Arnold Schwarzenegger
Governor

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

APPENDIX IV

Real Time Voltage Monitoring and VAR Management System (User's Guide)

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:

Lawrence Berkeley National Laboratory

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

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

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Real Time Voltage Monitoring and VAR Management System

User's Guide

FOR
CALIFORNIA INDEPENDENT SYSTEM OPERATOR
SECURITY COORDINATORS

Version 0.95
November 8, 2002

CERTS
Consortium for Electric Reliability Technology Solutions

California ISO

TABLE OF CONTENTS

Page

1	Introduction	3
2	VAR Management System Overview	3
3	VAR Management Utilization Overview	4
	• Wide-Area Visualization	4
	• Local Area Visualization	5
	• Data Sources and Periodicity of the Real Time Data	6
	• Accessing the System	7
4	Wide-Area Display Generic Components	7
5	Wide-Area Monitoring Displays	11
	• Voltage Selection	11
6	Wide-Area Alarming and Monitoring	12
7	Wide-Area Voltage Sensitivities	13
8	Wide-Area Voltage Collapse Distances	14
9	Wide-Area Corrective Action	15
10	Line Flows	15
11	WSCC Voltage Compliance	16
12	Transition to Local Area Monitoring	18
13	Local Area Monitoring	19
14	Local Area – Main Button Bar	20
15	Local Area – Menu	21
16	Local-Area Voltage Sensitivities	25
17	Local-Area Voltage Collapse Distances	26
18	Local-Area Voltage Remedial Action	27
19	WSCC Compliance	32
20	Outage Assessment	34
21	Save and Recall Cases	35
22	Setup	36
23	What If Simulations	37
24	Application Utilization	38
	Attachment # 1 - Security Coordinator Enhancement Suggestions, Trouble Report Log and Contact Phone Number	41
	Attachment # 2 - WSCC Voltage Guideline	43

1. Introduction

The Voltage Monitoring and VAR Management application is intended for the Western Systems Coordinating Council (WSCC) Security Coordinator, located at the California Independent System Operator (CAISO). One of the primary functions of the Security Coordinator is the monitoring of real time transmission operations and this application will serve as an effective tool in support of this critical monitoring function. The purpose of the application is to provide the Security 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.

2. VAR Management System Overview

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). The Voltage Monitoring and VAR Management application is intended for CAISO Security Coordinators. The purpose of the application is to provide the Security Coordinator with and integrated solution for geographic 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 WSCC guides for voltages and reactive reserves. The following table is an overview of the VAR application major functionality and corresponding user visualization

Table-1 VAR Management Functionality and Visualization Overview

Functionality / Target Areas	Monitoring and Alarming	Voltage Sensitivities	Distances From Voltage Collapse	Corrective Action and WSCC 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

3. VAR Management Utilization Overview

To respond to operations of larger and more complicated control areas, a fundamental goal for the design and development of the VAR application was to create both visualization displays and key reliability indicators that will enhances the Security Coordinators overall system monitoring function.

An effective use of the applications capabilities is to follow four (4) 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 on the original trouble.

To support the basic four-step utilization process described above, the VAR Management application uses three methods (see figures 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 is to plot the information on a graph that the engineering staff refers to as a "nose curve".

Wide Area Visualization (Figure #1) – The Wide Area Monitoring module of the VAR Management application displays real time and calculated data in a non-traditional format. As an example - the view screen displays simultaneously the San Diego area 230KV voltage alarming, patterns and sensitivities using geographic 3D visuals.

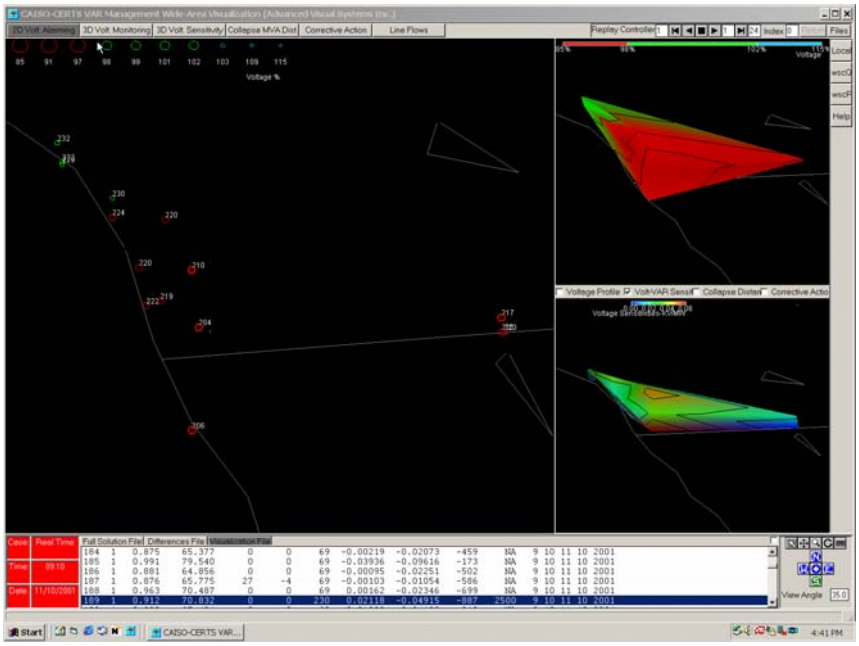


Figure #1 Wide Area Visualization

Local Area Visualization (Figure #2) - The Local Area Monitoring module of the VAR Management application takes real time data, converts it into meaningful information, and displays it on conventional interactive one-line diagrams and on a nose curve graph (Figure #3). Within the VAR Management application, for both wide and local areas, the user can evaluate the San Diego transmission system for voltage sensitivities, reactive reserve margins, corrective actions and compliance with the WSCC voltage guideline and historic replay.

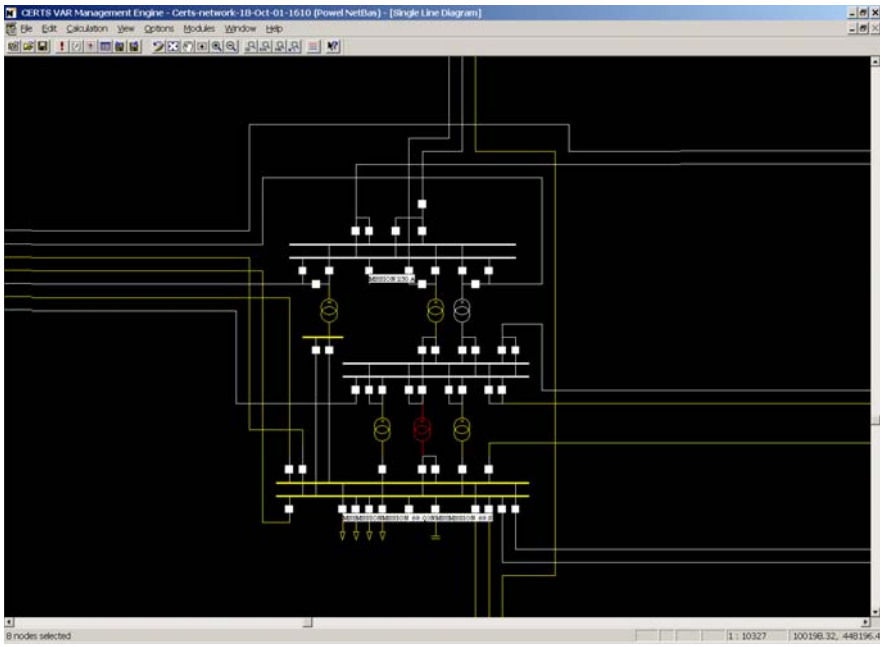


Figure #2 Local Area visualization

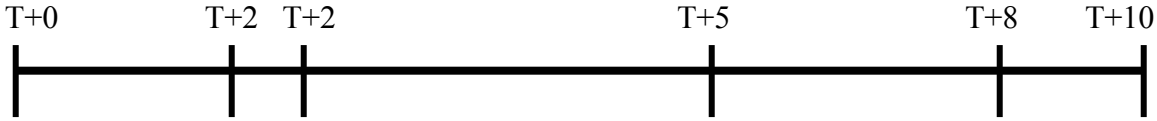
Figure #3 Voltage Collapse Curve (Nose Curve)

Following is a description of the VAR Management data sources, its collection, processing and displaying periodicities together of the options available to access the system. Further sections will serve to guide the CASIO Security Coordinator in the use of this application for performing their routine operations of voltage control and VAR management.

Data Sources and Periodicity (scan rate) of the Real-Time Data

The Voltage Monitoring and VAR Management System application was developed as a working prototype and therefore, the system does not have the capability of a fully integrated and developed commercial EMS application. Some of the current limitations of the working prototype system are the direct use of SCADA instead of estimated data, and the periodicity (scan rate) of the real-time SCADA used. Every ten minutes, a snapshot of San Diego transmission system is transferred from the CAISO SCADA data to this application. This application uses the SCADA data to run the internal models, algorithms and calculations in order to provide the Security Coordinator with meaningful information relative to the San Diego area voltages and reactive reserve margins.

The following is the time line for the VAR Management System data processing running in a client using a 1GHz PC:



Note: Time is in minutes

- At T+0, the CAISO transfers a snapshot of their SCADA data to the VAR Management data collection and conversion module.
- At T+2, the received and converted SCADA data is presented to the VAR application algorithms.
- At T+2 , the application calculates the voltage patterns and sensitivities for each station and updates the wide and local area displays using the new voltage and sensitivitie data.
- At T+5, the application calculates the distance to voltages collapse for each bus and updates the wide-area displays using that information.
- At T+8, the application calculates the MVAR requirement to take each bus-voltage to nominal and displays that information on the wide-area displays.
- At T+10, the VAR Management System again receives a snapshot of the CAISO's SCADA data.

Note: The time to perform the calculations and process the data can be enhanced with faster machines.

Accessing the System

Double clicking the VAR Management System - CAISO icon (located on the Windows Desktop) will open the application. In addition, the application can be selected by clicking the VAR Management System – CAISO icon from Programs on the Windows "Start" menu on your PC (see Figure #4). The workstation user name is "VAR Management" and the password is "CAISO_CERTS."

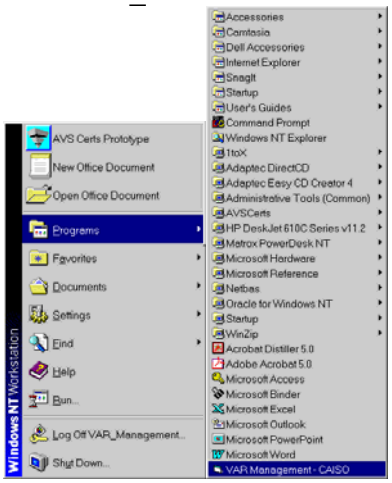


Figure #4 VAR Management Program Access

4. Wide-Area Display Generic Components

All the 2D and 3D displays described in Table-1 are designed using the main components shown in Figure-5. The following paragraphs describe in detail each of the major sections

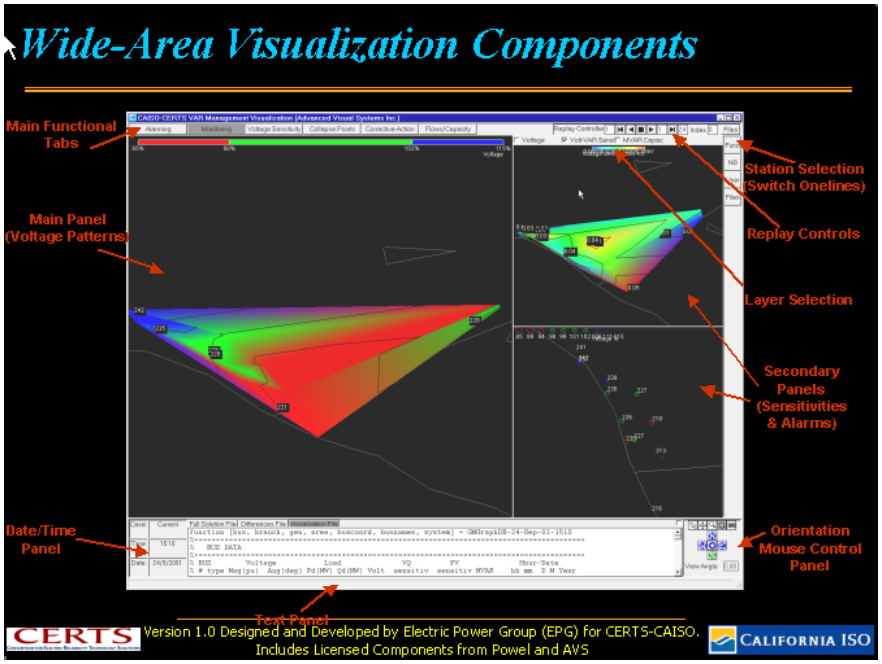


Figure #5 Wide-Area Visualization Components

Case Information - On the lower left side of the screen there is information pertaining to the case data you are viewing (see Figure #6). The appropriate boxes identify if the data is real time or historical, as well as the date and time of the case.

