Arnold Schwarzenegger
Governor

MAINTAIN, ENHANCE AND IMPROVE RELIABILITY OF CALIFORNIA'S ELECTRIC SYSTEM UNDER RESTRUCTURING

APPENDIX III

VAR Management – Functional and Design Specification for the California Independent System Operator (CAISO)

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

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CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

MARCH 2006
CEC-500-2006-035-APIII
LBNL-58939

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Consortium for
Electric
Reliability
Technology
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VAR
Management

FUNCTIONAL AND DESIGN SPECIFICATION

For the
CALIFORNIA INDEPENDENT SYSTEM OPERATOR
(CAISO)

Version 1.1

Date: July, 2003

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Background

Industry restructuring has driven the California Independent System Operator (CAISO) to manage a larger, more complicated, and dynamic grid. However, the existing support systems and tools used to manage the grid are based on the deterministic procedures of traditional energy management system (EMS) data and applications. To address the shortcomings of the current generation of tools, CERTS developed a vision for integrated, real-time reliability adequacy tools.

The Reliability Adequacy Tool for VAR Management is a component of CERTS' vision. It has been developed and prototyped for the CAISO operators so they can ensure compliance with the new Western Electricity Coordinating Council (WECC) grid reliability standards.

Value to CAISO and Industry

Today's operators lack the singular control of reliability and efficiency processes as they did in the past. In addition, there are many new players interacting with the network, each with differing levels of understanding and operating experience. This situation demands new tools to identify adequacy of suppliers (generation), distribution (transmission), and retail (distribution). To be efficient and effective, operators must monitor current performance, historical performance, and most important predict near term behavior. The VAR Management application delivers these capabilities to the system operator.

Real-time VAR Management

The Reliability Adequacy Tool for VAR Management delivered to CAISO contains five main functions: performance monitoring and alarming, voltage sensitivities, distances from voltage collapse, corrective action and WECC compliance, and replay.

- **Monitoring and Alarming -** The system monitors:
    - The voltage, reactive and active sensitivities, and margin reserves at key substation busses. The system calculates the voltage changes for increases in active and reactive. In addition, reactive reserves are calculated for selected critical buses to identify how much it is possible to increase the load at specified buses before voltage instability occurs.
    - The Control Area's overall VAR management performance against WECC or NERC standards established in NERC Policy 2, Policy 10 and WECC/RRWG. See Table-2.
- **Voltage Sensitivities –** The voltage at a substation is sensitive to changes (up and down) in the MW and MVAR demand. This module performs the sensitivity for a MW increase at any given substation. These sensitivities are used to identify the impact that a marginal load increase, at the critical buses, will have on the state of the network.

- **Distances from Voltage Collapse –** This function gives the user a visual indication of potential voltage collapse areas by calculating the MVA distance from voltage collapse.
- **Corrective Action and WECC Compliance –** This capability allows Reliability Coordinators to make prudent and timely decisions for reliable grid operation.

  The WECC has operating guidelines to ensure adequate reactive reserve margins at critical load busses, allowing the system to remain stable after a likely contingency. The VAR Management application evaluates the transmission grid for voltage compliance.

  PSCE calculates the amount of reactive resources required to return an area to its nominal voltage level. The reactive requirement of each station is calculated independent of the voltage behavior at the remaining stations.
- **Replay –** The function enables the user to save a current case to a working file to run specific analysis and review system performance.

The tool for VAR management includes an enhanced visualization subsystem that aids the Security Coordinator's identification and analysis of voltage stability problems. The visualization methods and techniques are better suited to the new operational challenges raised by the operation of bigger and more complex control areas under competitive market pressures.

System Hardware

The Reliability Adequacy Tool for VAR Management utilizes standard Intel/Windows based workstations interconnected using Ethernet. This straightforward hardware configuration facilitates integration to the CAISO's current and future information systems***.***

The applications are loosely integrated with the CAISO's PI information system for data extraction, and this integration can be enhanced as the PI data expands its repository of measured values.

Deliverables

Functional Specification	December 15, 2002
Factory Test completed	December 15, 2002
Field Test completed	December 15, 2002
Final Delivery	December 15, 2002

1 INTRODUCTION

The Consortium for Electric Reliability Technology Solutions (CERTS) has been formed to perform research, develop, and commercialize new methods, tools, and technologies to protect and enhance the reliability of the U.S. electric power system under the emerging competitive electricity market structure. The members of CERTS include former Edison Technology Solutions (ETS), Lawrence Berkeley National Laboratory (LBNL), Oak Ridge National Laboratory (ORNL), the Power Systems Engineering Research Consortium (PSERC), Pacific Northwest National Lab (PNNL) and Sandia National Laboratories (SNL). Southern California Edison (SCE) acts as a CERTS Research Provider.

Industry restructuring has driven the California Independent System Operator (CAISO) to manage a more complicated, dynamic and larger grid. However, the CAISO's support systems and tools used to manage the grid are based on old deterministic procedures and traditional energy management system (EMS) data and applications. New real-time integrated reliability adequacy tools are needed that can provide the following:

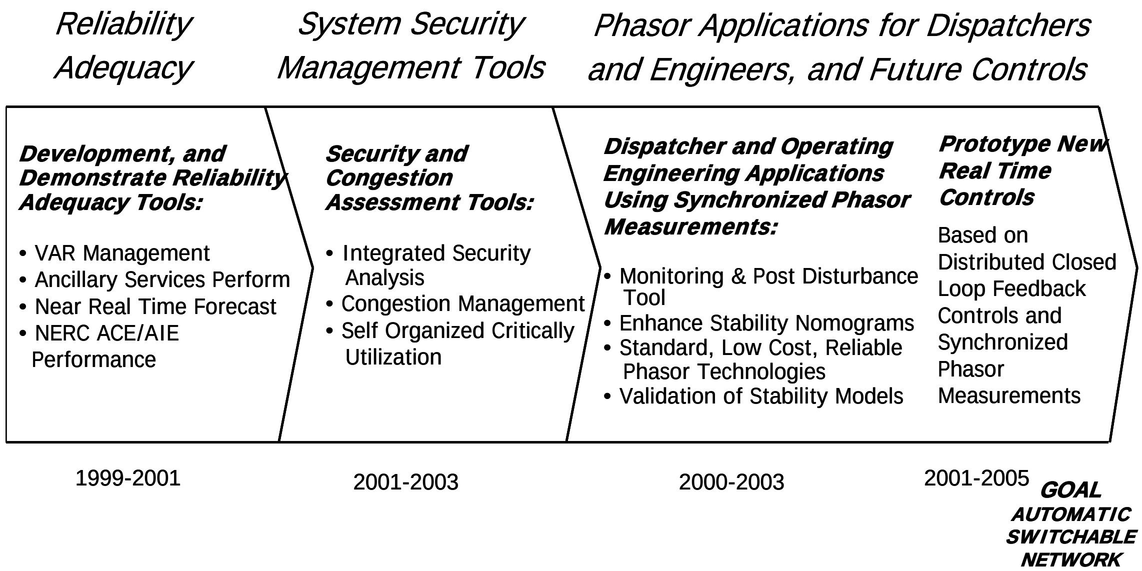
- Grid security assessment from a probabilistic approach.
- Information management systems to convert real-time operating data into meaningful operational information.
- Present real-time and security assessment data for larger control areas on appropriate visual components and perspectives that allow for effective visual monitoring analysis and assessment of power system events and its potential causes.
- Capability of early preventive warning indications of potential voltage problems (high or low) and reactive resource shortage problems with sufficient time to take the necessary corrective actions that would prevent voltage collapse or equipment damage.
- Capability to monitor adequacy performance for system and suppliers reactive resources.

CERTS is in the process of developing and prototyping a series of modular but integrated computer based reliability adequacy tools that will help CAISO to comply with the WECC grid reliability standards. A part of the integrated reliability adequacy series, the Real-time VAR Management application is being developed for CAISO. The Real-time VAR Management application is designed to measure performance and track system voltage and reactive reserves adequacy, in addition to providing predictive reliability conditions based on near real-time forecasts.

1.1 VAR Monitoring Functionality

Figure 1 shows CERTS' incremental approach for developing, prototyping and demonstrating adequacy applications with an ultimate goal to evolve and operate towards automatic switchable power networks. The first phase of the application series was to develop and demonstrate PC-based workstations for VAR Management and Ancillary Services application prototypes for dispatchers (see left side from Figure 1). The second phase is to develop and demonstrate a security monitoring application, designed for dispatchers and operating engineers, using Synchronized Phasor Measurements (SPM) (see center from Figure 1).

Figure 1 – CERTS Incremental Roadmap Towards an Automatic Switchable Network



The five main functions of the Real-time VAR Management reliability adequacy application are performance monitoring and alarming, voltage sensitivities, distances from voltage collapse, corrective action and WECC compliance, and replay. The performance parameters for each of the major functions are based upon NERC and WECC metrics for reliability standards and voltage stability.

The functionality of the Real-Time VAR Management system is based on a process defined by CERTS for reliability adequacy tools, and on the voltage-reactive reliability standards from two organizations:

- NERC Policies 2 and 10 which address transmission operations and ancillary services
- WECC and the following policies and guidelines:
    a) "Voltage Stability Criteria, Undervoltage Load Shedding Strategy and Reactive Power Reserve Monitoring Methodology",
    b) "Dynamic versus Static VAR Sources",
    c) "Undervoltage Load Shedding Guidelines".

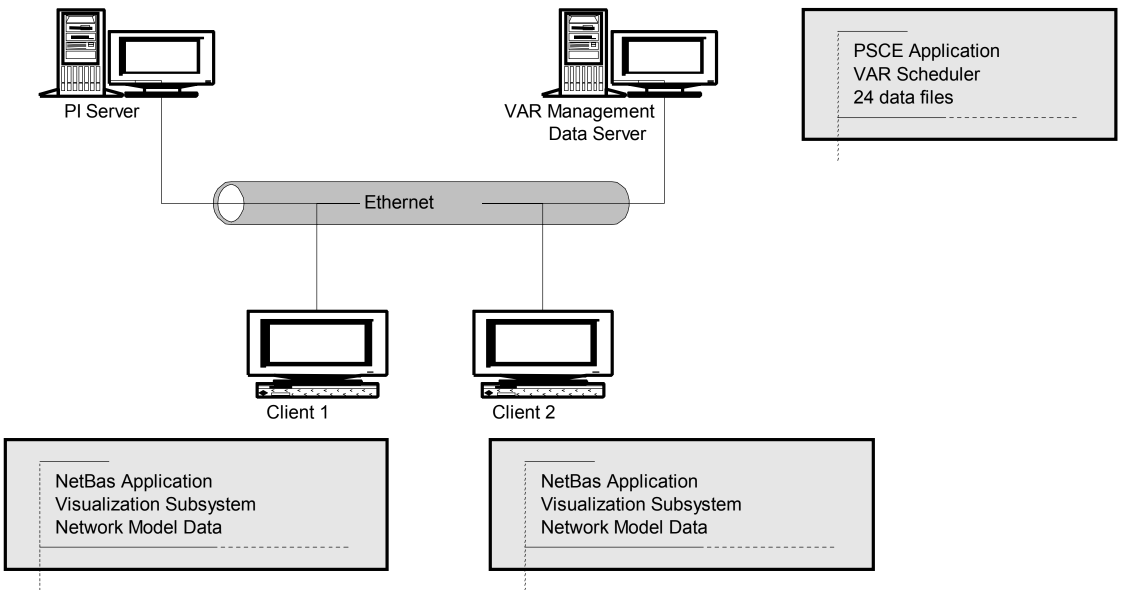
The Real-time VAR Management application can be used to evaluate CAISO's voltage stability compliance with NERC and WECC reliability standards at key substations. The network calculation determines the voltages, voltage sensitivities and distances before voltage collapse at key buses. It also calculates active and reactive flows through the network for current conditions and for near real-time forecast load.

The Real-time VAR Management system also includes a new information visualization subsystem to assist the Security Coordinator's identification and analysis of voltage stability problems. The visualization methods and techniques are better suited to the new operational challenges raised by competitive markets and the operations of bigger and more complex control areas.

1.2 System Hardware and Software Overview

Figure 2 shows an overview of the three PC-based computers that make up the hardware infrastructure for the VAR Management. The figure also shows the application software that will reside in each computer.

Figure 2 – Hardware and Application Software Overview



1.3 Overview of the VAR Management and Specification

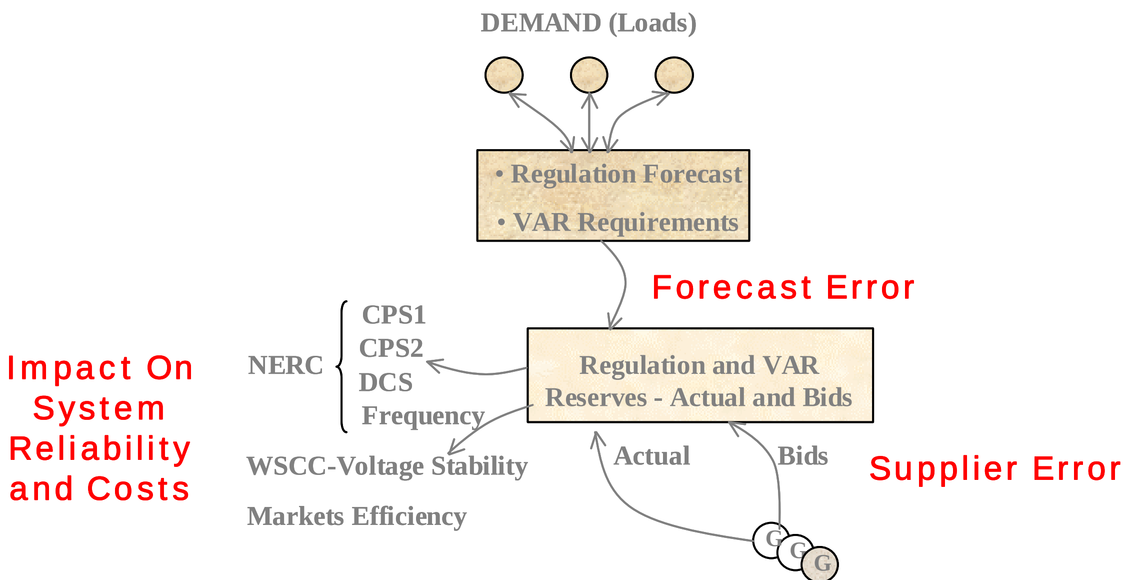
The remaining sections of this specification will cover the following areas - Section 2 describes how operational changes originated from deregulation and how competitive markets require tools to track adequacy of reactive reserves. Section 3 describes the target users for this tool, and Sections 4 and 5 describe the functionality information and visualization elements for VAR Management. Section 6 describes general characteristics of the design for the application.

