Study on Automation System for Startup and Shutdown Mode using Artificial Intelligence

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1. Introduction

From the Operational Performance Information System (OPIS) for Nuclear Power Plants (NPPs), which is the overall database for controlling safety performance, the scram by human error of total scram was found to be 15% during last 20 years in South Korea (Fig. 1.). As seen Fig. 2, among human error, human error under startup and shutdown was 51%. Thus, human error under startup and shutdown was found to be 9% during last 20 years in South Korea [1].

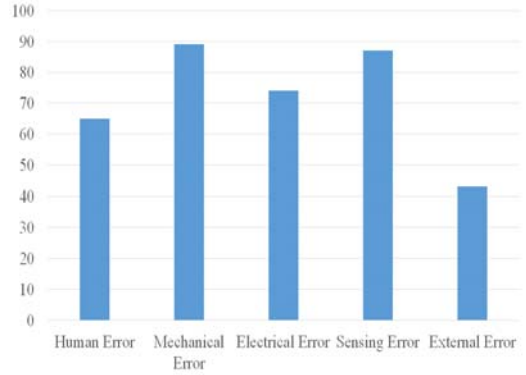

Fig. 1. The number of scram in NPPs within 20 years

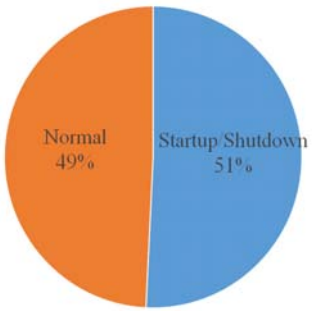

Fig. 2. The number of scram due to human error under the operating mode

For reducing the operator's load from the startup and shutdown operation of existing NPPs, it is necessary to develop an automation system based on deep learning which lead current Artificial Intelligence (AI) technology.

Therefore, in this study, an automation system for the startup and shutdown in NPPs has been developed using deep learning. a selected deep learning algorithm is a Recurrent Neural Network (RNN), which is a robust method for time series analysis. A feasibility study for the automation system is conducted by using Compact Nuclear Simulator (CNS) that is a simulator based on Westinghouse 3-loop NPPs The target scenario for the feasibility study is bubble creation in a pressurizer under startup.

2. Background

In this section RNN which is deep learning algorithm and operating procedure to create bubble in pressurizer under startup mode are described.

2.1 Recurrent Neural Network

Recently, AI technology has facilitated a breakthrough by accumulating data, advanced algorithms, and growing computing power. Though there are many AI technologies and applications, the key technology of the breakthrough is deep learning that leads current AI technology. In many technical fields, the development of automation and autonomous systems has been studied by using deep learning.

There are many method of deep learning. Among these method, the RNN has advantages to analyze time series analysis such as natural language processing and voice recognition. The basic structure of RNN is illustrated in Fig. 3.

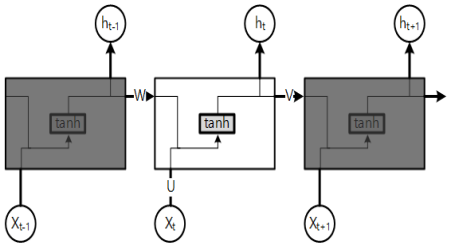

Fig. 3. The basic structure of RNN

In the Fig. 3, bottom-up processing shows general artificial neural networks. X indicated input layers, square indicated hidden layer, and h is output layers. Unlike general artificial neural networks, RNN is able to memory previous step weighting. In other word, when *h(t)* is calculated at the time step *t*, *h(t-1)* which is hidden value of previous step and *x(t)* are considered.

Even though RNN has advantage to be able to considering past step, it occurs problem about long-term time dependency. To overcome the long-term time dependency, Long Short Term Memory (LSTM) was developed [2, 3]. The concept of LSTM is that a cell of

RNN in the Fig. 3 re-design to solve long-term time dependency as seen the Fig. 4.

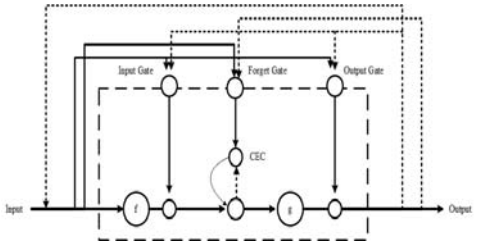

Fig. 4. The structure of LSTM cell

The characteristic of LSTM cell is introducing CEC (Constant Error Carousal), input gate, output gate, and forget gate.

2.2 Bubble Creation in Pressurizer under Startup

There are five operating modes of Nuclear Power Plants (NPPs): refueling, startup, low power, normal power, and shutdown. In these operating modes, the startup and the shutdown operating modes of NPPs are completely manually operated.

The automation system is based on an expert system due to characteristics of the startup and operating modes, and a variety of operating controls depending on each operator are simulated by deep learning. Automation strategies are established and a feasibility study is conducted by using CNS that is a simulator based on Westinghouse 3-loop NPPs. The target scenario for the feasibility study is bubble creation in a pressurizer under startup.

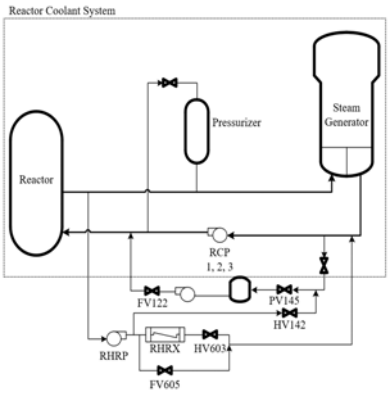

Fig. 5. Schematic diagram of nuclear system for heat up mode

To bubble creation in pressurizer, pressurizer heater is used for increasing temperature and pressure is controlled by HV 142 vale and FV 122 valve.

3. Results

The Fig. 6 shows the results of prediction of valve position by deep learning. As seen the Fig. 6, the prediction of HV142 valve is well followed with target HV142 valve position. However, after 1,400 seconds, it is not followed target valve position due to training dataset.

Table 1 described operating time of RCP (Reactor Coolant Pump) for target and prediction. In addition, a RCP operating time is predicted with an error of 1 second.

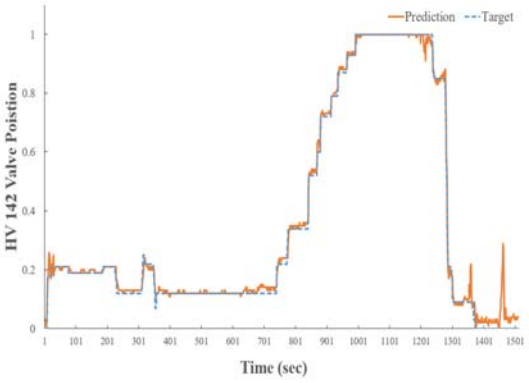

Fig. 6. The results of HV142 valve position

Table 1. The operating time of RCP

RCP	Target Time (sec)	Predicted Time (sec)
2	926	927
1	1163	1164
3	1280	1279

3. Conclusions

In this study, automation system for startup and shutdown in NPPs is researched. A feasibility study was conducted for target scenario which is bubble creation in pressurizer. The deep learning algorithm is RNN with LSTM cell. For further study, through gathering training dataset and feedback from simulator, model accuracy should be calculated.

ACKNOWLEDGEMENT

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