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Human Reliability Analysis in the Electric Grid Domain

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***Abstract*— Human Reliability Analysis (HRA) is a structured approach used to identify and assess human failure events (HFEs) and estimate the probability of errors occurring. HRA has been applied to many domains but never applied to the electric grid domain (to the authors' knowledge). Electric grid control room operators must work quickly and accurately to restore power for both planned and unplanned events and changes to the grid's infrastructure may impact their ability to do so. This paper proposes a novel approach for using the HRA method to better understand quantitatively how changes to the electric grid might impact human operator performance and, specifically, human error. The authors outline next steps to completing the proposed HRA.**

Keywords—human reliability analysis, electric grid, human factors

I. Introduction

Critical infrastructures are the assets, systems and networks so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety or any combination thereof [1]. The Department of Homeland Security has identified 16 of these critical infrastructure sectors that are the backbone of our nation's economy, security and health; one of these is the energy sector, which includes the electric grid. The focus for this paper is on the control centers for electric distribution utilities. Distribution centers, while smaller in scale than transmission centers, play a vital role in ensuring that electricity reaches the end user. Distribution control room operators must monitor grid load and coordinate with field crews for both routine, planned switching tasks (such as scheduled maintenance on a particular line) and unplanned switching tasks (such as outages due to weather).

Until very recently, distribution utilities operated using a traditional grid model in which the flow of information was one-way - from the utility to the consumer. However, these utilities are on the brink of a paradigm shift from traditional grids to grids using newer smart grid technology. Grid modernization will incorporate some of the newer technology available to the home user – such as solar panels and electric cars – which will result in a bi-directional flow of energy and information. It is unclear how this paradigm shift will impact control room operations and, in turn, grid resilience. Understanding control room operator decision-making is particularly important given the severe consequences of prolonged outages. There are many examples of past outages that have resulted in a high number of fatalities due to people not having power for extended periods of time and that took billions of dollars to resolve [2, 3, 4].

With these new impending changes, questions arise as to how these changes will impact control room operations and whether the impacts can be measured quantitatively. The goal of this paper is to outline a novel approach for using the HRA method to better understand quantitatively how changes to the electric grid might impact human operator performance and, specifically, human error.

II. Previous Electric Grid Research

Previous research collaborated with utility companies in the state of Vermont, one state in which grid modernization will be taking place, to begin understanding how changes to the electric grid model will impact control room operations [6, 7]. In the first study [6], the authors used Applied Cognitive Task Analysis [8] and the Critical Decision Method [9] methodologies to better understand daily control room tasks and decisions. These methods allowed for a better understanding of the current distribution control room operator's tasks and how the impending grid modernization changes might impact tasking and decision-making. In the second study [7], the authors interviewed control room operators, human resource personnel and managers to better understand expertise in control room operations. The fact that expert reasoning is specific to the domain within which the person is an expert [5] is a widely accepted statement regarding expertise and, thus, expertise is an important construct to understand in any particular domain. The results from these studies are described below.

A. Switching Tasks in the Control Room

Based on the Applied Cognitive Task Analysis findings, task diagrams highlighting the tasks necessary to complete both planned (Figure 1) and unplanned (Figure 2) switching were constructed. The red, diamond shapes in the Figures indicate tasks in which the grid operator had to make a critical decision.

As can be seen in the Figures, unplanned switching requires more steps and more decision points than does planned switching. Both task diagrams highlight the importance of operator communication with the field crew and interaction with

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Supervisory Control and Data Acquisition (SCADA) interfaces and tools.

