U.S. DEPARTMENT OF ENERGY

Electricity Delivery
& Energy Reliability

NASPI North American SynchroPhasor Initiative

American Recovery and
Reinvestment Act of 2009

Phasor Tools Visualization

NASPI Technical Workshop
Final Report
June 13, 2012

NASPI Synchrophasor Technical Report

SMARTGRID.GOV
RECOVERY ACT SMART GRID PROGRAMS

www.naspi.org

NASPI Synchrophasor Technical Report
Phasor Tools Visualization Workshop
Technical Summary

February 28, 2012 Workshop
June 13, 2014 Final Report

Context

This technical material was developed in June, 2012 by the North American SynchroPhasor Initiative, a collaboration between the North American electric industry (utilities, grid operators, vendors and consultants), the North American Electric Reliability Corporation, academics, and the U.S. Department of Energy, to advance and accelerate the development and use of synchrophasor technology for grid reliability and efficiency. The material attached was produced for one of a series of NASPI technical workshops intended to educate and document the stakeholder community on the state of the art for key synchrophasor technology issues.

Synchrophasor technology was developed thanks to early research investments by the U.S. Department of Energy and Bonneville Power Administration in the 1990s. With recognition that synchrophasor technology -- high-speed, wide-area, time-synchronized grid monitoring and sophisticated analysis -- could become a foundational element of grid modernization for transmission system, the Department continued and expanded its investment and industry partnerships in the areas of synchrophasor communications, applications, measurements, and technical interoperability standards.

In 2009, the Department committed a total of $412 million of funds from the American Recovery & Reinvestment Act of 2009 to twelve Smart Grid Investment Grants and one Smart Grid Demonstration Project that implemented and tested synchrophasor technology using matching private funds. While some of the ARRA funds was spent on other transmission assets, in aggregate over $328 million of federal and matching private investment was spent on synchrophasor technology and related communications networks.

Additionally, DOE has funded significant technical assistance for NASPI and synchrophasor advancement through the National Laboratories and the National Institute for Standards & Technology.

NASPI serves as a forum for information-sharing and problem-solving among the synchrophasor projects and stakeholders. Much of the work and insights reflected in this technical workshop was enabled by individuals and companies funded by DOE's on-going research and development projects and the ARRA investments. Thus it is appropriate to recognize the insights and work product documented in this workshop and technical report as one of many consequences and work products resulting from the federal Smart Grid investments. Therefore, the Department joins NASPI in re-releasing this material to the smart grid community to document additional impacts and value realized from the federal Smart Grid investments in synchrophasor technology.

The Purpose of the Visualization Workshop

In the on-going effort to improve grid reliability for the North American bulk electric system, this workshop looked at visualization and situational awareness applications based on data collected using Phasor Measurement Units. Synchrophasor technology is the most significant control center data improvement tool introduced in the last decade. Collecting phasor data and efficiently delivering it to operators in a structured fashion can enhance the quality, speed and effectiveness of operator actions.

Advanced visualization software allows control room operators to see what is happening on the bulk power system within fractions of a second, rather than the industry standard practice of every four seconds. This technology can give operators precise snapshots of current conditions, provides clear, timely information on unfolding events, and helps operators analyze the situation and take informed mitigation actions to protect and enhance grid reliability.

This workshop compared the visual presentations offered by several commercially available phasor data visualization software providers. The goal of the workshop was to look at how the visualization tools display specific grid events. It gave control room operators the chance to comment on the clarity, effectiveness and intuitiveness of differing displays. Vendors' visualization products were not explicitly identified during the presentations and all vendors were present to hear the operators' feedback on the pros and cons of each visualization tool and event. The workshop allowed operators and observers to discuss whether there might be any need or benefit to developing more common elements in a visual vocabulary for the grid.

This technical report includes the following elements:

1. The final report for the workshop, prepared by Dr. Jodi Obradovitch (human factors expert at the Pacific Northwest National Laboratory) and Alison Silverstein (project manager for NASPI).
2. The agenda for the workshop.

The workshop featured video clips prepared by the participating vendors to show how each vendor’s synchrophasor data visualization tool (as those tools existed in February 2012) handled each of the event data cases presented at the workshop. Those video clips can be found at:

- EPG's Event 1 and Event 2 clips
- OSISoft's video clips
- PowerWorld's Event 1, Event 2, Event 3, and Event 4 clips
- Alstom Grid's Event 1, Event 2, and Event 3 clips.

It is worth noting that each of the visualization tools compared in the workshop has been modified and improved since, based in part on the feedback provided and insights gained in this technical workshop.

North American Synchrophasor Initiative (NASPI)
Phasor Tools Visualization Workshop
February 28, 2012

Final Report

By

Jodi Heintz Obradovich, PhD
Pacific Northwest National Laboratory

and

Alison Silverstein
North American SynchroPhasor Initiative

June 13, 2012

NASPI North American SynchroPhasor Initiative

Contents

Executive Summary 3
  Introduction and purpose 3
  Attendance..4
  Structure...4
  Findings...4
  Next Steps 5
NASPI Visualization Workshop..6
Introduction 6
Purpose 6
Participants 7
  Real-Time Operators...7
  Visualization Tool Providers 7
  Human Factors Experts 7
  Observers 7
Structure..7
  Introduction to workshop...8
  Suggestions for watching the visualization clips 8
  Events...10
  Operators’ Reflections and Sharing of Reactions to Video Clips 13
Findings...13
Summary...18
References 18
APPENDIX A: *Companies with Operators Participating* 20
APPENDIX B: *Participating Vendors*..21
APPENDIX C: *Human Factors Visualization Experts* 22
APPENDIX D: *Operator Role and Organization Affiliation*...23
APPENDIX E: *Opening Comments by Alison Silverstein*...24
APPENDIX F: *Suggestions for Looking* 27
APPENDIX G: *Categorization of Operator Comments* 30
APPENDIX H: *A Selection of Principles of Display Design* 74

Executive Summary

Introduction and purpose

The mission of the North American SynchroPhasor Initiative (NASPI) is to "improve power system reliability and visibility through wide area measurement and control." (NASPI, 2012). Phasor measurement units (PMUs) provide precise grid measurements, called synchrophasor measurements. These PMU measurements are taken at high speed (typically 30 or more observations per second – compared to one every four seconds using conventional technology). Each measurement is time-stamped according to a common time reference, allowing synchrophasors from different utilities to be time-aligned (or "synchronized") and combined to provide a precise and comprehensive view of the entire interconnection. Synchrophasors enable a better indication of grid stress, and can be used to trigger corrective actions to maintain reliability.

NASPI is a collaborative effort between the North American Electric Reliability Corporation, the U.S. Department of Energy, and many electric industry members and experts, including electric utilities, vendors, consultants, federal and private researchers and academics. The NASPI community is working to advance the deployment and use of networked phasor measurement devices, phasor data-sharing, applications development and use, and research and analysis. Important applications today include wide-area monitoring, real-time operations, power system planning, and forensic analysis of grid disturbances. Phasor technology is expected to offer great benefit for integrating renewable and intermittent resources, automated controls for transmission and demand response, increasing transmission system throughput, and improving system modeling and planning.

Situational awareness is defined as, "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." (Endsley 1995) Within the electric industry we want grid operators to have good situational awareness; we know that effectively designed visualization tools can help operators understand grid conditions and react to them.

Advanced visualization software using synchrophasor data allows control room operators to see what is happening on the bulk power system within fractions of a second, rather than the industry standard practice of using data updated every four seconds. This technology can give operators precise snapshots of real-time conditions, provides clear information on unfolding events, and helps operators analyze the situation and take informed mitigation actions to protect and enhance grid reliability.

NASPI organized this workshop to compare the visual presentations offered by several commercially available phasor data visualization software providers, to see whether the tools are aiding operators' situational awareness in real time. The goal of the workshop was to look at how the visualization tools display specific grid events. We asked control room operators to comment on the clarity, effectiveness and intuitiveness of differing displays relative to both the events displayed and the operators' varying job responsibilities. The vendors' visualization products were not explicitly identified during the presentations, and all vendors and observers were able to hear the operators' feedback on the pros and cons of each visualization tool and event. At its close, the workshop participants discussed whether there might be any need or benefit to developing more common elements in a visual vocabulary for the grid.

This report summarizes the purpose of the workshop, the results, and offers an overview from a human factors perspective on the critical cognitive issues that need to be taken into account when designing visualization tools for real-time operations in the electric industry.

Attendance

There were 125 attendees at the workshop, including 20 operators from reliability coordinator organizations and balancing authorities, vendors who develop visualization tools, human factors experts, as well as others from government agencies, utilities, research organizations, and universities.

Structure

The structure of the workshop consisted of an introduction of the workshop purpose and process to set the context, suggestions from a human factors perspective on things to look for and think about while viewing the event clips, operator responses to the event clips, and a discussion on next steps.

Based on realistic synchrophasor data, the software vendors developed video clips (of approximately 2 minutes per event) to illustrate the visualization their products would provide to grid operators. The four grid events included three occurring in the western U.S and Canada: a large generation outage, islanding, and growing oscillation. The fourth event was of line outages and oscillations in the eastern U.S. The visualization tool vendors' video clips of these four events, based on phasor data, can be found at https://www.naspi.org/site/Module/Meeting/Reports/SubReports/workgroup.aspx (see the listing for February 28, 2012).

Findings

Operators' comments were categorized into general categories. These categories are listed below in order of the number of operator comments each topic received (i.e., operators made the most comments about category 1 and the least about category 13):

1. Trends, charts, numbers, and/or tables
2. Ease of interpretation
3. Dashboard/overview displays
4. Accessing more detail—zooming/drill down, pop-up displays, hover for more information
5. Color / contrast / highlighting
6. Flashing
7. Alarms
8. Relationship between data—cluttered displays
9. Contouring 23
10. Geographic overviews/map
11. Icons / symbols
12. Not operator-focused
13. Switching between displays—easily get lost

Next Steps

The NASPI Visualization workshop concluded with a discussion of participants' ideas for whether and what to do next about further improvements to phasor data-based visualization tools. One vendor representative noted that not all responsibility for visualization design rests on the vendors, because many visualization tool users customize and modify these products to reflect their own look and feel before handing the visualization tool to operations users.

Because grid reliability requires that all controls rooms and operators managing the grid must share a common understanding of its condition in real time, there was also discussion about whether and how to design visualization tools to increase the commonality of phasor data visualization displays to facilitate this common understanding. Although workshop participants recognized that the different organizations receiving simultaneous phasor data should reach the same conclusions about the state of the grid to effectively collaborate, coordinate, and communicate about grid operation, there was no agreement about whether it is appropriate to move toward common visualization displays across control rooms.

There was general agreement by all in attendance that this workshop was a useful exercise and a good beginning to a long-term effort to improve grid visualization tools for grid operators to maintain grid reliability. This workshop gave attendees a new appreciation of the challenges and requirements of high-quality visualization tools that enhance grid operators' situational awareness. The availability of phasor data gives the electric industry the opportunity to create a new, better set of visualization tools that can help operators with problem-solving and decision-making in the challenging task of managing and maintaining grid security.

Thanks to the efforts of this workshop's visualization tool providers and the operators who shared their time and expertise, we have gained valuable feedback and guidance that will help the electric industry further improve phasor data visualization tools.

Acknowledgments

NASPI thanks all those who helped design and execute this workshop successfully, including: all of the operators and commentators who shared their time and thoughts; the visualization tool vendors who shared their software; the human factors experts who shared their time and good advice; Dr. Dmitry Kosterev, Dr. Dan Trudnowski, Dr. Yilu Liu, and Dr. Joe Chow, who shared (or tried to share) event datasets; and Jim McIntosh, Vickie VanZandt, Tony Johnson, Kevin Frankeny, Wanda Peoples, Teresa Carlon and Jeff Dagle, whose insights and hard work made the workshop happen.

NASPI Visualization Workshop

Introduction

On February 28, 2012 the North American Synchrophasor Initiative (NASPI) sponsored a Visualization Workshop, with electric system operators, software vendors, human factors visualization experts, and observers from the electric industry. This workshop provided a venue for all of these electric system participants to come together to better understand what real-time operators of the bulk electric system need in the way of visualization tools as they manage the grid, and how to make those tools more effective.

Purpose

The mission of the North American SynchroPhasor Initiative (NASPI) is to “improve power system reliability and visibility through wide area measurement and control.” (NASPI, 2012). Phasor measurement units (PMUs) provide precise grid measurements, called synchrophasor measurements. These PMU measurements are taken at high speed (typically 30 or more observations per second – compared to one every four seconds using conventional technology). Each measurement is time-stamped according to a common time reference, allowing synchrophasors from different utilities to be time-aligned (or “synchronized”) and combined to provide a precise and comprehensive view of the entire interconnection. Synchrophasors enable a better indication of grid stress, and can be used to trigger corrective actions to maintain reliability.

NASPI is a collaborative effort between the North American Electric Reliability Corporation, the U.S. Department of Energy, and many electric industry members and experts, including electric utilities, vendors, consultants, federal and private researchers and academics. The NASPI community is working to advance the deployment and use of networked phasor measurement devices, phasor data-sharing, applications development and use, and research and analysis. Important applications today include wide-area monitoring, real-time operations, power system planning, and forensic analysis of grid disturbances. Phasor technology is expected to offer great benefit for integrating renewable and intermittent resources, automated controls for transmission and demand response, increasing transmission system throughput, and improving system modeling and planning.

Situational awareness is defined as, “the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.” (Endsley, 1995) Within the electric industry we want grid operators to have good situational awareness; we know that good visualization tools can help operators understand grid conditions and react to them.

Advanced visualization software using synchrophasor data allows control room operators to see what is happening on the bulk power system within fractions of a second, rather than the industry standard practice of using data updated every four seconds. This technology can give operators precise snapshots of real-time conditions, provides clear information on unfolding events, and helps operators analyze the situation and take informed mitigation actions to protect and enhance grid reliability.

This workshop centered on visual presentations (using synchrophasor data) created by several commercially available phasor data visualization software providers. The goal of the workshop was to have real-time control room operators look at how the visualization tools display specific grid events and to give those operators the chance to comment on the clarity, effectiveness, and usefulness of the different vendor representations of these events. The visualization products were not explicitly identified by vendor during the presentations, and all vendors were present to hear the operators' feedback of how each visualization tool represented each event.

