Computer-based Alarm Processing and Presentation Methods in Nuclear Power Plants

Jung-Woon Lee, Jung-Taek Kim, Jae-Chang Park, In-Koo Hwang, and Sung-Pil Lyu

Abstract—Computerized alarm systems have been applied increasingly to nuclear power plants. For existing plants, an add-on computer alarm system is often installed to the control rooms. Alarm avalanches during the plant transients are major problems with the alarm systems in nuclear power plants. Computerized alarm systems can process alarms to reduce the number of alarms during the plant transients. This paper describes various alarm processing methods, an alarm cause tracking function, and various alarm presentation schemes to show alarm information to the operators effectively which are considered during the development of several computerized alarm systems for Korean nuclear power plants and are found to be helpful to the operators.

Keywords—Alarm processing, Alarm presentation, Alarm cause tracking, Alarm logic diagram computerization, Alarm pattern recognition.

I. INTRODUCTION

MAJOR functions of alarm systems in nuclear power plants (NPPs) alert the operator to the fact that a system or process deviation exists and inform the operator about the priority and nature of the deviation [1]. Since many process systems in NPPs are interlinked together, a malfunction in a system affects other systems and consequentially activates many alarms. During plant transients, such as a setback, stepback, reactor trip, and turbine trip, several tens, or in some cases several hundreds, of alarms can occur during a very short period of time. Alarm systems in many operating NPPs, which do not use computers, display alarms on only alarm windows located at the top part of control panels in the control rooms. In these alarm systems, alarm window tiles are connected to alarm signals by hardwire. When an alarm avalanche occurs, these alarm systems cannot provide the operators with appropriate cues to the situation.

Computers have been utilized increasingly in NPPs. Alarm support systems are added to the control rooms of operating NPPs to help the operators to detect the situation and to respond to the malfunctions appropriately. Various alarm processing

Jung-Woon Lee is with the Korea Atomic Energy Research Institute, Daejeon, The Republic of Korea (corresponding author to provide phone: 82-42-868-8322; fax: 82-42-868-8916; e-mail: leejw@ kaeri.re.kr).

Jung-Taek Kim, Jae-Chang Park, and In-Koo Hwang, are with the Korea Atomic Energy Research Institute, Daejeon, The Republic of Korea (e-mails:. jtkim@kaeri.re.kr; jcpark@kaeri.re.kr; ikhwang@kaeri.re.kr).

Sung-Pil Lyu is with the Department of Computer System, Semyung University Jecheon Si, Chungcheongbuk-Do, The Republic of Korea (e-mail: lsp415@semyung.ac.kr).

methods such as alarm reduction, alarm prioritizing, and alarm grouping become feasible by use of computerized alarm systems. Many ways of alarm presentation, including not only on conventional alarm windows but also on visual display units (VDUs) in the computerized control rooms, become also possible. For new NPP designs, these functions are integrated into the instrumentation and control system and the human machine interface. Computerized alarm systems present processed alarms mostly in an alarm message list format on one or two VDUs. This type of alarm presentation still has problems for the operators in their recognition of alarm situations. Many alarms occurring during the plant transients may be displayed on many pages of alarm display screens, which cause the operators to be overwhelmed [2].

Computer-based alarm processing and presentation systems have been developed for several different Korean NPPs [3]-[7]. The alarm cause tracking function that these systems have is a unique feature helpful to the operators. This paper describes the methods for alarm processing, alarm cause tracking, and alarm presentation schemes.

II. ALARM PROCESSING METHODS

Many systems and equipment are interlinked together in NPPs, A malfunction in a system or equipment affects other systems to consequentially activate many alarms. Alarm avalanches during the plant transients cause problems to the control room operators with both conventional analog alarm systems and new computerized alarm systems. It is crucial to the operators that alarm systems select and present the alarms which are important and causal to the transient situations. In order to handle alarm avalanches, many methods to reduce the number of alarms have been implemented throughout the development of computerized alarm systems. With these systems, less than thirty causal alarms can be collected from hundreds of alarms during the plant transients.

A. Mode Dependency Processing

This is a very popular method to reduce the number of alarms. During a change in the plant operation mode, the following situations may occur; a) temporary plant transients, b) changes in a line-up configuration of systems, c) out-of-service systems or components, and d) on or off of some pumps or valves due to a change in the demand. Many alarms are temporarily generated due to the above situations. Alarms can be prioritized in accordance with their characteristics during a change in the plant operation mode. If alarms are activated temporarily and

consequentially to setback, stepback, reactor trip, or turbine trip, these alarms are treated as non-causal and usual.

