Proceedings of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 1995

Development of Advanced Annunciator System for Nuclear Power Plants

Jin Hyuk Hong, Seong Soo Choi, and Soon Heung Chang
Korea Advanced Institute of Science and Technology

Abstract

Conventional alarm system has many difficulties in the operator's identifying the plant status during special situations such as design basis accidents. To solve the shortcomings, an on-line alarm annunciator system, called dynamic alarm console (DAC), was developed. In the DAC, a signal is generated as alarm by the use of an adaptive setpoint check strategy based on operating mode, and time delay technique is used not to generate nuisance alarms. After alarm generation, if activated alarm is a level precursor alarm or a consequencial alarm, it would be suppressed, and the residual alarms go through dynamic prioritization which provide the alarms with pertinent priorities to the current operating mode. Dynamic prioritization is achieved by going through the system- and mode-oriented prioritization. The DAC has the alarm hierarchical structure based on the physical and functional importance of alarms. Therefore the operator can perceive alarm impacts on the safety or performance of the plant with the alarm propagation from equipment level to plant functional level. In order to provide the operator with the most possible cause of the event and quick cognition of the plant status even without recognizing the individual alarms, reactor trip status tree (RTST) was developed. The DAC and the RTST have been simulated with on-line data obtained from the full-scope simulator for several abnormal cases. The results indicated that the system can provide the operator with useful and compact information for the earlier termination and mitigation of an abnormal state.

I. Introduction

To perform their tasks effectively, operators must be able to process large amounts of information of various degrees of importance and different formats. Among this information, the alarm is the main information to detect abnormalities in NPPs. In existing alarm systems, there are a lot of alarms under one sensor one instrument strategy and individual alarms are spatially dedicated. This kind of alarm system has an advantage that all activated alarms can be perceived without the operator's efforts. But it has also such shortcomings as many alarm generations beyond the operator's cognition under the special situations like design basis accidents, difficulties of discrimination between important and unimportant alarms and so on.

To overcome the shortcomings associated with conventional alarm system, improved alarm processing schemes have been proposed and implemented with advanced computer technologies and a better understanding of the human factors associated with alarm systems. [1] They include expert systems concepts, [2] temporal reasoning, [3] and alarm generation model. [4] With these technologies, an on-line alarm annunciator system, called dynamic alarm console (DAC), was developed for the purposes of alarm elimination, suppression and dynamic prioritization. The main objective of the system is to improve considerably the quality of alarm information presented to the operator and relieve the operator's cognitive overload by filtering alarms during a multiple-alarm event. In order to assist the operator in identifying the cause that gives rise to the event before reactor trip, the reactor trip status tree (RTST) was also developed.

The target domain of those systems is the alarm annunciator system in the main control room of Yonggwang Units 1, 2. The systems are implemented on a SUN SPARC 2 workstation and the user interface is implemented by X window system for graphical presentation.

II. Development Strategies of the DAC

II.1 Alarm Hierarchical Structure

To provide necessary information effectively in the CRT-based alarm system, alarm information should be organized hierarchically and generated alarms should be processed. The hierarchy is an inherent characteristic of a large process plant and serves functional abstraction of the plant physical status.[5] From this point of view, all the alarms were organized in a four-level hierarchy in the DAC, as shown in Fig. 1.

- Level 1 alarms : critical function alarms related to the availability and safety of the plant,
- Level 2 alarms : subfunctional alarms that constitute level 1 alarms,
- Level 3 alarms : system alarms that indicate system-level anomalies,
- Level 4 alarms : individual alarms that indicate the anomalies of equipments or components.

The hierarchy was established on the basis of the physical and functional importance of alarms. If level 1 alarms, which consist of critical performance function (CPF) and critical safety function (CSF) alarms, are activated, that means plant safety or availability to be threaten. This alarm hierarchy infomation is provided through success paths, which are a kind of maps that bridges from level 1 alarms to level 3 alarms and displays alarm status in each level.

II.2 Individual Alarm Processing

Alarms are generated following "dark board at power" concept and the number of alarms generated is reduced by applying signal validation and by providing dynamic setpoints contingent on applicable operating mode. After individual alarms are generated, unnecessary alarms for situation awareness are eliminated followed by the suppression of less important alarms. Finally, the residual alarms are prioritized.

