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MOTION IN MIMIC DISPLAYS: EFFECTS ON THE DETECTION AND DIAGNOSIS OF ELECTRICAL POWER SYSTEM FAILURES

Douglas A. Wiegmann[1], Gavin R. Essenberg[1], Thomas J. Overbye[2], and Aaron M. Rich[1]
[1]Aviation Human Factors Division, Institute of Aviation
University of Illinois at Urbana-Champaign
Savoy, Illinois
[2]Department of Electrical and Computer Engineering
University of Illinois at Urbana-Champaign
Urbana, Illinois

New power system displays have been developed to aid operators in the detection and diagnosis of faults. The enhancement of integrated one-line diagrams of power system data with motion and motion cues was examined in this experiment. Participants acknowledged and solved power system failures on a simulated power network across a number of trials of varying complexity. Participants performed these tasks using interactive displays indicating power flow with digits, stationary arrows, or moving arrows. For high complexity scenarios, results indicated a general advantage for the motion display in the diagnostic task (problem resolution) but a slight advantage of the digital display on the fault detection task (problem identification). Performance with the stationary arrow display was generally between the other two groups, being nearly as good as with the digital display in the detection task and nearly as good as with the moving arrow display in the diagnosis task. Further research is necessary to determine the conditions where motion is most beneficial.

INTRODUCTION

The interconnected electric power grid in North America is one of the largest and most complex man-made objects ever created (Overbye, 2000). The grid consists of billions of individual components, tens of millions of miles of wires, and thousands of individual generators. Furthermore, each component in a power grid generates data that may be required by power systems operators. Normally, operators are engaged in typical process control tasks that require consistent monitoring of the power grid and detection of potential problems, such as low bus voltages, due to transmission overloads and line outages. When such violations occur, operators diagnose the causes of these low voltage problems and remedy them either through preplanned procedures or troubleshooting processes, such as opening new transmission lines or activating system capacitors within the power grid.

Traditional Displays

The current information visualization tools used by power system operators to perform process control tasks have evolved little beyond tabular displays and a static representation of a power grid posted on the control room wall (Overbye, Wiegmann, Rich, & Sun, 2001). However, recent industry restructuring has led to the creation of much larger markets that are under the control of a single system operator. Thus, operators are now often responsible for monitoring and controlling considerably larger networks than historically required, and traditional methods of presenting data in tabular and static wall-grid formats are insufficient to support operators in their tasks. Such traditional presentation methods are less than ideal for performing tasks that require rapid assessment of the state of the system as a whole in addition to the interrelationships among the multiple subsystems throughout the network.

Integrated One-Line Diagrams

Recently, new visualization techniques have been researched and developed to overcome the problems and deficiencies of traditional power system displays. One particular technique that has shown promise is the use of the integrated one-line diagram (see Figure 1). Integrated one-line diagrams are computer generated displays that combine the tabular and static one-line diagram displays used in many traditional power system control rooms. The benefits of these displays are derived from their ability to act as both mimic display and close spatial proximity display.

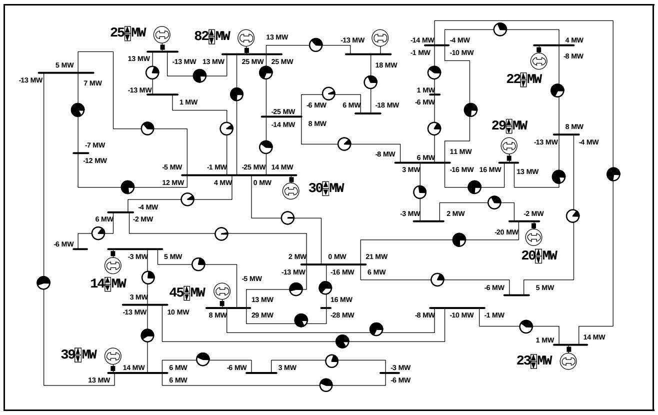

Figure 1. One-line diagram in digital display format.

