CERTS

CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Real-Time Voltage Monitoring and VAR Management System©

CALIFORNIA ENERGY COMMISSION

CONSULTANT REPORT

OCTOBER 2003
P500-03-087F

Gray Davis, *Governor*

CALIFORNIA ENERGY COMMISSION

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Acknowledgments

The technical leadership for the development of the CERTS Var Management Real-Time Monitoring System was provided by Carlos Martinez, Electric Power Group.

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The developers acknowledge the support of California Independent System Operator Operations, Reliability Coordinators, and Information Technology.

Departments, including; David Hawkins and Lisa Szot; Philip Overholt, US Department of Energy; Don Kondoleon, California Energy Commission; and Joe Eto, CERTS Program Office.

This work was funded by the Assistant Secretary for Energy Efficiency and Renewable Energy of the US Department of Energy, Distributed Energy and Electricity Reliability Program, Transmission Reliability under Contract No. DE-AC03-76SF00098 and by the California Energy Commission, Public Interest Energy Research Program, under Work for Others Contract No. BG 99-396 (00).

Abstract

The Consortium for Electric Reliability Technology Solutions (CERTS) has been working with NERC, Regional Transmission Organizations, Independent System Operators, and other electric industry organizations to research, develop, and disseminate new methods, tools and technologies to protect and enhance the reliability of the U.S. electric power system under the emerging competitive electricity market structures. This Summary Report provides a description of the Real-Time Voltage Monitoring and VAR Management System tool being developed to provide the capability to monitor grid and market performance in real-time and manage grid reliability.

Preface

The U.S. Electricity Grid Today The U.S. electric power system is in the midst of a fundamental transition from a centrally planned and utility-controlled structure to one that will depend on competitive market forces for investment, operations, and reliability management. Electricity system operators are being challenged to maintain the reliability of the grid and support economic transfers of power as the industry's structure changes and market rules evolve. Meanwhile, U.S. economy depends more than ever on reliable and high quality electricity supplies. New technologies are needed to prevent major outages such as those experienced on the Western grid on August 10, 1996, which left 12 million people without electricity for up to eight hours and cost an estimated $2 billion.

The Consortium for Electric Reliability Technology Solutions (CERTS) was formed in 1999 to research, develop, and disseminate new methods, tools, and technologies to protect and enhance the reliability of the U.S. electric power system and functioning of a competitive electricity market. CERTS is currently conducting research for the U.S. Department of Energy (DOE) Transmission Reliability Program and for the California Energy Commission (CEC) Public Interest Energy Research (PIER) Program. The members of CERTS include the Electric Power Group, Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, the National Science Foundation's Power Systems Engineering Research Center, and Sandia National Laboratories.

SUMMARY REPORT – WORK IN PROGRESS

REAL-TIME VOLTAGE MONITORING AND VAR MANAGEMENT SYSTEM©

February 28, 2003

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FOREWORD

The Consortium for Electric Reliability Technology Solutions (CERTS) has been working on research and development of tools and technologies for management of grid reliability. The Supplier and Control Area Performance Monitoring System© was developed by the Electric Power Group (EPG). The development team was led by Carlos Martinez of the Electric Power Group. The Supplier and Control Area Performance Monitoring System is one of the applications developed by EPG as part of a suite of applications using the Grid Real-Time **P**erformance Monitoring and **P**rediction **P**latform (Grid-3P©) to provide the capability to monitor grid reliability and market performance in real time. The Grid-3P can be used by Regional transmission Organizations (RTO's), Independent System Operators (ISO's), NERC Reliability Authorities, transmission companies, control areas, and utilities to monitor voltage, to provide VAR control, and for other applications to monitor grid reliability.

The VAR management application was developed for use by the California Independent System Operator (CAISO). The Real-Time Voltage Monitoring and VAR Management System, using CERTS' Grid-3P, is intended for the Western Electricity Coordinating Council (WECC) Reliability Coordinator, located at the California Independent System Operator (CAISO). One of the primary functions of the Reliability Coordinator is the monitoring of real time transmission operations on a wide area basis. This application will serve as an effective tool to support this critical monitoring function. The purpose of the application is to provide the Reliability Coordinator with the necessary information to effectively monitor all aspects of the system voltage control and reactive reserves management, such as actual voltage alarming and monitoring, sensitivities, distance-before-voltage-collapse and reactive reserve adequacy.

This CERTS project was funded by the Department of Energy, Office of Power Technologies, Transmission Research Program, Phil Overholt, Program Manager, and the California Energy Commission's Public Interest Energy Research (PIER) program. CERTS research program is managed by Lawrence Berkeley National Lab, Joe Eto, Program Manager.

