DISPLAY CONCEPTS FOR MAINTAINING ALARM STATE OVERVIEW DURING UNIT EVOLUTIONS

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Abstract

Control room operators rely on the plant annunciation system to alert them to abnormal operating conditions and changes in plant configuration. A key determinant in annunciation system effectiveness is how well the annunciation system displays support Operations staff to staff to maintain a full understanding of the alarm state and ongoing changes under all operating situations.

During unit evolutions, current CANDU alarm generation rates can frequently exceed 10 alarms per minute. With existing annunciation displays that list individual alarm changes, the rapid changes in display presentation can exceed an operator's ability to recognize the changes and maintain a full and up-to-date awareness of unit alarm state.

This paper describes annunciation display features and concepts for alternative presentation of unit alarm state and changes that can provide improved support to Operations staff during unit evolutions.

1. Introduction

This paper outlines some of the findings from an initial exploration of alternative annunciation display formats for presentation of unit alarm state in power plant control rooms when many alarms are active and/or high alarm generation rates occur.

The motivations for this study were two. First, the limitations with existing CANDU control room annunciation displays in supporting Operating staff during unit evolutions have been longstanding. Second, Operating colleagues within the Canadian CANDU community continue to encourage further exploration and definition of annunciation improvement possibilities.

2. Background

2.1 Annunciation role

Annunciation is a control room information function that supports operating staff with their plant supervisory control duties. Annunciation is one of several sources of information that support operating staff in developing and maintaining an overall awareness of plant status and performance. More specifically, annunciation alerts and conveys information on the moment-to-moment changes in plant processes, equipment, and automated systems with respect to a baseline reference condition. Given the large number of parameters associated with plant processes, equipment, and systems, it is impractical for Operating staff to monitor all parameters for changes on a periodic basis. As a

consequence, Operating staff are dependent on control room annunciation as the primary means for alert to and information about plant changes.

There are two kinds of change that CANDU annunciation has traditionally conveyed information about [1]:

- Problems - Changes that represents a potential or current challenge to achievement of operational goals (e.g., process disturbances or equipment faults). Annunciation of a problem requires recognition and intervention by Operating staff to correct the problem condition.

- Status - Changes that represents a planned or pre-delegated change in the state of a process, equipment, or system that does not represent a challenge to operational goals (e.g. confirmation of the completion of an automatic action). Annunciation of a status change requires only recognition by Operating staff.

Information on both types of plant changes is required so that Operating staff can maintain an up-to-date awareness of the current plant state and equipment configuration during changing conditions. A component of this awareness is the unit alarm state, specifically what problems are present, and what changes in problems and status have occurred since the last examination of annunciation. This overall awareness serves as the basis for planning, prioritizing, and directing all supervisory control actions.

Awareness is a cognitive or mental construct. It requires cognitive resources of attention, memory, and decision-making, and time to develop, update, and maintain. The way in which an annunciation system displays information on plant changes can have a substantial impact on the resources and effort required, and completeness with which alarm state awareness is maintained by Operating staff.

In conveying information about plant changes, annunciation must perform four functions [1]:

- Detect the occurrences of changes in processes, equipment, and systems,

- Alert Operating staff to the changes relevant to the current operating situation,

- Present information on plant changes in a way that enables operating staff to assimilate, understand, and use the information, and

- Provide or Point users to additional plant information to understand and respond to the changes.

The discussion in the main body of this paper will focus on the Present function aspect, specifically the support offered for awareness development and maintenance by the content and organization of information in annunciation displays.

2.2 Presentation challenges

An alarm is the individual expression of a plant change that an annunciation system is designed to detect and convey information about. CANDU plants are designed with several thousands of alarms and the alarm population per unit has grown with each plant generation.

To support Operating staff in maintaining awareness of the unit alarm state, annunciation must be capable of effectively conveying information on plant changes across all operating situations. A summary of the alarm state characteristics that must be accommodated is shown in Table 1 for representative operating situations [2]. Both typical and extreme values are shown to illustrate the variations in rate of alarm state changes and the number of problem alarms active for each operating situation routinely encountered.

Operating Condition	**Rate of Alarm State Changes**		**No. of Problem Alarms Active**	
	Typical	Extreme	Typical	Extreme
Stable Conditions				
• Full power operation	< 3/min	> 20/min	< 10	> 50
• Shutdown	< 5/min	> 20/min	> 40	> 150
Changing Conditions				
• Startup	> 5/min	> 50/min	< 40	> 150
• Shutting Down	> 5/min	> 50/min	<50	> 300
• Outages	< 5/min	> 20/min	> 150	> 250
• Upsets (0-3 min)	> 50/min	>200/min	> 200	> 1000
• Upsets (>3 min)	> 25/min	>100/min	> 150	> 800

Table 1 Alarm state characteristics for various operating situations.

The upper side of these variations in alarm rate and size of the alarm state present several challenges for annunciation display designers and Operating staff as display users. The remainder of this paper will discuss some of these challenges and the opportunities for improving existing annunciation display support during plant evolutions.

