Transactions of the Korean Nuclear Society Spring Meeting
Gwangju, Korea, May 30-31, 2013

Determination of the Recovery Time of Unhealthy SISs in LOCA

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1. Introduction

When operators do not exactly know the inner conditions of a reactor during severe accidents such as the Fukushima NPP accident in Japan, it is hard to predict the accident progress and the results. Furthermore, it is necessary to develop safety measures for the worst conditions such as natural disasters, terrorism, etc. Therefore, the NPP accident recovery aid system is necessary to achieve stable shutdown from Design Basis Accidents (DBA).

In this study, we have analyzed the changes of important timings for severe accident scenarios (core uncovery, reactor vessel failure, etc.) according to the Safety Injection System (SIS) status (no actuation, normal actuation, delayed actuation) as part of the successful control path analysis from DBA for the composition of accident recovery aid system.

These data were obtained by simulating severe accident scenarios for the Optimized Power Reactor 1000 (OPR1000) using the MAAP4 code.

2. Prediction of LOCA Scenario Using GMDH

A GMDH model [2] was used to predict the major transient time points accurately when LOCAs occurred. Generally, the GMDH algorithm can automatically find interrelations in the data and select the optimal structure of the model.

The GMDH algorithm uses a data structure similar to that of multiple regression models. The data set can be divided into the training data and test data. The reason of dividing the data set is to prevent over-fitting and maintain model parsimony. Fig. 1 shows the data structure used in the GMDH method with N being the number of observations and m the number of prediction model inputs. The GMDH uses a self-organizing modeling algorithm with the flexibility of deciding nonlinear forms of the basic inputs $\{x_1, x_2, \cdots, x_m\}$. Fig. 2 shows the branch structure of the GMDH algorithm. It begins with the basic inputs at the first level and becomes more complex according to the increasing number of layers.

The original GMDH method includes the following Eq. (1) at each level of the successive approximation:

$$y = f(x_i, x_j) = A + Bx_i + Cx_j + Dx_i^2 + Ex_j^2 + Fx_i x_j \quad (1)$$

The GMDH algorithm constructs a high-order polynomial of Kolmogorov-Gabor form as follows:

$$y = a_0 + \sum_{i=1}^{m} a_i x_i + \sum_{i=1}^{m}\sum_{j=1}^{m} a_{ij} x_i x_j + \sum_{i=1}^{m}\sum_{j=1}^{m}\sum_{k=1}^{m} a_{ijk} x_i x_j x_k \ldots \quad (2)$$

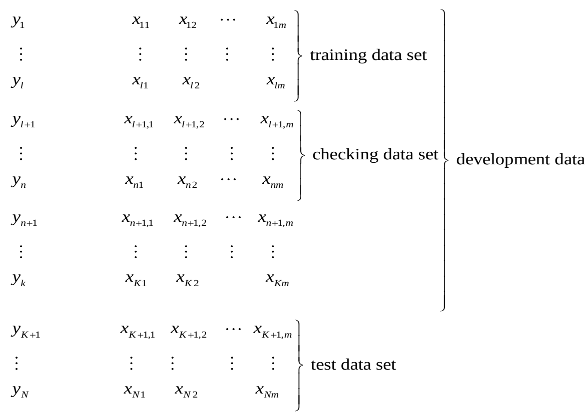

Fig. 1. GMDH data structure.

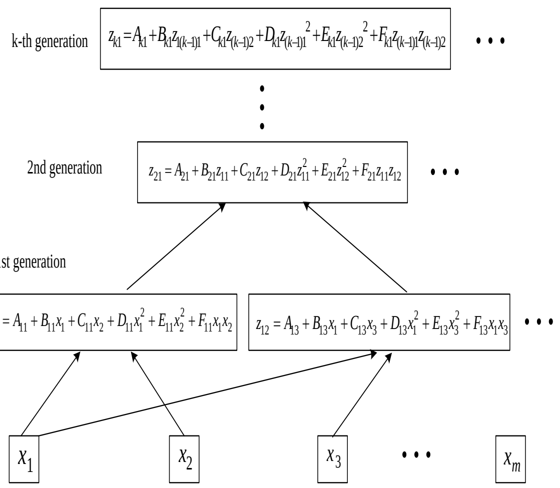

Fig. 2. Branch structure of the GMDH Model

Where, $\mathbf{x} = (x_1, x_2, \cdots, x_m)$ is an input variable vector and $\mathbf{a} = (a_0, a_i, a_{ij}, a_{ijk}, \cdots)$ is a vector of coefficients or a weight of the Kolmogorov-Gabor polynomial. The GMDH algorithm amalgamates lower order regression type polynomials at each generation to reach the next generation. This uses the composition of lower order polynomials mentioned above. This process continues until the GMDH model starts to simulate the noise in training or it exceeds maximum calculation time.

