AN ADVANCED VISUALIZATION PLATFORM FOR REAL-TIME POWER SYSTEM OPERATIONS

Ray Klump, Ph.D.
PowerWorld Corporation
Lewis University

David Schooley, Ph.D.
Exelon Corporation

Thomas Overbye, Ph.D.
University of Illinois at
Urbana-Champaign

Abstract – The size and complexity of the interconnected power grid pose significant challenges to system operators. The requirement of rapid response under diverse conditions in a highly complex environment underscores the need for tools that can help operators detect potential problems and identify solutions quickly and accurately. This paper discusses the design, development, and deployment of a software application that attempts to address this need. The software illustrates system conditions on a geographic map of the interconnection using a variety of innovative visualization techniques that help the application convey the current state of the system in a clear, unambiguous, and engaging way. This paper discusses the architecture of the application, the benefits, design, and implementation of each of its visualization tools, guidelines for designing displays that take maximum advantage of the platform's strengths, and planned future enhancements. It also emphasizes a key ingredient to the success of the application: seeking and responding to the ideas and needs of the operators who depend on the platform for the information they require to operate the power system. Several figures are included that demonstrate the types of displays currently being shown in the control room.

Keywords: Power systems, data visualization, real-time operations

1 INTRODUCTION

One of the few constants in power systems operations is the need to monitor large amounts of data and to respond to changing system conditions. Historically, these data have been displayed as text or represented graphically through trend plots and one-line diagrams. Plots of trends are useful, but they can only display a limited number of points at once. One-line diagrams can show the status of an entire control area, but they are limited in the number of measurements they can display legibly at each location. For instance, relevant measurements concerning the loading of a transmission line include the MW, MVAR, and MVA flow measured at one or both ends of the line. Other useful data include the ratings and perhaps the voltage at each end of the line. While it is possible to generate a single one-line display incorporating all of this information for a large transmission system, the amount of data on the display would likely overwhelm the operator.

The typical solution to this problem is to generate a large display or map of the entire transmission system that contains little or no numerical information and put the numerical data on separate displays for individual substations. While this approach has worked reasonably well, it has several drawbacks. It can be difficult for the operator to get a good perspective of the overall health of the system. In other words, how do the conditions at a particular substation or on a specific transmission line affect the system as a whole? The system-wide one-line diagram displays wide-area conditions, but it is usually limited to showing outages or flows exceeding their limits due to the large amount of data that would otherwise need to be shown on the display.

This paper chronicles the development a new software application that significantly advances data visualization in the power system control room. The application equips power system personnel with advanced visualization tools that help them identify system conditions in a clear and insightful way. It attempts to give dispatchers a better combination of information by providing them with an overview of the entire system and making it possible for them to see how the conditions at a particular location affect the rest of the system. The tool employs a variety of visualization techniques, including flow animation, voltage and line flow contour plots, area tie diagrams, substation views, color alarm indicators, movie recording and playback, and three-dimensional rendering to convey the current state of the power system in a clear, unambiguous, and engaging way. It uses the same techniques to demonstrate the evolution of the system over a past interval of time using archived data. This makes the tool useful for real-time system monitoring, post-mortem analysis, and operator training.

This paper discusses the design and development of the application based on experience with the tool at ComEd, a division of Exelon Corporation. In fact, the comments and suggestions of ComEd system operators helped shape the application and greatly enhanced its usefulness. The valuable contributions made by system operators illustrate the importance of having the target audience review and comment on the content of the application during the design process. The need to include users of the application in the development loop is a major theme of this paper.

2 PROJECT HISTORY

PowerWorld Corporation, the developer of the platform described in this work, designs, implements, and markets a power systems analysis tool called Simulator.

This tool enables users to conduct planning-mode studies of an interconnection. Simulator's biggest appeal is its pervasive use of visualization techniques to make conditions easier to understand and identify. However, because its use is limited to planning-mode studies, users must work with bus-based power flow models that describe the system in terms of projected or past load, generation, and interchange profiles and outage schedules, rather than with real-time data sets. The fact that Simulator's visualization tools display data only from power flow models and not from real-time data sources has limited its usefulness outside of the power system planning community.

Certainly, advanced visualization techniques could prove extremely helpful to power system operators as well. Tools such as flow animation, panning, zooming, contouring, and full-color alarm indicators could help those who manage the system in real time wade through the vast amounts of data they must survey to pinpoint the important characteristics and trends quickly. The complex relationships that sometimes exist between data, particularly in systems for which geographic considerations are important, elevate the use of effective graphical data representations to a necessity. The project described in this paper was launched to address this need.