The Real-time VAR Management system will reside in high-powered PC based workstations, running Windows 2000. As shown in Figure 2, the software and hardware, described in this document, have been specifically configured and implemented for this application.

2 BACKGROUND

Figure 3 shows an overview of the current and potential VAR market and operational processes that were used for the definition of the functional requirements for VAR Management application.

Figure 3 –Demand (Loads)



The process starts, as shown in Figure 4, with CAISO preparing their forecast of VAR requirements, and the supply bidders using that forecast to present their bids. Any errors in the forecast or deviation between suppliers' bid and actuals will impact voltage stability and consequently could result in CAISO's non-compliance with WECC voltage stability standards.

It should be noted that VAR suppliers in the above generic process can take different roles depending on the voltage and reactive reserve characteristics of particular regions. Today the CAISO requires Reactive Must Run (RMR) generation to satisfy region voltage requirements. In the future, the ancillary services market will enable the participation of CAISO's contract suppliers and other suppliers with capacitors in the transmission system.

3 TARGET USERS AND RELIABILITY STANDARDS

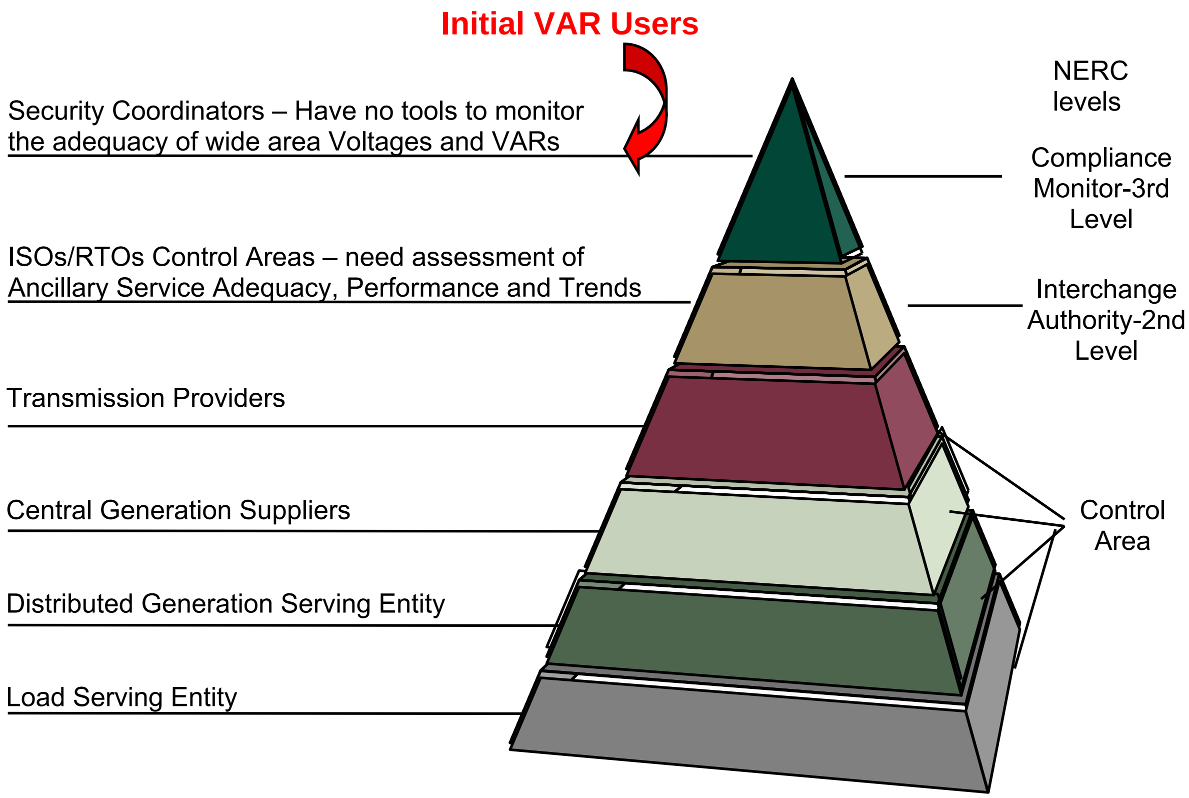
North American utilities formed the North American Electric Reliability Council (NERC) in 1968 to coordinate, promote, and communicate the reliability of their generation and transmission systems. NERC helps utilities work together to maintain and improve system reliability by:

- Developing and maintaining Policies and Standards, for the reliable operation and planning of the electric interconnections in North America.
- Measuring performance of systems for compliance with the reliability Policies and Standards.
- Ensuring compliance with the reliability Policies and Standards through well-defined,

effective, and timely procedures.

Industry stakeholders are recognizing new reliability jurisdictions and real-time controls within emergent market environments that follow a hierarchical structure with new jurisdictional levels that did not exist before. Figure 4 shows the current hierarchical levels for power system reliability and control management. The figure also shows the corresponding reliability levels identified by NERC and whose reliability roles and responsibilities are currently being defined.

Figure 4 – Reliability and Control Hierarchy



The functional requirements for new reliability adequacy operational tools and real-time control systems will depend on the operational level and approach that is being addressed, the traditional central approach or new distributed approaches. The functionality identified and described on this specification has been oriented towards the distributed control and monitoring environments, with the operating authority following the hierarchical control levels shown in Figure 5.

Figure 5 shows NERC roles and responsibilities of the top three operating entities shown in Figure 4 and who have oversight for the necessary reliability services. In Figure 5, the shadowed area corresponds to some of the reliability services that CERTS is addressing with the reliability adequacy tools currently under development.

Figure 5 – Reliability Hierarchy / Entity Responsibility

Reliability Hierarchy

3rd LEVEL (Interconnection **Security Coordinator**

2nd LEVEL (Subdivision of Interconnection)

ISO / RTO's

LOWEST LEVEL (ENTITY)

Generator	Transmission Provider	Load Serving Entity
• Single plant/single unit • Single plant/multiple units • IPP • Self Serve • Fleet of plant/units - common control • Generation Aggregator (Every source of Generation connected to the Grid)	• Each operator of segments of an overall grid • Transmission Aggregator under common control (Includes every segment of the grid within a defined area)	• Wholesale • Retail (Each load served with a defined area) • Reserves

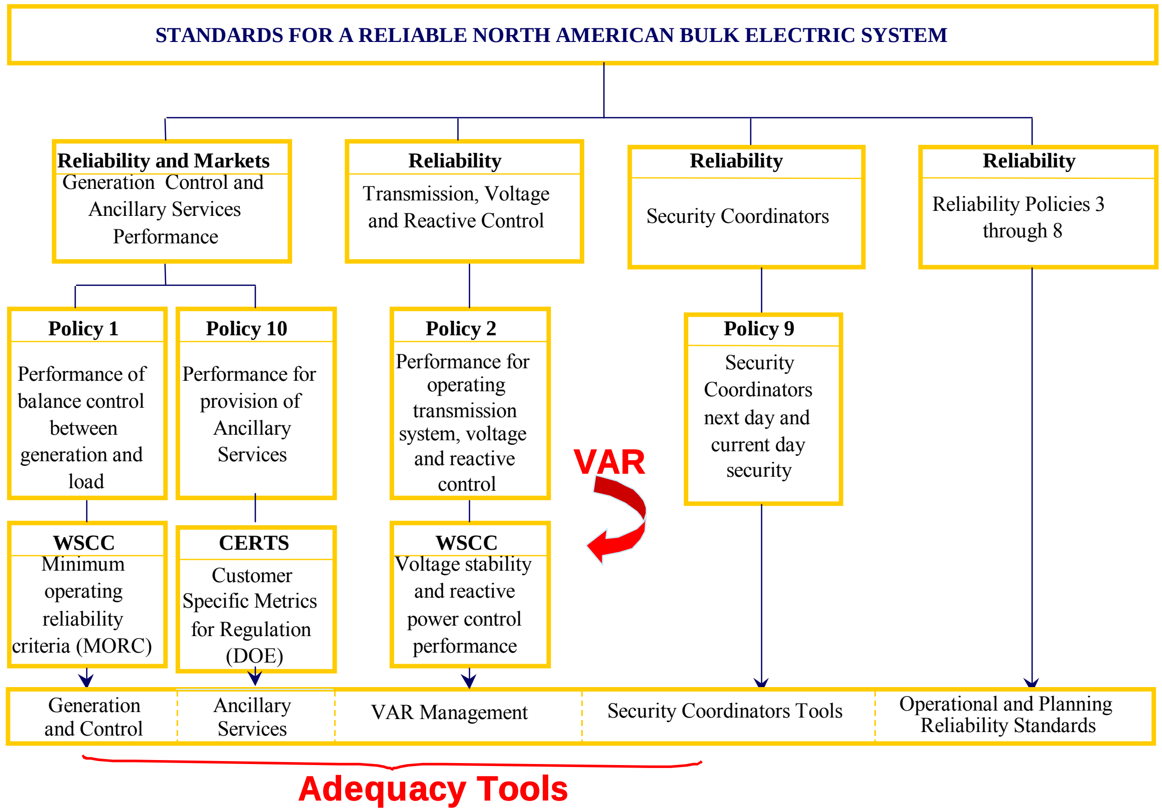
Reliability Services

• NERC	• Interchange Authority	• Compliance Monitor	• Control Area
>Reliability Policies/Standards >Compliance oversight >ADR	>Forecast load & aligns resources >Arrange transmission services >Submits schedules	>Monitor Grid Status >Monitor Reserves >MonitorsAppl. Of policies >Implements Compliance Procedures	>Generation/Load Balancing (ACE) >Control Performance

Figure 6 below is an overview of NERC's Policies and Standards with specific details on the interrelationships and performance parameters for Policies 1, 2, 9 and 10. CERTS is focused on these four NERC Policies and has identified the need for reliability adequacy operational tools (bottom of Figure 5) to assist Operating Authorities in effectively monitoring and tracking performance and anticipating short-term reliability needs. Performance tools for NERC's Policies 1 and 10 as well as the WECC Minimum Operating Reliability Criteria (MORC) are being addressed with the CERTS Ancillary Services Performance Tracking and Predictive specification. This Real-time VAR Management Reliability Adequacy Specification is addressing NERC's Policies 2, 10, and the WECC voltage stability guidelines.

It should be noted from Figures 4, 5 and 6 that independent of the restructuring approach and business infrastructures implemented in different areas of the nation, Operating Authorities such as ISOs, RTOs, Utilities, etc. will still be responsible for their control area reliability, and consequently they will need new real-time operational tools for reliably managing the grid.

Figure 6 – Standards for a Reliable North American Bulk Electric System



3.1 Generation Control and VAR Management – A Market Perspective

California's ISO has established hourly ancillary services markets (reactive reserves market could be added in the near future) for the purpose of ensuring reliability and creating competition among potential suppliers, thus enhancing market efficiency.

In the restructured marketplace, by design, generation operators (Suppliers) will be free to make their own decisions about how much VARs to generate in any given hour, subject only to the incentives and penalties embodied in market prices and in contractual relationships.

3.2 Voltage Control and Real-time VAR Management – A System Reliability Perspective

As shown in Figure 6, Security Coordinators and Control Area Operators are responsible for ensuring system reliability through the compliance of standards established by NERC and WECC. On November 1996 the WECC Technical Studies Subcommittee (TSS) formed the Reactive Power Reserve Work Group (RRWG) to address reactive power margin issues, as a response to two major disturbances that occurred within the WECC interconnected region. This specification incorporates RRWG's specific recommendations for reactive power margins and voltage stability criteria performance, and general recommendations from NERC's Policy 10, as described in Table 1, in section 4.2.

Reactive Reserves fall mainly under transmission providers or control areas voltage support requirements and must be available to mitigate the impacts of likely contingencies. Table 1 shows the WECC voltage stability criteria (minimum required margins for each member system) applied according to the type of disturbance and performance level. These criteria will be used as part of the metrics and calculations for the VAR Management application.

The need for measurable standards are driven by industry restructuring, namely:

- Industry competition that precludes the reliability councils from relying solely on voluntary compliance and peer pressure to maintain the current level of reliability.
- Divestiture of generation assets resulting in separation of generation resources from traditional reliability bodies, such as Control Areas;
- Separation of generation and transmission functions within previously integrated utilities requiring new protocols to re-integrate the supply and deployment of reliability services; and
- Development of procedures and protocols within emerging regional market structures.

