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Modeling the benefits (or detriments) of increased automation in electric power grid operations: Methodology and experiments☆

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1. Introduction

The continuing evolution of the electric grid brings with it many of the same challenges to utility operators as seen throughout the industry's history. From an industry dominated in its early years by small generating stations designed to serve local communities (Sulzberger, 2003), the grid evolved to one more centralized, taking advantage of economies of scale in a tightly regulated environment. In more recent years, its evolution has continued, as a restructured industry again reliant on the addition of smaller generation sources, much of it more cost-effective, distributed renewable energy (Sine and David, 2003). Improved data gathering and system control, designed to increase operator situational awareness and reduce system interruption time, have been utility objectives for decades (Amin and Stringer, 2008), and techniques once reserved for transmission systems, or for the distribution systems of large utilities, are increasingly finding their way into the control rooms of smaller, distribution-focused utilities (Northcotte-Green and Wilson, 2013). The acquisition and use of technologies for advanced system situational awareness and control comes with two major questions that must be addressed. First, will these advanced systems reduce system disruption duration (for distribution utilities, this comes in the form of customer minutes interrupted, or CMI)? Second, can one, prior to investment, quantify the benefits to customers in terms of reduced CMI that can be used to provide regulators with a cost justification of the benefits to the utility and its customers of the equipment investment?

Addressing each of these questions relies on an understanding of the human dimension in system control. While control systems developers and utilities aim for increased automation, the "human in the loop" maintains a presence, at minimum for observational system interaction, that must be considered (Muir, 1994). Interactions in systems create opportunities for systemic performance risk, whether it be interactions between automated systems and humans—who can be prone to doubt the output of an automated system (Muir, 1994)—or between humans and other humans—where misinterpretation can lead to erroneous decision-making (Baillieul and Antsaklis, 2007). Research at Sandia National Laboratories, with strategic industry partners, aims to address these questions within the construct of its Improving Grid Resilience through Informed Decision-making (IGRID) project. This work builds on Applied Cognitive Task Analysis work with utilities in Vermont that identified the value of field crews to situational awareness, and suggested that the replacement of such interactions with automation might degrade situational awareness (Stevens-Adams, et al., 2015).

2. Research process

2.1. Developing partnerships

Sandia developed essential partnerships as part of the IGRID project. On the utility side, Sandia worked with Green Mountain Power (GMP), a Vermont-based utility with substantial efforts in grid modernization, including distributed energy resources, system awareness and control. On the control systems side, Sandia developed a relationship with Oracle, whose Network Management System (NMS) software can support automated outage restoration including fault location, isolation, and service restoration (FLISR) actions.

This three-way partnership was designed so that each party would provide expertise in certain areas, while aiming for objectives beneficial to each party. GMP's objectives for the partnership were geared around increasing their confidence in new technologies prior to deployment, demonstrating the impact of new technologies on grid performance to better understand the return on investment, and improving operator training and effectiveness. Oracle's objectives included having operator feedback on their NMS software, quantifying the benefits of automation, with a long-term objective driven from these points of improving their market share. Sandia's objectives for the partnership focused on the collection of

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☆ A review of current research conducted at Sandia National Laboratories suggests that automation represents a paradigm change in the way in which grid operators interact both with elements of the grid under their control and with field crews whose deployment and activity may be necessary for system restoration. Utilities need to consider a complex set of interdependencies, including human factors, and the risks and benefits, in the process of deploying advanced automation.

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experimental data, using GMP operators working on a version of the Oracle NMS, to better ascertain the effects of use of the NMS in various levels of automation on restoration of the grid from outages.

2.2. Designing an analysis framework

Sandia created an analytic framework designed to meet the above objectives and to collect data on the interactions between operator and automation, including overall operator performance and behaviors with and without automation. Sandia, GMP, and Oracle team members worked in concert to develop elements of an analysis framework. This framework entailed data collection from a series of experiments conducted by Sandia utilizing the Oracle NMS, into which a portion of the GMP system was modeled, with GMP operators serving as test subjects. These experiments were designed to cover a range of outage events seen on the GMP system. The purpose of the data collection was to see if adding automation to the system (in the form of automated FLISR devices, which can automatically reroute power when an outage occurs) led to a reduction in CMI. Sandia extrapolated this from applying the experimental data onto historical response data, to estimate the benefits of NMS and FLISR in a way that is demonstrable. Multiple elements of this process are worth exploring in more detail.

