Characterizing Annunciation Use in a CANDU Nuclear Power Plant Through Task Analysis

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ABSTRACT

In large, complex process systems such as nuclear power plants, annunciation is used to alert operations staff to important changes in plant conditions that may impact on operational goals. Annunciation, along with the routine monitoring of control room displays, enables operations staff to keep up-to-date with the current plant conditions and predict future plant states.

During major plant upsets, process and equipment state changes can result in the generation of hundreds of annunciation messages. In some instances, this large number of messages may overload the presentation capacity of annunciation media and the ability of operations staff to assimilate them.

This paper summarizes the results of applying task analysis to characterize the use of annunciation by control room operators during major plant transients. The analysis confirms the long-held industry belief that operators are alerted to too many extraneous annunciation messages for immediate management of the upset. The analysis also demonstrates that operators rely on annunciation to alert them to both unexpected and expected changes in plant conditions to successfully manage upsets. In past plant designs, the operational need for annunciation of important expected changes in plant conditions has not been explicitly recognized as a design objective.

This paper reviews the background to the project, describes how upsets were characterized for the analysis, outlines how the analysis was performed and documented, and discusses the analysis findings. The paper concludes by providing suggestions for measuring annunciation effectiveness and by identifying areas for annunciation improvement to better support operator needs.

Introduction

CANDU nuclear power plants are large, complex electrical generation facilities that are operated under computer control. Overall plant operation is supervised by human operators using computer displays, and conventional instrumentation and controls from a central control room. Annunciation is used to ensure that control room staff are promptly alerted to important changes in plant conditions that may impact on operational goals.

Over the past thirty years, the amount of information annunciated to operators has continued to increase as a result of increases in plant size, the application of computers for process and equipment monitoring, and a continued reliance on annunciating the change in status of

individual sensors. Over the same time, the understanding of how to process and present this increasing amount of information to operators to best fit operational needs has not kept pace.

In 1992, a project was initiated with the Point Lepreau Generating Station (PLGS) to demonstrate improvements to annunciation for major plant upsets. This project is part of a larger research program funded by the Canadian nuclear industry to develop an improved architecture for CANDU plant annunciation. The first part of the project involves characterizing the use and effectiveness of the current plant annunciation for reference upsets (Sheehy, Davey, Fiegel & Guo, 1993). This 'benchmark evaluation' will serve as a baseline for comparing the use and effectiveness of alternative plant annunciation designs to be demonstrated later in the project.

This paper reviews background to the project, describes how upsets were characterized for the analysis, outlines how the analysis was performed and documented, and discusses the analysis findings. The paper concludes by providing suggestions for measuring annunciation effectiveness and by identifying areas for annunciation improvement to better support operator needs.

Background

Role of Annunciation

Annunciation is defined as a plant function that detects and may predict the occurrence of plant transitions, and provides directed attention to:

- alert users that a process parameter or system condition is abnormal for the current operating state, and
- point users to additional plant information to understand and respond to the transition.

The 'alerting' role redirects a user's attention by the way in which the annunciated condition is conveyed, and the perceived importance of the message content. The 'pointing' role supports users by directing them to appropriate procedures and equipment documentation to respond to the annunciated condition.

Annunciation within the Control Room Environment

The PLGS control room consists of an open room approximately 20 metres square. Instrumentation panels occupy two walls of the room. One wall contains instrumentation for the special safety, reactor, heat transport, boiler, feedwater, turbine and generator systems. Most of the routine plant operations and upset management can be performed from these panels. The other wall contains instrumentation for on-power refuelling, instrument air, process water, access control, and the electrical support and distribution systems.

The panels contain annunciation indicators at the top and conventional indicators (e.g., edgemeters, status lamps), computer displays, and equipment controls (e.g., handswitches and analog controllers) throughout the balance of the panel area. Operators use the computer displays as their primary source of information during supervision of stable plant operation and execution of startup, shutdown and power-change manoeuvres.

Annunciated information is displayed to operations staff by two centrally located computer displays and a limited number of window annunciators at the top of each panel. The

computer displays enable changes in the status of more than 6000 analog, contact inputs and calculated variables to be individually annunciated. However, these displays have a combined presentation capacity of only 40 messages. If more than 40 annunciation messages are available for display at one time, the most recent messages overwrite the oldest ones.