This application was developed in two (2) phases. The first phase was a proof-of-concept utilizing the data and transmission model for the San Diego area. This work was completed in 2002, beta tested by the CAISO staff and EPG provided the necessary users guide and training. Phase two of the project is the expansion of the application to include the entire CAISO transmission system. EPG is in the final stages of development and deployment is expected in the second quarter of 2003. At the completion of the project, EPG will have provided the Reliability Coordinator with a User's Guide, a Training Manual and associated documentation to describe the application. For more information contact Joseph Eto at LBNL or Carlos Martinez at EPG. This report is prepared as part of Ernest Orlando Lawrence Berkeley National

Laboratory Subcontracts 6496360 and 6508899 under Contract DE-AC03-76SF00098 with the U.S. Department of Energy.

This Summary Report provides a description of the Real-Time Voltage Monitoring and VAR Management System tool as part of the suite of applications being developed for the Grid-3P platform and other applications to provide the capability to monitor grid and market performance in real-time and manage grid reliability. This suite of tools include:

1. Area Control Error (ACE)-Frequency Real-Time Monitoring System
2. Area Interchange Error (AIE) Monitoring System
3. Supplier and Control Area Performance System
4. Phasor Monitoring Applications for Dispatchers and Operating Engineers
5. Grid Real-Time Performance Monitoring and Prediction Platform (Grid-3P)

INTRODUCTION

The Consortium for Electric Reliability Technology Solutions (CERTS) has been working with NERC, Regional Transmission Organizations, Independent System Operators, and other electric industry organizations to research, develop, and disseminate new methods, tools and technologies to protect and enhance the reliability of the U.S. electric power system under the emerging competitive electricity market structures. The monitoring system also offers a base from which grid security can be improved to help protect the market from “gaming” and other forms of market manipulations.

In particular, CERTS has developed the Grid Real-Time Performance Monitoring and Prediction Platform (Grid-3P) to manage grid reliability and monitor market performance in real time. Grid 3P complements and integrates with existing SCADA systems and utilizes real time data engines and graphic-geographic visualization tools to develop reliability applications to assist operating authorities, e.g., Independent System Operators (ISO's), Regional Transmission Organizations (RTO’s), Reliability Coordinators and Control Area Dispatchers in their management of grid reliability.

The Real-Time Voltage Monitoring and VAR Management System, using CERTS’ Grid-3P, is intended for the Western Electricity Coordinating Council (WECC) Reliability Coordinator, located at the California Independent System Operator (CAISO). One of the primary functions of the Reliability Coordinator is the monitoring of real time transmission operations on a wide area basis. This application will serve as an effective tool to support this critical monitoring function. The purpose of the application is to provide the Reliability Coordinator with the necessary information to effectively monitor all aspects of the system voltage control and reactive reserves management, such as actual voltage alarming and monitoring, sensitivities, distance-before-voltage-collapse and reactive reserve adequacy.

VAR MANAGEMENT SYSTEM OVERVIEW

Development of the Grid Performance Monitoring and Prediction Platform (Grid-3P) for Voltage/VAR System Use

The vertically integrated business model historically used by utilities has evolved to a segmented market with functions dispersed among different entities. Figure 1 shows the business functions segmented into generation, transmission, distribution, markets and security. The Grid Real-Time Performance Monitoring and Prediction Platform (Grid-3P) has been developed by CERTS to serve as a common platform for the development of reliability applications for real-time monitoring and prediction for the reliability performance of control areas, generation, grid, markets and security. Control area's ACE, interconnection's frequency and interchange data using the Grid-3P provides a common tool to be utilized by NERC Reliability Coordinators, Control Area Dispatchers, and Transmission Dispatchers. Control Area Dispatchers, and Transmission Dispatchers. The bottom of Figure 1 also shows that reliability applications developed using Grid-3P serve as complement to traditional SCADA/EMS systems and for the periodic reporting requested by NERC for performance assessment in real time and post disturbances.

