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Intelligent Software System for the Advanced Control Room of a Nuclear Power Plant

Soon Heung Chang[a], Seong Soo Choi[a], Jin Kyun Park[a], Gyunyoung Heo[a], and Han Gon Kim[b]
[a]Korea Advanced Institute of Science and Technology
[b]Korea Electric Power Research Institute

Abstract

The intelligent software system for nuclear power plants (NPPs) has been conceptually designed in this study. Its design goals are to operate NPPs in an improved manner and to support operators' cognitive tasks. It consists of six major modules such as "Information Processing," "Alarm Processing," "Procedure Tracking," "Performance Diagnosis," and "Event Diagnosis" modules for operators and "Malfunction Diagnosis" module for maintenance personnel. Most of the modules have been developed for several years and the others are under development. After the completion of development, they will be combined into one system that would be main parts of advanced control rooms in NPPs.

1. Introduction

Traditionally, the roles of digital computers have been much restricted in main control rooms (MCRs) of nuclear power plants (NPPs) such as gathering plant data and displaying safety parameters. They are being extended, however, in large programs on advanced control rooms (ACRs) which are underway with the strides in computer technologies, artificial intelligence (AI), and human factors engineering since mid 1980s. The control room of N4 PWR of France [1], that of ABWR of Japan [2], and Nuplex 80+ of USA [3] are the typical examples of the ACR.

Three important trends in the evolution of ACRs are 1) the increased automation, 2) the development of compact, computer-based work stations, and 3) the development of intelligent operator aids. Among these trends, however, the roles of intelligent operator aid systems have been limited such as alarm processing or computerization of operating procedures. Therefore, as the next step of technology development, operator aid functions will be enhanced in ACR design in order to replace or to assist operators' cognitive tasks. The application possibilities of AI techniques have been demonstrated in nuclear field through some of operator aid systems such as Operator Companion, IDA, DISYS, JOYCAT, and OASYS [4] and through the design of some ACRs such as ISACS-1 [5], the MCR of APWR, and Toshiba's intelligent man-machine system.

In this paper, we propose the intelligent software system that can be used as the core software of modern MCRs of NPPs. It will be installed on the mock-up system of the ACR being developed in Korea Advanced Institute of Science and Technology (KAIST).

II. Overall Concept of the Intelligent Software System

The operational states of NPPs can be divided into normal, abnormal, and emergency states. The operator's tasks under the states can be summarized as follows: monitoring of safety/performance related parameters, identification/prediction of plant behavior or abnormality, finding the strategy to maintain NPPs safe conditions or to protect unexpected reactor trip, and carrying out specific actions/procedures according to the strategy. That is, operators should perform many kinds of tasks not so easy to perform by one or a few crews according to plant states.

The objectives of the intelligent software system proposed in this paper are to automate both tedious or repetitive operations and mode-change operations except operational changes in safety systems, and to support operators on their cognitive tasks for the whole spectrum of plant operations. Operators' roles would be changed to a decision-maker or a supervisor from a performer by this system. Furthermore, it will make maintenance more effective by on-line monitoring and diagnosis of important systems/components. The intelligent software system is composed of six major modules such as "Information Processing," "Alarm Processing," "Procedure Tracking," "Performance Diagnosis," and "Event Diagnosis" modules for operators and "Malfunction Diagnosis" module for maintenance personnel as shown in Figure 1. These modules, which are under development, will be installed on the mock-up of the ACR shown in Figure 2 as the operating software. The key elements of the mock-up system are the large display panels that present the synopsis of the plant status and the compact, digital work stations for monitoring, control and protection functions. The work station consists of four consoles such as a dynamic alarm console (DAC), a system information console (SIC), a computerized operating-procedure console (COC), and a safety system information console (SSIC). In addition, there is an operation support console at the safety advisor work station which is not available at the other work stations. The "Performance Diagnosis," "Event Diagnosis," and "Malfunction Diagnosis" modules will be installed on this console to support a technical/safety advisor in the evaluation of plant status or equipment/component states.

III. Principal Functions of the Intelligent Software System

III.1 Information Processing

The main functions of "Information Processing" module are 1) providing processed data from field signals through signal validation for an ACR composed of a few compact work stations, 2) monitoring performance parameters to maintain normal conditions and safety parameters to identify threats to safety functions, 3) planning adequate procedure-based operational strategies, 4) displaying operating information within limited VDU area on the basis of the established information hierarchy of the plant, 5) providing equipment-level control means closely coupled with monitoring, and 6) coordinating the other modules in an efficient manner.

This module displays piping and instrumentation drawings (P&IDs) to provide the operator with system information required for situation awareness. The operating status of equipment, active paths, and necessary operating variables are dynamically displayed on the P&IDs. The plant information was organized in a four-level hierarchy as shown in Figure 3. On the basis of this hierarchy, success paths are also provided on the SIC for the operator's quick recovery action. Success paths are a kind of map that bridges from physical levels to functional levels to inform the operator of the plant functional status. A control action is performed using soft control after equipment/component to be controlled is selected on a P&ID, which provides a good sense of control because the effect of a control action is displayed on the same P&ID so that he can confirm feedback from the plant.