Participants

There were 125 attendees at this workshop, including 20 operators, four visualization tool vendors, three human factors experts, and almost 100 observers representing many different roles in the electric industry.

Real-Time Operators

Twenty control room operators and supervisors participated in the workshop. Appendix A lists the companies represented.

Visualization Tool Providers

Several software vendors who specialize in visualization software were invited to provide four-minute video clips of four different events occurring on the electric grid. Four, listed in Appendix B, were able to contribute event video clips for use in the workshop.

Human Factors Experts

Three human factors experts, currently working in the electric industry, attended and helped facilitate the conference. Appendix C provides a brief biography for each. Before the event videos were shown, these experts offered suggestions on things to look for as the operators viewed the different visualization tools.

Observers

Over 100 people, representing government agencies, utilities, research organizations, and universities, attended the workshop as observers. These observers viewed the visualization tool videos at the same time as the operators and listened as the operators shared their thoughts about the visualizations. At the end of the workshop, these observers were invited to share their reflections, ask questions, and suggest next steps.

Structure

The workshop consisted of an introduction of the workshop purpose and process to set the context, suggestions from a human factors perspective on things to look for and think about while viewing the event clips, operator responses to the event clips, and a discussion on next steps.

Based on realistic data, the software vendors developed video clips (of approximately two minutes per event) to illustrate the visualization their products would provide to grid operators. The four grid events included three occurring in the western U.S and Canada: a large generation outage, islanding, and growing oscillation. The fourth event was of line outages and oscillations in the eastern U.S.

Introduction to workshop

The workshop was introduced by Alison Silverstein, the NASPI Project Manager. (See Appendix E for a draft of her opening comments.) She reviewed the goals of the workshop, which were the following:

1. To improve situational awareness of the bulk power system through the use of effective visualization tools. Situational awareness is about getting information about what is happening on the grid, understanding whether those conditions are normal or not, and understanding how things are changing and what might be coming next. Following the 2003 U.S.-Canada blackout, there has been more emphasis on using visualization tools to improve operators' situation awareness.
2. To look at visualization tools that use synchrophasor data. Synchrophasor data, sampled at 30 measurements a second or faster, reveal much about grid conditions that isn't visible from slower SCADA data sampling rate. As a result, there has been much effort to develop new visualization tools that exploit the higher resolution of phasor data to transform it into usable information.
3. To learn from grid operators how these new visualization tools can be improved to better meet operators' needs. When working at the dispatch desk, the operator uses computer displays to help understand what is happening on the grid and anticipate what could happen next. Operators need these displays to support them in their work as efficiently and effectively as possible.

The workshop explored whether current visualization tools help operators understand "what is happening right now?" on the grid. The operators were asked to give feedback on what worked and what didn't work in each of the visualization tools' portrayal of simulated real-time events – what elements made the visualization tool more helpful, and what if anything made it harder to understand the event being presented through each tool. Silverstein emphasized that the operators were not being asked to compare the vendor products nor to assess the analytics 'under the hood' of each tool.

Suggestions for watching the visualization clips

Dr. Jodi Heintz Obradovich, a human factors expert, provided some suggestions to the operators for what to look for as they watched the event clips. She emphasized that this workshop was a great opportunity to leverage the collective expertise in this novel approach to understanding real-time operators' needs for how information is presented in the software tools that are used to help in operator problem-solving, decision-making, and action-taking. This workshop also gave visualization tool providers an opportunity to view their tools from a user's practice- or work-centered view. Appendix F is a synopsis of Obradovich's remarks to the operators.

The operators present at the workshop represented various organizations and had diverse roles in managing the grid (refer to Appendix D). These roles entail varying goals, responsibilities, and tasks as they manage the electric grid. These differences mean that, more than likely, the data and information they need to do their work, the way the information needs to be represented, and the time pressures they are under can be very different. However, despite these differences, there were common themes in what they need from real-time visualization tools.

Obradovich reminded the operators and observers that the workshop was designed as it was because operators are the experts at using tools to manage the electric grid. As experts, they know better than the electric engineers, product designers, and technology developers what information operators need to be more effective at the problem-solving, sense-making and decision-making that lead to taking the appropriate actions as they manage the grid.

One challenge in the workshop approach was that – unlike on a normal workday – the operators were inserted into the simulated grid events without any context of what had been happening before the event. And although several of the tools are already available in some of bulk power system control rooms, not all the operators were familiar with or trained to use one or more of the tools, as would be appropriate for a complex tool representing a complex system. Both of these factors would have made event diagnosis more difficult. But even so, the operators were able to figure out each event through the visualization tools and provide valuable feedback on the tools' strengths and drawbacks.

Obradovich offered suggestions on the types of things that the operators and observers might pay attention to as they viewed the various vendor clips of the four events. These suggestions were given not to confine the operators' thinking, but to broaden the potential scope of their feedback:

- Consistency—consistency on the use of color; consistency on the use of shapes and symbols, consistency on the placement of information, buttons for action, labeling; consistency on how things on the same display are scaled
- Number of items to remember meanings, i.e., too many colors to remember what each one means; too many shapes or symbols, etc.

  The number of items isn't necessarily the underlying concern. Designers need carefully consider how they can utilize the ability of humans to chunk information into meaningful wholes (Bennett and Flach, 2011).
- What information or data is presented that is necessary for you to understand what is happening on the grid in real time
- Conversely, what information or data needed by the operator that is not presented –

  Can you make a decision for action with the information presented or what additional information would you need?
- What information or data is present, but presented in a difficult way—is how the data/information displayed consistent with how you think about the problem?
- Relationships—are you able to easily pick out the relationships between the different pieces of data and information?
- Clutter – Is there more data/information/graphics/overlays on the display than you can use; does it distract or clutter the display, thus preventing you from "seeing" the information that is needed quickly?
- What did you expect to see but didn't?
- Does the design of the display draw your attention to something that is changing? Does it draw your attention to the most important changes? In re-directing your attention does it prevent you from noticing other critical data or information?

- If there is a dashboard, does it give you the information at a glance that you needed to achieve your objectives?
- If panning and zooming is a feature, were you able to maintain an overall perspective as it panned and/or zoomed, or did you find yourself getting lost?
- Are there characteristics in the displays that could become fatiguing or eye-straining if you had to view these things over your entire shift—e.g., is the background too bright, too dark; do you have to strain to read text?
- If the particular vendor clip offers multiple points of view at different levels of detail, how does that work for you? Does it provide you with additional information, or different views that you need to assess the situation?
- What features are particularly useful? What are missing? What are distracting?
- Is there any uncertain or suspect or incomplete information that is indicated? Is it displayed in a way that makes it clear that it was uncertain, suspect, or incomplete? If so, what makes it clear? If not, how could it be made clearer?
- Finally, are you able to make sense of the unfolding events? As you are viewing each clip, what do you think is happening on the grid in this event? On a scale of one two ten, how sure are you about your assessment?

Another thing mentioned was the "cool" factor, a common reaction that motivates us to want a new technology. "Cool" is an adjective often used for innovative technology with a slick presentation with flash and dazzle. The operators were asked to not focus on the "cool," but instead on those useful, usable features within the visualization tools that will let them manage the grid more effectively.

Obradovich reiterated Silverstein's statement that the goal of this exercise was not to compare the different vendors' products, but instead to focus on the positive features within each event clip as well as any features that create difficulty for the operators in assessing the situation occurring in the event clip. The operators were reminded that by sharing with the observers what features the operators would find useful in accomplishing their goals and those that they felt would make their work more difficult will help move the industry forward in successfully designing tools for real-time operators tasked with managing the grid.

Events

Instructions to vendors when creating videos

To let operators view and compare the visualization tools without bias toward or against any vendor or tool, several commercially available phasor data visualization software providers were given identical sets of phasor data for four different real or simulated grid events. The vendors were asked to run the data through their respective visualization tools and create a video of the resulting event portrayal for use in this workshop. The vendors were asked to delete or mask any identifier (for example corporate name or logo or name of software) from all displays in their video clips in order to provide some level of anonymity.

The vendors were also able to show additional video of interpretive material that their software would generate using the data provided. They were asked to preface each interpretive segment with a brief one-title screen that explains what the viewers would see next (e.g., "Replay oscillation period 0:30 to 0:49", "Narrow focus to central region", or "Compare frequencies between islands", etc.). The purpose of this material would be to suggest how the operator might use the tool as he or she was assessing the situation in the control room in real time. The vendors were instructed to not add any text annotations or highlighting for emphasis that would not be part of the software.

Additional instructions to the vendors included the following:

- Do not narrate or talk over the event or provide any audio explanation about the event or the tool.
- Do not use some clever idea that might give your software an interpretive edge relative to the other vendors. This workshop is not designed for vendors to gain a competitive edge, but for all attendees to learn from the operators' reactions to the events as they are represented across all vendor products.

Events

Synchophasor data for four different events served as the basis for the visualization tool comparisons and event video clips. The four events included:

1. Western Generator Outage

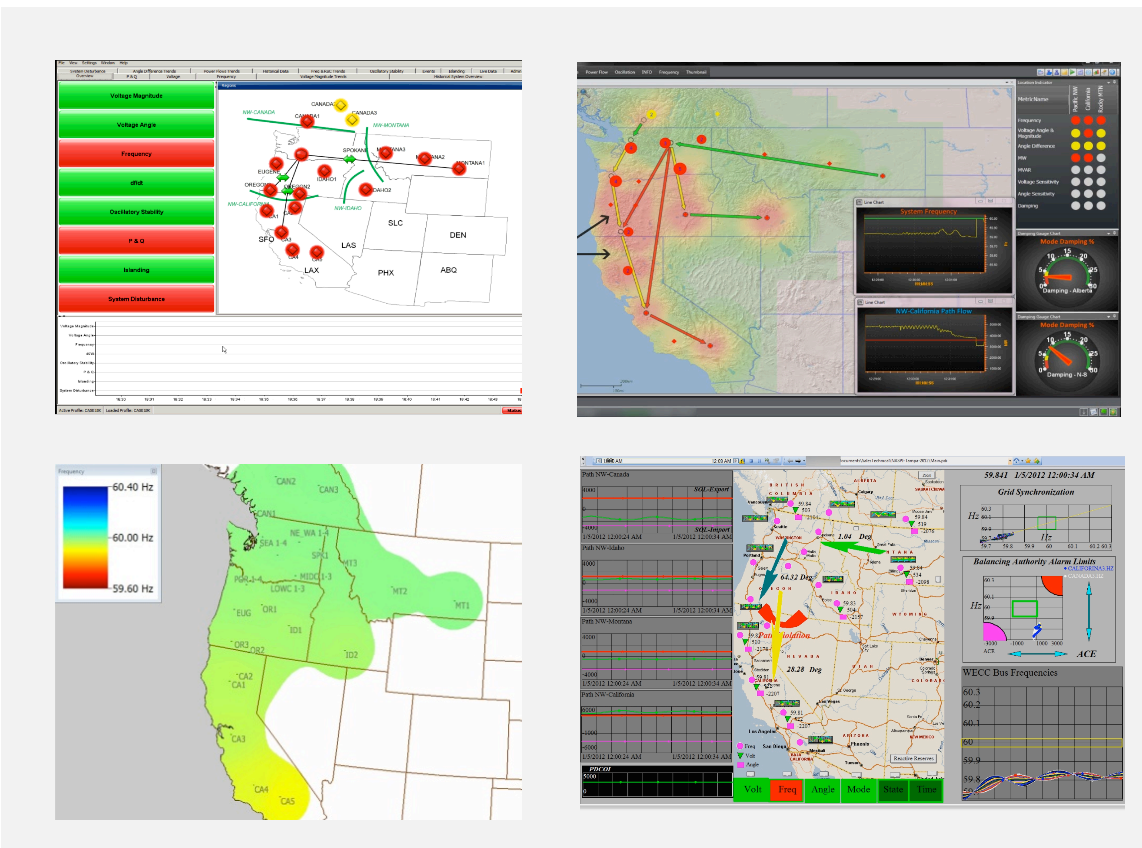


Figure 1. Snapshots from each vendor's visualization of Event 1—Western Generator Outage

2. Western Islanding

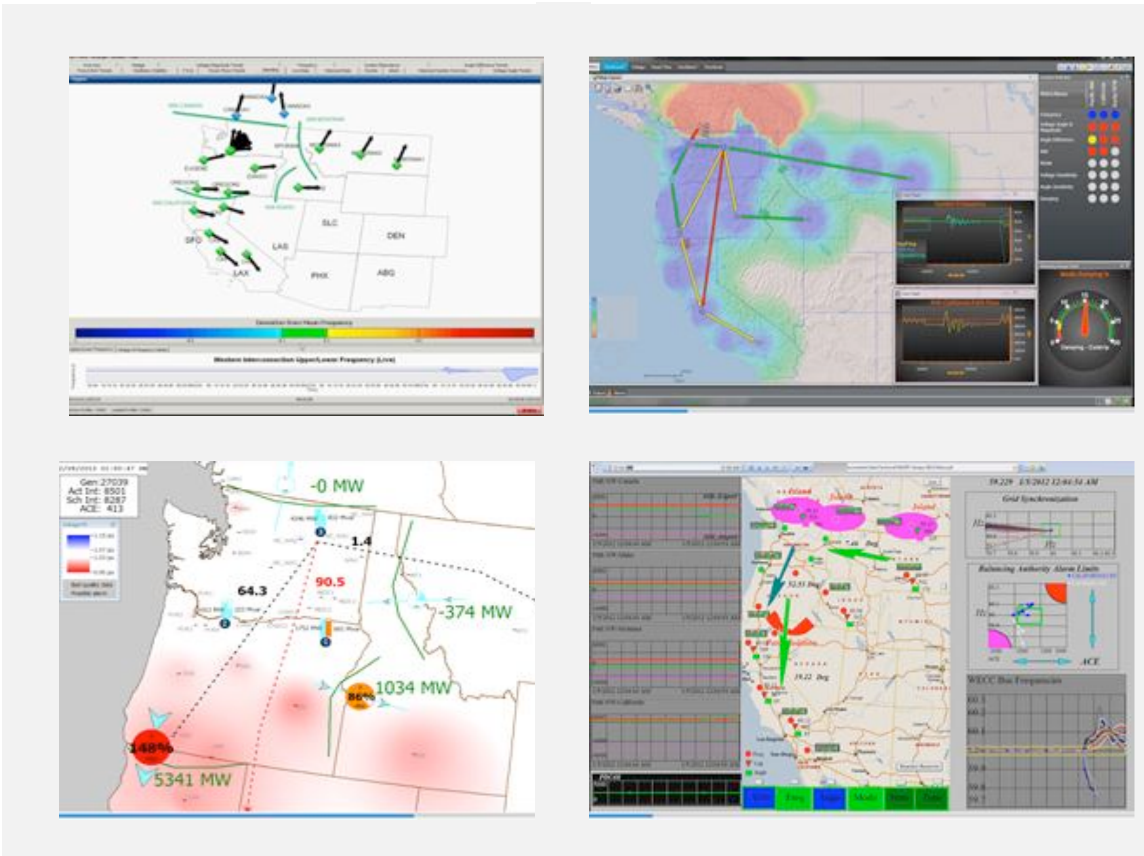


Figure 2. Snapshots from each vendor's visualization of Event 2—Western Islanding