Figure #6 – Case Information

Navigating Using the Mouse - You can use the mouse to perform a variety of useful functions in viewing and working with the graphical display. The mouse and view controls are located in the lower right hand of the screen (see Figure #7).

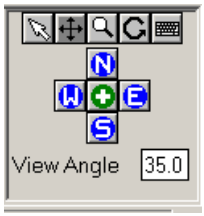


Figure #7 – Mouse Control and 3D Viewing Angle

The following are the features and how to launch them:

Function	Mouse Control Icon	What it Does
Zoom In	- Click on the magnifying glass icon, move the cursor to the viewing panel, click and hold the left mouse and move the mouse forward.	Enlarge the details of a selected picture.
Zoom Out	- Click on the magnifying glass icon, move the cursor to the viewing panel, click and hold the left mouse and move the mouse backwards.	Provide an aerial view for a selected picture.
Rotation	- Click on the open circle icon, move the cursor to the viewing panel, click and hold the left mouse	Rotate the axis of a selected picture.

	and move the mouse in the desired direction.	
Re-position Objects Being Display	- Click the crossed arrows, move the cursor to the viewing panel, click the left mouse and drag the object to the desired location in the panel.	Allows the user to re-position or center objects being displayed in the panel.
Selection Arrow	- Click the selection arrow, move the cursor to the viewing panel, click the left mouse on the desired location on any of the displays.	

3D View Angle – Click on the "3D Voltage Monitoring" button which places the 3D Voltage Monitoring display in panel # 1. The user has the ability to change the viewing angle of the 3D displays. This can be accomplished by changing the view angle (see Figure #8) by typing in a new angle, hit "enter", and then selecting the N, E, S, W or center cross point. The default viewing angle is set for 35 for the best viewing results.

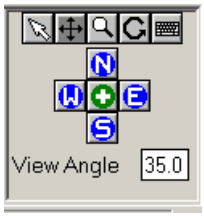


Figure #8 – Mouse Control and 3D Viewing Angle

Replay Function – Click on the "3D Voltage Monitoring" button which places the 3D Voltage Monitoring display in panel # 1 or another 3D display may be selected in panel # 1. The VAR Management application has the ability to store up to 24 real-time cases, six cases per hour, for a total of 4 hours of history. The most recent case or current one is number 1 and the oldest case is numbered 24. The controls for the replay function are located on the top right corner of the screen (see Figure #9).

Figure #9 – Replay Controller

The Replay Controller buttons from left to right:

- Go to start – will rewind to the first case selected.
- Reverse Play – will play the cases backwards.
- Stop

- Play – will start replaying the selected cases.
- Go to end – will advance the replay function to the last case selected.

To replay the past 4 (four) hours of history perform the following:

- Click on the "Files" button. On the top left portion of the screen a "Replay Files" window will pop up (see Figure #10). Using the scroll bar, scroll up to case 1; highlight it and all the cases down to and including case 24. Click on OK at the bottom of the window.

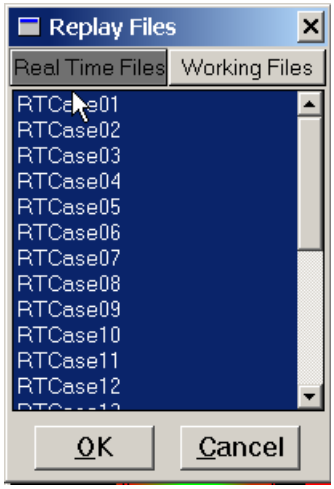


Figure #10 – Replay Files

- Press the "Go to start" button
- Press the "Play" button
- To return to real time press the "Return" button

Case Data Window – At the bottom center of the screen is a window that contains data relating to the case being viewed (see Figure #11). The case window has 3 (three) buttons associated with it and they are located on the top right portion of the window and that are labeled as follows:

- Full Solution File – This file contains text, in a tabular format, pertaining to the current case being viewed. The stations are listed by name, with the station voltage, generation and load (MW and MVAR)
- Differences File – This file will identify the MW and MVAR differences between this case and the previous case.
- Visualization File – This file also contains text, in a tabular format, but contains much more information pertaining to the current case being viewed. Stations are listed by bus numbers, with the bus voltage in per unit and angle, MW and MVAR load, sensitivities and reactive reserve margins. When a station is selected from one of the three panels the information pertaining to that station will be highlighted in this window.

Note – This data window can be enlarged by placing the curser over the small "white box" (located on the top right side of the data window) and clicking. To reduce the window to its normal size click the box again.

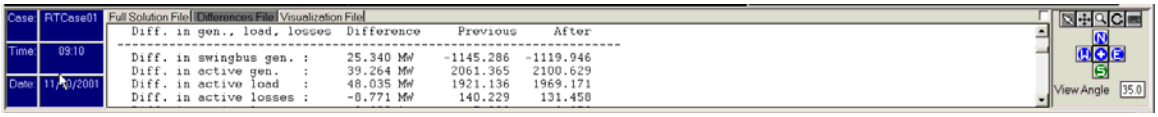


Figure #11 – Case Data Window

5. Wide-Area Display Overview

After the VAR Management application has opened, the first display the user sees is the Wide Area Monitoring display. This screen consists of three panels that are used to view the available displays.

Display Buttons – On the top right of the Wide Area Monitoring display there are 6 (six) buttons (see Figure 12) to select which display will be viewed from panel 1. Selecting a specific display in panel 1, also selects specific display in panels 2 and 3, as follows:

Figure #12 – Wide Area Monitoring - Display Buttons

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

Display Voltage Selection – By placing the curser in a panel and right clicking the mouse, a voltage selection window opens (see Figure 13). The user has the ability to select the voltage levels they would like to monitor. The lower voltages (22 kV and 12 kV) are generator terminal voltages not the San Diego distribution system. In addition to selecting the voltage levels the user has the ability to select the following:

- Station circles – Circles are shown that represents the geographic location for each of the stations associated with the voltage level selected.
- Station names – The station names are shown at the geographic location for each of the stations associated with the voltage level selected.
- Station crosses – On the 3D displays, red crosses are shown that represents the geographic location of each of the stations associated with the voltage level selected.
- Voltage values – Displays the actual voltage for the selected stations.

- Surface labels - On the 3D displays, the voltage is displayed on top of the 3D picture.
- Fixed width text – The font of the text (station names and voltages) will not change as you zoom in or out.
- Scalable text – The font of the text will change as you zoom in and out.

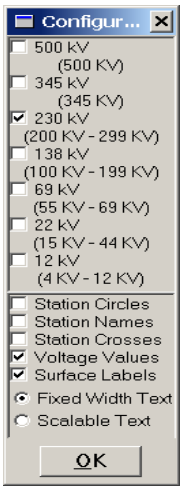


Figure #13 - Voltage Selection

If all the voltages are selected with names and actual voltages, the display becomes unreadable. It is recommended that if the user desires to monitor several voltages simultaneously, they should select the desired voltage and only the station circles, eliminating clutter. When monitoring single voltage levels, the names and/or voltages can be added without to much clutter. After making the desired selections on the Voltage Selection window click the OK button at the bottom of the window and the window will close.

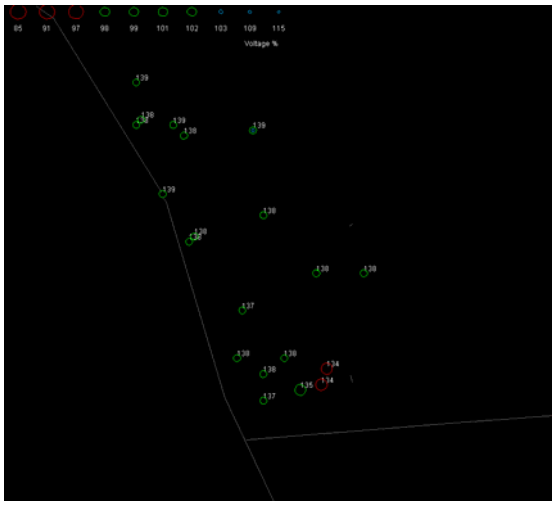
6. Wide-Area Alarming and Monitoring

2D Voltage Alarming Display (see Figure 14) – The voltage scale is from 85% to 115% of the nominal voltage. Each circle on the display represents a station in its exact geographic location. To denote an alarm condition the display uses color and the size of each station circle.

- **Red** – Red circle represents a station with a voltage below nominal and the circle gets larger as the voltage reduces. In addition, the red circle will flash if the voltage decays to 95% or below. At this time, there is no ability to reset a flashing circle.
- **Green** –Green circle represents a station with a voltage operating within the normal range.
- **Blue** – Blue circle represents a station with a voltage operating above the nominal range and the circle gets smaller as the voltage gets higher.

3D Voltage Monitoring Display (see Figure 15) – This display uses a 3D colored layer over the San Diego area to give the user a visual indication of the grids performance. This particular display shows the area voltage profile. The scale for this display is located at the top and uses the following convention:

- **Red** – Indicates the voltage is below nominal (85 to 98%).
- **Green** – Indicates the voltage is operating within the normal range (99 to 102%).
- **Blue** – Indicates the voltage is operating above the nominal range (103 to 115%).



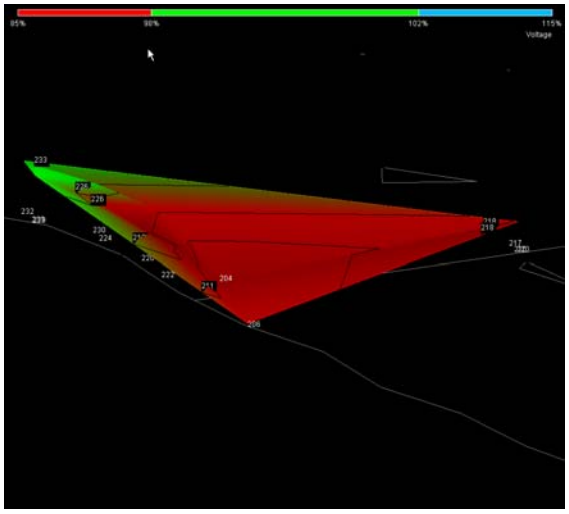


Figure #14 and 15– Wide Area Alarming and Monitoring Display

7. Wide-Area Voltage Sensitivities

3D Sensitivity Display (see Figure #16)– The voltage at a substation is sensitive to changes (up and down) in the MW and MVAR demand. This module of the VAR Management System is only performing the sensitivity for a MW increase at any given substation. After the program has performed the sensitivity analysis, assigned each substation a sensitivity color (as indicated below), then the aggregate of all the station is displayed as a 3D layer over the San Diego area. This display gives the user a visual indication of the areas voltage sensitivity. The scale for this display is located at the top center and indicates the voltage change, in kV, for a 1 (one) MW increase in load. The color convention is as follows:

- **Red** – Indicates a higher relative sensitivity to a MW load change – meaning the voltage will decay quickest at these locations. The ideal situation is to have a very low kV change (e.g. 0.01 or 0.02) for a one MW increase in load.
- **Green** – Indicates medium relative sensitivity.
- **Blue** – Indicates a low relative sensitivity.

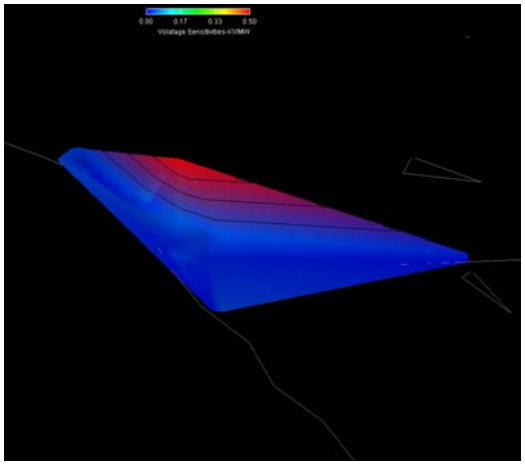


Figure #16 – Wide Area Voltage Sensitivity

8. Distance from Voltage Collapse

Collapse MVA Distance Display (see Figure #17) – The distance from voltage collapse can be expressed in MWs and MVARs, but the most accurate method of represent collapse is by using MVA, since it takes into consideration both MW and MVAR. This display, 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 3D display and that is an indication that a portion of the calculation could not solve. The scale for this display is located at the top center and indicates the MVA distance from voltage collapse. The color convention is as follows:

- **Red** – Indicates it requires the least relative amount of MVA increase to cause a voltage collapse.
- **Green** – Indicates it requires a greater relative increase in MVA to cause a voltage collapse.
- **Blue** – Indicates it requires the largest relative amount of MVA increase to cause a voltage collapse.

