Operators Working with Transmission Flexibility: Enhancing Utility Control Rooms with Dynamic Line Rating Technique

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Abstract. This paper reflects generally on the human factors approach of integrating the Dynamic Line Rating (DLR) technique into power utilities control room as well as other monitoring systems, investigates how to accommodate transmission operators' needs and incorporate the new technology into a control room regarding these needs.

Keywords: Control room · Dynamic line rating · Transmission operators

1 Introduction

Human-system interfaces in nuclear power plant control rooms usually include traditional analog technologies. Recently several advanced digital technologies have been proposed for incorporation into control rooms. Understanding human behaviors in control rooms and integrating this knowledge into the design of the system and user interfaces in control room has benefited both the safety and economics of plants and utilities [1]. The work in a control room is highly complex, which requires timely responses from operators in the constantly changing environment. A user-centered interface design can help operators to communicate and collaborate better with the system, lower the risk of performance failure and improve the work efficiency.

There have been many proven human factors methodologies in control room design and modernization for nuclear power plants. From the technical perspective, plant systems need to be observed and analyzed in detail in order to have a good understanding of the general operation with consideration of all possible conditions of the plant; from the organizational perspective, all the operators and engineers who will be responsible for the plant operations should be coordinated and connected. Therefore the design process is rather complex taking into account these technical and human factors under all possible scenarios [2]. These same methods for designing a nuclear power plant control room can be applied into utility control room design practices, such as a transmission control room, with considerations of its specific workplace scenarios.

Integrating New Technologies into the Control Room. Outdated systems are not the only driver for control room upgrades. Sometimes new technology development is another incentive to upgrade the control room. The industry may also seek to advance

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technology targets optimizing the effectiveness and efficiency of the system, reducing operation and maintenance cost or better protecting the environment. As a system is reshaped by a new technology, the control room needs to be redesigned to match the updated system.

Integrating a new technology into current control room system seems easier than redesigning the whole control room. However, it brings more challenges related to how new technology can fit into the current system seamlessly. Typically the existing system has been operated safely for many years. The operators are familiar with the system as it is. They have learned the system well and developed a mental model of the system operation in their long-term memory. Any new technology will disrupt the current workflow and processes that are well practiced. This may ultimately unintentionally increase mental and physical demands on operators. Research on air traffic control systems has shown that numerous research projects that proposed new ideas and tools have been ultimately rejected as unusable by the controllers due to unfamiliarity [3].

Operators are required to understand complex situations and perform tasks within a limited time. Human errors are inevitable in control room and have been increasingly cited as the cause of accidents. To reduce the risk of human error and to ensure the consequences of error are minimized, the user interaction of the control room should be designed to convey clear information and provide intuitive interaction without causing operators confusion. The successful integration of a new technology into an existing control room requires careful consideration of the operator tasks, working environment, and a full understanding of how the new technology will change how work is done in the control room.

Transmission Control Room. The purpose of this paper is to explore the integration of a new technology into transmission control rooms. Power transmission utilities need operators to monitor a large amount information in control rooms and make decisions quickly during emergent situations. A good monitoring display and control system can help them better perform these tasks.

Dynamic Line Rating. The advanced technology that we consider in this work is a tool that enhances the use of existing transmission systems called Dynamic Line Rating. The increase of power use by end consumers does not only stimulate more power generation from plants, but also increases the demand on power transmission. Transmission congestion has been a critical constraint of utilizing available generation capacity, particularly during peak hours. In order to solve this issue, transmission capacity in overhead power lines needs to be improved. However, building new or improving transmission infrastructure is expensive and time consuming.

One of the key factors that limit transmission capacity is line temperature. Transferring power on transmission lines heats them, which can cause excessive line sag and other conductor deteriorations if the power flows are not carefully monitored and kept below their limits. The current carrying limits of transmission lines is generally determined by static ratings based on the worst-case scenario environmental conditions. However, this estimation is very conservative, allowing usable transmission capacity to go unused. Dynamic Line Rating (DLR) is a technology that provides timely and accurate estimation of transmission line capacity based on real-time observation of the environmental conditions of overhead transmission lines such as conductor characteristics, real time current, and weather parameters such as ambient air temperature, wind speed and wind direction [4]. The technique is valuable because it can significantly increase the capacity of existing transmission lines. DLR techniques have been explored for several decades and some of them have already been implemented such as at the electric reliability council of Texas [5].

