Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 12-13, 2016

Smart Sensing of the Aux. Feed-water Pump Performance in NPP Severe Accidents Using Advanced GMDH Method

Young Gyu No [a*] and Poong Hyun Seong [a]
[a] Department of Nuclear and Quantum Engineering, KAIST
373-1, Guseong-dong, Yuseong-gu, Daejeon, Republic of Korea, 305-701
[*]Corresponding author: ygno@kaist.ac.kr

1. Introduction

Since the Fukushima nuclear plant accident, the public's concern regarding an integrity of safety-critical components and instrumentation of nuclear power plants (NPPs) has increased. This concern is deepened because an operator cannot quickly check the status of the plant in an incident or accident situation or respond appropriately to each situation. Especially, the safety-critical components are defined as the pumps or valves to perform the functions of accident mitigation. Therefore, monitoring systems for safety-critical component are needed in NPPs. In this study, as a result of review for safety-critical components, Aux. feed-water pump is selected to perform case study.

Most of monitoring systems for component have been suggested by using the directly measured data. However, it is very difficult to acquire data related to safety-critical component' status. Therefore, it is necessary to develop the new method that combines the data-based equipped with learning system and data miming technique. Many data-based modeling methods have been applied successfully to nuclear engineering area, such as signal validation, plant diagnostics and event identification. Also, the data miming is the process of analyzing data from different perspectives and summarizing it into useful information. In this study, the smart sensing technique was developed using advanced group method of data handing (GMDH) model. The original GMDH is an inductive self-organizing algebraic model. The advanced GMDH model is equipped with a fuzzy concept. The proposed advanced GMDH model enhances the original GMDH model by reducing the effect of outliers and noise. The advanced GMDH uses different weightings according to their importance which is specified by the fuzzy membership grade.

In order to develop and verify the models, a number of data obtained by simulating station black out (SBO) scenario for the optimized power reactor 1000 (OPR1000) using MARS code were used.

2. Smart Sensing of the Aux. Feed-water Performance Using Advanced GMDH Algorithm

In order to solve problems such as monitoring, prediction, diagnosis, and so on, many mathematical methods have been studied. The advanced GMDH algorithm is a data-driven mathematical model, a class of models to which methods like artificial neural networks (ANNs) belong. It can be used for the smart sensing of a concerned signal via other variables. In addition, data-driven models have many advantages such as easy implementation and accuracy.

In this study, the advanced GMDH algorithm was used to develop a smart sensing model for predicting the pump performance in severe accident conditions.

2.1 Advanced GMDH Algorithm

The original GMDH algorithm is a way of finding a regression function that accurately expresses a dependent variable from independent variables. This algorithm can automatically find a correlation in the data to improve the prediction accuracy and select the optimal structure of the model. The GMDH algorithm uses a data structure similar to multiple regression models where the data set is divided into three subsets: training, verification, and test. The main purpose for three subsets is to prevent over-fitting and maintain model regularization through cross-validation [1].

The advanced GMDH models is known as GMDH combined with a fuzzy concept. The proposed advanced GMDH model increases the performance by reducing the effect of outliers and noise. In order to apply a fuzzy membership grade, self-organizing feature map (SOFM) was used [2]. The SOFM is, usually, a two-layered network where the neurons in the output layer are organized into either a one or two-dimensional lattice structure. Therefore, by applying a fuzzy membership grade to each data point of the GMDH model, the general form function can be reformulated. Thus, the advanced GMDH model was suggested as follows:

$$y = x_0 + \sum_{i=1}^{m} \mu_i x_i + \sum_{i=1}^{m}\sum_{j=1}^{m} \mu_{ij} x_i x_j + \sum_{i=1}^{m}\sum_{j=1}^{m}\sum_{k=1}^{m} \mu_{ijk} x_i x_j x_k \dots \quad (1)$$

where, $\mathbf{x} = (x_1, x_2, \cdots, x_m)$ is an input variable vector and $\mu = (\mu_i, \mu_{ij}, \mu_{ijk,} \cdots)$ is the fuzzy membership grade. Generally GMDH model apply Kolomgorov-Gabor polynomial. The model apply an equal weighting to all data points. On the other hand, advanced GMDH model uses different weightings depending on the importance of the respective data points, which is specified by the fuzzy membership grade.

The GMDH algorithm can determine the structure of the model and simultaneously calculate the system output of the important inputs.

