Displaying Aggregate Data, Interrelated Quantities, and Data Trends in Electric Power Systems

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Abstract

This paper describes a number of effective techniques for visualizing some of the more complex data relationships that characterize an electric power system in real time. Power systems are large, dynamic physical entities that are constantly changing. While SCADA systems capture the quantitative aspects of these changes, visualizing their magnitudes, pinpointing their locations, and interpreting their collective significance for the current and future security of the interconnection pose tremendous challenges for system operators. This paper describes how advanced visualization techniques such as area tie diagrams, calculated data analogs, historical trend animations, and three-dimensional views clarify the complex relationships, aggregate subsystem characteristics, and emerging trends that describe the current state of the interconnection and help predict its future evolution. The paper provides a number of illustrations that demonstrate the effectiveness of the proposed techniques.

1. Introduction

Power system security personnel face the rather daunting task of monitoring a large, continuously changing system for a wide array of potential problems. Because the consequences of such problems can be rather severe, it is very important that this responsibility be met at all times, regardless of the uncertainties that happen to plague the system and despite the fact that some measurements may be missing or inaccurate. Meeting these challenges requires that security personnel have continuous access to accurate, timely, and complete system information and be able to interpret this information correctly and conveniently.

To help monitor the system accurately, security personnel use tools that display the current state of the system and raise alarms when conditions of concern are detected. Traditionally, these tools have consisted of a large analog map board for displaying the status and alarm conditions of individual transmission elements. The map board is then supplemented by computer displays that show system measurements using a combination of data tables and vector-based graphical displays. Some utilities have replaced the analog map board with a multi-screen computer projection system. Many of those that have chosen to replace their analog map board with new computer displays have sought to translate the appearance and content of the analog board directly rather than make use of the new graphics capabilities their updated hardware affords. While maintaining the look and feel of the original map board helps ensure a certain temporary comfort level among users, it also wastes an opportunity to exploit the capabilities of the new hardware. Given the proper modern data visualization platform, security personnel can craft displays that are both familiar in their content and enlightening in the breadth of information they show.

Reference [1] surveyed a number of innovative power system visualization techniques and described how they were being used at three electric utilities. The purpose of this paper is to continue that discussion. Specifically, it provides a more detailed look at some of the issues that must be addressed when designing displays that make use of the new techniques. It expands the arsenal to include tools for visualizing aggregate quantities such as total area load and generation and interface flows. It discusses how to make use of three-dimensional views to show more complex relationships among quantities. It also recommends ways to identify poor or missing data, to distinguish out-of-service elements, and to highlight alarm conditions. Finally, it serves as a feature list for vendors to use for developing visualization platforms that take advantage of today's more powerful and less expensive hardware to equip security personnel with the tools they need to make their jobs easier and more efficient.

2. Data views

A good deal of research has been performed on applying innovative visualization techniques to the study of electric power systems in both planning and operations settings. References [1] through [11] provide much of this background. This section begins to survey these techniques and to recommend practices for maximizing their benefits. Specifically, it discusses the different types of maps used to represent electric power systems that provide local-area, wide-area, and aggregate views. The techniques described in subsequent sections use these various types of maps as their canvas.

2.1. System maps

Electric power systems consist of buses, loads, generators, transmission lines, transformers, reactive compensation devices, circuit breakers and switches, and many other types of equipment. The operator must keep tabs on the status of all this equipment to ensure that it continues to work properly within defined safety limits. The number of pieces of equipment, combined with the expansiveness the region defined by the interconnection of these items, complicates this task considerably. The operator must understand not only the flows seen by each device, but also the way the individual pieces connect to and influence each other. A comprehensive, easy-to-read map that shows each piece of equipment, its status, and the position it occupies in the system can play an indispensable role in helping the operator achieve understanding.

Figure 1 provides an example of a map that serves this purpose. This map employs a number of techniques to enhance its expressiveness. These include color-coding, animated flows, line flow pie charts, and text analogs, all of which will be described shortly. However, consider the content of the illustration from a more general perspective. The map of Figure 1 conveys very clearly how each of the pieces of equipment that comprise the system connects with the other pieces. As a result, it suggests how each piece of equipment influences the other components with which it operates. This sort of information would be very difficult to ascertain from a table of equipment flows, because data tables convey little information about topology.

2.2. Local-area views

The type of topology information provided by a system map depends on the relative placement of the elements it shows. Depending on how elements are placed, the map can convey topology information in either a geographic sense or with an emphasis on how substations, rather than individual buses, connect. The latter, substation-centric approach is probably more familiar to power system operators because it more closely relates to the views provided by more traditional visualization engines. Such maps show the content of individual substations and the status of equipment comprising each substation very effectively. At a glance, the operator can learn the names and connectivity of the busbars that comprise the system, the transformers that step the voltage to various required levels, the switching devices that forge the connections, and the auxiliary equipment that provide such functions as reactive support and fault protection. Figure 2 provides an example of this type of view, where connectivity and status, rather than geographic placement, is the key concern.

