Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2015

Prediction of Golden Time for Recovering Reactor Core Coolability Using GMDH under Severe Post-LOCA Circumstances

Ju Hyun Back, Kwae Hwan Yoo, and Man Gyun Na*
Department of Nuclear Engineering Chosun University, 309 Pilmun-daero, Dong-gu, Gwangju, Korea
**Corresponding author: magyna@chosun.ac.kr*

1. Introduction

After the Fukushima nuclear accident the importance of accident management for nuclear power plants (NPPs) has being increased. For that reason, many countries have focused on the way of improving the NPP safety.

If loos-of-coolant accident (LOCA) that is a typical case of DBA happens, emergency core cooling system (ECCS) and depressurization system operating in emergency must work normally. Failure of the safety related systems may leads directly to loss of the reactor core coolability. In this case, DBA may be converted into serious accidents, such as the core uncovery and the reactor vessel (RV) failure. Therefore, predicting the recovery time of the safety injection system (SIS) for recovering reactor core coolability is very important to take initial actions promptly [2].

In this study, we have analyzed the golden time for recovering safety injection system (SIS) when the nuclear reactor lost the coolability by LOCA. Prediction of the golden time for recovering the reactor core coolability was performed by simulating many cases of LOCA accident condition using modular accident analysis program (MAAP4) code. Optimized power reactor (OPR1000) was used for target model. Also, the group method of data handling (GMDH) model was applied to predict the golden time for recovering the reactor core coolability.

2. Methods and Results

2.1 Group Method of Data Handling (GMDH)

GMDH method is used to solve the problem of complex multivariable modeling and is a method to find the most optimized single output from various inputs. Fig. 1 show a data structure using GMDH.

GMDH is a method for deriving a basic model function from the complex function equation by applying repeatedly to the basic model. High-fit basic models are used to make a function model by applying the survival-of-the-fittest-process in the iterative process [3].

Two independent variables x_i, x_j selected randomly were used to develop a basic model such as Eq. (1):

$$\hat{y} = A + Bx_i + Cx_i + Dx_i^2 + Ex_j^2 + Fx_i x_j \tag{1}$$

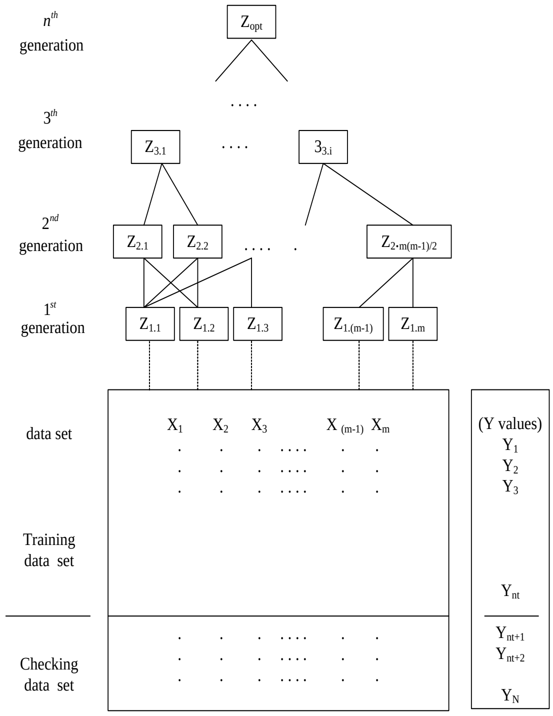


Fig. 1. Data structure of the GMDH model

x_i, x_j are independent variable and $\hat{y}$ is the estimated value generated by the basic model. The estimated value $\hat{y}$ of the dependent variable are derived by substituting the actual value of x_i, x_j for the basic model. A, B, C, D, E and F in Eq. (1) are called Ivakhnenko coefficients. The coefficients are derived from the independent variable by using a least squares method in arbitrary pair (x_i, x_j) and the estimated value $\hat{y}$ is calculated using Ivaknenko coefficients [1,3].

In order to evaluate the goodness of fit of the calculated estimated value, the evaluation value r_j is calculated as shown in Eq. (2):

$$r_j^2 = \frac{\sum_{i=nt+1}^{N} (y_i - z_{ij})^2}{\sum_{j=nt+1}^{N} y_i^2} \tag{2}$$

$1, 2, 3, \cdots, nt$: training data set
$nt+1, nt+2, \cdots, N$: checking data set.

The columns on the new parameters depend on the evaluation value r_j calculated through Eq. (2). Columns that satisfied a condition ($r_j < R$) are constructing a new matrix (R is an arbitrary reference value). As a result, using the estimated value $\hat{y}$ derived by the basic model function, the process of creating a new matrix as input variable is performed for the next generation [3].

