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Advanced Graphics Zoom in on Operations

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Decluttered maps ease the analysis of data associated with complex networks

The operation of an electric utility system, with its many interconnections to neighboring utilities and power pools, is analogous to air-traffic control. Dispatchers and air-traffic controllers monitor a large number of data variables spread over wide geographic regions to ensure secure operation (or, in the case of air-traffic control, secure flights). Secure (safe and reliable) operation of an interconnected system involves solving complex problems by analyzing large quantities of processed data. Information must be rendered effectively for the dispatcher to respond accurately and quickly, and advanced graphic applications and workstation technology are now cable of presenting this *better* information.

Dispatchers, who reside in the loop of large computer-based monitoring and control systems called energy management systems (EMSs), must take corrective actions when limit violations, equipment failures, and other system contingencies occur. The problem lies in the presentation of power system information, that is, how to display the information needed by the dispatcher in order to make corrective decisions. Large quantities of data (hundreds of megabytes) must be processed into usable information and then displayed in a form that ensures correct and timely decisions.

This article focuses on how advanced graphic facilities now available or under development may be used to provide dispatchers with *better* information for operating the power system. The term *better* is used here to mean more timely and accurate (both mathematically and geographically).

Functions and Facilities

Power system operating functions were listed and prioritized in a joint NSF/EPRI research project, and several of those functions were selected on the basis of their potential benefit to power system operation.

Graphics hardware and software facilities were studied, with consideration given to potential benefits to power system operation and the longevity of the hardware, software, and graphics standards. The hardware chosen for the demonstration was the DECstation 5000 RISC. In terms of software, this is a Unix-based workstation that uses the Ultrix 4.2a operating system, and supports X-Windows. The graphics programming facility is PHIGS 2.2a (which stands for Programmers Hierarchical Interactive Graphics Standard), and the programming language is C. The MIPS C compiler was used.

A software package was developed to demonstrate the presentation of power system information to the dispatchers. The facilities included are: the system map, transmission-line overload and contingencies, decluttering, voltage profile, alarm location, and system restoration.

System Map

A top-level (overview) map of the system and service area is shown in Figure 1. The map is geographically accurate, and county boundaries are included for geographical reference.

The top-level map provides an overview of the system and serves as a menu for selecting displays and informa-

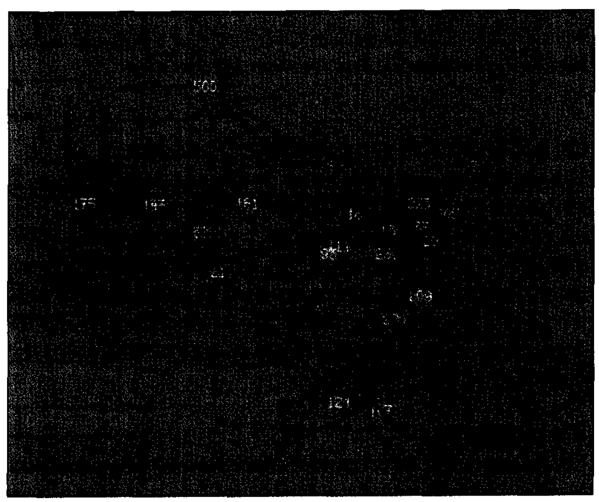

Figure 1. Top-level (overview) system map

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tion at a subsystem level, i.e., to zoom in on a smaller area of the system, such as a region or district, down to the substation level, which allows more details to be shown without excessive clutter.

Note that part of the map in Figure 1 is quite readable, the part of the system away from the cities/load center. In the city, located in the upper right quadrant, the map is not readable because there are too many lines and substations in a small area. The problem is solved by zooming in on the cluttered area (one or more times) for a clearer view of the desired part of the system. (Another method for decluttering will be presented later in the article.)

Rubber-band box zooming allows the dispatcher to select a specific area and the size of the area to view in more detail (see Figure 2).

Transmission lines are color-coded by voltage level with the following color scheme (which can be changed easily): gold represents 345 kV lines, magenta (purple) represents 161 kV lines, and dark green represents 138 kV lines.