Several companies showed enthusiasm for the prospect of applying advanced data visualization tools to real-time operations. One of these companies was Commonwealth Edison (ComEd), a division of Exelon Corporation. ComEd, which henceforth shall be referred to as *the client*, owns, operates, and manages generation and transmission assets in Northern Illinois, including the Chicago metropolitan area. The client had recently updated its control center, replacing an analog map board with a wall of twelve video screens arranged in a six-screen-by-two-screen matrix. The displays initially developed for the video board were designed to mimic the content of the original analog mapboards.

It became clear, however, that simply recreating the content of the original mapboard with the new video display did not realize the full potential of video. First, the displays were not particularly easy to interpret. They were limited to showing quantitative information solely through the use of text analogs. While this would be satisfactory in a display that shows a small set of data, attempting to convey all data that might be of interest for a particular view becomes counterproductive. Indeed, this was the case with the client's video displays. The need to show a great deal of information in a limited space resulted in cluttered displays that made it difficult to see the important information. Furthermore, the vector-based technology employed by the displays limited the client to using only text analogs to show information. Vector displays are quite limited in the type of information they can show.

To address these shortcomings, the developer and the client endeavored to bring an advanced visualization toolset to system operators. The goal of the project was to transfer the visualization tools found in existing planning-mode tools, including flow animation, contouring, area tie diagrams, bus views, and dynamic-view maps, to the control room with the hope of providing informative, easy-to-understand displays of real-time system conditions to system operators. The data for populating these displays would come from the client's PI Historian, a data aggregation tool developed and marketed by OSI Software, Inc. The data aggregator collects data from multiple data sources and makes it available to client applications through a comprehensive application programming interface (API). The proposed application would access collected measurement data through the data aggregator and display it on one-line diagrams. This would then permit the use of advanced visualization technology to make the data easier to manage and comprehend.

To give the project an initial impetus, the client identified two displays of particular interest: a phase-shifter map and a system-wide voltage contour. The phase-shifter display would show the flow of power into the city of Chicago and would assist operators in deciding how to adjust phase shifts to better manage the flow of power to protect stressed equipment. The system-wide voltage contour would be used to highlight regions of the system plagued by low voltage magnitudes so that operators could respond proactively to emerging voltage problems. Since the voltage contour would illustrate the geographic variation of voltage in the system, it would help operators dispatch additional reactive support in the most effective manner. These two displays became identified deliverables for the project and helped sharpen the focus of the development effort.

3 VISUALIZATION TECHNIQUES

The new platform uses a number of techniques to help users visualize real-time and archived system measurements. Most of these techniques stem from research presented in references [1] through [10]. This section describes the visualization tools the platform employs.

3.1 Maps

The application uses one-line diagrams to illustrate the structure of a power system. A one-line diagram consists of symbols representing buses, the transmission lines connected them, and the generators, loads, and switched shunts attached to them. Buses may be arranged geographically; in fact, the application offers a tool for automatically placing buses on the one-line diagram based on their geographic coordinates. Figure 1 provides an example of a simple one-line diagram that exhibits many of the tool's visualization techniques.

The one-line diagrams allow the user to pan the view port to display different regions of the system. Moreover, they enable the user to zoom the view port to display a wider area or to examine a particular region more closely. This means that the contents of the one-line diagrams are not limited by screen size. Furthermore, the user can save and return to particular zoom and pan settings easily so that he may quickly navigate among various views of the system.