Find the minimum value among calculated values, r_j and indicate the minimum value as $R_g^{\min}$. If the minimum value of the current generation is less than that of the previous generation, the process will be repeated. If the minimum value is greater than that of the previous generation, $R_g^{\min}$ will be the minimum value of the previous generation, the iterative process will stop. The basic model function in the generation that has a minimum value of $R_g^{\min}$ is the final basic model function, the value of the column is the final estimate value [1,3].

Figure 2 shows the typical $R_g^{\min}$ value trend versus generation.

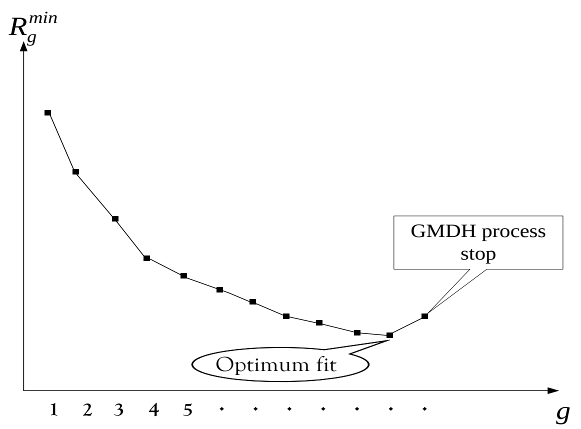


Fig. 2. Typical $R_g^{\min}$ value trend versus generation

2.2 Accident Scenarios

In this study, we used the MAAP4 code for simulating failure situations of the SIS. And the simulation period was seven days after the reactor trip. Scenarios were divided according to 270 different break sizes in the hot-leg and cold-leg. The data was obtained for each case according to the operations of low-pressure safety injection (LPSI) or high-pressure safety injection (HPSI). For case 1, the LPSI system was failed and the HPSI system operation was delayed in hot-leg break. For case 2, the HPSI system was failed and the LPSI system operation was delayed in hot-leg break. For case 3, the LPSI system was failed and the HPSI system operation was delayed in cold-leg break. For case 4, the HPSI system was failed and the LPSI system operation was delayed in cold-leg break. The conditions of each case are summarized in Table I.

Table I: Simulation Cases

Case	Location	SIT Operation	CSS Operation	MSIV	HPSI Operation	LPSI Operation
1	Hot-leg	Success	Inj & Rec	Close	Delay Inj & Rec	N/A
2				Open	N/A	Delay Inj & Rec
3	Cold-leg	Success	Inj & Rec	Close	Delay Inj & Rec	N/A
4				*Open*	*N/A*	*Delay Inj & Rec*

2.3 Determining Golden Time for Recovering Reactor Core Coolability

Table II summarizes the prediction performance results of the GMDH model for the cases that the LPSI system was failed and the HPSI system operation was delayed (HPSI delay). This table shows that the RMS errors for training data of the hot-leg LOCA are approximately 14.47% and 2.22% for the core uncovery and RV failure, respectively. The RMS errors for training data of the cold-leg LOCA are approximately 8.27% and 10.58% for the core uncovery and RV failure, respectively. The RMS errors for the test data of the hot-leg LOCA are approximately 10.41% and 17.48%, respectively. The RMS errors for test data of the cold-leg LOCA are approximately 1.67% and 2.98% for the core uncovery and RV failure, respectively.

Table III summarizes the prediction performance results of the GMDH model for the cases that the HPSI system was failed and the LPSI system operation was delayed (LPSI delay). This table shows that the RMS errors for training data of the hot-leg LOCA are approximately 1.53% and 2.68% for the core uncovery and RV failure, respectively. The RMS errors for training data of the cold-leg LOCA are approximately 0.56% and 2.55% for the core uncovery and RV failure, respectively. The RMS errors for the test data of the hot-leg LOCA are approximately 1.96% and 1.38% for the core uncovery and RV failure, respectively. The RMS errors for the test data of the cold-leg LOCA are approximately 0.39% and 1.94% for the core uncovery and RV failure, respectively.