These standards are necessary to ensure unbundled reliability services continue to be provided under a range of competitive market structures and conditions.

One reliability objective of the regional interconnected grid is to maintain system voltages within defined limits. This must be maintained under both normal and emergency conditions. The control area accomplishes this by coordinating the use of reactive resources (generators, transmission reactive resources, and load power factor) and ensuring that there are adequate reactive reserves available. The following are the minimum components of transmission system voltage control:

- Load power factor correction.
- Transmission reactive resources (capacitors, reactors, lightly loaded lines and static VAR compensators).
- Generator interconnection voltage and VAR schedule requirements with the local transmission provider.
- Control Area coordination.
- Reactive power supply and high speed voltage regulators at generation sources.

The Operating Authority must deploy the reactive resources necessary to maintain system voltages within established limits and avoid voltage instability or system collapse. One of the technical elements necessary to ensure a stable system voltage is the Automatic Voltage Regulator (AVR) and reactive production / absorption capability of the grids generating units. The following capabilities from generators (and possibly some loads) are essential to maintaining system voltages within limits under pre- and post-contingency conditions: reactive capacity, reactive energy, dynamic and fast acting responsiveness, and the ability to follow a voltage or VAR schedule.

In addition to the use of generation-based ancillary services, the Operating Authority coordinates the use of static reactive supply devices throughout the system, and may develop and impose reactive criteria on load-serving entities.

Voltage support and reactive power control requires that a Control Area meet the following criteria:

- **Voltage Schedule Coordination.** The Operating Authority shall establish, and update as necessary, voltage schedules at points of integration of reactive power supply from generation sources, to maintain system voltages within established limits and to avoid burdening neighboring systems. The Operating Authority shall communicate to the Supplier the desired voltage or VAR schedule at the point of integration.
- **Reactive Reserves.** The Operating Authority shall acquire, deploy, and continuously maintain adequate reactive reserves from Supplier resources, both leading and lagging, under both steady state and contingency conditions
- **Telemetry.** The Operating Authority shall monitor by telemetry the following data: (1) Transmission voltages, (2) Unit or Supplier resource reactive power output. (3) Unit or Supplier resource Automatic Voltage Regulator (AVR) status for units greater than 100 MW (and smaller units where an identified need exists).
- **NERC/WECC Planning Standards.** The Operating Authority shall comply with applicable NERC/WECC Planning Standards. These standards require that generation owners and Operating Authorities plan and test reactive power capability.

Each control area shall monitor its performance on a continuous basis against the established Standards, with the desired goal for the control area to meet or exceed the standard specified in Table 1.

In the simplest form, the resources to support the system voltage and meet the reactive power requirements are reactive capacity and the ability to raise and lower output or demand in response to control signals or instructions. Generators, controllable loads, or storage devices, capacitors, reactors, and static VAR compensators may provide this capacity and maneuverability.

Generator power factor and voltage regulation standards can be a condition of interconnection to satisfy area or local system voltage conditions. Voltage regulating capacity and capabilities that are provided to meet minimum interconnection requirements do not imply that those generators are qualified ancillary service suppliers.

Generators do not provide reactive power supply from generation sources simply because of connection to the transmission system. In order to provide the ancillary service, the resources must be:

- Under the direction of Operating Authority for the purpose of controlling system voltage, and
- Providing a service under contractual arrangement with the Operating Authority.

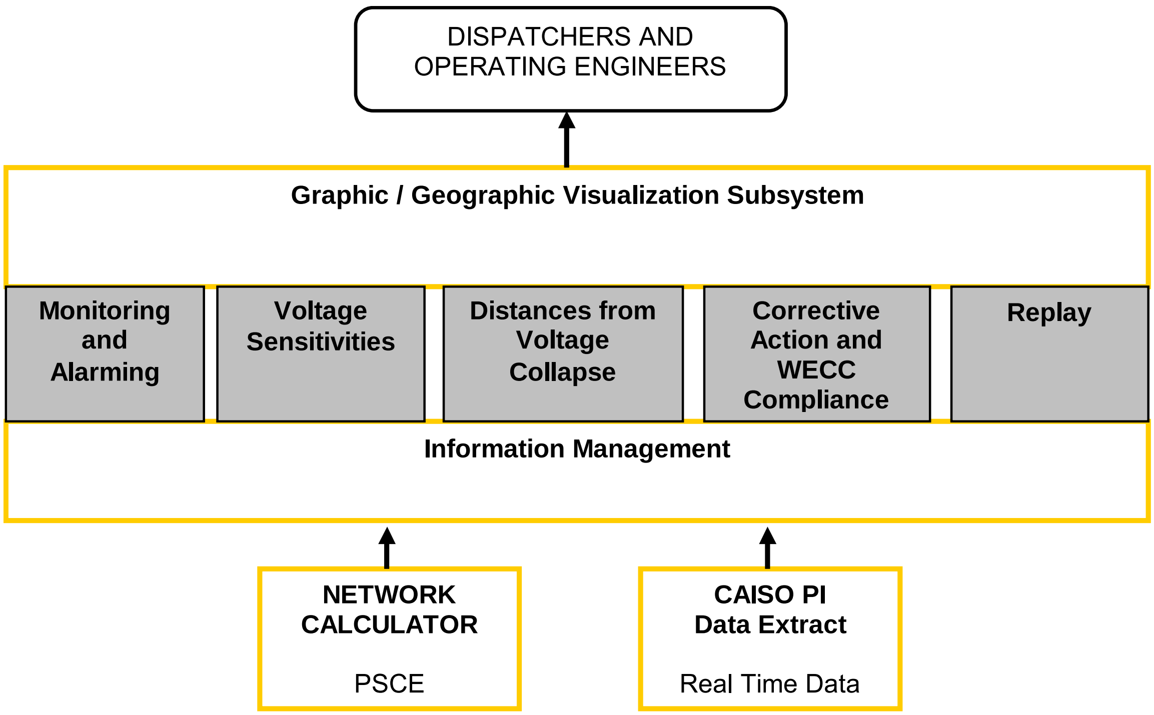
4 REAL-TIME VAR MANAGEMENT FUNCTIONAL REQUIREMENTS

The main purpose of the Real-Time VAR Management application is to provide the Reliability Coordinator with an integrated solution for geographic wide-area and local-area monitoring for voltages, voltage sensitivities, distance before voltage collapse, reactive reserve adequacy, and compliance with WECC guides for voltages and reactive reserves. In addition, the application has the capability to save and recall cases to run specific analysis and review systems performance.

4.1 Real-time VAR Management Integrated Functional Overview

Figure 7 shows a general overview of the Real-time VAR Management application functionality. It also illustrates the relationships among its major functional components: Real-time VAR Management database, PSCE, information management, and graphic/geographic visualization are used to provide the Operating Authority and/or Operation Engineers with meaningful information.

Figure 7 – Real-time VAR Management Integrated Functional Overview



The Real-time VAR Management application major functional capabilities are:

- **Monitoring and Alarming -** The system monitors:
  - o The voltage, reactive and active sensitivities, and margin reserves at key substation busses. The system calculates the voltage changes for increases in active and reactive. In addition, reactive reserves are calculated for selected critical buses to identify how much it is possible to increase the load at specified buses before voltage instability occurs.
  - o The Control Area's overall VAR management performance against WECC or NERC standards established in NERC Policy 2, Policy 10 and WECC/RRWG. See Table-2.
- **Voltage Sensitivities –** The voltage at a substation is sensitive to changes (up and down) in the MW and MVAR demand. This module performs the sensitivity for a MW increase at any given substation. These sensitivities are used to identify the impact that a marginal load increase, at the critical buses, will have on the state of the

network.

- **Distances from Voltage Collapse –** This function gives the user a visual indication of potential voltage collapse areas by calculating the MVA distance from voltage collapse.
- **Corrective Action and WECC Compliance –** This capability allows Reliability Coordinators to make prudent and timely decisions for reliable grid operation.

  The WECC has operating guidelines to ensure adequate reactive reserve margins at critical load busses, allowing the system to remain stable after a likely contingency. The VAR Management application evaluates the transmission grid for voltage compliance.

  PSCE calculates the amount of reactive resources required to return an area to its nominal voltage level. The reactive requirement of each station is calculated independent of the voltage behavior at the remaining stations.
- **Replay –** The function enables the user to save a current case to a working file to run specific analysis and review system performance.

The Graphic-Geographic Visualization subsystem facilitates rapid and accurate interpretation of the results for each function. It presents past and current information in a variety of forms:

- Tabular
- 2-Dimensional and 3-Dimensional displays
- Geographic Maps
- Animated visualization

4.2 NERC/WECC Performance Criteria to comply with Voltage Control Reliability Standards - System Level View

The WECC voltage stability criteria are specified in terms of real and reactive power margins. These criteria are used to evaluate compliance with voltage schedules at critical sub-stations. All member systems must provide the minimum margins specified in Table 1 below.

Table 1 – WECC Voltage Stability Criteria

WECC VOLTAGE STABILITY CRITERIA

Performance Level	**Disturbance** (1)(2)(3)(4) **Initiated By:** Fault or No Fault DC Disturbance	**MW Margin** **(P-V Method)** (5)(6)(7)	**MVAR Margin** **(V-Q Method)** (6)(7)
A	Any element such as: One Generator One Circuit One Transformer One Reactive Power Source One DC Monopole	≥ 5%	Worst Case Scenario (8) 50% of Margin Requirement in level A
B	Bus Section	≥ 2.5%	50% of Margin Requirement in level A
C	Any combination of two elements such as: A Line and a Generator A Line and a Reactive Power Source Two Generators Two Circuits Two Transformers Two Reactive Power Sources DC Bipole	≥ 2.5%	
D	Any combination of three or more elements such as: Three or More Circuits on ROW Entire Substation Entire Plant Including Switchyard	> 0	> 0

Notes: (From WECC Standards: "Voltage Stability Criteria, Undervoltage Load Shedding Strategy and Reactive Power Reserve Monitoring Methodology")

(1) This table applies equally to the system with all elements in service and the system with one element removed and the system readjusted.

(2) For application of these criteria within a member system, controlled load shedding is allowed to meet Performance Level A.

(3) The list of element outages in each Performance Level is not intended to be different than the Disturbance Performance Table in the WECC Reliability Criteria. Additional element outages have been added to this table to show more examples of contingencies. Determination of credibility for contingencies for each Performance Level is based on the definitions used in the existing WECC Reliability Criteria.

(4) Margin for N-0 (base case) conditions must be greater than the margin for Performance Level A.

(5) Maximum operating point on the P axis must have a MW margin equal to or greater than the values in this table as measured from the nose point of the P-V curve for each Performance Level.

(6) Post-transient analysis techniques shall be utilized in applying the criteria.

(7) Each member system should consider, as appropriate, the uncertainties in Section 2.3 to determine the required margin for its system.

(8) The most reactive deficient bus must have adequate reactive power margin for the worst single contingency to satisfy either of the following conditions, whichever is worse: (i) a 5% increase beyond maximum forecast loads or (ii) a 5% increase. The VAR Management will calculate, display and archive these margins and identify those network points that will not meet the WECC criteria.

The criteria noted in Table 1 apply equally to the system with all elements in service as well as the system with one element removed and the system readjusted. System adjustments after one element is removed in the base case (for performance levels A-D analyses) include all adjustments that can be made within 60 minutes to bring the system to the next acceptable steady state operating condition following the removal of the element (e.g., generation re-dispatch, start up of new generation, phase shifter and tap changer adjustments, area interchange adjustments, etc.).

The margin should be provided at all critical buses during all stressed system conditions. Stressed cases represent worst-case conditions for various load levels and interface flows such as:

- Peak load conditions with maximum generation
- Low load conditions with minimum generation
- Maximum interface flow conditions with worst load conditions.

The WECC Reactive Power Research Work Group (RRWG) recommends that no less than a 1 in 2 year probability load forecast for voltage stability studies of load serving areas should be used. The 1 in 2 year occurrence load forecast (also referred to as a "50/50" or average load forecast) represents a forecast with a 50% chance of being exceeded in each forecast year.

Determination of credibility for contingencies is based on the definitions used in the WECC Reliability Criteria. Appropriate measures must be taken to ensure that the margin criteria are met. Reactive power margins must be monitored and maintained in real-time.

The VAR Management Network Calculation engine, PSCE, calculates and archives the parameters required for the following assessments:

V-Q (Voltage (V) vs. Reactive Power (Q)) analysis provides a way to investigate the potential for voltage collapse during the post-transient period within 3 minutes after a disturbance. Besides having sufficient voltage control devices to sustain credible contingencies, it is prudent to have enough margins to account for variations in system conditions. The effects of these variations are considered in the determination of the required reactive power margin. For the V-Q methodology, the reactive power margin is measured from the bottom of the V-Q curve to the V axis. If reactive power compensation is used, the margin is from the bottom of the V-Q curve to the intersection of the V-Q curve and the compensation characteristic.

P-V (Real Power (P) vs. Voltage (V)) analysis is a steady-state tool that develops a curve, which relates voltage at a bus (or buses) to load within an area or flow across an interface. Bus voltages are monitored throughout a range of increased load and real power flows into a region. In the P-V methodology, the MW margin is measured from the nose point of the P-V curve to the operating point on the P-V curve.

The criteria include the following provisions for application to internal systems:

- Controlled load shedding is allowed for Performance level A contingencies in order to meet the margins specified in Table 1.
- The margins in Table 1 do not have to be met if (a) the local area is radial or is a local network and (b) the contingency under consideration does not cause voltage collapse

of the system beyond the local area.

