A NEW APDS APPROACH – ALARM PROCESSING BASED ON ALARM PRIORITIZATION

Cristina Corrales, Alberto Fuentes & Fernando Ortega
Tecnatom SA
1, Montes de Oca, 28703 San Sebastián de los Reyes (Spain)
ccorrales@tecnatom.es; afuentes@tecnatom.es; fortega@tecnatom.es

ABSTRACT

We take for granted that the advances in technology bring improvements to the conditions in which humans perform activities associated to them. Is that the case for digital alarm systems in nuclear power plants? The answer is not that simple.

A review of the related literature, shows that still, the single most significant problem with alarm systems, is the large number of alarm messages presented to the operator at once. This is an issue that affects analog I&C control rooms with conventional annunciators and gets aggravated in digital I&C based control rooms. Digital alarm systems present the alarms in the form of lists in computer screens. This kind of presentation forces the operator to scroll or navigate pages to review the active alarms. Also, the alarm lists do not allow the operator to apply the pattern recognition practices acquired during training when using with fixed position alarm systems.

An Alarm Processing and Diagnostic System (APDS) facilitates the alarm monitoring task by applying alarm reduction techniques based on alarm priorities. It allows the operators to focus on the most important alarms during plant upsets.

A new generation of APDS should be based in an improved alarm analysis methodology. To develop such methodology, Tecnatom reviewed applicable standards and our own alarm analysis experiences. This paper documents the process and conclusions of the methodology development.

Key Words: Alarm Processing and Diagnostic System (APDS), Overload, Priorities

1 INTRODUCTION

The safe operation of the nuclear power plants depends on the operator's capability to monitor and control plant equipment in all situations. To do so nuclear power plant operators rely on instrumentation and control systems in conjunction with the associated Human-System Interfaces (HSI). Significant advances have been made in computer-based I&C systems and HSI. Digital systems widely applied in the I&C and control room design of the new reactors are being incorporated (mainly for non-safety related systems), in the current fleet of operating reactors which were designed and built using pre-1980s analog I&C technology.

The technology shift has also affected the concept of alarm system. Alarm systems based on conventional annunciators with fixed position alarms displayed in tiles in the panels, are now coexisting or being replaced by the newer digital systems.

The new digital alarm systems (either as standalone or embedded on digital control systems and process computers) have clear benefits:

1. facilitating the creation of new alarms, and

2. providing much more capability to implement alarm processing[1] techniques and innovative ways to display the alarms.

Due to the first factor, there is a tendency for alarms to proliferate with digital alarm systems, if no proper alarm identification methods are applied (as recommended by ISA 18.2 [1]). Meanwhile the enhanced processing capabilities or rationalization methods are not used to its maximum extent. The immediate consequences of this are:

1. the presence of a higher number of alarms during normal conditions (other than 100% of rated thermal power), and
2. that alarm overloads occur during abnormal or emergency conditions.

These two facts render the digital alarm system as a not usable tool for its intended purpose. The use of an Alarm Processing and Diagnostic Systems (APDS) need to be complemented with an improved alarm prioritization definition methodology.

During 2015-2016 Tecnatom experts in human factors engineering, I&C and plant operation have been working together on developing a methodology and the support tool to better define the alarm priorities and APDS processing capabilities. The sections below discuss the process followed and its results.

2 ALARM MANAGEMENT IMPROVEMENT PROJECT

The activities involved in the project to improve the APDS are depicted in the Figure 1 and discussed in the following sections:

