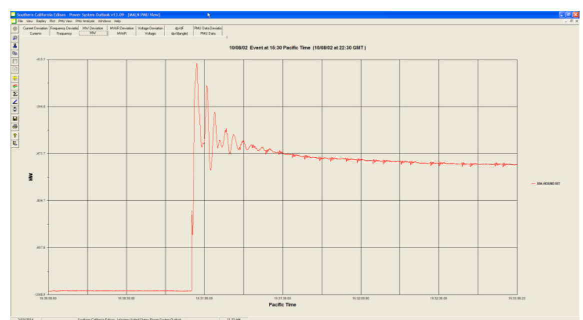


Figure 19: Power oscillations at Malin substation October 8, 2002 – Simulation

2.1.3 WECC System Oscillations due to malfunctioning steam valve in Canada area – November 29, 2005

This event was caused by a faulty steam extractor control valve that malfunctioned at the Nova Joffre cogeneration plant in Alberta, Canada. The System oscillations caused by the control valve were amplified in the US and lasted for almost 6 minutes. The oscillations created by the faulty valve were at the natural frequency of the WECC North-South mode (About 0.28 Hz). The damping ratio dropped below 2% for 0.279 Hz dominant mode while the turbine control valve was malfunctioning. The normal damping was restored as soon as the steam supply to the host process was reduced.

Simulation of this event captured fairly well the oscillations, the dominant frequency and damping of the event in spite of not having a very good system model representation. Figures 20 to 27 show the plots from PSO for the real event and the simulated event. The event was simulated by injecting a oscillatory signal with frequency of about 0.28 Hz at the Nova Jaffre plant in Alberta, Canada. The injected signal caused power oscillations on the North- South intertie. These North-South intertie oscillations were monitored at Southern California Edison's Vincent substation. Figures 20 and 21 show the oscillations in voltages and different busses and figures 22 and 23 show the oscillation at Vincent substation on one of the Midway- Vincent power line which is part of the 500 kV North-South Pacific Inter-tie.

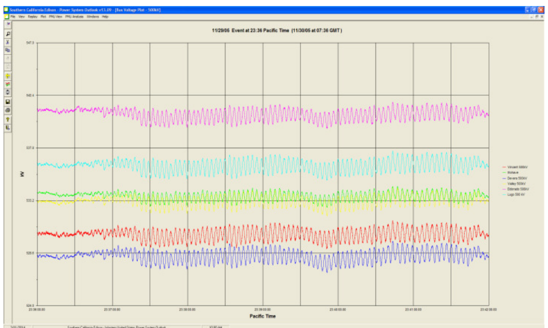


Figure 20: Voltage oscillations plot for 500 kV System November 29, 2005 – Real event

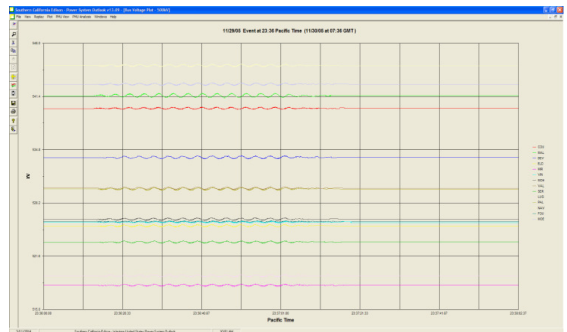


Figure 21: Voltage oscillations plot for 500 kV system November 29, 2002 – Simulation

Figure 22: Power oscillations at Vincent substation substation November 29, 2005 – Real event