3. Determination of the Recovery Time

To check up the recovery time, Simulations were carried for LOCAs in the hot-leg of the OPR1000 using the MAAP4 code to acquire data.

Simulations were conducted according to break size (0.1%, 1%, … , 100%), and High Pressure and Low Pressure safety injection system (HPI, LPI) actuation status. It was assumed that Containment Spray System (CSS) and Recirculation (REC) mode were normally actuated. If the GMDH model has the capability to accurately predict the core uncover time and RV failure time, it is possible to determine the recovery time of the safety injection systems for preventing the core uncovery and RV failure.

3.1 The influence of the high pressure safety injection

Table 1 shows that core uncovery does not occur in case of HPI normal actuation, but in case of more than approximately 30% break area, core uncovery is occurred by the massive coolant leaks.

In case of less than 30% break area, it is possible to prevent core uncovery although HPI is delayed. And in case of more than 30% break area, it is possible to prevent RV failure according to the HPI actuation time. Table 1(a) shows core uncovery and RV failure times according to break area and the normal actuation of HPI and its delayed actuation.

3.2 The influence of the low pressure safety injection

The situation that only LPI actuates is similar to that of HPI, but it is different in less than 3% break area. The LPI does not actuate normally by primary side system pressure in case of less than 3% break area. Fig. 3 shows the pressure, LPI time, and main time points in the 1% break area. Table 1(b) shows core uncovery and RV failure times according to break area and the normal actuation of HPI and its delayed actuation.

4. Conclusion

To check the status of the reactor is very important, depending on the actuation change of the safety systems. So, we confirmed an alteration of significant timing according to the actuation status of the safety injection system through the simulations of OPR 1000.

As a result of determination, we could find the elements that interfere with the proper operation of the safety system such as pressure and time delay.

According to the previous study[3], the GMDH model has the capability to accurately predict the core uncover time and RV failure time, it is possible to determine the recovery time of the safety injection systems for preventing the core uncovery and RV failure.

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Table I: The influence of the SIS operation.

(a) The influence of the HPI

Break Area	HPI nomal		Delay time	HPI delay	
	Uncover	RV failure		Uncover	RV failure
0.1%	-	-	3180	3404	-
1%	-	-	350	436	-
10%	-	-	610	665	-
20%	-	-	440	488	-
30%	13.2	-	7590	7672	7672
50%	10.1	-	7550	7636	7636
70%	8.3	-	7620	7734	7734
100%	6.7	-	7430	7627	7627

(b) The influence of the LPI

Break Area	LPI nomal		Delay time	LPI delay	
	Uncover	RV failure		Uncover	RV failure
0.1%	3406	11321			
1%	435	60045			
3%	-	-	1180	1238	-
10%	-	-	610	665	-
20%	-	-	440	488	-
30%	13.2	-	7590	7672	7672
50%	10.1	-	7550	7636	7636
70%	8.3	-	7620	7734	7734

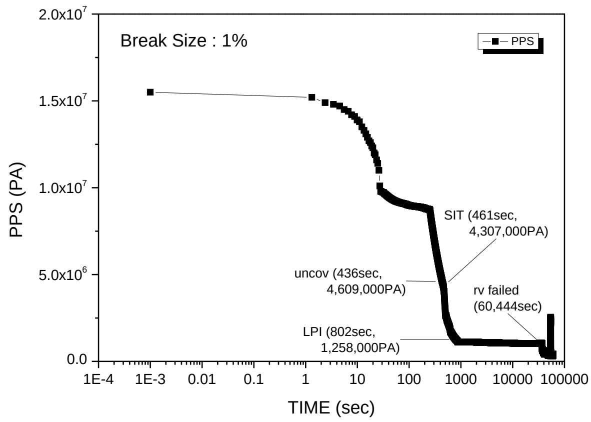

Fig. 3. Pressure and main time points