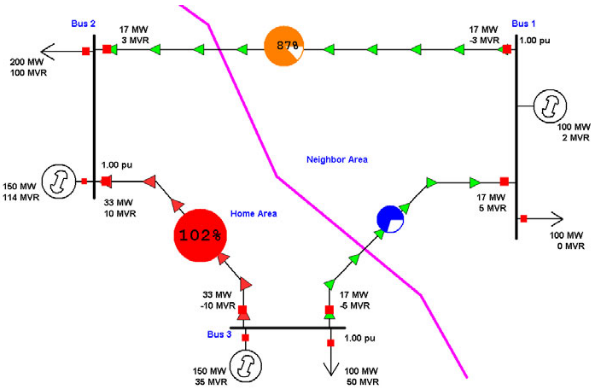

Figure 1: Simple one-line diagram example

3.2 Flow Animation

The flow of power into and out of buses is portrayed as colored arrows that move in the direction of the power transfer. The magnitude of each flow is indicated by the size of the arrows and the speed with which they move through the associated equipment. Larger, faster-moving arrows symbolize larger power flows. The application can show real power and reactive power flows either separately or simultaneously using different color schemes for each. Furthermore, it represents the difference in metered flow values at opposite ends of a transmission line by scaling the size and speed of the arrows along the line. This feature is particularly important for visualizing the flow of reactive power. Additionally, the tool indicates device status using breaker-like symbols that appear solid when the device is closed and hollow when the device is open.

3.3 Localized Views

A display called the *bus view* helps users identify all flows into and out of a particular bus. The bus view is automatically generated and clearly indicates both the magnitude and direction of all power flows located at that bus. The bus view enables users to inspect not only the node for which the bus view was generated, but also its neighboring buses. The bus view shows the neighbors of the central bus as hyperlinked boxes. When clicked, a hyperlink generates the bus view for its corresponding bus. By clicking on the neighboring buses of interest, a user may navigate throughout a region of the system, obtaining a clear picture of the real-time flows associated with a set of buses.

3.4 Area-Tie Diagrams

Area-tie diagrams describe the system in terms of control areas and the interfaces joining them. Control areas are represented graphically as bubbles. Each interface, which actually represents one or more transmission lines or transformers, is shown as a single connecting line. Area-tie diagrams help clarify the direction and magnitude of an area's power exchanges with its neighbors. This information is important both for economic reasons as well as security maintenance, as security personnel often prescribe limits on the flow of power between areas as a way to guard against problems such as voltage and angular instabilities.

3.5 Graphical Alarms

Power system operators must monitor transmission branch flows to ensure they remain below levels that could damage equipment. They need to monitor bus voltage magnitudes to protect against induction motor stalls, reactive power shortages, and voltage collapse. They must note the sum of flows leaving and entering their system along its tie lines to respect interchange agreements and stability proxies. Furthermore, they must know how the present real and reactive power output of generators and shunts compare with their rated capabilities so that these devices may be properly scheduled. Clearly, the operator has many alarm conditions to monitor.

Several tools help operators recognize both potential and present alarm conditions. For example, a line-flow pie chart represents the flow of power on a transmission line as a percentage of its rating. When the flow on a branch is at safe levels, the pie charts appear at normal size and are colored blue. As the branch flow approaches warning levels, the size of the pie chart increases, and the color changes to orange. This draws the operator's attention to the potential for trouble. When the branch flow exceeds safe levels, the pie chart increases in size again and changes color to red, indicating an alarm state. The user may customize the behavior of the pie charts to use different colors and sizes to represent alarm and potential alarm states, and he may adjust the threshold levels at which the changes in appearance occur. In addition to line-flow pie charts, operators can monitor area interchange levels using interface-flow pie charts, which behave identically.

Pie charts provide a particularly effective mechanism for dramatizing stressful conditions. Color-coded text analogs also perform this role. Text analogs display measurements of bus voltages, line flows, interface flows, loads, and the outputs of generators and shunts. The analogs change color when their associated quantity reaches a level that violates their defined limit. A quick scan of a one-line diagram with color-coded analogs will reveal for the operator the location and nature of his system's current alarm states. The one-line diagram of Figure 1 demonstrates the use of both line-flow pie charts and color-coded text analogs.

3.6 Contouring

Contour plots illustrate how a particular quantity varies with location. Since one-line diagrams usually reflect the geographic arrangement of system equipment, contour plots provide a valuable picture of how quantities such as voltage or transmission loadings vary across the system. Such plots give the operator a birds-eye view of the system, enabling him to pinpoint specific regions of concern when inspecting the system as a whole.

Figure 2 shows a contour plot of bus voltage superimposed on a transmission system map. Although the map shows an area of roughly 20,000 square miles, it conveys very localized information. It computes the color of each screen pixel as a function of the voltages of buses in the vicinity of each pixel. The contribution of each bus voltage to the color of a particular pixel is weighted by the bus's distance from the pixel. Reference [9] details how the contouring algorithm works. This particular contour plot shades low-voltage regions red and high-voltage regions blue. Using red to highlight low-voltage regions reflects the added concern low-voltage conditions cause. The user may adopt a different color scheme and fine-tune the voltage levels at which different shades begin to emerge. Furthermore, he may use contour plots to reveal other types of geographic variation, including how generator real and reactive reserves, load levels, and transmission line flows change with location.