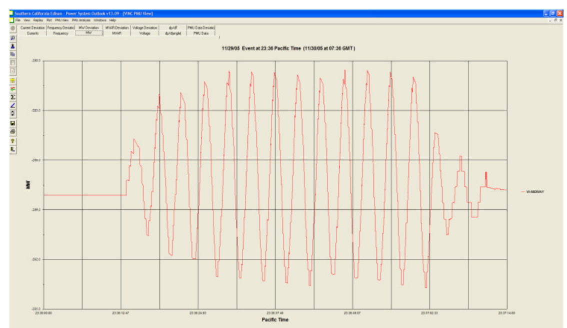


Figure 23: Power oscillations at Vincent November 29, 2005 – Simulations

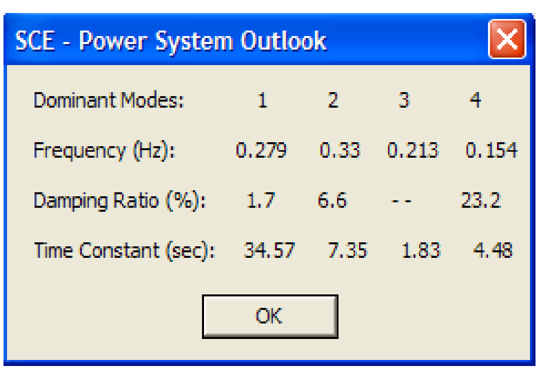


Figure 24: Display of dominant modes and Damping - November 29, 2005 – Real event.

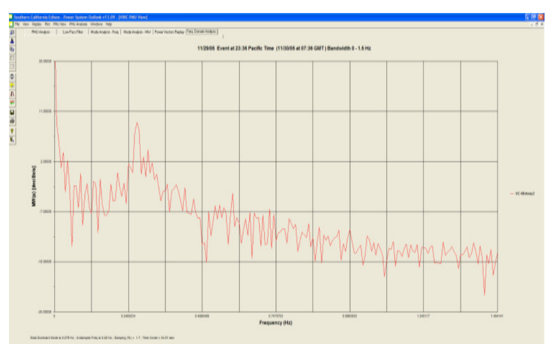


Figure 25: Frequency spectrum in 0-1.5 Hz Bandwidth - November 29, 2005 – Real event

Figures 24 and 25 show the oscillatory modes displayed by the PSO program for the real event and the simulated event. The frequency of oscillations and damping in the simulations are little lower, but the simulation did capture the 0.33 Hz mode observed in the real event.

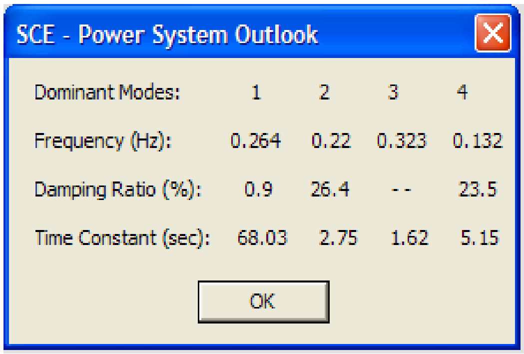


Figure 26: Display of dominant modes and damping - November 29,2005 – Simulation Damping is slightly lower (0.9 percent).

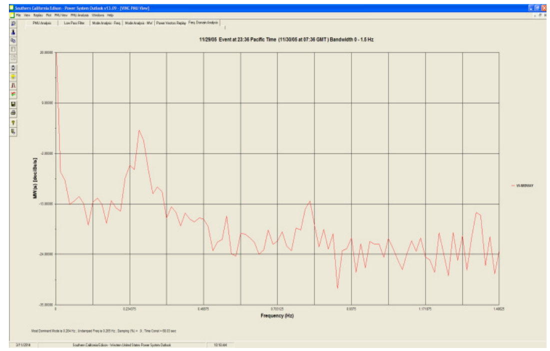


Figure 27: Frequency spectrum in 0-1.5 Hz November 29, 2005 - Simulation. The modal frequency is slightly lower. About 0.264 Hz.

2.2 Visualization of simulated dynamic power system events for operator training

- Several disturbances and blackouts have occurred in recent times because of lack of wide area visibility of the power systems. In past the systems were small and disturbances were limited to one control area. Control areas are mostly monitored using SCADA or State Estimator systems. These tools are mostly limited to their own control area. The tools are slow and cannot visualize dynamics in the system. These tools update information every 2 to 4 seconds. Even though relatively slow, they can alert the operators within their own control area, but cannot monitor things happening outside the control area. The SCADA technology cannot see the system dynamics.

