Reliability Engineering and System Safety 94 (2009) 759–762

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

Diagnostic system for identification of accident scenarios in nuclear power plants using artificial neural networks

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ARTICLE INFO

Article history:
Received 10 June 2008
Received in revised form
28 July 2008
Accepted 4 August 2008
Available online 13 August 2008

Keywords:
Artificial neural networks
Loss of coolant accident
Nuclear power plant
Operator support system

ABSTRACT

This paper presents the work carried out towards developing a diagnostic system for the identification of accident scenarios in 220 MWe Indian PHWRs. The objective of this study is to develop a methodology based on artificial neural networks (ANNs), which assists in identifying a transient quickly and suggests the operator to initiate the corrective actions during abnormal operations of the reactor. An operator support system, known as symptom-based diagnostic system (SBDS), has been developed using ANN that diagnoses the transients based on reactor process parameters, and continuously displays the status of the reactor. As a pilot study, the large break loss of coolant accident (LOCA) with and without the emergency core cooling system (ECCS) in reactor headers has been considered. Several break scenarios of large break LOCA have been analyzed. The time-dependent transient data have been generated using the RELAP5 thermal hydraulic code assuming an equilibrium core, which conforms to a realistic estimation. The diagnostic results obtained from the ANN study are satisfactory. These results have been incorporated in the SBDS software for operator assistance. A few important outputs of the SBDS have been discussed in this paper.

1. Introduction

Nuclear reactors have become much more complex with an accompanied growth in supporting technology. Maximum care is exercised to keep the likelihood of potential risks to a very low value. However, in the event of an unlikely abnormal occurrence, the operator has to take necessary actions relatively faster, which involve complex judgments, making trade-offs between partly incompatible demands and requires expertise to take proper decision. It is a commonly shared belief that timely and correct decisions in these situations could either prevent an incident from developing into a severe accident or mitigate the undesired consequences of an accident. Moreover, in such situations, poor decisions may be taken because of the short time available for sorting out the relevant information and lack of expert knowledge.

The objective of the plant diagnostic system is to give the plant operators appropriate inputs to formulate, conform and perform the corrective actions. The event detection can be classified as a pattern recognition problem. When an event occurs starting from the steady-state operation, instruments' readings develop a time-dependent pattern and these patterns are unique with respect to the type of an event. Therefore, by properly selecting the plant process parameters, the transients can be distinguished. To tackle this problem, a number of linear and nonlinear pattern recognition techniques can be utilized [1,2]. For this work, artificial neural networks (ANNs) will be utilized for event identification.

Analysis has been carried out for 32 break scenarios of loss of coolant accident (LOCA) in inlet and outlet reactor headers with and without an emergency core cooling system (ECCS). These break scenarios have been modeled with a single neural network consisting of 37 input, 3 output and 2 layers of hidden neurons. The time-dependent transient data have been generated using the RELAP5 thermal hydraulic code assuming an equilibrium core that conforms to realistic estimation [3]. The training and testing of neural networks were carried out using BIKAS Neural Networks Simulator developed by IIT Kanpur in collaboration with Bhabha Atomic Research Centre. The results obtained from the study are satisfactory. These results have been incorporated in the symptom-based diagnostic system (SBDS) software for operator assistance.

2. Symptom-based diagnostic system

SBDS is an operator support system that diagnoses the initiating events (IEs) of nuclear power plant based on reactor process parameters, detects deviations from normal operating conditions, determines the significance of the situation and

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doi:10.1016/j.ress.2008.08.005