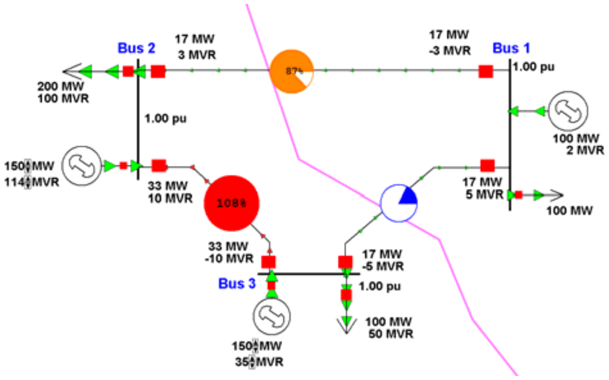


Figure 1: Simple one-line diagram example

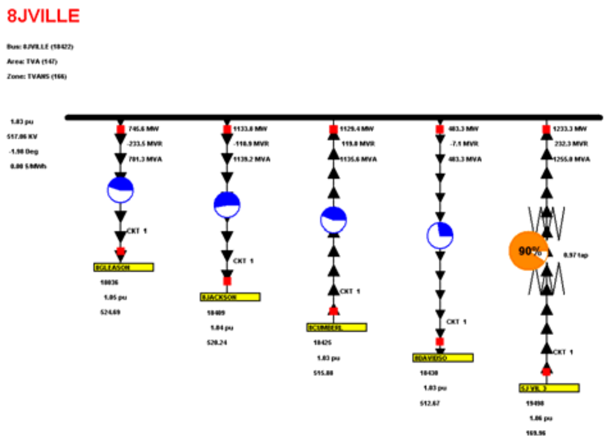


Figure 2: Substation-centric data view

The topology of localized, substation-centric views depends solely on the connectivity of elements. Thus, such diagrams can be automatically generated rather easily, provided the connectivity information is available. A power flow model is one example of a database that provides sufficient connectivity information to automatically generate a localized view such as Figure 2.

Furthermore, by taking advantage of the power of the modern event-driven graphical user interface (GUI), an application can greatly enhance the power of a localized view by enabling the user to easily navigate through a region of the system. For example, in Figure 2, the thick, wide horizontal line drawn along the top terminal of each transmission line represents the `8JVILLE` bus, which is the focus bus for this drawing. The shaded, text-filled rectangles drawn at the bottom terminal of each transmission line in Figure 2 represent the buses to which the focus bus is connected. These busbar symbols are actually hyperlinks, text areas that, when clicked, redefine the focus bus to be the node represented by the hyperlink. Thus, when the user clicks on a busbar hyperlink, the application redraws the localized view to show the connections to the corresponding bus. The application also includes a history list of previously visited buses, as well as forward and backward arrows for traversing the history list. By clicking on the hyperlinks and using the history list, a user can explore a small region of the system in great detail, discovering its topology, composition, and current status.

2.3. Wide-area views

While localized views facilitate quick study of a small region, they fail to convey information about the system as a whole. The power of a map such as that shown in Figure 1 is that it shows the system in its entirety, rather than an isolated substation within the system. Such views are particularly useful for showing how a quantity such as bus voltage, for example, varies with position in the system. This can provide keen insight into where the system's problem areas lie and, thus, where and what reinforcements should be committed.

Accurately depicting the geographic relationships between components yields the most intuitive wide-area representation of a system because it provides a context for interpreting system-wide characteristics. Designing a system map that reflects the geographic relationships between equipment requires knowing, at least approximately, the geographic coordinates of each element. Many utilities have assembled detailed databases of component locations, particularly for use with global positioning systems, so this information should be readily available. An application can import a text file containing these geographic coordinates and use them to position system components on a map. The resulting display provides a wide-area view of the system that can illustrate trends, characteristics, and problems.

As with the localized views, the user requires some means of maneuvering about the system. For example, Figure 3 provides a wide-area view of the Tennessee Valley Authority (TVA) system. This map shows the system as a whole. When used with the contouring technique described in Section 3.2, this view provides a powerful look at how the system varies with location. However, the view is akin to what one might find looking down from an airplane during flight: the terrain is visible, but the details are muted. By providing a dynamic view port, a modern visualization engine allows the user to zoom into or out of a display, increasing the magnification of a particular area when a more detailed look is desired and reducing the magnification to recover the wider area perspective. The visualization engine should enable the user to control the zoom level in a number of different ways: by directly specifying the zoom level as a number, by using keyboard keys or a mouse wheel to step the magnification through a range of levels, or by using the mouse to select a portion of the view port to fill the entirety of the display, thus magnifying the details of that region.

