Monitoring and Recording Power System Disturbances at SCE Using Synchronized Phasor Measurement Technology

By

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Abstract

This paper presents the **Synchronized Phasor Measurement Technology** presently applied at Southern California Edison (SCE) Co. This technology has the ability to record the occurrence of transients on the interconnected power system, as well as the capability to record various system parameters, such as frequency, current and voltage phasors. The Phasor Measurement Units, which is the main Voltage, current phasors and frequency recording device are installed at the strategic points within the power system. The data from these devices is time synchronized and is transmitted at a very high speed to a central Data Concentrator. This data is used to determine the differences in phase angle that exist throughout the power system and to calculate rate of change of frequency, power flow, reactive power flows, modes of oscillations and their damping.

SCE has spent the past eight (8) years aggressively pursuing an enhanced understanding of the power system's response during various events, through the application of its **Synchronized Phasor Measurement Technology.** Several Phasor Measurement Units (PMUs) and two Phasor Data Concentrator (PDC) units have been installed on the SCE system, along with a link to Bonneville Power Administration to link the data from their Grand Coulee generating station to SCE Phasor Measurement System over 900 miles away. SCE is searching for methods to apply this technology in an effort to monitor the stresses on the power system in real-time. It is believed that this technology has the potential to enhance the stability and transfer capabilities of a large inter-connected power system. This technology also offers the data needed to investigate the performance or post disturbance analysis during system disturbances and anticipating ways to prevent these events in the future.

SCE has been working with the staff at the California Independent System Operator (Cal-ISO) and several other members of the Western Electricity Coordinating Council (WECC), to develop a program which will allow the open exchange of phasor data between parties. This paper will explore the usefulness of this data in the areas of real-time monitoring, as well as its potential for performing control actions in response to changing system conditions.

SCE has developed an automated program tool called the "**Power System Outlook program**", which has the capability to display and analyze the recorded data. The phasor data recorded during some recent system events will be presented as a part of this paper.

Introduction:

Monitoring the power systems has become lot more complex today as they are becoming larger and are interconnected over thousands of miles apart. Their operation is also becoming very challenging as events occurring in remote areas can have significant impact even to the extent of causing system breakups and blacking out large remote areas. This has been seen in several system disturbances that occurred in US, Canada, Italy, Sweden etc in 2003. With the increasing complexity of power systems

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it has become essential to monitor and be aware (Situational Awareness) of events that may be taking place in remote areas of the system but could have significant impact in the Utility Control area. The power systems have also become so inter-dependent that the events in one area can cascade and have significant impact on other remote areas. This change in the industry is putting pressures to develop new tools to monitor wide area system stability and reliability which is becoming very essential and can cause losses in billions of dollars. Also, modern monitoring tools are needed for post-disturbance analysis without which it is very difficult and time consuming to determine what may have been the real cause of power failures.

The advances in the field of communications, computers and Global Positional System (GPS) technologies have led to the development and use of **Synchronized Phasor Measurement technology** which has the capability to monitor and manage dynamic system security of large power systems. In addition, this has also enabling Utility or Power System operators to keep an eye on other neighboring power systems. Southern California Edison (SCE) Co., which is part of the Western Electric Coordinating Council in the United States, has been working on the "**Synchronized Phasor Measurement System (SPMS) Technology**" for the past eight years and has installed a network of Phasor Measurement Units (PMUs), Phasor Data Concentrators (PDCs), a high speed reliable fiber optic communication system and suitable data storage servers to collect the phasor data. This has enabled SCE also to exchange data from a Phasor Data Concentrator installed by Bonneville Power Administration from its Dittmer station in real-time. SCE has also developed a program, entitled **"Power System Outlook (PSO)**" to view and analyze the data collected by the PDCs. The data from this Phasor Measurement System has been collected and analyzed over several years for different types of disturbances.

Operation of the Western Electric Coordinating Council (WECC) System:

Since power systems today are being pushed to maximize the power transfer limits for long distances, the monitoring and managing of power system stresses has become very essential. It has become necessary also to be aware of what is happening in the other interconnected parts of the power systems. The SPMS technology is able to provide tools that can monitor the key indicators of system stress such as (1) the phase angle separation between distant generators, voltage support, inter-area oscillations (which can provide early indications of upcoming dynamic insecurity), loss of major generation or load.

The phase angle separation between two large interconnected areas is one of the simplest stress measurement indicator. Large power systems as in WECC, which span over thousands of miles and often operate at large phase angle separations. This can, however, be done only when continuous voltage/var support is available at intermediate substations. The SPMS system is a very useful tool to track all these system parameters.

In general, power systems are designed to be secure for peak system loading conditions and for outage of an element at these loading levels. Since these peak load conditions occur only for a short duration, generally adequate operating margins are available most of the time. Thus, most system disturbances however, occur, not for the loss of one element, but multiple contingencies occurring over a time period. Very often, the system/line loadings and margins are not adjusted when the line outages occur, especially, if they are outside one's control area. SPMS is a tool that can help in monitoring wide area systems and manage stress by tracking the phase angle separation, voltage phasors and line loadings. The SPMS along with the SCE PSO program can also track inter-area system oscillations, which can fore-warn dynamic instability within the power system.

The SPMS, which is also commonly known as Wide Area Measurement System (WAMS) can enable monitoring some of the following critical system operating indices which are essential for secure operation of a large power system:

- Monitor, establish and operate within the static phase angle limits (system stress).
- Monitor/ensure Critical Intermediate voltage support when operating at large phase angle separation

- Monitor dynamic/transient phasor movements for dynamic/transient swings between different areas.
- Monitor Modal inter-area oscillation frequencies and their modal damping.
- Monitor path loadings and line flows and key tie line status etc.
- Monitor and arm Special Protection Scheme (Remedial Action Scheme) operations
- Real-time Phasor Measurement system Monitor

Synchronized Phasor Measurement System at SCE:

Presently, SCE has fourteen PMUs installed as shown in figure 1 and is in installing two more in year 2005. The PMUs in use at SCE record three phase voltages, currents and frequency at a rate of twelve samples per cycle, convert the voltage and current phase quantities to positive sequence phasor data. Using the GPS system, the PMUs time tag the phasors recorded at the different PMU locations with a high degree of accuracy. This phasor data is transmitted to a central location to the PDCs every two cycles or thirty samples a second and tabulated based on the time stamp. The basic records in the disturbance file consist of the time tagged voltage, current phasors and frequency deviations. The megawatts and megavars are calculated easily from this phasor data.

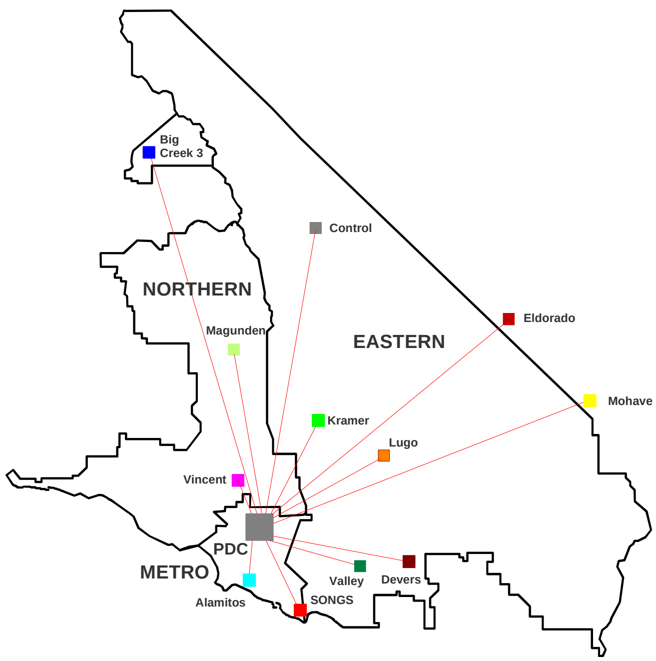


Figure 1: PMUs installed on the SCE system communicating to PDC at SCE Grid Control Center.

Figure 1 shows the PMUs installed at SCE showing transmission of data to a PDCs. The data from the various PMUs and the BPA PDC (not shown in the figure) is transmitted to the SCE PDCs located at SCE Grid Control Center. The data from the PDC is also transferred and stored on to IT servers. The data can be accessed by SCE engineers/staff through the network. Files are also time compressed in various time lengths for viewing a longer time span as may be necessary. The files are stored as event files or as stream files. The event files are created by the PDC whenever there is a disturbance in the system and the frequency, rate of change of frequency, voltage or voltage deviation set limits are exceeded. The stream files are files that are continuously downloaded and recorded. The stream files are also used to create time-compressed files. Each event file or the stream file is three minutes long. The event file has one minute of pre-trigger and two minutes of post trigger data. The data can be viewed using a program called "**Power System Outlook**", or the **Phasorfile** viewer developed by BPA. SCE **Power System Outlook** program has the capability of data display and do FFT analysis of the stored files. The events presented below use the SCE Power System Outlook program for data display and analysis. The SCE system also stores the event files and the time compressed the files.

<u>Monitoring and Operating within established Static Phase angle separation limits (system stress):</u>

The phase angle separation between two locations can be considered as the direct indicator of the stress on that part of the system. The static phase angle separation is the static stress on the system caused by the normal operating condition of the system. SCE is able to monitor the static and the dynamic stresses by monitoring the phase angle separation between Grand Coulee generating station in the BPA area in US Northwest with SCE Devers and Vincent substations in the US Southwest. It has been observed that at the time of two system events this static phase angle had exceeded 90 degrees and the loss of some transmission lines or load in the northwest increased the stress further causing a system disturbance on August 10, 1996 and a system event on August 4, 2000. These phase angle limits have also been verified by off-line system studies conducted by WECC Modeling and Validation group.

