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Situation Awareness in the Power Transmission and Distribution Industry

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This paper describes active research on situation awareness (SA) as it applies to the power transmission and distribution (T&D) industry. Goal-Directed Task Analysis (GDTA) interviews were conducted with Specialist Reliability Analysis & Operation and Reliability Coordinator/System Operators from two large U.S. power companies to achieve a clear understanding of the power T&D domain. The resulting GDTA and lessons learned are presented.

INTRODUCTION

On August 14, 2003, an estimated 50 million people were without electricity as the largest power blackout in North American history impacted eight U.S. States and the Province of Ontario. Total projected costs due to the power outages in the United States alone ranged between \$4 billion and \$10 billion (Electricity Consumers Resource Council, 2004).

Leadership in the United States and Canada immediately established the joint U.S.-Canada Power System Outage Task Force to investigate the causes of the blackout and ways to reduce the possibility of future outages. The mandate of the joint Task Force was to (1) identify the causes of the power outage, and (2) develop recommendations to reduce the possibility and scope of future outages.

In a final report issued on April 5, 2004, the joint Task Force identified four major causes of the blackout. Prominent among these causes was “inadequate situational awareness,” (U.S.-Canada Power System Outage Task Force, 2004, p. 18). The Task Force remarked that training deficiencies, ineffective communications, and inadequate reliability tools and backup capabilities all contributed to a lack of situation awareness (SA) for the operators involved.

The August 14 blackout is not the first example of a large-scale power systems event to exhibit a lack of situation awareness. A common factor cited among major outages was the inability of system operators and coordinators to visualize events on the entire system. For example, the recommendations provided by the Department of Energy in response to the electrical power outages of July 2-3,

1996 noted that a “system operator must... effectively monitor and assess the state of the [transmission and distribution] systems,” (1996, p. 90). In addition to the mechanical failures experienced during the West Coast Blackout of December 22, 1982, system operators could not assess the extent of the disturbance or what corrective action should be taken due to the volume and format in which data were displayed, making real-time evaluation of the situation more difficult.

Recent emphases on situation awareness in the power transmission and distribution (T&D) industry have highlighted the lack of SA-related research in this domain. This gap has been recognized by several organizations, leading to the development of new commercial energy management systems, reactive reserve monitoring tools, and visualization systems designed to assist T&D operators in monitoring, predicting, anticipating, and preventing potential problems that could lead to major power outages. The essential element in each of these endeavors is a focused effort on understanding and increasing operator SA in T&D control centers.

PRACTICE INNOVATION

Situation awareness is defined as “...the perception of the 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, p. 36). In order to provide sound system designs to support SA in power transmission and distribution operations, a clear understanding of this domain is necessary. The Goal Directed Task Analysis (GDTA) methodology supports a user-centered design approach and

was used to determine the SA requirements for power T&D operations.

GDTA is a form of cognitive task analysis that delineates the user’s goals in a particular domain, the decisions that must be made in order to accomplish each goal, and the optimal information needed to make each decision. The GDTA is used to support the development of interface design specifications by providing a detailed description of not only the specific data the operator needs to accomplish a specific goal, but also by indicating the manner in which the operator integrates the data in order to develop a robust understanding of the current situation, thus including the higher levels of SA (Endsley, 1993; Endsley, Bolte, & Jones, 2003).

Interviews were performed for the Specialist Reliability Analysis & Operation (SRAO), and the Reliability Coordinator/System Operator (RCSO) positions for power T&D. This analysis was conducted based on the input of operators in these positions at two U.S. power companies. A total of seven experienced operators in these two positions were interviewed to develop the GDTA. As the goals and SA requirements of the two positions are very closely linked, a single GDTA was developed to cover both positions. A slightly different naming convention may be in place in different T&D operations to describe operators that perform this function.