Mimic displays depict a physical representation of a system and present information at the level of physical function of a system (Bennett, 1993; Bennett & Malek, 2000; Hollan, Hutchins, McCandless, Rosenstein, & Weitzman, 1987). A mimic display represents important components, systems, or subsystems as they appear in the physical world, using pictorial realism to show physical connections and limitations of important system components to provide better support for the detection and diagnosis of faults within a system (Bennett & Malek, 2000).

The integrated one-line diagram also serves as a type of integrated display known as a close spatial proximity display. Close spatial proximity displays integrate multiple sources of information and create a "psychological closeness" between display elements through physical manipulations (Wickens & Carswell, 1995). This is usually accomplished by placing sources of information physically close to each other in the display. This type of display capitalizes on the predictions of the proximity compatibility principle, which states that displays that present multiple sources of information closer together better support tasks requiring mental integration of those information sources (Barnett & Wickens, 1988; Wickens & Andre, 1990; Wickens & Carswell, 1995).

Given that one-line diagrams are computer-generated, they are adaptable and flexible, enabling multiple methods of visualizing power systems data, such as color contouring, three-dimensional figures, and motion. However, with these expanded possibilities comes the concern for human factors issues related to information visualization and the possible cost/benefit trade-offs between different display formats. The particular issue of interest in the present study was the use of motion to convey power flow information to system operators.

Animation/Motion Displays

Motion in a display has the potential to aid visual search for faults. Since changing and moving items in a display attract attention (Ware, Bonner, Knight, & Cater, 1992; Watson & Humphreys, 1997; Wickens & Hollands, 2000), motion in a display can indicate where faults are occurring. However, incoherent non-target motion (e.g., in areas of a display where faults are not occurring) can distract attention and slow search for target motion (Dobkins & Bosworth, 2001; Driver, McLeod, & Dienes, 1992). Some studies have found, however, that distraction caused by non-target motion can be mitigated if the moving distractors share a common feature that distinguish them from a moving target (Olivers, Watson, & Humphreys, 1999; Watson & Humphreys, 1998).

Research on animation in mimic displays has also been conducted (Bennett, 1993; Bennett & Madigan, 1994; Bennett & Malek, 2000; Bennett & Nagy, 1996). However, these studies have focused on different methods of animation rather than whether animation has an advantage over stationary cues. Nonetheless, research in computer-based instruction has found significant benefits for animated displays over stationary displays (Baek & Layne, 1988; Blankenship & Dansereau, 2000; Park & Gittelman, 1992, 1995). Park and Gittelman (1995) found that an animated display supported instruction in electronic troubleshooting better than stationary displays with and without arrows. Rieber, Boyce, and Assad (1990), though not finding significant effects for animation, noted that it aided information organization and retrieval. In general, animation seems to enhance viewers' mental models of systems. Therefore, the benefits of animation may also apply to situations where the task is carried out at the same time the display is viewed, such as with process control in electrical power systems.

Present Study

The present study examined the potential costs and benefits of using animation to represent information in power system displays. Three display conditions were used to represent power flow in a simulated power distribution system: digital values without arrows, stationary arrows, and moving arrows. We assessed the time needed to acknowledge and solve simple and complex system failures using these displays.

METHODS

Participants

Participants were 46 students with self-reported normal color vision recruited from Power Systems classes in the Department of Electrical and Computer Engineering at the University of Illinois, Urbana-Champaign. Participants were paid $12.00 for their participation, which did not last more than 1 hour.

Apparatus

A modified version of Power World® Simulator software (Overbye, Klump, & Weber, 1999) was used to simulate a high-voltage power system, running on a Dell Dimension XPS B800 computer with an 800-MHz Pentium III processor, 128 MB of RAM, and a 20-inch Dell Ultrascan P1110 monitor, with a mouse used for all input.