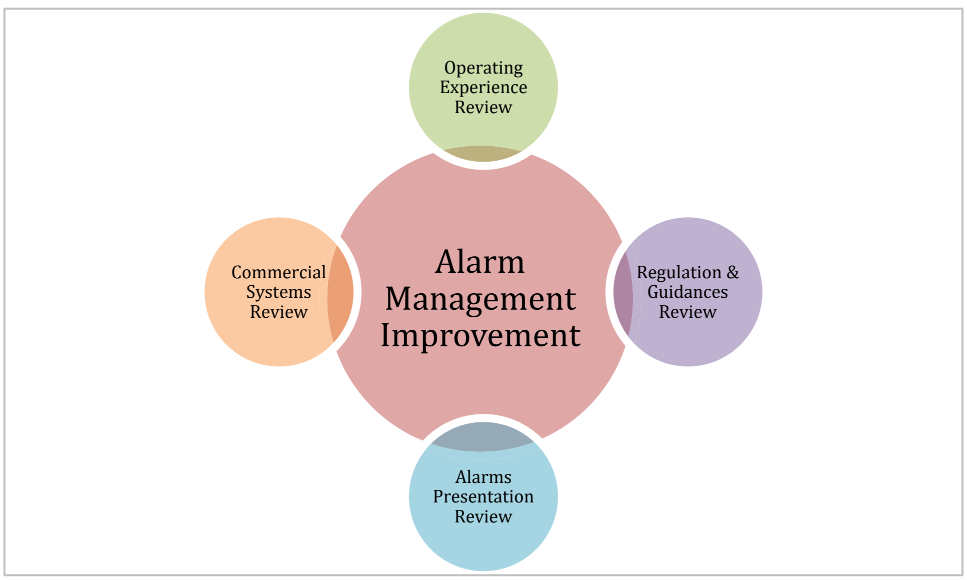

Figure 1: Activities involved on the alarm management improvement project

2.1 Operating Experience Review (OER)

The operating experience review had different focuses:

1. Review of plant events related experiences: the search was conducted in INPO database, the analysis of the events, pointed mainly to alarms being disregarded or being unnoticed by the

[1] Processing may include assignment of priorities, alarm filtering, alarm suppression, creation of higher-level alarms, routing of alarms, and archiving of alarms.

operation crew. The conclusion was that a more context aware processing system for the alarms could have prevented those events.

2. Review of previous industry experiences: several industry experiences that inform the requirements for the alarm systems in the Utility Requirements Document [2] were reviewed to identify the best methods, incorporate them in Tecnatom methodologies, and help shape the requirements for the alarm systems and tools.
3. Review of Tecnatom's own alarm management projects: after many alarm analysis and improvement projects, both in nuclear and fossil plants, the team wanted to understand the nature of the challenges faced and learn what could have been done better. The team learned that, for the processing method to be accepted by the operators, they must be involved in the process from the beginning. Verification and validation of the defined criteria are important steps also, but there is no viable way to validate that, in each situation, the processing is the ideal one. It was also identified that the nature of the alarm problems is different in fossil and nuclear power plants (NPPS). While the first ones, must focus their efforts in improving the alarm definition[2], the alarms in NPPs are in most cases, properly defined and the challenge is to get the most out of the processing methods.

2.2 Requirements and guidelines review

The review's goal was to examine the requirements and acceptance criteria for alarm systems, in this paper we will focus on the results of US regulations, but similar requirements were found in other international standards and guidelines (EPRI, IEC, ANSI/ISA).

2.2.1 Instrumentation and Control aspects

The Chapter 7 on the Standard Review Plan (SRP) [3], provides the requirements applicable to annunciator systems, recommending review emphasis on:

1. The requirements for reliability, redundancy, independence, separation and self-test provisions for the alarm system, and
2. The specific requirements (Class 1E equipment and circuits) for those alarms provided for manually controlled actions for which no automatic control is provided and that are required for the safety systems to accomplish their safety functions.

The plant designers provide evidences that the acceptance criteria are met, by demonstrating that:

1. The architecture of the alarm system meets the cited requirements.
2. The alarms and plant logic design are such that there are no alarms that require manual actions for safety related systems to accomplish their safety functions.

For Advanced Light Water reactors, the review is directed also by the SRM to SECI 93-087 ii. T [4].