3. Western oscillation

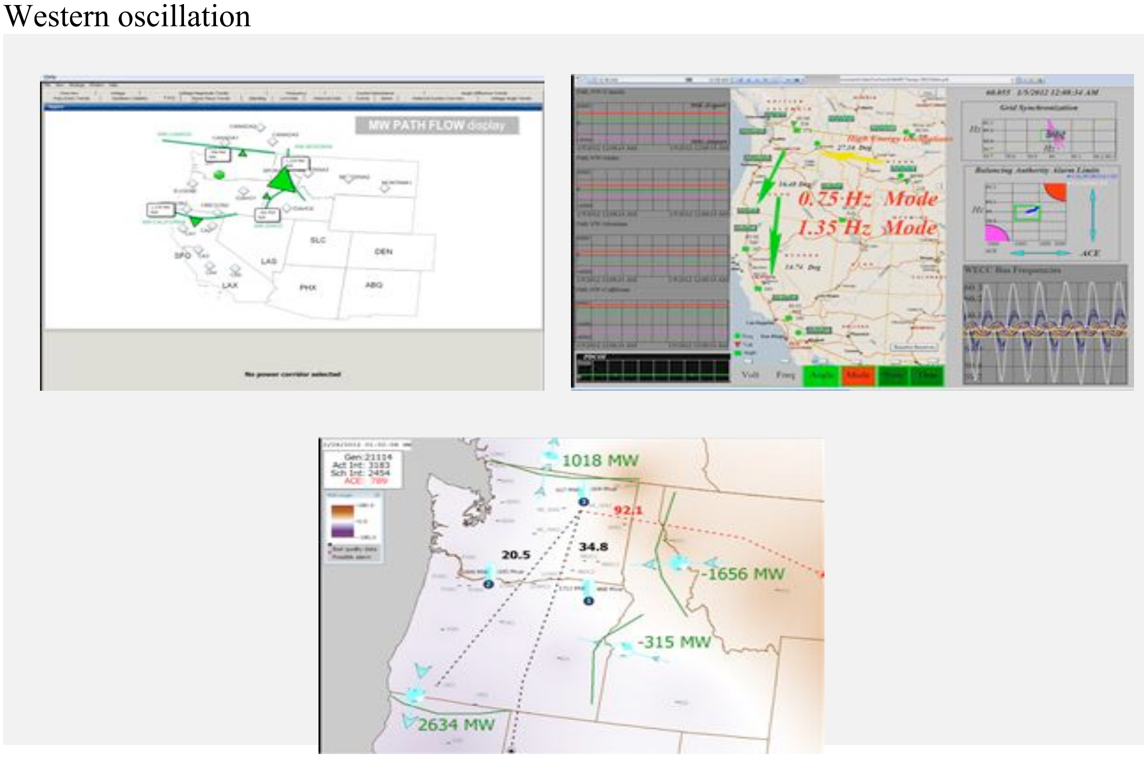


Figure 3. Snapshots from each vendor's visualization of Event 3—Western Oscillation

4. Eastern oscillation

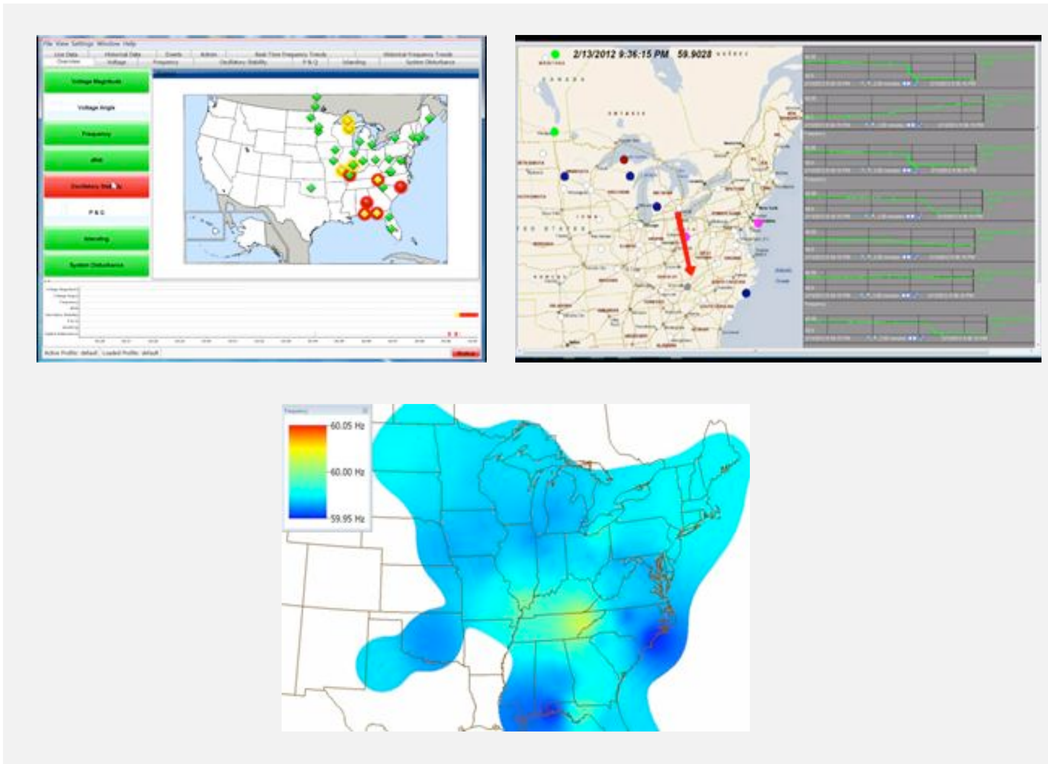


Figure 4. Snapshots from each vendor's visualization of Event 4—Eastern Oscillation

The full video clips (modified since the workshop to identify the vendors and now with some narration) are posted on-line and can be accessed at https://www.naspi.org/site/Module/Meeting/Reports/SubReports/workgroup.aspx (go to the February 28, 2012 meeting material).

Operators' Reflections and Sharing of Reactions to Video Clips

After each event visualization clip was played, the operators were given time to record their thoughts on paper. When all video clips for an event had been shown, the operators were asked to share their thoughts with the broader audience. This activity was facilitated by several NASPI members. The Findings section of this report describes and categorizes the operators' reflections and reactions to the event clips.

Findings

This section reorganizes the operators' notes (taken as a memory aid for each operator's use when sharing with the broader audience) and the comments they shared aloud with the workshop attendees, to identify the common themes in their reactions to the visualization tools' event portrayals. The categories are listed first; after the list are some thoughts from a human factors design perspective that may help visualization tool designers as they work to further improve visualization tools for this complex and dynamic operational environment. These categories are listed below in order of the number of operator comments each topic received (i.e., operators made the most comments about category 1 and the least about category 13):

1. Trends, charts, numbers, and/or tables
2. Ease of interpretation
3. Dashboard/overview displays
4. Accessing more detail—zooming/drill down, pop-up displays, hover for more information
5. Color / contrast / highlighting
6. Flashing
7. Alarms
8. Relationship between data—cluttered displays
9. Contouring
10. Geographic overviews/map
11. Icons / symbols
12. Not operator-focused
13. Switching between displays—easily get lost

Appendix G provides the operators' notes (written for their own reference directly after each video clip for each event was played). These notes have been organized into the above categories as they best fit. These notes also include observations from one workshop observer.

The following are things for designers to think about when considering the design of visualizations to aid real-time operators in their work. These considerations are placed within each of the categories listed above, but it is important to understand that when designing visualizations and representations to aid work, the context of the work environment needs to be considered in its entirety (i.e., the technologies, the work environment, and the human operators). The goals and tasks in which the operator is engaged will determine what are the requirements for design.

1. Trends, charts, numbers and/or tables

There were many comments concerning how trends, charts, numbers and tables were useful, or not so useful, in determining what was happening during the event. One of the ways we often think about the visual appearance of displays is by thinking in terms of different elements (e.g., tables versus graphs, numbers versus icons/symbols). Much research – yet inconclusive -- has gone into the attempt to determine which one of these components is the most effective way to present data and/or information. Visualization tool designers should consider both what is the best way to present each type of information to be useful and informative to operators, and the characteristics and capabilities of the operators to absorb information quickly in a complex, time-constrained environment.

In general, the operators were unenthusiastic about large data tables relative to dynamic graphs and maps; several noted that data tables are more useful for operations support engineers than for control room operators who need to make decisions in real time.

2. Ease of interpretation

The operator comments in this category fit across multiple categories, and included such statements as 'It was hard to decipher what I was looking at…,' 'ease of interpretation questionable,' 'could clearly see there was a problem,' and 'clear islanding detection.' The most effective visualizations understand the context of the situation, establish clear relationships between the data and information represented, and organize the information for ease of perceptual and cognitive processing.

3. Dashboard/overview display

Most of the operators noted their reactions to the dashboard or overview display provided by the different vendors. The sheer number of comments on this item points to how important it is to give operators an overview of the system so they can have a wider view of what is happening on the grid.

An overview display is intended to orient the operator's attention to changing situations. An overview or summary display should capture global relationships, allowing the operator to take a step back from the details of the process being monitored to assess the overall system status at a glance. This display needs to deliver a view that helps them decide where to look next (Watts-Perotti and Woods, 1999). It is clear that not every summary display is effective at presenting the right information at the right time in the most effective way to be useful for control room operators.

4. Accessing more detail—zooming/drill down, pop-up displays, hover for more information

The majority of the operators commented positively on the ability in the software to drill down to access more detailed information when necessary. They gave mixed reactions to the pop-up windows, while most operators who commented on the ability to "mouse over" to get more detail responded favorably.

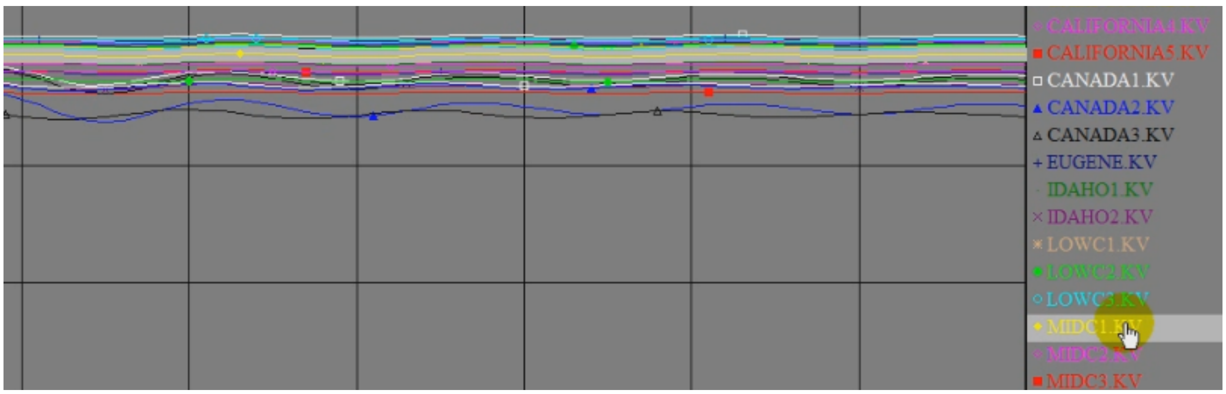
Traditionally, the way to access more detail in computer displays has been to navigate through many different windows or pages or menus, much as it is in contemporary control rooms. But scrolling and windowing can create a discontinuity between the information displayed, and can result in an operator getting lost in the overall structure of the information space. One remedy to this has been to place multiple monitors at an operator's workstation, with each monitor containing multiple views into the monitored system that the operator can glance at quickly.

5. Color / contrast / highlighting

Most of the operators commented on the use of colors and contrasts and the use of highlighting. Some stated that the preference in their control rooms was to have darker backgrounds on the displays rather than white or lighter backgrounds. This preference can vary based on the ambient lighting in the work environment and the eyestrain that can occur with the continual monitoring of the displays.

Comments varied across vendor products concerning consistency of colors used and/or the number of colors used. There was some concern with how text was highlighted, e.g., it's hard to read black text on a red background (see below). Positive comments were made regarding how some graph lines were highlighted when the mouse hovered or selected the label corresponding to the line. (See Figure 5 for examples.)

a. Example of contrast creating difficulty in reading



b. Example of use of highlighting

Figure 5. Examples of use of contrast and highlighting

Some operators commented positively on the changing colors of numbers, icons/symbols to flag operators' attention to important changes in grid condition.

6. Flashing

Some of the visualizations used features that flashed on and off (e.g., flashing arrows, flashing dots, flashing alarms). Most of the operators reported that this flashing was distracting, making it difficult to know where to focus.

Flashing or blinking can be a positive attribute if it is used in a way that is meant to draw an operator's attention to an important event. However, if a display has too many tokens that are flashing or blinking, it can confuse the operator and possibly drawing her attention away from high priority information or goals.

7. Alarms

This category received many comments from the operators, ranging from positive comments about placement of alarms on the display to concern about the distraction of how many and often alarms were flashing to a desire to have alarm summaries displayed.