Sensitivities will be calculated to probabilistically predict whether the network is approaching voltage instability. The following sensitivities will be calculated:

- Change in reactive production for an increase in active power
- Change in reactive production for an increment of reactive power
- Voltage changes for increases in active power, and
- Voltages changes for increases in reactive power

5 VISUALIZATION SUBSYSTEM

The VAR Management application provides an integrated solution for geographic wide-area and local-area monitoring as shown in Table 2. The table is an overview of the VAR application major functionality and corresponding user visualization.

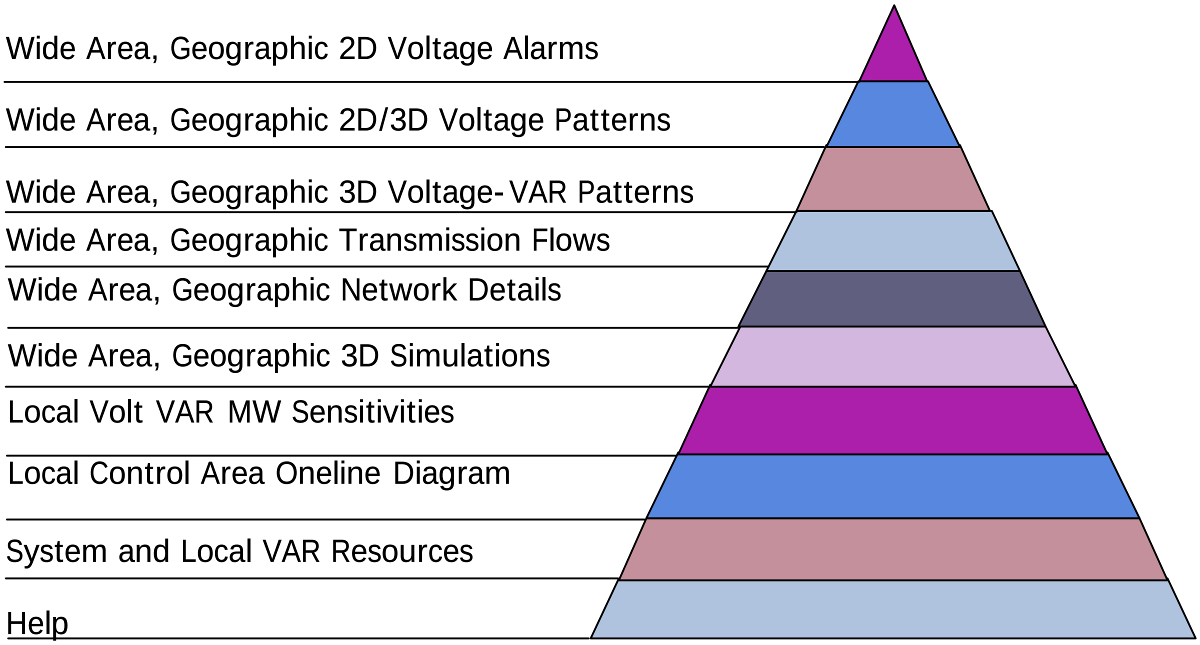
Table 2 – Visual Analysis Definition Process

Functionality / Target Areas	Monitoring and Alarming	Voltage Sensitivities	Distances From Voltage Collapse	Corrective Action and WECC Compliance	Replay
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	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	Interactive One-line and Graphic Diagrams

The design criteria for the User's visual components layout is following an equivalent approach to the one traditionally used for PI and EMS displays. It has been demonstrated by Dispatchers that the more effective displays are those that follow a hierarchical approach to present operational data. In this approach, very critical system data is presented on very simple system displays. From the high-level system displays, Dispatchers can go to lower level displays in the hierarchy.

Figure 8 shows the various levels of visualization in the Real-time VAR Management system. Most displays are 3D or 2D graphic-geographic displays.

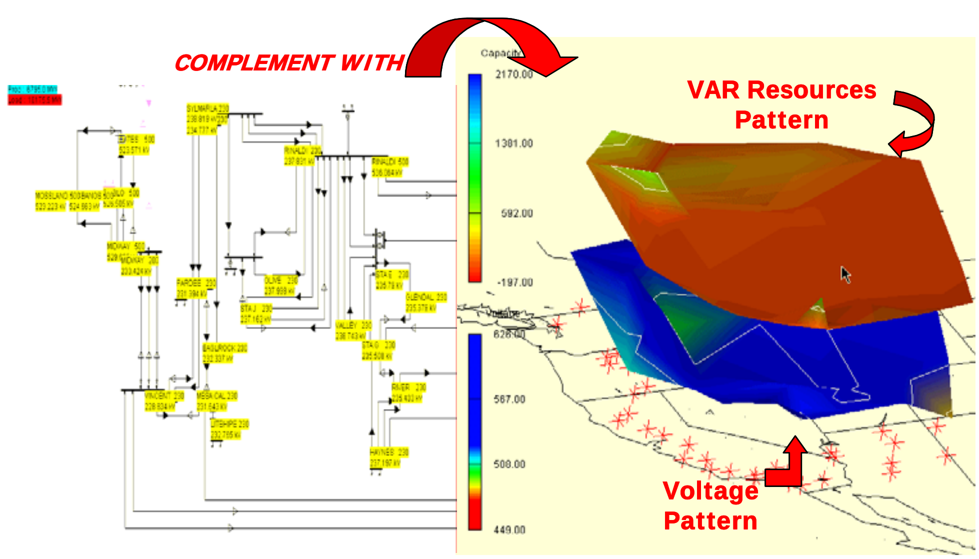
Figure 8 – Hierarchical Levels for VAR Management Visual Analysis



5.1 VAR Management Utilization Overview

Figure 9 indicates the overall visual approach this application is offering in the area of user interface by complementing traditional one-line diagrams with graphic-geographic visual components at the higher levels of the display hierarchy. The 3D graph for voltages and reactive resources shown is part of the visual analysis hierarchy shown in Figure 5.

Figure 9 – New Geographic / Graphic Visualization Technologies



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

The 6 displays in Figure 10 show what the Security Coordinator would use to identify:

- voltage abnormal events
- the relationship with reactive-reserves conditions
- the sensitivities at critical buses
- loading distances before voltage collapse.

The VAR Management application uses three methods to display information. The first method consists of Wide Area Visualization using geographic 2D and 3D displays, as shown in Displays 1-4. The second method uses the traditional one-line diagram to display local conditions (Display 5) and the third method is to plot the information on a nose curve graph (Display 6).

Display 1 – 2D Voltage Flashing Alarms – Visual component showing specific stations with voltages under predetermined thresholds.

Display 2 – 3D IsoVoltage Patterns – Visual component showing some specific stations as in Display 1 but in a graphic 3D display with isovoltage contours included.

Display 3 – Voltage / VAR Patterns – Visual component that correlates voltage trouble- areas with corresponding reactive reserve patterns.

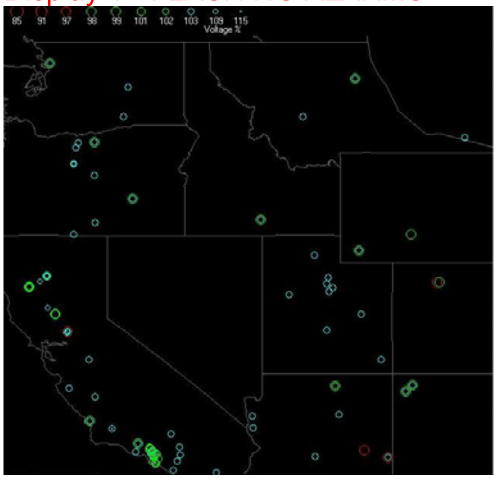
Display 4 – Animated / Encoded Flows – Visual component showing the power flows with line-capacities and flow direction encoded with animated arrows.

Display 5 – Voltage Sensitivities – Visual component with vertical bars in a one-line diagram showing voltage changes to marginal load increase for pre-selected buses.

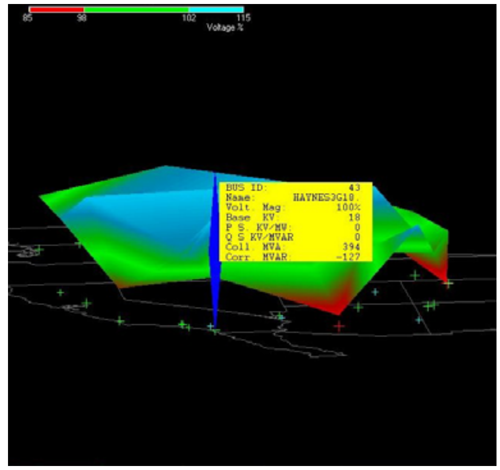
Display 6 – Distance from Voltage Collapse – Visual component showing how much it is possible to load up pre-selected buses before voltage instability occurs.

Figure 10 – Visual Monitoring, Assessment and Analysis Displays

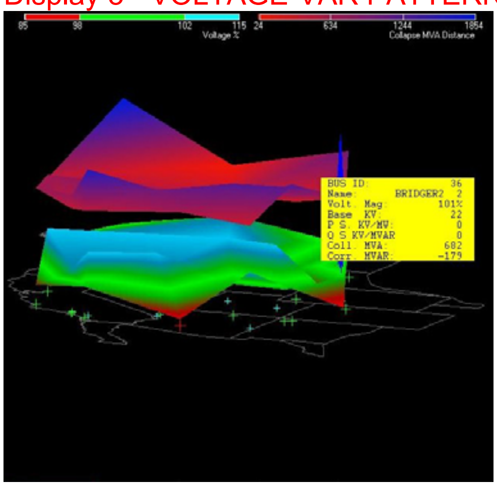
Display 1 - FLASHING ALARMS



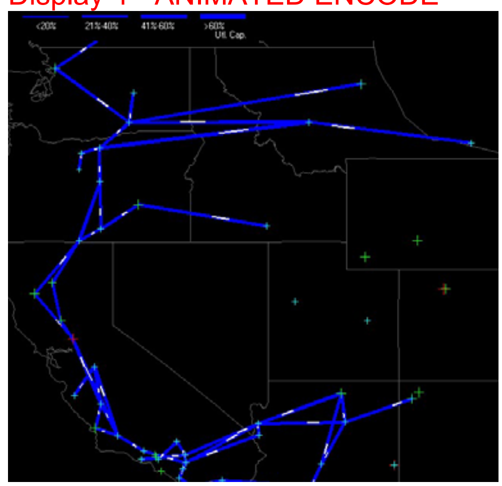
Display 2 - 3D ISOVOLTAGE PATTERN



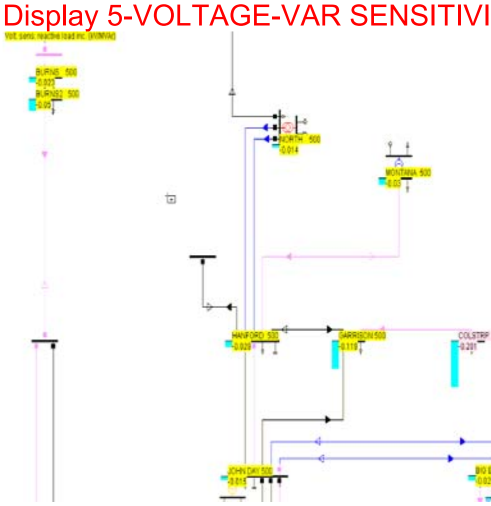
Display 3 - VOLTAGE-VAR PATTERNS



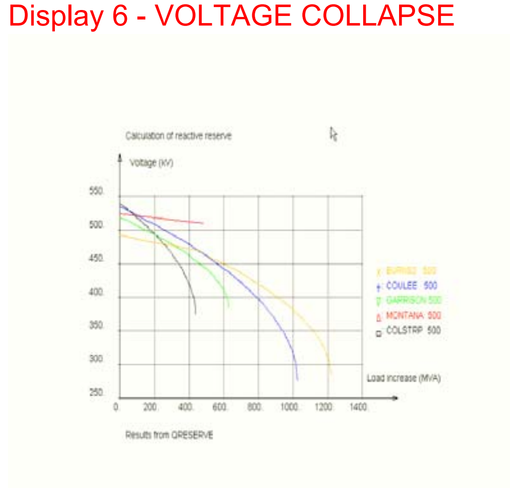
Display 4 - ANIMATED ENCODE



Display 5-VOLTAGE-VAR SENSITIVITES



Display 6 - VOLTAGE COLLAPSE



5.2 Wide-Area Visualization

Figure 11 shows the visual perspective is comprised of three views in three separate panels. The labeled portions of the display are:

Section A - On the bottom of the display is a text area with:

- General information related to the time and date of the data displayed.
- System data for:
  - d) Total Generation capacity in MW and MVAR (This last as GnQ-Min and GnQ-Max)
  - e) Generation (current) in MW and MVAR
  - f) Load, in MW and MVAR
  - g) Losses, in MW and MVAR

Section B – On the upper left corner are the tabs that control the information displayed in the Master Visual Perspective:

- 2D Volt Alarming
- 3D Volt Monitoring
- 3D Volt Sensitivity
- Collapse MVA Distance
- Corrective Action
- Line Flows

Section C is the main panel. The selected display shows the WECC map and graphic representation for voltages. On the upper left corner is displayed the color bar(s) which represent the spectrum measured values.