B. Cause-Consequence Relationship Processing

Some alarms are generated by cause-consequence relationships with other alarms. In this cause-consequence processing, once causal alarms and consequential alarms are identified by the analysis of alarm relationships, consequential alarms are treated as not-important alarms. Fig. 1 shows a concept of this cause-consequence relationship when the feedwater pump 04P trips due to the alarm signal "FWBP 04P Lube Oil Press LoLo [P2]." The alarms, "RCPS ACTu[P1-P2]" and "MFWP 01P Trip [P2-P3]" are generated due to "FWBP 04P Trip [P2-P3]." Here, "FWBP 04P Lube Oil Press LoLo [P2]" becomes a causal alarm and the other alarms are the consequential alarms.
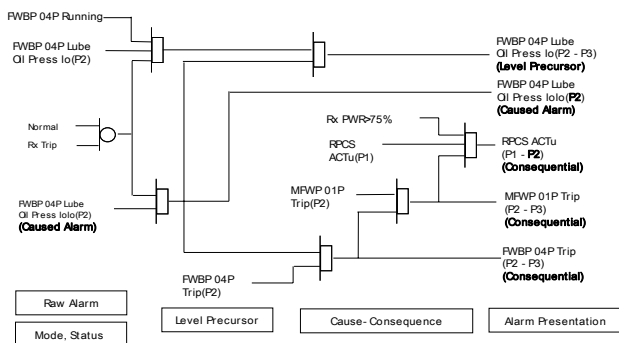

Fig. 1 An example of cause-consequence relationships of alarms

C. Level Precursor Processing

There are many alarms related to the same monitoring parameter. For example, alarms related to the levels of steam generators, condenser hotwells, and deaerators exist at several alarm set-points according to the significance of plant transients. In the case that an alarm for a more severe state is activated, alarms for less severe states are not meaningful and can be treated as usual alarms. For instance, the priority of the alarm "Steam Generator A Water Level Low" is lowered when the alarm "Steam Generator A Water Level Low-Low" is also activated.

D. Interlock Equipment Processing

Some alarms are interlinked to plant components. These alarms do not have meanings if the components are out of service. For example, an alarm "CEP DISCH HDR PRESS LO" has no meaning if the condenser pumps (CEPs) are out of service and can be represented by a composed input alarm "CEP TRIP."

E. Common Resource Processing

There are common resources such as compressed air or electricity to be supplied to plant components. These common resources are supplied in common lines with multiple trains. When a malfunction occurs in a common resource supply system, many alarms are activated in relation to the components receiving resources from the common resource supply system. These alarms can be represented by an alarm of the common resource supply system. For example, when many alarms occur due to trips in the air supply system or the electrical supply system, "Air Supply System Train A Trip" or "Electrical Supply System Train B Trip" can be a representative alarm and other alarms can be treated as usual alarms.

F. Alarm-Status Separation Processing

In some cases, alarms may indicate an automatic activation of plant components. These alarms are classified as status alarms in our alarm processing and displayed separately to other alarms. Operators also expressed that alarm-status separation would be necessary [8]. Not important alarms are also classified separately from causal alarms. Some examples of these are deviation alarms by a malfunction of reluctant sensors or equipment, alarms for a door open or key-unlock related to periodic tests, and minor alarms not affecting power reduction such as one for blocked strainers.

III. ANALYSES OF ALARM DATA AND PROCESSING

In order to apply the above alarm processing methods, a careful analysis of alarms becomes critical in the development of computerized alarm systems. All alarms of the NPPs, to which these alarm systems may be applied, were analyzed by using the alarm signal information, the alarm procedures, the abnormal and emergency operation procedures, the control logic drawings, and the plant process drawings. A standard sheet of the alarm analysis as shown in Fig. 2 was developed and used for the alarm analysis. Information related to alarm signals, alarm processing, alarm causes, alarm classification, and so on, can be filled after the analysis. The results are stored in a database. Hence a database management program can handle them easily to perform the alarm processing.

Fig. 2 Alarm analysis sheet

IV. ALARM CAUSE TRACKING

A. Two Alarm Cause Tracking Methods

Alarms are originally generated from malfunctions in the

plant components or sensors. It is helpful to the operators to show active causes when alarms are generated. We used two methods to track alarm causes. One is to use the alarm database which has information of alarm causes. When an alarm is activated, the alarm system can check and report whether any signals of alarm causes corresponding to the alarm are alive. In another way, the control logic diagrams were computerized and used for the alarm cause tracking. The alarm system tracks logic links in computerized logic diagrams from an activated alarm to alarm cause signals to find the causes of the alarm. The alarm system reports active alarm signals resulted from the logic diagram tracking. With this unique feature, the operators can see only active causes for the situations and need not to see other inactive causes for alarms.