A. Elimination and suppression

In the DAC, possible momentary alarms that may be occurred due to equipment startup are eliminated by using time delays. After the elimination of unnecessary alarms, following alarms, which do not contribute significant new information or are not urgent, are suppressed: consequential alarms, level precursors, and state dependent alarms. Alarm suppression has a different meaning from alarm elimination. Eliminated alarms are considered as non-alarms, so they are not presented to the operator. On the other hand, suppressed alarms, that form level 4 in alarm priority levels, are not taken off completely and is presented under the operator's request.

B. Prioritization

The DAC assigns one of three discrete priority levels to individual alarms according to urgency of recovery actions and severity of their impacts. For the dynamic prioritization, system-oriented prioritization is performed followed by mode-oriented prioritization. And then, individual alarm priority is determined by synthesizing system-oriented priority with mode-oriented priority.

System-oriented prioritization aims to identify the importance of the alarm within the system to which it belongs. In this step, the importance of the system itself in plant function is not considered. System-oriented priority is determined from three points of view: equipment/component role, severity of alarm impact, and response type.

- Equipment/component role : essential, support,
- Severity of alarm impact : severe, middle, and slight,
- Response type : urgent manual, followup manual, and just confirmative.

Considering the above viewpoints, system-oriented prioritization is performed using the logic matrix, as shown in Table 1. To assign larger value to higher system-oriented priority, system-oriented importance function, $S(x)$, is defined as follows:

$$S(x) = 19 - S_p(x)\ , \tag{1}$$

where x is the individual alarm and $S_p(x)$ is system-oriented priority given in Table 1.

Mode-oriented prioritization aims to identify the importance of the system to which the alarm belongs in current operating mode because its importance is dynamically varied depending on operating modes. This prioritization is not directly associated with the importance of the alarm itself. In this step, each system is classified into two types: safety or indispensable system and support system.

- Suppose the system to which the alarm belongs be removed from service in current operating mode. The system is classified into safety system if the plant safety is directly jeopardized, or indispensable system if immediate mode change is occurred.
- Support system is defined as the system that operates always or periodically in current operating mode, and its abnormalities or inoperability cannot give rise to immediate mode change.

By classifying all the systems into the above two types, each system takes its own weight according to mode-oriented weight function, $M_w(x)$, which is defined in the following formula:

$$M_w(x) = \begin{cases} 1 & \text{if } x \in \textit{safety or indispensable systems} \\ 0.55 & \text{if } x \in \textit{support systems} \end{cases} . \quad (2)$$

After completing system-oriented and mode-oriented prioritization, the final prioritization function, $F_p(x)$, is calculated by multiplying the $S(x)$ value in Eq. (1) by the $M_w(x)$ value in Eq. (2), and the rule for final prioritization is as follows:

$$Priority = \begin{cases} \textit{1 (immediate action – required alarm)} & \textit{if } F_p(x) \geq 16 \\ \textit{2 (warning alarm)} & \textit{if } 8.8 \leq F_p(x) < 16 \\ \textit{3 (incidental alarm)} & \textit{if } F_p(x) < 8.8 \end{cases} . \quad (3)$$

II.3 Alarm Hierarchical Propagation

The prioritization of individual alarms aims to discriminate relative importance of them. The prioritized alarms give an important clue that can lead the operator to easily identify the status of systems to which they belong. Therefore, individual alarms may indicate system-level anomalies as well as equipment-level failure. In the DAC, the individual alarms of level 4 are propagated to higher levels according to the following rules:

[IF] Level 4 alarms activated has priority 1,
[THEN] The related higher level alarms are colored in red. The operator should immediately take action to restore the impaired function.
[IF] Level 4 alarms activated has priority 2,
[THEN] The related higher level alarms are colored in orange. The operator should check related system and take action as soon as possible.
[IF] Level 4 alarms activated has priority 3,
[THEN] The related higher level alarms are colored in yellow. The operator should continue to monitor the plant status.

The high-level information based on alarm propagation is able to relieve the operator from inferring plant-wide functional impacts caused by individual alarms with much cognitive burden.