III.2 Alarm Processing

The main roles of "Alarm Processing" module which uses both spatially dedicated alarm tiles and variable, hierarchical CRTs are as follows; 1) eliminating meaningless alarms using time delay technique, suppressing less important ones with various suppression techniques such as mode dependency and state dependency, and dynamically assigning ranks on individual alarms by discerning important ones, 2) improving operators' situation awareness by structuring alarm hierarchy, and 3) providing suitable procedures timely. Figure 4 shows alarm display on the DAC. In addition, with the view of maintaining the knowledge base for alarm processing efficiently, the knowledge input tool for alarm (KIT-A) has been developed.

On the DAC, all the alarms were organized in a three-level hierarchy: plant alarms, system alarms, and equipment-level alarms. The hierarchy was established to show the propagation of alarm impacts from equipment levels to plant functional levels. "Alarm Processing" module assigns one of three discrete priority levels to individual alarms according to the urgency of recovery actions and the 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, whereas mode-oriented prioritization aims to identify the importance of the system to which the alarm belongs in current operating mode because the importance is dynamically varied depending on operating modes.

III.3 Procedure Tracking

The hard copy operating procedures exist for virtually all aspects of reactor operation including plant startup and shutdown. These procedures written sequentially, however, may not be possible to implement in the situation where many complex knowledge-based tasks should be performed simultaneously. Because of that, “Procedure Tracking” module has been developed.

Each step of operating procedures is composed of perception, judgment, and control. Because perception is to simply detect parameter values or equipment/component status by the human sensory systems, there are no qualitative portions in this task. Therefore, perception was readily automated as a kind of soft automation. Judgment is mainly a cognitive action to compare current states with predetermined states in operating procedures. Quantitative judgment can easily be automated because it has deterministic characteristic. In case of qualitative judgment, it is up to the operator considering software reliability in “Procedure Tracking” module.

The information processing model developed by Rasmussen was utilized to decide the level of hard automation during procedure execution. The three categories of skill-, rule-, and knowledge-based behavior were chosen on the basis of the model. To distinguish skill- or rule-based behavior from knowledge-based behavior, task-verb analysis was performed. Skill- or rule-based tasks were automated with the operator's intervening opportunity in the procedure execution at any time if necessary. On the other hand, in the case of knowledge-based tasks, there are several technical problems such as software reliability in automating the tasks. Therefore, manual control is more appropriate in knowledge-based tasks, so long as proper information is provided. Regarding cooldown and depressurization of the plant, however, their automating strategies have been developed for the purpose of lessening the operator's workload.

III.4 Performance Diagnosis

In a normal power operating state, the important operators' tasks are to maintain normal conditions and to enhance the performance. Generally, the performance of all components is degraded as time goes by, so is the performance of the plant. To protect that, "Performance Diagnosis" module is being developed where the following calculations are performed: In the baseline calculation, the optimal state values of balance of plant, which will be the design values, are calculated using the given information such as geometry and operational conditions. In the heat balance calculation, operational performance of equipment of a cycle, effects of operating variables on equipment performance, turbine cycle efficiency, and turbine cycle heat rate, and effects of equipment performance on turbine cycle efficiency are calculated using the measured parameters. Finally, in the corrective calculation, the electric power and heat rate are corrected so as to compare those values with their design values.

III.5 Event Diagnosis

Operators should carry out proper actions/procedures if incidents or accidents occur in operation and thus they should identify the causes of events. So the main objective of "Event Diagnosis" module is to identify and to diagnose the causes of events using fuzzy logic. In its diagnostic knowledge base, the relation between symptom and symptom group is represented using crisp relation whereas the relation between symptom and abnormal state is represented using fuzzy relation. In order to diagnose plant disturbances using predefined fuzzy relations, the following three compositional inference rules are established: hypothesis and confirmation rule, exclusion rule by present symptoms, and exclusion rule by absent symptoms.

V. Conclusions

The intelligent software system proposed in this paper has the integrated functions to reduce operators' physical loads and to support their cognitive interfaces over all the spectrum of plant operation including emergency conditions. In addition, the system will improve plant availability through preventive maintenance. This system, which is sponsored by Korea Electric Power Research Institute, is being developed by KAIST and Massachusetts Institute of Technology. Some of major parts of the software system have already been developed and some of them are under development. After the development of the major modules is completed, the system will be structured and demonstrated using a simulator to validate its performance and reliability.