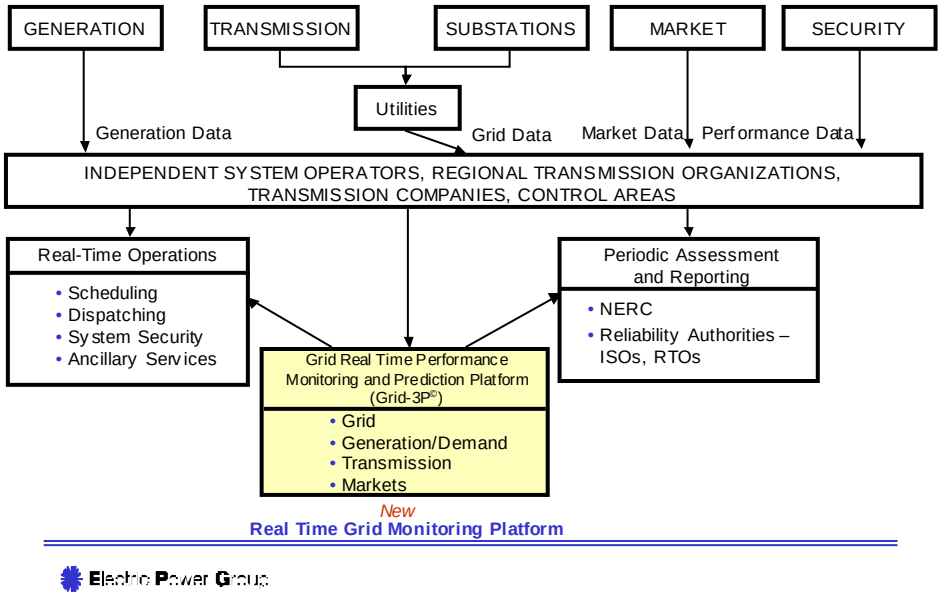
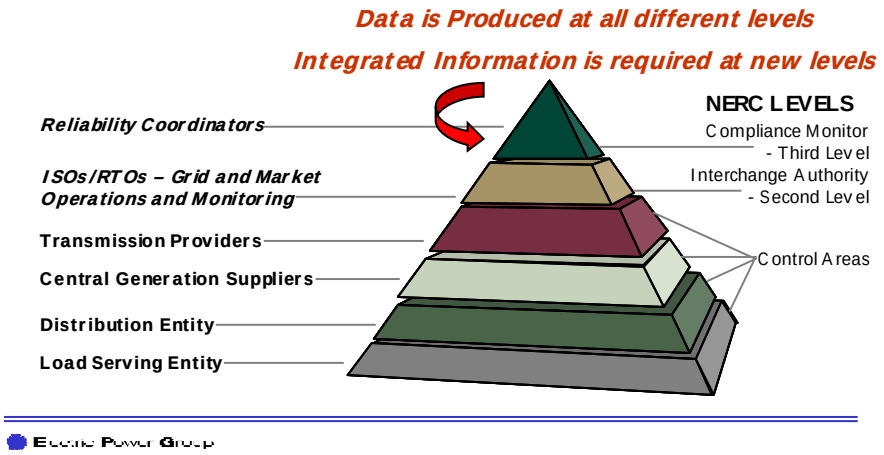


Figure 1: Segmented Market Functions

The Grid-3P visualization model encompasses displays developed in a hierarchical structure to meet the needs of different reliability application users. Thus, monitoring applications are developed for wide-area and local area users. The hierarchal structure in Figure 2 shows that Reliability Coordinators need to have a wide-area view of their