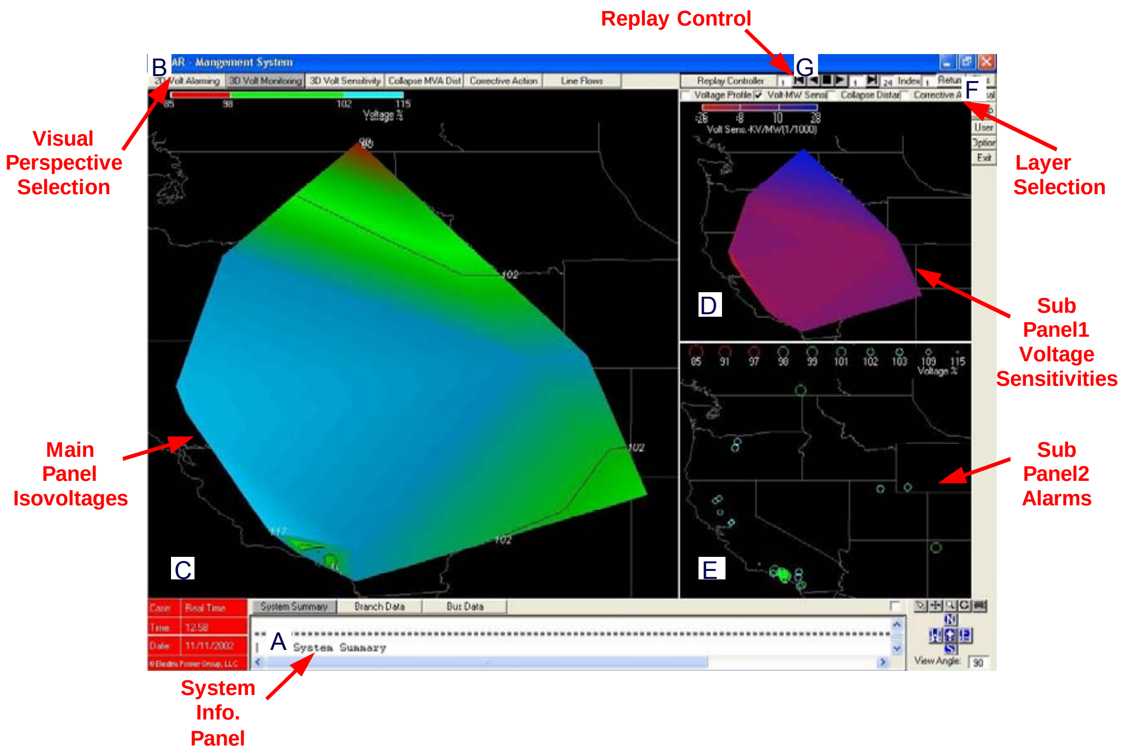
Sections D and E are fixed sub-panels. Selecting a specific display in the mail panel, also selects specific displays in panels 2 and 3, as follows:

Panel # 1	Panel #2	Panel #3
2D Voltage Alarming	3D Voltage Monitoring	3D Sensitivity
3D Voltage Monitoring	3D Sensitivity	2D Voltage Alarming
3D Sensitivity	3D Voltage Monitoring	3D Voltage Alarming
Collapse MVA Distance	3D Voltage Monitoring	3D Sensitivity
Corrective Action	2D Voltage Alarming	3D Voltage Monitoring
Line Flows	3D Voltage Monitoring	2D Voltage Alarming

Section F contains boxes that are used to select the information layers displayed in the sub-panels. Any combination of 3D voltage profile, voltage sensitivity, collapse distance, and corrective action layers can be selected to overlap in the display.

Section G shows the "VCR" controls for running the replay controller. The application has the ability to store up to 24 real-time cases. The user can select how many past cases to replay and start/stop the replay.

Figure 11 – Master Visual Perspective

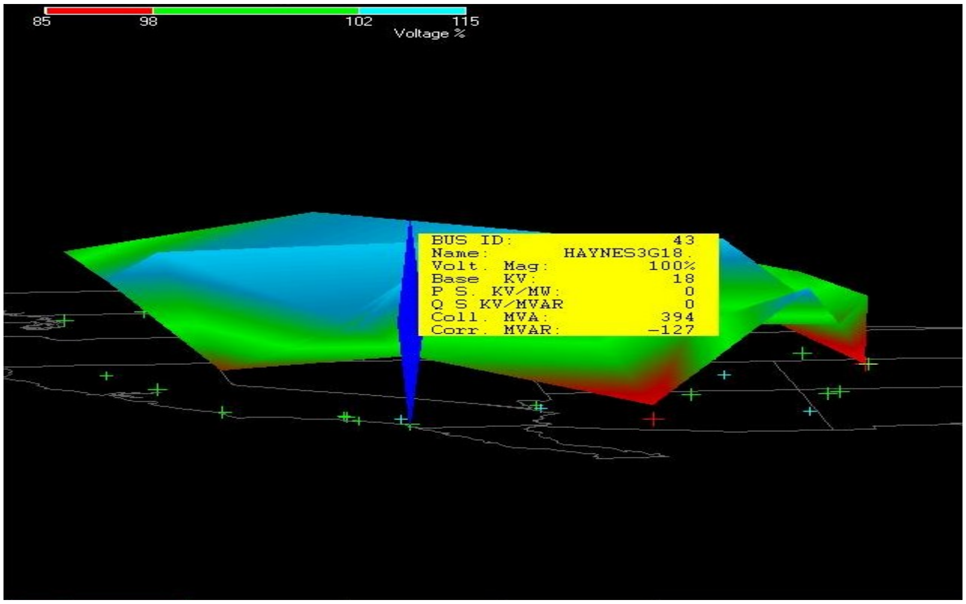


5.2.1 3D Voltage Patterns

Figure 12 shows a 3D presentation of voltage using a surface map, with voltage scale colors, superimposed over the WECC map. The figure corresponds to a PSCE run. Red indicates the area with the lowest voltage condition.

The stars on the map indicate the geographical locations of the monitored substations. The view can be rotated, panned and zoomed using the mouse buttons and the control/shift keys. Different voltage levels can be selected with the right mouse click.

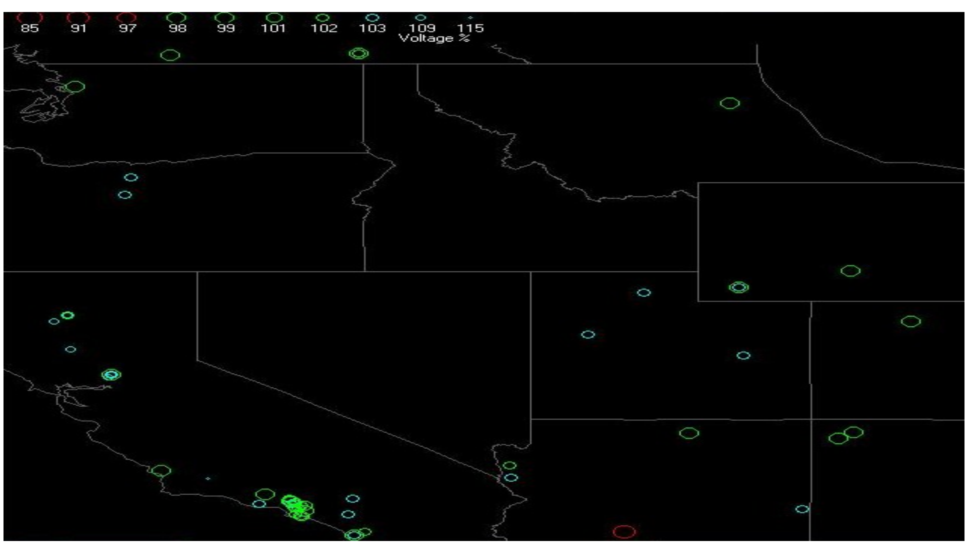
Figure 12 – 3D Voltage Patterns



5.2.2 Voltage Alarms

Figure 13 shows the WECC map with the monitored substation voltages. Each circle on the display represents a station in its exact geographic location. The display uses color and size to denote an alarm condition. The voltage scale is from 85% to 115% of the nominal voltage. The user may also select to display station names and actual voltage values.

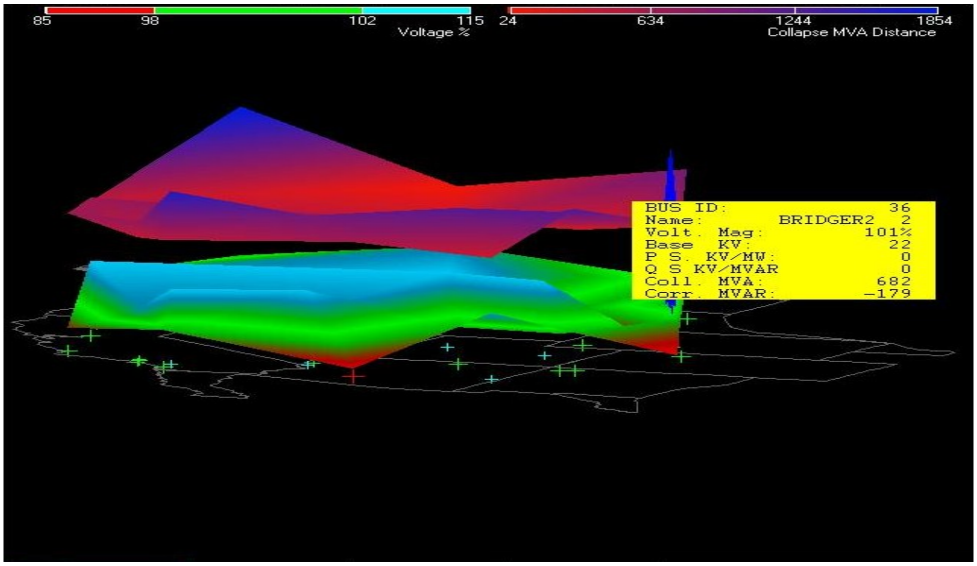
Figure 13 – Voltage Alarm Visual



5.2.3 Voltage Profile with Corresponding Distance from Voltage Collapse

Figure 14 overlays the voltage profile and voltage collapse distance displays. The values are presented in the form of 3D surfaces. The distance from voltage collapse is expressed in MVA.

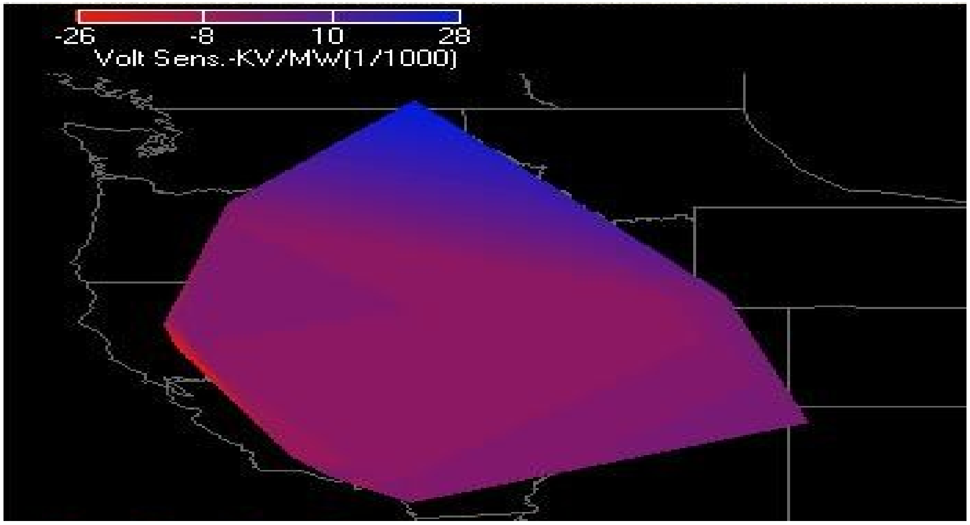
Figure 14 – Voltage / VARS Patterns



5.2.4 Voltage Sensitivities

The voltage at a substation is sensitive to changes in the MW and MVAR demand. This module performs the sensitivity for a MW increase at any given substation. As displayed in Figure 15, the scale is located at the top left and indicates the voltage change, in kV, for a 1 MW increase in load.

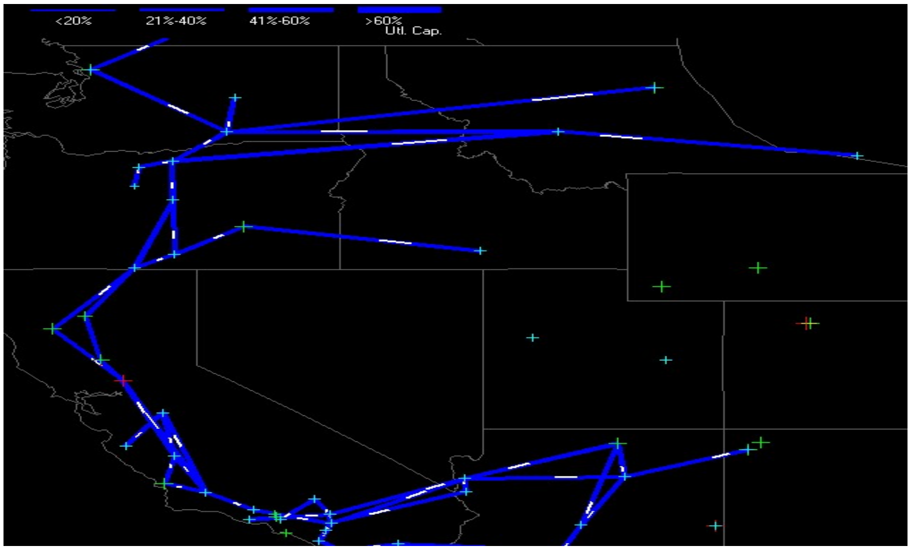
Figure 15 – Voltage Sensitivities



5.2.5 Transmission Line Flows

Figure 16 is a display that shows the flow of MVARS on the interconnected transmission lines. The thickness of the line indicates the utilized transmission capacity of a line. The thicker the line, the more line capacity remains available. The arrows over the lines represent the direction of MVAR flows.