FINDINGS

Figure 1 shows the hierarchical structure of the SRAO/RCSO goals. The top item in Figure 1 is the SRAO/RCSO position’s overall goal: *to keep all elements and voltages within limits in real time and for first contingencies*. Power T&D representatives informally refer to this goal as “keeping the lights on.” *Contingencies* are defined as the unexpected failure or outage of a system component, such as a

generator, transmission line, circuit breaker, switch or other electrical element (NERC, 2006). By planning for first contingencies, T&D operators attempt to prevent the uncontrolled successive loss of system elements (i.e., cascading) that results in widespread electric service interruption.

Four primary goals were identified beneath the overall goal. A primary SRAO/RCSO goal is determining if violations have occurred for elements in the T&D system, or if a potential violation is likely. A second primary goal involves determining the cause of a violation or potential violation. The remaining primary goals focus on determining the remediation of violations and ensuring that remediation is complete. Typically, secondary goals are identified beneath each primary goal. The nature of the SRAO/RCSO position, however, did not necessitate subgoals beneath the primary goals.

Each goal in the GDTA can be examined in greater detail via a goal-decision-SA requirement graph. Figure 2 is provided as an example of the structure. Below each goal in a goal-decision-SA requirement graph are boxes listing the critical decisions in the form of questions that operators need to ask themselves to meet the goal. At the bottom of the structure, beneath the critical decisions, is a list of SA requirements that the operator would like to have in order to answer the questions correctly and meet the goal.

An indented format is used in this SA requirements blocks for two reasons. First, indentation provides a general indicator of level of SA. Level 3 (projection) information is placed flush against the left side of the box, Level 2 (comprehension) information is indented once, and Level 1 (perception) information is indented twice. Second, the indentation illustrates the manner in which lower level information is integrated to form the higher level information requirements.

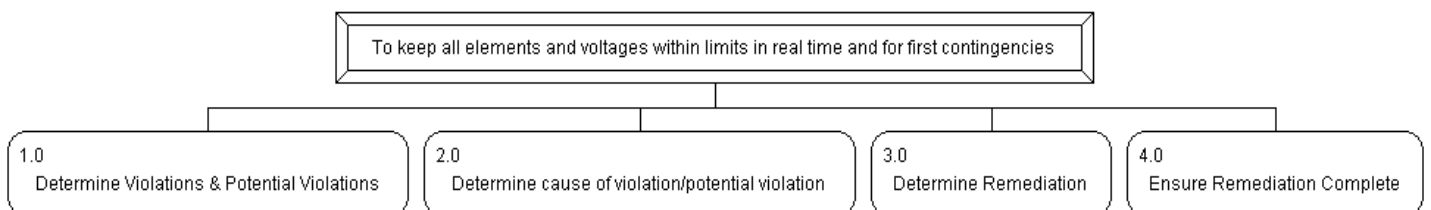


Figure 1: Overall goal structure for the SRAO/RCSO position

Table 1 summarizes the critical decisions for each primary goal shown in Figure 1. The first two decisions for Goal 1.0 share information requirements such as projected violations, projected loads over time, and projected output over time. These requirements emphasize the importance of maintaining awareness of current system conditions such as load, output, rate of change, and causes of variations in load and output.

Thus, it is essential for operators to continuously seek concurrence with other power T&D organizations to validate limits and potential violations on systems that affect their operations. Operators also seek concurrence with other T&D organizations when attempting to find the cause of violations or potential violations (Goal 2.0) within their companies, stressing the importance of good communication.

Table 1: Critical decisions for SRAO/RCSO position

Goal	Critical Decisions
1.0	Is there a violation? Is a parameter approaching limits? Is the limit correct? Is data correct from the tool or telemetry?
2.0	What is causing a violation or potential violation? Who has the limiting element?
3.0	How do I best prevent problems from occurring? What is the best way to mitigate the problem quickly?
4.0	Has the problem been resolved? When will the problem be resolved? Does the problem require further remediation?

The critical decisions identified for Goal 3.0 are heavily reliant on projection information requirements (i.e., Level 3 SA). The SRAO/RCSO position depends on the results of contingency analysis (CA) and state estimation (SE) software to project the impact on the system of adding or removing elements in service, and the potential impact on customers. In extreme cases, operators must consider the potential impact of shedding load, a highly undesirable condition where electric current is terminated on certain lines when demand exceeds supply.