B. Computerization of Alarm Logic Diagrams

Alarm logic diagrams are drawings graphically representing the status of links between logic elements implemented on plant equipment. A hard copy logic diagram as shown in Fig. 3 can be represented by using a simple text editor then converted into a computerized logic diagram as shown in Fig. 4 by using a logic diagram execution program.
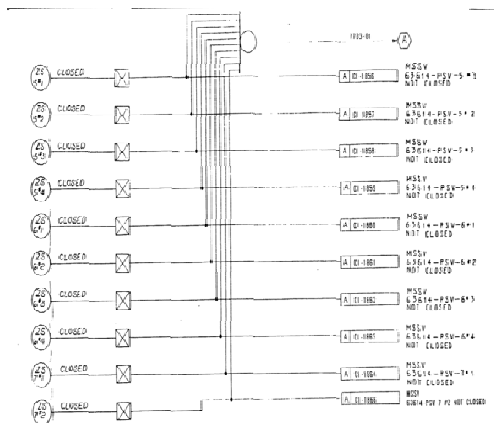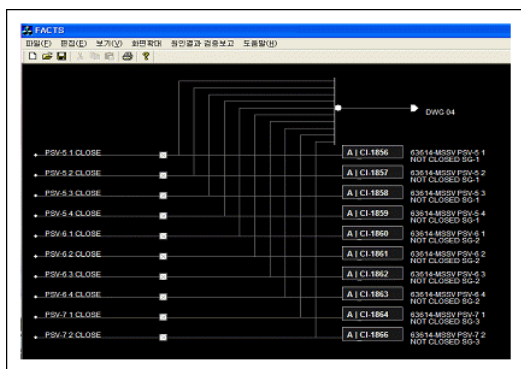

Fig. 3 A hard copy logic diagram

Fig. 4 A computerized logic diagram of the hard copy logic diagram

When these alarm systems are executed, if the value of a logic element implies that the logic element is active, then the colors of the logic element and adjacent signal lines are changed to show signal flows. Fig. 5 shows an example of the active logic elements and the signal flows.
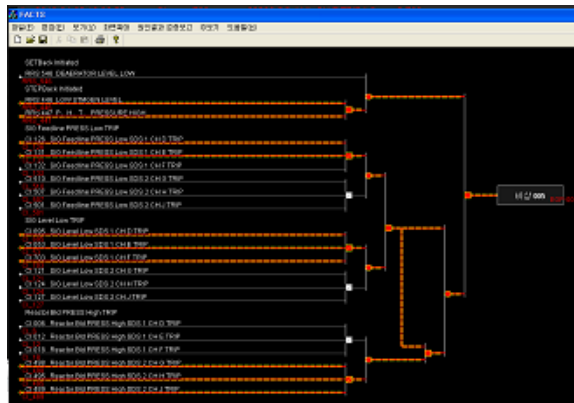

Fig. 5 An example of the active logic elements and the signal flows

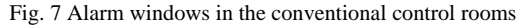## V. LINKS TO ALARM RESPONSE PROCEDURES (ARPs)

The operators can handle alarms by using ARPs. The causal alarms are linked to a corresponding ARP in our alarm system. ARPs are computerized for this purpose. The operators can select a causal alarm then they can view ARP corresponding to the alarm. ARPs usually note many causes of an alarm. In these systems, only causes which are active at the situations are highlighted as shown in Fig. 6. In this way, the operators can follow the ARPs without questioning which causes are active.

Fig. 6 An ARP display with the active cause highlighted

VI. PRESENTATION OF ALARMS

As shown in Fig. 7, alarm windows are placed at the top of the control panels in the conventional control rooms of NPPs. Alarm windows are grouped by the systems, and sometimes, alarm tiles have different colors according to their importance. During the plant transients, since too many alarms are activated, the operators do not look at the windows. However, in cases where not many alarms are activated, the operators can figure out the situations at a glance by recognizing a pattern of activated alarm tiles.

Fig. 7 Alarm windows in the conventional control rooms

Fig. 8 shows an example of a computerized alarm system display. This alarm system is a part of the Korean advanced control room design.

Fig. 8 An example of computerized alarm system displays

In this type of display, alarm messages are presented by text lines. Alarm messages can be rearranged and sorted according to alarm priorities or related plant systems as the operators want to. However, the operators who have an experience of operating this alarm system complain that the system does not support their alarm pattern recognition and sometimes gives difficulties to their understanding of the situations in a short time.