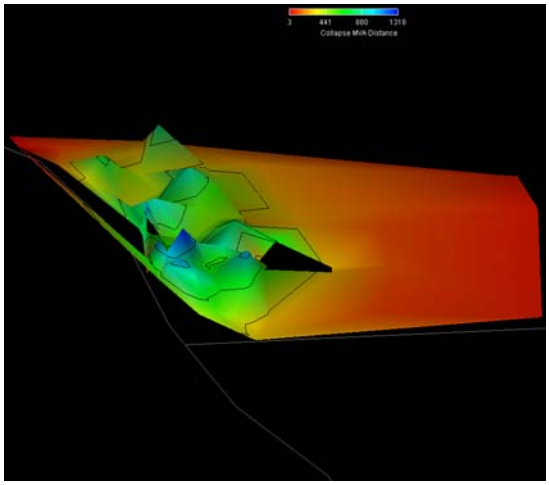


Figure #17 – Distance from Voltage Collapse

9. Corrective Action

Corrective Action (see Figure #18) – This display, using the 3D colored layer, 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 and each stationed is assigned the appropriate color, as indicated below. The 3D layer is an aggregate of the colors for all the stations associated with the voltage selection the user has made. The scale for this display is located at the top right and indicates the MVAR requirement to bring the area voltage back to nominal. The color convention is as follows:

- **Red** – Indicates a larger relative MVAR requirement to restore the area to nominal voltage.
- **Green** – Indicates a medium relative MVAR requirement to the area to nominal voltage
- **Blue** – Indicates a low relative MVAR requirement.

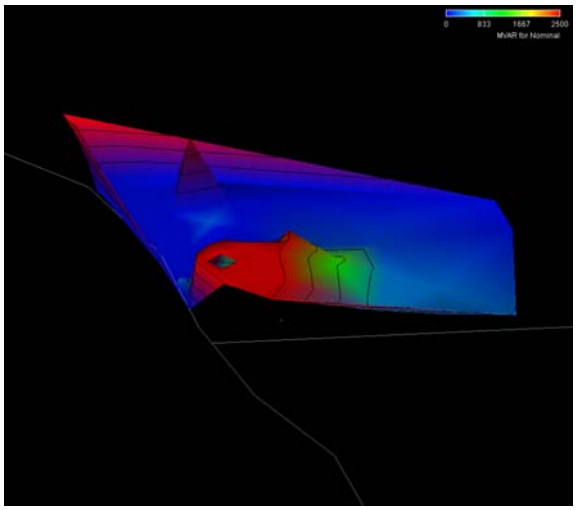


Figure #18 –Corrective Action

10. Line Flows

Line Flows (see Figure #19) – There are 2 (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 line capacity remains available. The second scale "Actual MVAR" uses two colors to indicate the level of the MVARs flowing on the line.

- **Green** – Indicates the MVAR flow on the line is above a pre-defined range for each voltage.

- Blue – Indicates a low level of MVAR flowing on a line, the range varies for each voltage.

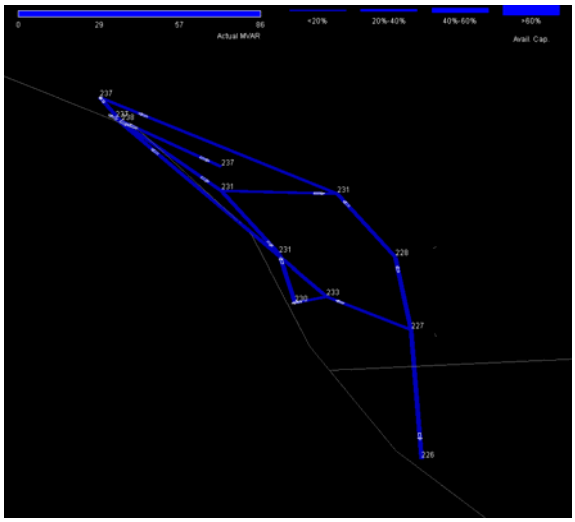


Figure #19 – Line Flow Display

11. WSCC Voltage Compliance

WSCC Reactive Reserve Margin Guideline (see Attachment #1) – The WSCC has established operating guidelines to ensure there is an adequate reactive reserve margin at critical load busses. The reactive reserve margin provides sufficient reactive resources (MVARs) to the system allowing it to remain stable after a likely contingency. The VAR Management application has the ability to analyze the San Diego transmission grid for compliance with the WSCC guideline. It is recommended to run this function at least once per hour, especially during the on peak periods. This compliance assessment is performed as follows:

- Click on the "WSCQ" button, located on the top right of the screen (see Figure #20). This assessment can take a few minutes to complete.

Figure #20 – WSCC Guideline Compliance Assessment

- The application will start the 11 (eleven) step process required to evaluate compliance with the WSCC VQ guideline (sensitivity of voltage to increments of reactive load).
- When completed, a text window (see Figure #21) will appear identifying the worst contingency that was evaluated, most deficient bus, actual reactive margin, results for the 20 worst busses under n-0 and the most deficient bus performance under n-0 and n-1.
- Closing the text window will display the portion of the San Diego transmission system (one-line diagram) that is most deficient with a summary of the performance displayed in the top left corner of the screen.
- To run the second portion of the evaluation click on the "Wide Area VAR" button located on the Windows application bar, on the lower portion of your PC. This will return you to the Wide Area Monitoring screen.
- Click on the "WSCP" button, located on the top right of the screen (see Figure #14). This assessment can take a few minutes to complete.
- The application will start the 7 (seven) step process required to evaluate compliance with the WSCC PV guideline (sensitivity of voltage to increments of MW load).
- When completed, a text window will appear identifying the worst contingency that was evaluated, most deficient bus, required active power margin, results for the 20 worst busses under n-0 and the most deficient bus performance under n-0 and n-1.
- Closing the text window will display the portion of the San Diego transmission system (one-line diagram) that is most deficient with a summary of the performance displayed in the top left corner of the screen.
- To return to the Wide Area Monitoring screen click on the "Wide Area VAR" button located on the Windows application bar, on the lower portion of your PC.

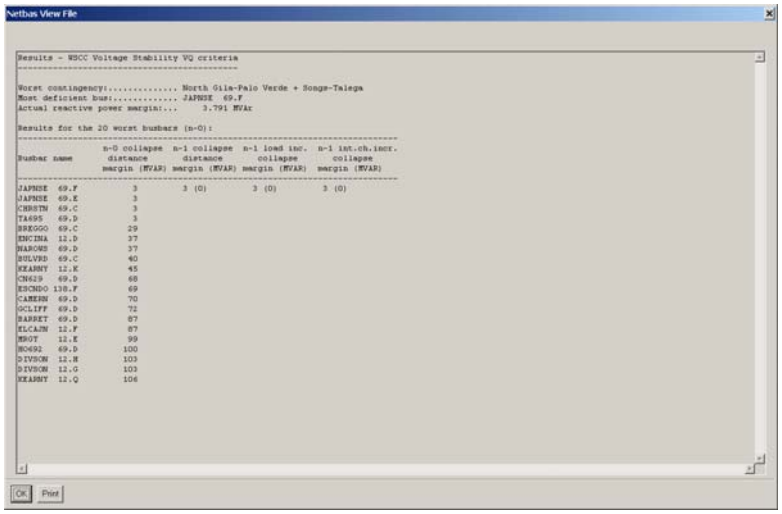


Figure #21 – WSCC VQ Tabular Output

12. Transition to Local Area Monitoring

Transition to the Local Area Monitoring Displays - From the Wide Area Monitoring displays a user can access a local station by performing the following steps:

- Click on the "white arrow" button located on the mouse controller panel.
- On one of the 3 (three) panels of the Wide Area Monitoring screen (see Figure 22), point the curser on the location you want to view on the local level (i.e. a station circle or a point on the 3D layer) and click the left mouse. You will notice the reference point turns "blue" on all associated displays.
- Put the curser on the "Local" button (located on the top right of screen) and click the left mouse. A "Station Selection" window will appear on the top left of the screen. On the station selection window, highlight the station name and click on the "One Line" button below. Note: If there are several station names in the station selection window and you click on "One Lines" the display will show a single line diagram that covers all the involved stations. Therefore, it is recommended that the user remove (using the "Remove Selected" button) those undesired stations.
- A one-line diagram will appear (see Figure #23).
- To return to the Wide Area Monitoring display, at the Windows application bar at the bottom of your PC screen, click on "Wide Area VAR" icon

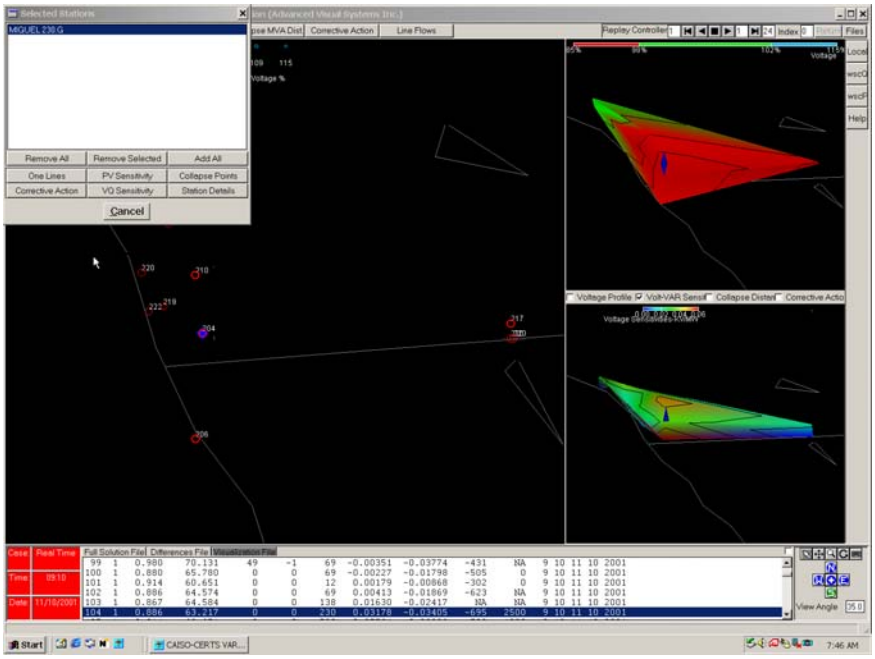


Figure #22 - Transition to the Local Area Monitoring Displays

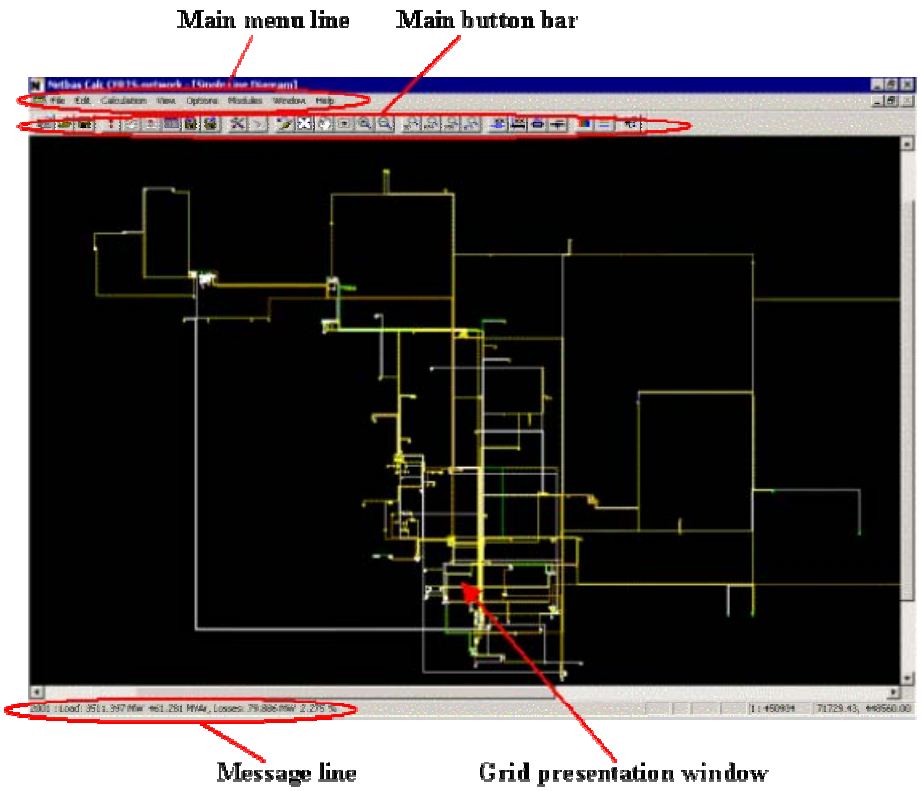


Figure #23 - Local Area Monitoring Display

13. Local Area Monitoring

The Local Area Monitoring main window comprises four main elements:

- The grid presentation window - The grid is presented as a schematic one-line diagram.
- The main menu line with the 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.
- The main button bar, where some of the most frequently used functions are available with just a mouse click.
- The message line, where messages from the program to the operator are displayed continuously.