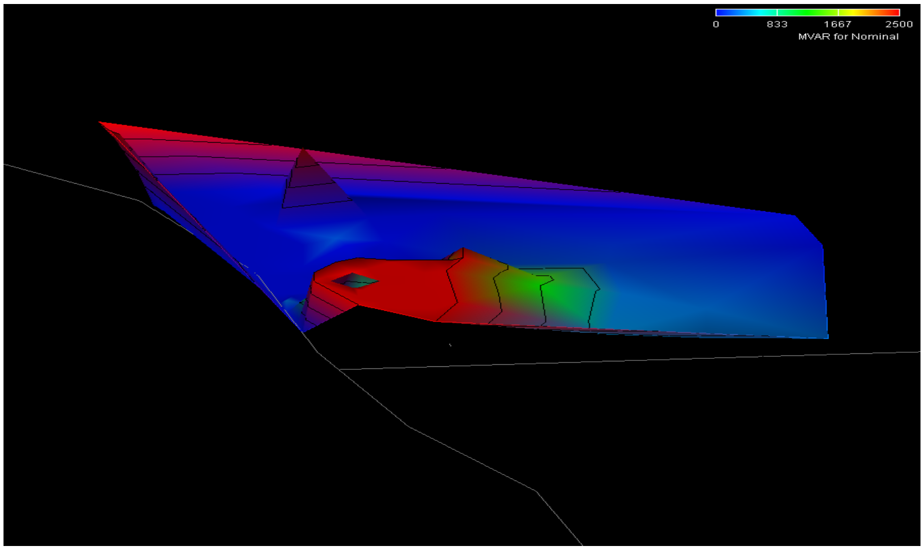
Figure 16 –Transmission Line Flow



5.2.6 Corrective Action

Figure 17 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 behavior at the remaining stations.

Figure 17 –Corrective Action

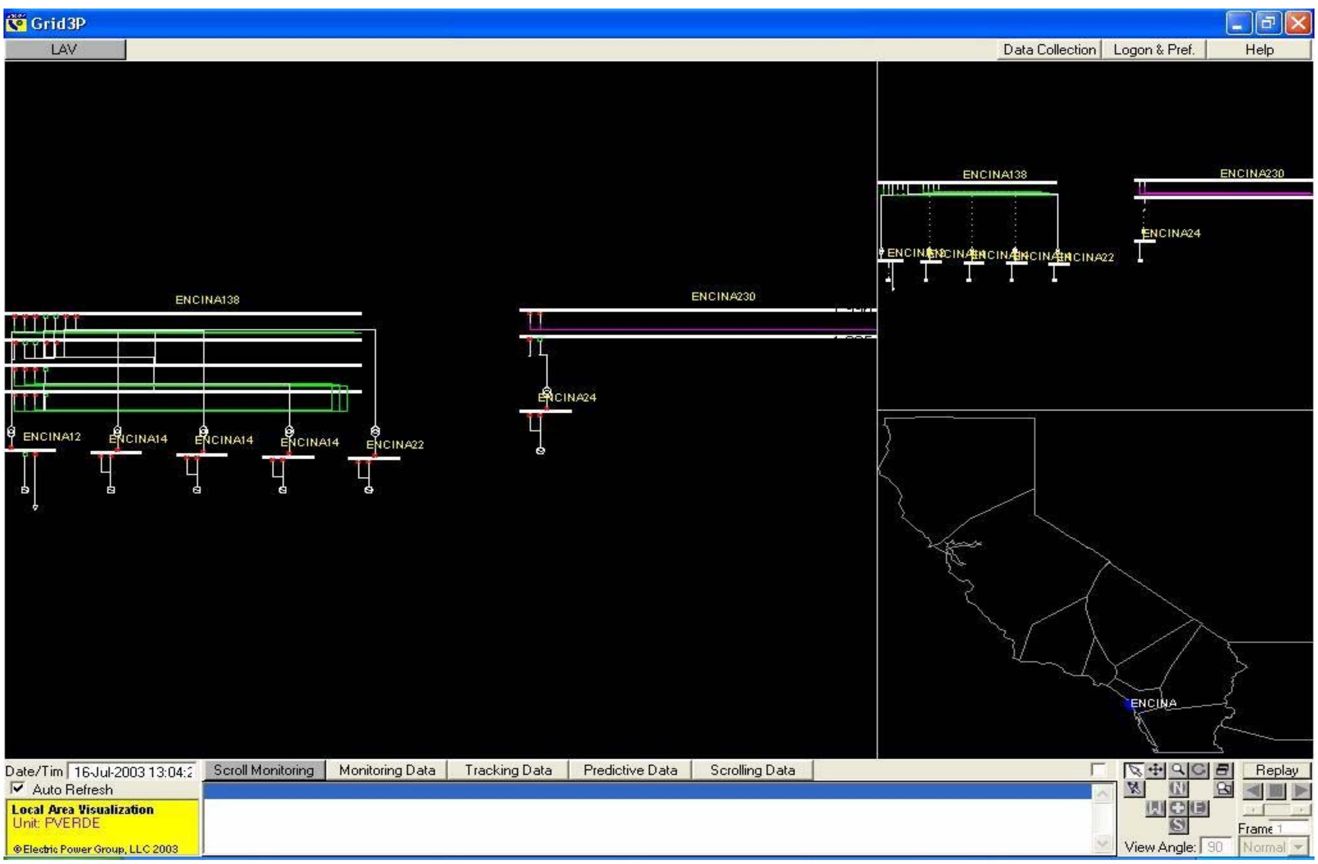


5.3 Local Area Visualization

The Local Area Monitoring main window comprises four main elements as shown in Figure 18:

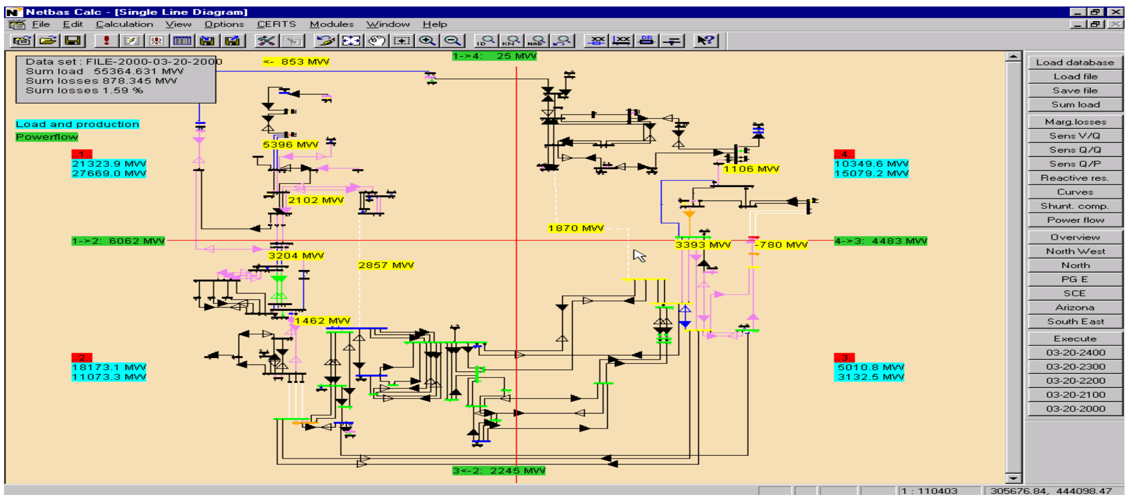
- Grid Presentation Window – Presents grid as a schematic one-line diagram.
- Main Menu Line – Contains general menus for the module. These menus are **not used** in the VAR Management module. Pressing the right mouse button in the grid presentation window background activates the menus and functions for this module.
- Main Button Bar –Lists the most frequently used functions.
- Message Line – Continuously displays messages from the program to the operator.

Figure 18 – Local Area Monitoring Display



The one-line diagram, as shown in Figure 19, is a complex visual display of the local network details. The diagram identifies four areas with numbers in red backgrounds. Below them, the numbers with blue background show the Area's net load and power production. Numbers inside the diagram with background in light green show the active power flows. Those numbers with background in dark green show the magnitude and the sense of the power interchange between the indicated Areas. Arrows in the lines indicate direction of MW (solid) and MVAR (empty) flows. The buttons in the right side of the screen are the diverse options to get to deeper levels in the visual analysis structure. The buttons in the upper side allow selection of different functions from the PSCE network calculations.

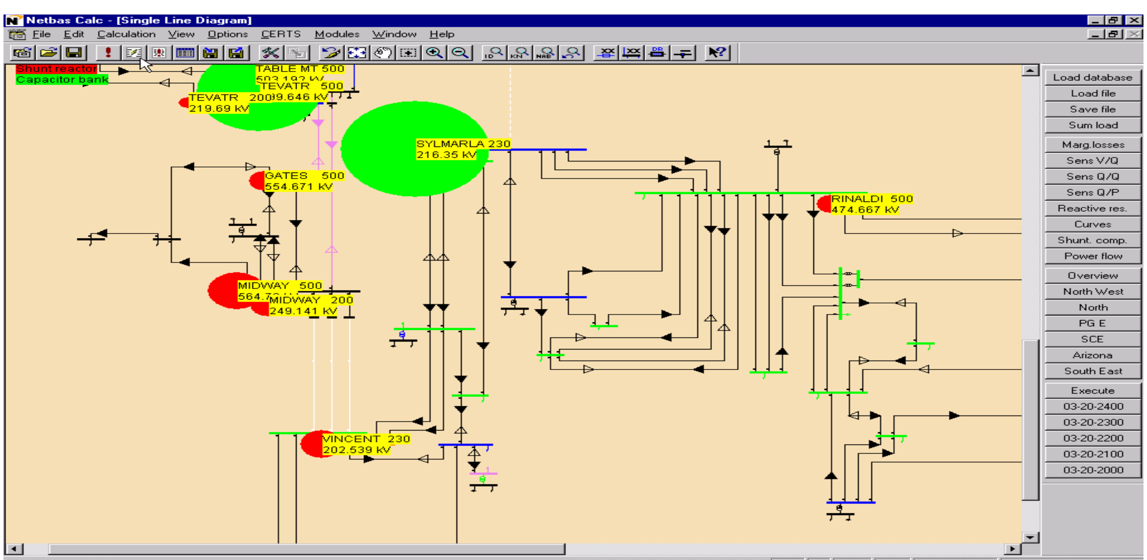
Figure 19 – One Line Diagram Visual Component



5.3.1 Shunt Reactor and Capacitor Bank Reserves.

Figure 20 shows the compensation reserves in the network as dark green circles. The red circles show the location and the capacity of the shunt reactors and the green ones show the capacitor bank reserves. The names and the numbers with the background in light green show the names of the substations and the actual voltage on those stations.

Figure 20 – Shunt Reactor and Capacitor Bank Reserves



5.3.2 Sensitivities V-Q and Q-P

The local area sensitivity functions analyze how each station, within the display window, respond to changes in active and reactive load. Sensitivity is measured in kV/MVAR, and it indicates how much the voltage will change by a load increase of one MVAR in the actual station. As a MVAR load increase always results in a voltage drop, a negative number represents the sensitivity.

Figure 21 and Figure 22 show the V-Q and Q-P voltage sensitivities, respectively. The red bars represent positive values and blue bars the negative values. Labels and numbers with background in light green color show the names of the substations and sensitivity values represented by the bars. The labels with orange and pink background show the biggest positive and the lowest negative sensitivity values.