- Most large disturbances generally initiate with some minor violation, but continue to escalate as no preventive or remedial action is taken in the early stages. These minor violations may be:
    - Overloading of a path or multiple paths
    - Outage of transmission line resulting excessive power flow on the other parallel line. (This type of outage occurred in India resulting two major blackouts in July, 2012.)
    - Operating in an unsafe operating zone.
    - Over stressing the system either due to heavy loading on the system or reduced transmission system capability.
    - Malfunction of control systems resulting in system oscillations.
    - Degrading voltage support leading into voltage collapse.

- Today's Synchro-phasor technology has provided tools that can be used by operators in real-time to:
    - Continuously monitor vital system parameters,
    - improve power system performance,
    - monitor vital system parameters and identify early enough the impending breakups of the systems, and
    - take appropriate action to avoid escalating situations that could lead into power system breakups.
- These tools are highly advanced and can be used by operators but using these tools properly requires training
    - Programs are available that can help the operators monitor these events in real-time.
    - These tools can also be used with simulated events to show operators what they will see and what will occur if such an event unfolds in the system. In fact, the simulations can be conducted to simulate the worst scenarios.
    - The simulations can be used to recreate the event scenarios such as those that occurred on:
        - August 4, 2000 in the western US system, and
        - On July 4, 2012 (loss of Palo Verde Unit 3 while carrying 1320 MW) also in the western US system.

2.3 SMART Program:

a) SMART program has the capability to replay the dst files whether from a real event or created from a PSLF program simulation. Figures 28 to 33 show the plots for Alberta separation real and simulated event which occurred on August 4, 2000.

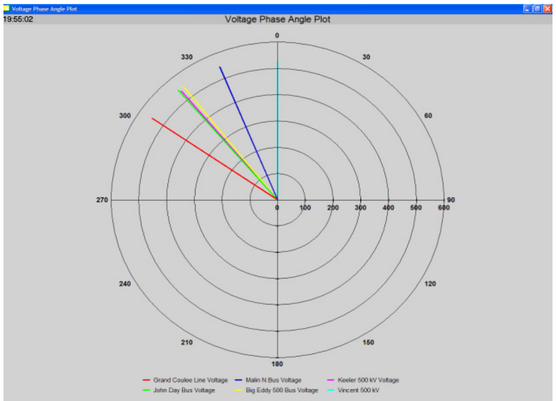


Figure 28: Voltage phase angle plot for 500 kV system on August 4, 2000 – Real event.

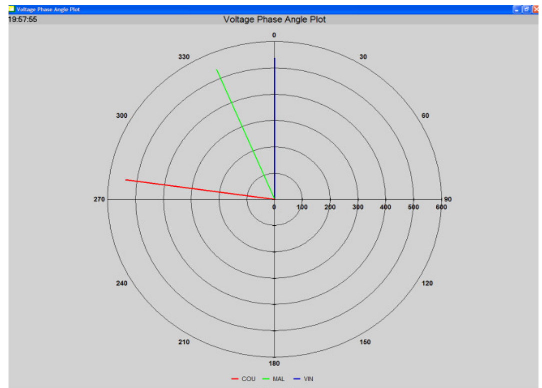


Figure 29: Voltage phase angle plot for 500 kV system on August 4, 2000 – Simulation

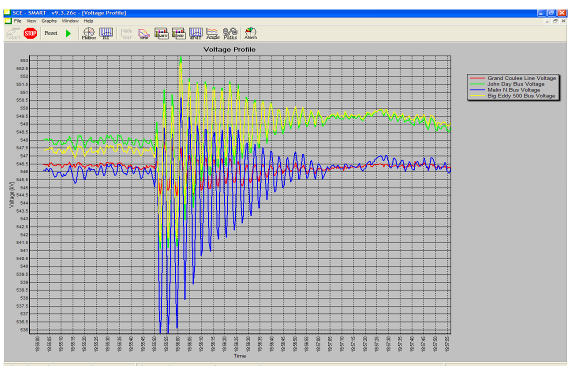


Figure 30: Voltage oscillations plot for 500 kV system on August 4, 2000 – Real event.