3. Alarm State Awareness

Developing and maintaining an awareness of the plant alarm state involves a number of information processing tasks that need to be repetitively performed often in a dynamic information environment. Essentially overall awareness is constructed from the repeated recognition, interpretation, and organization of an ongoing stream of plant changes represented by individual alarms. This information transformation process begins with machine detection of changes, and ultimately ends with a cognitive construct of awareness in the minds of Operating staff. There are many practical ways to divide the information processing tasks between automation and Operating staff. However divisions of responsibility that minimize the need for continual vigilance, and repetitive sorting,

transformation, and retention of changing information reduce the cognitive effort and time required by Operating staff in awareness development and maintenance.

Operating staff mentally organize and relate alarm information in specific ways as part of awareness development and retention. The organizations and relations preferred assist in planning and directing alarm response emphasis. For example, problem and status alarms are treated differently. Problem alarms are initially placed in a list ordered by importance to assist in prioritizing selection of individual alarms to attend to. Once response resources have been allocated, they are transferred to a second list until they are observed to clear. Once cleared, they are removed from the second list and deleted from the current alarm state record. The occurrence of individual status alarms are used to update expectations and understanding of system actions, states, or configurations as they are recognized. No list of status alarms is retained as part of the alarm state.

Control room annunciation displays mark the division in the information processing chain where automation processing ends and the cognitive resources of Operating staff must carry on to create the alarm state awareness desired. Consequently, the degree to which the information content and structure in annunciation displays departs from or matches the information content and organization used for awareness representation determine the level of effort required by Operating staff.

When the communication through annunciation displays between automation and Operating staff breaks down, or Operating staff can't bring sufficient cognitive resources to bear, the awareness of overall alarm state can become stale and incomplete. When this occurs Operating staff may initiate a number of compensatory actions to keep abreast of plant changes, and eventually recover full alarm state awareness. These actions can involve limiting the amount of information communicated in annunciation displays, increasing directed monitoring activities, or conducting reviews of printed alarm summaries.

4. Current Annunciation Displays and Usage

Control room annunciation presents information about plant changes through lists of text-based alarm messages. The primary annunciation display consists of dedicated computer monitors that are centrally located in control room panels. Most implementations employ two display monitors providing a message capacity of about 40 messages overall. At Darlington, four display monitors provide individual listing of alarms within four functional areas of an individual unit. Alarms lists can also be presented on console displays or printouts via Operating staff selection.

With the primary annunciation displays, alarms are primarily listed according to their order of occurrence. If an alarm changes state while still displayed, the original alarm display location is updated with the new alarm state, rather than a new alarm message being added. When the list becomes full, new alarm messages begin to overwrite the oldest previously displayed alarms.

Each alarm is presented as a single text message with a preceding message state indicator (i.e., alarm active or returned to normal). Message components and coding can include a description of the alarm condition, relative importance, system or program affiliation, instrumentation source, and alarm limits. There can be considerable variation in message text structure both within and across plant implementations.

The sequential list form of annunciation display is effective in supporting Operating staff develop and maintain alarm state awareness when a small number of alarms are active and alarm occurrence

rates are low. When the number of active problem alarms exceeds the list capacity, Operating staff can no longer see the full alarm state and awareness becomes incomplete. When the generation rate increases, Operating staff are required to devote more time to attending to annunciation displays to avoid missing alarms as old alarms are overwritten by new ones. Even when continually attending to annunciation displays, alarm presentation rates of 10 alarms per minute can begin to challenge the ability of Operating staff to keep up in maintaining alarm state awareness and avoid missing individual alarms.

As shown in Table 1, alarm generation rates and number of active problem alarms can be very high during portions of plant evolutions. In such instances, the amount of alarm information and rates of change combine with the sequential list form of presentation to become an ineffective means for conveying information to Operating staff to maintain alarm state awareness. In such instances, it is common for Operating staff to abandon attendance to annunciation displays and full alarm state awareness may be lost completely for a period of time.

During the early nineties, Atomic Energy of Canada (AECL) in partnership with Canadian CANDU utilities undertook an annunciation improvement program under CANDU Owners Group sponsorship [3]. The outcome of this research effort was the development and simulator validation of improved control room annunciation capabilities. The display portion of these annunciation improvements retained the list-based form of alarm presentation. However problem and status alarms were separated into two lists. Problem alarms were ordered by importance and status alarms were ordered sequentially. This form of presentation offered several advantages and was effective in enabling Operating staff maintain alarm state awareness for the most important problem alarms even during evolutions. However, periodic Operating staff selections of console annunciation displays and subsequent display interactions were required to maintain awareness of the overall alarm state and its degree of change.

5. Alternative Display Development

5.1 Direction

Many control room and simulator observations combined with numerous discussions with Operating colleagues over a period of several years led to selection of a preferred strategy for improving annunciation display support during plant evolutions. The strategy selected was one of existing display supplementation rather than replacement.

The approach selected was to explore display concepts that would assist in preserving overview aspects of alarm state awareness during those periods when existing control room annunciation displays provide an incomplete or unusable basis for doing so. With this approach, Operating staff would retain existing annunciation display usage practices during the majority of time when the alarm state is small with few or slow changes. Only when the alarm state exceeded the presentation capacity of existing control room annunciation displays or the alarm state changed rapidly, would the supplementary display be selected for use along with the existing list-based displays.