The annunciation system supports operations staff well during normal operating conditions, and minor equipment failures or process upsets. During major plant upsets (e.g., reactor or turbine trip), process and equipment state changes can result in the annunciation of hundreds of messages. In some instances, this large number of annunciation messages may overload the presentation capacity of annunciation media and the ability of operations staff to assimilate them.

Purpose of Task Analysis

As a part of the benchmark, a task analysis was undertaken to characterize the current PLGS annunciation use. The specific objectives were to:

- identify and characterize operator tasks in response to plant upsets,
- identify the information needs, and specifically the use of annunciated information by operators in performing tasks in response to upsets, and
- identify performance measures and criteria for judging the effectiveness of plant annunciation.

Upset Characterization

The task analysis characterized operator tasks for a class of plant upsets that involve:

- rapid shutdown of the plant from a normal high-power electrical-generation state (e.g., 100% full-power production) by activation of safety shutdown systems,
- recovery of the plant to an intermediate power state within about 30 minutes, to avert a reactor poison-out that would result in two days of lost production capability, and
- restoration of steam supply to the turbine, and generation of electrical power to the grid.

With plant upsets of this class, the large number of annunciation messages generated in the first few minutes of the upset (e.g., greater than 100), regularly exceed the presentation capacity of the computer-based annunciation displays.

Upsets can be characterized in terms of the plant response and the operations staff response. The plant response can be characterized by the initiating conditions for upsets, and the state of plant systems and major plant parameters as a function of time throughout the upset. The operations staff response can be characterized by the operating team who manage the upset, their assigned roles, the working environment in the control room and the strategy used to manage upsets.

Strategy for Managing Upsets

The activities performed by the operations staff and plant automation in managing any upset can be grouped into five phases:

- actuation of special safety-system functions and confirmation of their effectiveness,
- stabilization of the plant processes and systems,
- diagnosis of the fault conditions,
- correction of the fault conditions, and
- restoration of electrical-generation capability.

The initial objective of the operations staff in managing upsets is to confirm the effectiveness of the actions of automated systems to stabilize the plant processes. During this period, the operations staff are guided by an appropriate procedure or limited set of actions committed to memory. The specific procedure(s) to apply are selected from a hierarchy of corrective procedures that address differing levels of upset severity.

Once the plant is safely stabilized, the operations staff diagnose the cause of the upset. Fault-condition correction and restoration of power-production capability are addressed by procedures in station operating manuals.

Analysis Approach

The sources of information for our analysis included plant design, operating and training documentation, observations and analysis of the management of upsets in both the plant control room and full-scope simulator, and interviews with operations personnel.

The following key assumptions were used in performing the analysis:

- The scope was limited to those tasks performed by control room operators.
- Tasks were identified and organized in relation to when they usually occur in the upset response sequence.
- Tasks were identified independent of the staff member who may perform them.

The task analysis was recorded in three parts:

- Task flow diagrams were used to identify tasks and illustrate the relationships between tasks. Tasks were grouped by upset response phase and organized hierarchically. Operator tasks directly supported by annunciated information were annotated.
- A database of task description records was used to characterize key attributes of each task. The attributes recorded included:
  - initiating conditions,
  - performance or completion criteria,
  - performance parameters,
  - subtasks,
  - terminating conditions, and
  - execution characteristics (i.e., duration, priority, and frequency).

- An annunciation and task timeline diagram was used to record task concurrency, relative priority and the points in time that annunciation messages were presented in support of each task.

Analysis Findings

Current Use of Annunciation

The task analysis found that annunciation plays a central role in supporting operators in upset management at PLGS. This is done by providing:

- alerts to unexpected changes in plant conditions, and
- alerts to, or reminder of, expected changes in plant conditions.

With the first group of alerts, annunciation is used to compensate for the inability of operators to maintain high vigilance in extended monitoring tasks and to recognize and track all important changes when many changes are occurring. With the second group of alerts, annunciation is used to simplify operator tasks and lower workload by reducing the operators' need to continually check for anticipated changes in the plant.