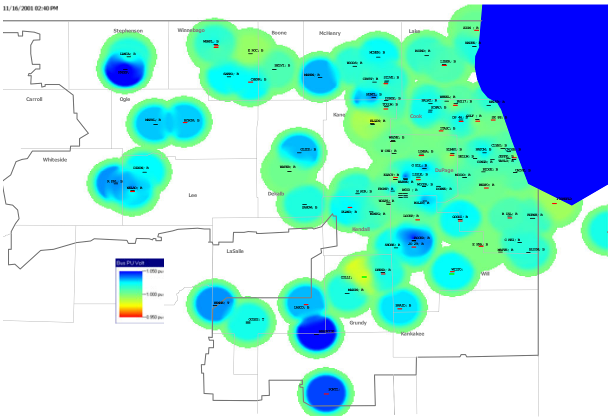

Figure 2: Contour plot of real-time bus voltage

3.7 3D displays

Showing more complex data relationships requires novel visualization approaches. Three-dimensional views answer the challenge by demonstrating how multiple types of quantities vary simultaneously. For example, Figure 3 uses a voltage contour in the x-y plane to show how bus voltages vary geographically in a system. Then, it draws a cylinder coincident with each generating unit. The height of the cylinder indicates the amount of reactive power the generator has left to provide.

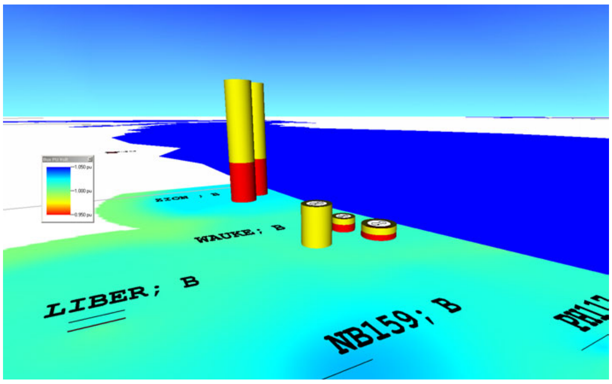

Figure 3: Three-dimensional plot of reactive power reserves

Like two-dimensional contour plots, then, three-dimensional views such as this example identify critical regions and help focus problem-solving strategies. The three-dimensional view, however, answers the most likely question the operator might ask when formulating a solution: which nearby sources offer the greatest reactive support. This technology has also been applied to show generator real and reactive output versus capability and to identify the most power-rich neighbors from which to buy power in an ATC-constrained interchange market [10].

4 APPLICATION ARCHITECTURE

The real-time data retrieval system that provides system data to the visualization application operates as a client-server system. The server consists of one or more data sources that provide the information to the client, which is simply the visualization application running on an operator's PC. Since the visualization application does not actually have to perform expensive system calculations, its hardware requirements are actually rather modest, with memory and video card performance being the most important criteria. How the application obtains information depends on the type of server with which it is trying to communicate. For the project described in this paper, data is stored in a remote server running a data aggregator called PI Historian. The visualization tool requests information from it using the aggregator's API function calls. The application may also extract information from flat text data sources located either on the local area network or at a remote site accessed by FTP.

The application establishes the topology of the system from information contained in a power flow model. The power flow model defines how devices are connected and specifies the thermal ratings of transmission equipment. The power flow model also provides the context for display objects that appear on the one-line diagram. Each component on the one-line diagram corresponds to a component in the underlying power flow model. The power flow model need not be solved; it merely describes the structure of the system.

Objects called *aliases* and *alias subscriptions* are used to link power system objects to real-time measurements. An alias simply provides a name, or tag, for a data value. Power system objects register to receive the value named by the alias by subscribing to it. The alias subscription identifies not only the associated alias but also the attribute of the power system component to fill with the corresponding value. Thus, the alias subscription serves as a conduit between the information source and a power system object. Alias subscriptions may involve either a single alias or an arithmetic expression involving one or more aliases.