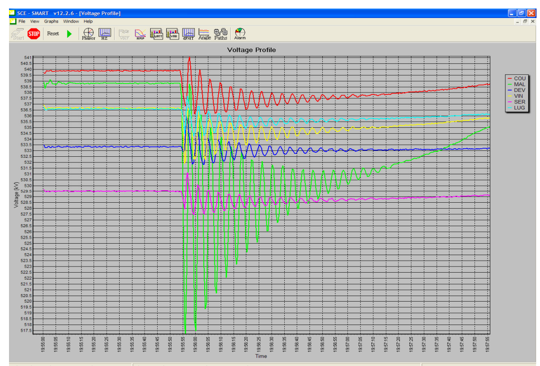


Figure 31: Voltage oscillations plot for 500 kV system on August 4, 2000 – Simulation

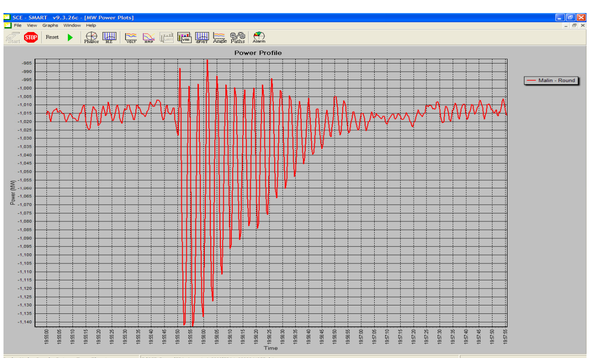


Figure 32: Power oscillations at Malin substation August 4, 2000 – Real event

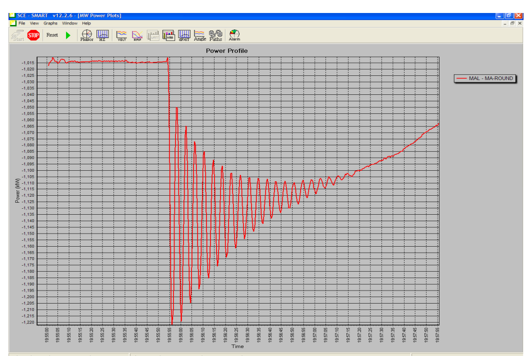


Figure 33: Power oscillations at Malin substation August 4, 2000 – Simulation

b) Figures 34 to 39 show the SMART plots of real event and simulation event on July 4, 2012 when Palo Verde Unit #3 relayed while carrying 1320 MW. System frequency dropped to 59.817 Hz.

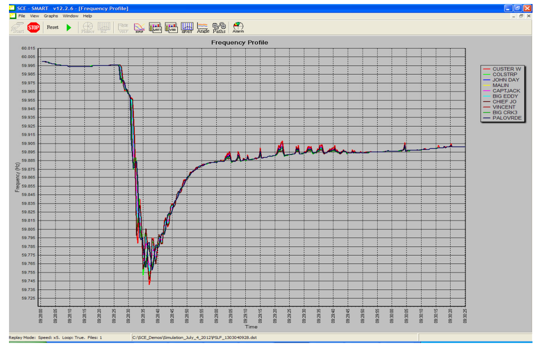


Figure 34: Frequency plot for 500 kV system on July 4, 2012 – Simulated event .

Figure 35: Frequency plot for 500 kV system on July 4, 2012 – Real event

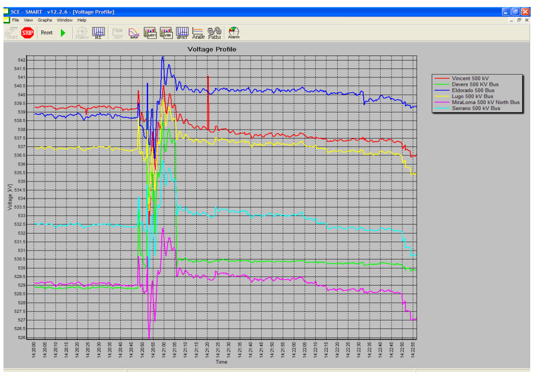
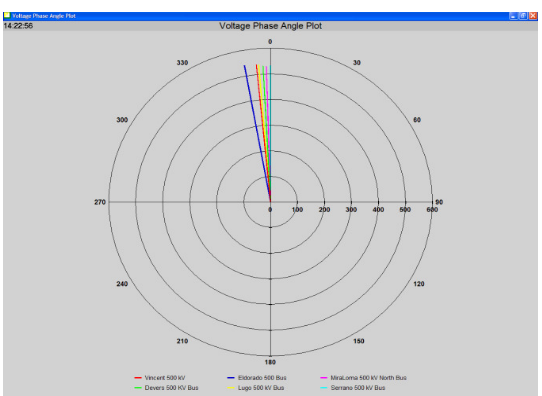