Table II: Prediction Performance of GMDH Model (HPSI Delay)

Break position	HPSI delay	Training Data		Test data	
		Maximum Error (%)	RMS Error (%)	Maximum Error (%)	RMS Error (%)
Hot-leg LOCA (Case1)	Core uncovery	47.03	14.47	14.99	10.41
	RV failure	12.57	2.22	62.93	17.48
Cold-leg LOCA (case3)	Core uncovery	35.39	8.27	3.34	1.67
	RV failure	13.91	10.58	2.45	2.98

Table III: Prediction Performance of GMDH Model (LPSI Delay)

Break position	LPSI delay	Training Data		Test data	
		Maximum Error (%)	RMS Error (%)	Maximum Error (%)	RMS Error (%)
Hot-leg LOCA (Case2)	Core uncovery	5.68	1.53	2.87	1.96
	RV failure	12.5	2.68	3.09	1.38
Cold-leg LOCA (case4)	Core uncovery	1.71	0.56	0.59	0.39
	RV failure	9.76	2.55	3.45	1.94

2.4 Performance Results of GMDH

Figs. 3 through 6 show the predicted golden time using the GMDH model. These figures compares the estimated values by the GMDH model and the simulation data (target value) of MAAP4 code.

Fig. 3 shows the HPSI golden time prediction of the case 1 for the hot-leg LOCA. Fig. 3(a) shows the prediction results of the golden time for preventing the core uncovery, and Fig. 3(b) shows the prediction results of the golden time for the reactor vessel failure prevention.

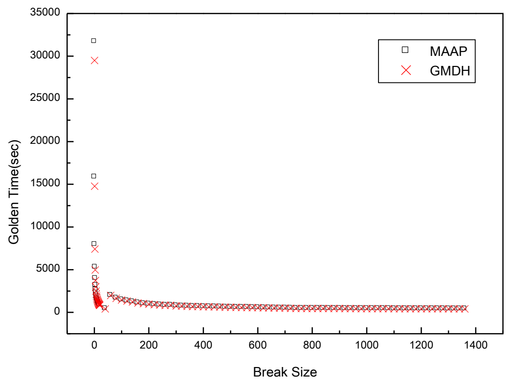
Fig. 4 shows the LPSI golden time prediction of the case 2 for the hot-leg LOCA. Fig. 4(a) shows the prediction results of the golden time for preventing the core uncovery and Fig. 4(b) shows the prediction results of the golden time for the reactor vessel failure prevention.

Fig. 5 shows the HPSI golden time prediction of the case 3 for the cold-leg LOCA. Fig. 5(a) shows the prediction results of the golden time for preventing the core uncovery, and Fig. 5(b) shows the prediction results of the golden time for the reactor vessel failure prevention.

Fig. 6 shows the LPSI golden time prediction of the case 4 for the cold-leg LOCA. Fig. 6(a) shows the prediction results of the golden time for preventing the core uncovery, and Fig. 6(b) shows the prediction results of the golden time for the reactor vessel failure prevention. From the results given in Figs. 3 through 6, it is confirmed that GMDH model accurately predicts the golden time.

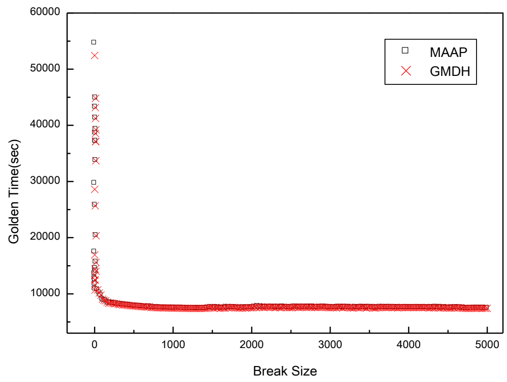
3. Conclusions

In this study, to predict the golden time for recovering reactor core coolability in severe accident, the GMDH model has been developed. The golden time for the prevention of core uncovery and RV failure was obtained by analyzing the MAAP4 code. If the failed SISs are recovered inside the golden time, it is possible to prevent the core uncovery and RV failure. Moreover, by predicting the golden time, it is possible to determine the recovery time of the SIS and secure a time to cope with the severe accident. As a result of this study, the proposed GMDH model was able to accurately predict the golden time, and the golden time for recovering core coolability can be applied usefully in accident situations.



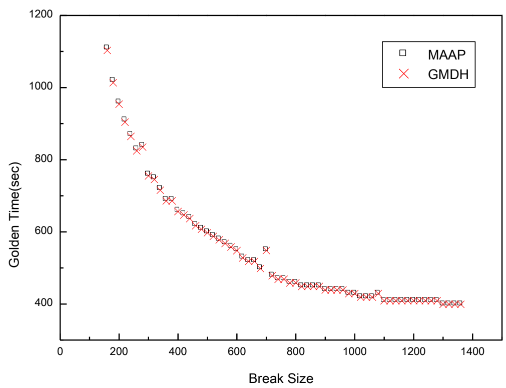
(a) Core uncovery

Fig. 3. Golden time prediction of case 1 (HPSI delay).