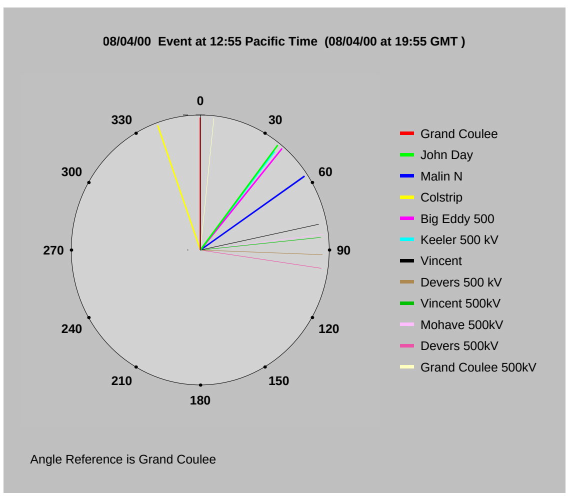


Figure 2a

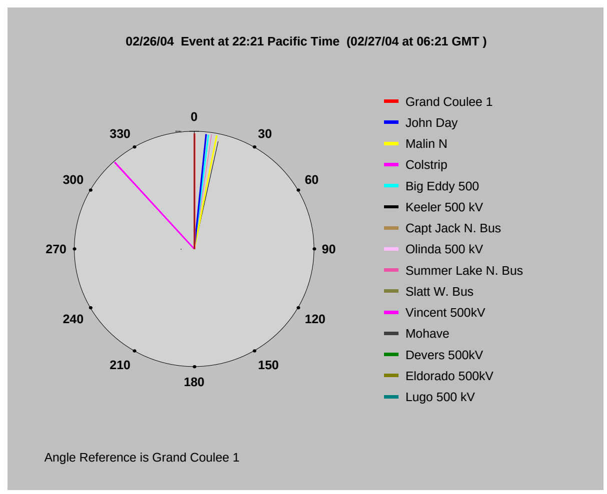


Figure 2b

***Figure 2a & 2b**: Phase angle displays from the Power System Outlook program showing the phasors (phase angle and magnitude) from the various 500 kV substations for two different dates. The phase angle separation is a measure of the static system stress on the system between BPA, PG&E and SCE substations. In figure 2a, the system is operating highly stressed with phase angle between Grand Coulee and SCE Vincent substation at above 90 degrees. The voltage support at John Day, Big Eddy, Malin and Keeler substations which are the intermediate substations is very important for the system to operate at this large phase angle separation. In figure 2b, the system is operating at much lower stress between Grand Coulee and Vincent, but is stressed between Colstrip and Grand Coulee.*

Figure 2 shows the snapshots of the voltage phasors of the 500 kV substations along the AC Pacific Inter-tie lines for two different events caused by separation of Alberta from British Columbia in Canada, just before the events on August 4, 2000 and on February 26, 2004. The plots have been produced from SCE Power System Outlook program. Both these plots have been created by merging the two PDC disturbance files created by these events by Bonneville Power Administration PDC and the SCE PDC. Combining the files from different areas is essential for viewing the entire North-South WECC picture. Merging this data would be essential continuously for monitoring the WECC North-South system oscillations real-time. The Voltage phasor magnitude and their relative phase angles can be seen in these figures. The reference in the plots has been selected to be Grand Coulee in BPA area in both these events. The difference between the voltage phasors at Grand Coulee and Vincent in figure 2a is more than 90 degrees, while in figure 2b is only about 30 degrees. Figure 2a shows the operation at a much stressed level, while the figure 2b at a very low stress level. The operation of a system at such large phase angles as shown in figure 2a, is only possible when continuous voltage support is available. This operation may be considered like a very long beam which can support the loading when it has intermediate supports all along.

<u>Monitor to ensure Critical Intermediate voltage support at Intermediate substations:</u>

Monitoring and ensuring voltage/ Var support at all the intermediate substations is very essential when systems are operating at large phase angle deviations. The plots shown in figure 2a show the intermediate voltage support at several substations between Grand Coulee and Devers substation. When operating stressed at such large angles, the system is very vulnerable to loss of voltage support at any of the intermediate substations. Figures 3a and 3b show the 500 kV voltages for entire two events. As would be seen in Figure 3a, significant voltage oscillations occurred on August 4, 2000, when the system was operating highly stressed. In fact the voltage oscillations started growing initially, but were damped when a shunt capacitor closed near Keeler substation and the voltage support increased at Keeler and John day substations. In figure 3b, the oscillations damped rapidly as good damping was available at the reduced phase angle separation. In figure 2, the voltage support at Keeler, Malin and Big Eddy substation is the key for the system to operate at such large phase angle separation. The phasors at these substations should be close to the circumference that is that the voltage should be around the nominal system voltage. This voltage support and adequate reactive margin should be available for static system loading and also during dynamic or transient loading.

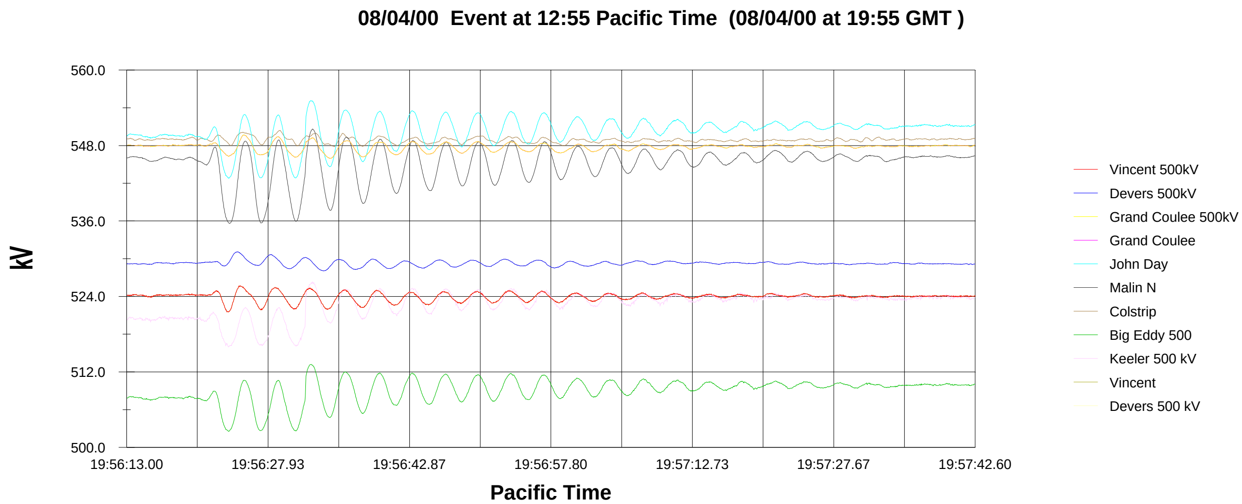


Figure 3a

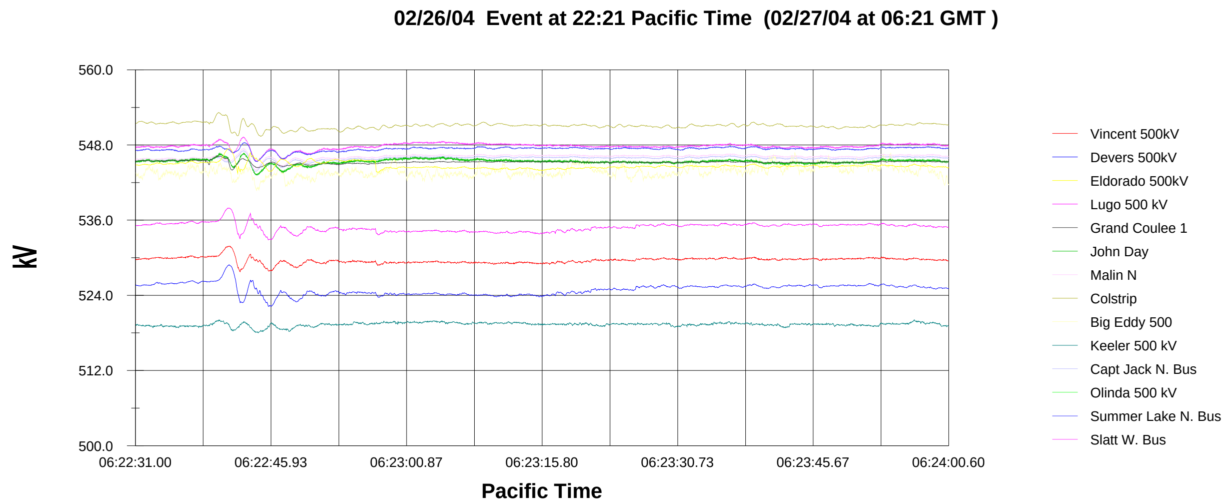


Figure 3b

Figure 3: *Voltage magnitude time plots for August, 4, 2000 and February 26, 2004 events caused by the loss of 500 kV line between Alberta and British Columbia in Canada.*