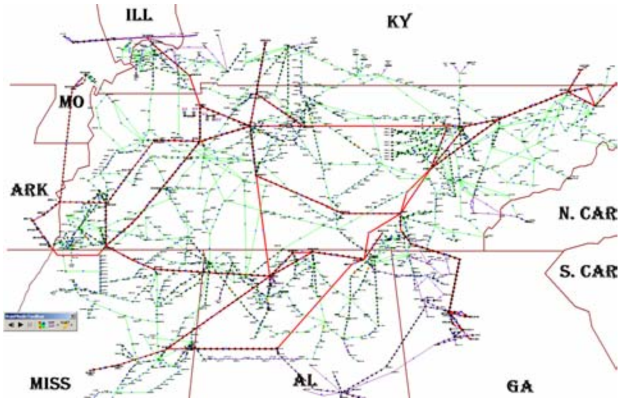


Figure 3: Wide-area data view

Figure 4 shows a magnified view of a particular region of the map displayed in Figure 3. This view provides detailed flow and status information to the user, just as a localized view would, but over a larger region and with geographical information retained. Of course, at this level of magnification, it is possible that an area of interest now lies slightly outside the view port. The user can pan the view port horizontally or vertically to see components that lie off screen. The user controls the pan using the arrow keys on the keyboard or by clicking on the map's background and dragging the mouse. Furthermore, if there is a particular component of interest, the user can instruct the visualization engine to center the view port about it by specifying its name. In addition, the user can save particular combinations of zoom and pan settings and return to them easily by selecting the desired view from a menu. This enables users to navigate around the system while keeping track of the regions they have visited. Using a view port that supports pan and zoom operations helps the modern visualization engine transcend screen size and resolution limitations. Such maps may then represent even very large interconnections in a way that encourages exploration and discovery.

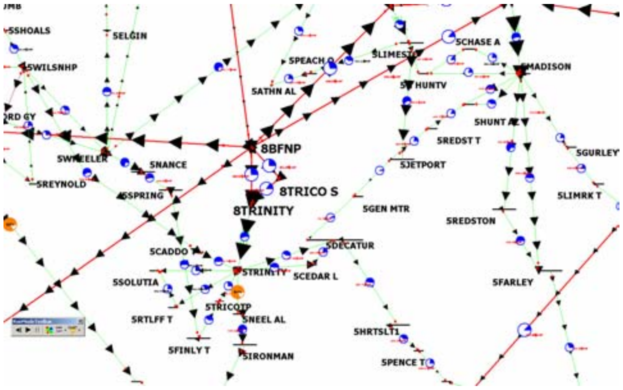


Figure 4: Magnified view of a region

The dynamic view port functionality is further enhanced by using a second, wider-area view to control the focus of a magnified display. The wider-area view is called a thumbnail. Figure 5 illustrates the relationship between the thumbnail and its associate display. The thumbnail occupies the upper right corner of the display. The rectangular box that appears in the center of the thumbnail outlines the contents of the associate display which are currently visible. The thumbnail shows a much wider area than its associate because its magnification level is only a fraction of its associate's (in this example, it is one-fourth). The user can pan and zoom the view port using either the thumbnail or its associate. The thumbnail view helps the user determine the location of a particular local area within a much wider area. The context and control the thumbnail view provides can help the user investigate how a region's flows or voltages are affected by the characteristics of its surroundings.

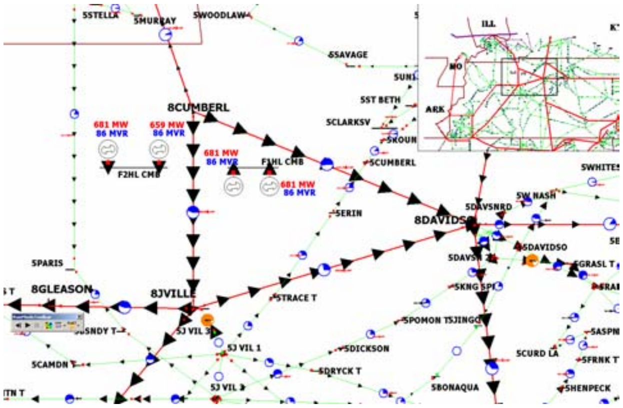


Figure 5: Thumbnail view

2.4. Hybrid views using conditional display

It is possible to create a single display that exhibits the benefits of both local-area and wide-area views. The approach involves associating the visibility of a piece of equipment with the magnification level of the map on which it resides. If a particular piece of equipment is defined to be visible only beyond a certain zoom level, then it will be hidden from view when the display covers a wide area. Then, as the user zooms into a particular region, the piece of equipment will become visible once its target zoom level is reached. In other words, local detail can be hidden from view when the user is interested in viewing a large area of the system, and it can be revealed when the user decides to look at a particular region, or even a particular substation, more closely. Conditioning the display of equipment on zoom level reduces clutter in wide-area views and empowers a single, detailed map to function as both a system-wide view and a substation-centric view.

