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Analysis of operator support method based on intelligent dynamic interlock in lead-cooled fast reactor simulator

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ABSTRACT

In nuclear systems, operators have to carry out corrective actions when abnormal situations occur. However, operators might make mistakes under pressure. In order to avoid serious consequences of the human errors, a new method for operators support based on intelligent dynamic interlock was proposed. The new method based on full digital instrumentation and control system, contains real-time alarm analysis process, decision support process and automatic safety interlock process. Once abnormal conditions occur, necessary safety interlock parameter based on analysis of real-time alarm and decision support process can be loaded into human-machine interfaces and controllers automatically, and avoid human errors effectively. Furthermore, the new method can make recommendations for further use and development of this technique in nuclear power plant or fusion research reactor.

1. Introduction

In 20th century, there are two famous nuclear incidents. One is the Three-miles Island meltdown in USA 1979; the other is the Chernobyl Disaster in Soviet Union 1986. These two incidents were caused by human errors and have influenced the development of nuclear power plants (NPP). Some research indicated that human errors is the major contributor to accidents at NPPs (Hsieh et al., 2012). In an analysis of 180 significant events in NPPs have been reported in the United States, it was found that 48% of the incidents were attributed to human factor failures (Hwang and Hwang, 2003). Therefore, a lot of new operator support systems have been developed since the 1980s (Marcille et al., 1984; Wahlstrom, 1984). With the development of computer technology, the developing trend that digital instrumentation and control (I&C) system will supplant traditional analog I&C system in nuclear power plant is emphasized. It is proved that the application of digital I&C system has a broad prospect in nuclear area, not only in the third generation of NPPs, but in the future nuclear fusion research reactors such as fusion-driven hybrid system (Wu et al., 2002; Wu and Team, 2006, 2008).

The digital system is more precise than analog system, while the digital system brings too much information and too many alarms, which make it difficult for the operator to comprehend what is actually happening in the plant. For these reason, scientists and engineers are trying to develop such advanced man–machine-system (Kato et al., 1991), computerized procedures system (Pirus and Chambon, 1997), artificially intelligent monitoring system (Schirru and Pereira, 2004), integrated decision support system (Lee and Seong, 2007), neural network based system (Hadad et al., 2008), On-line monitoring system (Hashemian, 2011), and so on, for operators support in recent years. And some original research results have been applied in research reactors or simulators.

In this study, a new advanced operator support method based on intelligent interlock was proposed. The objective of the new method is to offer an integrated aid process to reduce the working strength of operators and help them avoid dangerous, irreversible actions. The new method might be originally applied in the High Intensity D-T Fusion Neutron Generator (Wang et al., 2015) and the future 10 MW China Lead-based Research Reactor (CLEAR) Wu and Team, 2009; Wu et al., 2012, 2015 if it pass the test in ADS-CLEAR Simulator.

2. Overview of intelligent dynamic interlock method

The development of reactor monitor and control operation process could be classified into two types, common operation process and operation process with support systems. In the common operation process, the instrumentation data is acquired by display system, then operators obtain plant information through the display system. In the next step, operators judge operational status of the reactor and implement the operations using control system. The common operation process can solve the single alarm quickly

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and effectively. However, in an reactor, many alarms from different systems often occur at the same time during an incident (Hsieh et al., 2012), the operation process with support systems could help the operators to select a correct response efficiently.

Intelligent dynamic interlock method is a powerful framework for developing operator support system. It converges the advantages of both two types of the operation process. Fig. 1 shows the block diagram of intelligent dynamic interlock method.

Instrumentation system, protection system and control system are three indispensable base systems, and the thinner lines flowing represent the common operation process. Instrumentation system directly picks up signals from the plant, and send them to display system and protection system. The protection system works independently, and main function of this system is reactor trip and to drive the engineering safety feature actuation system. The control system can overcome the disturbance and maintain the stability of the reactor.

Knowledge-based database is an important basic part of the method, which based on Data Warehouse. It supports information management for decision making by integrating data form instrumentation system and protection system. In this intelligent dynamic interlock method, knowledge-based database analyzes the state of reactor, then it sends the analyze result to real-time alarm analysis process and decision support process. The two processes are to suggest support system to aid every activity of the human cognitive process and to integrate these support systems into one system to maximize efficiency (Lee and Seong, 2007). And the dynamic computerized operating procedures aid operators with the strictly correct reaction.