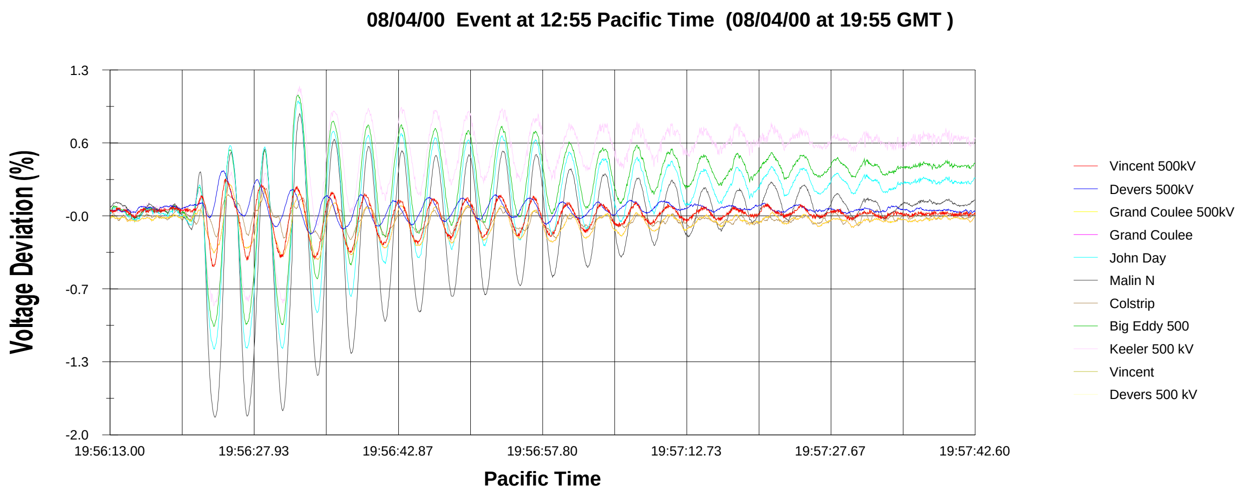
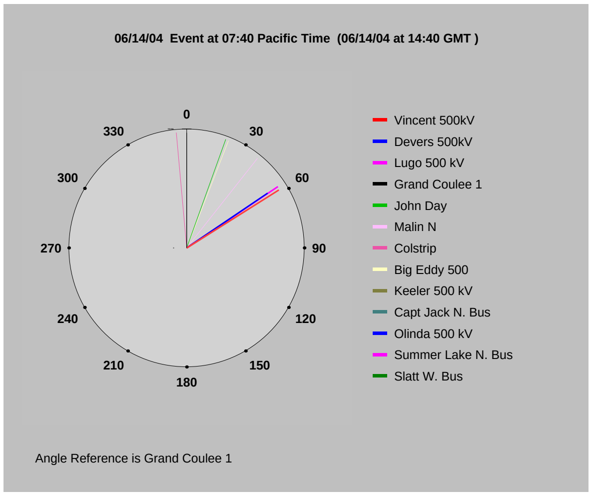


Figure 4: *Voltage magnitude deviation time plot for August, 4, 2000 event.*

Figure 4 shows the percent voltage deviation at different 500 kV busses for the August 4, 2000 event. The Malin and Keeler substation showed higher voltage oscillations, which were damped when the shunt capacitor closed near Keeler substation providing additional voltage support at the intermediate substation.

Figure 5 shows the voltage phasors of the WECC North-South system for a different event which occurred on June 14, 2004. The figure 5a shows the phasors just before this very significant event occurred when several transmission lines and generating units tripped in Arizona and California area resulting in a loss of over 4700 MW in the southwest US and the figure 5b shows the phasor display for the June 14, 2004 event when the phasors are displaced to their maximum. This is a case illustrating a disturbance with low static stress, but very high dynamic stress. The plots show the phasor separation between Grand Coulee in north and Vincent/Devers substations in south and also the intermediate voltage supports at Big Eddy, Malin, Keeler and some other substations. The dynamic phase angle change caused by a system event is the direct dynamic stress caused by that event on that part of the system. The dynamic stress in this case was additive as it increased the phase angle separation between two monitored locations.



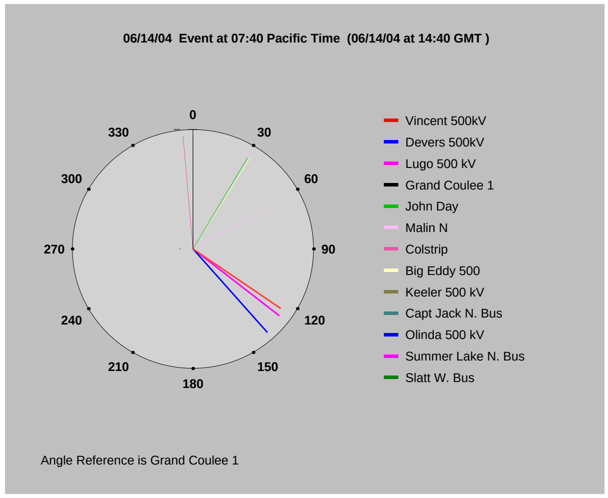


Figure 5a **Figure 5b**

Figure 5: *Voltage phasor plots and phase angles for the June 14, 2004 system event in Southwest US. Figure 5a shows the phasors before the event and figure 5b during the event at maximum phase separation. Notice the voltage phasor at Malin substation reduced in magnitude indicating almost exhausted voltage support. The phase angle between Grand Coulee and Devers/Vincent is about 55 degrees which increased to about 145 degrees at its peak. .*

When the dynamic change in the phase angle causes the phase angle separation to increase on an already stressed system, then it is putting additional stress and can lead the system into separation. Fortunately, the system on June 14, 2004 was operating at a much lower initial stress level at a phase angle separation of about 50 degrees between Grand Coulee in the Northwest and Devers/Vincent in the Southwest. The system was able to ride through and survived this major disturbance even though the southwest lost several 500 kV lines and above 4700 MW of generation.

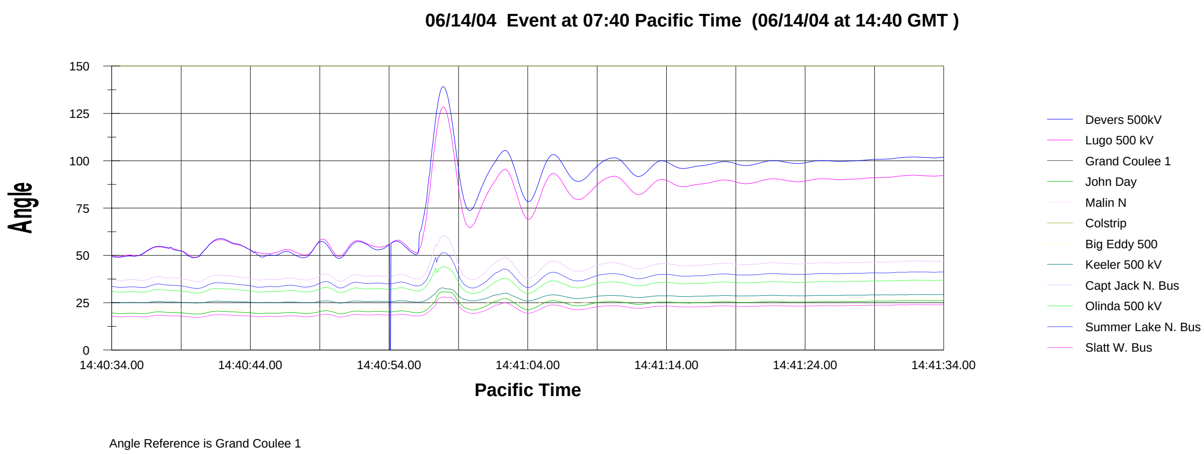


Figure 6: *Phasor angle plots for 500 kV substations along the Pacific Inter-tie for the June 14, 2004 system event. The dynamic swing exceeded 90 degrees, but oscillations damped rapidly. .*

Figure 6 shows the phase angle plots for this event. The dynamic phase angle changed from about 55 degrees to about 145 degrees at its peak. The dynamic swing exceeded 90 degrees and the system was able to survive as it was operating at a low initial static stress. Also, the North-South WECC system dynamic oscillations damped rapidly. Since the system was operating at low stress, the modal inter-area oscillations damped rapidly. The system event caused the voltage at Devers substation to reduce to about 0.76 per unit and resulted in a 500 kV line to trip on Zone 1. Figure 7 shows the voltage plots for the entire time of the system event. The magnitude of the phasors at Malin, Keeler can be seen to reduce considerably during the peak of the transient. The Malin voltage in fact reduced to about 0.81 per unit indicating exhausted reactive margin. Any further additional stress could have caused separation at Malin. Figure 8 shows the percent voltage deviation at the 500 kV busses. Maximum voltage deviation occurred at Devers substation, which exceeded 25 percent and resulted in a 500 kV line trip. The voltage deviation at Malin substation was about 19 percent and barely managed the system to stay stable.