Each alias names a value stored on a particular *data source*. Data source objects specify connection information such as network addresses, authentication data, and communication protocol. Moreover, each data source maintains a list of aliases for which it must retrieve a value. At specified intervals or on the user's cue, each data source will establish communication with its data server and make the appropriate requests to obtain the values for its aliases. Data acquisition occurs on a separate background thread and thus has minimal impact on the user interface and display performance. This particular project employed a single data source object, which represents the client's data aggregation server.

The application supports two modes of data acquisition. In *snapshot mode*, the application queries its data sources for their most recent values and displays them on all open one-line diagrams. This provides a real-time picture of system conditions. The application produces snapshots either upon the user's command or automatically at intervals the user defines. In *archive mode*, the application seeks and displays historical system conditions corresponding either to a single instant in time or over a period specified by the user and displays them on all open one-line diagrams. To display conditions over a time window, the application obtains the values for a time instant, displays them for a specified number of animation cycles, and repeats the process, advancing the time instant by a user-defined interval each iteration. This ability to replay system conditions over an interval helps the user animate the evolution of a system. This can serve as a powerful training tool and as a means for determining how problem conditions arose.

The UML diagram of Figure 4 illustrates the application's architecture and suggests the process it performs during each data acquisition. Each data source establishes a connection with its associated data server and issues the appropriate commands, whether API calls or text parse operations, to retrieve the values for each of its registered aliases. The value of each alias is then piped to all associated alias subscription objects. An alias subscription then communicates either the alias's value or the result of an arithmetic expression involving the alias's value to the appropriate attribute of all power system objects that have registered with it. The display objects shown on all open one-line diagrams then update their appearance to reflect the new characteristics of the power system objects with which they are linked. This describes how the application maps real-time and historical data to its one-line displays.

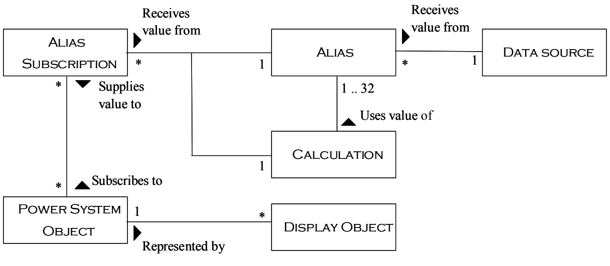

Figure 4: Class relationships

5 CONTROL ROOM IMPLEMENTATION

Several utilities have contributed ideas and feature suggestions for the application, and three utilities currently use it to illustrate real-time and historical information in their control rooms using advanced visualization techniques. This section describes specifically how ComEd, the client that participated in this particular project, uses the application in its control room.

The client's installation includes a data server called PI Historian, multiple client Windows PCs running the visualization application, and multiple display controllers that supply content to the six-by-two array of video monitors that comprise a video wall. The application converses with the remote data server over a local area network using the server's proprietary API commands. The display controllers are implemented as a mix of Windows and Unix boxes. The application sends its one-line diagrams to these display controllers either directly or through a remote display system called VNC.

Initially, two one-line displays were created for the client, a phase-shifter display and a system-wide voltage contour. The phase-shifter display illustrates the flow of power into the city of Chicago and helps operators determine how to tweak phase shifter settings to mitigate heavy flows. The contour plot of system voltages describes the variation of voltage with location and helps operators locate low-voltage problems very easily. The voltage contour plot was shown in Figure 2, and the phase shifter display appears in Figure 5. These displays helped demonstrate the benefits of advanced visualization techniques in the control room and paved the way for additional displays, including an area-tie display showing flows into and out of the client's system, and a 3D plot illustrating generator real and reactive reserves. These displays occupy portions of the client's expansive video display wall and are clearly visible to system operators. Figure 6 and Figure 7 provide photographs of some of the displays currently presented in the client's control room.

The phase shifter and contouring displays exhibit the one-line features described previously. The phase-shifter display of Figure 5 employs moving colored arrows to demonstrate the direction and magnitude of power flow along a transmission element. More heavily