2.5. Aggregate views

Not all quantities of interest pertain to individual buses or substations. Sometimes, security personnel need to know information about a group of buses and how they behave as a whole. For example, an operator may want to learn the total load and total generation in a control area, or the control area's net interchange, or the reactive power reserve of a group of generators and capacitors that were identified by system planners as crucial reactive supports. The modern visualization engine includes symbols and tools for displaying such aggregate, group-related quantities.

For example, Figure 6 shows an aggregate data view called an area-tie diagram that represents the system in terms of control areas and the interfaces joining them. Control areas are represented graphically as bubbles. These bubbles represent all the buses that belong to a specific control area. The lines that connect the bubbles represent the interfaces between each area. Each interface, which actually represents one or more transmission lines or transformers that serve as tie lines, is shown as a single connecting line.

Figure 6 shows the same land area as Figure 3, but its emphasis is obviously quite different. Area-tie diagrams such as Figure 6 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. Furthermore, using the visualization techniques described in the next section, an aggregate view can be used to show how groups of buses differ in consumption, generation, and reserves.

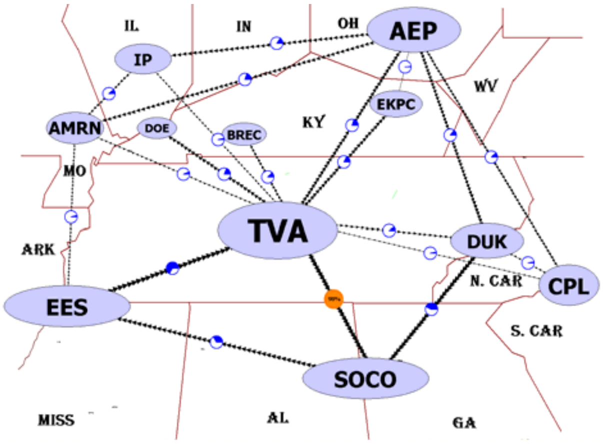


Figure 6: Aggregate data view showing areas

A potential stumbling block for the display of aggregate data in the control room is that many operations data bases store little, if any, aggregate data. When that is the case, the user has a few options. The first is to add such quantities as calculated fields to their database so that they can be retrieved by the visualization tool. For example, the flow on a particular interface could be calculated as the sum of flows on the transmission lines that comprise it. Alternatively, the user may write auxiliary programs that extract the required data from the database and produce an additional data set at regular intervals. This secondary data set of auxiliary values will also be queried by the visualization engine so that the aggregate quantities can be displayed. Finally, the visualization engine itself should provide some rudimentary arithmetic capabilities and an interface for defining expressions for aggregate quantities. Then, during data retrieval, the application can retrieve the required data and compute and plot the values of these user-defined expressions.

3. Data representation

The nature and purpose of the data suggest the type of view to use to display it. If the data set describes flows and statuses of equipment at a particular substation, then a local-area view is appropriate. If the data set contains voltage measurements for buses scattered throughout a region, and the purpose of the study is to inspect how voltages vary with location, then a wide-area view is desired. Once the type of the view has been identified, the next step is to determine the best combination of visualization tools to use to represent information on it. This section describes some of the advanced data representation techniques offered by a modern power systems visualization engine and offers suggestions for maximizing their benefits.

3.1. Branch and interface flow measurements

Monitoring the real, reactive, or complex flow of power through a single transmission line or across an interface requires knowing the direction and the absolute value of the flow and the limits the flow must obey. Text analogs provide one means of expressing this information. For example, if the user needs to monitor real power flow on a transmission line, he can add text fields to the map that reveal this information. However, this approach requires that two text analogs be added to the one line to describe each flow of interest: one that expresses the absolute flow, and the other that indicates its magnitude. If there are a large number of flows to monitor, or if the map contains a number of elements, this approach yields a rather cluttered map.

Modern visualization engines provide a number of techniques for reducing clutter. These tools provide a single visual indicator that reveals the direction and absolute value of the flow as well as its limit. One such technique is to animate the flow of power through an interface or branch. Figure 1 illustrates some of the features of animated flows especially clearly. The flow of power across a branch is represented using arrows. The direction of the arrows matches the direction of the power flow, and the size of the arrows indicates the flow's magnitude. If the user desires, the application can set the arrows in motion and animate the flow of power into and out of each element in the system. Furthermore, if a flow violates its limit, the arrows may be filled with a different color to indicate an alarm state. During animation, the application may also distinguish the magnitudes of different flows by adjusting the speed with which their corresponding arrows flow. Flow animation may be configured to represent magnitude either in terms of absolute value or as a percentage of rating, and it may be set to illustrate real power or reactive power exclusively or simultaneously, using a different color scheme for each.