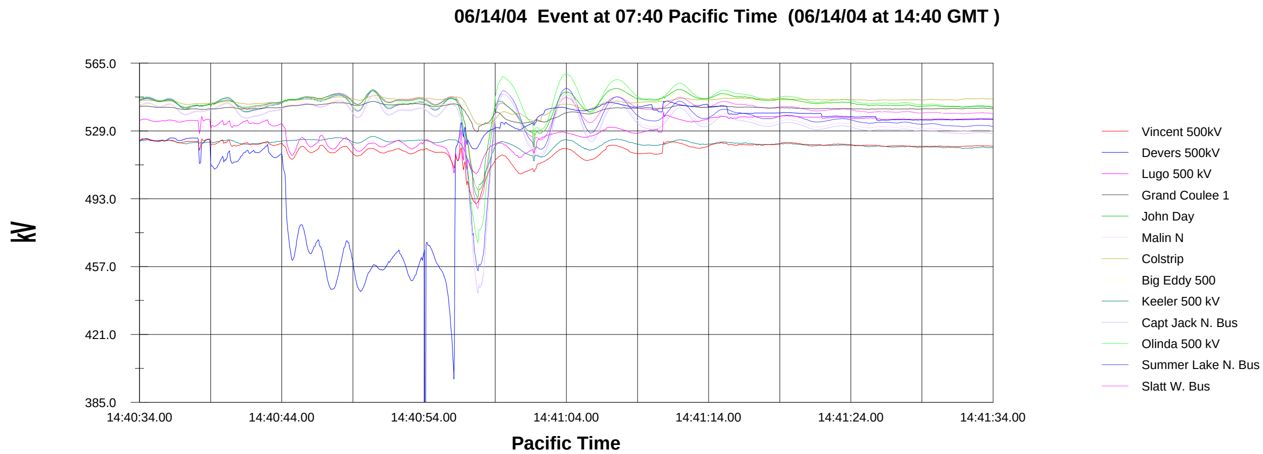


Figure 7: *Plot showing 500 kV buss voltages on the BPA and SCE substations.*

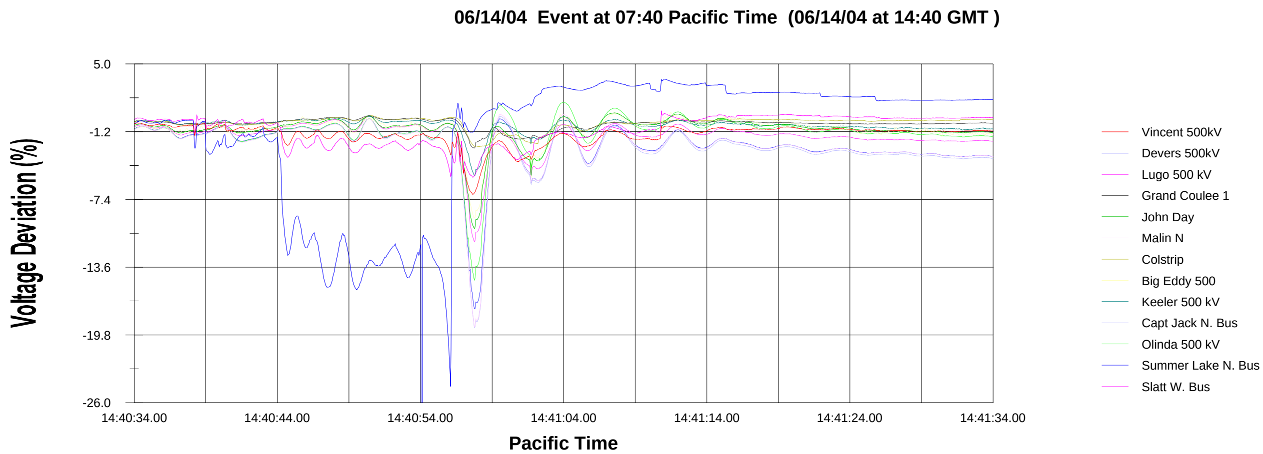
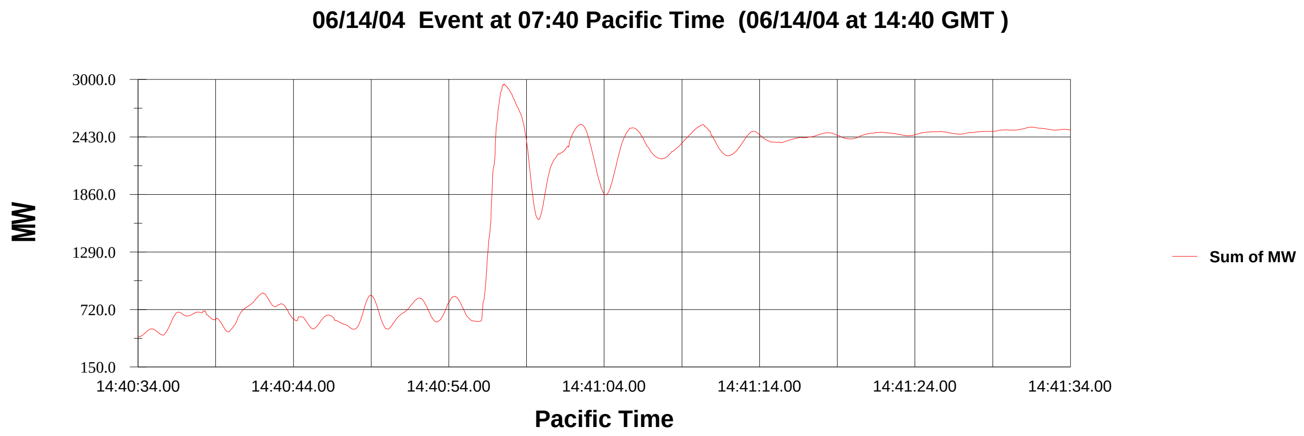


Figure 8: *Plot showing **percent** 500 kV buss voltage deviations on the BPA and SCE substations.*

Figure 9 shows the power interchange at SCE Vincent substation. Initially, before the event SCE was importing about 180 MW which increased to about 2980 MW, a change of about 2800 MW from generation trip. Figures 10 and 11 show the frequency and the df/dt plots respectively for this event.



Sum of MW = VC-Midway1 + VC-Midway2 + VC-Midway3

Figure 9: *Plot showing total power flow on the Midway-Vincent lines.*

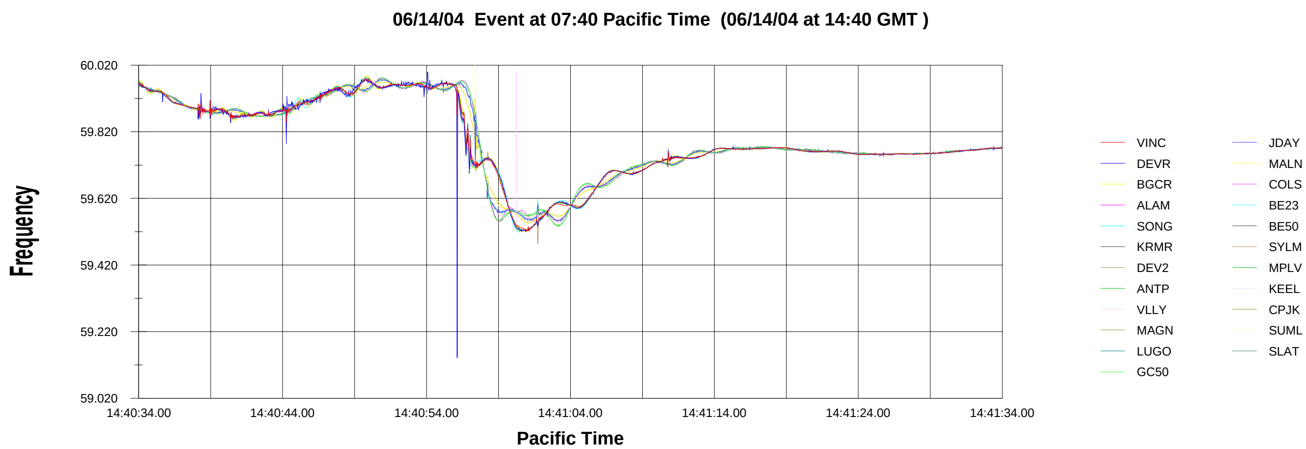


Figure 10: *Frequency plot from different SCE and BPA PMUs for the June 14th, 2004 event.*

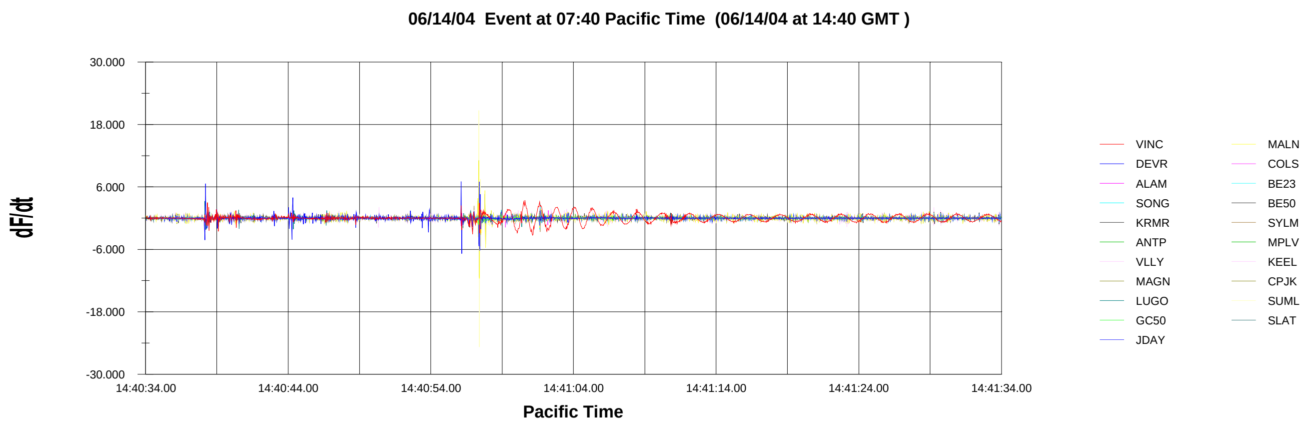


Figure 11: *Rate of change of Frequency (df/dt) plot from different SCE and BPA PMUs for the June 14th, 2004 event.*

Monitoring inter-area system oscillations and dynamic stability:

A system will show high dynamic stability when the static stress is low, but would show poor dynamic stability when the static stress is high. Low or reducing inter area modal oscillation damping could be an early indicator of a weakening system. As the static phase angle or the system loading increases, the system may start showing the signs of instability. This is generally seen in the reduced damping of the system and increasing time durations for the oscillations of the system. The modal oscillations are generally present in the system although are at a very small level. The inter-area power oscillation magnitude can increase as the system is stressed. The oscillation frequencies are dependent on the system inertia and the system transmission strength; however, the damping may be more dependent on the system stress or the phase angle separation and control systems parameters. Monitoring these oscillations and their damping can alert if the system starts weakening or is likely to become dynamically unstable. The loss of a major transmission path or a line can result in increasing the static and dynamic stress and the system should be able to withstand this increased stress as it is or with appropriate remedial measures. At times, the system itself may be stressed to levels that it starts showing very low and reducing damping and increase in inter-area oscillations. The Power System Outlook program with SCE SPM system can monitor the AC system oscillation modes, damping and oscillating power to identify signs of instability and to alert the system operators so that appropriate remedial measures could be taken to avoid the system breakup.

