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Original Article

PREDICTION OF SEVERE ACCIDENT OCCURRENCE TIME USING SUPPORT VECTOR MACHINES

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ABSTRACT

If a transient occurs in a nuclear power plant (NPP), operators will try to protect the NPP by estimating the kind of abnormality and mitigating it based on recommended procedures. Similarly, operators take actions based on severe accident management guidelines when there is the possibility of a severe accident occurrence in an NPP. In any such situation, information about the occurrence time of severe accident-related events can be very important to operators to set up severe accident management strategies. Therefore, support systems that can quickly provide this kind of information will be very useful when operators try to manage severe accidents. In this research, the occurrence times of several events that could happen during a severe accident were predicted using support vector machines with short time variations of plant status variables inputs. For the preliminary step, the break location and size of a loss of coolant accident (LOCA) were identified. Training and testing data sets were obtained using the MAAP5 code. The results show that the proposed algorithm can correctly classify the break location of the LOCA and can estimate the break size of the LOCA very accurately. In addition, the occurrence times of severe accident major events were predicted under various severe accident paths, with reasonable error. With these results, it is expected that it will be possible to apply the proposed algorithm to real NPPs because the algorithm uses only the early phase data after the reactor SCRAM, which can be obtained accurately for accident simulations.

1. Introduction

Because both size and complexity of nuclear power plants (NPPs) are increasing, understanding system problems and their mitigation poses significant challenges to operators [1]. If a transient occurs in an NPP, operators will try to predict which kind of abnormality has occurred by checking various plant status variables to protect the NPP from hazardous situations such as severe accidents. Because the operator's actions are heavily affected by the instructions written in the procedures, it is very important for operators to determine the initiating events. However, due to the many complicating factors, such as overload of information, high workload in urgent situations, and the short time available

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for diagnosis, operators can become confused and make wrong decisions, thereby leading to dangerous situations. To help operators mitigate abnormalities of NPPs properly and effectively, various operation support systems with artificial intelligences (AIs) have been developed. For example, AI techniques were applied to signal validation systems [2–4], fault diagnosis systems [5,6], and many other support systems.

Similarly, operators take actions based on severe accident management guidelines (SAMGs) when there is the possibility of a severe accident occurrence in an NPP. In such a situation, information about the occurrence times of severe accident-related events is very important to operators so that they can set up severe accident management strategies. Currently, there are many computer codes that can perform severe accident-related analyses, but because they require a long time for both the simulation and the setting of parameters, it is hard to apply such codes in real-time support systems. Therefore, support systems that can quickly provide this kind of information to operators would be very useful when they try to manage severe accidents.

A previously conducted study that dealt with severe accident monitoring using several AI techniques [7] successfully predicted the occurrence times of several severe accident-related events, including core exposure time, time when core exit temperature exceeds 1,200°F, and reactor vessel (RV) failure time. However, the study was only conducted for a case in which no action was taken for mitigation of the accident. In a real situation, however, operators would take certain mitigation actions before a severe accident happens, and these cases also need to be considered. Therefore, various paths to severe accidents should be considered to develop more realistic support systems.

To monitor and predict severe accidents, diagnosis of initiating events should be the first step. In this research, fault diagnosis using support vector classification (SVC) and support vector regression (SVR) algorithms that were suggested by Na et al. [8] were applied with some modifications. The similarity between this study and the reference comes from the use of the same algorithms, that is, SVC and SVR. However, the main difference is that the reference trained two SVRs for break size estimation in the loss of coolant accident (LOCA) case, with consideration of the hot leg LOCA and cold leg LOCA, whereas there were six SVRs for break size estimation with consideration not only of the hot leg and cold leg but also of small break (SB), medium break (MB), and large break (LB) LOCAs. Because of this major difference, two SVCs were applied to classify the SB, MB, and LB LOCAs before the detailed break size estimation was conducted by the trained SVR.

SVC and SVR are included in support vector machines (SVMs); an SVM is a machine-learning algorithm that has been successfully used in pattern recognition for cluster analysis [9]. SVM is applied in many fields of research because of its high performance in finding global optimums, and high performance in real applications as well as in artificial neural networks, which have been applied for a comparatively long time.

This research also proposes an algorithm based on SVR that predicts the occurrence time of major events of severe accidents, such as maximum core temperature exceeding 1,200°C, RV failure, and containment (CTMT) failure when operators fail to mitigate transient. By using event-tree (ET) analysis, which is widely used in the field of probabilistic risk assessment, our method is able to classify various paths that lead to core damage; in addition, severe accident scenario occurrence times can be predicted for each major path.

Because there are many kinds of initiating events and severe accident paths, considering all of them is very labor intensive. However, if it is possible to show that these methodologies can predict the occurrence time successfully, expanding the coverage of the research will be much easier. In this regard, only an LOCA transient was considered as an initiating event and eight severe accident paths under this LOCA situation were selected as parts of a case study. The eight severe accident paths contain four severe accident paths from the SB LOCA, and two paths each from the MB and LB LOCAs, according to probabilistic priority. In addition, for further simplification, conservative assumptions (i.e., assuming the worst cases) were made for each path. For example, severe accidents can occur when three or all four safety injection lines fail to inject water in an LB LOCA condition. In this regard, it is assumed that all four safety injection lines failed to inject water in the safety injection failure-related paths, because this is the most serious case.

The proposed algorithms were trained and validated using data obtained from the MAAP5 (modular accident analysis program) code simulations. The reference plant for this research is the Advanced Power Reactor 1400 (APR1400).

2. LOCA identifications

Prior to the prediction of occurrence time under LOCA cases, it is necessary to identify the break location because the occurrence time differs according to the break location. In this regard, hot leg LOCA and cold leg LOCA were identified using SVC in this study. Similarly, because the severe accident path and occurrence time differ according to the break size, SB LOCA, MB LOCA, and LB LOCA were classified using multiple SVCs and SVRs. In addition, the detailed break size was estimated to verify the accuracy of the suggested methodology, although the results were not used for occurrence time prediction.

2.1. *Data acquisition*

To estimate the break location and break size of an LOCA, it is necessary to collect data sets that indicate how plant status variables will change when an LOCA occurs. Because there are only a few sets of accident data, data should be obtained from computational simulations.

Data sets obtained from the simulation were used for training the SVC and SVR algorithms; properly trained SVC and SVR algorithms have the capability to classify break locations and estimate break sizes with the inputs of the plant status variables. In addition, the trained algorithms are able to perform such classification or estimation in a short time after transient occurrence, so that operators can start the mitigation process as quickly as possible.