Figure 7 demonstrates how real and reactive flows can be shown simultaneously. Real power, symbolized by filled arrows, flows from bus 1 to bus 2. Reactive power, symbolized by unfilled arrows, flows out at both ends of the line, indicating that this line generates vars. The size of the reactive power arrows varies along the line to simulate the variation in reactive power due the shunt admittance of the line.

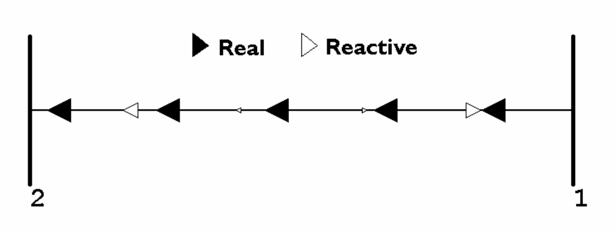


Figure 7: Animating real and reactive flows

Pie charts offer another technique for illustrating transmission flows. A pie chart shows how the plotted quantity relates to its maximum value. For line and interface flows, a map may use pie charts to show what percentage of the line or interface's rating is currently flowing on it. Users interpret branches with nearly empty pie charts as carrying only a small fraction of their rating; branches with nearly full pie charts transmit close to their rated flow. Thus, pie charts provide transmission personnel an intuitive view of the information they seek most: the proximity of a line or interface to its thermal rating.

Pie charts also serve as excellent indicators of violated limits. When the flow on a branch is at safe levels, the pie chart appears at normal size and is 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. Each transmission line in Figure 1 demonstrates a different pie chart state: normal, warning, and violation. The ease with which line flow pie charts suggest thermal problems makes them indispensable aids for transmission personnel. Interface flow pie charts behave identically.

Another approach for showing line and interface flows involves shading transmission elements according to the power they carry. For example, Figure 8 shades transmission lines that carry over 50% of their rated power. Most of the lines on this plot are not shaded. Those that are range from bright yellow (50% loading) to bright red (75% loading) to fuchsia (100% loading). (In grayscale, this translates to darker shading for more heavily loaded elements.) The advantage the shading approach has over animated flows and pie charts is that it reveals problem elements even at very distant zoom levels. The user can then zoom into the red regions and study the causes of the heavy loading more closely.

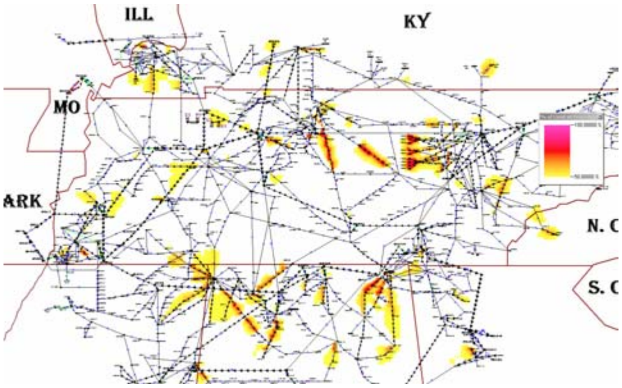


Figure 8: Shading heavy flows in wide area views

Of course, line and interface flows can also be represented using text analogs. System displays have employed text analogs for years to reveal the actual transmission flows and bus voltages in the system. Text analogs provide an unequivocal reading of a monitored quantity. Thus, system personnel depend on text analogs and expect to see them on any system map. The problem with text analogs is that they can be difficult to read from maps that attempt to show a large portion of the system; consider, for example, the ineffectiveness of text analogs in Figure 8. Furthermore, they can make an already dense system map seem even more crowded. If the map designer attempts to address these problems by reducing the text analogs' font, they will be difficult to read from far distances. Still, no other tool reveals the absolute values of measured quantities as directly or as clearly as text analogs.

Following a few guidelines can maximize the benefits of text analogs while avoiding their ill effects. First, if only limit violations are of interest rather than flow magnitudes, use pie charts instead of text analogs, since they convey this information much more intuitively and compactly. If flow magnitudes are of interest, then define the visibility of text analogs in terms of the map's zoom level to avoid needlessly cluttering the display with illegible text at remote zoom levels. Furthermore, if a map must contain both animated flows and text analogs, avoid the ambiguity that comes from including negative signs with the text analogs for subzero values. Rely on the arrows to indicate the direction of power flow, and use the text analogs to indicate magnitude. Finally, using text analogs to highlight limit violations can easily draw attention to problem elements. The visualization platform should assign a different color to text analogs that correspond to measurements that violate their limits. Alternatively, the visualization platform should be able to blink the display of such problem measurements. Depending on the users' needs and preferences, it may even be wise to hide all text analogs except those that correspond to violations. When a violation is detected, the analog for that measurement will become visible.