II.4 Alarm Presentation

Alarm information that may be dynamically variable according to the plant status should be displayed on the CRT irrespective of the operator's intervention. In addition, its presentation should be clear and compact so that the operator can easily detect and identify the plant anomalies. In accordance with these principles, how to restrict the number of displayed alarms within the operator's cognition and how to present alarm information were deliberately designed in the DAC.

Critical function alarms of level 1 and system alarms of level 3 are spatially dedicated using alarm tiles.

When the system alarms are activated, the alarm tiles on the DAC will be used for system-wise alarm sorting. The same coloring rules are applied in discriminating the alarm impacts in each alarm hierarchy level.

Fig. 2 shows the CRT display of the DAC. In the figure, the left window displays individual alarm list in activated time order. The alarm list takes following string form:

"Time Related system Alarm description Priority"

The right window provides following options for efficient alarm dialogue:

- Operating mode is identified and reflexed in alarm processing.
- The priority levels can be manually adjusted.
- Action guidance for a single alarm is provided which includes possible causes, automatic actions, emergency actions, and follow-up treatments.
- Ringback function that informs the disappearance of alarms is achieved by dimming the colors of alarm strings. [6]
- Paging technique is used to display activated alarms over several pages.
- Audible tone is generated, if a new alarm is activated, to draw the operator's attention.

II.5 Reactor Trip Status Tree

Before reaching the reactor trip, the operator's identification of the cause that gives rise to the reactor trip is important in the aspects of response to the event or post-accident management that makes clear the cause of the trip. In this paper, the RTST was developed to enable the operator to know the status of each trip signal and discern what signal is closest to the corresponding trip setpoint by the following rules:

- divide the interval between the normal and trip setpoint of reactor trip signals into 4 status,
- divide the signal status into on/off as alarm tiles.

The closest signal to trip setpoint is the most possible cause of the trip.

III. Validation and Conclusions

As the results of simulation of the DAC with on-line data generated by full-scope simulator for Yonggwang (YG) Units 1 and 2, multiple fired alarms have been reduced by 58.6% on an average if the priority 1 alarms and priority 2 alarms are considered as alarms worth deliberating. As shown in Fig.3, which shows the comparison of the conventional alarm system in the YG NPPs with the DAC during loss of coolant accident (LOCA) scenario, the DAC has the capability of reducing the number of alarms generated in a logical manner for the operator not to suffer from cognitive overload due to excessive alarm information. The informing capabilities of plant situations of the DAC are generally acceptable as shown in Table 2. In conclusion, the DAC provides the operator with clean alarm pictures and compact information for the earlier termination and mitigation of an abnormal or emergent states.

References

1. L.R. Lupton, P.A. Lapointe, and K.Q. Guo, "Survey of International Developments in Alarm Processing and Presentation Techniques," AECL Research, Chalk River Lab., Chalk River, Ontario, Canada K0J 1J0, 1990.
2. S.S. Choi, K.S. Kang, H.G. Kim, and S.H. Chang, "Development of an On-Line Fuzzy Expert System for Integrated Alarm Processing in Nuclear Power Plants," IEEE Transactions on Nuclear Science, Vol. 42, No. 4, pp. 1-13, August 1995.
3. Z.A. Vale and A.M. e Moura, "An Expert System with Temporal Reasoning for Alarm Processing in Power System Control Centers," IEEE Transactions on Power Systems, Vol.8, No.3, pp.1307-1313, August 1993.

4. N. Naito and S. Ohtsuka, "Intelligent Alarm-Processing System for Nuclear Power Plants," Nuclear Technology, Vol. 109, pp.255-264, February 1995.

5. I.S. Kim, "Computerized Systems for On-Line Management of Failures : A State-of-the-art Discussion of Alarm Systems and diagnostic Systems applied in the nuclear industry," Reliability Engineering and System Safety, Vol. 44, pp.279-295, 1994.