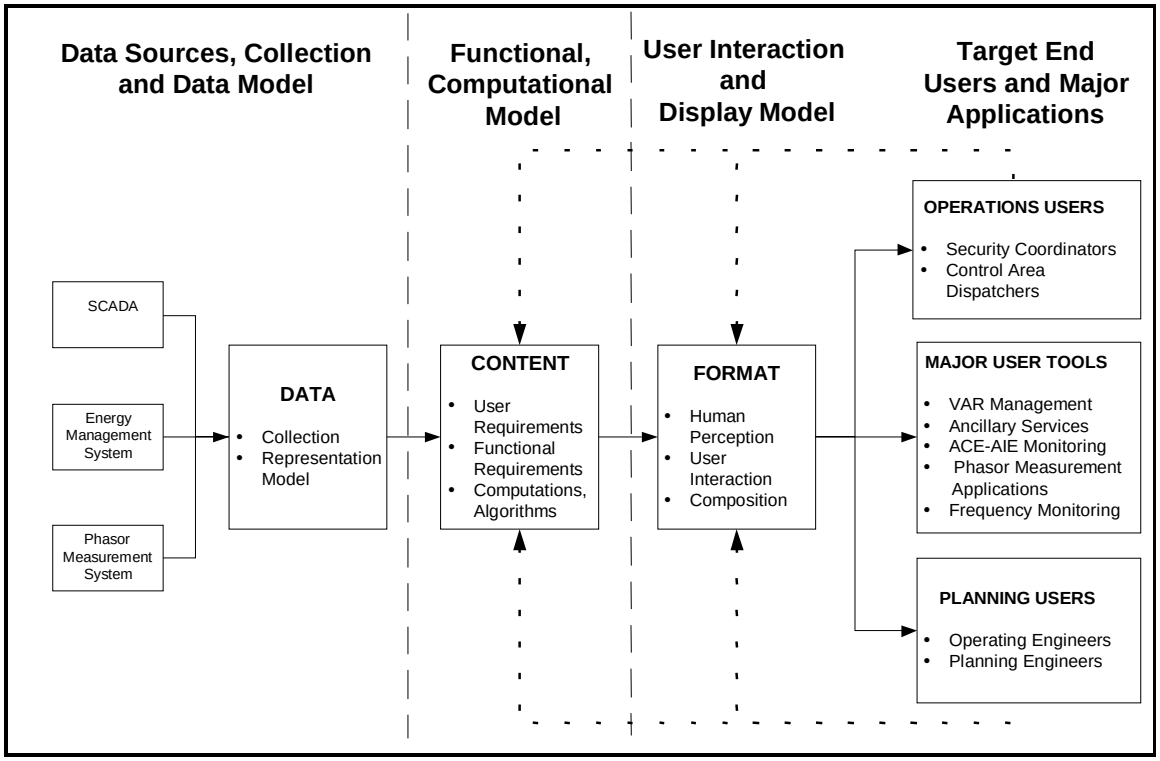
jurisdictions for reliability compliance monitoring. ISO's and RTO's need the ability to assess performance and trends of their control areas. In turn, Control Areas need local area information to pinpoint specific supplier's reliability performance issues. The Real Time Voltage Monitoring and VAR Management System enables the CAISO Reliability Coordinator to monitor voltage and to initiate actions for appropriate VAR corrections in real-time. The impact of the action can be viewed using the wide area visualization graphics prior to implementation to allow optimization of the proposed voltage correction. Other application tools built upon the Grid-3P platform allows utilization of the full hierarchy as shown in Figure 2.

Figure 2: Reliability Functional Levels and Visualization Hierarchy



Real time data required for the Voltage/VAR management system is compiled by the Reliability Coordinator located at the CAISO location. This data is then processed and the performance parameters are calculated in the Grid 3-P computational engines (computational model); the design and deployment of each the displays follow the three steps shown in the display model section of Figure 3, i.e. Data Sources, Collection and Data Model; Functional, Computational Model; and User Interaction and Display Model. The Grid 3-P platform allows the End User multi-functional applications to enhance grid reliability.

Figure 3: CERTS Grid-3P Integrated Visualization Model



VAR Management and Functionality

ISOs/RTOs do not have direct operational control of the elements of the interconnected grid as utilities did in the past under a vertically integrated structure. In addition, there are many new players interacting with the network, each with different levels of understanding and operating experience. This situation demands new tools to identify adequacy and performance of suppliers (generation), transmission, and distribution. The Voltage Monitoring and VAR Management System application was developed for use by CAISO Reliability Coordinator. The purpose of the application is to provide the Reliability Coordinator with an integrated view of wide-area and local-area monitoring for voltages and reactive resources, voltage sensitivities, the distance-before-voltage-collapse, reactive reserve adequacy, and the capability for monitoring compliance with WECC guides for voltages and reactive reserves. Figure 4 is an overview of the VAR application's major functionality and corresponding user visualization.

The 3-D graphics are particularly effective in presenting large amounts of data in graphical form to allow rapid interpretation of the grid condition. These 3-D views can be utilized to allow the grid operator the best possible overall view for interpreting information from many nodes. In addition, tabular presentation of data allow for "drill down" of trouble spots to further assess remedial actions that may need to be taken.

Figure 4: VAR Management Functionality and Visualization Overview

Functionality / Target Areas	Monitoring and Alarming	Voltage Sensitivities	Distances From Voltage Collapse	Corrective Action and WECC Compliance
WIDE-AREA	2D and 3D Animated Geographic Displays	Multiple, Interactive 2D and 3D Geographic Displays	Multiple, Interactive 2D and 3D Geographic Displays	Multiple, Interactive 2D and 3D Geographic Displays
LOCAL-AREA		Interactive One-line Diagrams	Interactive One-line and Graphic Diagrams	Interactive One-line Diagrams and Tabulars