The alarm problem is well known. It is important to consider how to provide as much information as possible when displaying alarms, so the operator does not have to search through a multitude of displays to understand what is happening. The literature is replete with examples pointing out that operators "can have difficulties identifying, prioritizing and responding to abnormal conditions despite the presence of various types of alarm systems and diagnostic aids"

(Woods, 1995, p. 2373). The FERC/NERC report on the September 8, 2011 SW outages cites cascading alarms as an issue for one entity, which might have led to the "overburdening the real-time operator…[which] could undermine his or her ability to perform the critical functions of monitoring system conditions and directing necessary corrective action" (FERC/NERC, 2012, p. 93).

8. Relationship between data — cluttered displays

Many operators commented about cluttered displays, saying there was 'too much information on the screens' and 'too many items on some displays,' which made them 'a little overwhelming.' This data overload problem is common in complex environments that require monitoring a system though the virtual world of computer displays. Designers try to minimize this data overload with measures such as using only a limited number of colors or objects on the screen.

An important goal to keep in mind when designing visualizations is that of designing for "information extraction" as opposed to designing for "data availability." (Woods, 1991). Tufte states, "It is not how much [data] there is, but rather how effectively it is arranged." (Tufte, 1990, p. 50) The operators' feedback about cluttered screens reinforces the importance of organizing the data and information in a way that takes advantage of the human perceptual system to organize elements into meaningful representations.

9. Contouring

The operators had mixed reactions to the use of contouring in some of the event portrayals, and the comments were even mixed across events for the same vendor. Some concerns addressed not knowing what the different colors in the contouring meant, what they referred to, and some thought too many colors were used. Some also mentioned that the "jerkiness" of the contours might prove distracting. Some operators reported positively about the use of contouring, stating that it was effective in communicating what was occurring in the event; others felt that it did not provide enough information to diagnose what was happening.

10. Icons / symbols

The operators commented positively on the different icons used by the various vendors, stating that these symbols and icons helped to direct their attention to what was important. Some operators had concerns that the animation of some of the icons created distractions and , e.g., the 'rotating arrows.'

Iconic references are tokens that resemble the objects they represent (e.g., an image of a printer on a computer display), acting as a metaphor for the object or action in a particular domain (Bennett and Flach, 2011). An icon can be static or dynamic (e.g., through animation), but the information it is meant to convey should relate to the underlying thing represented, and designers should use animation only when it provides critical information and not create distractions.

11. Geographic overviews / map

Several of the operators commented on the map views presented by all the visualization tools. Most comments were positive, supporting the use of a map view. Research validates the usefulness of providing tangible visual system analogues such as maps, which give the operator an underlying geographic reference to the events occurring on the system.

12. Not operator-focused

Many of the operators commented that some of the visualizations across events were more focused on the engineering activity of post-event analysis, rather than providing valuable data and information for real-time diagnosis and decision-making. The most effective visualization tools for operators are based on an understanding of how operators work and what they need in the control room during normal operations and critical events. These tools will incorporate the information requirements operators need for these cognitive tasks and deliver the information in ways that serve operators' decision-making needs and compressed time requirements.

13. Switching between Displays—Easily Get Lost

Several operators commented that in some of the event clips there was a lot of switching back and forth between different displays, making it difficult to determine what was going on in any individual display or between displays. This was likely caused by the vendors' choices in how to show each tool's interpretive capabilities in the limited time available for their event portrayals.

However, it is important to understand that the computer systems used by real-time operators consist of thousands of displays, combinations of which may be needed at any given time, depending on the event and context. Designers of these systems face a challenge in designing the navigation strategies within these systems so that the design will enable operators to obtain the information that is relevant to the tasks, decisions, and goals in which they are engaged at any given time (Watts and Woods, 1999).

Summary

This NASPI Visualization Workshop gave attendees a new appreciation of the challenges and requirements of high-quality visualization tools that enhance grid operators' situational awareness. The availability of phasor data gives the electric industry the opportunity to create a new, better set of visualization tools that can help operators with problem-solving and decision-making in the challenging task of managing and maintaining grid security. Thanks to the efforts of this workshop's visualization tool providers and the operators who shared their time and expertise, we have gained valuable feedback and guidance that will help the electric industry further improve phasor data visualization tools.

References

Bennett, K.B. and Flach, J.M. (2011). *Display and Interface Design: Subtle Science, Exact Art*. Taylor and Francis Group: Boca Raton, FL.

Endsley, M.R. (1995). Measurement of situation awareness in dynamic systems. *Human Factors*, 37(1), 65-84.

FERC/NERC (2012). *Arizona-Southern California Outages on September 8, 2011. Causes and Recommendations*, April 2012, http://www.ferc.gov/legal/staff-reports/04-27-2012-ferc-nerc-report.pdf

North American SynchroPhasor Initiative (2012). https://www.naspi.org/

Tufte, E.R. (1990). *Envisioning Information*. Cheshire, CT: Graphics Press.

Watts-Perotti, J. and Woods, D.D. (1999). How experienced users avoid getting lost in large display networks. *International Journal of Human-Computer Interaction*, *11*(4), 269-299.

Woods, D.D. (1991). The cognitive engineering of problem representations. In G. R. S. Weir and J. L. Alty (Eds.), Human-Computer Interactions and Complex Systems (p. 169-188). London: Academic.

Woods, D.D. (1995). The alarm problem and directed attention in dynamic fault management. *Ergonomics*, *38*, 2371-2393.

APPENDIX A: *Companies with Operators Participating*

American Transmission Company (ATC)
Bonneville Power Administration (BPA)
California ISO (CAISO)
Dominion VA Power
Duke Energy
Midwest ISO (MISO)
New York ISO (NYISO)
Salt River Project (SRP)
Southern California Edison (SCE)
Tennessee Valley Authority (TVA)
Western Electricity Coordinating Council (WECC)

APPENDIX B: *Participating Vendors*

Alstom
EPG
OSISoft
PowerWorld

APPENDIX C: *Human Factors Experts*

Jodi Heintz Obradovich, PhD

Dr. Obradovich has a PhD in Cognitive Systems Engineering from The Ohio State University. She is a Scientist at Pacific Northwest National Laboratory in the Energy and Environment Directorate. Her cognitive systems engineering and human factors expertise ranges from healthcare to aviation to military command and control, and finally to the electric utility domain. As well as her current position with PNNL, she has worked as a researcher at Ohio State and was the lead human factors engineer at Intel Corporation. Jodi spent two years working with the operational staff at a major western transmission provider on a DOE funded project to design real-time operational tools for the integration of wind energy resources.

Michael Legatt, PhD

Dr. Legatt is the principal human factors engineer at ERCOT and has been instrumental in the design and implementation of several data visualization systems now in use at ERCOT, including the Macomber Map. Mike has a PhD in neuropsychology and clinical health psychology, is an experienced programmer, and is working toward a graduate degree in energy systems engineering.

James Merlo, PhD

Dr. Merlo is NERC's Manager of Human Performance and is a trained human factors engineer. James has served with the U.S. military in Iraq and taught at West Point. He has researched helmet-mounted displays and multi-modal displays that use eyes, ears, and the human skin to deliver information. James has his Bachelor of Science in Human Factors Psychology from West Point, his Masters in Engineering Psychology from the University of Illinois and his PhD in Applied Experimental and Human Factors Psychology from the University of Central Florida.

APPENDIX D: *Operator Role and Organization Affiliation*

Role	Company
Senior System Dispatcher	Bonneville Power Administration
Senior Power Systems Dispatcher—Transmission	Bonneville Power Administration
Senior System Dispatcher	Bonneville Power Administration
Power System Operation Specialist 4	Southern California Edison
Transmission System Operator	Salt River Project (SRP) – PHX, AZ
System Lead Coordinator	Duke Energy BA/RC
Manager, Reliability Operations	TVA RC
EMS Energy Manager	Duke Energy
Power System Operator (Transmission & Voltage)	NYISO
Reliability Engineer (Real-time operations)	Dominion T.O.
Systems Operations Engineer	Dominion T.O.
Reliability Coordinator	Not specified
Principal Engineer	Commonwealth Edison Co.
System Operations EMS	American Transmission Company
Not specified	Not specified
Executive Advisor	CAISO
Director, Operations	Not specified
Generation Dispatcher	CAISO

APPENDIX E: *Opening Comments by Alison Silverstein*

NASPI VIZ WORKSHOP
OPENING CONTEXT NOTES
DRAFT 02/13/12 *DRAFT*

Good afternoon. Thanks for coming to be part of this workshop.

I'm Alison Silverstein, project manager for the North American SynchroPhasor Initiative.

As far as we know, this is the first ever cross-company effort to compare how different visualization tools improve situational awareness by looking at how they deliver information to operators. And this is the first time, we think, that there's been an effort to ask operators what works for you, rather than leaving it to the many excellent engineers and human factors people to decide what the operators get.

Let's take a minute to review the goals of this workshop. First, this is about improving situational awareness of the bulk power system through the use of effective visualization tools. You all know that situational awareness is about getting information about what's going happening on the grid, understanding whether those conditions are good or bad, and understanding how things are changing and what might be coming next. Since the 2003 blackout, there's been more emphasis on using visualization tools to improve operators' situational awareness.

Second, our goal is specifically to look at visualization tools that use synchrophasor data. SCADA data are pretty good, and you all have screens back home that show you what's going on at a 4 to 6 second sample rate. But synchrophasor data, sampled at 30 samples per second or faster, reveal a lot about grid conditions that you just can't see from slower SCADA systems, so there's been a lot of effort to develop new visualization tools to exploit the higher resolution of phasor data, transforming it into usable information.

Third, we want to learn how operators think these new tools are meeting their needs. When you're working the dispatch desk, there's a lot going on and you need displays that help you understand as much as possible about what's happening on the grid, and what could happen next, with as little effort and time as possible. Our focus for today will be on the, "What's happening right now?" question, and we won't be poking the tools for predictive information. But we are looking for you operators to give us feedback on whether it's easy for you to understand and interpret what each tool is showing you on the screen. We want your thoughts about whether what and how each tool shows you makes it possible for you to quickly understand what's happening on the grid in real time; we're not trying to compare the analytics under the hood of each tool.

We're delighted to have four vendor-created visualization tools, and one user-created tool, to look at today. We'll be comparing their displays for several different grid events and asking you to take some notes about what works and what doesn't work for you during each display and event. Every tool has some excellent techniques and elements, and every one is different. Our fourth goal is to be fair and clear about what works for you as operators, and what could be improved to make your job easier. Please don't let your prior experience with any particular tool or vendor bias your feedback or make you see or talk about any tool or vendor as “bad” or “good”.

Additionally, all of you have different jobs and roles – and therefore, different needs for a visualization tool to help you maintain situational awareness. So although your neighbor likes this symbol and you don’t, or you want to see voltage instead of frequency, this doesn’t mean your feedback is more valid than his or he’s right and you’re wrong. Each of your views is valid in the context of your job requirements, and that’s what we want to hear about and understand. You’ll find a set of comment forms on your chair. The comment forms give you space to enter some notes and reactions to each display for each grid event. At the top of each form is space for you to fill in your job title (like, Operator or Dispatcher or Operations Support Engineer), so we can understand your role and needs and how that informs your comments. We’ll give you a couple minutes to jot down a few comments after each tool display so you can keep everything straight.

I’m not a human factors or visualization expert, and most of you probably aren’t either. We are lucky to have three electric industry human factors experts with us today to give us some suggestions about what to look for as we watch these event clips. They’ll also be listening to the conversation this afternoon and offering some closing observations for your consideration.

Our experts and coaches for the afternoon are:

- Dr. Jodi Heintz Obradovich is a PhD in Cognitive Systems Engineering on the staff of the Pacific Northwest National Laboratory. Jodi has done research on human factors in the areas of military, medical and electric utility applications, and has worked for Ohio State, Intel and PNNL. She’s currently working with BPA staff on several transmission and dispatch projects.
- Dr. Mike Legatt is the principal human factors engineer at ERCOT and has been instrumental in the design and implementation of several data visualization systems now in use at ERCOT, including the Macomber Map. Mike has a PhD in neuropsychology and clinical health psychology, is an experienced programmer, and is working toward a graduate degree in energy systems engineering.
- Dr. James Merlo is NERC’s Manager of Human Performance and a trained human factors engineer. James has served with the U.S. military in Iraq and taught at West Point, and researched helmet-mounted displays and multi-modal displays that use eyes, ears and skin to deliver information.

Jodi will be giving us some suggestions about what to look for as you watch these event video clips. And after we’ve watched all the event clips and talked them over, she and James and Mike will offer some closing observations and suggestions based on what they see and hear from the videos and your collected responses.

At the end of the workshop, we will take a few minutes to ask you what you want to do next. We pulled together this workshop because one of the synchrophasor project managers expressed some frustration that there isn’t much commonality in how visualization tools show what’s happening. Maybe that’s ok, or maybe that’s not – we’ll see what you think in a few hours. So before we end the workshop, we’ll ask you whether you think the industry, or maybe just a small group, should do something else based on what we see and learn today. With or without a specific plan for next steps, I’m confident that the vendors and tool developers participating today will learn a lot from your comments and that you will have some impact on what shows up on your operators’ screens in a few months.

One more thing – I want to recognize and thank the people who pulled this workshop together.

- Jim McIntosh with the CAISO, Vickie VanZandt with WECC, and Jeff Dagle with PNNL worked with me to develop the initial idea and format.
- Tony Johnson of SCE and Kevin Frankeny of MISO made sure it was both sensible and operator-centric.
- Jodi Obradovich, James Merlo, and Mike Legatt offered a wealth of expertise, enthusiasm and common sense to make sure we get what we need out of this workshop.
- Dr. Dmitry Kosterev of BPA, Dr. Dan Trudnowski of Montana Tech, Dr. Joe Chow of RPI, Dr. Yihu Liu at the University of Tennessee Knoxville, and Ian Grant of TVA were critical at wrangling all the datasets for the events we're about to see (and one we won't see).
- And the good people of Alstom Grid, Electric Power Group, OSISoft, PowerWorld, SpaceTime Insight and WECC have put a lot of time into developing the event visualization clips you'll see next.
- Larry Kezele and Mark Lauby of NERC have been very supportive and helped get the word out about this workshop to all of you.
- Last, Teresa Carlon of PNNL and Wanda Peoples of NERC have worked magic to make all the logistics work smoothly.