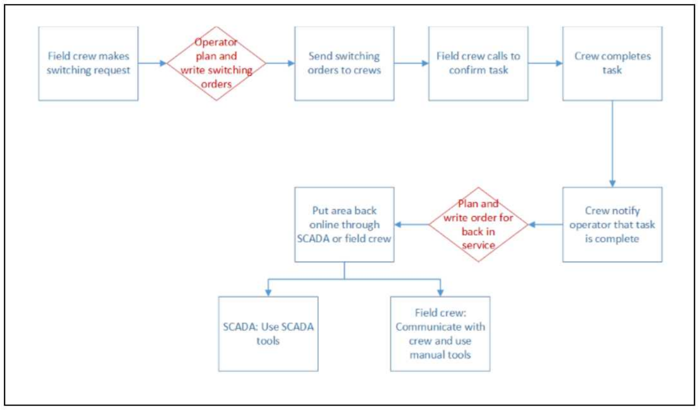

Fig. 1. Planned switching tasks

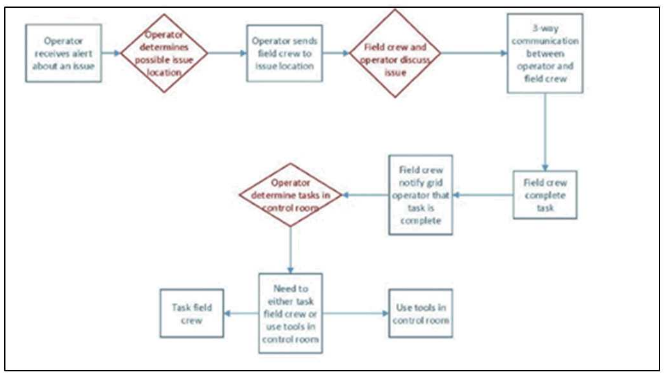

Fig. 2. Unplanned switching tasks

B. Expertise in the Control Room

The authors also conducted structured interviews with the managers, human resources personnel, and control room operators and found that an expert in the control room was defined as someone having 7-9 years' experience in the control room as well as possessing certain traits, such as the ability to remain calm under pressure, effectively multi-tasking and quickly synthesize large amounts of data [7].

III. Human Reliability Analysis (HRA)

The previous research [6, 7] gives a good idea as to the task differences between planned and unplanned switching and the characteristics of an expert in the electric grid domain (and where novice operators may make mistakes). This qualitative data is important and informative, but it begs the question as to whether a more quantitative approach could provide even more information.

Human Reliability refers to the probability that a given human task will be successfully completed at any stage in a given operation. Human Reliability Analysis (HRA) is a structured approach used to identify and assess human failure events (HFEs) and estimate the probability of errors occurring. Catastrophic events such as Three Mile Island and Chernobyl illustrate potential consequences of human errors in high-consequence industries and thus demonstrate the need for assessing human error in the context of a larger system (possibly compounded by man-machine incompatibilities, work environments, organizational context, etc.) to reduce system vulnerabilities.

Historically, HRA developed over three stages, focusing on:.

- Human error probabilities and operational human error (1st Generation HRA)
- Human performance factors and cognitive processes (2nd Generation HRA)
- Dynamic modeling approaches (3rd Generation HRA, still in development)

An HRA analysis sets out to answer the following questions:

- Which types of human error may occur (e.g. action error, information retrieval error, communication error, violation)?
- What is the estimated probability of such errors being made?
- What factors may influence this probability (e.g., time pressure, stress, poor working environment, low morale)?
- How can the identified human errors be prevented in the design or how can their impacts be reduced by additional mitigating controls? [11]

During the execution of an HRA, two primary activities occur. First, a qualitative task analysis defines how and under what conditions the task is to be carried out. This step also informs error identification. Second, a quantitative analysis transforms the probable errors identified in the task analysis to estimate the likelihood of a human error occurring during task execution. Typically, this begins by identifying nominal error rates to the task/steps. These nominal error rates are adjusted according to performance shaping factors (PSFs) that influence the execution of the task. PSFs are posited to increase or decrease the likelihood of error for a given task (note: different methods use different PSFs; for example, NUREG-1792 [12] identified 15 PSFs while SPAR-H has 8 PSFs [13], including stress/stressors, experience/training, procedures, work processes, complexity, available time, ergonomics and fitness for duty).

Different HRA methods have varied approaches/nuances for how this is completed (see Table 1).