VAR MANAGEMENT UTILIZATION OVERVIEW AND ILLUSTRATIVE EXAMPLES

Wide Area Geographic Visualizations

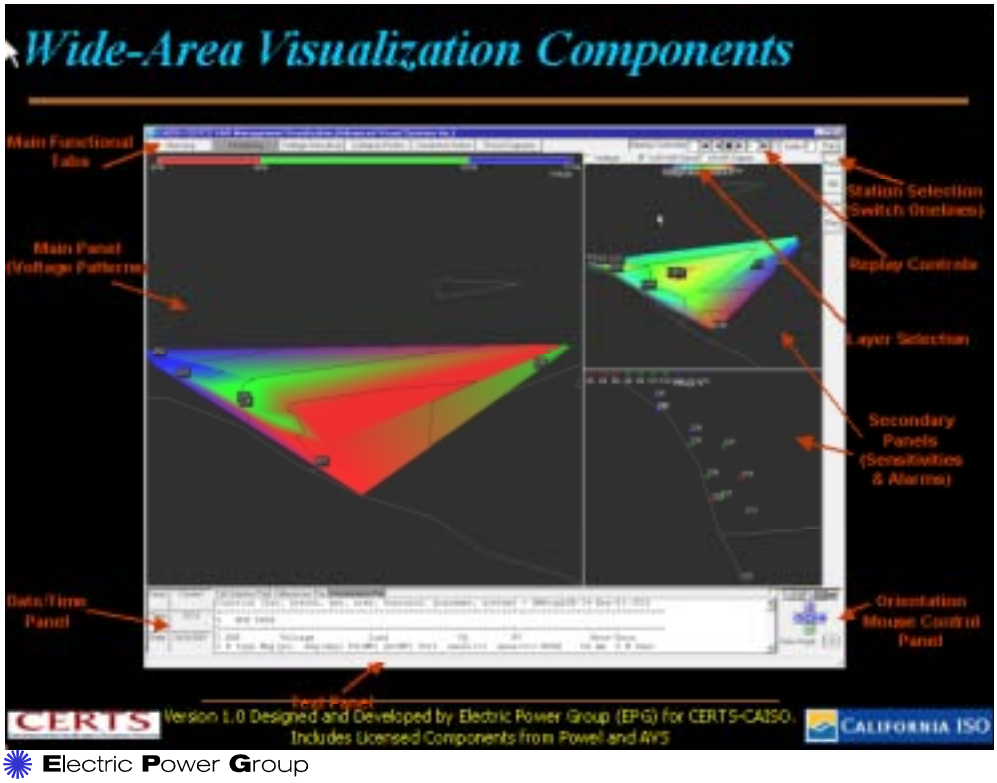
To respond to operations of larger and more complicated control areas, a fundamental goal for the design and development of the VAR Management application tool was to create both visualization displays and key reliability indicators that enhance the Reliability Coordinators' overall system monitoring capability.

An effective use of the applications capabilities is to follow a four-step approach: 1) use the wide-area displays to monitor voltages and reactive reserves, 2) upon seeing indications of trouble, zoom or drill down into the local-area displays for further and more detailed trouble assessment, 3) explore, analyze, and test corrective actions, and 4) return to the wide-area visuals to assess the impact and effectiveness of actions.

To support the basic four-step utilization process described above, the VAR Management application uses three methods (see figures 5, 6 and 7 below) to display information. The first method consists of Wide Area Visualization using geographic and 3D displays, the second uses the traditional one-line diagram to display local conditions and the third method plots the information on a graph that is commonly referred to as a "nose curve".

The Wide Area Monitoring module of the VAR Management application displays real time and calculated data in a non-traditional format. Noted in Figure 5 are the callouts of major components of the visual graphics, in particular, the major viewing panels are identified; the main panel shows voltage patterns in three dimensions and also color coded with the "depth" of color indicating magnitude. The two secondary viewing panels to the right of the main panel show sensitivities (top right) and alarms (bottom right). The particular case shown in Figure 5 is the San Diego area 230 kV system with alarming voltage patterns and sensitivities using geographic 3D and 2D visuals. Another major feature of this graphic is the ability to replay past events. The VAR Management System has the ability to store up to 24 real time cases, six cases per hour for a total of four hours of history. The user has full command of the visuals, whether stored or in real time, as the graphics can be utilized to show information from different viewing angles, including aerial views and the visual can be rotated for best viewing position.

Figure 5: Wide-Area Visualization – Voltage Patterns, Alarms, and Sensitivities



Wide-Area Alarming and Monitoring (Figures 6 and 7)

The software application sets specific limits for voltage alarms; the scale ranges from 85% to 115% of nominal voltage. Specific stations of measurement are located visually on the screen in an accurate geographic manner and are denoted by a circle as shown in Figure 6 below. A red circle represents a station with a voltage below nominal and the circle increases in size as the variance grows; the red circle will flash if voltage falls below 95%. A green circle represents a station with a voltage operating within normal range. A blue circle represents a station operating above the normal range and the circle decreases in size as the voltage increases.