Figure 36: Voltage oscillations plot for 500 kV system on July 4, 2012 – Real event.

Figure 37: Voltage oscillations plot for 500 kV on July 4, 2012 – Simulation



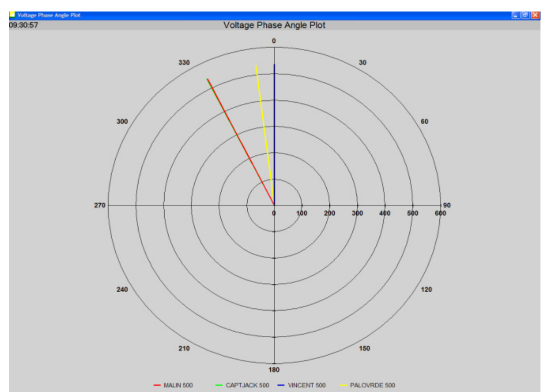


Figure 38: Voltage phase angle plot for 500 kV system on July 4, 2012 – Real event.

Figure 39: Voltage phase angle plot for 500 kV on July 4, 2012 – Simulation

3. CONCLUSIONS

Power Systems are becoming very complex and events in remote areas can cause problems and blackouts. The lack of wide area visibility has led to several system disturbances in the past and because of that a Wide Area Monitoring System (WAMS) has been recommended in the 1996 and 2003 blackout reports. Today WAMS is possible with SPMS and this technology can be used not only for monitoring power system operation, but also for training operators by replaying and analyzing real events that happened in the system. Typically dynamic simulations are conducted for major disturbances in the WECC. From a planning point of view, simulation of actual events is paramount and it is being used for model validation purposes. The tools presented and discussed in this paper provide the necessary platform required for engineers to conduct in-depth analysis of system events and their impacts on transmission systems. These tools also allow engineers to analyze and explore methods to mitigate or limit the effect of similar disturbances on the system in future cases. Additionally, the tools developed by SCE to analyze the outputs of the large set of dynamic simulations from the GE-PSLF program significantly reduced the time for these analyses and improve the analysis capabilities of the engineers.

References

[1] B. Bhargava, “Synchronized Phasor Measurement System project at Southern California Edison Co.”, IEEE Summer Power Meeting held at Edmonton, Alberta, Canada, July 18-22, 1999.

[2] J. Ballance, B. Bhargava, G. D. Rodriguez “Synchronized Phasor Measurement System at Southern California Edison Co. for Monitoring and Enhancing System Reliability” presented at the Power-Tech conference, Bologna, Italy, August 2004.

[3] R. Baldwin, B. Bhargava, G. D. Rodriguez, A. Salazar, “Monitoring and Recording Power System Disturbances at SCE Using Synchronized Phasor Measurement Technology” presented at the Disturbance Monitoring Workshop at Georgia Tech, April 2005.

[4] J. Ballance, B. Bhargava, G. D. Rodriguez, “Use of Synchronized Phasor measurement System for Enhancing AC-DC Power System Transmission Reliability and Capability” presented at the CIGRE Meeting, Paris August 2004.

[5] B. Bhargava, G. D. Rodriguez, A. Salazar “Use of Synchronized Phasor Measurement System for Monitoring Power System Transmission Reliability and Capability” presented at the DistribuTECH, January 2005, San Diego, CA.

[6] B. Bhargava, A. Salazar, “Use of Synchronized Phasor Measurement System for Monitoring Power System Stability and System Dynamics in Real-time,”, presented at the Transmission & Distribution Conference at Bogotá, Columbia, August 2008.