Please help me thank them all.

APPENDIX F: *Suggestions for Looking*

by Dr. Jodi Heintz Obradovich

DRAFT 02/26/12 *DRAFT*

Good afternoon. As Alison said, this is a great opportunity for us to be able to leverage of your collective expertise as we try a quite novel approach to understanding some of your needs for how information is presented in the technological tools you use to help you in problem solving, decision making, and action taking. This workshop is a step in providing the designers in the vendor organizations the ability to view their designs from a user- or use-centered view.

Each of you have different goals, different responsibilities, and perform different tasks as you manage the electric grid, and those differences mean that, more than likely, the data and information you need, the way that information is represented, and the time pressure you are under are very different. Even though there may be differences, I expect there will also be many things that you all find in common. This session will clarify for us, as observers, what are those differences and what are those commonalities, and what do we do with that valuable information.

But what is important for us and for you to remember as we go through this exercise is that you are here because you are experts in what you do. And being experts means that you know better than the product designers and technology developers what it is that you need to support you in your work. It also means that just because the person beside you says something about how a particular feature in one of the vignettes works or doesn't work for him or her, doesn't mean that you in any way, shape, or form have to agree with that critique. Your information and decision support needs and preferences are just that, yours; and we need to hear from you, as the expert in your particular area of managing the grid, what you think and what you need. Remember, as an expert, you have adapted often to less than ideal products, making them work. You have made your business in not complaining, but often just making things work, using e.g., sticky notes and moving screens around. Now is our chance to get in front of the challenge and not make you fit the system, but make the system fit your work as operators!!

One challenge for you in the approach we are taking today is that we are inserting you into events that don't contain the context of what has been happening during your shift up until the time the events begin. So you won't have a sense of the state of the system as it is evolving throughout your shift. Where normally you would have an assessment of the larger system status prior to an event unfolding, you won't here. However, given that, I think that the today's exercise is going to be fun and very informative.

Another thing that we realize in the exercise today is the lack of your ability to become familiar with the displays you will be viewing today. The system you work in is a complex one, so it is expected that the technology designed to provide you with problem solving and decision support will also be complex to the untrained user. So normally you would expect to have some training on any system that you use to manage the grid, and you would be right in that expectation. So, understanding this limitation, we will still learn a lot from your initial reactions to these new views into the system you manage.

I'm going to give you a few suggestions on the types of things you might pay attention to as you view the various vendor clips of several events. I'm giving these suggestions, not because you necessarily need them, and definitely not to confine you to only these things, but to provide you with a base to start from or to spark your thinking. I've worked with some of you before, and I know that you don't need me to tell you what to look for, and I suspect that is the same for the rest of you. But as a way to jumpstart your looking the following are suggestions that I and my other human factors colleagues here have arrived at:

For each of the vendor presentations, look for:

- Consistency—consistency on the use of color; consistency on the use of shapes and symbols, consistency on the placement of information, buttons for action, labeling; consistency on how things on the same display are scaled
- Number of items to remember their meanings, i.e., too many colors to remember what each one means; too many shapes or symbols, etc.
- Ease of interpretation—ease with which you can understand what is happening on the grid in real time
- What information or data is presented that you need to understand what is happening
- And conversely, what information or data is not present that you would need
- And at even a different angle, what information or data is present, but making sense of it in the way it is presented, is difficult—is how the data/information displayed consistent with how you think about the problem?
- Relationships—are you able to easily pick out the relationships between the different pieces of data and information?
- Is there more data/information/graphics/overlays on the display than you can use; does it distract or clutter the display, thus preventing you from "seeing" the information you need quickly?
- Can you make a decision for action with the information presented or what additional information would you need?
- What did you expect to see but didn't?
- Does the design of the display draw your attention to something that is changing? Does it draw your attention to the most important changes? In re-directing your attention does it prevent you from noticing other critical data or information?
- If there is a dashboard, does it give you the information at a glance that you needed to achieve your objectives?
- If panning and zooming is a feature—were you able to maintain an overall perspective as it panned and/or zoomed, or did you find yourself getting lost?

- Are there characteristics in the displays that you feel might become fatiguing or eye-straining if you had to view these things over your entire shift—e.g., is the background too bright, too dark; do you have to strain to read text?
- If the particular vendor clip provides you with multiple points of view at different levels of detail, how does that work for you? Does it provide you with additional information, or different views that you need to assess the situation?
- Are you able to make sense of the unfolding events?
- What features are particularly useful? What are missing? What are distracting?
- Is there any uncertain or suspect or incomplete information that is indicated? Is it displayed in a way that makes it clear that it was uncertain, suspect, or incomplete? If so, what makes it clear? If not, how could it be made clearer?
- Finally, as you are viewing each clip, what do you think is happening on the grid in this event? On a scale of one two ten, how sure are you about your assessment?

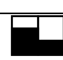
Another thing that I want to mention is the reaction we often have when we see a new technology, and that is the "cool" factor. "Cool" is an adjective often used for innovative technology with a slick presentation with flash and dazzle. Today, your task is looking for a usable, useful tool to meet the goals and decisions that lead to successful management of the grid. Please don't focus on the "cool", but instead on those useful, usable features within these products that will allow you to be efficient and effective in your work.

As Alison mentioned, the goal of this exercise is not to compare the different vendors' products, but instead to focus on the positive features within each event clip as well as any features that create difficulty for you in assessing the situation that is occurring in the event clip. Sharing with us will help move us forward in successfully designing tools that will allow you to be more effective and efficient in your work. Thank you.

APPENDIX G: *Categorization of Operator Comments*

Category 1: Trends, charts, numbers, and/or tables
Event 1—Tool A
Written Notes
On trend charts, having label names same color as lines would help; oscillation trends showed disturbance & recovery with dumping
Like the zoom on trend; takes all trends to the same x scale.
Being able to zoom to desired trend size nice.
Easily read graphs.
Too much emphasis on trends.
The plots were hard to understand without an understanding of the system.
Trends were good.
Consider using multi-scale for trends with different path flows, especially if a path is at 4000 MW and another path is only a couple hundred MW's.
Aloud Comments
put multiple path flows on a trend, but all scaled the same….so don't even see some trends because they are too low; need exact number of trends;
Event 1—Tool B
Written Notes
Would like to see actual numbers for flow and angle in addition to vectors on the overview.
graphs appear easy to manipulate
Be good to change all trend scales to same x axis values when zooming. Trend scales hard to read but value not necessarily important if you can see a trend/event.
better charts with black background.
Charts/odometers are nice. Detailed charts nice.
Trend plot seemed to make sense as far as labeling scales, etc.
Like damping gauges.
Very good graphics and drill down. Like event analysis report. Well done.

Category 1: Trends, charts, numbers, and/or tables
Graphs look good, scale looks good, need to show actual value as well instead of having operator guess what the value is on the graph.
don't want to see trends until choose to dive into further analysis
Event 1—Tool C
Written Notes
hard to understand the bar chart for oscillation detection.
Trend charts contained a confusing amount of lines. … Trends with limits?
PI graphs could not see.
Did not understand what state graphs were displaying.
Too much info on trends…. State charts not clear on info they are presenting, could be good but don't understand. No idea what the island chart was trying to show.
Better way to see fewer metered points (way to remove sources from graphs)
Trend screens on left side – useless – too small
otherwise way too much info on one chart…. Unstable pattern charts give no historical data so I don't know what I'm looking at or what it should be. What was the last chart showing? Looks like a nice picture but could not make sense of it.
Dashboard display has too many charts
Too much information on one-line.
Plots on left have very large scales (+/- 6000 MWs) so hard to see change.
Not sure what some of the trends toward the end of the presentation were trying to show. It would show a trend, then it got smaller, then it disappeared.
Event 1—Tool D
Written Notes
Seemed to be good information in the table at the end.
Tabular display not as easy to distinguish changes as with graphical displays.
The text display was useless with trend information.
Strictly tabular data is hard to read and see trends and no baseline normal
Table helped analyze after the fact.
Tabular data not of much help without highlights of what's important.

Category 1: Trends, charts, numbers, and/or tables
Text table not helpful at all.
Tabular display good for after the fact.
A trend is better because it shows what the value was in the past…. The data lists need to show only data of interest, not everything. This list will become overwhelming when all data is included.
Event 2—Tool A
Written Notes
Trending was good, not so much that it could overwhelm you.
Still way too many charts, but at least I can select them when I want. Still like the damping odometer; These are nice, maybe more use of these.
The trends look customizable which is good. Oscillation trends are good. I would rather see a trend instead of a bar graph.
Event 2—Tool B
Written Notes
Other trend displays are too cluttered or congested to view real time.
but I need to see actual numbers and differences. Trends and scales may be better for this purpose.
trending good but too many colors
Event 2—Tool C
Written Notes
Table at the end didn't seem like a good tabular display.
Drill down displays were good, especially the P/Q bar graphs. Tabular needs to change color for out of tolerance conditions to provide value.
Like MW and MVAR bar graphs. Text views need to show or flag exceptions only.
Text display - too much data
Bar graphs good – (showed margin) 
The data table without something to highlight significant change is of little value.
Don't like the tables of info.
Tabular still doesn't work.
Too much info on text display.

Category 1: Trends, charts, numbers, and/or tables
The text display tells me nothing. It only shows current values.
Event 2—Tool D
Written Notes
Trending and traces very busy…Hard to pick out.
Liked trends that clearly showed Canada splitting off. Frequency trend showed split but couldn't identify data.
State charts (whatever they are) should become visible on exceptions.
Did like drill downs, too many points on charts – would like to be able to define or remove points for better analysis.
Charts to left could go as you don't see enough change. … The data on charts is very hard to understand, more of a post mortem analysis by engineering or planning. not ops.
Islanding graph was difficult to interpret.
Good capturing change analysis.
There is too much data on the trends, trends should be customizable.
Event 3—Tool A
Written Notes
Spreadsheet is not useful real time, nice after the fact.
Again tabular display didn't help either.
Need popup or trend to tell or show the oscillation
Needed a trend display.
Tabular display useless for real-time as presented.
What do bar charts represent?
Table info not useful to operator.
Text display not helpful
I can tell the angles are swinging in the north but I don't know by how much and don't know exact locations. Some trends may be better here. The tabular display does not tell me anything.
Test screens for ?????

Category 1: Trends, charts, numbers, and/or tables
Event 3—Tool B
Written Notes
[better if] trends smaller or on-request. Not sure what was happening when navigating the trace data? Need break-in.
On the charts too many trend points to pick out what you needed, too much clutter.
trend display graphs look like an engineering tool.
The charts are good, but historical data has to be shown from event start; otherwise I don't see what was normal or typical.
It showed general area and then the trends showed exact locations. Not sure how to interpret oscillation trend exactly.
Event 3—Tool C
Written Notes
What's a Locus Plot?
Chart data needs more explanation.
Some of chart trends were not useful; hard to see what they were trying to show.
Historical data review good for post analysis.
Like power flow trends screen.
better color for graphs could be used.
Locus plot was useless. Voltage angle analysis useless
Not sure what the loci plots are showing me. I like synched chart d??? (zoom is on ??? all appeared to change time duration.
Very good analysis visualization.
Good oscillation display. Not sure operator would use locus plot
Good trends showing growing oscillations. Not sure that locus plot is useful.
Event 4—Tool A
Written Notes
Too many flashing dots – drop in trend display? That would be handy. Last chart – couldn't see what was going on.

Category 1: Trends, charts, numbers, and/or tables
last display had what appeared to be Danbury at lower than rest of traces but at monitored frequency.
Charts didn't have a legend to show what was being traced and they seemed cluttered and not crisp or clear. A lot going on but what it was hard to discern.
Trend was very busy.
graphs that you can't read
Charts not very useable in real time
Charts were not very high quality (for lack of better wording)
Too many lines and colors.
Event 4—Tool B
Written Notes
Very busy trace plot.
Unit 756 did not display on trend charts.
Like that all trend axis change when you zoom in.
Graphs and presentations followed suit [i.e., not labeled well], not clear as to where/what I was seeing in the trending
Frequency oscillations from the graphs possibly indicate units tripping off. I'm not positive.
Good trend of frequency oscillation.
Event 4—Tool C
Written Notes
Text display was too much information to get what was the event or to direct that way (just a bunch of numbers and letters).
Also text display only good for small company.
Tabular is of no interest to operators.
Table not useful.
Tabular display is not good for control room real time analysis.
Tabular screen is useless without usual indicators.

Category 2: Ease of interpretation
Event 1—Tool A
Written Notes
Ease of interpretation was somewhat confusing.
Confusing
Not easy to interpret
Well document large gen drop and associated impacts to flows, Φ angles, MVARs, state of grid conditions – great wide area view. Very good.
Event 1—Tool B
Written Notes
Simple representation of Data. Easier to see the different problems develop/evolve. Easier to gain understanding real-time of the situation.
intuitive
Event 1—Tool C
Written Notes
It was hard to decipher what I was looking at other than there was a system disturbance.
Confusing at first glance. … Ease of interpretation questionable
Never able to understand what the event was. No Analysis
Missed the secondary oscillations?
screens seemed too vague and not clearly defined.
Event 1—Tool D
Written Notes
Appeared event occurred in S. Calif because frequency excursion started there.
Event 2—Tool A
Written Notes
Could clearly see there was a problem.