2.3. Data analysis and scenario construction

The team agreed to study a portion of the GMP grid, which GMP had already identified as a test bed for the rollout of FLISR technology. Sandia reviewed historical outage data for this portion of the GMP network to identify potential causes of disruptions, and to use the historical data as a basis for building outage scenarios of varying complexity. With GMP's help, Sandia created five scenarios, all of which were vetted and refined by former GMP operators to clarify interactions, and make the scenario process as close as possible to actual processes under a disruption, including alarms, phone calls from external parties, and other elements beyond the NMS interface.

Performing a detailed analysis of the scenarios as they were developed allowed for the development of a work breakdown structure (WBS) capturing the interchanges between the operator and external parties in detail, including the originator and receiver of the communication or action, the means of communication or action, and the content of the communication or action. The WBS was beneficial in three ways:

- First, in error correction of the scenarios (e.g., identifying inconsistencies in switching or identification of assets used in the scenario);
- Second, in identifying the elements of each scenario that should be timed (e.g., the time from receipt of an alarm to awareness of its' cause and dispatch of a crew to the scene) during the course of the experiment; and
- Third, identifying elements of each scenario for which timing would be neither operator-response dependent nor predictable (e.g., the time for a repair crew to reach a location once dispatched, the time for a repair crew to exact a repair once provided a switching plan).

The latter category was valuable in scenario execution within the experiment, as it created opportunities for acceleration of the scenario far beyond real timing, allowing for more scenarios to be explored (and more data gathered) in a shorter period of time. For those elements for which timing was deemed to be important, these were often grouped. For example, a timed sequence might involve the operator opening three reclosers, closing three others, and placing the first three breakers on non-reclose so that repairs can be done to a circuit within the now-opened are of the system. Capturing this group of events as a group places less importance on the order and more on the fact that the group of events is completed. Grouping occurred because the sequencing of individual tasks within the sequence could vary. Grouping also occurred so as to make certain that the method of data capture (discussed in Section 2.5) was consistent at the beginning and end of the sequence.

In addition, the scenarios provided a likely path, as determined by highly experience operators, for operators to follow, serving therefore as a de facto baseline of operator performance, though (as we shall see) the scenario script does not prevent actions beyond the expected path from being pursued.

2.4. Interface construction

Oracle, in turn, used geospatial data provided by GMP to model this portion of the GMP network in their NMS software environment, and developed and delivered a training program to instruct GMP operators on its use.

2.5. Experiment execution

After running a number of field tests to clarify scenario elements, NMS interactions, and data collection, Sandia conducted a series of experiments running individual operators through the five scenarios, designed to capture different degrees of scenario difficulty and automation. Difficulty of the scenario was defined using the work breakdown structure (described above) and was based on the number of steps required to return the system to a state in which all customers have power (note that this does not mean full system restoration). Scenarios with automation included guidance within the NMS on a preferred path for use of FLISR-enabled controls, while scenarios lacking automation had no guidance from the NMS. In each scenario, operators were presented with an initial "ground truth" of the system prior to any disruptive event within the scenario, including weather, time of year, and crew availability. The operator was instructed to restore the outages they encountered as safely and efficiently as possible.

Data on the timing of particular actions (both human— human and human—machine interactions) was captured using several methods: stopwatch for human-to-human interactions; screen capture software for general interactions with the NMS software environment; and NMS timing data for actions recorded by the NMS in the scenario. Two individuals observed the experiments and coordinated the tracking of each action taken by the operator. They recorded times where appropriate, identified inconsistencies with the planned scenario actions, and corrected the path of the scenario when diversions occurred. Additionally, a post-experiment interview was conducted with each operator, to review decisions made during each of the scenarios and to assist the observers in clarifying the operator's decision-making process.

3. Preliminary findings

Data analysis from the experiments is ongoing. Nonetheless, some observations can be made based on the data collection effort that are helpful to outlining future activities.

3.1. Expertise, speed and accuracy

Researchers proposed that experienced operators, defined in other research as part of this overall effort (Stevens-Adams and Hannigan, 2016), would perform tasks faster and with greater accuracy than non-experts. In the collected data, the most experienced operator was slowest at completing the tasks. Post-exercise interviews did not clarify whether this was due to the