2.2.2 Human Factors Engineering aspects

The Chapter 18 on the SRP [3], recommends the Human Factors Engineering (HFE) review to include alarm systems even though they are non-safety related. This is because the alarm systems "*provide significant input into command and control activities, event diagnostics, and operator situational awareness*". The acceptance criteria for this review can be found in:

1. NUREG-0711 [5] establishes the NRC expectations on the acceptable HFE design process to be applied. Considerations related to the alarm system design, definition, processing and management

[2] As defined in reference [2], the design activity that identifies alarm conditions and defines associated setpoints. This activity also should define logic or cutouts needed to insure against unnecessary occurrences of the alarm.

requirements by the operator are embedded in the mentioned NUREG-0711. Explicitly, the following elements require attention to the alarms design in the following aspects:

- Operating Experience Review: requires interviews with plant personnel to discuss issues based on their operating experience with alarms and annunciators applicable to the new design.
- Task Analysis: requires the identification of the alarms needed to perform the tasks, the compilation of alarms in a list, the details needed to define them and their relation with Important HAs.
- HSI Design: requires early tests and evaluations during the alarm system design process, to provide details on alarm system design, and the inventory of alarms for Important HAs and degraded I&C conditions.
- Procedure development: requires the development of alarm response procedures.
- Verification: requires to verify that the needed alarms are provided. It also requires the sampling for verification to include:
    - the loss of alarm system (processing or display),
    - alarm procedures guided tasks, and
    - human cognitive tasks requiring interpreting alarms to diagnose faults.
- Validation: validation testbeds need to include high physical fidelity on the alarm presentation.
- V&V for plant modifications: requires the consideration of alarms.

2. NUREG-0700 [6] describes in its Part II, Section 4 the acceptance criteria for the physical and functional characteristics of the alarm system. As discussed in it, “the single most significant problem with alarm systems, as reported in the literature, is the large number of alarm messages presented to the operator at once”.

The **conclusion** of regulatory requirements and guidelines review is that the challenge still strives in need to improve the alarm processing to help the operator in the diagnosis of events. To increase the operator situation awareness during plant transients, alarm overloads need to be prevented.

2.3 Alarm presentation methods review

There are fundamental differences between the alarm presentation when we refer to analog I&C versus digital I&C based control rooms. Let’s examine these differences:

2.3.1 Analog I&C based control rooms

The analog I&C based control rooms presented the alarms to the operators by means of alarm tiles (normally color coded per their static priority) located in the upper section of the control room panels. The tiles constitute a form of Spatially Dedicated, Continuously Visible (SDCV) form to present alarms. Alarm tiles are arranged by system, so that all alarms tiles within a system are in the same panel or close to the indications and controls of the system.

A 1000 MW LWR might have around 2000 alarms distributed all around the control room panels. The alarms are defined so that the requirement for darkboard configuration (no alarms present in normal conditions) is met at nominal power. In other normal conditions, many alarms are active although they are not representing off-normal conditions. During significant plant transients, the number of active alarms is normally too high for the operators to manage them effectively.

The plant process computers (PPCs) in analog-based control rooms also provide alarms' monitoring capability. Most of the times though, this capability is only used for monitoring local alarms (such as the emergency diesel generators ones) that are not presented in the control room panels. Typically, the number of alarm points in the PPCs is bigger than the alarms in the panels, because it is easy to create new alarms. Also, the actions taken by the operator to silence, acknowledge, reset and test the alarms are not synchronized with the panels' ones, requiring redundant operator actions in both environments to align the alarms information. During the operating experience review, some events were identified in relation with the lack of attention to the PPC alarms.

The modernization projects in these control rooms introduce digital I&C systems with alarm monitoring capabilities as well. Although analog displays and controls are replaced by digital ones, the alarms tend to remain as they were and the digital alarm system capabilities are not used at all, or disregarded if implemented. Again, the operator is presented with redundant, or what he feels is not needed information (most of the times messages to I&C or maintenance groups), increasing his workload in relation with alarm assessment.

2.3.2 Digital I&C based control rooms

In digital I&C based control rooms the alarms are presented in visual display units (VDUs), in form of message lists. Generated by the Distributed Control System (DCS), the same alarms presented in lists are also included in control and monitoring displays (process or logic diagrams) associated to the equipment or process to which they are related. Digital I&C based control rooms make also use of SDCV alarms, but the number of them is much smaller compared to analog control rooms, ranging from less than hundred to, as much as few hundreds (for plants that use the Back-up Panel concept[3]).

Compared to SDCV alarms digital alarm systems provide more flexibility in how the alarms are presented. The introduction of digital alarm systems brings the opportunity to help the operators using alarm processing techniques in the situation assessment. But up to now there has been a tendency of presenting the alarms in the form of message lists in VDUs that are difficult to manage when the number of active alarms is high.