3.2. Node voltage measurements

Security personnel monitor bus voltages very carefully to ensure that they remain within an acceptable range. Abnormal voltages risk damaging costly equipment. Furthermore, inadequate voltages may suggest more severe voltage problems, such as a voltage collapse. Inadequate voltages are usually precipitated by a lack of reactive power support, which may be worsened by the stalling of induction motors at low voltage levels. Because the reactive power resources for a region tend to be local, abnormal voltages also tend to be localized. In other words, a bus's voltage tends to be similar to that of its neighbors, with large variations in voltage occurring gradually as one moves through groups of buses.

Contour plots capture this type of gradual variation quite well. The purpose of a contour plot is to illustrate how a particular quantity varies with location. Since wide-area views usually reflect the geographic arrangement of system equipment, contour plots provide a valuable picture of how quantities such as bus voltage 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 9 shows a contour plot of bus voltage superimposed on a transmission system map. Although the map shows a large land area, 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 [10] 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. He may also choose to contour only voltages that lie within a certain range. For example, Figure 10 highlights only the low voltages from Figure 9, as all voltages above a specified threshold are omitted from the plot. To realize the full benefit of contour plots, the visualization engine should offer the user great flexibility in customizing the appearance and content of the contour.

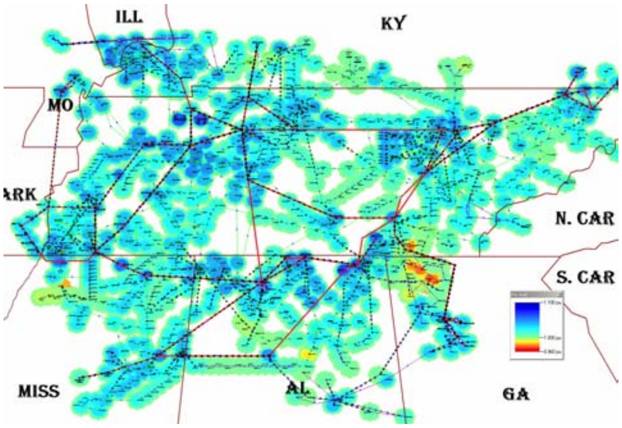


Figure 9: Voltage contour

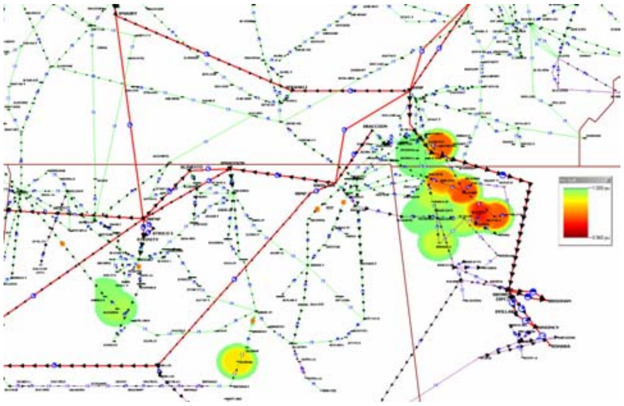


Figure 10: Contour of low voltages only

Contour plots are not limited to showing the variation of bus voltages in a system. They can depict any quantity that varies with location. Thus, contours of load, generation, reserves, and even bus marginal pricing have proved useful. Note that the highlighting of heavily loaded transmission lines in Figure 8 was accomplished using contouring. Similar plots have been drawn to show the impact of proposed transfer on inter-area flows, with the most heavily impacted interfaces highlighted by the contour [1]. The unique strength of contouring is its ability to highlight areas of concern or abnormality in wide-area views.

3.3. Alarm conditions

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.

Most of the techniques described thus far aim to highlight conditions of concern. For example, the dynamic sizing and coloring of pie charts to reflect problematic flows draws attention to transmission bottlenecks. The color-coding and blinking of text analogs performs a similar function for both transmission flows and bus voltages. By their very nature, voltage contour plots draw attention to pockets of abnormal bus voltages. In fact, the driving force behind much of this research into advanced visualization techniques has been to identify and implement some of the most poignant indicators of alarm conditions so that operators can unequivocally identify and address security issues.

Several other techniques can be used to highlight alarm conditions or exceptional data. Equipment that is out-of-service, including open transmission lines, offline generators, disconnected loads and reactive supports, and isolated buses and substations can be represented in either a different color, a different pen style (for example, dashed rather than solid), blinking, or a combination of these effects. A piece of equipment that violates some specified alarm criteria can be circled or highlighted in some other way to draw attention to it. If the user has access to sites such as NERC's list of transmission loading relief events [13], the application can be told to highlight transmission elements that are currently limited by transfer constraints.

Furthermore, the visualization engine should be able to interact with a number of additional external data sources, including, perhaps, a database of line outage distribution factors. Using these factors and the current measured flow values, the visualization engine could perform a rapid contingency screening for transmission overloads. The application would then highlight transmission elements that violate their limits under post-contingency conditions.

