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Assessment of human–machine interface design for a Chinese nuclear power plant

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Abstract

A nuclear power plant (NPP) is a complex system but requires high reliability. The human–machine interface (HMI) design plays very important role in reactor safety. This paper describes an assessment on HMI design of a Chinese NPP, using a software system named Dynamic Interaction Analysis Support (DIAS). DIAS can give not only quantitative indices for dynamically assessing the HMI design, but also allow modify the values of these indices by taking into account human error probability during specified emergent operation procedures. The operation procedures dealing with postulated accidents and transients recorded from a full-scale plant simulator in the training center of a Chinese NPP were selected as references. According to the results of simulation and analysis, the potential problems in the HMI design and the operation procedures were detected. Suggestions to improve the HMI design and the operation procedures were addressed.

Keywords: Nuclear power plant; Human–machine interface; Assessment; Human error; Simulation

1. Introduction

Rapid economical growth in China has demanded much more energy supply [1]. China will probably become one of the major countries worldwide to construct new nuclear power plants in the first half of this century. Different types of foreign nuclear power plants (NPPs) (e.g. French-designed Daya-Bay PWR NPP, Canadian-designed Qin-Shan CANDU NPP and Russian-designed Tian-Wan VVER NPP) have been imported to meet the growing requirement for electric power supply in Chinese energy market. On the other hand, developing indigenous hardware and software technologies has been the basic Chinese national policy [2]. The development has been conducted through adopting and converting the imported foreign technologies.

NPP is a kind of 'man-in-the-loop' system. The importance of interactions between man and the machinery system has been recognized because of the accidents resulted from human errors, such as the TMI accident and the Chernobyl disaster. Efforts have been made to study and improve the design of human–machine interface so that the safety and reliability of NPP operation can be enhanced. However, the approach of general human–machine interface (HMI) design in China still remains in its primitive phase. It means that the attention is mainly paid to 'make something can be used'. The detailed scrutiny on HMI and man–machine interactions is still on its developing stage in China, although the assessment of safety functions, the reliability of equipment, the operational procedures and the principles of quality assurance plan have been well conducted. Under such a situation, China does need to establish assessment methodology and tools for evaluating HMI design of NPPs so that it can better fit the convenience for Chinese operators in Chinese culture and tradition. Therefore, the importance of HMI assessment tools must be addressed by pursuing the development strategy of Chinese nuclear power industry, either importing NPPs from other countries or accelerating the construction of indigenous NPPs.

The Institute of Nuclear Energy and Technology (INET) of Tsinghua University has conducted a co-operation with MITSUBISHI Electric Corporation on HMI evaluation for light water reactors since 1998. DIAS, a computer-simulation-based evaluation software system [3], has been applied and modified for assessing HMI design of a typical

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Chinese NPP. The project aims at verifying the applicability of DIAS and finding potential problems in the HMI design of a selected Chinese NPP.

This paper illustrates the application of DIAS to HMI assessment of an actual Chinese NPP. Some operation procedures related to postulated accidents and transients are selected as reference. The quantitative evaluation indices, such as the operation time, horizontal moving distance, etc. are given by DIAS simulation. The human error probability in each operation action is also estimated when the results from DIAS are analyzed for all operation procedures.

2. Description of DIAS

To design an HMI having high quality of usability, reliability and safety, the ideal design process is to iterate the cycle of analyzing, designing, making a prototype, evaluating, and giving feedback to the design. Especially, the design for NPP HMI requires several iterations, which is time and money consuming. Recently, computer-simulation plays a great role in solving engineering problems. DIAS is such a system for HMI design and assessment developed by MITSUBISHI Electric Corporation [4].

DIAS is a distributed simulation system combined with the function of analyzing interactions between man and machine. By simulating and assessing the same operating procedure for different designs, the advantages and disadvantages of different HMI designs can be mutually compared. Fig. 1 depicts the configuration of DIAS.

2.1. Distributed simulation system

The distributed simulation system [5] consists of two simulators, the operator simulator and the HMI simulator. It simulates the interaction between the operator and the HMI. The data editors are sub-systems of the distributed simulation system. They are employed to edit the operating procedure data and the HMI design data.

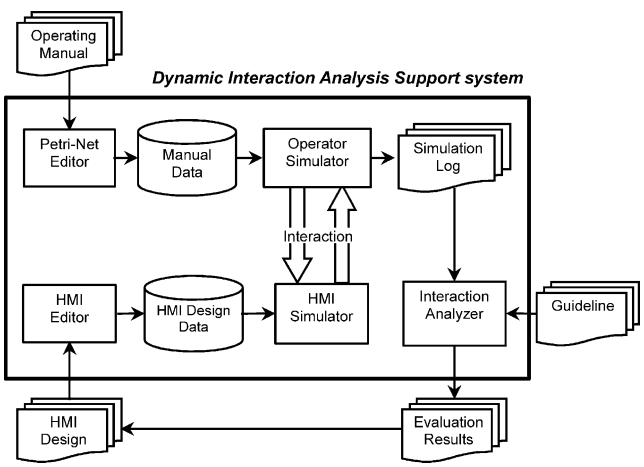

Fig. 1. Configuration of DIAS.

Operator simulator. It simulates the operator actions in a designated operating procedure by taking into account the cognitive and behavioral features, such as visual aspects (focal view and peripheral view), human cognitive model [6], operational speed, and walking speed, etc. The operating procedure data are included in the Petri-net model and edited by the Petri-net editor.

HMI simulator. It constructs a virtual control room where the virtual operator in the operator simulator works. It displays the layout of the equipment, the moving course and the visual scope of the operator, etc. The HMI data are input from the HMI editor.

2.2. Interaction analyzer

The distributed simulation system records a list of sequential executed tasks, operator positions, visual points, time, and so on. Interaction analyzer calculates several indices by analyzing the simulation results, which are related to physical workload and mental workload.

Some evaluation activities, such as checking guidelines and estimating HEP, require the analyst's judgment depending on the interaction situation. The interaction analyzer shows details of the interaction, such as the layout of the equipment and the visual scope of the operator. The Technique for Human Error Rate Prediction (THERP) [7] forms the basis for estimating HEP of the operators in operation procedures. The analyzer prompts questions to guide the user to select a suitable human error rate for each task according to the rules of THERP. It also determines if the action of each task should be taken by checking operation procedures in order to prevent subjective judgment.

3. Assessment of the HMI design of a Chinese NPP

3.1. Evaluation subject

A two-loop Chinese NPP was built in early 1980s by Chinese nuclear engineers. Its main control room is based on traditional analogue control technology with a number of control panels. The operation activities are performed by a group of operators in either normal condition or accident situation. The operation group normally consists of three operators and a supervisor. One of the operators is responsible for nuclear reactor operation. The rest two are responsible for operating turbine and electric power systems, respectively. Operators' activities are directed by the supervisor in case of an accident or an abnormal transient. The supervisor reads the predefined operation procedures loudly to guide the operators to execute operation actions.

The control room of this Chinese NPP is very large compared with modern digital-computer-based advanced