Figure 7 below is a 3D colored layer to give a quick visual indication of grid performance. The same color scheme as in the alarm graphic is used and the severity of the variance can be noted by the profile of the 3-D visual.

Figure 6: Wide-Area Alarming Display

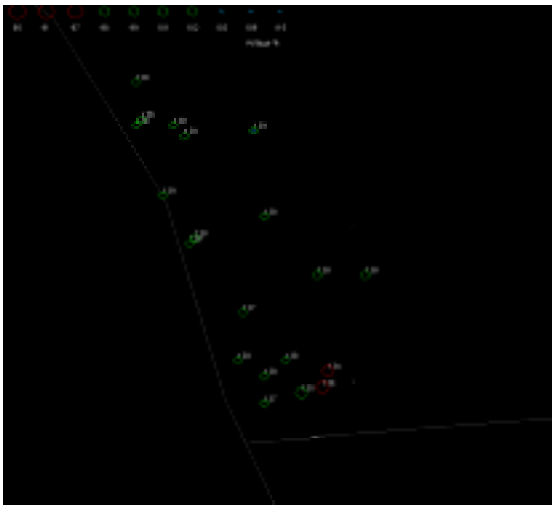
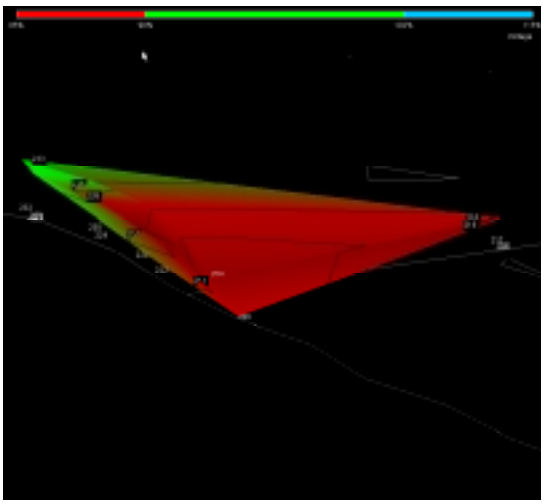


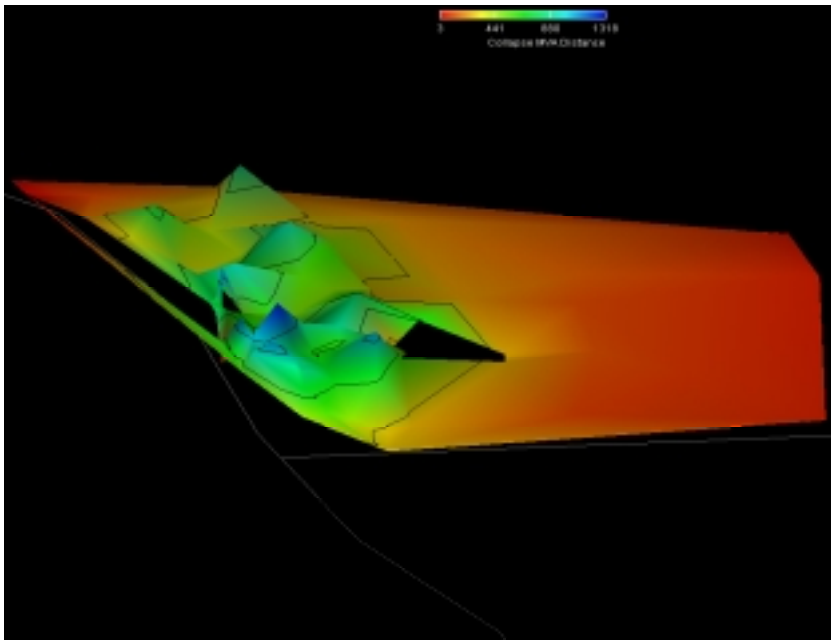
Figure 7: Wide-Area Monitoring Display



Distance From Voltage Collapse

The distance from voltage collapse can be expressed in either MW's or MVAR's; however, the most accurate method to represent voltage collapse is MVA since it takes into consideration both MW and MVAR. Referring to Figure 8 "Distance from Voltage Collapse" the 3-D graphic, using a colored layer, gives the user a visual indication of potential voltage collapse areas. At times, the user may observe black holes in the display, which represent a portion of the calculation that could not be solved. The scale for this graphic can be seen at top center and indicates the MVA distance from voltage collapse. The color convention used is as follows: "red" for least relative amount of MVA to cause collapse; "green" for a greater relative amount of MVA to cause collapse; and, "blue" for largest relative amount of MVA to cause collapse.