On contour plots, missing or inaccurate measurements can be highlighted by circling them or having them blink. Such invalid measurements will distort the appearance of the contour and therefore must be omitted. For example, Figure 11 and Figure 12 compare two contours of the same bus voltage data. In Figure 11, the meter for the voltage at bus `5White P` has malfunctioned, returning a near-zero voltage. This results in a large red area on the contour plot. Ordinarily, dark red suggests to system operators that there is cause for alarm, so personnel might incorrectly conclude that the voltage collapsed in this region. Including inaccurate measurements on the voltage contour adds some doubt on how to interpret the contour at exactly the time the contour could be most useful: during potential alarm situations. Distinguishing alarm conditions from bad measurements, either by reporting a quality flag with the field data, checking the measurement source against a catalog of known metering problems, or by comparing the measured value against a defined cutoff value for bad measurements, allows the visualization tool to portray bad measurements in a distinctive way. For example, Figure 12 distinguishes the bad measurement by circling it in red and omitting it from the contour plot. This takes a good deal of guesswork out of interpreting the display.

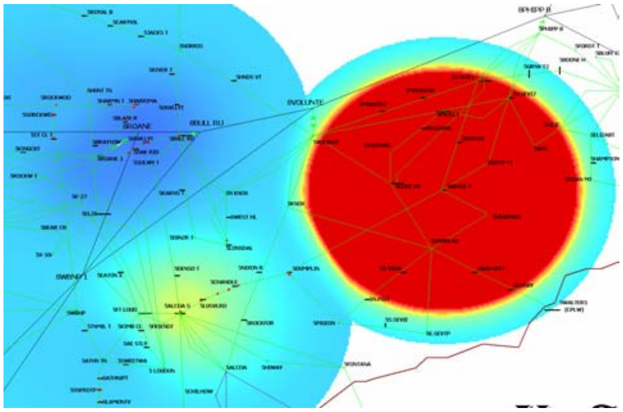


Figure 11: Effects of including bad data

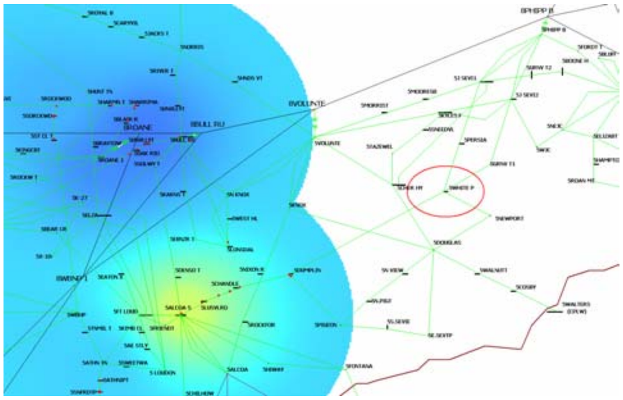


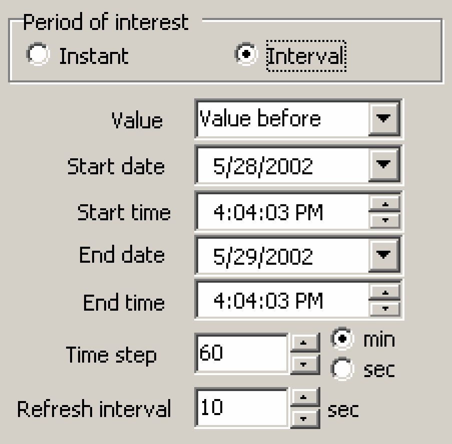
Figure 12: Highlighting bad data

3.4. Trend playback

When an interesting event occurs, such as depressed voltages, high transmission flows, or an unexpected sequence of outages, it is often beneficial to recreate the event. Replaying how the system evolved over a particular period can provide insight into the conditions that led up to the event and may yield lessons on how to prevent the event in the future. Provided the data for the period of interest are available, a visualization engine should be able to simulate the system over the period, displaying the state of the system at user-specified intervals much like a movie player displays a movie as a sequence of frames.

To demonstrate the possibilities of this feature, Figure 13 identifies the parameters the user can enter to control the simulation of the system over a past time period. The visualization engine should allow the user to replay a single instant in time or an extended period. This is similar to playing a single frame of a movie or an entire scene. If the user chooses to simulate just an instant in time, he will specify the date and time for that instant. (The *Value* dropdown box specifies which set of archived values to retrieve: the points immediately before the start date or the points immediately after.) If, instead, the user elects to simulate the system over an interval, he will specify both the start and end dates and times. He will also specify the size of the sample interval for the simulation, as well as how frequently to retrieve the data.