Troubleshooting – Local Area Screen is not open (see Figure #24). Inside the Window panel (top left hand corner) you find a minimized display labeled "Sin…", expand the display by clicking the square box

. Place the curser over the display

and right click the mouse, which brings up the menu. Scroll down the menu to "Recall/Save" and click on "Recall Real-Time" and this will bring up the San Diego system one-line.

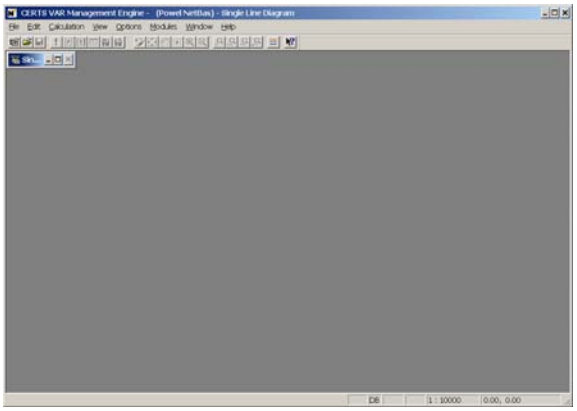


Figure #24 - Local Area Monitoring Troubleshooting

14. Local Area Monitoring – Main Button Bar

Main Button Bar:

- - Load flow - this will run the load flow module in the local area monitoring mode only, with constraints.
- and - Show calculations and results – this is the same information that is available in the lower center section of the Wide Area Monitoring display.
- - Refresh or clean the one line diagram (i.e. remove station names).
- - Adjust network diagram – this button will take the user to a global overview of the San Diego transmission system.
- - Move view – allows the user to manually move what is being viewed on the screen. To release this function hit the "Escape" key on the keyboard.
- - Zoom – allows the user to zoom into a specific section of the transmission system. With the left mouse button depressed, drag the mouse drawing a box around the area you want to zoom into, and release the mouse. While the zoom function is activated, clicking the left mouse will continue zooming in and clicking the right mouse will zoom out. To release this function hit the "Escape" key on the keyboard.
- and - Zoom in and Zoom out - allows the user to zoom in and out, but not to a specific area. The use of these buttons will require the coordinated use of the "move view" function.
- - Zoom by ID – allows the user to find a station and zoom in. Used by the support staff with the appropriate ID numbers.
- - Find Node (Station) – allows the user to find a station and zoom in. A selection "Find Node" window will open with a blank space for the node name. Enter the station name and click OK. If you are not sure of the name

click on the box next to the blank node name field and a selection window will pop up. After selecting the station, click OK and then click OK on the "Find Node" window.

- - Show Marked Nodes - allows the user to zoom into a specific station. With the left mouse depressed, drag the mouse drawing a box around the area you want to zoom into, and release the mouse. The station will change color indicating it has been selected, and then click the "Show Marked Nodes" button to zoom in. To eliminate the color over the station just click the left mouse.
- - Show Previous – will display the previous display.
- - Display Voltage Levels – Normally, the color of the lines in the Local Area Monitoring mode is based on utilization of the available transfer capability (ATC). See the "Setup" section for "utilization" colors. The "display voltage levels" button allows the user to select different colors for three of the San Diego transmission voltages

15. Local Area Monitoring – Menu

Local Area Action Menu - Pressing the right mouse button in the background (not over a station or line) of the grid presentation window, activates the menus and functions for the Local Area Monitoring module, see Figure #25.

Figure #25 - Local Area Action Menu

Most of the functions available in the module are found using this menu. These functions are described in the following chapters.

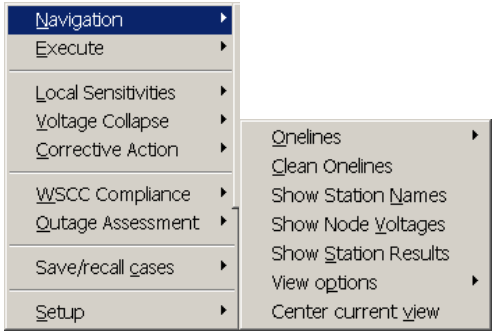


Figure #26 – Navigation Sub-menu

Navigation (see Figure #26)- The navigation functions allow you to alter the appearance of the display for the grid area you have loaded, or to load a new grid area. Highlighting "Navigation" will bring up a sub-menu.

Navigation Sub-menu:
One-Line Diagram (see Figure #27) – This option allows the user to display the whole grid or portion of the grid. In the current version of the VAR Management Application, only a detailed grid for the San Diego area, and a simplified grid layout for the WSCC area can be displayed.

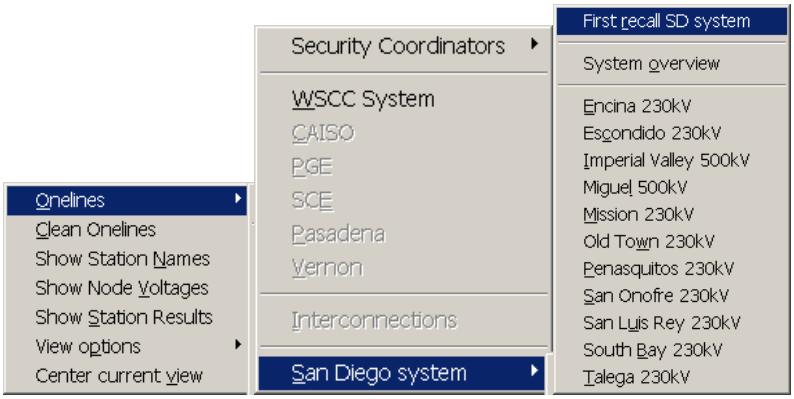


Figure #27 – One-Line Diagram Selection

First recall SD system - Used to get back to the detailed San Diego system from the reduced WSCC model. It can also be used to get back to the present base case San Diego.

System overview - Displays the whole San Diego detailed model in a one-line diagram.

The specific station choices - Encina 230kV, Escondido 230 kV etc. a detailed one-line diagram of that particular station, including station voltage and line flows.

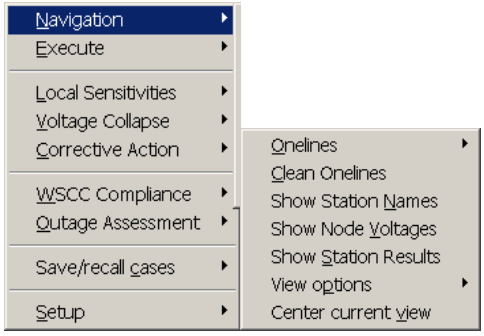


Figure #28 – Navigation Sub-menu (continued)

Clean One Lines - The "Clean One Line" option is used to clear the graphical view of result presentation bars or other results, or simply to restore the last view if the view for some reason is not updated.

Show Station Names - The "Show Station Names" displays the names of the stations currently displayed in the one line diagram.

Show Node Voltages - Displays the node (station) voltages for nodes currently being displayed in the one line diagram.

Show Station Results - Displays quantities associated with a single node.

View Options:

- One Line – Displays the San Diego transmission system in a classical one-line diagram format.
- Geographic - As an alternative, the grid can be viewed in a correct geographic layout.

Center Current View - This function centers the one line diagram viewed on the display.

Executing Calculations - The execute functions are functions to run load flow analysis and create files for the Wide Area Monitoring 3D visualization program. 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 "Execute" menu, see Figure #29.

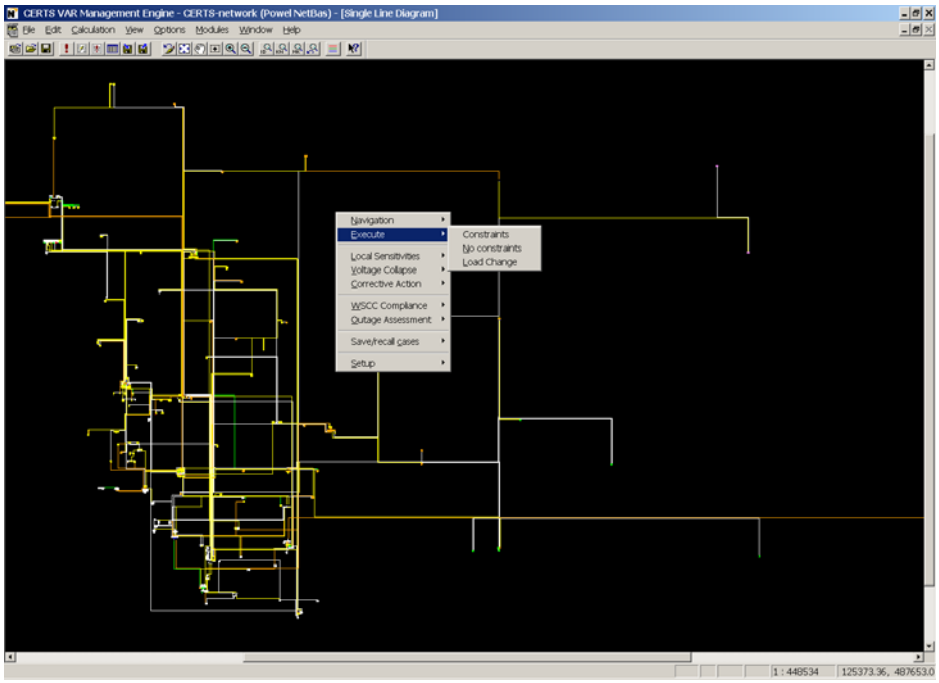


Figure #29 – Execute Functions

The execute functions always runs the load flow on the data set loaded into the system with the changes that have been previously entered. This means that changing e.g. the load of the entire system will be effective until a fresh data set is loaded or the program is closed.

Constraints – By choosing the "Constraints" option in the "Execute" menu a load flow with a predefined set of maximum and minimum voltages is performed. The results are presented by coloring the components and buses in the window according to the load of the components (as a percentage of rated capability) and the voltage drop for the buses (as a percentage of the base voltage). At the message line at the bottom of the screen, the program displays the total active and reactive power in the system for the load flow, along with the active losses in the system.

No Constraints – In some cases there could be a problem making the load flow calculation converge (solve) with narrow voltage limits. The "No-constraints" option in the "Execute" menu allows the user to run a load flow calculation without the voltage constraints. The result presentation is similar to the presentation of the results from the "Constraints" option.

Load Change (see Figure #30) – The "Load change" option allows you to change the load for the entire system. This is useful for analyzing load changes from the current state. Selecting the "Load change" function activates a window where the user enters a new total load. The load in the current system is displayed for the user.

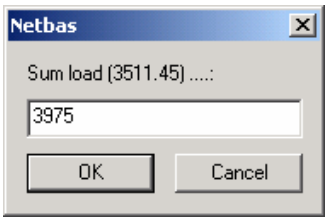


Figure #30 – Load Change Option

All the loads in the network are scaled with the factor $P_{new/}$ P_{old}, where P_{new} is the new load written in the dialog box and P_{old} is the current sum load. The load change will be active for all calculations performed until a new data set is loaded.