The conclusion of the presentation methods review was that the alarm overload issue seems to be aggravated in the new reactor designs, or with the increasing digitalization of I&C systems on the existing fleet due to two factors:

1. Increased number of alarms when introducing digital I&C in the control room.
2. Loss of perspective of the overall alarm condition, since the physical presentation means, do not allow the operator to apply the pattern recognition skills acquired in training sessions.

The research conducted using nuclear industry guidelines ([7] to [12]) and Tecnatom's experience on evaluating new control rooms designs and control room modifications, has shown that the most effective alarm presentation is the one that provides multiple ways of viewing alarms. There is a need to provide a plant and event context to the new alarm systems, using overview displays, establishing a hierarchy in the alarms and providing a graphical representation for it.

The Figure 2 depicts the concept of a hierarchical alarm definition and presentation that can be built e ffectively on the basys of a plant hierarchical human factors analysis.

[3] Certain plant designs include a Back-up Panel, intended to maintain the plant at full power for a few hours, bring it to safe shutdown and cope with some design base accidents, in the event of a loss of the digital interface.

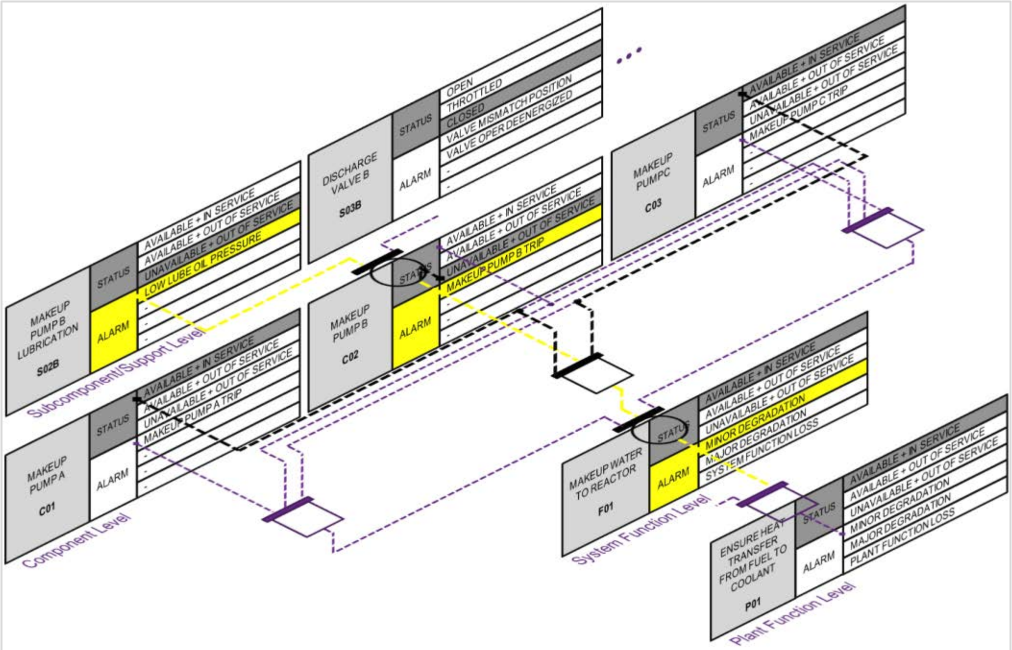

Figure 2: Concept for hierarchical alarm analysis and presentation

2.4 Commercial systems review

To effectively apply alarm processing techniques to eliminate alarm overloads in transients and facilitate alarm assessment by the operators, the team reviewed the capabilities of the most popular alarm systems and how they were typically integrated in the control rooms.