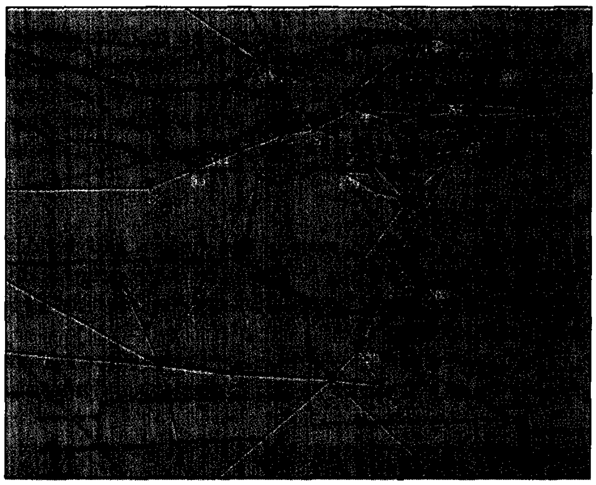

Figure 2. Zooming in one level on system map

Line Overload and Contingencies

Transmission lines that are overloaded are shown in brighter colors than lines operating within their megawatt limits (see Figures 1 and 3): bright yellow instead of gold represents 345 kV lines, bright magenta (pink) instead of magenta represents 161 kV lines, and white-green instead of dark green represents 138 kV lines. Lines that have tripped off or are out of service are shown as black broken lines.

Decluttering

Both automatic and manual decluttering are provided. Manual decluttering via *rubber-band box* zooming allows the dispatcher to view an area that is small enough to

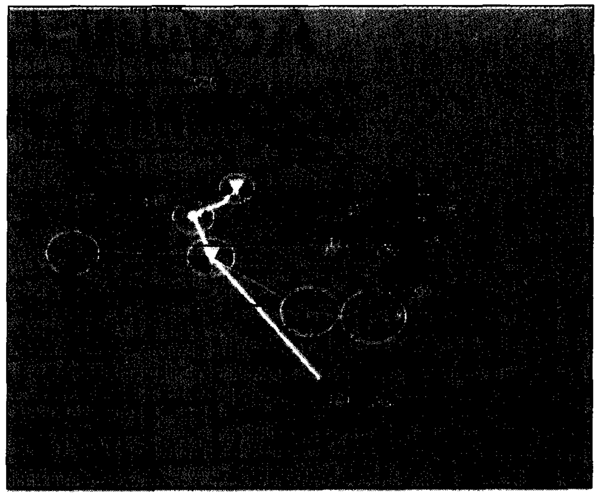

Figure 3. Overloaded lines are shown in brighter shades of color than lines operating within limits

read all the necessary details. Four levels of automatic decluttering are provided to ensure that any picture displayed will not contain more information than can be read easily. The levels range from the top level (overview) system map down to the station one-line diagrams, which are in use today in all energy control centers.

- **Level 1.** In the top level map, only the highest voltage stations (345 Kv) are visible (see Figure 4).
- **Level 2.** All stations within the zoomed area are visible. This is the first zoom into a smaller area of the system map (see Figure 5).
- **Level 3.** All stations and transmission lines within the zoomed area are visible (see Figure 6).
- **Level 4.** The one-line diagram for the station selected is displayed in a window insert. The remainder of the display is Level 3.

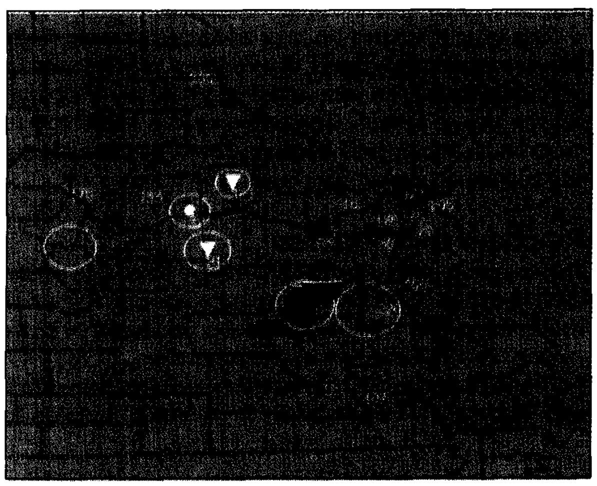

Figure 4. Level 1 displays only the highest voltage (345 Kv) stations

Voltage Profile

The voltage profile shows locations of both low and high voltage problems and possible voltage collapse. Voltage across the system map is rendered as a solid color contour map, with low voltages darkening to red below 95 percent and lightening to pink and gray above 105 percent. The system map described previously is drawn on top of the voltage profile to show the result in Figure 4. (Note that use of three-dimensional graphics provides beautiful pictures of voltage profiles, but does not provide help in finding the location of a low or high voltage problem.)