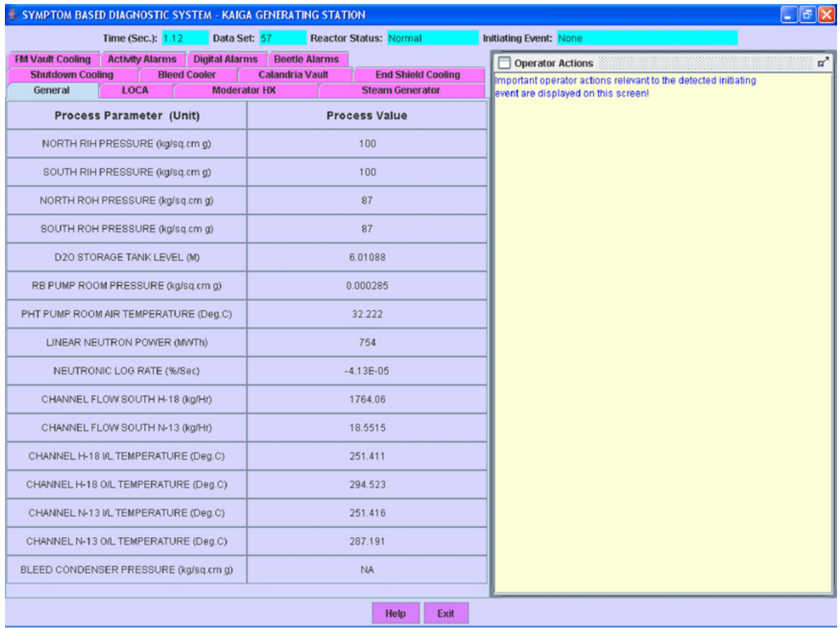

Fig. 1. Main screen of SBDS.

recommends an appropriate response in a short time. It performs these tasks with the help of ANNs by operating on a large knowledge base, which is developed by collecting the time-dependent transient data from various data sources. It provides necessary and sufficient information to the plant operator to take appropriate actions to mitigate the abnormal situations in an adequate time [4]. SBDS enables the operator to know the status of the plant at any instant of time during reactor operations. Whenever an event is detected, this system will record the type of the event, time at which the event has occurred and the relevant process parameters and their values at the time of initiation of the event. The main window of SBDS is shown in Fig. 1.

The window shows several panels containing process parameters such as primary heat transport (PHT) pressure, PHT temperature, storage tank level, PHT feed, bleed flow, etc. and their time-dependent process values, text fields showing current process time, data set at current time, current status of the reactor and type of IE if occurred. There is also an operator actions screen showing the operator actions for the identified transient. There are unique sets of parameters for different transients and they are categorized under different panels. By selecting a suitable panel, relevant parameters and their current process values can be seen on the operator screen. For example, under the LOCA panel, a list of all relevant parameters to this IE is given. Under the general panel some important parameters, which are common to most of the IEs, have been given. All the process parameters that are being seen in Fig. 1 are Computerized Operator Information System (COIS) parameters.

3. Large break LOCA identification using ANNs

A large break LOCA, although highly unlikely, is the most severe process failure with which the protective system must cope. It can cause fast coolant voiding from the core and hence fast positive reactivity transient that the reactor shutdown system must be able to terminate. As a pilot study, the entire spectrum of break sizes and locations is analyzed to assess the system performance/behavior. As the location of the break in the PHT system affects the system response, breaks in both reactor inlet and reactor outlet headers (ROH) are considered. Also, the break scenarios are analyzed by considering with and without ECCS. The break area is represented in terms of percentage of maximum possible break area from a double-ended guillotine break of the reactor header.

3.1. Event description

Following the large breaks, the PHT system depressurizes rapidly, which causes voiding in the reactor core. This coolant voiding in the core causes positive reactivity addition and consequent power rise. Several trip signals will be activated, namely, high log rate, low PHT pressure, high neutron power, low PHT coolant flow and high reactor building pressure one after the other in a short time. The sequence of actuation of trip signals is largely dependent on break location. In general, for breaks on the reactor inlet header (RIH) side, high log rate signal is a first signal followed by high neutron power, while for breaks on the ROH side, low-pressure signal is usually the first signal followed by high log rate.

3.2. Network modeling

Several important process parameters identified from the COIS, Radiation Data Acquisition System (RADAS) and Beetle Monitoring System (BMS) are selected for transient analysis [5–8]. Table 1 lists the process parameters for the case of LOCA. It consists of 35 analog and 2 digital parameters. The analog parameters will have time-dependent transient data whereas digital parameters indicate the status of certain process states such as reactor trip, pump room pressure high, etc. This type of problem is modeled as a pattern recognition problem in neural networks wherein a set of input values with respect to time represents a class of output. Thus, the events are classified into several classes based on the input patterns.

In order for training the neural networks, continuous time-dependent data are needed [9–11]. For this purpose, the time scale of the transient duration is divided into several intervals such that