The critical decisions for Goal 4.0 involve information related to problem resolution. Operators monitor remediation efforts, specifically looking at the actions taken to alleviate a problem and the entities responsible for those efforts. The history of alarms represents a significant consideration for this goal as operators supervise progress towards the clearing alarms from their alerting systems. Since some alarms may remain present for extended periods of time during remediation, operators are similarly concerned with the historicity of alarms. This involves monitoring whether their alarm systems are reporting correct and timely alarm histories over the course of remediation.

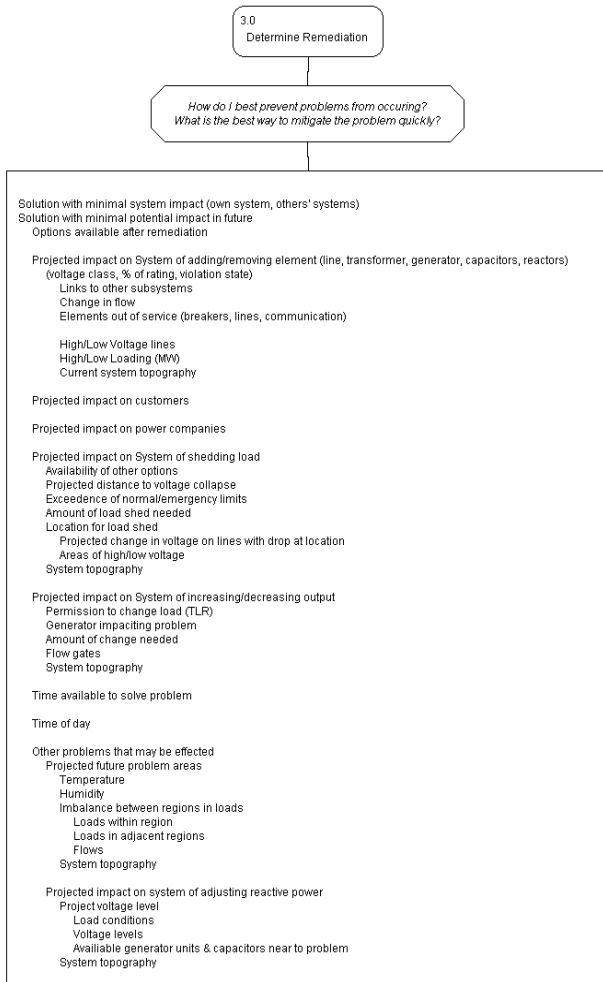


Figure 2: Goal-decision-requirement graph for Goal 3.0

The remaining critical decisions for Goal 1.0 stress the importance of current system data, such as the current alarm limits and weather conditions at an element. The SRAO/RCSO position is highly dependent on the accuracy and timeliness of monitored data. Operators expressed significant problems with determining whether or not a given alarm on their system was associated with correct and valid limit data. Operators also lack direct access to data from systems outside their control region.

DISCUSSION

Challenges

Maintaining SA in power T&D control centers can be difficult due to the presence of several SA demons (see Endsley et al., 2003 for discussion). The most prominent of these demons in power T&D is misplaced salience. Each software tool utilizes its own color scheme, alerts, and animated cues that continuously vie for the operator's attention. Inconsistent colors and fonts among these programs create an unnecessary strain on operators to maintain awareness of the system and monitor changes. A lack of standardization and consistency further complicates operations. Additionally, most systems could benefit from the application of basic human factors principles.

While essential to performing an operator's job, the automation behind CA/SE technology also introduces a second SA demon, the out-of-the-loop syndrome. This demon was at the center of the August 14, 2003 blackout. For the region in which the power outage originated, the SE was scheduled to update every five minutes. While addressing another contingency on the system, an operator took the SE offline. The operator failed to return the tools to normal automatic operation. Operators went unaware of the software's failure for nearly four hours (U.S.-Canada Power System Outage Task Force, 2004). Thus, the automation introduced a direct loss in operator SA leading to a serious error.