The unique Idaho National Laboratory concurrent cooling model applies the effect of wind cooling and incorporates a weather-based system that is usually less costly than other monitoring systems such as conductor sag monitors. When the wind is blowing, it can cool the lines and provide more capacity for transmitting current, thus can increase the current limit that the line can carry. Idaho National Laboratory has developed a DLR system, which includes weather measurement equipment installed near transmission lines, computational fluid dynamics models and software to consume the weather data to model and calculate transmission line ampacity limits in real time and with forecast weather and line current information provide a predicted future limit.

In order to utilize these DLR tools without increasing operator workload, the information needs to be carefully integrated into the control room. Technologies will not be optimally used if they are not well designed and implemented in human-system interfaces. Our goal is to integrate DLR technology into current transmission control rooms using human factors proven approaches.

2 Methods

To facilitate DLR integration, human factors professionals have begun by investigating the utility control rooms and existing tools and interfaces used by operators in great details using field observations and interviews. These observations informed the design of DLR tools, which are evaluated by operators to provide feedback on the designed user interactions. Three utilities have been investigated and their operators are interviewed. We summarized the observations and generalized the design requirements and prototypes based on the observation results.

3 What Are Operators' Needs?

We have observed three utility control rooms and interviewed their operators. The goal of these investigations is to understand how the current static line rating method is being used and how the dynamic line rating is going to change the current operation process if integrated.

Among different operators in these control rooms, we targeted transmission operators because they will be the primary users of DLR information. In a transmission control room, the responsibilities of a transmission operator usually include:

1. Control the physical assets of the transmission systems in response to scheduled maintenance and activities by operating equipment.
2. Monitor power flows to ensure that system is maintained within its limits.
3. Respond to any alarms or emergent events.

One of the routine activities of transmission operators is monitoring power flows against static line ratings in real-time to make sure the lines are carrying an acceptable amount of current. Most control rooms present the current load relative to the limit (typically expressed as a percentage) on the monitor. Some of the control rooms also provide other monitoring information such as n–1 contingencies for particular lines in their transmission system. According to the interviewed operators, they do not need additional information on how line rating numbers are generated or how the limit is developed as long as they can trust that the limits are accurate and conservative. Operators also indicated that they are not likely to have time to view additional detail on line ratings, and if they need to in order to make an effective decision, it would likely overload operators.

4 How Can DLR Fit into These Control Rooms?

According to the operators' feedback and working scenarios, we learned that transmission operators have limited time to make decisions especially in emergency, so they need intuitive information to reduce uncertainty especially in a highly complex situation. If DLR is integrated, operators do not need an additional display to present the new information. Otherwise, they are likely to avoid using the DLR information because it will add additional burden. What they need is the simple and clear information that can directly scaffold their decision making. Therefore, we decided to integrate the DLR calculation in the operation system behind the scenes and replace the original static line limit information with a new current load relative to limit percentage based on DLR information. This will bring a minimum change in the information for operators without increasing any workload. Apart from that, we only add one piece of information into the operator displays, which is the time to the maximum line temperature, which will indicate to the operator how much time is left for the line to hit its maximum temperature under the current or n–1 contingency current. The timing information is only shown when the line is close to its limit. This will give operators more intuitive information for decision-making. To sum up, the following information in Table 1 will be presented to operators on the monitoring display:

Table 1. Information presented on the control room display

Information	Purpose
Line name/location	To identify lines
Percentage of current load to limit based on DLR	To present line status
Time to maximum temperature	To provide intuitive information users need

Apart from the main screen, we also provide options for operators when they want to drill down to more details. Because DLR is more complex than static ratings, operators might want to look into detailed weather information to ensure the accuracy of line status occasionally. We designed an alternative display that operators can switch to for specific weather station information over a period of line, including wind, air temperature and solar heating.

Figure 1 shows two prototype examples of the monitoring displays.