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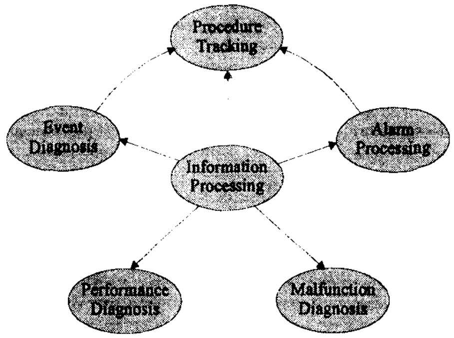

Figure 1. Structure of the intelligent software system

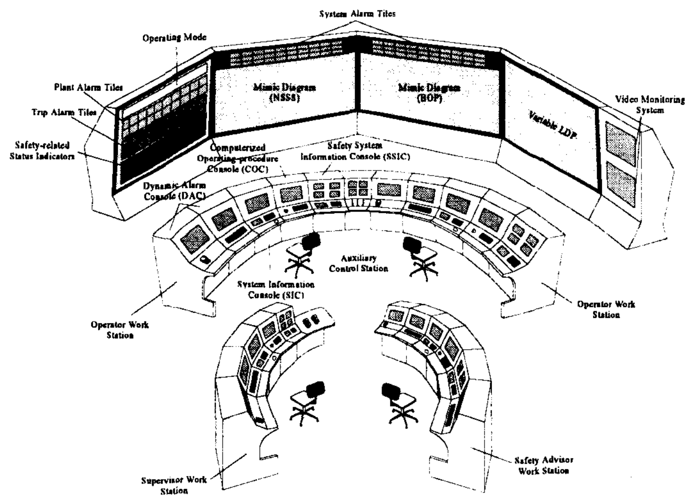

Figure 2. Configuration of an intelligent human-machine interface

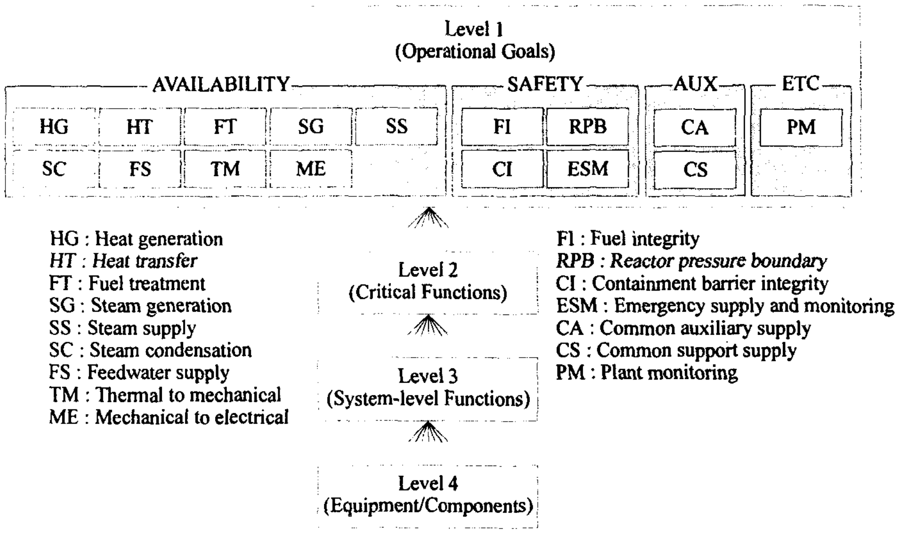

Figure 3. Hierarchical structure of plant information

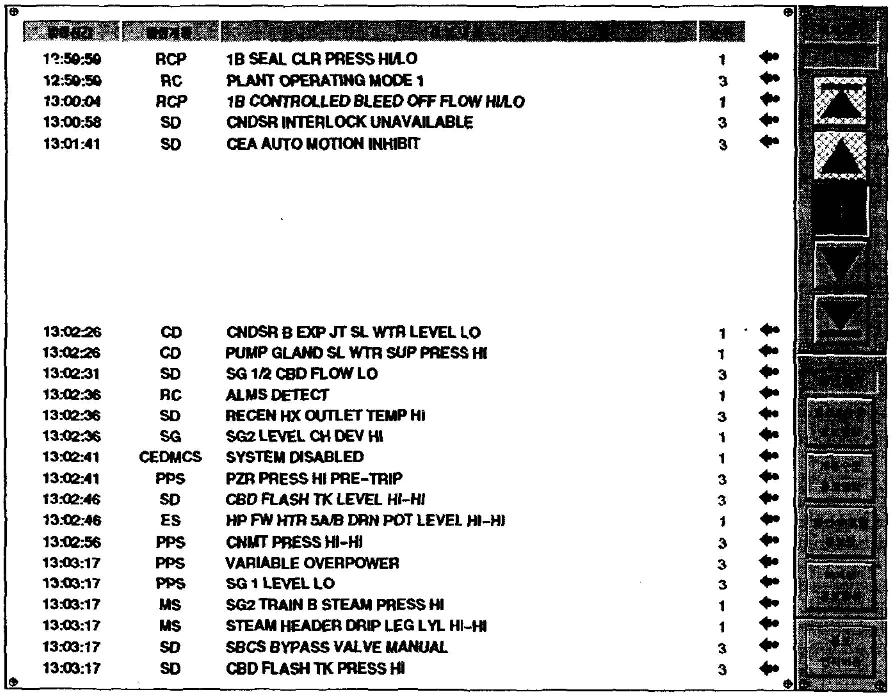

Figure 4. Alarm display on the DAC