Figure 21 – V-Q Sensitivity

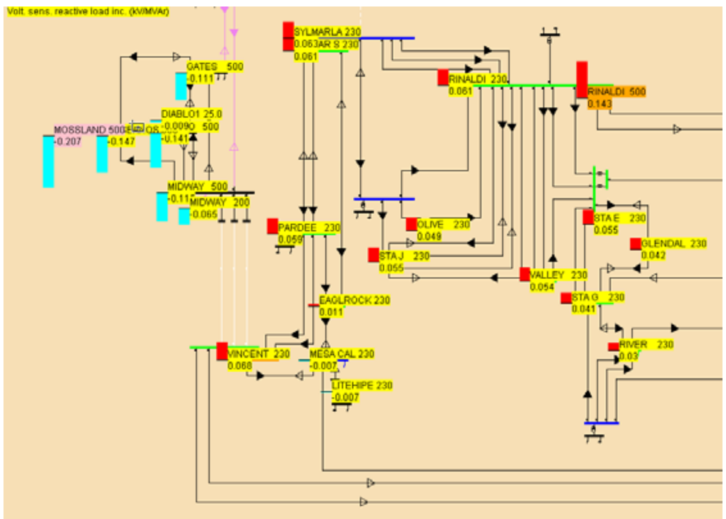
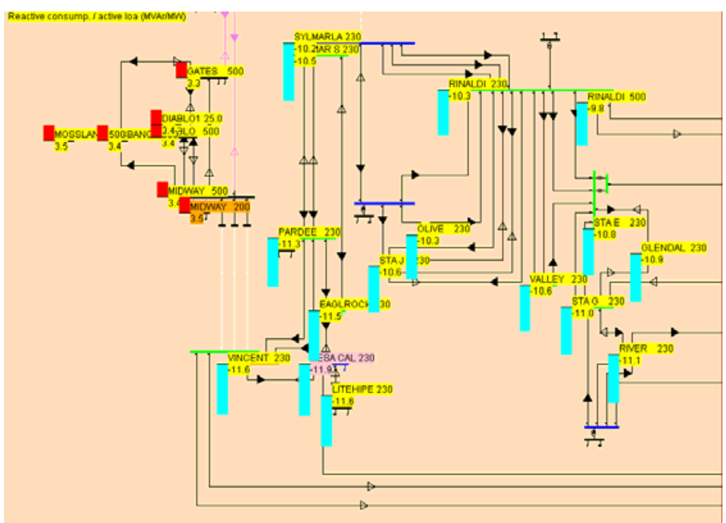


Figure 22 – Q-P Sensitivity

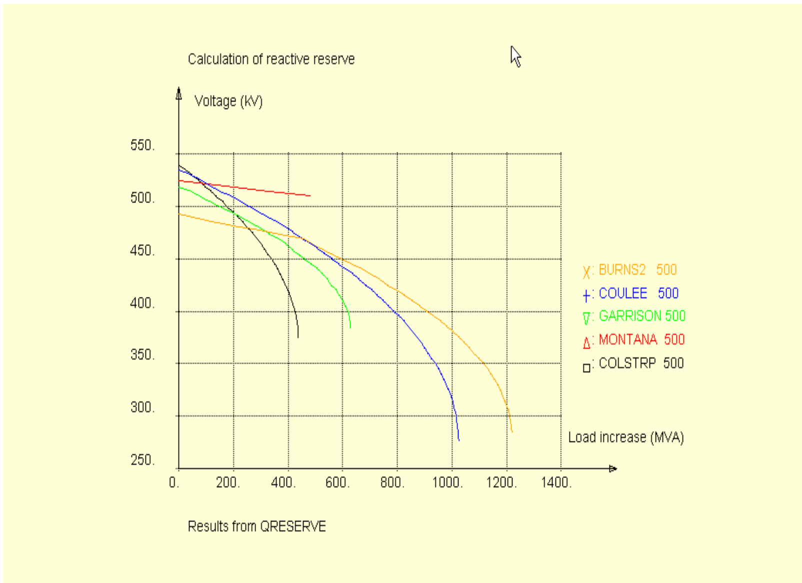


5.3.3 Distance from Voltage Collapse

Local area voltage collapse has two display options, Collapse MVA Distance and Worst Collapse Curves. The Collapse MVA Distance option analyzes the grid displayed in the main graphical window with respect to distance to voltage collapse from each bus displayed. The result from the analysis is displayed as bars indicating the distance to voltage collapse, measured in MVA.

The Worst Collapse Curves option calculates and displays nose curves for the four most critical and the least critical bus. The result of the analysis is displayed as curves indicating the distance to voltage instability, measured in MVA, as shown in Figure 23.

Figure 23 – Voltage Collapse Curve



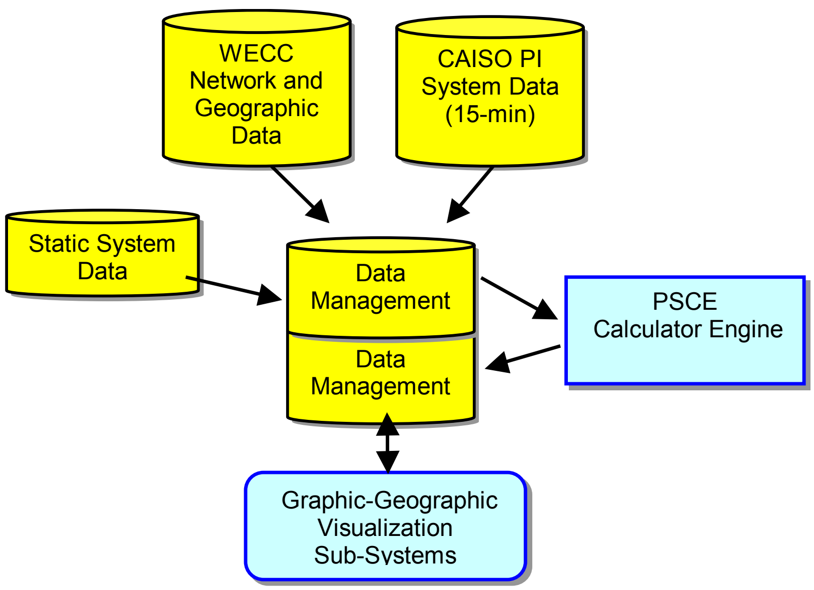
6 DESIGN SPECIFICATION

The Real-time VAR Management application has been designed to provide five main functions: monitoring and alarming, voltage sensitivities, distances from voltage collapse, corrective action and WECC compliance, and replay.

6.1 Real-time VAR Management Overview

Figure 24 is an integrated high-level view of the Real-time VAR Management design and its primary components.

Figure 24 – Real-time VAR Management Application Integrated Functional Infrastructure



The following are functional overviews for each of the components layers:

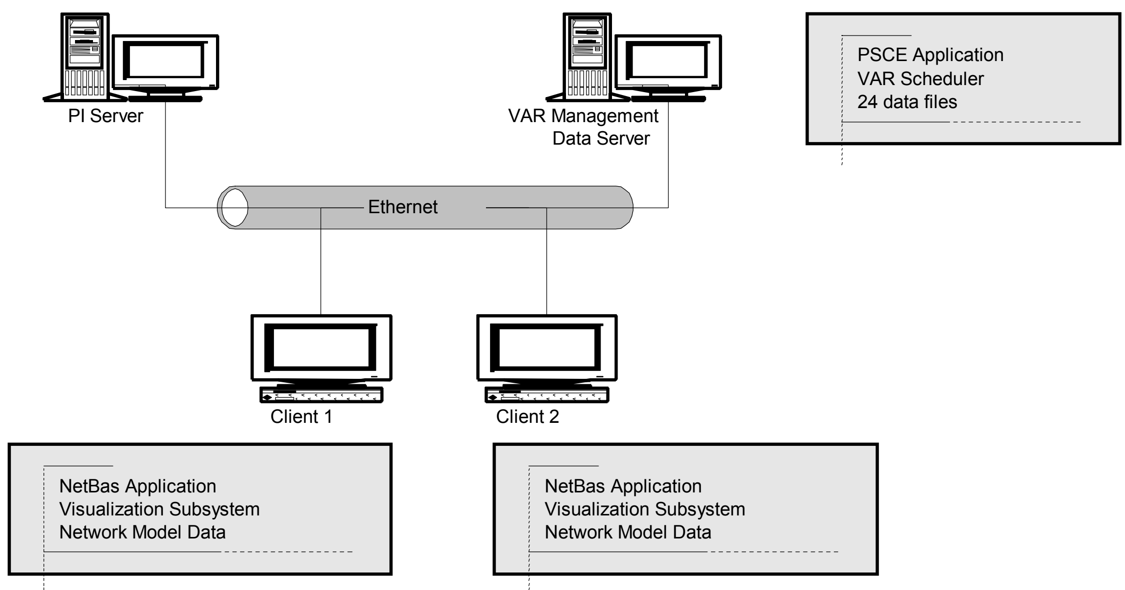
- **Graphic-Geographic Visualization** – The visualization subsystem enhances the interpretation of the modeling results. It incorporates geographic, graphic, and tabular information as well as animated presentation of results. This integration method allows extension and enhancement without extensive software modification.
- **Power System Calculating Engine (PSCE) -** This program calculates voltages in all the system busses, sensitivities for key busses, and real and reactive power flow in the network's lines.
- **Data Management**. There are two major elements of data management. The first element supports data collection from the CAISO PI system, the WECC Network data, and the static/non-PI system data. It also supports the mapping of the data into PSCE. The second element is the interface between the PSCE system and the Visualization subsystem.

- **WECC Data** – This data contains the network topology and configuration data for the transmission network.
- **CAISO PI Data** – This data contains the near real-time updates of measured values extracted from the EMS.
- **Static System Data** – This data is not updated through the PI system.

6.2 Real-time VAR Management Hardware and System Software Requirements

The computer and network configuration for the VAR management system requires three workstations and network connections as shown in Figure 25.

Figure 25 – VAR Management Hardware / Network Configuration



Following are the main hardware and software components for the Real-time VAR Management desktop workstation.

- Computer Hardware – PC based, network ready workstation. The platform for the Real-time VAR Management application allows users an easy interaction with the application and visualization subsystems. The main characteristics of the workstation will be:

Table 3 – Computer Hardware

Client Machines (2)

Processor:	Pentium® III processor, 733MHz
Memory:	512 MB RDRAM
Monitor:	19” Very High Quality Monitor
Graphics Card:	Matrix Millennium or equivalent

1st Hard Drive:	18GB Ultra SCSI (15,000 rpm)
Floppy Drive:	3.5" 1.44MB Floppy Drive
Operating System:	Microsoft® Windows 2000®
Mouse:	Microsoft Intellimouse® (2-button w/scroll)
CD Read-Write Drive:	8X/4X/32X IDE CD Read-Write
Additional Software	MS Office Professional

Data Server

Processor:	Pentium® III processor, 933MHz
Memory:	1GB RDRAM
Monitor:	19” High Quality Monitor
Graphics Card:	Matrix Millennium or equivalent
1st Hard Drive:	18GB Ultra SCSI (15,000 rpm)
Floppy Drive:	3.5" 1.44MB Floppy Drive
Operating System:	Microsoft® Windows 2000®
Mouse:	Microsoft Intellimouse® (2-button w/scroll)
CD ROM, DVD, and Read-Write Drives:	8X/4X/32X IDE CD Read-Write
Additional Software	MS Office Professional

6.3 Functional Design

6.3.1 Monitoring

The monitoring functions are functions to display abnormal conditions in the grid. These display functions apply to the nodes displayed on the screen at the moment you apply the function. To check the entire grid, make sure that you zoom out to include the entire system on your screen.

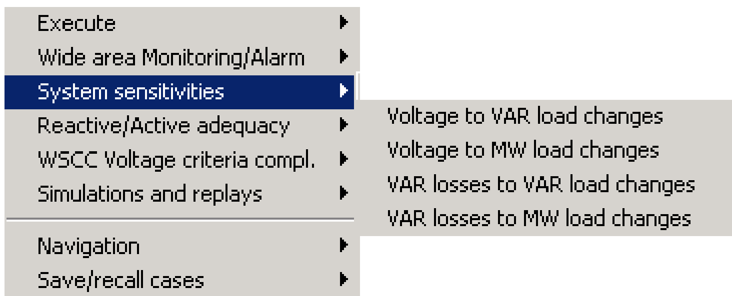
Abnormal Voltages

Selecting the “Abnormal voltages” option from the “Wide area monitoring” menu will identify busbars having a voltage drop or a voltage increase of more than 5% compared to the nominal voltage for the busbar.

Voltage drop is displayed with red bars, while too high voltages are displayed using blue bars. For each of the bars, the voltage drop is presented as a number (in percentage of the nominal voltage for the busbar) along with the name of the busbar. A negative number indicates voltage increase.

6.3.2 Sensitivities

The system sensitivity functions are functions to analyze how each and every node in the system responds to changes in active and reactive load. These functions are activated in the VAR Management function menu by pressing the right mouse button in the grid presentation window background, and choosing the “System sensitivity” menu.



Voltage to VAR Load Changes

The “Voltage to VAR load changes” displays how sensitive the nodes are with respect to voltage change with an increase in the reactive load.

The sensitivity is measured in kV/MVAR, and indicates how much the voltage will change by a load increase of 1 MVAR in the actual node. As a load increase always results in a voltage drop, a negative number represents the sensitivity.

The sensitivity is displayed as light blue bars on the busbars in the graphical window. The magnitude of the busbar indicates the sensitivity for the node, compared to the worst node analyzed. A display is shown on the next page. The results for the worst and the best node are printed on the screen with different background colors, the pink background color representing the worst sensitivity.

Voltage to MW Load Changes

The “Voltage to MW load changes” displays how sensitive the nodes are with respect to voltage change with an increase in the active load. The display is similar to the display for the reactive load changes, described above.

VAR Losses to VAR Load Changes

The displays how sensitive the system is with respect to how much reactive power must be produced to cover an increase in the reactive load. This is a positive number that will be displayed with a red bar in the graphical window. A display is shown on the next page.

VAR Losses to MW Load Changes

The “VAR losses to MW load changes” displays how sensitive the system is with respect to how much reactive power must be produced to cover an increase in the active load. The display is similar to the “VAR losses to VAR load changes” as described above.

6.3.3 Distance from Voltage Collapse

The “Reactive adequacy” option analyses the grid displayed in the main graphical window with respect to distance to voltage instability for each and every busbar displayed. This is a time consuming analysis, so make sure you have zoomed to the busbars you wish to analyze before activating the function.

The result from the analysis is displayed as bars indicating the distance to voltage instability, measured in MVAR. The worst and the best busbars are indicated by printing out the result, the pink background indicating the busbar closest to voltage collapse.

Worst adequacy curves

The “Worst adequacy curves” option calculates and displays nose curves for the four most critical and the least critical busbar in the “Reactive adequacy” calculation.

After displaying the curves the user can close the curve window by pressing the ‘x’-field in the upper right corner of the window, or return to the main graphical window using the “Windows” option.

6.3.4 Corrective Action

Calculations identify the MVAR required to drive all voltages to a nominal value.

6.4 Visualization

6.4.1 Wide-Area Visualization

Need text

6.4.2 Local-Area Visualization

Need text

6.5 Process Performance Parameters

Data Protocols. Three different data protocols are used in the application; one is the data interface protocol with the PI real-time data system. This protocol utilizes the PI system’s API and TCP/IP for data interchange. The second interface is to the PSCE using command line arguments. The third interface is with the Visualization Subsystem using command line arguments.