During those periods when both displays are in use, the supplementary display would assist in maintaining overview aspects of alarm state awareness. The existing annunciation displays would continue being available to provide information on individual alarm detail when it is feasible to use them.

5.2 Guiding principles

Several principles were established through discussion with Operating colleagues to guide exploration of supplementary annunciation display concepts:

- Preserve Overview - Favour preservation of alarm state overview versus detail. Maintaining user understanding of the extent of the alarm state provides a context for directing monitoring and response emphasis.

- Align Information to User - Display presented information consistent with the way Operating staff organizes information in developing and maintaining alarm state awareness. This simplifies understanding and eliminates mental effort in repetitive translation and organization.

- Maintain Information Completeness - Ensure the information displayed is always complete. This eliminates the need for Operating staff to draw on memory resources at a time when memory demands are high with other tasks.

- Reduce Display Attendance - Display information so that frequent and lengthy display attendance is not required to avoid missing changes. This reduces the disruptive need to interrupt other tasks to update alarm state understanding.

- Avoid Interaction - Limit need for Operating staff interaction to simple display selection. This simplifies involvement to simple display observation at a time when many other tasks are being performed.

5.3 Information elements and organizations

A range of information elements and arrangements are being explored for use in maintaining overview of alarm state awareness. Initial work centered on identifying meaningful metrics that could be repetitively updated from existing annunciation system processing data and individual alarm properties. Examples include alarm counts, generation and clearance rates, alarm distributions, and current direction of metric changes.

For display arrangements, a number of organizations for numeric based metrics have been explored. Recent work has begun examining the potential effectiveness of graphical forms of representation in place of or to complement the arrangements of numeric based metrics.

One of the supplementary annunciation displays developed is shown in Figure 1.

Separate display regions are used for problem and status alarm information consistent with the separate manner in which Operating staff organize and think about each type of alarm. Three metrics for problem alarms, shown across the top of the display, characterize the overall alarm state in terms of size and degree of change. A single rate metric is used to describe overall status alarm occurrence activity at the same display level on the right-hand side.

The problem alarms are further represented with two distributions, first by system affiliation and second by alarm priority within a system. The system-based distribution is ordered with respect to

decreasing numbers of problem alarms per system. With this organization, those plant systems most contributing to the alarm state are given prominence on the top of the list. An alternative ordering would order the system distributions by number of Priority 1 alarms consistent with Operating staff problem alarm sorting.

ALARM STATE OVERVIEW

		PROBLEMS					STATUS
		Number Active	Change Direction	Rate (No/min)			Rate (No/min)
	Total	87	↑	17			6
System Group	Share (%)			Priority Distribution 1	2	3	
Turbine	38	33	↗	5	7	21	2
Boiler FW	24	21	↑	6	11	4	3
Reactor	16	14	↘	4	6	4	
Condensate	15	13	↗	1	5	7	1
SDS1	7	6	→		2	4	
……							
……							
VISIBILITY	Fraction Displayed (%)		Displayed Duration Change Direction	Time (min)			
	46		↘	1.7			

Figure 1 Example supplementary annunciation display.

Along the bottom of the display, three metrics are shown that are indicative of alarm state visibility within the existing annunciation list-based displays. The left most metric indicates what fraction of the full problem alarm state is currently visible in the annunciation list-based displays. The other two metrics provide indication of how long an individual alarm may be visible in a list-based display before being overwritten.

Potential benefits of the display include representations of:

- Overall alarm state size and current degree of change,
- Identification of those systems where most and/or the highest priority problem alarms have occurred,
- The size and current degree of change for the alarm state within specific systems,

- Identification of those systems where automatic or operator actions have initiated changes of equipment states or configuration, and

- Indications of the visibility of individual alarms and overall alarm state within current list-based displays.

6. Conclusion

This paper has outlined the rationale for and exploration of annunciation display features and concepts for alternative presentation of unit alarm state. It is envisioned that such displays could serve as an effective supplement to conventional and improved list-based annunciation displays to assist Operating staff in maintaining alarm state awareness during plant evolutions.

7. References

[1] E. Davey, M. Feher, and K. Guo, "An improved annunciation strategy for CANDU plants", American Nuclear Society Conference 'Computer-based Human Support Systems: Technology Methods and Future', Philadelphia, Pennsylvania, 1995 June 25-29.

[2] T. Long and E. Davey, "Darlington annunciation: user information needs, current experience and improvement priorities", International Atomic Energy Agency Specialist Meeting on 'Experience and Improvements in Advanced Alarm Annunciation Systems in Nuclear Power Plants', Chalk River, Canada, 1996 September 17-19.

[3] R. Doucet, R. Brown, D. Trask, R. Leger, G. Mitchel, R. Judd and E. Davey, "Annunciation - building product team capabilities to support utility operational improvement", Canadian Nuclear Society Conference, Toronto, Ontario, 2005 June 08-11.