Figure 12 below shows the frequency plot from this SPMS system for the August 4, 2000 system event. The inter-area oscillations occurring between the PMU locations in the north and in the south can be seen clearly on this plot. As can be seen the system continued to oscillate for over 60 seconds and had very low damping. In general the systems should be allowed to have modal damping of less than 5 percent. The busses in the North can be seen to swing in opposition to the busses in the South. The busses in the middle of the swinging busses saw smaller oscillating frequency changes.

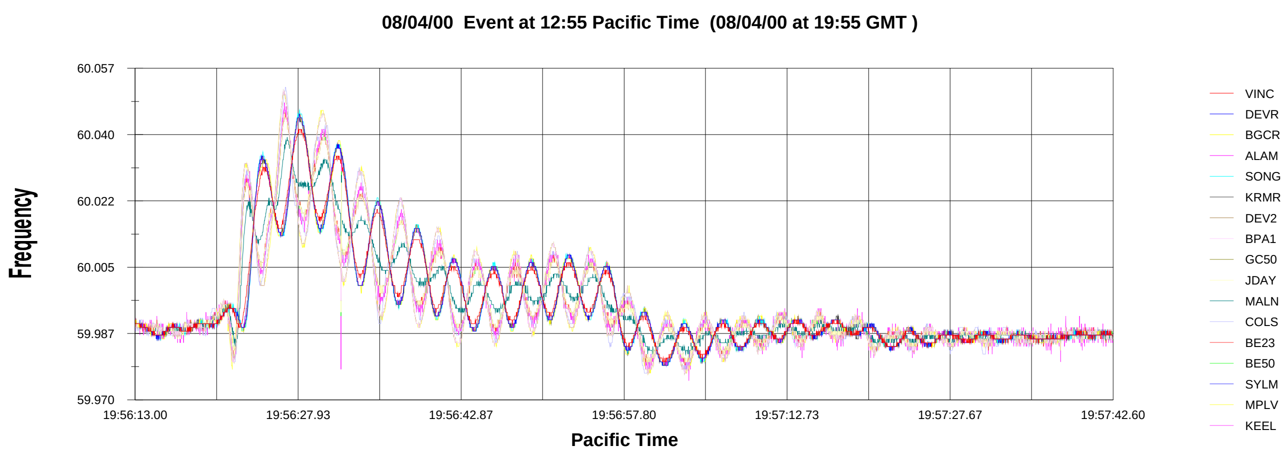


Figure 12: *Frequency plot from all the SCE and BPA PMUs. The plot shows frequencies from the two major masses in opposition, while the substations at the middle of the oscillating masses show small oscillations.*

When the system is already stressed by static stress, even a small additional dynamic stress can create dynamic instability. Figure 13 shows the voltage phase angle plot for August 4, 2000 event from different PMU locations, when the system was operating at a high static stress level. The reference is Colstrip, which leads Grand Coulee by about 22 degrees. The phase angle difference between Grand Coulee and Devers is initially about 90 degrees (static stress) before the event, which increases by about 18 degrees to about 108 degrees. The combined effect of the static and dynamic stress is that the system oscillated for about 60 seconds showing fairly low damping of this mode. Figure 14 shows the power oscillations at the Malin substation, which in the middle of the oscillating busses.

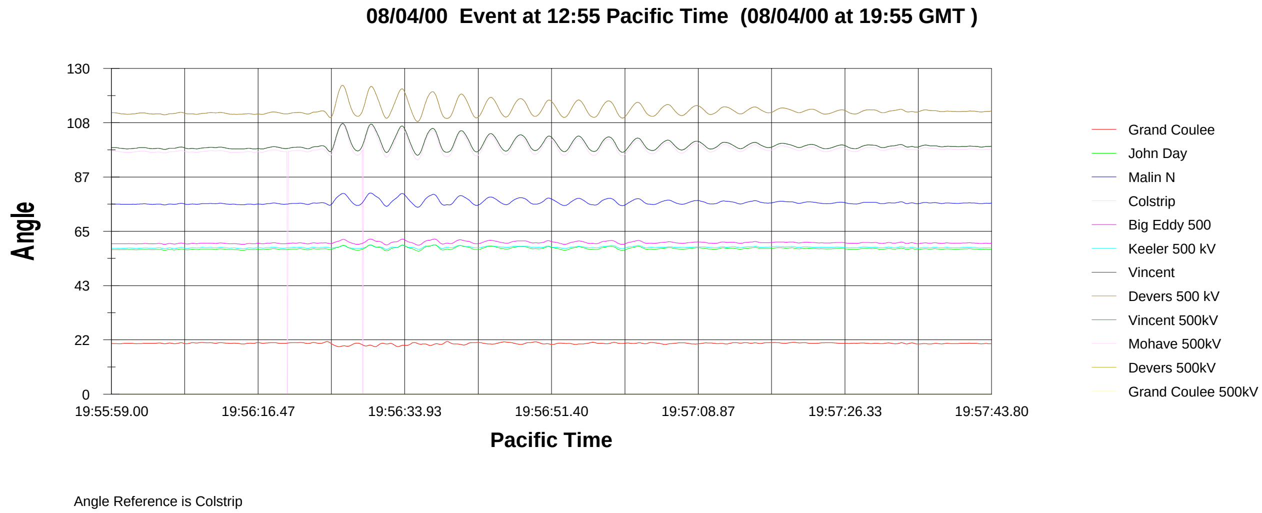


Figure 13: *Voltage phase angle plot for the 500 kV busses. From the BPA and SCE system event merged file. The angle reference is Colstrip and leads Grand Coulee by about 22 degrees. The dynamic stress is 22 degrees (112-90) additive.*

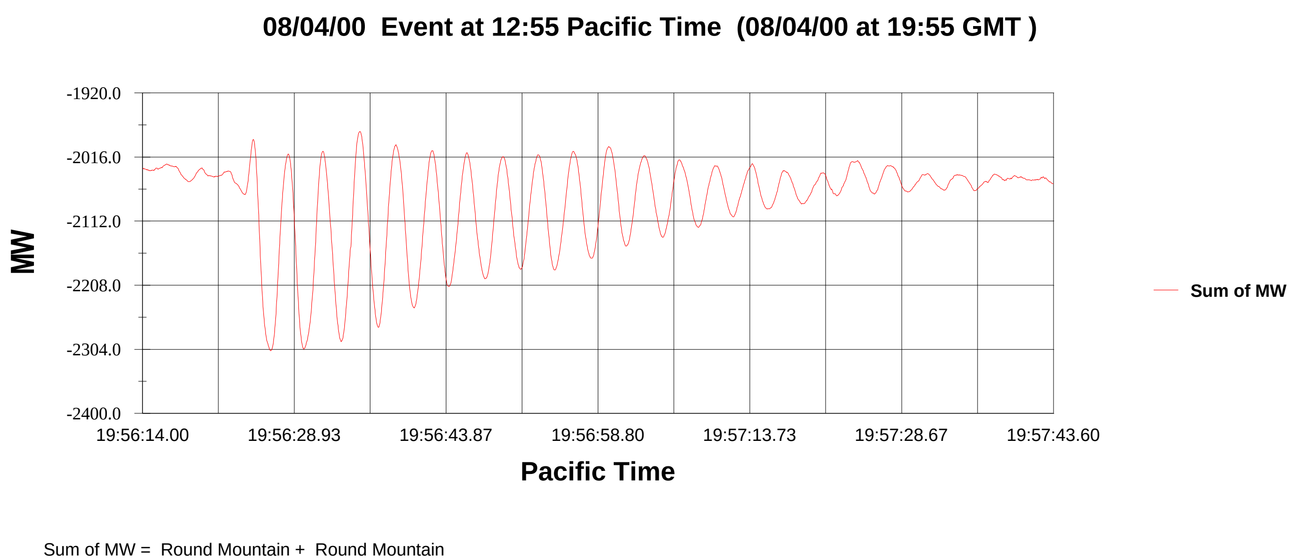
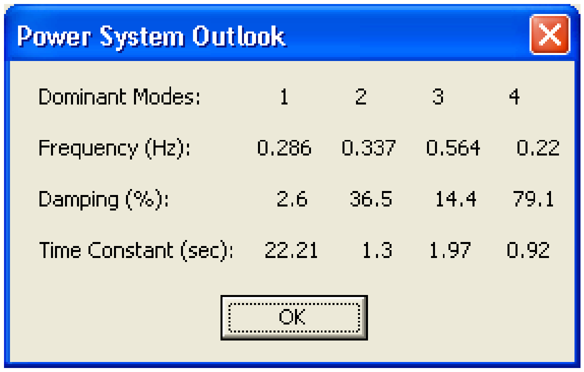


Figure 14: *Power swings recorded at Malin substation for the August 4, 2000 event.*

Measurement of modal oscillation frequencies, modal damping and oscillating power levels on major interaction transmission paths can help in avoiding coming too close to instability regions. The PSO program has the capability to determine these indicators. Figure 15 shows the Table displayed by the PSO program for the above event at Vincent substation. Figure 16 shows the FFT analysis for this event. Notice that the 0.286 Hz mode has risen to about +10 db level indicating lack of dynamic stability.