Figure 8: Distance From Voltage Collapse



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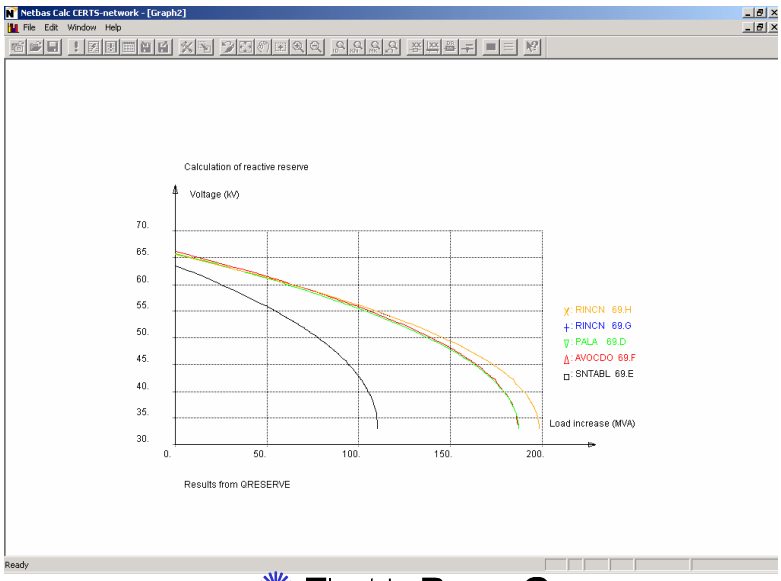
Another method to more accurately depict the “distance from voltage collapse” is the utilization of “nose curves”. The nose curve analyzes critical buses with respect to distance from voltage collapse; the application calculates and depicts the four most critical buses and also shows the least critical bus for comparison. As shown in Figure 9 “Voltage Collapse Curve (Nose Curve)”, reactive reserve is calculated as a function of voltage and load increase (MVA).

Figure 9: Voltage Collapse Curve



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Correction Action

Figure 10: Corrective Action To Return To Nominal Voltage

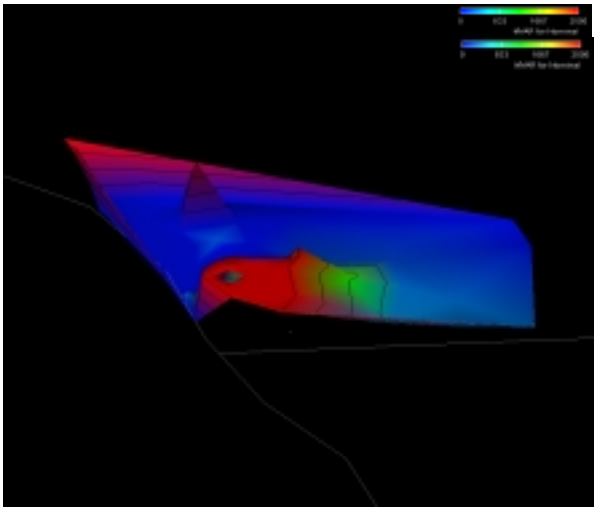
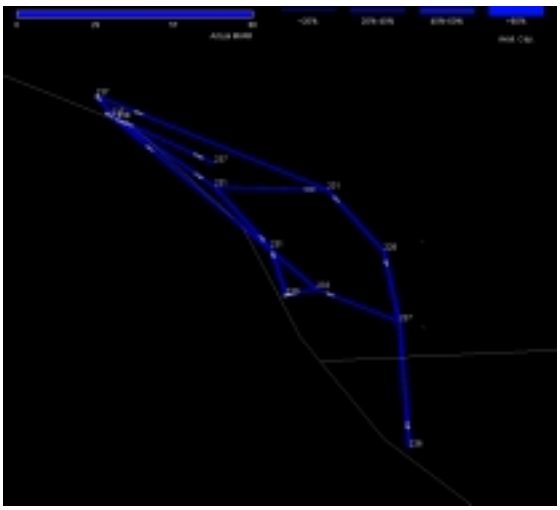


Figure 10 "Corrective Action To Return To Nominal Voltage" uses a 3-D colored layer that gives the user a visual indication of the amount of reactive resources required to return an area to its nominal voltage level. The reactive requirement for each station is calculated independent of the voltage level at the remaining stations and each station is assigned the appropriate color scheme; "red" indicates a larger relative MVAR requirement to restore nominal voltage; "green" indicates a medium relative MVAR requirement to the area to nominal voltage; and, "blue" indicates a low relative MVAR requirement. The 3-D layer is an aggregate of the colors for all stations associated with the voltage selection the user has made. The scale for this display is located at top right and indicates the MVAR requirement to bring voltage to nominal value.