Tasks and Display Types

Each participant was assigned to a display group in which power flow through transmission lines was represented in one of three ways (see Figures 1 and 2). These included digits at the end of each line indicating power flow, stationary arrows whose size was proportional to power flow, or moving arrows whose size and speed were proportional to power flow. During each trial a contingency occurred, causing one or more transmission lines to overload. A beeping alarm then sounded continuously, and large solid red circles with yellow digits indicating the load percentage appeared in place of the line load pie charts to indicate each line overload. In addition, in the two displays with arrows, the arrows on the overloaded lines turned from green to red.

Participants were required to acknowledge the line with the highest violation and then to resolve all power overloads. Power overloads were acknowledged by clicking on the red circles associated with the overloaded lines, and overloads were resolved by reducing the power output of generators electrically nearest the points where power was flowing into the overloaded lines or by increasing the power output of generators electrically nearest the points where power was flowing out of the overloaded lines.

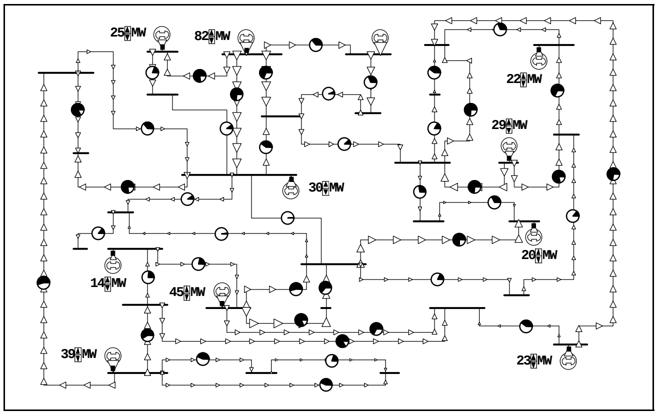

Figure 2. One-line diagram in stationary arrow or moving arrow display format.

Procedure

Participants were randomly assigned to a display group and each participant completed 4 practice trials and 25 experimental trials. In each trial, after a randomly chosen interval between 5 and 15 seconds, a contingency occurred, causing one or more line overloads, after which the participants were allowed two minutes to complete the acknowledgement and solution tasks. Approximately half of all trials involved a single line overload whereas the other half involved the overloading of more than one transmission line. The same power grid was used across all trials and all display groups, and the same buses and lines experienced contingencies across the three display groups in each trial. The times to complete both the acknowledgement and solution tasks in each trial were recorded.

RESULTS

Response times were analyzed using a 2 (Problem Complexity: single violation, multiple violations) x 2 (Task: acknowledgement, solution) x 3 (Display

Group: digital, stationary arrows, moving arrows) analysis of variance (ANOVA). Results of the ANOVA revealed a marginally significant three-way interaction among problem complexity, task, and display type, *F*(2,43) = 2.57, *p* = 0.089. Analysis of simple interactions (Keppel, 1982), which involved the systematic removal of one of the three groups and then re-computation of the thee-way interaction, indicated that the three-way interaction was significant only when comparing performance of participants in the moving arrow and digital display groups, *F*(1,29) = 4.34, *p* = 0.044.

Figure 3 illustrates this interaction by depicting response times for the three display types across task and problem complexity; note the separate scales for acknowledgement and solution times. In general, the performance differences between groups occurred on trials involving complex system failures. On complex trials, acknowledgement times of participants in the digital group were generally faster than acknowledgement times of participants in the moving arrow group. In contrast, solution times of participants in the moving arrow group tended to be faster than solution times of participants in the digital display group, at least on complex trials. Both acknowledgment and solution times of participants in the stationary arrow group tended to fall between the two other groups.

DISCUSSION

Overview of Results

Animation was expected to improve users' ability to solve violations by making power flow rates and directions immediately apparent. There were no main effects of display type, but the three-way interaction among task, problem complexity, and display type suggests that the motion display provided better support for solving voltage violations than did the digital display, at least on complex trials. This finding supports the results of previous research indicating that animation enhances the user's mental model of a system, improving troubleshooting performance (Park & Gittelman, 1992, 1995).