Dominant Modes:	1	2	3	4
Frequency (Hz):	0.286	0.337	0.564	0.22
Damping (%):	2.6	36.5	14.4	79.1
Time Constant (sec):	22.21	1.3	1.97	0.92

Figure 15*: Table from Power System Outlook program showing modal frequencies, damping and time constants for first four modes from the FFT plot below (August 4, 2000 system event).*

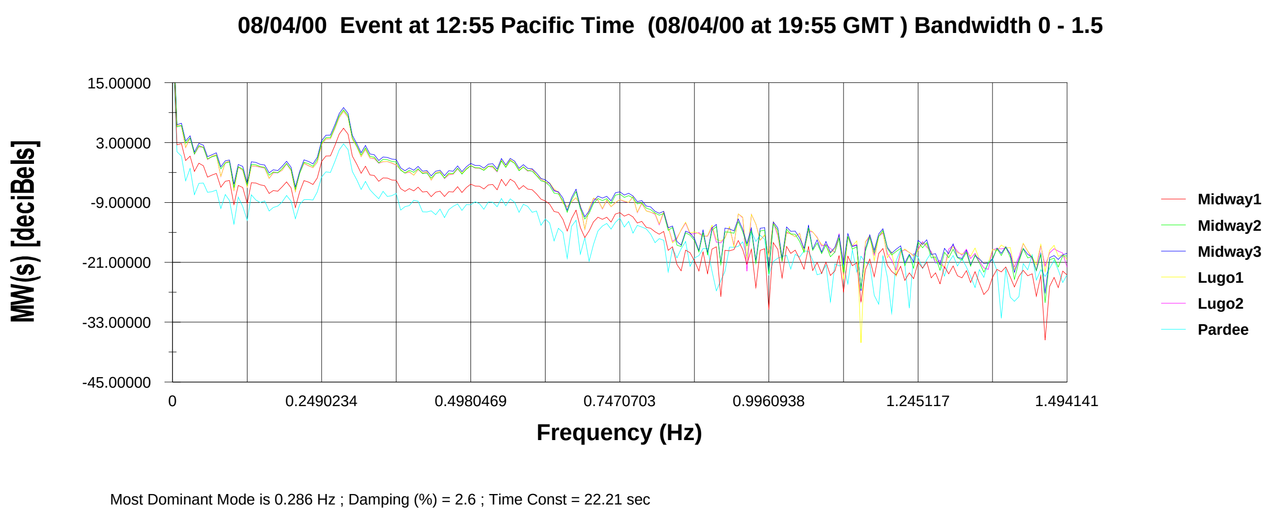


Figure 16*: FFT showing the frequency spectrum at Vincent substation. Notice the 0.286 Hz mode showing high power level of about 10 db*

Figure 17 shows the power oscillations on the SCE Midway-Vincent power path under normal conditions. The oscillations generally are at the low level that is below 0 db and less than about 20 MWs. They start growing and increase if the system is stressed too much or some control system introduces them in the system. Figure 18 shows the Modal frequency Table and figure 19 the FFT chart for this system condition. The modal frequency is about 0.26 Hz and damping at about 8.6 percent. The peak power level is also below 0 db indicating good damping of this North-South mode. The other modes are also very well damped.

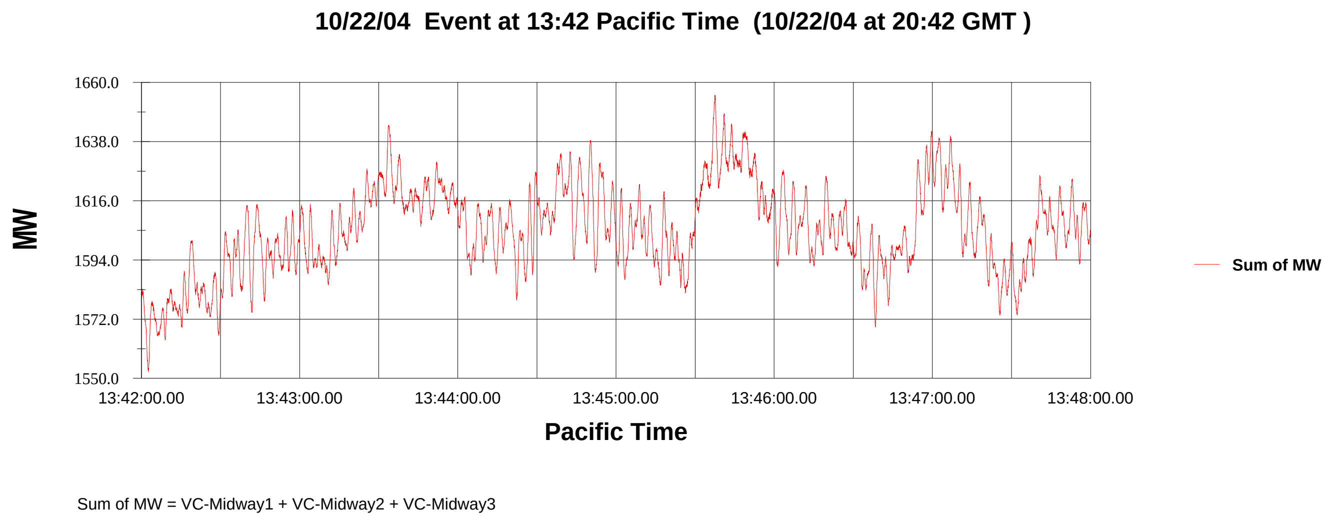
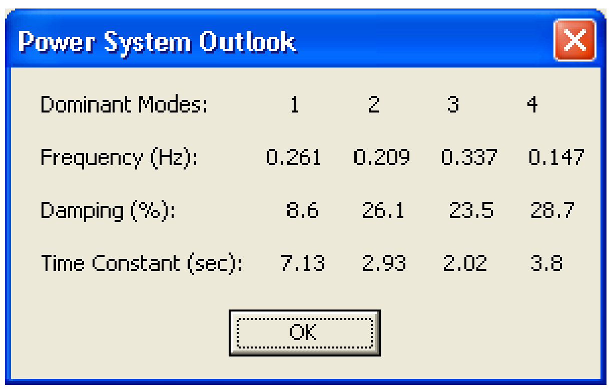


Figure 17: *Total power oscillations on Midway-Vincent path under normal conditions. The peak oscillating power in 0.28 Hz mode is around 20-24 MW.*



Dominant Modes:	1	2	3	4
Frequency (Hz):	0.261	0.209	0.337	0.147
Damping (%):	8.6	26.1	23.5	28.7
Time Constant (sec):	7.13	2.93	2.02	3.8

Figure 18*: Table from Power System Outlook program showing modal frequencies, damping and time constants for first four modes from the FFT plot below (October 22, 2004 at 13:42 PM).*

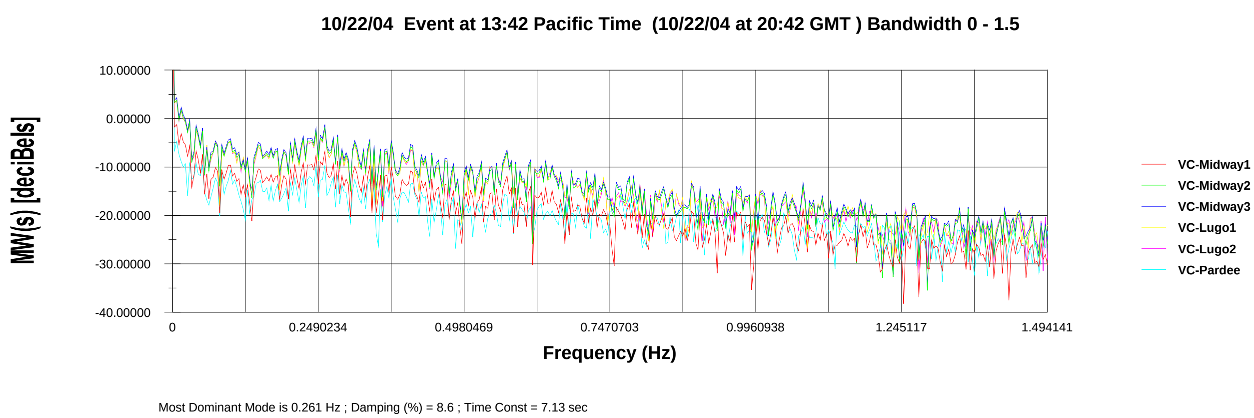


Figure 19*: Fast Fourier Transform (FFT) showing the frequency spectrum at Vincent substation. At* 13:42 PM on October 22, 2004. *Notice the 0.28 Hz mode with 0.26 HZ frequency and about 8.6 percent damping. The modal power is also below 0 db. .*

Monitoring df/dt for identifying generation or load loss:

The PSO program can also display the df/dt at different PMU locations. By monitoring df/dt it is possible to identify the area/location and the severity of the system disturbances such as generation and load drops. The df/dt plot shown in figure 20, shows the df/dt recorded at Grand Coulee from loss of about 2300 MW of generation on July 15, 2002 at about 15:04 PDT. Figure 21 shows the actual frequency plot from the Phasor Measurement system. The fast frequency change at Grand Coulee indicates the generation lost in that area. The df/dt (about 6 Hz/second /second), indicates about one-tenth of the generation loss.

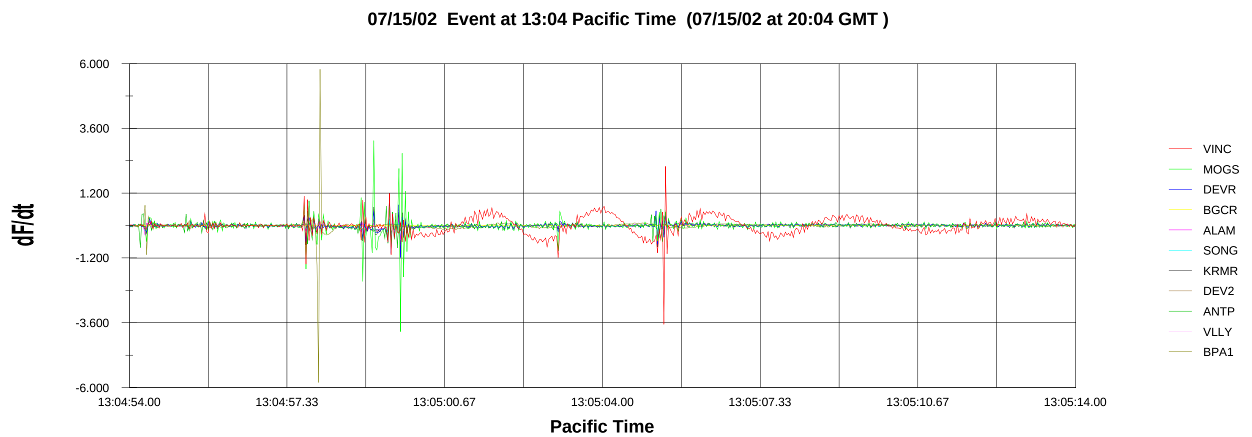


__Figure 20:__ Df/dt for system event when about 2300 MW of generation was dropped in the Pacific Northwest. The df/dt is highest at Grand Coulee, which is PMU location closest to the generation drop