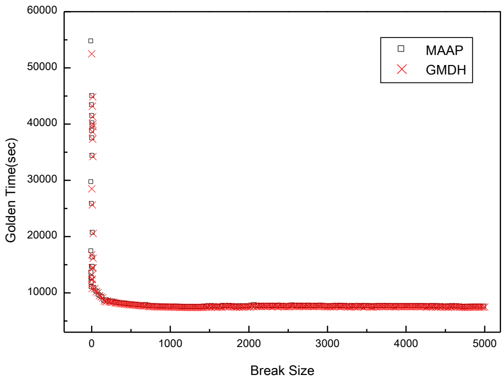
(b) RV failure

Fig. 3. Continued.



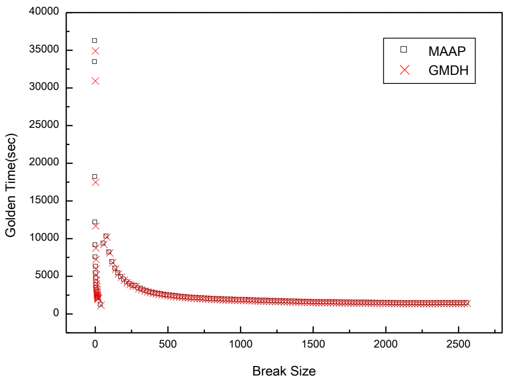
(a) Core uncovery

Fig. 4. Golden time prediction of case 2 (LPSI delay).



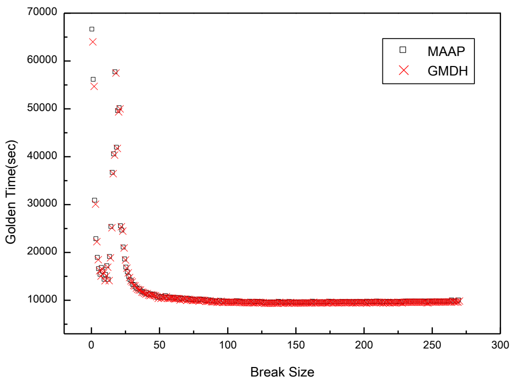
(b) RV failure

Fig. 4. Continued.



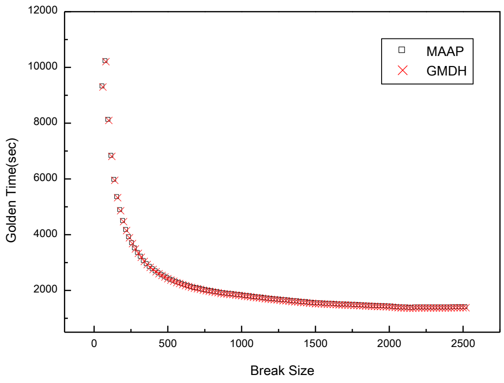
(a) Core uncovery

Fig. 5. Golden time prediction of case 3 (HPSI delay)



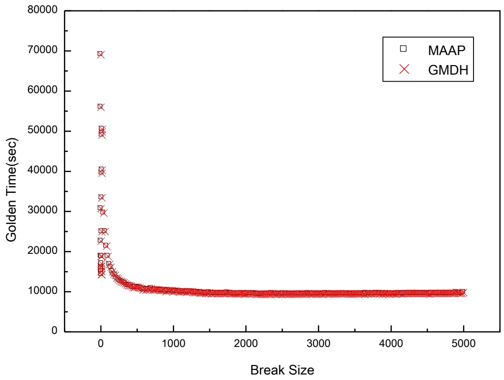
(b) RV failure

Fig. 5. Conltinued.



(a) Core uncovery

Fig. 6. Golden time prediction of case 4 (LPSI delay).



(b) RV Failure

Fig. 6. Continued.

REFERENCES

[1] A.G. Ivakhnenko, The Group Method of Data Handling; a Rival of Method of Stochastic Approximation, Soviet Automatic Control, Vol. 1,no. 3, pp. 43-55, 1968.

[2] Y. Choi and J. H. Park, A study on severe accident management scheme using LOCA sequence database system, Journal of the Korean Society of Safety, Vol. 29, No. 6, pp. 172-178, Dec. 2014.

[3] Stanley J. Farlow, Self-Organizing Method in Modeling: GMDH Type Algorithm, Marcel Dekker Inc., pp. 1-24, 1984.