The following aspects were contemplated:

1. Presentation capabilities: reviewing the spatial disposition, combination of different alarm presentation methods, customizable and user friendly interface, information about the applied filters.
2. Information processing: the capabilities related to this aspect were parsed in:
    a. Filtering capabilities: does the system allow the application of filters and to which extent? Is there any risk of missing information while doing it?
    b. Suppression capabilities: can the operator suppress alarms (shelving maintenance and nuisance alarms)?
    c. Prioritization capabilities: does the system allow to define priorities? Static? Dynamic? Re-prioritize?
    d. Diagnosis capabilities: does the system allow to define events?
3. Management activities: the capabilities the team was looking for were:
    a. Definition of expected alarms
    b. Access to alarm response procedures, operation procedures or monitoring and control platforms.
    c. Transferring information to other departments

    d. Access to or creation of related trend graphics
    e. Means to share the information with other crew members
4. Integration with other systems, historian and capabilities to apply analytics were also other reviewed aspects.

The conclusion of this review was that there is no system that encompasses all the desired capabilities to effectively manage alarms in digital alarm systems. But they do provide enough functions to significantly improve the alarm processing.

3 IMPROVING THE MANAGEMENT OF ALARM LISTS

The process explained above informed the team about the best methods to minimize alarm overloads, what were the standing issues and ideas to overcome them. One of the products of this project was the new APDS methodology that is explained here.

3.1 A new APDS methodology

As explained in the section 2.3 above, introduction of digital systems in analog-based control rooms and advanced control rooms is turning to alarm lists, presented in VDUs, as the main alarm presentation and management mechanisms available to the operator. To help the operators to effectively assess off-normal conditions, the number of alarms in the list in each condition needs to be reduced.

An Alarm Processing and Diagnostic System (APDS) facilitates the alarm monitoring in a list format by applying alarm reduction techniques based on filters[4] that adjust the length of the alarm list depending on the number of alarms and their priorities. Previous experiments with APDS concluded that incorporating a form of event-based suppression into APDS could be beneficial.

Tecnatom's proposal for an APDS consists on an analysis of the alarms to determine their priority based on two priority factors:

1. Intrinsic priority: it is a static priority, inherent to the alarm definition and the hierarchical importance of the alarm in relation to the fulfilment of functions at a component, system and plant levels.
2. Condition-based priority: it is a dynamic priority, that characterizes the alarm importance based on the plant conditions. Plant conditions are combinations of plant modes and plant events (such as turbine or reactor trips) and that are defined by plant design logics.

The priorities are combined into a final prioritization that comprises three levels of priorities: emergency (E), warning (W) and incidental (IC). Alarms related to Limiting Conditions for Operation as defined by the plant Technical Specifications are given special consideration depending on the time allocated to meet the required actions.

To efficiently conduct this analysis, a support tool is needed, the Figure 3 shows Tecnatom's support tools to apply the APDS methodology.

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[4] By filter we are referring to the mechanisms of selecting which alarms should be presented to the operator in a primary list and which can be included in a secondary one (suppression). Alarm filtering and alarm suppression are often used as synonyms, even though NUREG/CR-6691 gives a different definition for each term.