2.2 Accident Simulation Data

In order to apply the proposed advance GMDH-based smart sensing models to the pump performance, it is necessary to obtain data by numerical simulations because little real accident data sets exist. Therefore, the test and development data for the proposed models were obtained by simulating severe accidents using MARS code for the OPR1000 nuclear power plant. The measured signals are as follows: SG steam flowrate, SG pressure, SG temperature, SG wide-range level, Hot-leg flow, Cold-leg flow, Pressurizer pressure, Pressurizer temperature, Pressurizer water level, Aux. feed water temperature, Reactor power, Aux. feed-water pump suction pressure and core water level. Through the simulations, a total of 1000 simulations were performed. The acquired data are divided into three types. The training data are used to train the model. And the test data are used to independently verify whether or not the models work well. At last, the verification data are used to prevent over-fitting. Also, the acquired data consist of 600 training, 200 verification, and 100 test data by using SC method.

3. Application

During the occurrence of a SBO accident, our greatest concern is the Aux. feed-water flowrate. The input variables are strongly correlated with the output variable. In order to predict the Aux. feed water flowrate, the input signals are selected by considering the correlation between the measured or predicted signals and the Aux. feed water flowrate.

Figs. 1 and 2 show the predicted Aux. feed water pump's performance by predicting flowrate and their errors using advanced GMDH model. Fig. 1 shows Aux. feed water flowrate and their estimation error in case that Aux. feed water pump's performance is 100%. Fig. 2 shows the estimated flow rate and their error when Aux feed water flowrate is declined since pump performance was degraded to 80%. As shown in these Figs. the proposed model can accurately estimate the flowrate. In other words, advanced GMDH model can accurately predict the performance for Aux. feed water pump. And Table 1 shows the estimation RMS error and maximum relative error for respective events. As shown in Table 1, the proposed model has small errors. Table 1 shows that the RMS errors for the training data are approximately 0.014, 0.85, and 0.35 for respective events. The RMS errors for the test data are approximately 0.10, 0.42, and 1.78 for respective events.

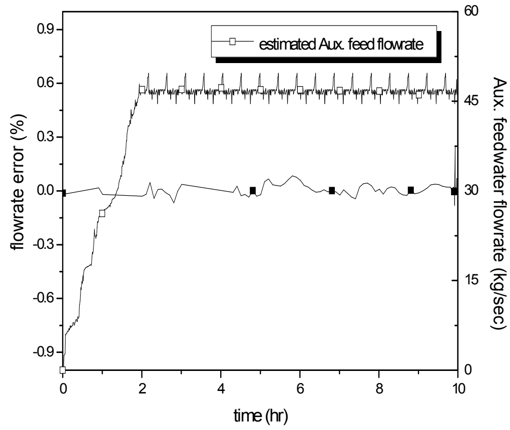

Fig. 1. Prediction performance of the advanced GMDH model in case that Aux. feed water pump's performance is 100%

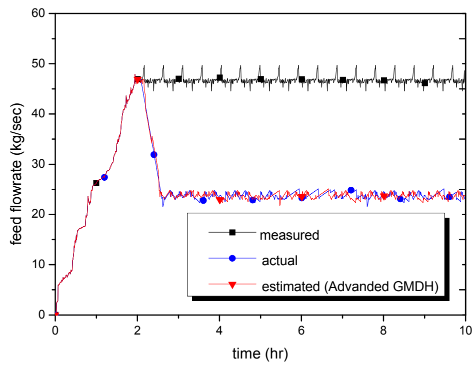

Fig. 2 Prediction performance of the advanced GMDH model in case that Aux. feed water pump's performance is 80%

Table I: RMS errors and maximum relative error

	No degradation		Degradation up to 80%		Degradation up to 50%	
	RMS error	Max. relative error	RMS error	Max. relative error	RMS error	Max. relative error
Training data (%)	0.0138	0.4534	0.8470	1.9600	0.3472	1.0130
Verification data (%)	0.0673	0.7400	0.0461	0.9415	0.6541	2.4652
Test data (%)	0.0993	0.7756	0.4244	1.4918	1.7758	3.9243

4. Conclusions

In this study, the advanced GMDH algorithm was used to develop smart sensing models for Aux. feed water pump's performance by predicting flowrate. The developed model predicted the Aux. feed water pump's performance using measured or predicted signals without the flowrate signal.

The developed model was verified using SBO accident simulation data for the OPR1000 nuclear power plant acquired with MARS code. Also, the advanced GMDH model was trained using the simulated development data and verified with simulated test data. The development and test data sets were independent.

The simulation results show that the performance of the developed advanced GMDH model was very satisfactory, as shown in Table 1. Therefore, if the developed model can be optimized using diverse and specific data, it will be possible to predict the performance of Aux. feed water pump accurately.

REFERENCES

[1] S.J. Farlow, "Self-Organizing Methods in Modeling: GMDH Type Algorithms," Marcel Dekker, New York, 1984.

[2] Chih-Chung Yang, and N.K Bose "Generating fuzzy membership function with self-organizing feature map", Pattern Recognition Letters 27, p. 356-365, 2006.