Advanced graphics software, facilities, and tools help dispatchers make decisions needed for secure/economic operation

Alarm Location

While expert systems are being developed for alarm processing, it is useful to the operator to know how alarms are distributed across the system, in particular, those related to storm conditions. To annunciate alarms associated with a station, a circle is placed around the station symbol. The diameter of the circle is proportional to the number of alarms affecting that station (see Figures 3 through 5). An alternative to the alarm circle is an alarm triangle, which replaces the station symbol with an open triangle large enough to contain a number that indicates the number of alarms affecting that station.

System Restoration

An attempt is made to show the operator the state of the system during a blackout/restoration scenario. For one method, a system map is used to display the lines and stations energized and the location of operating islands. Transmission lines that are not energized are shown as black broken lines. Stations not energized are shown with the station symbol in black. (This is against a light gray background.) Stations and lines that are connected and energized are shown in the proper voltage color code (see Figure 7).

A second method for showing connectedness is to shade the energized regions. An algorithm was developed to draw cross-hatched shading over an energized region to make it more visible, which it would, if the system is islanded or operating as two or more islands (see Figure 8). As the operator views the parts of the system energized versus the parts that remain blacked out, he or she should be aided in deciding where the next reconnection can be made and whether or not synchronization has to be done.

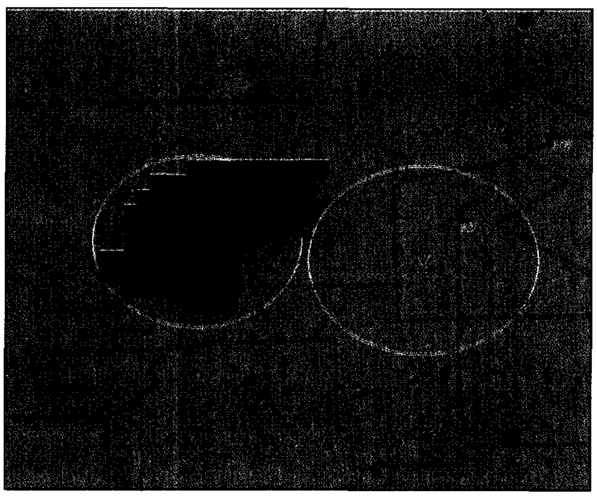

Figure 5. Level 2 displays all stations (no lines) within the selected area

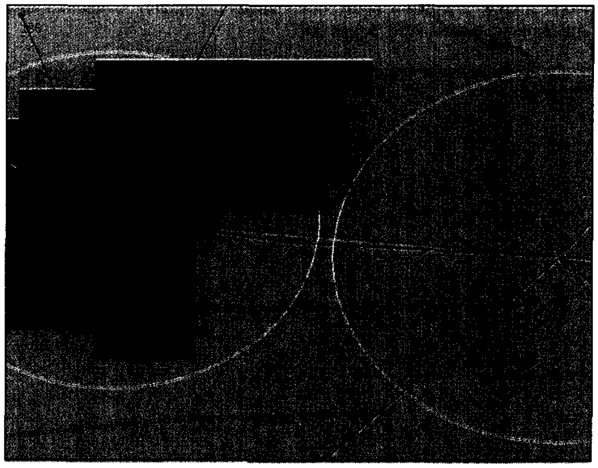

Figure 6. Level 3 shows all stations and transmission lines

Visualizing Solutions

The NSF/EPRI advanced graphics project has shown how graphics can be used to provide *better* information to the dispatcher for power system operation. The rendering of this information should enable the dispatcher to do his or her job more accurately and quickly. At the present time, and for several years in the future, it is necessary to keep a human dispatcher in the loop to do the monitoring of security and performance, and to make the decisions necessary for secure and economic operation.