6. ALWR URD, EPRI, Vol. II, Chapter 10, 1991.

Equipment Role	Severity	Response Types	System-oriented Priority
essential	severe	urgent manual	1
essential	severe	followup manual	2
essential	severe	just confirmative	3
essential	middle	urgent manual	4
essential	middle	followup manual	5
essential	middle	just confirmative	6
essential	slight	urgent manual	9
essential	slight	followup manual	10
essential	slight	just confirmative	11
support	severe	urgent manual	7
support	severe	followup manual	8
support	severe	just confirmative	12
support	middle	urgent manual	13
support	middle	followup manual	14
support	middle	just confirmative	15
support	slight	urgent manual	16
support	slight	followup manual	17
support	slight	just confirmative	18

Table 1. System-oriented prioritization logic matrix

Priority	Alarms
1	CTMT PRESS HIGH SI RCT TRIP 1E RAD HI MONITOR WARN NON-1E RAD HI MONITOR WARN CTMT SUMP A,B LEVEL HI/HI-HI SSPS T AVG LOW-LOW PRZR LEVEL LOW RCP SEAL INJ WTR FLOW LOW STM LN PRESS STM LN ISO SFTY INJ RCT TRIP
2	PZR CONT LEVEL LOW DEVIATION PRZR PRESS LOW RCS TEMP LO AUCTIONEER LETDN HX OUTLET FLOW LOW PRZR PRESS LO/BACK UP HEATERS ON LETDN RELIEF LINE TEMP HIGH LETDN RH HX OUT TEMP HIGH
3	PRZR RELIEF TK T HIGH PRZR RELIEF TK LVL HI/LO PRZR SPRAY LINE TEMP LOW MOIST SEP DRN TK A,B,C,D LVL HI/LO
4	PRZR SURGE LN TEMP LO PRZR SURGE LINE TEMP LOW RCP SEAL DP LOW RCP SEAL LEAK OFF FLOW LOW RCP A,B,C THERM BARR CLG COIL FLOW HI/LO PRZR PRESS LOW SI ALERT PRZR PRESS LOW ALERT PRZR PRESS LO(P-11) PRZR PRESS LOW/BACKUP HEATERS OFF T REF/AUCT T AVG HIGH LOW TEMP T AVG OR T ERROR SYSTEM BB TRN A,B TROU/DISA