Real-time alarm analysis process can receive real-time data from the instrumentation system, pick and store the real-time data. At the same time, it can pre-processing these data by combining with the historical data of knowledge-based database during a cycle time. If the reactor in a normal state, control system performs the default operations. If the reactor is under accidental conditions, according to the information acquired from instrumentation, knowledge-based database sends an "expert" opinion to the process. Then it analyses and judges these fault messages with the "expert" opinion. The list of tasks will be ordered by importance. The most urgent and important tasks are on the top of the list. Then the dynamic display system shows the list to the operators. Meanwhile, real-time alarm analysis process sends the list to decision support process.

The main function of decision support process is to aid operators select the most suitable emergency operating procedures (EOP) or abnormal operating procedure (AOP). It guides operators through all phases of the troubleshooting process, starting with the problem symptoms and ending with an implemented solution.

Automatic safety interlock process is an important part in Intelligent Dynamic Interlock method. It is a "bridge" between decision support process and the reactor control system, which based on the Digital/Distributed Control System (DCS). With the development of computer and information technology, DCS have shown high reliability, good flexibility and programmability, so it is widely used in Operator Support System. Because of these characteristic of DCS, we can use the coding system, computer memory and configuration system to construct and deploy fully configured, integrated, and dynamic environments.

The thickest lines flowing show execution process of automatic safety interlock process. Once an abnormal plant condition occurs, automatic safety interlock process can add necessary safety interlock into the dynamic computerized operating procedures and control system. Meanwhile, it can drive the dynamic display system to highlight the most important information in the graphical user interface.

3. Test and analysis of advanced operator support method

3.1. Test platform

The advanced operator support method based on intelligent dynamic interlock will be applied firstly in Institute of Nuclear Energy Safety Technology (INEST), Chinese Academy of Science (CAS), FDS team. INEST have four main research projects: lead-based reactor (Wu et al., 2015), fusion nuclear technology and material (Huang et al., 2007; Qiu et al., 2000), safety technology of nuclear power plant (Wu et al., 1999), and nuclear technology and application (Wu et al., 2008). So we have serval facilities for verification and application of the new method.

The basis experimental hardware system is the ADS-CLEAR Simulator (ACSIM). ACSIM is an important assistant system for reactor engineering design, reactor security analysis, research of neutron transport simulation. As the first full-scope prototypes simulation system of 10 MW CLEAR-I, ACSIM has been developed by utilizing computerized Human Machine Interface (HMI) as well as digitalized instrumentation and control system.

In the advanced ACSIM main control room, the new operator support method based on intelligent dynamic interlock can be tested by researchers. Fig. 2 shows the main control room of ADS-CLEAR simulator.

3.2. Test database

Knowledge-based Database is a basis software system of ACSIM. Fig. 3 shows schematic diagram of the Knowledge-based Database.

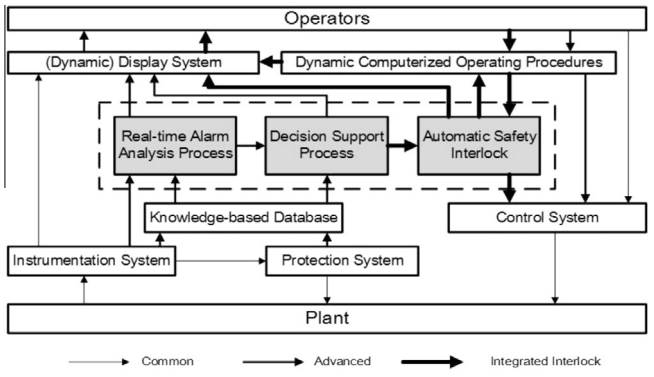

Fig. 1. Simplified intelligent dynamic interlock method block diagram.

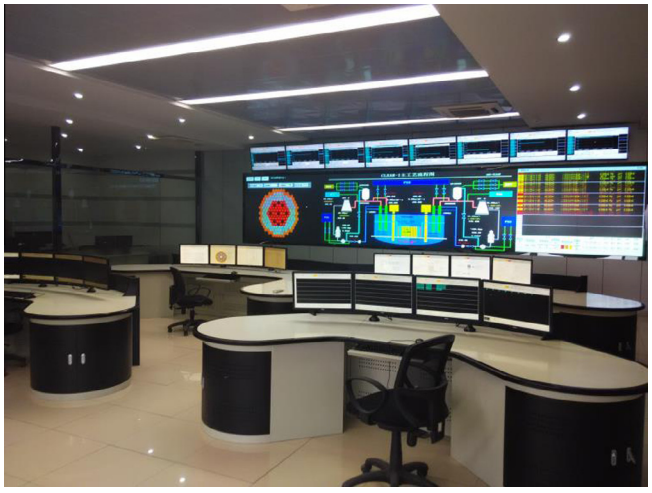

Fig. 2. Main control room of ADS-CLEAR simulator.

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