16. Local Area – Load Sensitivities

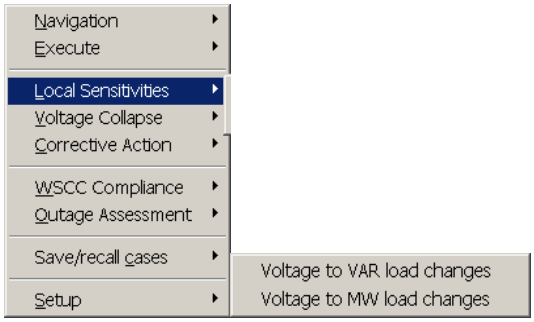


Figure #31 – Local Sensitivity Analysis

Local Sensitivities - The local area sensitivity functions are functions to analyze how each station, within the display window, responds to changes in active and reactive load. These functions are activated from the menu by clicking the right mouse button in the grid presentation window background, and choosing the "Local Sensitivity" menu, see Figure #31.

Voltage to VAR Load Changes - The "Voltage to VAR load changes" displays how sensitive the stations are with respect to voltage change with an increase in the reactive load.

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

The sensitivity is displayed as light blue bars on the buses in the graphical window. The magnitude of the bus indicates the sensitivity for the station, compared to the worst station analyzed. The results for the worst and the best node are printed on the screen

with different background color, the pink background color representing the worst sensitivity.

Voltage to MW load changes - The "Voltage to MW load changes" displays how sensitive the stations 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.

17. Local Area – Voltage Collapse

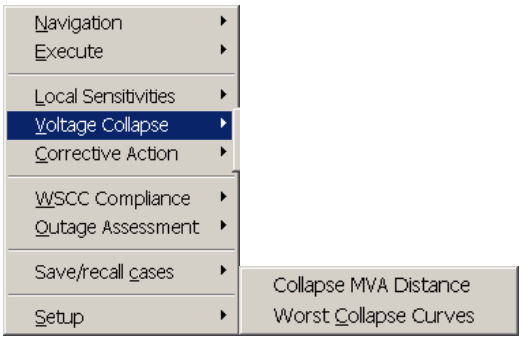


Figure #32 – Voltage Collapse Functions

Voltage Collapse (see Figure #32)- The "Collapse MVA Distance" option analyzes the grid displayed in the main graphical window with respect to distance to voltage collapse for each bus displayed. This is a very time consuming analysis, so make sure you have zoomed to the buses you wish to analyze before activating the function.

The result from the analysis is displayed as bars indicating the distance to voltage instability (collapse), measured in MVA. The worst (for the stations being evaluated it's the bus closest to voltage collapse) and that stations name has a pink background. The best bus is indicated with an orange background.

The "Worst Collapse Curves (see Figure #33)" option calculates and displays nose curves for the four most critical and the least critical bus in the "Reactive adequacy" calculation.

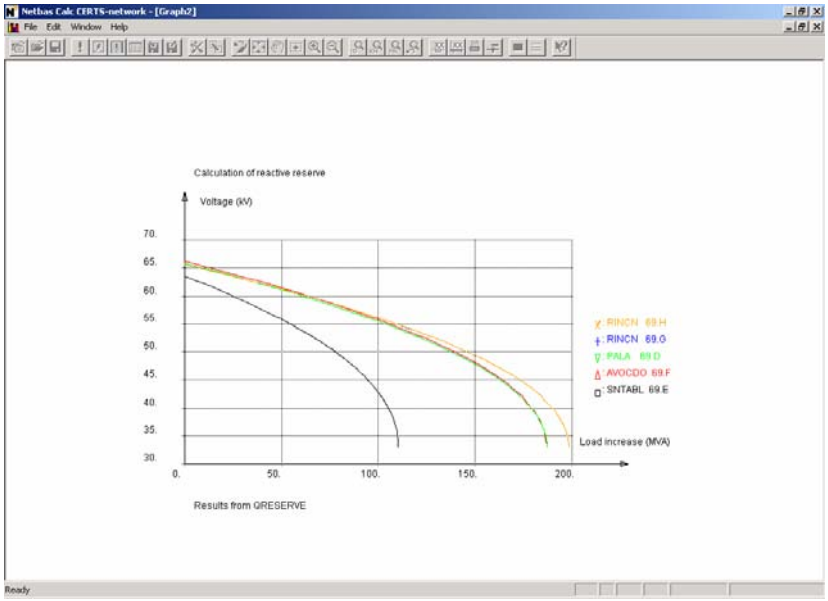


Figure #33 – Voltage Collapse Curves

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 on the menu line.

18. Local Area – Corrective Action

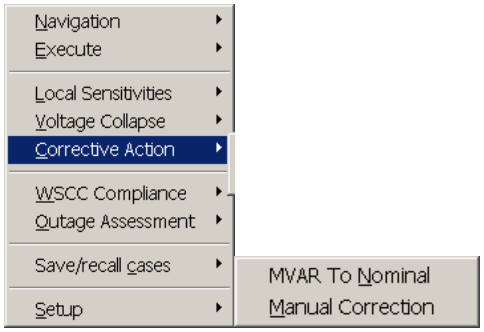


Figure #34 – Corrective Action Functions

Corrective Action (see Figure #34) - MVAR to nominal calculations are performed for all the selected stations, those located within the display window. There is also an option to initiate MVAR calculations manually for the selected stations.

The "MVAR to Nominal" calculation results are presented in the one line diagram as, see Figure #35:

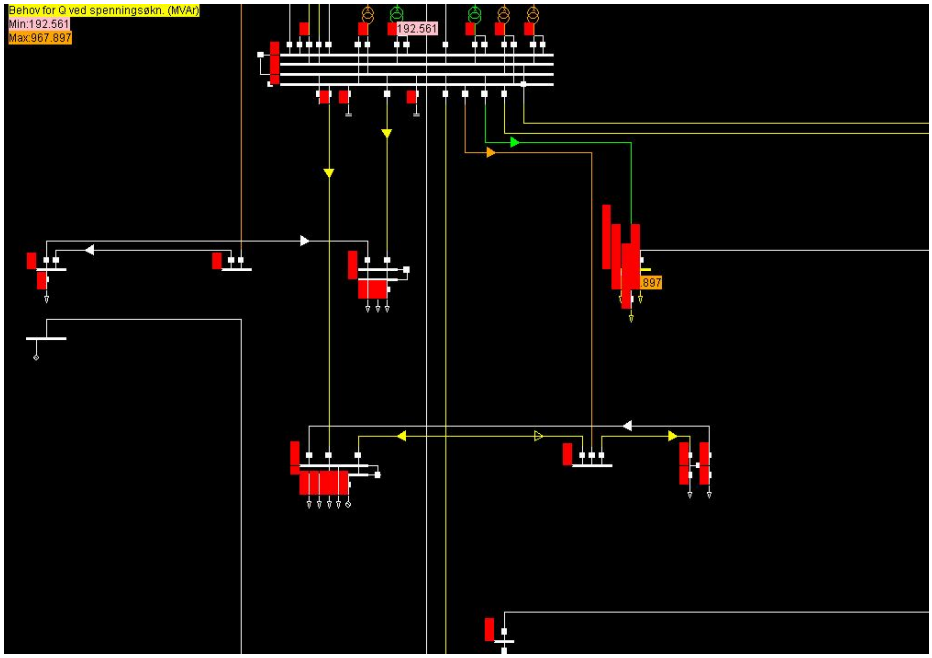


Figure #35 – MVAR to Nominal Calculation Results

Bars show MVARs required that would bring the actual voltage to nominal. If the application is not able to find a solution (not enough available MVAR resources to bring actual voltage to nominal), the MVAR result is set equal to –1. For the latter stations a circle indicates that no solution has been found. The largest and smallest MVAR requirements are indicated with a color legend as displayed in the top left corner.

Manual Correction - Selecting "Manual Correction" for voltage and the following window is displayed, see Figure #36:

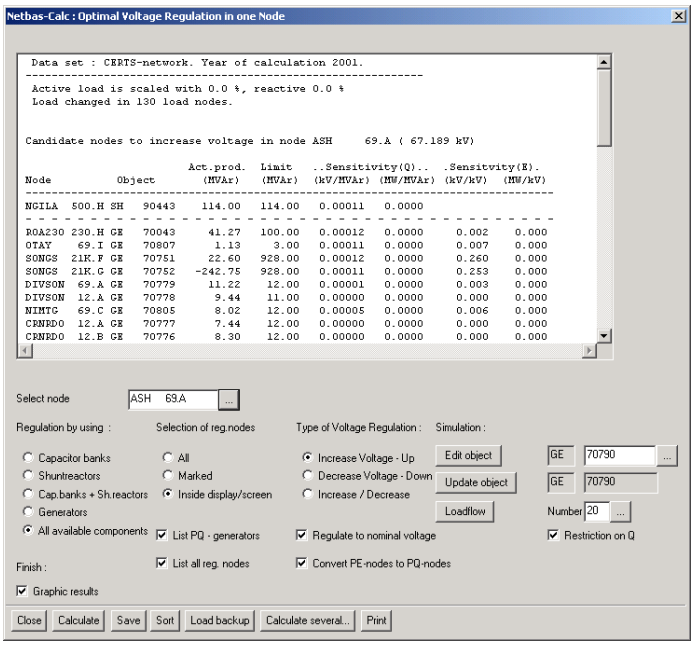


Figure #36 – Manual Correction Display

The heading highlights which dataset is being used, and also included is the information on the scaling, if any, of the active and reactive loads in the dataset, including information on how many stations have a registered load change.

The Select node function provides the user with an option to filter and select a specific node that can be analysed with respect to voltage properties.

For analysing the voltage in the node the following components and combination of components can be used: (bottom left column): "Regulation by using"

- Capacitor banks
- Shunt reactors
- Cap.banks + Shunt reactors
- Generators
- All available components

The second column from the left "selection of reg. Nodes" allows the user to select which area the regulation nodes come from:

- All
- Marked
- Inside display/screen

The third column from the left "Type of Voltage Regulation" gives a choice between up, down or both up and down voltage regulation mode.

For the last column to the right, "Simulation" there are 4 options:

- Edit object (edit any chosen object)
- Update object (apply voltage regulation to the chosen node)
- Load flow (apply a load flow solution as an alternative to sensitivity approach)
- Number (number of candidates to be considered one by one in the load flow)

In addition there are the following tick/ no tick alternatives:

- List of PE generators, which are at their max MVAR limit and are considered as PQ nodes during the MVAR calculations. (Can be switched off by removing the tick List PQ Generators)

- Regulate to nominal voltage (applies MVAR resources to regulate the voltage up or down to nominal values)

- Restriction on Q (applies limits to MVAR resources produced in components)

- List of all reg. nodes (in the window above a list of all the regulation nodes appear)

- Convert PE-nodes to PQ-nodes (convert during the simulation the PE-nodes to PQ nodes)

In the window is a display for converted generators, list of best candidates for regulating the selected node, list of the best candidate within each subgroup, e.g. best generator, and a result of the MVAR calculation for the same node.

SOBAY	15.F	GE	70814	50.57	58.00	0.00041	0.0000	0.035	0.000
ESCO	69.G	GE	70790	4.77	12.00	0.01857	0.0000	0.597	0.000
SOBAY	15.C	GE	70813	56.95	58.00	0.00003	0.0000	0.003	0.000
SAMPSN	69.W	GE	70811	75.02	100.00	0.00007	0.0000	0.023	0.000
DIVSON	12.C	GE	70780	13.52	15.00	0.00000	0.0000	0.000	0.000
TJI230	230.J	GE	70044	-11.95	100.00	0.00094	0.0000	0.019	0.000
NGLAPS	500.A	GE	70003	137.10	200.00	0.00013	0.0000	0.000	0.000
NGILA	500.H	SH	90443	114.00	114.00	0.00011	0.0000		
ESCO	69.G	GE	70790	4.77	12.00	0.01857	0.0000		
ESCO	69.G	GE	70790	4.77	12.00	0.01857	0.0000		

Node Name			Volt. (kV)	Volt.sens. (kV/MVAr)	Q-act (MVAr)	Q-max (MVAr)	Q-step (MVAr)	Q-sum (MVAr)	Q-tot (MVAr)
ASH	69.A		67.189	0.02801					
ESCO	69.G	GE	67.323	0.01857	4.766	12.000	7.234	7.234	-0.013
ENCINA	24.A	GE	67.323	0.00164	127.720	212.000	0.000	7.234	-0.013
ENCINA	22.A	GE	67.333	0.00150	143.375	150.000	6.639	13.874	-0.012
TJI230	230.J	GE	67.439	0.00094	-11.951	100.000	111.981	125.854	-1.608

Figure #37 – Manual Correction Results Display

Above:
List of candidates at the top, the best shunt reactor (SH), the best generator (GE), and the best candidate (total), in this case the ESCO generator.