Category 2: Ease of interpretation
Not sure of status of interties to Canada.
Ease of interpretation was somewhat confusing.
until analysis was done wasn't sure of problem.
Phasor magnitude and direction were clear – showed overload.
Harder to determine event.
Having said that, the tool clearly showed the islanding due to frequency differences. Would this be true if frequency stayed cl???
Very good. Easy to figure out what happened with Canada thru layering of info with contours and specifics.
Event 2—Tool B
Written Notes
Seemed to point operator in wrong direction – loss of exporting tie to Canada forced gen into California, alarms CAL import too high*.
This system was clear on the islanding condition.
But does display nicely you have an island.
Clear islanding detection
Good island detection.
Event 2—Tool C
Written Notes
Good job of showing lower voltage, and line overloads. Islanding with Canada not as obvious
Clearly showed overload between NW & California. MW flow to Canada went to zero but could easily be missed. Changing voltage contour showed swings across system. Not sure where data displayed was referenced from.
Hard to decipher the screens, however the MW, tie data, voltage indications were good you still (?) couldn't tell where they were coming from
Path flows on the display helped to find problem areas.
Only indication of separation to 0 MW flow to Canada
Easier to determine problem then tool B.
Could see zero flow to Canada - island. Showed line overloads with color circle good

Category 2: Ease of interpretation
Did not clearly show islanding.
It is less intuitive to tell what happened. It becomes clear after Canada-NW slows go to 0 in slight colored path indicator.
Hard to follow what is going on unless you know system. Path overload clear.
Event 2—Tool D
Written Notes
Clearly showed path violation, lots of data and flashing on screen. Clearly showed islanding (could be initially mistaken for more than one island in Canada).
A lot of points were flashing red, green, and blue. What did that mean or what were those points was hard to determine. How far out of tolerance were the values was also hard to discern as well.
Overview of area good, ease of interpretation allowed to see what was happening.
Not sure what red indicator was telling operators.
Wasn't clear what exactly transpired.
Identified island well.
Islanding graph was difficult to interpret.
Clear that island from display.
Path overload discerned ok, took a while to determine islanding.
Good island detection/good path violation.
Event 3—Tool A
Written Notes
Could see oscillation between Canada <–> Montana
Oscillations with Montana – Easy to see large angle and like having power flow data available.
Liked number turning red when over defined limit.
Main display did not make it easy to determine problem.
Seeing oscillations on NW – Montana path, possible VC?
Clearly showed values an area. Very nice simple state map.
Minimum information but did demonstrate oscillations.

Category 2: Ease of interpretation
Not clear what the large #'s are for. I assume phase angles but relative or between specific situations or…? … Not certain what happened on data provided (unit trip in ???).
Oscillation evident in 300-400 MW swing between E. Montana and NW.
300 MW oscillations little E??E.
Hard to tell what is going on. System swinging?
I can tell the angles are swinging in the north but I don't know by how much and don't know exact locations.
Event 3—Tool B
Written Notes
Way easier to see the Oscillation.
clearly identified Montana as source of oscillations.
With the event appearing to be of low magnitude, the displays seemed to be too high level to discern what the event was quickly.
Ease of interpretation questionable, had a lot of information being displayed.
Data too hard to interpret for operators.
You can typically tell what is going on from these, but it is not easy to come to the conclusion and the displays are busy and not designed for human factors.
Good indicator of mode frequency growing in severity. Then 2nd mode not indicated in others. High energy oscillation indicated. Good way to determine where problem initiated (Montana bus).
Pick up oscillation and mode – growing and second mode. Fault analysis. Nice features.
Not sure how to interpret oscillation trend exactly.
Event 3—Tool C
Written Notes
Easy identification of a problem.
Clearly showed event beginning in Montana and high voltage and angle violations.
Immediately determines disturbance in Montana. Better for operator.
Alerted to a disturbance. Volt angle and frequency appeared to work as a very good tool for this condition or event.
Very good indication/presentation of oscillatory behavior – don't know what initiating event was.

Category 2: Ease of interpretation
Good disturbance indication.
Event 4—Tool A
Written Notes
I don't know the overview wasn't telling me anything I could use other than something is amiss and start looking in Ohio.
Showed a large angle difference between northern and southern eastern interconnection. Not sure if there was islanding
Seemed to be a lot of information but there was no identification of what the information was so that it could be interpreted.
Ease of interpretation was difficult.
Visual did not pinpoint problem.
Unable to determine what happened.
Not clear event was but were able to locate in Ohio
Unable to determine cause of event.
Unclear to me what happened.
Not sure what happened.
The map view showed a lot of blinking different colored dots spread out all over the east. Not easy to determine where exactly the problem is.
Event 4
Written Notes
Maybe a better view. Was not sure I was looking at the same event as Tool A. Multiple gen loss in Southeast oscillation with mid-West
Showed a disturbance beginning in Carolinas (unit 756?) with an oscillation within the eastern interconnection.
Very hard to interpret displays for the events. kept showing frequency and frequency rate of change charts. What happened with voltage or other elements. Was able to see that the initial event happened in the south and migrated north but no way to see what was the initial event by drill down.
Ease of interpretation good could visually see what was happening with dashboard.
Like dashboard. Identified original problem.
Good indication of location of initial problem.

Category 2: Ease of interpretation
Was not able to tell what the event was.
Did not pinpoint event, just oscillations. Gen loss?
Frequency oscillations from the graphs possibly indicate units tripping off. I'm not positive.
Showed a better layout of disturbance. But maybe say "freq. sys. disturb" would help lead instead of having to investigate what is the event. I think data with dots or just the red dots would help. if it's a freq. event, show freq. data with the dot.
Hard to tell from displays there was an oscillation "event" occurring. Substations turned "red" good. Hard to tell what initiated oscillation.
Good picture of where problem started and where it was in relation to the rest of the world. Not certain if a line trip or unit trip initiated the event.
System disturbance. Not sure what occurred.
Not sure exactly where the problem was though.
Event 4—Tool C
Written Notes
Although the contour displayed changes in frequency happening in the interconnection I could not tell that this was a problem. May be due to lack of familiarity with the tool.
Frequency map was good but no other information appeared to be able to drill down toward. It was just frequency.
No idea what idea what happened.
Frequency oscillations - showing dips where gen units are tripping off – gives a general area – not a particular unit or units.
Looked like noise on the system.
Unable to determine a general location. Unable to determine what event happened.

Category 3: Dashboard/overview displays
Event 1—Tool A
Written Notes
The dashboard was good

Category 3: Dashboard/overview displays
Event 1—Tool B
Written Notes
Dashboard confusing.
Liked dashboard design
Seemed to be able to access information from the dashboard fairly easily.
Good dashboard. Like automated analysis of what happened on dashboard.
dashboard too busy, Better design needed on dashboard, more generic (higher overview) – nice feature auto analysis but is it based upon pre-disturbance levels? Use drill downs for more details.
Liked the system overview with the dashboard to the right.
Good wide area awareness. One screen gave a good view of system conditions.
"Dashboard" at highest level
Like dashboard and de-cluttering.
Less things to look at. Good summary. Simpler, clearer than tool A. Easier to view changing conditioning. Less clutter/good "dashboard" approach.
I like showing indicators initially, then having the ability to see additional details if necessary.
Event 1—Tool C
Written Notes
Overview is simple to understand but I don't feel it leverages the data. SCADA data can get me the same
Good combination of dashboard, overview, and trends.
Dashboard too busy, too much flashing.
Did like the analytical data on dashboard.
Too much data on the dashboard of the map
Dashboard display has too many charts.
Too much data presented; need more focus on event
Event 1—Tool D
Written Notes

Category 3: Dashboard/overview displays
Initial display easy to read. Simple to use.
Liked overview, but no other detail, besides frequency changing
Like the frequency view.
Main display didn't show power transfer differences.
Need a dashboard.
Great Hi-level overview without distractions.
Event 2—Tool A
Written Notes
Good display overview.
First display was great--high level view not cluttered and very crisp and clean.
Dashboard kind of distracting with colors changing. Liked detail of overview.
Overall the display has a clean look.
Dashboard busy
Event 2—Tool B
Written Notes
Liked initial overview display and color relations on the map to the buttons on the left to alert operator quickly to what the issue is.
Liked the status overview and the ability to see the frequency, damping, and voltages tabs turn color on left side of display in respect to the overview.
I like this display. it showed red indicators and then synch. scopes not synch. Like the detailed analysis. Overview should have shown line open points.
Overview is good.
Like alarms on dashboard
Dashboard – the rectangle boxes on left take up too much space.
Islanding display very intuitive.
Great frequency visualization. Clear islanding detection and system speed. Cool sync slope visualization.
I like the indicators on the dashboard. The arrows used on the dashboard are "cool" but I need to see actual numbers and differences. Trends and scales may be better for this purpose.

Category 3: Dashboard/overview displays
Dashboards good, only need “red.”
Event 2—Tool C
Written Notes
Overview of area good,
Event 2—Tool D
Written Notes
The overview is good.
Overview should be bigger percentage of display.
Overview of area good, ease of interpretation allowed to see what was happening…. Dashboard on bottom flashing with different color could become confusing, and/or distraction.
Main display is too busy with all the graphs as well as geographic display. Display did help identify the problem areas, though too many alarms being presented.
Too much information on this screen.
Identified island well. Also displayed frequency at key locations in the interconnection. Overview had a lot of information that some might view as cluttered but it gave me a good view of system conditions.
map display is too “busy.”
Event 3—Tool A
Written Notes
Profile display showed a problem centered in the Montana area with an increasing phase angle difference with the rest of the interconnection.
Overview provided good information, angle information was a little hard to see.
Main display did not make it easy to determine problem.
Tool okay (dashboard) but color contour?
Clearly showed values an area. Very nice simple state map.
Angle turning “RED” on one line depicting oscillation was good.
Event 3—Tool B
Written Notes

Category 3: Dashboard/overview displays
Again, [better if] main overview bigger,…
clearly identified Montana as source of oscillations
With the event appearing to be of low magnitude, the displays seemed to be too high level to discern what the event was quickly.
Dashboard again was too busy and confusing.
It did identify problem area but display is too busy.
You can typically tell what is going on from these, but it is not easy to come to the conclusion and the displays are busy and not designed for human factors.
Voltage alarm on dash…. Clearly see frequency oscillations on dashboard
I like the tabs at the bottom of the dashboard flashing event type volt, frequency, etc. Does flash a lot though
A lot of useable information on the dashboard.
It showed general area and then the trends showed exact locations.
Nice to show oscillation modes
Event 3—Tool C
Written Notes
First display – easy to see problem. (dashboard)
Clearly showed event beginning in Montana and high voltage and angle violations.
Did show well that Montana had the initial event and that created oscillations in the west.
Liked dashboard that indicated basic info: Start of disturbance, voltage instability, that was good. Ease of viewing. Provided actionable information to see if event would cascade any further.
Like the dashboard view.
Detected and displayed area where disturbance occurred pretty well.
Simple dashboard is nice. With the nice simple dashboard, could you not click the left buttons and instead of jumping to a new page simply show the trend below? This way you have data trends and overview the user selects.
Flow path detail on one-line was useful.
It was clear that the problem started in Montana. The more I see the dashboard the more I like the idea of one central display with jumps to needed data.
Very good indication/presentation of oscillatory behavior – don't know what initiating event was.

Category 3: Dashboard/overview displays
Picked up system disturbance. Picked up dual modes. Good summary screens.
Event 4—Tool A
Written Notes
I don't know. The overview wasn't telling me anything I could use other then something is amiss and start looking in Ohio.
UI not labeled as to what I am looking at could not determine event. Gen loss?
Event 4—Tool B
Written Notes
Overview – easy to see initial disturbance. Like the dashboard. No legend for colors…? Didn't see it.
Very hard to interpret displays for the events. kept showing frequency and frequency rate of change charts. What happened with voltage or other elements. Was able to see that the initial event happened in the south and migrated north but no way to see what was the initial event by drill down.
Ease of interpretation good could visually see what was happening with dashboard.
Like dashboard. Identified original problem.
Good indication of location of initial problem.
Overview shows where and what. Be better to bring other info upon so that overview display is not hidden.
Software not labeled well (unit #s)
You could see a disturbance and additional disturbances.
Good overview data. Good representation of the events as the developed.
Good picture of where problem started and where it was in relation to the rest of the world. Not certain if a line trip or unit trip initiated the event.
Good indicator of location of disturbance initiation.
Event 4—Tool C
Written Notes
Frequency map was good but no other information appeared to be able to drill down toward. It was just frequency.
Nice overview of oscillation by color.

Category 3: Dashboard/overview displays
Display did not provide much information.
Frequency oscillations - showing dips where gen units are tripping off – gives a general area – not a particular unit or units.
Freq. contour nothing more. Just data.

Category 4: Accessing more detail— zooming/drill down, pop-up displays, hover for more information
Zooming/Drill Down
Event 1—Tool A
Written Notes
Drill downs very good
The detail at different zoom levels is helpful.
Good zoom in and drill down.
Event 1—Tool B
Written Notes
Drill downs worked well,.
The essential information was there with the ability to drill down to obtain more
– drill down data was too much – operator not interested in oscillations
Good drill downs
Very good … drill down.
Zooming intuitive
Event 1—Tool C
Written Notes
Didn't show the ability to drill down even more or show substation buses.
Ease of viewing on drill down.
Drill down data-- too much data and confusing. No oscillations.