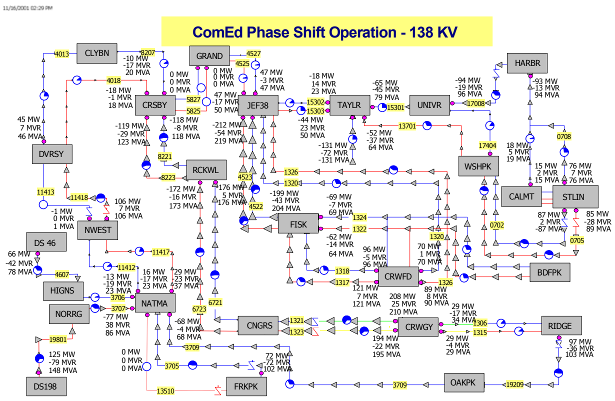

Figure 5: Real-time phase shifter flow display

Figure 6: Advanced displays in the control room

Figure 7: Close-up of advanced displays

loaded branches have faster moving arrows, which identify them as more heavily loaded elements. Furthermore, the arrows change color when the branch becomes overloaded. Each line flow pie chart illustrates the magnitude of the flow relative to its corresponding element's rating and changes size and color when that measure reaches warning and alarm levels. The phase shifter display uses a number of text analogs to convey real, reactive, and complex power flows along each transmission element. These analogs change color when their associated flows reach alarm magnitudes. By using color-coding and pie charts, the application captures both absolute flows values and ratings in a way that consumes minimal display area. The operators who use the display selected combination of animation features used in the phase-shifter display of Figure 5. The application is flexible enough, however, to allow the users to employ a different set of visualization tools as their preferences and needs change.

The voltage contour display of Figure 2 superimposes selected buses on a map showing county boundaries. This emphasizes the map's geographic relevance, a key ingredient to the usefulness of contour plots. Whenever the application acquires new data values from the data server, it updates the contour to describe the new voltage distribution. The plot shades high-voltage regions in blue and low-voltage regions in red, dramatizing their alarm status. If a particular region becomes increasingly deficient, the display envelops it in a deepening and expanding pool of red, an obvious indication that a problem either exists or is developing. An operator may then zoom into that area to determine what reactive power resources could be tapped to help restore voltages to nominal levels.

Early experiences with the voltage contour revealed an interesting challenge: how should the one-line diagrams identify missing or bad-quality measurements? Temporary communication interruptions could make updates of particular data values unavailable. Furthermore, the data server applies tunable criteria to judge suspect measurements of poor quality. In the initial implementation, the application ignored these exceptions and colored problem states in the usual way, resulting in large red regions on the contour that conveyed misleading alarm signals. False alarms obviously compromise the contour's effectiveness in highlighting regions of concern. Fortunately, discussions with the operators revealed an effective solution. The application encircles locations with missing voltage measurements in open white circles; it draws open red circles around locations where poor measurements are detected. Although these points are ignored when coloring the contour plot, their special status is clearly noted.

6 IMPLEMENTATION LESSONS

The partnership between the developer and the client helped forge a very enthusiastically received and useful tool for the client's operators. The operators recognize the new displays as a significant enhancement of their previous system views. Beyond fashioning a quality deliverable, however, the development process also underscored important general guidelines that may benefit any data visualization effort. These emerged most often through the close dialog that transpired between the developers of the application and the operators who use it.

When designing a visualization platform for real-time operations, it is imperative to keep system operators in the decision loop. This should perhaps be an obvious objective, but, unfortunately, it is often neglected. After all, the operators are the ones who will be using the platform and depending on it for guidance in performing their jobs. Since they work on the front lines of system security, they recognize and can express their needs most clearly. To maximize the benefit of the tool, therefore, the developer must seek and respond to the recommendations of those who will ultimately use the product.

There is also a behavioral benefit to embracing this philosophy. It is perhaps natural for professionals to resent and ultimately ignore tools and technologies that have been foisted upon them if they have not been consulted for their opinions and expertise. Legislating that an expert group adapt the way they perform their jobs carries an aura, if not an actual element of, condescension. Neglecting to poll the target audience for its opinions not only sacrifices the quality of the resulting platform, but it also risks compromising its eventual acceptance. The effort to include the operators in designing the application resulted in a superior tool, immediately useful displays, and a more enthusiastic response.

How to seek and acquire input from the operators is primarily a question of style and company culture. The developer and the client may elect to take a formal approach involving interviews, formal specification documents, written requests for comment, and frequent prototypes. With this approach, the developer would first review the characteristics and uses of existing displays and how they apply to the operators' responsibilities. He would then submit written surveys to operators requesting that they evaluate their current tools and prioritize their needs by answering close-ended questions. These surveys would then be supplemented by interviews with operators to gain additional detail. The results of the surveys and interviews would then be codified in formal requirements documents that the developer, the client's management team, and the operators review for completeness and accuracy. Once the requirements are established, the developer would then begin crafting the application and the displays, offering the client opportunities to review prototypes to verify progress.