Considering the pattern recognition, a replica of alarm windows was implemented as an alarm presentation display of the alarm systems for an operating Korean NPP (Fig. 9). With this type of alarm display, the operators can maintain their visual momentum that they have formed through the real alarm windows. They also can feel familiar when they operate the alarm system.

Fig. 9 An alarm display to support alarm pattern recognition

Another example of the alarm system display is shown in Fig. 10. This NPP has already a computerized alarm system. However, since the system was designed a long time ago, the display is very primitive and presents only 20 alarm message lines on a screen as shown in Fig. 11. As shown in Fig. 10, the alarm support system for this NPP shows an original alarm message list on the right window and a list of causal and important alarm messages compressed from the original alarms on the top left window. The operators can see the causes of a specific alarm selected from the list of causal and important alarm messages on the bottom left window. Further by selecting a cause from the alarm cause window, the operators can view a logic diagram pop-up window demonstrating the logic links from the alarm to the cause.

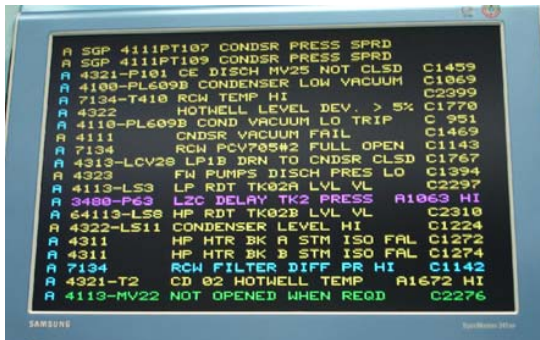Fig. 10 Another example of our alarm system displays

Fig. 11 A CRT alarm message display of an old NPP

VII. DISCUSSION

Alarm systems are important in safe operations of NPPs. In order to handle alarm avalanches, alarm processing is necessary to reduce the number of alarms. It is found that showing causal and important alarms separately during the plant transients helps the operators to mitigate the transients. The alarm cause tracking function, which shows active causes of a specific alarm, is also helpful to the operators. Also, links to the ARPs with active cause highlighting in these alarm systems help to reduce operator response time.

For alarm presentation matters, it is important that the systems should provide alarm presentation formats in ways familiar to the operators. Alarm pattern recognition capabilities, which the operators have acquired through their operation with conventional alarm systems, should be supported also in a new computerized alarm system design.

REFERENCES

[1] William S. Brown, John M. O'Hara, and James C. Higgins, *Advanced Alarm Systems: Revision of Guidance and Its Technical Basis, NUREG/CR-6684*, U.S. Nuclear Regulatory Commission, Washington, DC, 2000.

[2] John M. O'Hara, William F. Stubler, and James Higgins, *Hybrid Human-System Interfaces: Human Factors Considerations*, BNL Report J6012-T1-4/96, December 11, 1996.

[3] Jung Taek Kim, et. al, "An Evaluation Approach for Alarm Processing Improvement", IAEA Specialists Meeting (IWG-NPPCI) on Experience and Improvements in Advanced Alarm Annunciation Systems in Nuclear Power Plants, Chalk River, Ontario, Canada, 1996.

[4] Jung-Taek Kim, Kee-Choon Kwon, In-Koo Hwang, Dong-Young Lee, Won-Man Park, Jung-Soo Kim, and Sang-Jeong Lee, "Development of advanced I&C in nuclear power plants: ADIOS and ASICS", *Nuclear Engineering and Design*, **207**, pp.105–119, 2001.

[5] Sung P. Lyu, "An Identification of Alarm Cause by Tracking Logic Diagram", 2002 Spring Conference , Korea Nuclear Society, May 2002.

[6] Jung-Taek Kim et al., "An Application on Alarm Root Cause Tracking System (ACTs)," Joint 8th Annual IEEE Conference on Human Factors and Power Plants (HFPP) and 13th Annual Workshop on Human Performance / Root Cause / Trending / Operating Experience / Self Assessment (HPRCT), Monterey, CA, 2007.

[7] Jung-Woon Lee et al. "LOGACTS (Logic Alarm Cause Tracking System) for a Nuclear Power Plant Operation," Sixth American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control, and Human-Machine Interface Technologies, NPIC&HMIT 2009, Knoxville, Tennessee, April 5-9, 2009.

[8] Emilie Roth and John O'Hara, *Integrating Digital and Conventional Human-System Interfaces: Lessons Learned from a Control Room Modernization Program*, NUREG/CR-6749, U.S. Nuclear Regulatory Commission, Washington, DC, 2002