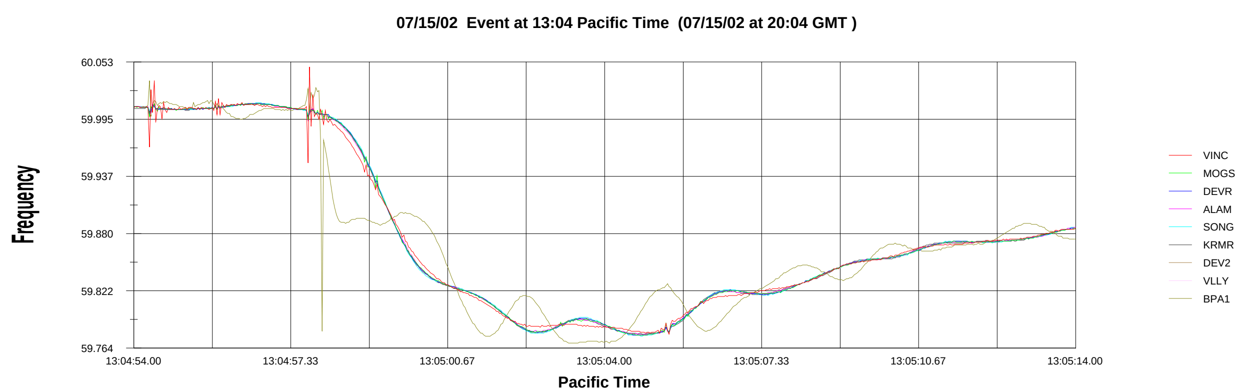


__Figure 21:__ Frequency plot for the July 15, 2002 generation drop event showing fast frequency decline at Grand Coulee.

Monitor and arm Special Protection Scheme (Remedial Action Scheme) operations:

The SPMS system can also be used to monitor performance of the Special Protection Schemes or the Remedial Action Schemes (RAS). Figures 22 to 24 show some plots for this event. The event recorded on March 8, 2005 by the SCE SPMS shows that the RAS scheme in the Pacific North West operated for a fault on a 500 kV lines. These RAS schemes have been designed to reduce loading primarily on the Pacific AC Inter-ties by tripping generation in the North West and slowing Northwest acceleration by application of the 1400 MW brake. However, these actions are needed when the loading on the inter-ties are high and the system is operating at large phase angle. The phasor measurement system can be used to supervise the generation trip and the brake application which could reduce unwanted operations. Figure 22 shows the phase angle plot for an event on March 8, 2005 when the generation was tripped for a 500 kV line fault. The phase angle separation at this time is fairly low and would not have threatened the North-South WECC system stability and the power flow on the inter-ties between Midway-Vincent was low. Even the fault and the outage of the 500 kV line did not result in any significant angle change but the phase angles reduced considerably because of the generation drop. The frequency declined to about 59. 87 Hz because of generation drop as shown in figure 23.

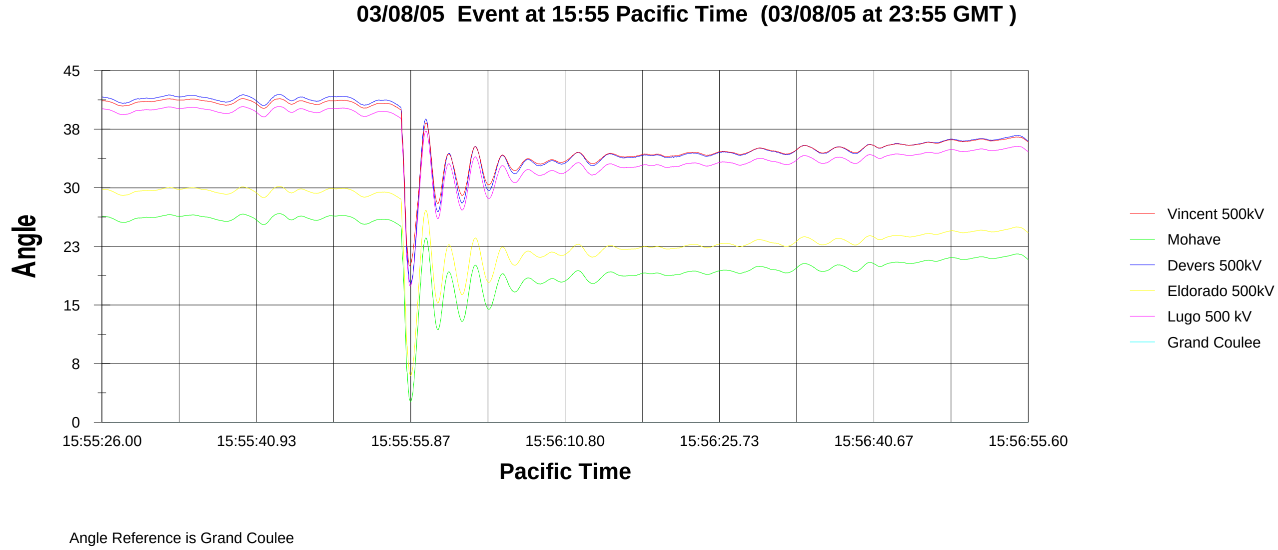


Figure 22: *Voltage phase angle plot for the 500 kV busses for the March 8, 2005 event. The system was operating at a low stress level and the line outage did not cause significant angle change. Generation trip and brake application, however, reduced the angle separation 20 degrees dynamic and 8 degrees static change.*

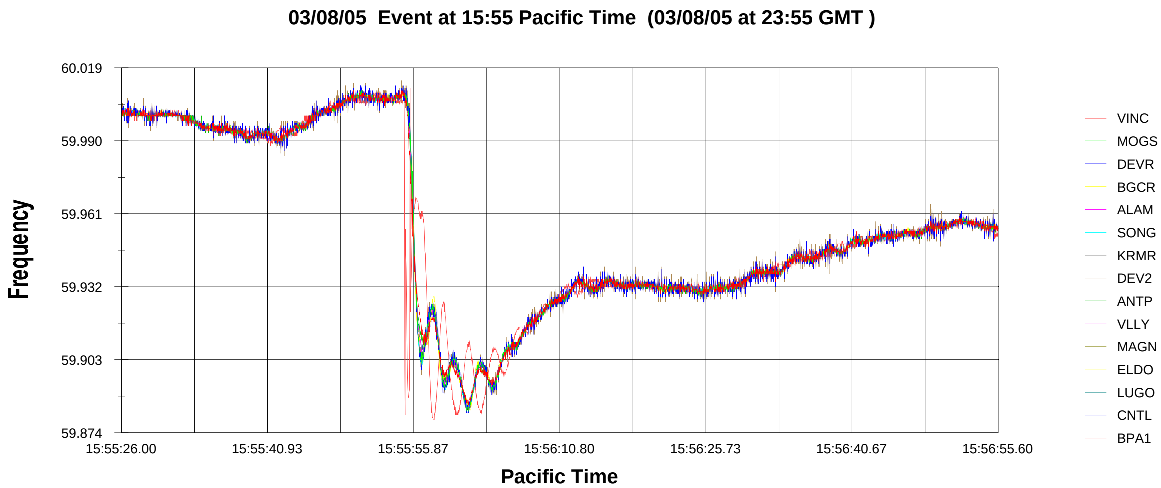


Figure 23: *Frequency plot for the March 8, 2005 generation drop event showing fast frequency decline at all SCE locations and Grand Coulee in BPA.*

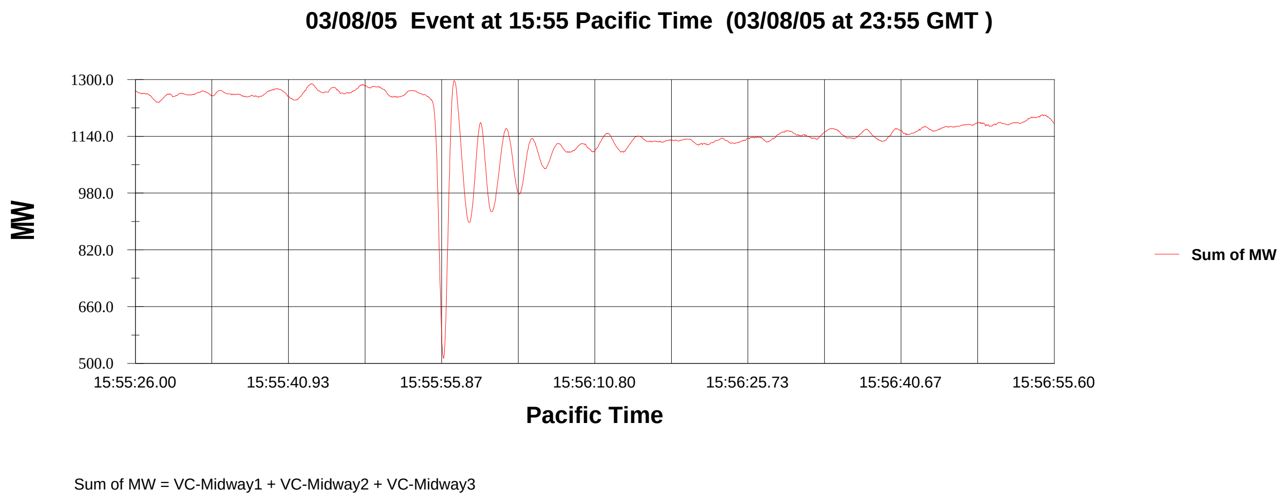


Figure 24: *Total power interchange at SCE Vincent substation. The oscillations on Midway-Vincent path damped rapidly in about 10 seconds indication high damping*

<u>Real-time Monitoring Capability of the Synchronized Phasor Measurement system:</u>

The SCE Synchronized Phasor Measurement system has the capability of obtaining data real-time from the Phasor Data Concentrator in real-time. Presently the screens have been developed to display Phase angle separation, frequency from all the PMUs, power, reactive power on some selected lines. SCE intends to use the system for monitoring some Remedial Action Schemes and arm them only when those systems are stressed. The system is capable of getting the data in less than tenth of a second. Figure 25 and 27 below show the screen shots of the Real-time monitor developed at SCE.