TABLE I. HRA METHOD DESCRIPTIONS

Method	Description
THERP [10] (Technique for Human Error Rate Prediction)	Identification, modeling, and quantification of human failure events. General model of influence on human behavior is considered, describing a large range of potential PSFs. Nominal Human Event Probabilities (HEPs) selected for tasks and subtasks are modified by multiplicative PSF model, five-level dependence model, and recovery.
HEART [11] (Human Error Assessment and Reduction Technique)	Identifies major influences on human performance in a systematic and repeatable fashion. Used for assessment and reduction of error. Human reliability is expected to degrade as a function of the extent to which identified Error Producing Conditions (EPCs) might apply.
SPAR-H [13] (Simplified Plant Analysis Risk – HRA)	General psychological model of human information processing as its basis. Uses a fixed set of eight PSFs to adjust the generic error rates to reflect the scenario conditions then adjusts for dependence.
CREAM [14] (Cognitive Reliability and Error Analysis Method)	Addresses cognitive failures for action and execution errors related to a desired action(s). Used as a prospective tool for high-risk critical operations/tasks and retrospective tool for historical occurrences.
ATHEANA [15] (A Technique for Human Event Analysis)	Identification, modeling, and quantification of post-initiator human actions, including treatment of errors of commission, and consideration of dependencies. Addresses potential cognitive failures for a human action, failures in implementing the desired action, and situations that could cause them to occur.
Petro-HRA [16] (Petroleum HRA)	Quantifying the likelihood of human error and identifying the impact of human actions on the post-initiator barriers in the main accident scenarios in the petroleum industry.

The overall error probability represents the estimated probability of error for a given task, accounting for the impact of situational influences. Once potential sources of error have been identified, human error reduction techniques such as mitigative strategies or engineered controls are proposed.

Historically, HRA has been applied to the nuclear power plant domain (from above, THERP, SPAR-H, CREAM, and ATHEANA relate to nuclear power with wider applications) but has also been extended to other domains (e.g., aerospace [13], petroleum [16], healthcare [17], aviation [18]). To the authors' knowledge, this paper is the first attempt to apply the HRA methodology to the electric grid domain.

IV. HRA APPROACH TO ELECTRIC GRID DATA

HRA applied within an electric grid domain might be difficult because there are two different types of human activities that must be assessed, planned and unplanned switching. First, for known/planned switches, operators rely on well-established procedures to complete their task (see Figure 1). In contrast, unplanned switches rely on operators triaging the situation as new information comes in and branching decisions as they troubleshoot (see Figure 2). This represents a knowledge-based behavior where the crew interprets, diagnoses, and decides accordingly.

The error modes differ whether the crew is following an established procedure versus employing assessment and planning of unexpected failures. The former case has more execution errors as it relates to carrying out the procedures correctly. The latter, in contrast, can have errors of assessment (misunderstanding the cause of the issue), planning errors (employing an incorrect approach to resolve the issue, though their assessment was correct), or execution errors (the assessment and course of action are correct, but carrying out the planned resolution is done incorrectly).

An HRA technique known as Integrated Decision-Tree Human Event Analysis System (IDHEAS) [19] was designed with the intent of assessing tasks that involve human interpretation decision making. IDHEAS may be an attractive approach to adapt for the electric grid domain because it accounts for a branching decision structure and captures tasks created by crews. The approach uses decision trees to map out branching points that account for the influences that may lead to human error. At each branch, several PSFs may have an influence. Constructing decision trees like this accounts for the types of decisions being made and the ability of experts to make assessments and plan activities during operations.

The categories of human error between the two types of switches are fundamentally different (see Table 2), so a feature of an HRA within the electric grid domain should be a method that can handle both well-established/procedure-based processes and branching decisions/expert-reasoning based processes, making IDHEAS a potentially attractive candidate.

TABLE II. FAILURE TYPES FOR PLANNED AND UNPLANNED SWITCHING

Planned or Unplanned	*Response Phase*	*Type of Failure*
Unplanned	Assessment	Diagnose cause incorrectly
Unplanned	Planning	Choose inappropriate strategy
Planned	Planning	Incorrect path selected
Planned and Unplanned	Execution	Fail to execute correctly
Unplanned	Execution	Response incorrectly

In terms of being able to conduct an HRA, the research team currently has data based on the past research [6, 7] that would support the qualitative assessment. The high-level task flow for the two types of switching (planned and unplanned) and the information regarding operator expertise will be used to evaluate the types of human errors that may occur (error identification). Results from the Applied Cognitive Task Analysis support the understanding of task demands, task flow, decisions made, etc. Human errors are identified as credible based upon the qualitative analysis and task flow. However, the research team will need to gather additional information about the exact decisions being made, how they relate to each other, and the extent to which they are supported by or leverage procedures (either during assessment, planning, execution, or a combination thereof) to conduct the quantitative assessment.