In contrast, the digital display tended to benefit the detection task compared to the motion display. Perhaps irrelevant motion in the moving arrow display (i.e., the motion on non-overloaded power lines) distracted attention from the important overloaded lines. This finding is consistent with that of Dobkins and Bosworth (2001), who found that non-target motion distracted attention and slowed search for target motion. Dynamic changes that occurred throughout the display due to system-wide power flow changes induced by the faults may have interfered with users' abilities to inhibit processing of irrelevant motion, thus interfering with the focused attention required for the detection task.

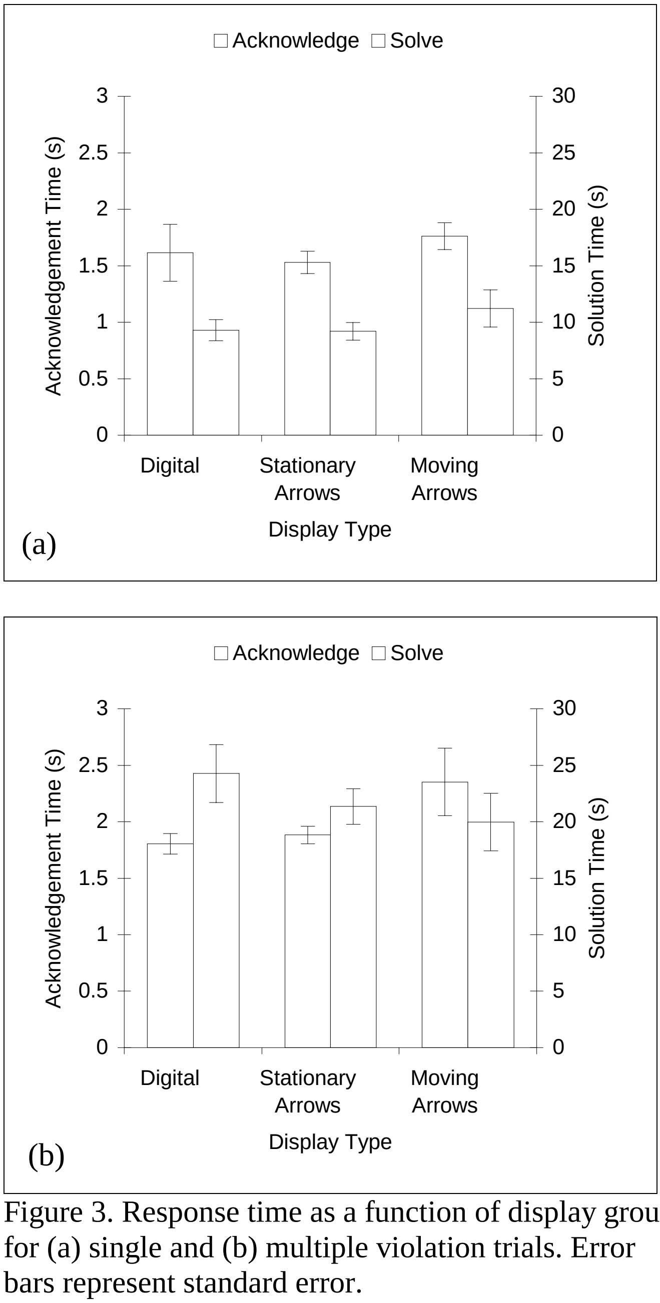

Figure 3. Response time as a function of display group for (a) single and (b) multiple violation trials. Error bars represent standard error.

Implications for Display Design

The results of the present study suggest that analog motion in a display has both costs and benefits. Therefore, designers of such displays need to consider the particular task that motion is intended to support. A compromise between the two display types might work best across the majority of operator tasks. Indeed, in the present study, performance with the stationary arrow display tended to lie between that of the digital and moving arrow displays, but closer to the display with the best performance for each task. Another option might be to toggle between display modes, which has been shown to be effective in improving performance (Regal & Knapp, 1984). Toggling would provide operators the ability to select a particular display type based on the specific task being performed. Further research is needed, however, to explore these possibilities.

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