End User Displays Response Time. There are three cases of display response time measurements:

(1) Call a display of existing data

For case one, the elapsed time between an end user calling a display and the time validated or calculated data already residing in the PSCE results appears on the user display will be less than 15 seconds.

(2) The time required for real-time data extraction from the PI system, the data validation, and new forecast and network calculations.

For case two, the elapsed time after a user requests a display and the new data appears on the display is no more than 1 minute. This case includes the time required for the PI System data transfer, data validation and new forecast/network calculations for a maximum of 1000 time series.

(3) Calling a display simultaneous to the calculation of new network values

For case three, the elapsed time between a user calling a display of data already in the database, while a new set of network calculations is requested, will not exceed 1 minute.

6.5.1 Real-time VAR Management Integration Scheme

As previously shown in Figure 24, the Real-Time VAR Management Application's integrated system includes PSCE input/output data, algorithms, and wide and local area visualization. Automatically, the Data Management subsystem extracts data from CAISO's PI server every 5 minutes. The Master Scheduler pulls data, runs PSCE calculations, and distributes data to clients from the VAR management data server. Clients utilize the visualization program to switch between real-time and working data. Each client can store up to 24 10-minute cases.

The following is the summary description of the main processes:

Data Input. The CAISO PI server saves data in a time-series database. The data archived includes control area loads, voltages, and reactive reserves. WECC data provides the network topology and configuration data for the transmission network.

Data Management. This VAR Management Data Server is used to store the entire Real-time VAR Management application's input, filtered and output data, parameters of the models, as well as data mining queries and selected data mining results.

Data Filtering and Validation. To assure data quality, the application includes an input data filtering process for raw actual data. Outputs of the different models will be consolidated and also archived on the clients' hard drives in order to allow Operating Authority Dispatchers and System's Operators to interact with these results via the Information Management System.

PSCE. The Real-time VAR Management application runs a load flow of the power system periodically, or on demand, using voltages in all the system's buses and real and reactive power flow in network's lines. The program saves a maximum of 24 cases from the most recent periodic execution.

APPENDIX A

SUMMARY OF REQUIREMENTS FOR CAISO HARDWARE / SYSTEM SOFTWARE AND DATA REQUIREMENTS FOR THE VAR MANAGEMENT PROJECT – October 12, 2000

CERTS has summarized the following hardware, system software and data requirements needed from CAISO to be able to continue with the deployment of the VAR Management and project in accord with revision-0925K of the project schedules submitted to CAISO.

7 Hardware / System Software Requirements For The VAR Management Project

- Characteristics of CAISO Security Coordinator Console Workstation

  Processor: Pentium® III processor, 733MHz
  Memory: 512 MB RDRAM
  Monitor: 19" Very High Quality Monitor
  Graphics Card: Matrix Millennium or equivalent
  1st Hard Drive: 18GB Ultra SCSI (15,000 rpm)
  Floppy Drive: 3.5" 1.44MB Floppy Drive
  Operating System: Microsoft® Windows 2000®
  Mouse: Microsoft Intellimouse® (2-button w/scroll)
  CD ROM, DVD, and Read-Write Drives: 8X/AX/32X IDE CD Read-Write
  Additional Software: MS Office Professional
- Characteristics of CAISO Security Coordinator Support Workstation

  Processor: Pentium® III processor, 733MHz
  Memory: 512 MB RDRAM
  Monitor: 19" Very High Quality Monitor
  Graphics Card: Matrix Millennium or equivalent
  1st Hard Drive: 18GB Ultra SCSI (15,000 rpm)
  Floppy Drive: 3.5" 1.44MB Floppy Drive
  Operating System: Microsoft® Windows 2000®
  Mouse: Microsoft Intellimouse® (2-button w/scroll)
  CD ROM, DVD, and Read-Write Drives: 8X/AX/32X IDE CD Read-Write
  Additional Software: MS Office Professional
- VAR Management Data Fetcher from CAISO-PI System

  Processor: Pentium® III processor, 933MHz
  Memory: 1 GB RDRAM
  Monitor: 19" Monitor
  Graphics Card: Matrix Millennium or equivalent
  1st Hard Drive: 18GB Ultra SCSI (15,000 rpm)
  Floppy Drive: 3.5" 1.44MB Floppy Drive
  Operating System: Microsoft® Windows 2000®
  Mouse: Microsoft Intellimouse® (2-button w/scroll)
  CD ROM, DVD, and Read-Write Drives: 8X/AX/32X IDE CD Read-Write
  Interface Card to connect to CAISO PI System
  Additional Software: MS Office Professional

8 VAR Management Data Requirements Needed From CAISO

- The initial SDG&E model supplied by CAISO is missing the following buses:

15021 PALOVRDE 500 kV
19220 N GILA 69 kV
20118 ROA-230 230 kV
20149 TJI-230 230 kV
21025 ELCENTRO 230 kV
24131 S ONOFRE 230 kV
An updated network model including all SDG&E buses is required.

- 24-hour schedules for load distribution factors and breakers schedules for data not available from the CAISO PI-system, and any other network data required to solve a GE-type power flow.
- Identification of ten worst outages for the initial CAISO SDG&E network.

9 CERTS Database Questions for CAISO

- How many and what data points CAISO estimates coming from the PI system for the SDG&E system?
- Will be there multiple input PI-nodes? Or, will be only one input PI-node?
- For the WECC reduced model included in the initial network, what additional data besides SDG&E could be available from the CAISO-PI system?
- Could CAISO email CERTS a layout or list of the PI data that will be available for the VAR Management project?

10 CAISO Setup and Authorization to Work at CAISO-Alhambra

CERTS already is running the SDG&E model in the VAR prototype. CERTS is ready to start testing the application algorithm in the CAISO Alhambra environment.

[illegible]PENDIX B

REAL-TIME VAR MA[illegible] [illegible]ND GRID MANAGEMENT TOOLS DESIGN OVERVIEW

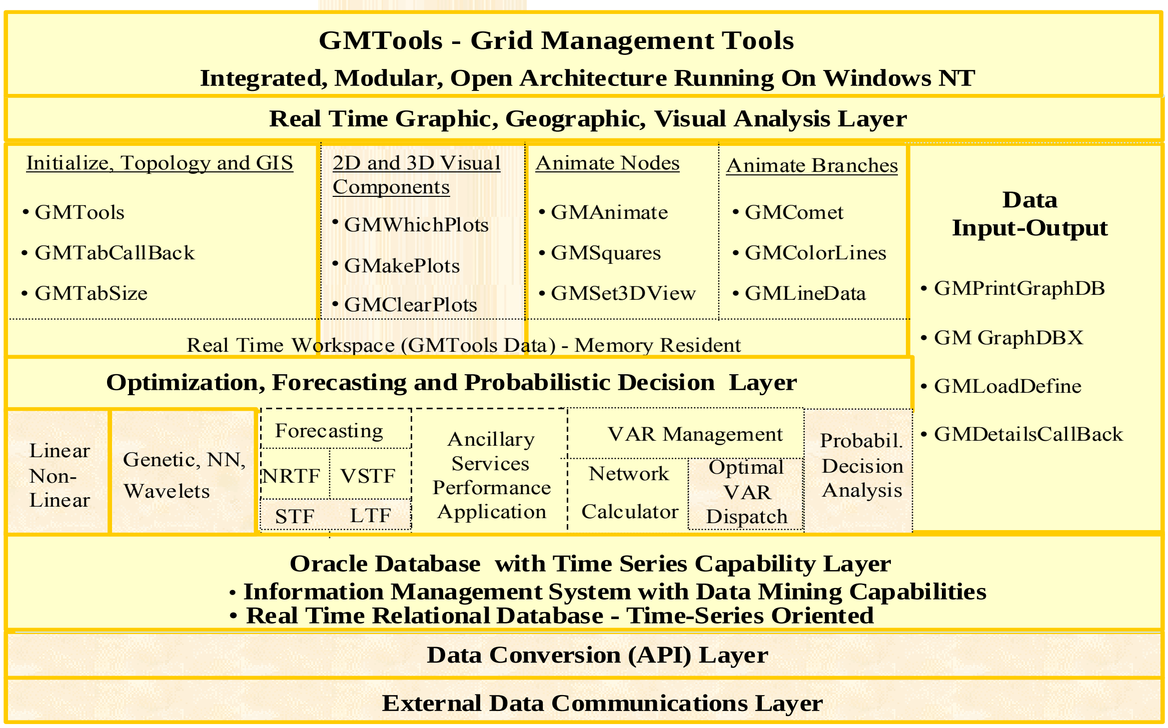
11 CERTS Grid Manag[illegible] (GMTools)

Figure 26 is a view of C[illegible] [illegible]agement Tools (GMTools); an integrated, modular open architecture structu[illegible] for developing and prototyping CERTS reliability adequacy applications, ar[illegible] [illegible]e CAISO VAR Management.

Figure 26 below shows [illegible] modular design components of Real-time VAR Management application [illegible]r with details for the routines currently available in the GMTools visualization[illegible]

GMTools is being specif[illegible] and implemented to develop end user reliability applications, training aids [illegible]on technology solutions. These tools will assist in the development of too[illegible] with the monitoring, operational and marketing requirements originated [illegible]ulation and energy markets currently underway worldwide.

Figure 26 –Real-time V[illegible] [illegible]nt Application as an Integrated Component of [illegible]ment Tools (GMTools)



Real-time VAR Management application will utilize GMTools as its primary infrastructure for: data communications, data format conversions, real-time time-series oriented database, data mining and the generic forecasting and probabilistic routines. The ASPTP prototype will also use the same GMTools infrastructure.

Real-time VAR Management application uses the GMTools visualization layer to create the hierarchical performance, tracking and prediction displays. Visualization routines are shown in the upper part (dark line) grouped in five classified blocks according to their utilization. The Visualization Toolbox Layer is a subset of routines, which interface with output data from the optimization, forecasting, probabilistic and decision analysis solvers to present past, current and near term future information for Operating Authority, Operators and Marketers on tabular, 2D and 3D graphical, geographic, concurrent and animated visualization displays.

APPENDIX C

EXECUTIVE SUMMARY OF THE FUNCTIONAL AND DESIGN SPECIFICATION FOR THE CAISO PROTOTYPE

RELIABILITY ADEQUACY TOOL FOR VAR MANAGEMENT PROTOTYPE

Background

Industry restructuring has driven the California Independent System Operator (CAISO) to manage a larger, more complicated, and dynamic grid. However, the existing support systems and tools used to manage the grid are based on the deterministic procedures of traditional energy management system (EMS) data and applications. To address the shortcomings of the current generation of tools, CERTS developed a vision for integrated, real time reliability adequacy tools.

The Reliability Adequacy Tool for VAR Management (prototype) is a component of CERTS' vision. It has been developed and prototyped for the CAISO operators so they can ensure compliance with the new WECC grid reliability standards.

Value to CAISO and Industry

Todays operators lack the singular control of reliability and efficiency processes as they did in the past. In addition, there are many new players interacting with the network, each with differing levels of understanding and operating experience. This situation demands new tools to identify adequacy of suppliers (generation), distribution (transmission), and retail (distribution). To be efficient and effective, operators must monitor current performance, historical performance, and most important predict near term behavior. The VAR Management application delivers these capabilities to the system operator.

Real Time VAR Management

The Reliability Adequacy Tool for VAR Management delivered to CAISO contains four main functions: performance monitoring, tracking, probabilistic predictions and simulations.

- Performance Monitoring – monitor CAISO's compliance with National or WECC Reliability standards for adequate voltages and reactive reserve margins.
- Tracking – The program time tags and tracks substation bus voltages, reactive reserves and the CAISO's voltage performance.
- Probabilistic Prediction – The program uses Powel's Network Calculator (NetBas) engine and the Near Real Time Forecast (NRTF) algorithm. Using real time data these programs provide short-term probabilistic predictions for load, reactive reserves needs, voltages sensitivities and distances before voltage collapse.
- Simulation – This function provides the CAISO Security Coordinators with preventive security assessment and self-training capabilities utilizing interactive simulations with historical and forecast data.

The Application evaluates CAISO's compliance with NERC and WECC reliability standards for voltage stability at key substations. The performance parameters for each of the four major functions above are based on the NERC and WECC metrics for reliability standards and voltage stability.

- NERC Policies 2 and 10 which address transmission operations and ancillary services
- WECC and the following policies and guidelines:
  h) "Voltage Stability Criteria, Undervoltage Load Shedding Strategy and Reactive Power Reserve Monitoring Methodology",
  i) "Dynamic versus Static VAR Sources",
  j) "Undervoltage Load Shedding Guidelines".

The network calculation determines the voltages, voltage sensitivities and distances before voltage collapse at key buses. It also calculates active and reactive flows through the network for current conditions and for near real time load forecast.

The tool for VAR management also includes an enhanced visualization subsystem that aids the Security Coordinator's identification and analysis of voltage stability problems. The visualization methods and techniques are better suited to the new operational challenges raised by the operation of bigger and more complex control areas under competitive market pressures. A key question that the dispatcher can now answer is *"how much can I demand from the system before it causes a blackout?"*

System Hardware

The Reliability Adequacy Tool for VAR Management utilizes standard Intel/Windows based workstations interconnected using Ethernet. This straightforward hardware configuration facilitates integration to the CAISO's current and future information systems.

The applications are loosely integrated with the CAISO's PI information system for data extraction, and this integration can be enhanced as the PI data expands its repository of measured values.

Deliverables

Functional Specification	October 20, 2000
Factory Test completed	December 22, 2000
Field Test completed	January 31,2001
Final Delivery	February 2, 2001