Table 2. Test results of the DAC during LOCA

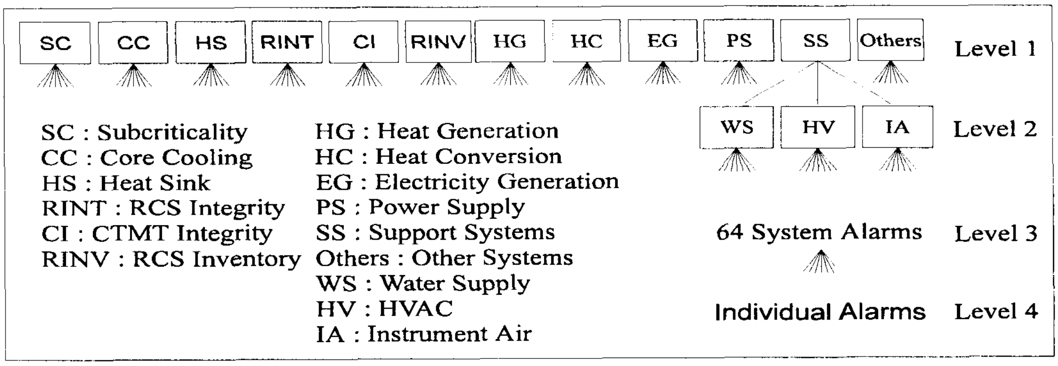

Fig. 1. Alarm hierarchical structure

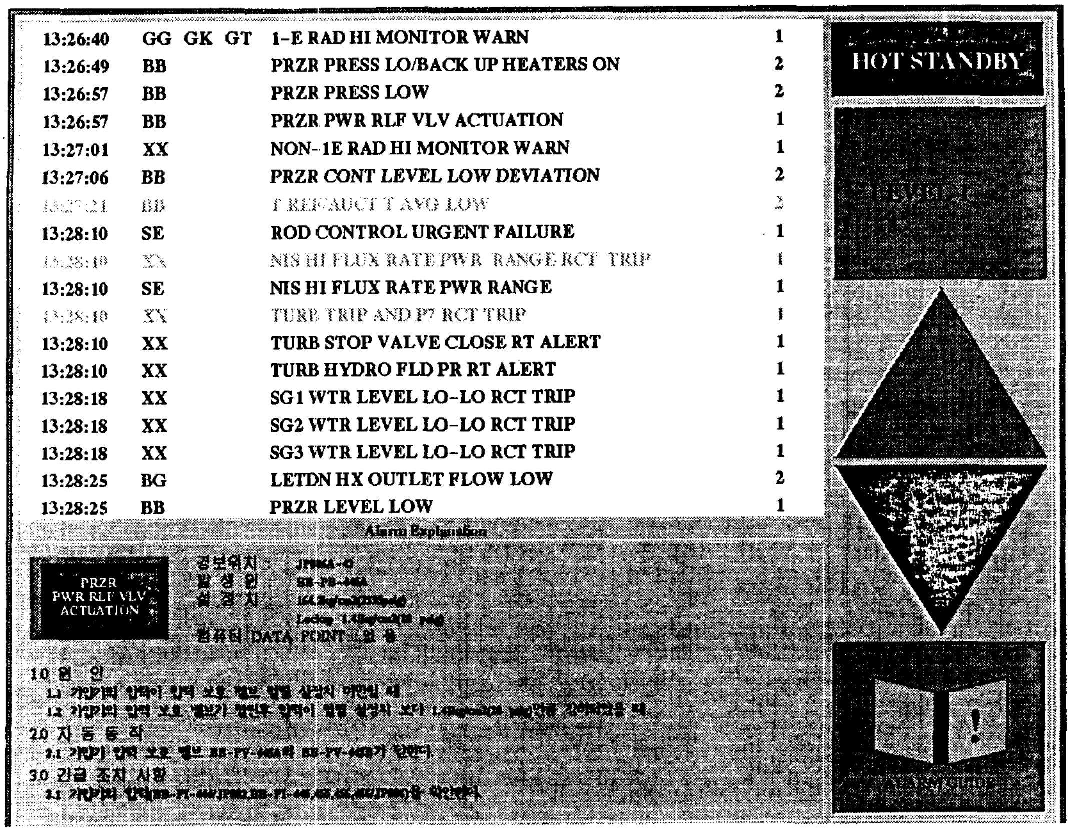

Fig. 2. CRT display of the DAC

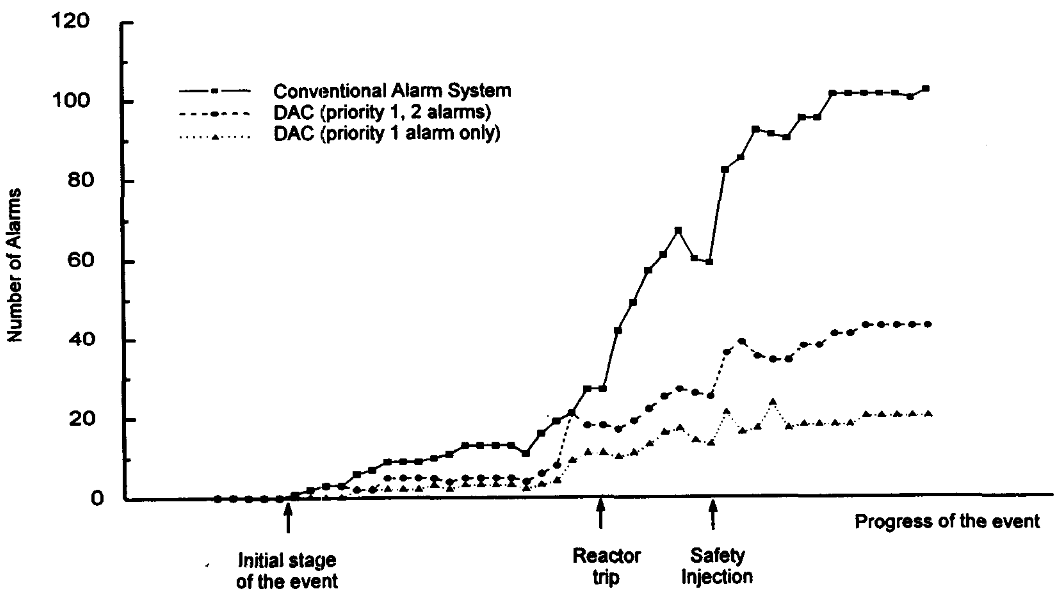

Fig. 3. Comparison of the number of alarms during LOCA