Line Flows

Figure 11: Reactive Line Flows – Magnitude and Direction



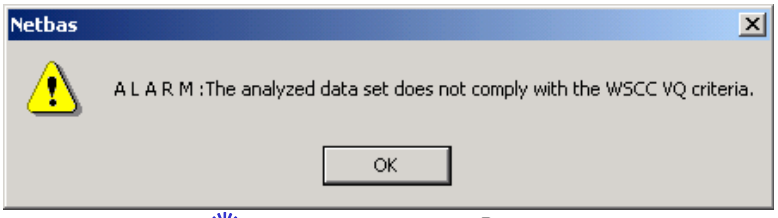
Referring to Figure 11 "Reactive Line Flows – Magnitude and Direction," there are two scales associated with this display and they are both located at the top of the screen. The first scale "Available Capacity" is used to indicate the remaining MW of transmission capacity available on a line. The "thicker" the line, the more capacity. The second scale "Actual MVAR" uses two colors to indicate the level of MVARS flowing in the line; "green" indicates that MVAR is above user defined limits; and "blue" indicates a low level of MVAR on a line.

WECC Reactive Reserve Margin Guideline

The WECC has established operating criteria to determine whether the transmission system is in a state close to voltage instability or not. The WECC uses two guidelines: VQ (voltage reactive) and PV (voltage-MW) to evaluate the system for voltage

instability. The VAR Management System will, upon demand, analyze the system to determine the 20 worst busses under “n-0” and “n-1” conditions; if a variance to the WECC guidelines is found, then the system displays a message alarm.

Figure 12: WECC Alarm Display



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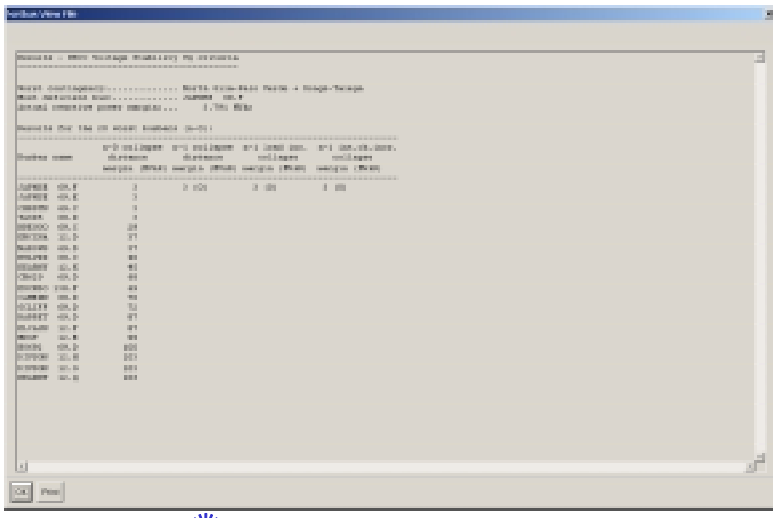
After clicking the OK button, the results of the analysis are then displayed as shown below. If there are no variances to the WECC guidelines, then the 20 worst busses are displayed directly.

Figure 13: Display of 20 Worst System Busses



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SUMMARY AND CONCLUSION

The Real-Time Voltage Monitoring and VAR Management System provides the grid operator with tools to help manage grid reliability. This and other real time application tools are needed to protect and enhance the U.S. electric grid under the emerging competitive market structures. The Voltage/VAR Management System provides the Reliability Coordinator with the necessary information, much of which is presented in easy to understand geographic visualizations, to effectively monitor the voltage characteristics of the system. This information allows the operator to manage voltage control and reactive reserve through active voltage alarming and monitoring, sensitivities, distance before voltage collapse readings and reactive reserve adequacy.

This Real-Time Voltage Monitoring and VAR Management System tool is part of the suite of applications being developed for the Grid-3P platform and other applications to provide the capability to monitor grid and market performance in real time and manage grid reliability. This suite of tools include:

1. Area Control Error (ACE)–Frequency Real-Time Monitoring System
2. Area Interchange Error (AIE) Monitoring System
3. Supplier and Control Area Performance System
4. Phasor Monitoring Applications for Dispatchers and Operating Engineers”
5. Grid Real-Time Performance Monitoring and Prediction Platform (Grid-3P)