Present-day advances in graphics and workstation technology show continued improvements and new tools for energy control center operations. Workstations

are becoming faster, more capable, and less expensive. New graphics software, facilities, and tools are coming on the market for these applications.

> ***Graphics and visualization tools and techniques permit dispatchers to sift through volumes of data***

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Funding for this project was provided by the EPRI and NSF. Union Electric Company of St. Louis, Missouri, provided system maps and voltage profile data, as well as advisory support. The UM-Rolla team is very grateful to all of the project supporters.

For Further Reading

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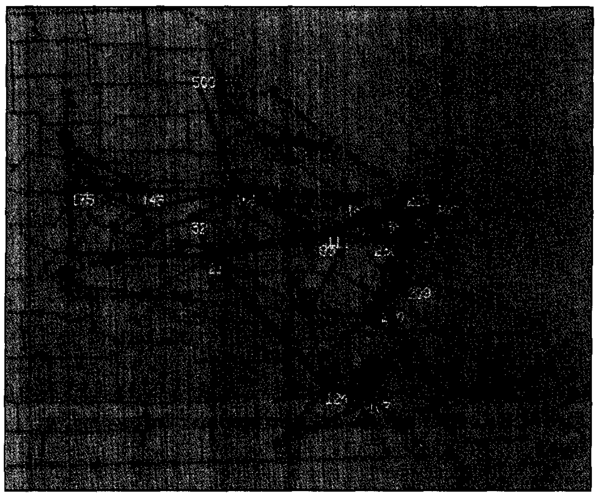

Figure 7. Restoration: system map display of the lines and stations energized and the location of operating islands

Biographies

Max D. Anderson received his BSEE and MSEE from Oklahoma State University, attended Northwestern University, and received his PhD from Arizona State University. He is a professor of electrical engineering at the University of Missouri, Rolla, when he has been a faculty member since 1975. His research interests include electric utility systems, energy control centers, system operation and training, digital simulation, and computer applications. He is a senior member of IEEE and past chairman of the Working Group on Operator Training. He is a registered professional engineer and a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.

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Curt Schroeder received his BS and MS in computer science from the University of Missouri, Rolla. He has been both an undergraduate and a graduate co-op student with the McDonnell Douglas Corporation since 1985, where he is presently employed. His research interests include data visualization, general rendering issues, animation, and robotics. He is a member of the IEEE Computer Society and Upsilon Pi Epsilon.

Rambabu Adapa received his BSEE from Jawaharlal Nehru Technological University, his MSEE from the Indian Institute of Technology, and his PhD from the University of Waterloo, Ontario, Canada. He joined the Power System Planning and Operations program of the Electrical Systems Division of EPRI in 1989. He is a senior member of the IEEE, member of the DC Transmission Subcommittee of the Transmission and Distribution Committee, CIGRE, and the local IEEE Santa Clara chapter. He is a registered professional engineer in Wisconsin.

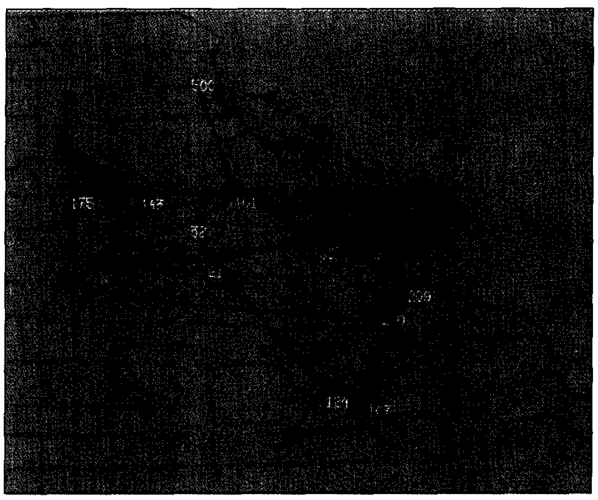

Figure 8. Restoration: two islands highlighted by color shading