Category 4: Accessing more detail— zooming/drill down, pop-up displays, hover for more information
Drill down screens seemed too vague and not clearly defined
Zoom and drill down ok.
Good drill down capability.
Event 1—Tool D
Written Notes
However did not see any ability to drill down and get more information. (voltage, MW, Hz and other values)
Event 2—Tool A
Written Notes
Liked the ability to get more information with ease. Using check boxes to allow user to pick what they want to see.
auto analysis and drill downs nice.
Like the mouse over display and drill down data graphs.
Overview with drill down capability was good.
Event 2—Tool B
Written Notes
Like the R-Y-G indicators on left and drill down capability
Event 2—Tool C
Written Notes
Drill down displays were good, especially the P/Q bar graphs.
Liked being able to change/zoom overview.
Drill down views were good.
Event 2—Tool D
Written Notes
Drill down data confusing.
Did like drill downs, too many points on charts – would like to be able to define or remove points for

Category 4: Accessing more detail— zooming/drill down, pop-up displays, hover for more information
better analysis.
Event 3—Tool A
Written Notes
Also didn't see a great ability to drill down to get more information
Drill down displays did show operators taking in large amounts of VARs, though no alarming of it.
Zoom down good, but final zoom lost interface flows?
Zoom feature showed all gen units taking in VAR. No info on sys. voltage.
Drill down nice to show local angle data.
Event 3—Tool B
Written Notes
Several of the drill down displays did not seem useful
Drill down for an operator was too time consuming.
The drill-down displays are confusing and not designed for an operator.
Event 3—Tool C
Written Notes
Drill downs showed growing oscillations; some were not too useful due probably to unfamiliarity with tool. Showed Montana unit # 3, is this available for all generating facilities?
Don't know the drill down information.
drill down showing oscillations
Event 4—Tool A
No notes written
Event 4—Tool B
Written Notes
Zoom in, drill down good.
Event 4—Tool C

Category 4: Accessing more detail— zooming/drill down, pop-up displays, hover for more information
No notes written
Pop-Up Displays
Event 1—Tool A
No written notes
Event 1—Tool B
Written Notes
Pop us display is easy to read, although somewhat busy.
Pop up provided analysis of event.
Distraction with the automated analysis popping up -- distract.
(during discussion added: "I didn't 'get' that there was a popup analysis tool on tool B").
Event 1—Tool C
No written notes
Event 1—Tool D
No written notes
Event 2—Tool A
Written Notes
Not sure I like the pop-up diagnosis… maybe as an option by the user.
Pop up analysis was helpful in the scenario.
Pop up identifying island was good. Pre-defined island.
Event analysis tool pop up is a good thing.
Event 2—Tool B
No written notes
Event 2—Tool C
No written notes
Event 2—Tool D

Category 4: Accessing more detail— zooming/drill down, pop-up displays, hover for more information
No written notes
Event 3—Tool A
No written notes
Event 3
No written notes
Event 3—Tool C
No written notes
Event 4—Tool A
No written notes
Event 4—Tool B
No written notes
Event 4—Tool C
No written notes
Hover for More Information
Event 1—Tool A
No written notes
Event 1—Tool B
Written Notes
liked mouse-over for expanded data feature
Liked the ability to hover over certain points with the cursor and more information was available.
Event 1—Tool C
Written Notes
Could not see what was going on while hovering cursor over traces?
I do like the "hover over" the line to highlight the data on the graph,

Category 4: Accessing more detail— zooming/drill down, pop-up displays, hover for more information
Event 1—Tool D
No written notes
Event 2—Tool A
Written Notes
Liked the drag over feature for a summary.
Like the mouse over display and drill down data graphs.
Event 2—Tool B
No written notes
Event 2—Tool C
No written notes
Event 2—Tool D
No written notes
Event 3—Tool A
No written notes
Event 3—Tool B
No written notes
Event 3—Tool C
No written notes
Event 4—Tool A
No written notes
Event 4—Tool B
No written notes
Event 4—Tool C
No written notes

Category 5: Color / Contrast / Highlighting
Event 1—Tool A
Written Notes
Prefer darker screen backgrounds. Highlighted text difficult to read.
Color and contrast made info hard to see.
Color's consistent with frequency and open and closed conditions.
but the multiple colors in graphics make it more difficult/straining – change background color to black?
Icons on map were solid colors; this hides the names, etc.
White background not something our group would want.
Event 1—Tool B
Written Notes
Data pair coloring (phasor lines) changed fairly frequently (time frame)
Colors consistent.
Colors were soft and not overpowering
Event 1—Tool C
Written Notes
color contrast was not good
Colors were consistent
Colors not clear what they mean.
Maybe a more consistent color code for all charts/graphs or is it based upon metering type?..
too many colors
Event 1—Tool D
Written Notes
Need more defined for 60 Hz. Text data should have changed colors to identify set points
Colors alone, esp. changing of colors don't tell me what I have other than extremes, red, yellow, blue.

Category 5: Color / Contrast / Highlighting
I need to see values as well. Also how red or blue is the event, could be zero, but I don't know because red is 59.60 + -
Event 2—Tool A
Written Notes
Color contrast was good.
Consistency – color good.
Color scheme (black background nice).
Not sure what color contours mean
Not sure what "Red" flashing lines in CA meant (overload)
I find all the color changing to be annoying.
Event 2—Tool B
Written Notes
Pop up highlighted text hard to read with red background.
PMU's turning red ok if you initially observed event in Canada or they persisted. Red arrow display for flows to California evident.
Liked initial overview display and color relations on the map to the buttons on the left to alert operator quickly to what the issue is.
change charts colors – straining…. Color scheme could use work – straining.
Red box with black text hard to read a pop up.
Like the R-Y-G indicators on left and drill down capability
Event 2—Tool C
Written Notes
Good use of color
Color contrast was good
Color scheme needs to be easier to view.
Colors bring attention to things and data/values adds meaning to them.
Various contour colors confusing
Too many color changes for my liking. Always show Red and Southern Calif. CAS. Is that normal?

Category 5: Color / Contrast / Highlighting
I'd assume not.
Event 2—Tool D
Written Notes
Not sure what red indicator was telling operators.
Color scheme needs work
Too many colors.
Event 3—Tool A
Written Notes
Liked number turning red when over defined limit.
Angle turning "RED" on one line depicting oscillation was good.
Like use of colors.
Event 3—Tool B
Written Notes
Liked arrows on display and turning red when over defined limit… Liked red circle over Montana.
Too many colors,
Event 3—Tool C
Written Notes
better color for graphs could be used.
Event 4—Tool A
Written Notes
Color scheme horrible,
Too many lines and colors.
Event 4—Tool B
Written Notes
No legend for colors.

Category 5: Color / Contrast / Highlighting
Substations turned “red” good.
Do not like black text in red boxes.
Event 4—Tool C
Written Notes
Nice overview of oscillation by color.
Tabular helped but still did not help operator.
Operator would miss dark blue change.

Category 6: Flashing
Event 1—Tool A
No written notes
Event 1—Tool B
Written Notes
Would need more time to get adjusted to flashing dots on top right.
Too many flashing lights.
Too much flashing/blinking. Can’t tell where the problem is with everything red and blinking.
Event 1—Tool C
Written Notes
Slow down the flash rate for abnormal state.
Too many flashing indications on display.
Dashboard too busy, too much flashing.
Lots of blinking. Hard to see where the problem was at first glance.
Blinking of indication more distracting than attention focusing.
Too much blinking

Category 6: Flashing
Event 1—Tool D
No written notes
Event 2—Tool A
Written Notes
Do not like the strobing effect.
Contours are helpful, but the flashes of them is distracting.
Not sure what "Red" flashing lines in CA meant. (overload)
Event 2—Tool B
No written notes
Event 2—Tool C
Written Notes
but too much other data and information flashing
Too much flashing/changing colors.
Event 2—Tool D
Written Notes
Rapid flash distracting.
lots of data and flashing on screen
A lot of points were flashing red, green, and blue. What did that mean or what were those points was hard to determine.
Dashboard on bottom flashing with different color could become confusing, and/or distraction.
Too much flashing.
Too much flashing.
Flashing magenta and red dots re: frequency distracting
Flashing, then things go away, not sure if I missed something
Event 3—Tool A
No written notes

Category 6: Flashing
Event 3—Tool B
Written Notes
Boxes at bottom flipping between voltage and mode were distracting.
I like the tabs at the bottom of the dashboard flashing event type volt, frequency. Does flash a lot though.
Event 3—Tool C
No written notes
Event 4—Tool A
Written Notes
Too many flashing dots – drop in trend display? That would be handy.
Too many alarms flashing.
Too much flashing and business.
Color scheme horrible, flashing lights
Just a screen with blinking lights.
Blinking lights didn't tell me anything.
Lots of "flashing" dots.
Too much stuff blinking on initial display. … What did the blinking dots relate to?
Lots of flashing.
Event 4—Tool B
No written notes
Event 4—Tool C
No written notes

Category 7: Alarms
Event 1—Tool A

Category 7: Alarms
Written Notes
I liked the alarm bars on side of dashboard.
Good incorporation to EMS for alarming.
Dashboard alarms nice,
Event 1—Tool B
Written Notes
No SOE -- alarms?
alarms on right just looked like blinking lights, not as easy to discern
Event 1—Tool C
Written Notes
No alarms populated other than the red across COI.
Alarm bar on bottom was nice.
Good alerts to operator.
Event 1—Tool D
No written notes
Event 2—Tool A
Written Notes
Still no alarm summaries, which would be very useful.
No alarming or SOE (sequence of events) visible.
alarm dots look like blinking lights
Did like the alarm viewer
Event 2—Tool B
Written Notes
Alarm buttons on left clearly showed different events.
Still no alarm or event summary windows.
Three things were in alarm on overview, hard to determine how they related on the overview (e.g.

Category 7: Alarms
what showed island, oscillations)
Like alarms on dashboard…
Red “system disturbance alarm” good.
Event 2—Tool C
Written Notes
It didn’t show any alarm status numbers etc.
Event 2—Tool D
Written Notes
too many alarms being presented.
I like the overload and island alarms
Event 3—Tool A
Written Notes
No alarm/event summary screens to alert to what the issue is.
Drill down displays did show generators taking in large amounts of VARs, though no alarming of it.
I need some visual alarms.
Event 3—Tool B
Written Notes
Mode? Alarm (75 Hz Mode)?
Tool bar alarms were good.
Voltage alarm on dash.
Mode meter alarms clearly displayed oscillations
Good alarms showing oscillations.
Event 3—Tool C
Written Notes
Good alarms showing disturbance, angle difference, and oscillations.

Category 7: Alarms
Like alarm summary.
Event 4—Tool A
Written Notes
Too many alarms flashing.
Event 4—Tool B
Written Notes
Good visual alarms on map.
Event 4—Tool C
No written notes

Category 8: Relationship between data—cluttered displays
Event 1—Tool A
Written Notes
Too much information on the screens, cluttered appearance for a disturbance. An operator needs the best information possible, but not too much so that they can make a decision quickly. For instance: alarms, voltage, breaker operations, MW, frequency. All that information was there and more.
Too many items on some displays.
Too much data – Data need to point to problem area and next contingency or worst next contingency
Relationships between data seemed portrayed ok.
Dashboard a little busy, drill downs very good.
Event 1—Tool B
Written Notes
Liked the layout, displays and information was clean and crisp. Minimal information but just the essential information was there with the ability to drill down to obtain more.
Event 1—Tool C
Written Notes

Category 8: Relationship between data—cluttered displays
Data and labels on the right are busy and hard to read.
Display appeared cluttered
Too much data on display – did like the WECC frequency displayed.
Screen too busy with graphs on both sides.
Too much data on the dashboard of the map
Too busy.
Can a de-clutter tool be used? Fatigue for the eyes.
Cluttered overview.
A little overwhelming. Too much data presented; need more focus on event and state of the system was demonstrated but overstated.
Map looked very busy, may not be necessary to show all of that data at once on the map.
Event 1—Tool D
Written Notes
Relationships between data seemed portrayed ok.
Event 2—Tool A
No written notes
Event 2—Tool B
No written notes
Event 2—Tool C
Written Notes
Not sure where data displayed was referenced from.
Event 2—Tool D
Written Notes
Don't understand symbols and meanings to frequency, angle dashboard below overview display.
There were small red blinking triangles pre-separation. No idea why.
Event 3—Tool A

Category 8: Relationship between data—cluttered displays
Comments
Relationship between data was good.
Event 3—Tool B
Written Notes
On the charts too many trend points to pick out what you needed, too much clutter.
had a lot of information being displayed. … Dashboard again was too busy and confusing.
too much information on screen.
Event 3—Tool C
No written notes
Event 4—Tool A
Written Notes
Charts didn't have a legend to show what was being traced and they seemed cluttered and not crisp or clear. A lot going on but what it was hard to discern.
Trend was very busy.
Event 4—Tool B
Written Notes
Relationships between data not clear.
Event 4—Tool C
No written notes

Category 9: Contouring
Event 1—Tool A
No written notes
Event 1—Tool B
Written Notes

Category 9: Contouring
The contouring was nice,
Contours are ok, but change so fast.
Event 1—Tool C
No written notes
Event 1—Tool D
Written Notes
Interesting way to display frequency data across a region.
Like frequency contour.
Frequency contours o.k. but needs more specific locations and values.
Contour map is too general. I need to know which busses are having issues.
Event 2—Tool A
Written Notes
Although I was not sure what the contouring was showing me voltage frequency angle?
Frequency contour showed difference between Canada & rest of interconnection.
The contouring changing so rapidly (seemed jerky) could be distracting.
Good use of contour in background of path info.
Voltage contours in background helpful…..
Contours are helpful
Not sure what contour colors mean.
Event 2—Tool B
No written notes
Event 2—Tool C
Written Notes
Changing voltage contour showed swings across system.
Contouring seemed jerky which could be distracting.
Various contour colors confusing.

Category 9: Contouring
Event 2—Tool D
No written notes
Event 3—Tool A
Written Notes
Tool okay (dashboard) but color contour?
Not sure what the contours were telling me.
Event 3—Tool B
No written notes
Event 3—Tool C
No written notes
Event 4—Tool A
No written notes
Event 4—Tool B
No written notes
Event 4—Tool C
Written Notes
Although the contour displayed changes in frequency happening in the interconnection I could not tell that this was a problem. May be due to lack of familiarity with the tool.
Again color contour not useful.
Freq. contour nothing more. Just data.
Frequency contours provided meaningful info. Looked like noise on the system. Should contours extend into the ocean?
Contours gave frequency indication only.

Category 10: Icons/Symbols

Category 10: Icons/Symbols
Event 1—Tool A
Written Notes
Arrows clearly showed power flow direction after event, location of event; Swinging power angles?
It would have helped if I had known what the dashboard symbols meant
Arrows (bidirectional) confusing (assume dashboard).
Icons on map were solid colors; this hides the names, etc.
“Red cherries” too big.
Event 1—Tool B
Written Notes
Would need more time to get adjusted to flashing dots on top right.
Event 1—Tool C
Written Notes
Large red flowgate with directional arrow clearly showed problem in southern region;… For paths would show increase/decrease do they change if violation?
Event 1—Tool D
No written notes
Event 2—Tool A
Written Notes
Also liked the flow arrows ►►►, they seemed helpful.
Event 2—Tool B
Written Notes
Red arrow display for flows to California evident.
Like the easily read large icons on the left of the main screen displaying event type. The rotating angles arrows are very distracting.
I like the rotating arrows pres??? for phase angle
Didn’t like swing arrows, but they did get your attention.