Another SA demon that the SRAO/RCSO position experiences is data overload. Operators regularly scan through thousands of pages of SCADA data tables and tie lines. Station diagrams typically span several screens and are dense with element data such as bus voltages and voltage flow information. When coupled with weather reports, SCADA alarms, CA results tables, and SE calculations, operators tend to become inundated with data, creating severe losses in situation awareness.

Non-integrated information presents a serious challenge to the SRAO/RCSO position. A typical SRAO/RCSO's working environment consists of three or more computer monitors, plus large screen displays. Operators are continuously monitoring contingency analysis and state estimation software,

as well as Supervisory Control and Data Acquisition (SCADA) displays in an effort to incorporate data from each. Unfortunately, this real estate is not used to optimum efficiency, with information being spread across six or more different non-integrated software systems.

Similarly, the organization of power T&D operations in the current grid system introduces a barrier to maintaining SA for the SRAO/RCSO position. Each T&D provider is connected to neighboring companies in an effort to transmit and distribute power across the United States. Despite the connectedness of the grid, these companies operate blindly outside of their own operations with the exception of voice communications. Each company's tools (e.g., CA, SE, and SCADA) work independently and data and results are rarely, if ever, shared. This lack of awareness regarding potential problems outside a company's operational scope reduces the operator's ability to project the impact of contingencies on their systems, which could lead to errors and failures across the grid.

Recommendations for Power T&D

The SA demons and challenges present in power T&D management systems can be alleviated through the use of SA Oriented Design (SAOD; see Endsley, Bolté, & Jones, 2003). The GDTA reported in this paper represents the first step of SAOD: determining the information needs of the user. The next step calls for designing systems based on these information needs. Governing this second step is a set of fifty SAOD principles. While all of these principles should be considered, several are predominantly applicable to the power T&D domain given the GDTA and challenges reported here.

The principle of *organizing information around goals* is highly valid to the design of future power T&D systems. The data overload currently experienced by the SRAO/RCSO position is a function of technology-oriented displays designed around the particular sensor equipment used in the domain. Operators could benefit from information that is specifically organized around the critical decisions listed in Table 1 – for example, presenting voltage parameters in terms of their proximity to limits for elements of interest). Similarly, effective integra-

tion of data from different system displays (e.g., SCADA alarms, SE results, and CA results) into a single presentation element may serve to improve operator decision-making. This also incorporates another SAOD principle, *reducing display density without sacrificing coherence*, by eliminating the operator's need to wade through excessive display data and improving the integration of information.

The SAOD principles of *supporting sensor reliability assessment* and *using data salience in support of certainty* are pertinent in power T&D. As evidenced by the GDTA, the SRAO/RCSO position is highly dependent on the accuracy and timeliness of monitored data. Specific presentation techniques that leverage information salience, such as luminance levels, should be considered to represent reliability and uncertainty in the timeliness and accuracy of sensor data.

Direct losses of SA induced by the out-of-loop syndrome in power T&D management systems can be avoided by *keeping the operator in control and in the loop*. This can be accomplished by increasing the operator's involvement with state estimator and contingency analysis software via confirmation of these processes' results. Additionally, *making the automation modes and system states salient* to the operator through the use of cues such as color (e.g., a green icon for solved contingencies, red for failures) can lead to improved SA and keep operators cognizant of the system's current state.

Conclusions

The power T&D domain presents multiple vantage points upon which operator SA can be improved. For example, one distinct advantage that T&D operators have is multiple monitors across their workstations and numerous large screens displays. Surprisingly, much information remains hidden below other screens in layered windows, leading to a loss in SA. By employing SA-oriented design principles, new energy management systems could be provided with well-organized screens that promote easy scanning of key information and im-

mediate access to information across the multiple displays.

The power T&D industry continues to seek a solution to its situation awareness gap. The work described in this paper helps to identify areas where SA needs are lacking within the industry, and provides valuable insights to inform the development of future technology to support SA in the power T&D domain. Future research will focus on refining the GDTA for the SRAO/RCSO position and the practical application of GDTA results to future EMS tools and operator training.

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