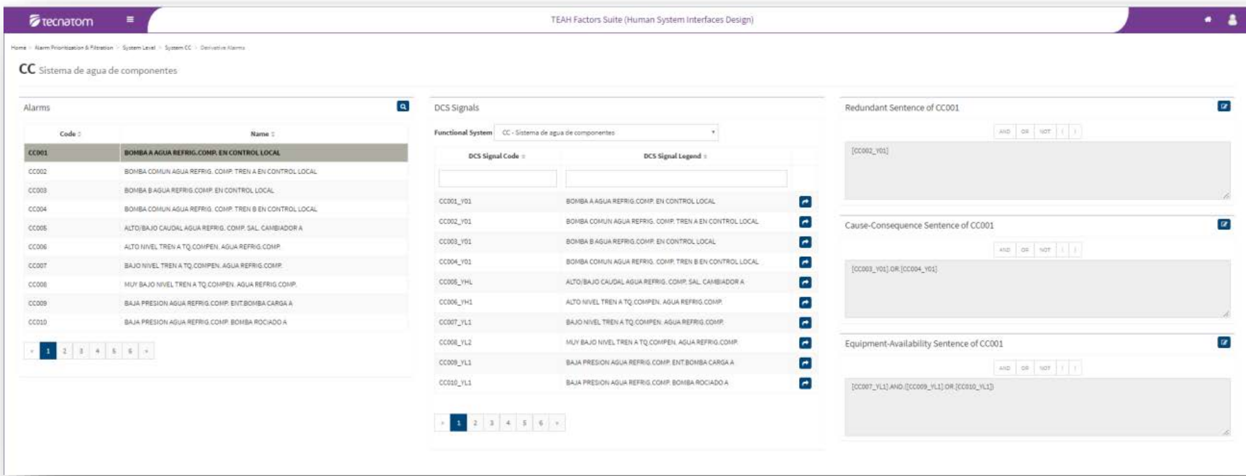

Figure 3: Support tool for application of APDS methodology

The order in which alarms are presented to the operator depends on the application of a set of sequential filters and the threshold of the alarm list as shown in the Figure 4. The threshold is the number of alarms that can fit on the alarm list without the need to scroll or navigate pages. The filters applied are:

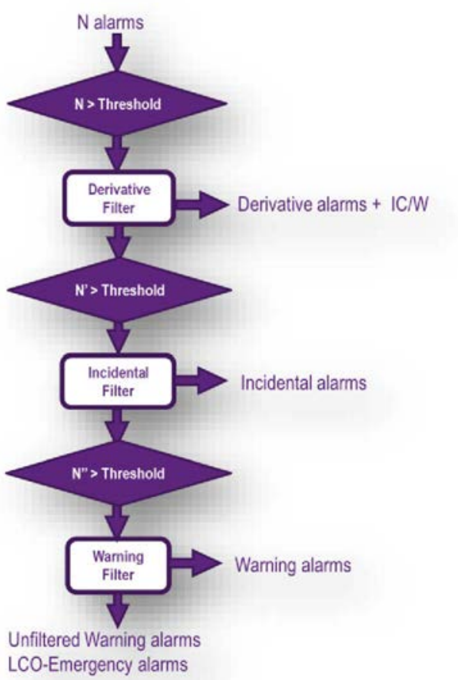

Figure 4: Sequential application of filters

1. **Derivative**: this filter helps the operator to not divert his attention by irrelevant (redundant) alarms when the number of alarms is greater than the threshold.

2. **Incidental**: this filter removes the alarms with the lowest final priority level (incidental priority alarms) when the number of non-derivative alarms is greater than the threshold.

3. **Warning**: this filter will remove from the primary alarm display the warning priority alarms, when the number of non-derivative and non-incidental alarms is greater than the threshold.

The criteria to sort the alarms on the list presented in the VDU is thus based on the time when the alarm was activated and on the filters explained above.

4 CONCLUSIONS

Although nuclear industry is successfully incorporating the digital I&C in the plant designs, the issue of the alarm overloads is still unresolved. It can even be said that it is getting more difficult for the operators to assess the alarms during off-normal conditions using digital alarm systems.

As an industry, nuclear specific guidance need to be updated or other industries guidance need to be adopted, most of the relevant nuclear material related to alarms is more than ten years' old and the experiences and lessons learned in the last few years of increased plant digitalization need to be incorporated into the standards and reference guidelines.

The benefits of solving the alarm issue are not only an increased safety in the plants operation, but economic as well. The plant events related to mismanaged alarms cause extra administrative burdens (trespassing LCOs) or even plant trips. The opportunity cost also needs to be considered, the capabilities that the digital systems bring for alarm management are not being used.

The problem needs to be addressed by a combination of changes:

- The definition of a proper alarm philosophy that guides the alarm definition/identification phase. This alarm philosophy should consider the features and constrains of the alarm management system. The alarm identification and management concepts need to be defined by a team of plant designers, human factors engineers and operators.
- A shift in the representation formats, that combined alarm lists and fixed position alarms (the two preferred methods nowadays), with some other kind of representation (high level displays) that gives the operator more context.
- The use of the existing processing capabilities of the digital alarm systems and the evolution of those to support new processing techniques.
- The application of new methodologies to process the alarms, such as the improved APDS one detailed in this paper.

None of this can be sustained without the involvement of the operators, they need to understand and own the alarm processing concept, maintain it and engage in a continuous effort to improve the alarm management in the control room.

5 ACKNOWLEDGMENTS

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