In Figure 13, the user has chosen to retrieve data over a twenty-four hour period beginning at 4:04 PM on 5/28/02. The visualization engine will animate system conditions for 4:04 PM for ten seconds. It will then retrieve the data for 5:04 PM (note that the user specified a time step of 60 minutes) and animate that for 10 seconds, and so on. To maximize the usefulness of trend playback, the visualization engine should enable the user to pause, stop, and rewind the simulation, as well as to record it as a movie file for presentation purposes.



Period of interest
○ Instant ● Interval

Value: Value before
Start date: 5/28/2002
Start time: 4:04:03 PM
End date: 5/29/2002
End time: 4:04:03 PM
Time step: 60 ● min ○ sec
Refresh interval: 10 sec

Figure 13: Options for trend playback

3.5. Complex data relationships

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 14 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. Since reactive power reserves strongly influence a region's voltage profile, a three-dimensional plot that shows information about both quantities helps security personnel pinpoint the probable causes and most promising solutions for voltage deficiencies.

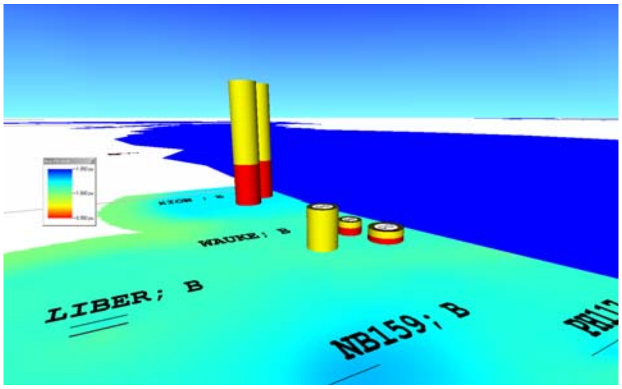


Figure 14: Voltages and reactive reserves

The design of the visualization engine should make the move from two-dimensional to three-dimensional plots as easy as possible. For example, the user should not be required to draw a separate set of maps for use specifically with 3D views. Instead, the tool should be able to render an existing map in three dimensions. Furthermore, specifying the data content for the three dimensions should be straightforward. Users should recognize that the plane of the plot is simply their familiar two-dimensional map drawn in a different direction. The visualization engine must encourage this understanding by offering the same tools for customizing the animated flows, text analogs, exception highlighting, and symbol sets for this plane. Then, the tool must offer the user flexibility for specifying the data that should be plotted along the new vertical dimension of the plot.

Although the use of 3D visualization in power systems is rather new, some common practices have emerged for rendering data along the third dimension. Flow data for a line or interface is rendered by drawing the flow pie chart as a partially filled cylinder, the filled portion of which represents the magnitude of the flow relative to its rating. Generator real and reactive output and reserves are rendered in a nearly identical manner: a cylinder coincident with the generator symbol represents the magnitude of the plotted quantity for each generator, and comparing the filled and unfilled portions of these cylinders reveals information about reserves. Figure 14 demonstrates this practice.

In addition to giving the user freedom to specify the data content for a 3D display, the tool must equip the user with tools to explore this new world. The user can now move the plot along three directions. The visualization engine must allow the user to "walk" in all directions, to rotate his viewing angle about the vertical axis, to change his elevation relative to ground level, and to tilt his viewing angle up or down. Since the view port can be controlled in so many more ways, it is a big challenge for the visualization engine designer to make the user interface as simple and as convenient to use as possible. A major part of making the 3D navigation simple involves giving him the ability to choose which input devices control which types of movements. Furthermore, the engine must provide lighting effects to enhance the 3D appearance. The user should be able to control the lighting angle, direction, and intensity.

Three-dimensional views express complex data relationships with unrivaled clarity. As with contouring, to make the most of the 3D approach, a visualization engine must give the user as much flexibility as possible to customize the view so that it expresses the information he requires in the manner he wants to see it.

4. Conclusion

This paper has surveyed a number of advanced visualization tools that are currently in use in several control rooms. The techniques discussed here far exceed the capabilities of tools that use older computer technology and software development methods. Yet, these innovations merely suggest the promise and possibilities the technology holds.

Some may argue that the map shown in Figure 1 is rather cluttered, particularly considering that the system it represents is so small. This is a valid argument. The primary intent of that map was to demonstrate some of the many tools a modern visualization engine offers. The flexibility of well-designed visualization platform, however, is that it allows the user to enable a variety of system indicators and, just as importantly, to *disable* them if the objectives of a display can be attained without them or if certain conditions are not met. The visualization engine must give the user the ability to customize how the various data representation tools are used to create an easy-to-read, visually appealing display. Furthermore, the map designer must use good judgment in selecting the best combination of tools to use for a display. Ultimately, the users who will use the display should be consulted, perhaps through a formal survey, at each stage of the design to ensure that they agree with and will benefit from the design choices [12].

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