Node Name			Volt. (kV)	Volt.sens. (kV/MVAr)	Q-act (MVAr)	Q-max (MVAr)	Q-step (MVAr)	Q-sum (MVAr)	Q-tot (MVAr)
ASH	69.A		67.189	0.02801					
ESCO	69.G	GE	67.323	0.01857	4.766	12.000	7.234	7.234	-0.013
ENCINA	24.A	GE	67.323	0.00164	127.720	212.000	0.000	7.234	-0.013
ENCINA	22.A	GE	67.333	0.00150	143.375	150.000	6.639	13.874	-0.012
TJI230	230.J	GE	67.439	0.00094	-11.951	100.000	111.981	125.854	-1.608
KEARNY	12.M	GE	67.440	0.00050	30.708	32.000	1.343	127.197	-1.608
KEARNY	12.B	GE	67.440	0.00050	30.709	32.000	1.343	128.540	-1.607
SOBAY	15.F	GE	67.443	0.00041	50.565	58.000	7.941	136.481	-1.607
OLDTWN	12.A	GE	67.444	0.00025	10.983	12.000	1.067	137.548	-1.607
NGLAPS	500.A	GE	67.448	0.00013	137.105	200.000	31.728	169.276	-2.410
ROA230	230.H	GE	67.448	0.00012	41.274	100.000	5.161	174.436	-2.443
SONGS	21K.F	GE	67.553	0.00012	22.601	928.000	906.097	1080.533	-2.501
SONGS	21K.G	GE	67.686	0.00011	-242.747	928.000	1176.577	2257.110	-2.611
OTAY	69.I	GE	67.687	0.00011	1.127	3.000	2.420	2259.530	-2.612
NGILA	500.H	SH	67.699	0.00011	114.000	114.000	114.000	2373.530	-33.113
PTLOMA	69.C	GE	67.700	0.00010	5.217	12.000	7.888	2381.418	-33.113
KYCORA	20.A	GE	67.708	0.00009	-2.687	100.000	103.507	2484.925	-33.113

Above:
For MVAR calculations with reference to the ASH 69.A node, it has an actual voltage value of 67.189. By applying candidates for MVAR regulation in merit order starting with ESCO the voltage in ASH is regulated up to 67.323 and ESCO is at it's limit of 12

MVAR. The total MVAR generation for the whole model Q-tot has been reduced by 0.013 MVAR.

```
 Data set : CERTS-network. Year of calculation 2001.
-------------------------------------------------------------
 Active load is scaled with 0.0 %, reactive 0.0 %
 Load changed in 130 load nodes.

Results from loadflow :
Node                ... Voltage  ...   Q-step
Name                Loadfl.    Sens.
---------------------------------------------
ASH     69.A        67.967
---------------------------------------------
ESCO    69.G  GE    68.101    67.323     7.23
ENCINA  24.A  GE    68.101    67.323     0.00
ENCINA  22.A  GE    68.111    67.333     6.64
TJI230 230.J  GE    68.216    67.439   111.98
KEARNY  12.M  GE    68.217    67.440     1.34
---------------------------------------------
ASH     69.A        68.109

 Results generators :
 Name        Voltage    Act.Q     Max.Q
-----------------------------------------
```

Above:
As an alternative, a load flow solution can be performed step-by-step using the regulation candidates in merit order. Due to non-linear ties in a power system, the load flow results might differ slightly from results obtained via the sensitivity method.

```
 Results generators :
 Name        Voltage    Act.Q     Max.Q
-----------------------------------------
ESCO    69.G   68.299    -5.000   12.000
ENCINA  24.A   24.000    68.681  212.000
ENCINA  22.A   23.449   130.672  150.000
TJI230 230.J  231.774   100.000  100.000
KEARNY  12.M   13.439    29.774   32.000
-----------------------------------------
KEARNY  12.B   13.391    28.344   32.000
SOBAY   15.F   15.536    40.965   58.000
OLDTWN  12.A   12.833     8.873   12.000
NGLAPS 500.A  550.000   120.312  200.000
ROA230 230.H  250.000    -0.600  100.000
SONGS  21K.F   20.522  -228.040  928.000
SONGS  21K.G   20.586    59.588  928.000
OTAY    69.I   69.800     0.000    3.000
PTLOMA  69.C   71.665    -5.000   12.000
KYCORA  20.A   20.184    86.514  100.000
SAMPSN  69.W   69.535    39.604  100.000
NIMTG   69.C   69.854    -5.000   12.000
SOBAY   15.C   15.753    52.190   58.000
```

Above:
Finally a list of the generators containing voltage, actual MVAR generation and MVAR limits is presented.

19. WSCC Voltage Compliance

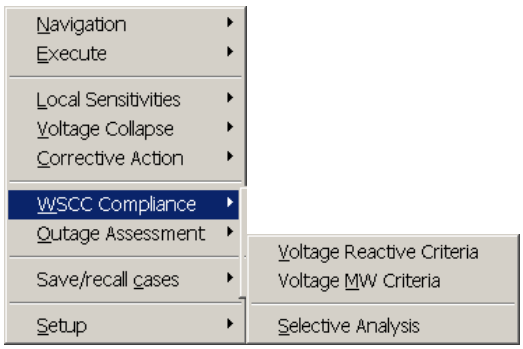
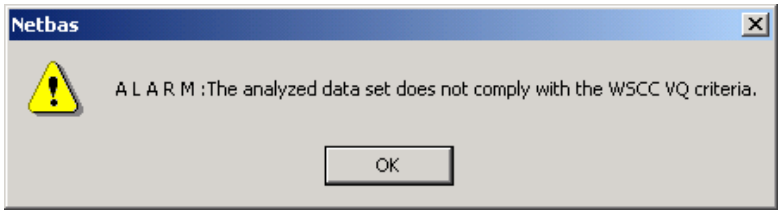


Figure #38 – WSCC Compliance Guideline Analysis

WSCC Compliance Guideline Analysis (see Figure #38) - The WSCC voltage stability assessment guideline will determine whether the transmission system is in a state close to voltage instability or not. The WSCC uses two guideline, VQ (voltage-reactive) and PV (voltage-MW), to evaluate the system for voltage instability. The VAR Management application supports both methods. Clicking the right mouse button in the grid presentation window background, and choosing the "WSCC Compliance" and clicking on "Voltage-Reactive Guideline" activate the WSCC criterion in the Local Area Monitoring function menu.

- Click on the "Voltage-Reactive Guideline" activities the analysis and takes a few minutes to complete. The application will start the 11 (eleven) step process required to evaluate compliance with the WSCC voltage-reactive guideline.
- When completed, a text window (see Figure #39) will appear identifying the worst contingency that was evaluated, most deficient bus, actual reactive margin, results for the 20 worst busses under n-0 and the most deficient bus performance under n-0 and n-1.
- Closing the text window will display the portion of the San Diego transmission system (one-line diagram) that is most deficient with a summary of the performance displayed in the top left corner of the screen.
- To run the second portion of the evaluation click the right mouse to open the menu, select "WSCC Compliance" and click on "Voltage MW Guideline" This assessment can take a few minutes to complete.
- The application will start the 7 (seven) step process required to evaluate compliance with the WSCC sensitivity of voltage to increments of MW load.
- When completed, a text window will appear identifying the worst contingency that was evaluated, most deficient bus, required active power margin, results for the 20 worst busses under n-0 and the most deficient bus performance under n-0 and n-1.
- Closing the text window will display the portion of the San Diego transmission system (one-line diagram) that is most deficient with a summary of the performance displayed in the top left corner of the screen.

When the analysis is completed, an alarm window will appear if the analyzed data set does not comply with the WSCC VQ criterion.



After clicking the OK button, the results of the analysis are displayed in a text window. If the data set complies with the criterion, the results will be presented directly.

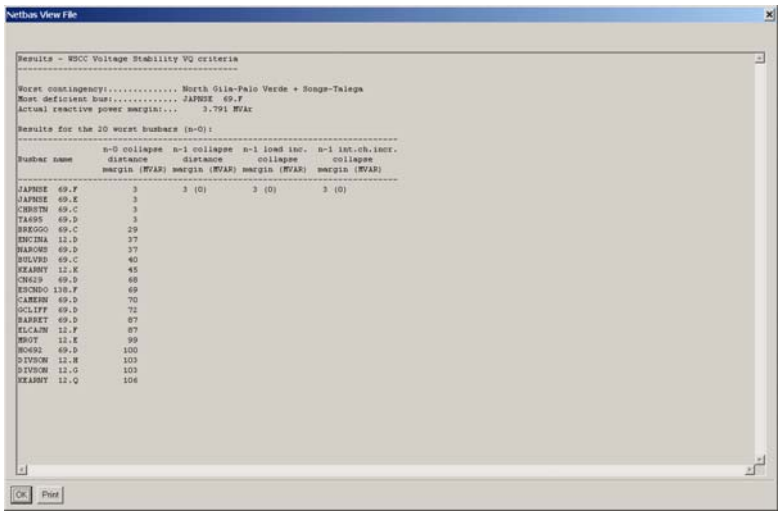


Figure #39 – WSCC VQ Tabular Output

The tabular output of the analysis indicates the most deficient bus was Japanese 69 kV bus "F" for the worst-case contingency, and it has an actual reactive reserve margin of 3.79 MVARs. The WSCC only requires an assessment of the worst station. Pressing the Print button can print out the results.

After closing the tabular output window, the one-line diagram (see Figure #40) will show the distance to voltage instability by displaying bars for the worst five nodes. The results for the worst node are printed in a pink background color. The result for the best of the five nodes is printed in an orange background, while the other results are printed in a yellow background. If the data set complies with the criterion, the bars are colored blue, for non-compliant data sets, the bars are colored red.

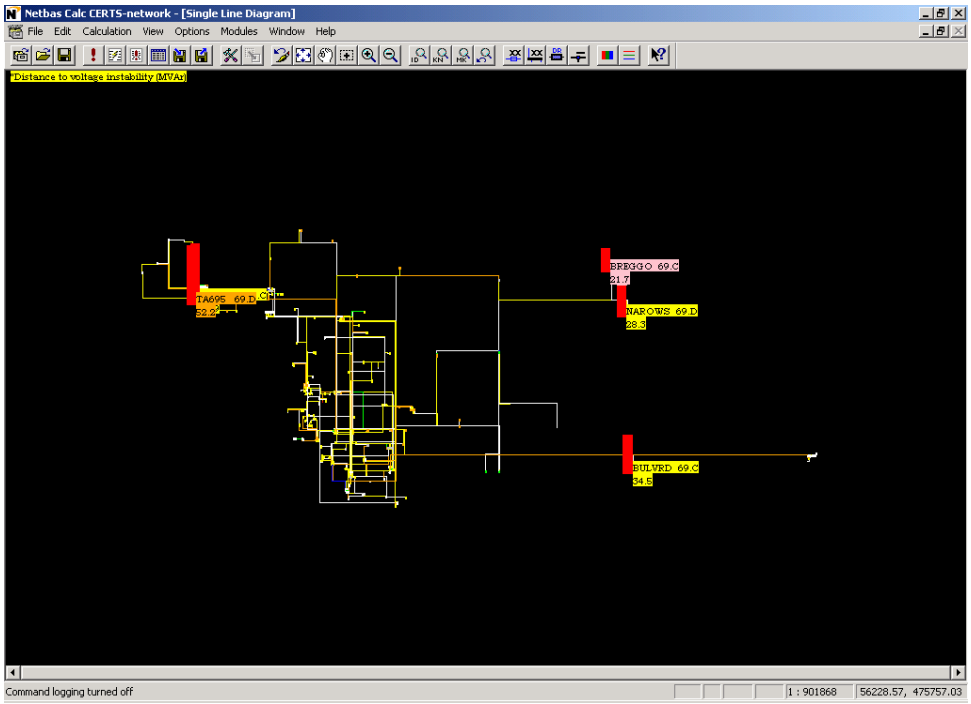


Figure #40 – WSCC VQ One-line Output

20. Outage Assessment

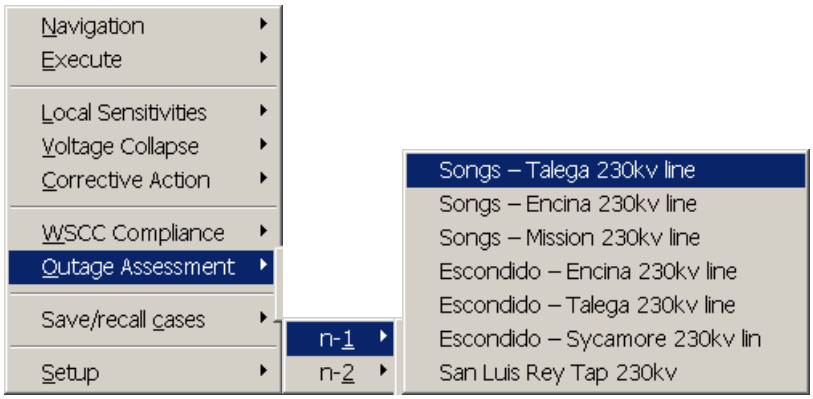


Figure #41 – Outage Assessment Functions

Outage Assessment (see Figure 41) - The "Outage Assessment" functions allow you to load a fixed set of contingencies for more detailed analysis. To perform the desired analysis, select the desired level of contingency (N-1 or N-2) and then select the actual contingency to be evaluated.

