Development of Diagnostic Process for Abnormal Conditions of Ulchin Units 1&2

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1. Introduction

Diagnosis of abnormal conditions during operation is one of difficult tasks to nuclear power plant operators. Operators may have trouble in handling abnormal conditions due to various reasons such as 1) many alarms (around 2,000 alarms in the Ulchin units 1&2 each) and multi alarms occurrences, 2) the same alarms occurrences in different abnormal conditions, and 3) a number of Abnormal Operating Procedures (AOPs). For these reasons, the first diagnosis on abnormal conditions largely relies on operator's experiences and pattern recognition. Then, this difficulty may be highlighted for inexperienced operators.

This paper suggests an approach to develop the optimal diagnostic process for appropriate selection of AOPs by using the Elimination by Aspect (EBA) method. The EBA method uses a heuristic followed by decision makers during a process of sequential choice and which constitutes a good balance between the cost of a decision and its quality. At each stage of decision, the individuals eliminate all the options not having an expected given attribute, until only one option remains [1]. This approach is applied to steam generator level control system abnormal procedure for Ulchin units 1&2. The result indicates that the EBA method is applicable to the development of optimal process on diagnosis of abnormal conditions.

2. EBA Strategy

The EBA strategy has been already used for developing diagnosis procedure on Emergency Operating procedures (EOPs) of Korea Standard Nuclear Power Plants (KSNP) [2]. The merit of EBA is to find optimal test sequence that identifies many failure states with a reasonable test cost and time.

In producing an optimal test sequence, a problem domain is described by the four-tuple (S, p, T, c) and test matrix.

- S = $\{s_1,\ldots,s_i\}$ specifies different system states ($1 \leq i \leq m$).
- p = $[p(s_1),\ldots,p(s_i)]^T$ means the prior probability vectorfor system states.
- T = $\{t_1;\ldots;t_j\}$ represents a set of n available tests toidentify system states ($1 \leq j \leq n$).
- c = $[c_1,\ldots c_j]^T$ indicates the test cost vector measured bytest time, required resources to perform a test, etc. Generally, it is assumed that all test costs are identical (i.e. setting to one).
- The test matrix describesa relationship between system states included in *S* andavailable tests included in *T*.

Fig. 1 shows the first and second test matrix for better understanding of test sequence and table 2 summarizes detailed meaning with how to quantify each term in the below Discriminatory Function (DF) equation (1). In the Fig. 1, symbol '●' denotes that the result of test t_j is 'Yes' if system state is s_j. In contrast, the blank means that the result of test t_j is 'No' if system state is s_j. In addition, symbol 'x' indicates that test t_j has no relationship with system state s_j (i.e. unrelated test). In this case, an optimal test sequence can be decided so that a value of the DF for test t_j is maximized.

Discriminatory function for test

$$DF(t_j) = \frac{-p\cdot(p_y \cdot log_2 p_y + p_n \cdot log_2 p_n)}{c_j} \quad \cdots\cdots (1)$$

<An example to determine the first test>

System state	Available set of tests					
	t_1	t_2	t_3	t_4	t_5	Prior probabilit
s_1	●	●	●	x		0.480
s_2		●	●		●	0.010
s_3		●		x	x	0.010
s_4						0.250
s_5				●	●	0.150
s_6			●	●	●	0.100
Test cost	1	1	1	1	1	
p	1.000	1.000	1.000	0.510	0.990	
p_y	0.480	0.500	0.590	0.490	0.263	
p_n	0.520	0.500	0.410	0.510	0.737	
Value of DF	0.999	1.000	0.977	0.510	0.822	

<An example to determine the second test>

System state	Available set of tests					
	t_1	t_2	t_3	t_4	t_5	Prior probabilit
s_4						0.250
s_5				●	●	0.150
s_6			●	●	●	0.100
Test cost	1	1	1	1	1	
p	0.500	0.500	0.500	0.500	0.500	
p_y	0.000	0.000	0.200	0.500	0.500	
p_n	1.000	1.000	0.800	0.510	0.510	
Value of DF	0.000	0.000	0.361	0.500	0.500	

Fig. 1. Examples to determine the first & second test.