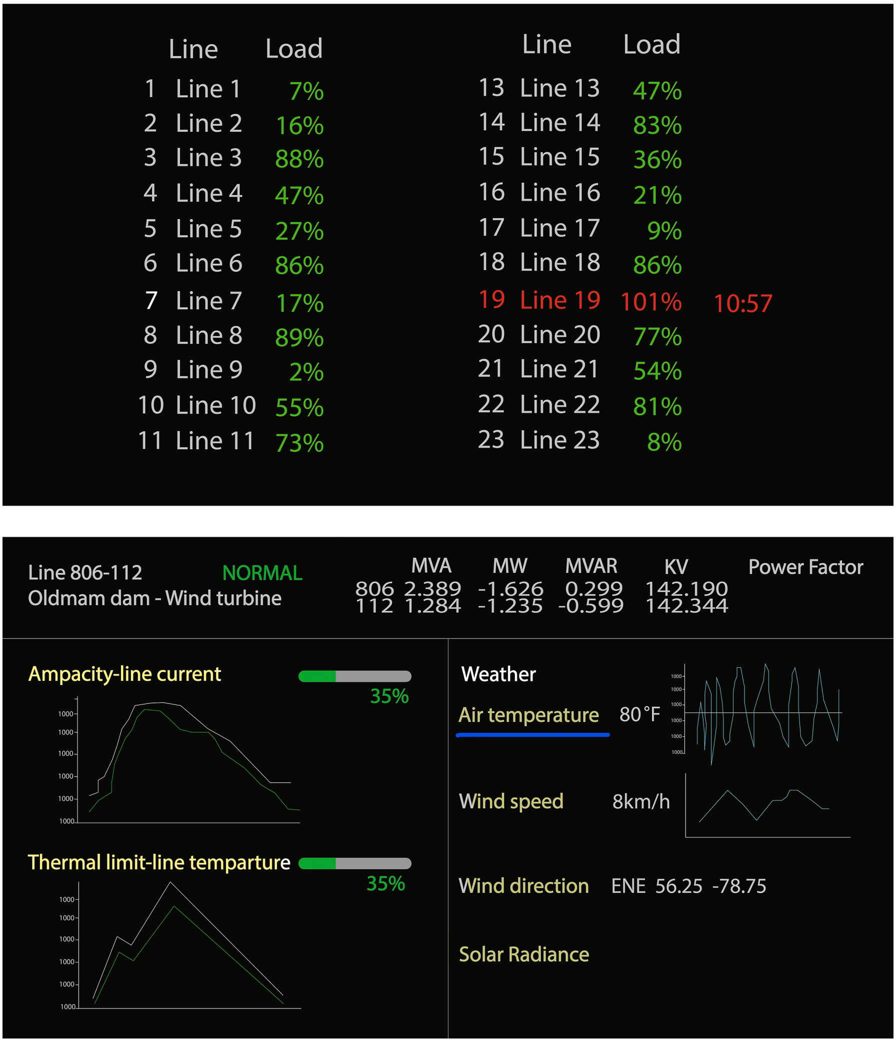

Fig. 1. Prototype examples of monitoring displays integrated with DLR information.

5 Conclusions

We have investigated the operators' activities in the control room of power utilities, including planning, scheduling and real-time operations. Based on these observations, we developed a series of tools to integrate DLR information into the current control room monitoring systems. The tools utilize DLR techniques to calculate line current behind the scenes and represent the current load relative to line limit the same as previous monitoring system shows. Additionally, we added intuitive information to show the time for a line to hit its maximum temperature limit. The system also provides detailed weather information in case operators need it. The tools will be evaluated in simulated scenarios using objective metrics in future phases of the control room integration of DLR.

As designers and implementers are responsible for introducing the new technology to users, how they frame and present the information will impact what information would be provided to operators and how this information would cue the operators' actions. Integrating a new technology is likely to increase operators' workload because it often adds new information and work processes. The additional information may also increase the uncertainty and make decision making harder. To avoid these problems, we designed a straightforward human-system interaction that is based on minimizing the changes to the information displayed and the existing work processes.

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