The following contingencies are available in this version

- N-1: Songs – Talega 230kv line
  Songs – Encina 230kv line
  Songs – Mission 230kv line
  Escondido – Encina 230kv line
  Escondido – Talega 230kv line
  Escondido – Sycamore 230kv line
  San Luis Rey Tap 230kv

- N-2 N.Gila–P.Verde + Songs–Talega
  N.Gila–P.Verde + Songs-Mission
  Songs–Mission + Songs–Encina
  Songs–Talega, both 230kv lines

21. Save and Recall Cases

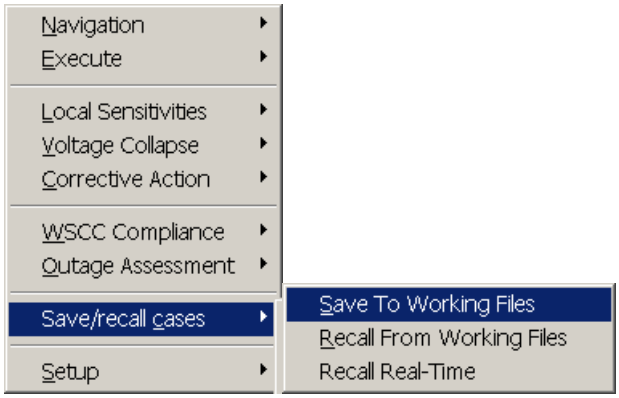


Figure #42 – Save and Recall Cases

Save and Recall Cases (see Figure #42) - By selecting the "Save" option in the "Save/recall cases" menu, you are able to store the current case you are working with into a working file. Saving a case to a working file means saving all relevant component data, loads, generating values etc. After clicking on "Save to Working Files" a window will pop up (see Figure #43) and you are asked to select a location to save the file. **Do <u>not</u> use file #1**. Look for a file that does not have a case residing in it, if none exist, select a file with an older case date and your case will overwrite it. Highlight the file you wish to save your case in and click "save". Once a case is in a working file the user can run some specific analysis and review the systems performance.

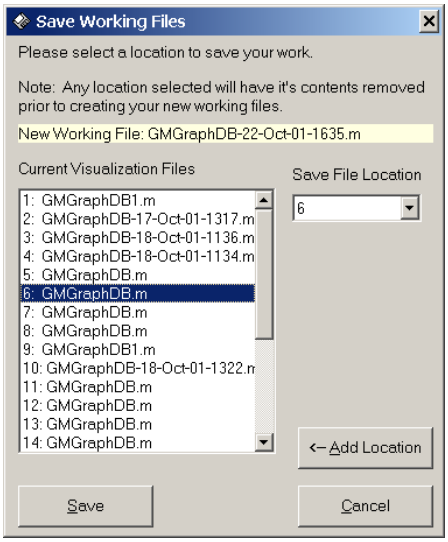


Figure #43 – Save to Working Files

To recall a previously saved case of the transmission you select the "Recall" option in the "Save/recall cases" menu. An "open working files" window will appear, highlight the case you desire to open and click "open".

Recall Real-Time – By selecting "recall real-time" in the "Save/recall cases" menu, you will return the local area Monitoring to real time.

22. Setup

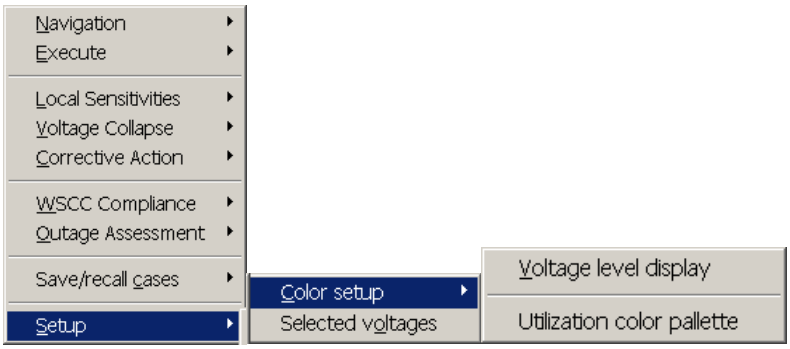


Figure #44 – Setup Functions

Setup (see Figure #44) - Color Setup allows the user to determine if the lines, stations and electrical devices are colors based on ATC utilization and voltage drop or independent of those factors. The color setup "voltage level display" was discussed earlier under the "main button bar" section. Selecting (left clicking the mouse) color setup "utilization color palette" will cause the color palette (see Figure #45) to appear on the top left hand side of the screen.

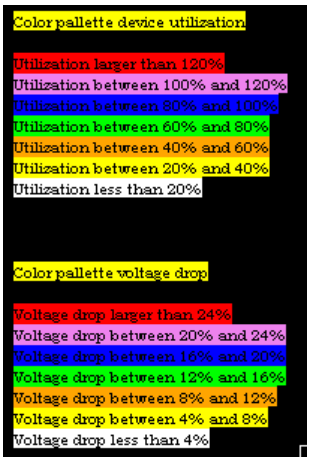


Figure #45 – Utilization Colors

The "Selected Voltage" option is for the support staff in setting up the voltage levels for MVAR calculations.

23. What If Simulations

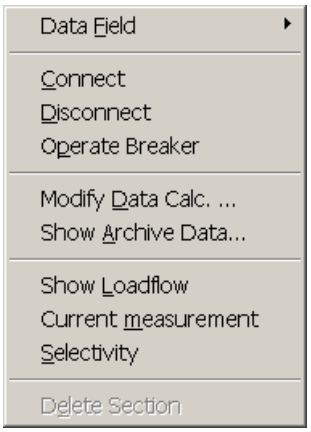


Figure #46 – What If Simulations for Lines and Equipment

What If Simulations for Lines and Equipment (see Figure 46) – The VAR Management application provides the user to perform some "what if" scenarios. In order to perform this function the user can select specific lines and/or equipment they desire to have taken out of service or returned to service, prior to running a power flow and other analysis. There are several ways to get to a specific station to operate equipment, but as a reminder here are two of the methods, using the buttons on the "Main Button Bar":

- - Zoom – allows the user to zoom into a specific section of the transmission system. With the left mouse button depressed, drag the mouse

drawing a box around the area you want to zoom into, and release the mouse. To release this function hit the "Escape" key on the keyboard.

- - Find Node (Station) – allows the user to find a station and zoom in. A selection "Find Node" window will open with a blank space for the node name. Enter the station name and click OK. If you are not sure of the name click on the box next to the blank node name field and a selection window will pop up. After selecting the station, click OK and then click OK on the "Find Node" window.

Once at the desired station, click on the line or equipment that you wish to operate and click the right mouse to get the "What If Simulation" menu. Scroll down and click on the desired operation "Connect", "Disconnect" or "Operate Breaker". There will be a visual change in the line or equipment status (i.e. breaker will change from solid box to open box) to confirm the desired operation. To return the line or equipment to its previous status repeat the above step and click on the desired operation.

Once the line or equipment status has been changed, any of the simulation options, such as sensitivity, distance-to-collapse, WSCC voltage compliance, n-1/n-2, and corrective action can be executed for the "what if" condition. The "what if" results are shown both at the Local Area level via the vertical bars on the one-line display and at the Wide Area level via the 2D and 3D displays.

The balance of the items on the menu is for viewing and modifying some of the data associated with the lines or equipment and should be only modified by the support staff.

24. Application Utilization

The following is a suggested method for utilizing the VAR Management System:

- On the Wide Area Monitoring display select the "2D Voltage Alarm" button to display 2D Voltage Alarm in panel 1. This will also place the 3D Voltage Monitoring display in panel 2 and the 3D Voltage Sensitivity display in panel 3
- Using the "Voltage Selection" menu (right click of the mouse) select the voltage level that you believe is the most critical for the area and should be continuously monitored. Keep in mind that selecting to many voltage levels will clutter the screen.
- While at the Wide Area level the Security Coordinator (SC) can review the other displays, such as:
  - Voltage Monitoring
  - Voltage Sensitivity
  - Collapse Distance
  - Corrective Action and
  - Line Flows
- As voltage problems are observed or suspected trouble the SC can transition to the Local Area displays (see Section #17).

- At the Local Area level the SC can perform a more in depth analysis of problems such as:
  - Voltage Sensitivity
  - Collapse Distance
  - Corrective Action
  - WSCC Voltage Compliance and
  - Outage Assessment
- After the analysis phase the SC can go evaluate his next step by going to the "Corrective Action" menu, select "Manual" and on the pop up window select the manual action to be taken and click "calculate". SC can review the results on the tabular display, Local Area one-line, and also the Wide Area displays.

ATTACHMENT # 1
Security Coordinator Enhancement Suggestions and Trouble Report Log

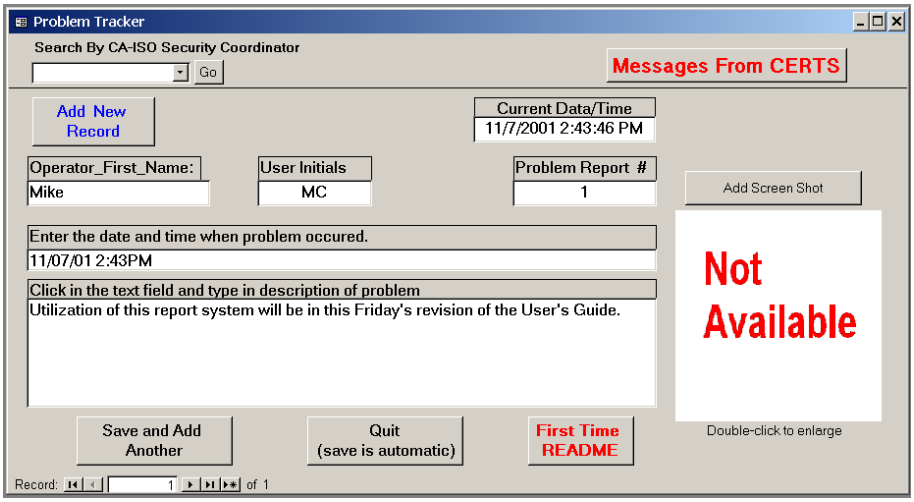
Security Coordinator Enhancement Suggestions and Trouble Report Log

Purpose of Report Log – This report log is for bi-directional communications between the Security Coordinator and CERTS/EPG.

How to Access the Report Log – On the Wide Area display, top right of screen, click the "Reprt" button, see below, this will open an interactive reporting data base.

Security Coordinator will provide trouble reports and enhancement suggestions as follows:

- Click on "Add New Record" button.
- Enter first name and initials.
- Check the "Current Date/Time" field, if you are reporting a problem that occurred at a different time please enter the date and time of the problem in the field below "Operator First Name" field.
- Enter a brief description of problem or suggested enhancement.
- Click the "Save and Add Another" if you wan to save this entry and make an additional entry.
- Click the "Quit (save is automatic)" after completing all entries. This will close the report data base application, avoiding any negative performance of the VAR Management System.