Only a portion of the currently annunciated conditions are used by the operators in managing an upset. Some are used individually to either initiate, re-cue, or terminate operator mental processes, actions or plant tasks, while others are used in association with supporting information to:

- maintain overall plant situational awareness,
- predict future plant conditions and states,
- recognize the nature of plant events,
- recognize and identify the causes of an upset,
- plan and prioritize upset management actions, and
- identify specific procedures to undertake.

Many of the current messages require no action beyond acknowledgment as they provide redundant, out-of-context information of no immediate operational use. For major upsets, these messages provide an unnecessary distraction to operators in two ways:

- they interrupt operators from useful tasks, because every annunciated message must be attended to and interpreted to determine whether new action is required, and
- they clutter the annunciation computer displays and printer logs, thus making it more difficult for operators to locate the important messages they must act on.

Measures of Annunciation Effectiveness

Annunciation, along with the routine monitoring of control room displays, enables operators to keep aware of current plant conditions and predict future plant states. Thus, measures of annunciation effectiveness should assess how well annunciation helps keep operators up-to-date with changing plant conditions and assists them in decision-making and upset recovery.

The following three measures are proposed for assessing annunciation effectiveness in our future work:

- evaluation of operator 'situational awareness' using adaptations of the approaches developed by Endsley (1988) and Patterson (1991),
- collection of objective measures of operator performance (e.g., maintenance of operational margins on key parameters), and
- assessment of the potential disruptive role irrelevant annunciation messages play in temporarily distracting operations staff from upset response tasks (e.g., time spent in acknowledging irrelevant annunciation messages).

Areas for Annunciation Improvement

To improve an operator's understanding of evolving situations such as upsets, annunciation needs to better direct that operator's attention to the most relevant changing information. Improvements to message presentation alone are likely to be of marginal benefit as long as the message generation and presentation rates during an upset remain as high as they are. Thus, the demonstration of improved message prioritization to identify and segregate the most relevant information prior to presentation will be essential for improving annunciation effectiveness. A key element for this work is the recognition that the priorities of messages should be permitted to change in response to changing plant conditions and operational objectives.

At the same time, further emphasis should be focussed on how to optimize the presentation of annunciation information for operator assimilation. Important presentation issues that will need to be addressed in the context of providing improved support for operator tasks include:

- the composition of annunciation messages (i.e., what information attributes should be included),
- the relationships between groups of annunciated messages (e.g., sequence, chronology, cause/consequence, system or functional relatedness, time frames) to show in annunciation displays,
- the roles for specific presentation media, and
- the assignment of messages to presentation media.

Lessons Learned in Conducting the Task Analysis

The following are the main lessons learned in conducting these analyses:

- Access to plant staff with operational experience is essential to clarify operational intent and understand the relative priority and attention given to specific tasks. In several cases, the information obtained through discussions is not available in the plant's systems, training, or procedures documentation.

- The upset response strategy provides a unifying framework for the analysis. This establishes the 'big picture' for structuring and representing the analysis.

- The definition of a general set of attributes to characterize tasks helps establish consistency in the development of the task descriptions and provides a goal-oriented framework for structuring the discussions with operators.

- A dictionary of standard terms or descriptors would enforce more consistency in characterizing tasks and would lead to less ambiguity due to differences in interpretation.

- For any analyses of similar or larger size, effective information handling tools are necessary. Better tools than just a basic text editor and drawing tool are needed to minimize the documentation effort.

Conclusions

The task analysis summarized in this paper has increased the understanding of the role that annunciation plays in supporting operators to respond to plant upsets. The key conclusions from this analysis are:

- operators rely on the annunciation of both unexpected and expected changes in plant conditions (i.e., not just fault occurrences) to successfully manage upsets,
- operators use annunciation throughout all phases of upset management and especially during the diagnosis of fault conditions and the restoration of power-production capability phases,
- for large upsets, operators are alerted to many extraneous annunciation messages, and
- to better support operators in responding to major upsets, improvements to the prioritization and presentation of annunciation messages should be developed.

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