While the formal approach to soliciting operator involvement may certainly have merit in some situations, a far less formal approach was taken for this project. The operators' dissatisfaction with the existing displays was well known to management through frequent discourse. The key concerns that the operators raised were how cluttered the existing displays were, how difficult they were to see from across the room, and how their lack of flexibility limited the types of information they could show. The developer demonstrated its planning-mode visualization tool for the operators during an afternoon, and their positive comments and suggestions for applying the same ideas to their environment justified pursuing the development. Once the application had been written and the phase shifter and contouring displays were assembled, they were shown to the operators continuously on the video display board over several days. During this time, the developer and the client personnel who oversaw the project talked with the operators in the control room, asking for their comments, suggestions, and questions. The developer then responded to their input by modifying the application and the system displays accordingly. This process continued over a few iterations, until an acceptable set of displays and the desired program behavior were realized. This iterative, prototype-intensive approach worked extremely well.

The operators were particularly helpful regarding the appearance and content of the one-line diagrams. The opinions they offered during trial runs of the application suggested a number of ideas regarding what constitutes an effective display. These include the following:

- Be wary of clutter. The benefit of tools such as line flow pie charts and animated arrows is that they convey not only the absolute sizes of transmission flows but also how the flows compare with device ratings. This benefit must not be compromised by filling the display with numerous, difficult-to-read text analogs that add no new information. While distinguishing useful features from clutter is somewhat subjective, the key criteria to consider are (1) whether the addition of a display item adds new, vital information or simply restates already existing information, and (2) when it is desirable to show the same information in multiple ways, can this be accomplished without consuming additional display area.
- Adhere to the theme of a display. For example, voltage contours show the variation of bus voltage with location. Showing transmission devices on such a display detracts from its purpose, adding extraneous components to what should be purely a bus-related plot.
- Exclude complicated details where appropriate. For example, notice how the phase shifter display of Figure 5 represents buses not individually but rather as substations drawn as labeled boxes. The arrangement of buses within a substation is not relevant to the phase shifter display, which aims to show how power flows into Chicago. Including individual bus connections would obfuscate the display's primary content.
- Use color to focus the user's attention, not to monopolize it. Color-coding flows, pie charts, and analogs to reflect warning conditions help sharpen the operator's awareness of emerging problems. However, if a display employs an awkward mix of colors, exhibits poor color contrast, or employs a counter-intuitive color scheme that operators must ponder to interpret, the display will miss its mark. For example, the voltage contour originally shaded high voltages red and low voltages blue. This conflicted with the operators' normal interpretation of red as suggesting the highest state of concern. Thus, the color scheme was changed to concur with the operators' expectations.
- Respect the importance of time. Data can be called "real-time," of course, only if it has been retrieved recently. The application's displays include a time stamp in the upper left corner that indicates the time at which the data currently showing was fetched. The developer added this feature to increase operators' awareness of the timeliness of the data before them.

Respecting these guidelines will result in more effective and expressive displays of real-time power system data. These will assist operators in recognizing and responding to system trends quickly and appropriately.

7 FUTURE WORK

The developer and the client will continue to work together to enhance the visualization platform presented in this report. Specifically, the organizations hope to increase the opportunities for personnel to access advanced system displays. For example, the developer plans to recast the client as a server application that listens for commands from individual operators, allowing each to control the content of the central video display. Futhermore, it intends to provide a Java version of the interface so that the displays may be accessed securely over the web. This will allow supervisors to inspect emerging problems from home during off-hours. This would also enable the application to run on many operating systems, increasing its usefulness to the organization as a whole.

8 CONCLUSION

Using advanced visualization techniques, a utility can significantly increase its operators' ability to monitor system conditions and to pinpoint emerging problems and possible solutions. This paper has presented a case study of an effort to incorporate such displays in the control room. The package that emerged from this effort employs tools such as flow animation, contouring, localized views, pie charts, color alarm indicators, and 3D maps to demonstrate variations in and relationships between data sets. If displays are designed intelligently to minimize clutter and to focus attention on only the important details, they can convey information about the system in a far more dramatic and intuitive way than simple text analogs and conventional vector-based one-line diagrams. Regardless of the quality of the visualization platform and its displays, the tool will be most effective only if the opinions of those who will use it are sought and respected.

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