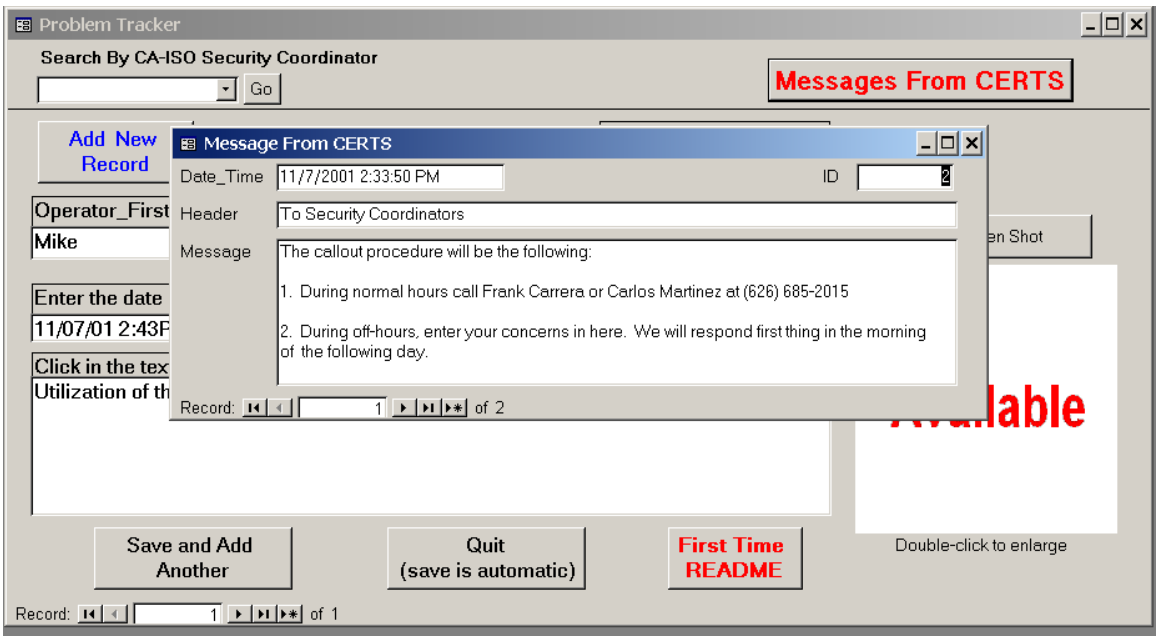


Review of past problems and suggestions:

- If you wish to do a search by Security Coordinator name, at the top left corner of the form, enter the first name and click "Go" and you get a list of the reports submitted by that person.
- If you desire to review all of the reports, at the bottom left corner of the form, Record: 1 of 1 click the rewind button (far left button) and this will bring you back to report #1 and display the comments in the text window. To advance to the next report click the "next" button (third from the left) and repeat for additional reports.

Review messages from CERTS:

- In the top right corner of the form, click the "Messages from CERTS" button and a message window will appear, see below.



- To search all the messages from CERTS, at the bottom left corner of the message window, Record: 1 of 1 click the rewind button (far left button) and this will bring you back to message #1 and display the comments in the text window. To advance to the next message click the "next" button (third from the left) and repeat for additional reports.

If you have a question and need assistance contact please Frank Carrera , CERTS/EPG, during normal working hours, at the following phone number: 949-337-0489

ATTACHMENT # 2
WSCC VOLTAGE GUIDELINE

Summary of WSCC Voltage Stability Assessment Methodology

This document is intended to provide clear summary guidelines to WSCC members as to how these types of analysis should be conducted. It also provides additional guidance by suggesting a path for the user at instances where the WSCC Report on Voltage Stability Criteria, Undervoltage Load Shedding Strategy, and Reactive Power Reserve Monitoring Methodology, dated May 1998 (hereafter referred to as the RRWG Report) offers choices. For more information members should refer to the RRWG report.

Among the methods for assessing voltage stability, the most frequently used are P-V and V-Q analysis. Two flowcharts are provided in this summary; one describing P-V analysis and one describing V-Q analysis. Many of the assumptions used to complete the power flow simulations in these types of analysis are common to the two methods and are provided in Attachment A and referenced in the flowcharts. Even though the description here only covers load increase (Item a) and transfer path flow increases (Item m) out of the eighteen items listed in Section 2.3 of the RRWG Report and repeated below, the responsible entities should also investigate the remaining uncertainties to ensure that all reasonably severe operating conditions are covered.

The uncertainties for establishment of the voltage stability criteria in Section 2.3 are:

(a) Customer real and reactive power demand greater than forecasted
(b) Approximations in studies (Planning and Operations)
(c) Outages not routinely studied on the member system
(d) Outages not routinely studied on neighboring systems
(e) Unit trips following major disturbances
(f) Lower voltage line trips following major disturbances
(g) Variations on neighboring system dispatch
(h) Large and variable reactive exchanges with neighboring systems
(i) More restrictive reactive power constraints on neighboring system generators than planned
(j) Variations in load characteristics, especially in load power factors
(k) Risk of the next major event during a 30-minute adjustment period
(l) Not being able to readjust adequately to get back to a secure state
(m) Increases in major path flows following major contingencies due to various factors such as on-system undervoltage load shedding
(n) On-system reactive resources not responding
(o) Excitation limiters responding prematurely
(p) Possible RAS failure
(q) Prior outages of system facilities
(r) More restrictive reactive power constraints on internal generators than planned.

P-V Methodology
Part 1: Developing the P-V Curves

A. Develop a series of system normal condition base cases with increasing loads or transfer paths to run contingencies from **(Assumption Set A)**

A1. For load Serving Systems: Develop a series of load increase base cases starting from the expected load level corresponding to the planning standards and extending to the point at which voltage collapse is expected to be reached following contingencies. **(Assumption Set B)**

Note: The interface path(s) should measure all imports into the receiving region.

A2. For Transfer Paths: Develop a series of interface flow increase base cases starting at rated transfer and extending to the point at which voltage collapse is expected to be reached following contingencies. **(Assumption Set B)**

Note: All Transfer Path(s) into the receiving region should be monitored.

B. For each of the base cases from the series created above, select several contingencies judged to be the most severe. Run the Post-Transient power flow for each of the severe contingencies. **(Assumption Set C)**

C. Identify the critical bus(es) –
Select a group of 3-5 buses in the load area or that are expected to be severely impacted by the transfer path flow for each of the selected contingencies studied in B above to monitor voltage. These may be the buses with the lowest voltage or the highest voltage deviation. The buses electrically close to the outage may not be the ones that would be closest to the collapse point (e.g., Table Mt is closest to the collapse point for DC Bi-pole outage, but not electrically close to either DC termini).

D. Produce the P-V Curves –
For each selected contingency in B, develop the P-V curves by plotting the post-contingency voltages (at the buses selected in C) against the system load for the load area studies, and the post-contingency voltages (at the buses selected in C) against the pre-contingency flows for the transfer paths studies, until the voltage collapse point is reached.

P-V Methodology:
Part 2: Determine the Maximum Load or Transfer allowable using the P-V Curves

(After the P-V curves are run)

A. Assess performance under various operating conditions
The maximum load or transfer limit operating point should be the lower of the following:

1. 5% below the load (for load areas) or path flow (for transfer paths) at the collapse point on the P-V curve for Category A.
2. 5% below the pre-contingency flow or load corresponding to the collapse point on the P-V curve for Category B contingencies.
3. 2.5% below the pre-contingency flow or load corresponding to the collapse point on the P-V curve for Category C contingencies.

Note: The categories named above refer to the disturbance categories described in Table I of the NERC Planning Standards.

V-Q Methodology:
Part 1: Setting "Reactive Power Margin Requirements"

A. Create the 100% load or 100% transfer path base case **(Assumption Set A)**

A1. For load area studies, create the 105% or 102.5% load area base case **(Assumption Set B)**

Note: The interface path(s) should measure all imports into the receiving region.

A2. For transfer path studies, create the 105% or 102.5% transfer flow base case **(Assumption Set B)**

Note: All Transfer Path(s) into the receiving region should be monitored.

B. By running the post-transient power flow, develop post-contingency cases for each of the most severe contingencies for the cases with 100% load or transfer path flow and for the cases with 105% load or transfer path flow. **(Assumption Set C)**

C. Identify the critical bus(es)

- Identify the sub-set of the most critical buses (3-5) for each of the selected contingencies studied in B above. These may be buses with the lowest voltage or the highest voltage deviation. The buses electrically close to the outage may not be the ones that would be closest to the collapse point (e.g., Table Mt is closest to the collapse point for DC Bi-pole outage, but not electrically close to either DC Terminal).

D. Produce the V-Q Curves for each contingency:

- Apply a fictitious synchronous condenser at each critical bus identified earlier; one at a time.
- Solve the power flow case (either a standard or post-transient power flow solution can be used).
- Record the bus voltage (V) and the reactive output of the condenser (Q).
- Reduce the condenser scheduled output voltage in small steps (e.g., < 0.01 p.u.).
- Continue varying the condenser's output (or scheduled voltage) until sufficient points to identify the voltage collapse point have been collected.

E. Establish the Reactive Power Margin Requirements.

- Reactive Power Margin is defined as the value of the condenser output at the voltage collapse point on the V-Q curve where dQ/dV=0.
- The change in the reactive power margin between the two different load levels (100% and 105%) for the same Category B contingency and at the same bus is the Reactive Power Margin Requirement at that bus for that Category B contingency.
- The change in the reactive power margin between the two different load levels (100% and 102.5%) for the same Category C contingency and at the same bus is the Reactive Power Margin Requirement at that bus for that Category C contingency.
- Identify the Reactive Power Margin Requirement for other study years as desired by repeating the above steps for other years as necessary

Note: The categories named above refer to the disturbance categories described in Table I of the NERC Planning Standards.

4 7/11/01

V-Q Methodology:
Part 2: Assessing Performance against the "Reactive Power Margin Requirements"

(After the Reactive Power Margin Requirements have been established for the years of interest, the system can be tested to see if it meets these Requirements)

A. Create the 100% load or 100% transfer path base case **(Assumption Set A)**

B. By running the post-transient power flow, develop post-contingency cases for each of the most severe contingencies **(Assumption Set C)**

C. Plot V-Q curves and assess performance against the margin requirements
- Create V-Q curves for the selected contingencies (Categories B and C) in the study area for the study year to be investigated at the 100% load level or 100% transfer path flow level.
- Check to see if the VAR margin meets the Reactive Power Margin Requirements established previously for the same study year, bus and contingency.
- If the required VAR margin is not met, additional facilities, implementation of appropriate remedial action schemes, or reduction in load or interface flow would be required.

Attachment A : Power Flow Assumptions for P-V and V-Q Analysis

Assumption Set A: Modeling the 100% load or 100% Transfer Base Cases

- For load area studies, the load in the area of interest should be modeled based on the load forecast normally used for planning that area. (For the purpose of developing an extended P-V curve, base case may be developed at less than 100% load level.
- For transfer interface studies, the interface transfer should be modeled at its maximum rating and under the most critical system conditions for which the interface is rated (a range of conditions may be necessary for nomograms ratings).
- Assume constant MVA load models unless more accurate load models are available.
- Move the area slack and system swing bus outside the study area.
- Use standard power flow to solve the base case. Post-transient power flow should not be used to develop these cases.

Assumption Set B: Modeling the Load or Transfer Increase Case(s)

- Generation to supply the increasing load for load serving systems should come from generation that would normally have been dispatched to meet the load increase. Generation to supply increasing transfers should come from generation that would place the highest stress on the facilities of interest. The generators' outputs should not exceed the generators' maximum capability.
- The system swing bus can be used to account for system losses but its output should not exceed the generator's capability, otherwise the generation should be re-dispatched.
- When increasing load, also increase loads in closely neighboring systems if they have similar climatic or geographic characteristics.
- Although the load power factor is typically held constant when the load is increased, the power factor may be adjusted based on engineering discretion.
- As load is being increased, adjust automatic and manual devices (including generators) as needed that would operate within 30 minutes. Ignore overloads that cannot be corrected using such automatic and manual switching action. The 30 minute limit assumes that the load increase can be anticipated within a few hours to allow operator action. However, it is intended to avoid the addition of thermal units to the load increase cases without being specifically identified. If these units are needed, they should be included in the 100% base case.
- As transfer is being increased, adjust automatic devices as needed that would operate within 3 minutes. Ignore overloads that cannot be corrected using such automatic switching action. The 3-minute limit assumes that transfer path flow increases cannot be anticipated with enough time to allow corrective action(s) by the operator. It is intended to avoid the addition of *manual* devices to support the increase in transfer path flow without being specifically identified. If these devices are needed, they should be included in the 100% base case.

Assumption Set C: Modeling of Contingency Cases

- When the contingency involves load shedding, generator tripping, or a large change in system losses, a post-transient power flow should be used to re-establish the generation-load balance based on approximated governor action. Otherwise a standard power flow can be used.
- In accordance with WSCC's post-transient power flow methodology, allow switching of only those automatic devices that can complete switching in 3 minutes (e.g., automatic LTCs, automatic phase shifting transformers, SVCs, and other automatic switching devices)
- If the post-transient solution indicates that automatic actions would occur (such as automatic RAS, load shedding and generator tripping schemes), then rerun the case applying those actions.
- If discrete devices are required to solve contingencies for the 105% or 102.5% load (or transfer) case, these devices should be modeled in the 100% load (or transfer) case as well.