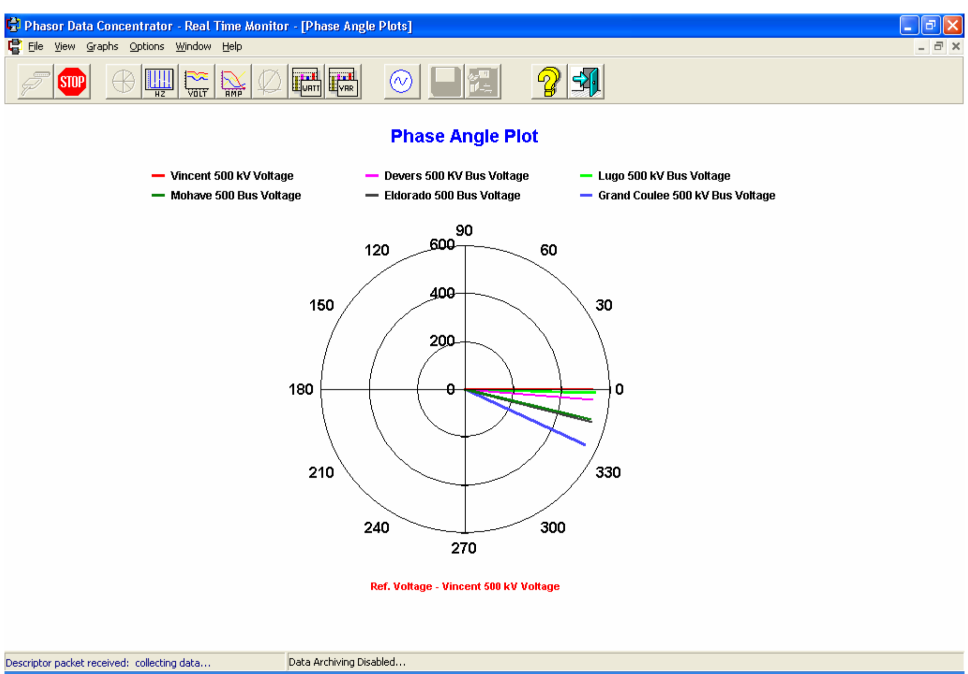


Figure 25: Phasor plot from the real-time phasor display program.

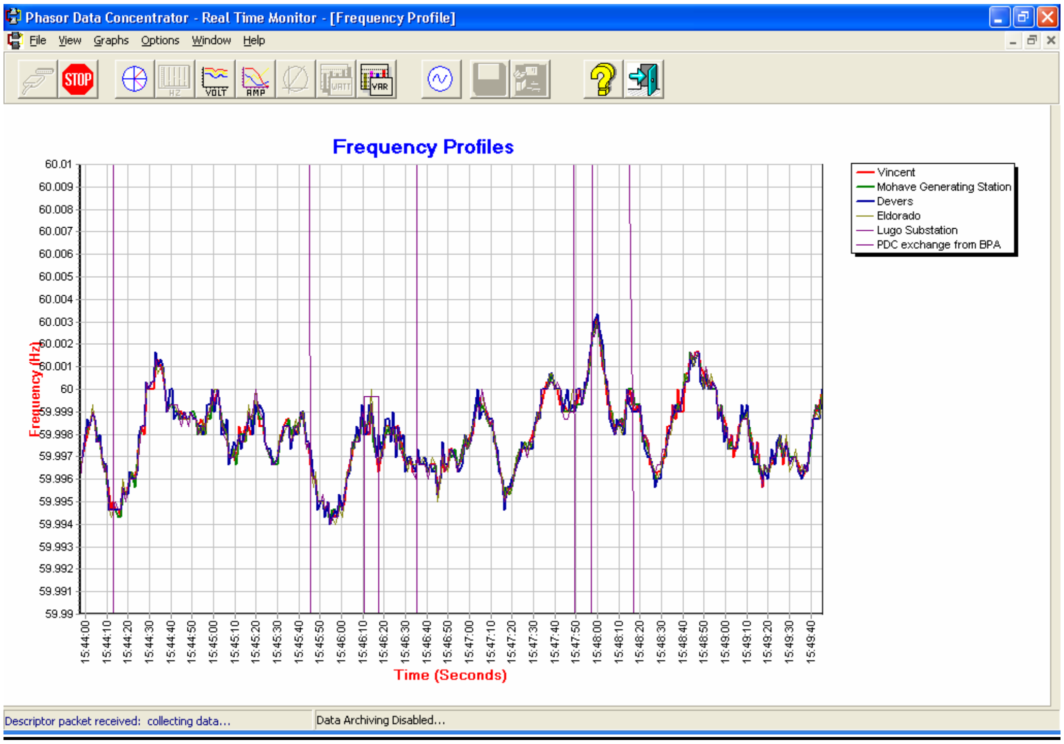


Figure 26: Real-time display of frequencies from the selected Phasor Measurement Units. The signal from BPA PMU which is about 1000 miles away does drop and the communication channel needs to be improved.

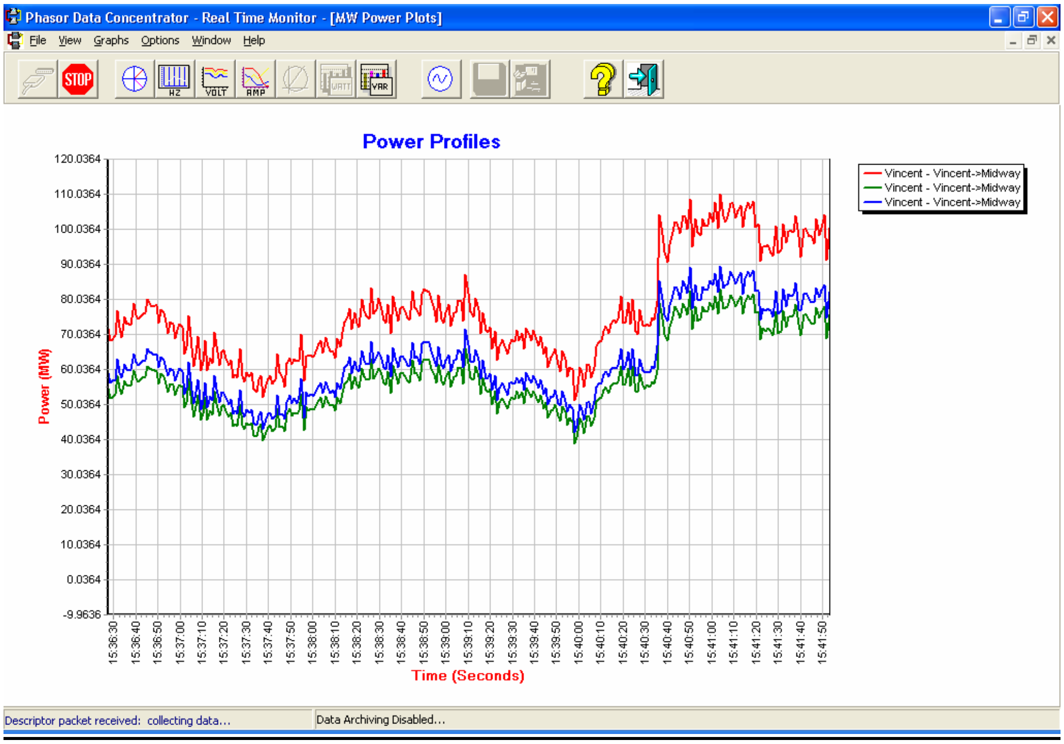


Figure 27: Power flow plot for Midway-Vincent lines the Real-time monitor

Conclusions

The Synchronized Phasor Measurement Technology has very high potential for monitoring and increasing reliability of large power systems. Considerable development and progress has been made at Southern California Edison Co. in using the SPMS technology for monitoring the system stability and system stresses, modes of dynamic oscillations and their damping. This technology can provide many more benefits for monitoring system events, understanding system dynamics, validating models and can help in improving the operating reliability of the electric power systems. The technology can be used for real-time monitoring and control.

SCE is continuing to work with this technology to provide real-time voltage phasor angle and magnitude displays to Grid operators and California ISO so that the system stress, dynamic system oscillations and associated damping can be monitor continuously for improving the system reliability.

Note/Disclaimer

This paper represents the views of its author and does not necessarily represent the views of Southern California Edison Co. or its parent organization Edison International.

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Mr. Bharat Bhargava graduated from Delhi University in 1961 with a Masters from Rensselear Polytechnic Institute in 1976. He worked with the UP State Electricity Board in India from 1961 to 1975. Mr. Bhargava is a Senior Member of PAS, IAS Communication and Vehicular Societies of IEEE and a Member of CIGRE.

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Mr. Rodriguez has over 25 years of electric utility program and project management experience in the development, and commercialization of energy-related technologies for Edison and customer needs. He managed research activities in the advanced energy storage technologies including, super-conducting magnetic energy storage and advanced battery storage systems. He managed the installation and operation of the largest battery system at SCE Chino substation.

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Before joining Edison, Armando was an Energy Consultant in South America. For 6 years he worked for the Latin American Energy Organization (OLADE). He also worked for the Bogotá Power Company. Armando graduated in Electrical Engineering with major in Power Systems from the National University of Colombia.