V. CONCLUSIONS

The authors, leveraging past research, have outlined a novel approach for using HRA methodologies to quantify human performance in the electric grid domain. The next steps in this work include re-establishing relationships with electric grid companies, identifying the most appropriate HRA method(s) and actually conducting the analysis. Additionally, the authors will elicit the help from electric grid experts to improve the fidelity of the HRA.

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REFERENCES

[1] The Department of Homeland Security. www.dhs.gov. Accessed March 27, 2015.

[2] National Weather Service Forecast Office, Burlington, VT. http://www.erh.noaa.gov/btv/events/IceStorm1998/ice98.shtml. Accessed March 27, 2015.

[3] Final report on the August 14, 2003 blackout in the U.S. and Canada: Causes and recommendations. U.S.-Canada Power Systems Outage Task Force, April 2004. https://reports.energy.gov

[4] December 2013 North American ice storm. http://en.wikipedia.org/wiki/December_2013_North_American_ice_storm#cite_note-8. Accessed on March 27, 2015.

[5] J. F. Voss, T. R. Greene, T. A. Post and B. C. Penner, "Problem-solving skills in the social sciences" in The Psychology of Learning and Motivation: Advances in Research and Theory, G.H. Bower Ed, New York: Academic, 1983, pp. 165-213.

[6] S. Stevens-Adams, K. Cole, M. Haass, C. Warrender, R. Jeffers, L Burnham and C. Forsythe, "Situation awareness and automation in the electric grid control room", Procedia Manufacturing, 3, 5277-5284, 2015.

[7] S. S. Adams and F. P. Hannigan, "Defining expertise in the electric grid control room", In Advances in Human Factors in Energy: Oil, Gas, Nuclear and Electric Power Industries. Advances in Intelligent Systems and Computing, S. Cetiner, P. Fechtelkotter and M. Legatt (Eds), Springer, Cham, 2016, pp. 69-77.

[8] L. G. Militello and R. J. B. Hutton, "Applied cognitive task analysis: A practitioner's toolkit for understanding cognitive task demands," Ergonomics, vol 41(11), pp. 1618-1641, 1998.

[9] G. A. Klein, R. Calderwood and D. MacGreggor, "Critical decision method for eliciting knowledge", IEEE Transactions of System, Man and Cybernetics, vol. 19(3), pp. 462-472, 1989.

[10] A. D. Swain and H. E. Guttman, "Handbook of human reliability analysis with emphasis on nuclear power plant applications", Final report. NUREG/CR-1278. Washington, DC: US Nuclear Regulatory Commission, 1983.

[11] J. C. Williams, "HEART – a proposed method for assessing and reducing human error", In 9th Advances in Reliability Technology Symposium, University of Bradford, 1986.

[12] US Nuclear Regulatory Commission, "Good practices for implementing human reliability analysis", NUREG-1792, Washington, DC, 2015.

[13] D. Gertman, H. Blackman, J. Marble, J. Byers and C. Smith, "The SPAR-H human reliability analysis method", US Nuclear Regulatory Commission, 2005.

[14] X. He, Y. Wang, S. Zupei, and X. Huanga, "A S-CREAM prospective quantification process and its application", Reliability Engineering and System Safety, vol 93, pp. 298–306, 2008.

[15] US Nuclear Regulatory Commission, "Technical basis and implementation guidelines for a technique for human event analysis (ATHEANA)", NUREG-1624, Rev. 1, Washington, DC, 2000.

[16] A. Bye, K. Laumann, C. Blackett, M. Rasmussen, S. Øie, K. van de Merwe, et al., "The Petro-HRA Guideline", 2007.

[17] M. Lyons, S. Adams, M. Woloshynowych and C. Vincent, "Human reliability analysis in healthcare: A review of techniques", International Journal of Risk & Safety in Medicine, vol. 16(4), pp. 223-237, 2004.

[18] K. Yang, L. Tao, and J. Bai, "Assessment of flight crew errors based on THERP", Procedia Engineering, vol. 80, pp. 49-58, 2014.

[19] G. W. Parry, J. A. Forester, V. N. Dang, S. M. L. Hendrickson, M. Presley, E. Lois and J. Xing, "IDHEAS–a new approach for human reliability analysis (No. INL/CON-13-29100)", Idaho National Laboratory (INL), 2013.