Category 10: Icons/Symbols
Do not like rotating arrows
Event 2—Tool C
No written notes
Event 2—Tool D
Written Notes
Don't understand symbols and meanings to frequency, angle dashboard below overview display.
There were small red blinking triangles pre-separation. No idea why.
Event 3—Tool A
No written notes
Event 3—Tool B
Written Notes
Liked arrows on display and turning red when over defined limit…. Liked red circle over Montana.
Event 3—Tool C
No written notes
Event 4—Tool A
Written Notes
Not sure what the large arrow was…
Event 4—Tool B
No written notes
Event 4—Tool C
No written notes

Category 11: Geographic Overviews / Map

Category 11: Geographic Overviews / Map
Event 1—Tool A
Written Notes
Geographic overviews were intuitive.
Good geographic view of voltage and angle conditions in an alarm state.
Event 1—Tool B
Written Notes
Like the geographic relief on the overview
I like the map beside the large chart capability so I can still watch but also analyze at the same time. Still no system map.
Geographic overview ok.
Aloud Comments
had more geographical information—good (said also about Tool C)
Event 1—Tool C
Written Notes
Like the Map Style
Map display contained large amounts of text/number data.
Geographical overview was good. Some frivolous information
Good geographical representation
Map looked very busy, may not be necessary to show all of that data at once on the map.
Aloud Comments
had more geographical information—good (said also about Tool B)
Event 1—Tool D
Written Notes
Map visualization was minimalistic and great. As an operator you understand what the change in frequency means. When you see a display show that information gives a great overview.
Event 2—Tool A

Category 11: Geographic Overviews / Map
Written Notes
Good geographical shapes
Event 2—Tool B
No written notes
Event 2—Tool C
No written notes
Event 2—Tool D
No written notes
Event 3—Tool A
Written Notes
Very nice simple state map.
Event 3—Tool B
Written Notes
Again – map – lose details.
Event 3—Tool C
Written Notes
Easier to discern on map overview display where the event started.
Event 4—Tool A
Written Notes
The map view showed a lot of blinking different colored dots spread out all over the east. Not easy to determine where exactly the problem is.
Event 4—Tool B
No written notes
Event 4—Tool C
No written notes

Category 12: Not operator focused
Event 1—Tool A
No written notes
Event 1—Tool B
No written notes
Aloud Comments
need better operator lingo
Event 1—Tool C
No written notes
Event 1—Tool D
No written notes
Event 2—Tool A
No written notes
Event 2—Tool B
No written notes
Event 2—Tool C
No written notes
Event 2—Tool D
Written Notes
Engineer focused, not Operator focused.
Displays seem to be more for an engineer, not an operator.
Good data for engineering analysis. But not for operations.
The data on charts is very hard to understand, more of a post mortem analysis by engineering or planning. not ops.

Category 12: Not operator focused
Too much "technical" stuff.
Event 3—Tool A
No written notes
Event 3—Tool B
Written Notes
More engineering analysis data than operator data.
trend display graphs look like an engineering tool.
not for operators.
Aloud Comments
lot more engineer oriented—after-the-fact
Event 3—Tool C
No written notes
Aloud Comments
lot more operator oriented
was better as transmission operator
Event 3—Tool D
No written notes
Event 4—Tool A
Looks like an engineering tool not an operator tool.
Did not tell ops anything.
Event 4—Tool B
No written notes
Event 4—Tool C
No written notes

Category 13: Switching between displays—easily get lost
Event 1—Tool A
Written Notes
Seemed to switch between data at a high rate of speed. I don't know if that is because the attempt to show everything it would do.
but it seemed a bit confusing in switching between screens after the dashboard view.
Lots of screens to view, not enough time to determine what is going on.
Aloud comments
All different screens—I would easily get lost; I have lots of monitors ok?; if I have to flip back and forth to displays in real-time, can't do
flipping too quickly to displays; needed overview
Event 1—Tool B
Written Notes
Used one screen without having to change screen views for the event. Calm in control feel to this tool.
Event 1—Tool C
No written notes
Event 1—Tool D
No written notes
Event 2—Tool A
No written notes
Event 2—Tool B
Written Notes
Too much switching between screens to determine info
Switching between screens is confusing
Event 2—Tool C
No written notes

Category 13: Switching between displays—easily get lost
Event 2—Tool D
No written notes
Event 3—Tool A
No written notes
Event 3—Tool B
No written notes
Event 3—Tool C
No written notes
Event 4—Tool A
No written notes
Event 4—Tool B
No written notes
Event 4—Tool C
No written notes

APPENDIX H: *A Selection of Principles of Display Design*

The Point of Contact for the following principles of display design is Dr. James Merlo. Please address any questions to james.merlo@nerc.net.

Thirteen Principles of Display Design

The purpose of this document is to introduce, describe and provide examples of thirteen important principles that should be considered and appropriately applied when designing displays for humans. These notes are provided at the request of industry personnel who attended the NASPI visualization workshop on 27 February 2012.

Display design

When a computer operates in a manner that is not intended, humans often demonstrate their disgust by striking the monitor. This monitor, or visual display, is simply the portal that allows one to interact with the technology. The display (be it visual, auditory, tactile, etc.) is an artifact designed to support the perception of relevant system variables and to facilitate further processing of that information. Before a display is designed, the task that the display is intended to support must be defined (e.g. navigating, controlling, decision making, learning, entertaining, etc.). A user or operator must be able to process whatever information that a system generates and displays; therefore, the information must be displayed according to principles in a manner that will support perception, situation awareness, and understanding.

Engineering psychologist Christopher Wickens has placed these principles into four categories as depicted in the chart below.

Perceptual Principles	Principles Based on Attention	Memory Principles	Mental Model Principles
1. Make displays legible (or audible)	6. Minimizing information access cost	9. Principle of consistency	12. Principle of pictorial realism
2. Avoid absolute judgment limits	7. Principle of multiple resources	10. Principle of predictive aiding	13. Principle of the moving part
3. Similarity causes confusion: Use discriminable elements	8. Proximity compatibility principle	11. Replace memory with visual information: knowledge in the world	
4. Top-down processing			
5. Redundancy gain			

THIRTEEN PRINCIPLES OF DISPLAY DESIGN

These principles of human perception and information processing can be utilized to create an effective display design. A reduction in errors, a reduction in required training time, an increase in efficiency, and an increase in user satisfaction are a few of the many potential benefits that can be achieved through the proper application of these principles.
Certain principles may not be applicable to different displays or situations. Some principles may seem to be conflicting, and there is no simple solution to say that one principle is more important than another.
The principles may be tailored to a specific design or situation. Achieving a functional balance among the principles is critical for an effective design.

Perceptual Principles

1. Make displays legible (or audible)

If the characters, objects or sounds being displayed are not discernible, then the operator cannot effectively make use of them. From bad handwriting to small pitch font or even faint buzzers and bells, if something cannot enter the consciousness from the very beginning, then the chances of it reaching the intended user or consumer for use is extremely low. If a display is difficult to use in perfect situations (good lighting and quiet), it probably won't work well at all in a noisy high tempo environment that routinely make perception more difficult.

Small pitch font and some none standard fonts are hard to read.

Light or faint text is often difficult to read.

Can you hear me now? Cell phones often become problematic in loud outdoors situations and in poor communication provider coverage areas.

2. Avoid absolute judgment limits

Avoid making the operator or user judge the represented variable level on the basis of a single sensory dimension (color, size, pitch, etc.) If a judgment is required, set the user up for success. Limit the number of possible levels or differentiations required to no more than 5 to 7.
----- ----- ----- ----- ----- ----- There are 6 different dashed lines with six different saturation levels on the left or beginning of this paragraph. Using the single variable of saturation, a human could probably only reliably differentiate between the second one, the third one and the sixth one, and probably could only do this in ideal environmental conditions.
Use multiple parameters to code something (shape, size, tone, loudness, etc.) and be careful with pushing the edges of human's ability to differentiate similar qualities.

3. Similarity causes confusion: Use discriminable elements

Similar appearing signals are likely to be confused. The ratio of similar features to different features is what causes signals to be noted as similar. For example, JLM456 is more similar to JLM457 than 56 is to 57. Unnecessary similar features should be removed and dissimilar features should be highlighted.

Looking at the switches below, the only differentiation is 1A and 7A, and depending on where you are standing and looking up to read, the differences might not be noticeable at all.

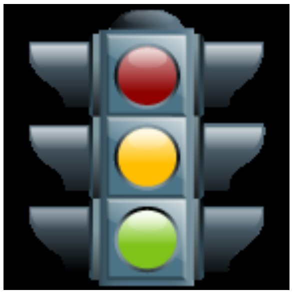
4. Top-down processing

Signals are routinely perceived and interpreted based on an operator's past experience. Humans see and hear what they expect. If the presentation of a signal is contrary to expectations, or is the result of some unlikely or rare event, then more physical evidence of that signal must be presented to ensure that it is interpreted correctly.

Relay or line trips during a thunderstorm will usually immediately drive an operator to perceive things that are related to impacts associated with that weather phenomena (such as lightning strikes). Signals that can be associated with certain phenomena will drive that type of decision making even if the signal might not be associated with that impact. The context that the operator is in always matters, as one's expectations can drive perception.

5. <u>Redundancy gain</u>

Presenting a signal in more than one way increases the likelihood it will be interpreted correctly. This can be done by presenting the signal in alternative physical forms (e.g. color and shape, voice and print, etc.), as redundancy does not imply repetition. One of the most striking examples of this is a traffic light, as color and position are redundant. A person that is red and green color blind can simply use the position of the light to discern the meaning of the signal, thus if one portion of the signal fails to effectively penetrate the signal, the other may prevail. When both signals are successfully received, the confluence of the two signals, particularly if the signals are from different modalities (sight and sound), can actually produce a greater impact at the human physiological level, resulting in greater chances of the signal being received. However, if the signals are not congruent, meaning the sound says one thing and the visual signals says something else, perception and comprehension will suffer both in latency (or time) and accuracy (increased misperception). An example of this incongruent pairing of modalities of sight and sound can be experienced in watching an old martial arts movie where the voice and lip movements are not in synch.



Principles Based on Attention

6. <u>Minimize information access cost</u>

Frequently accessed sources of information should be readily available. There is a cost of time and effort when a user's attention must be moved from display to display in order to gather information. Computer menus are sometimes deep and cumbersome as the user tries to figure out the appropriate steps or processes. Visible menus, strategies to keep mode awareness and efficient place keeping functions all help in this endeavor. An example of this principle is the right mouse button on a computer will often bring up a menu of common commands.

Certain information is always important and should not require anything but minimal effort to access (e.g. speedometer on a car). When the user's attention is diverted from one location to another to access necessary information, there is usually an associated cost in time or effort. A display design should minimize this cost by allowing for frequently accessed sources to be located at the nearest possible position. However, adequate legibility should not be sacrificed to reduce this cost.

7. <u>Principle of multiple resources</u>

A user can more easily process information across different resources. For example, visual and auditory information can be presented simultaneously rather than presenting all visual or all auditory information. This principle supports information or signals that are not necessarily the same, as was discussed in the concept of redundancy gain. Certain signals are better for directing attention, like a localized or directional auditory alarm, while other signals are better for providing information in depth, such as an error message or warning sent in a visual text message. By using multiple resources, a trained operator can receive information simultaneously through the different modalities.

8. <u>Proximity compatibility principle</u>

Often, two or more sources of information are related to the same task. These sources must be mentally integrated and are defined to have close mental proximity. Divided attention between two information sources may be necessary for the completion of one task. Information access costs should be low, which can be achieved in many ways (e.g., close proximity, linkage by common colors, patterns, shapes (e.g., see Gestalt Principles). Care must be taken when applying this principle as close display proximity can be harmful by causing too much clutter. Close spatial proximity increases the likelihood to parallel processing, which is critical for integrated tasks.

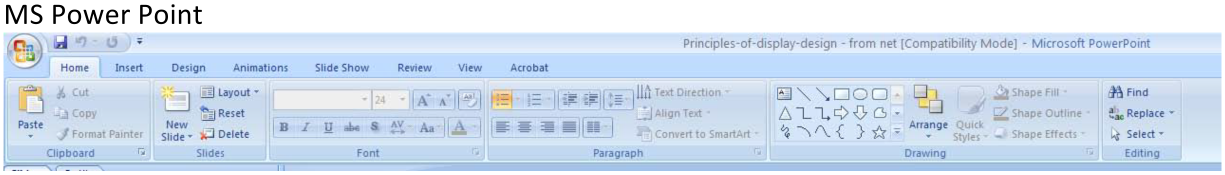
Principles Based on Memory

9. <u>Principle of consistency</u>

A user's long-term memory will trigger actions that are expected to be appropriate. Familiar icons, actions and procedures from other displays will easily transfer to support processing of new displays if they are designed in a consistent manner. A design must accept this fact and utilize consistency among different displays. Microsoft programs are a good example of this principle, as most of their products share standard main menu functionality.

MS Word

MS Power Point



10. Principle of predictive aiding

Proactive presentations of information are usually more effective than reactive actions. A display should attempt to eliminate resource-demanding cognitive tasks and replace them with simpler perceptual tasks to reduce the use of the user's mental resources. This will allow the user to not only focus on current conditions, but also think about possible future conditions. An example of a predictive aid is a road sign displaying the distance from a certain destination. Predictive aiding anticipates what information people will need to remember in order to execute tasks they intend. The verbal and visual warning that the GPS gives before a directional event, prepares the user or sets the conditions for successful future execution (e.g., lane change, speed reduction, etc).

The above sign examples are useful when driving if they are presented in advance of the actual required action, allowing a driver to anticipate or prepare.

11. <u>Replace memory with visual information: knowledge in the world</u>

A user should not need to retain important information solely in working memory (what one is currently thinking about) or to retrieve it from long-term memory (one's permanent storage of memories). A menu, checklist, or another display can aid the user by easing the use of their memory. However, the use of memory may sometimes benefit the user by eliminating the need to reference some type of knowledge in the world (e.g. an expert computer operator would rather use direct commands from memory than refer to a manual). The use of knowledge in a user's head and knowledge in the world must be balanced for an effective design.

Principles Based on Mental Models

12. Principle of pictorial realism

A display should look like the variable that it represents (e.g. high temperature on a thermometer shown as a higher vertical level). If there are multiple elements, they can be configured in a manner that looks like it would in the represented environment.

13. Principle of the moving part

Moving elements should move in a pattern and direction compatible with the user's mental model of how it actually moves in the system. For example, the moving element on an altimeter should move upward with increasing altitude.

Reference:
Christopher D. Wickens, John D. Lee, Yili Liu, and Sallie E. Gordon Becker (2004) **An Introduction to Human Factors Engineering**. Second ed., Upper Saddle River, NJ: Pearson Prentice Hall, 185–193.