Table 1. Meaning of each term in the test matrix

	Meaning	Quantified by
p	The probability of getting a definite result when the test t_j is performed	1 − (sum of the prior probabilities for the system states that are denoted by the symbol ' x ')
p_y	The conditional probability of getting Yes when the test t_j is performed	(Sum of the prior probabilties for the system states that are denoted by the symbol '●')/p
p_n	The conditional probability of getting No when the test t_j is performed	$1 - p_y$
c_j	Test cost for the test t_j	

Through Fig. 1, the t_2 should be selected as the first test to be done, since the t_2 has the largest DF value. Similarly, the same process can be applied to determine which test should be done as the next test. For example, when the result of the first test is No, the next test could beeither t_4 or t_5.

In this way, the optimal test sequence for the test matrix can be determined as depicted in Fig. 2.

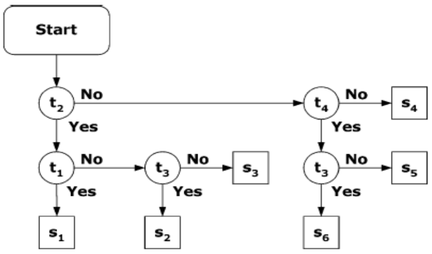

Fig. 2. The optimal test sequence for the Fig. 1 test matrix.

3. Development of Diagnostic Process for Abnormal Conditions for Ulchin Units 1&2

This paper applies the EBA method to develop a diagnostic process for the steam generator level control system abnormal procedure of Ulchin Units 1&2, which includes fourteen (14) abnormal states.

3.1 Test sequence determination matrix

First, this paper constructs the test sequence determination matrix based on the abnormal procedure [3]. The first test determination matrix is shown in Fig. 3. The failure rates for the abnormal states were obtained from the generic data base for PSA [4]. DF values for alarms and symptoms are calculated by (1). As shown in the table, the calculation indicates that the alarm t_8, i.e., “Steam Line Flow or Pressure,” is the most informative for the first diagnosis of 14 states.

3.2 The optimal diagnostic process

Based on the DF values of the test determination matrix, this paper develops the optimal diagnostic process for the AOP. The first question, i.e., t_8, is chosen from the first test matrix, i.e., Fig.3. The states s_2, s_7, and s_9 are firstly diagnosed by using the EBA method. Then, the next test determination matrix is developed to find the second informative alarms or symptoms. This process is carried out iteratively until all the abnormal states are identified. Fig. 4 shows the whole optimal diagnostic sequence for the abnormal procedure.

4. Conclusion

This paper investigated the applicability of the EBA method to develop diagnostic process for abnormal conditions in nuclear power plant. Then, the suggested process is coincident with actual practice in the plant. For example, t_8 (‘STEAM LINE FLOW OR PRES’ alarm) selected as the first test is related to Safety Injection which is considered as the most sever accident among tests in this study. Furthermore, t_9 and t_{10} selected as the second test and t_1~t_3 and t_7 selected as the third test are related to Reactor Trip.

However, the scope of this study is limited to a single abnormal procedure. In order to examine the plant-wide applicability, it is necessary to extend the scope to all the abnormal operating procedures. In addition, the further study needs to take into account the frequency or importance of information as well as the probability of states.

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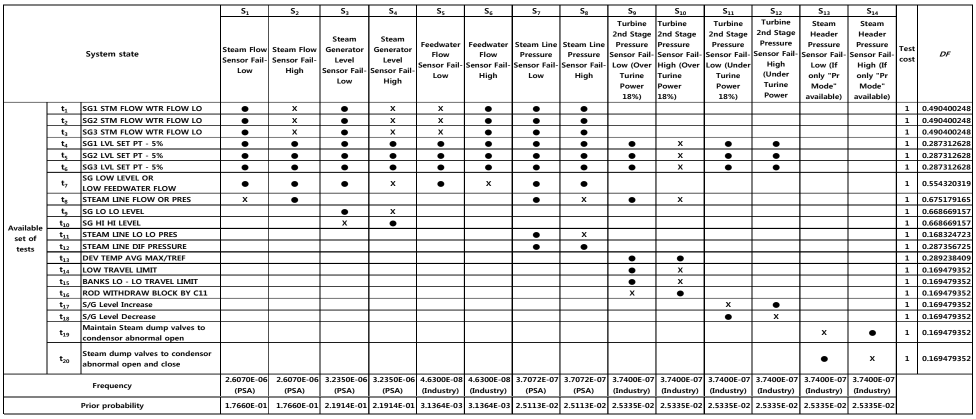

System state			S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	Test cost	*DF*
			Steam Flow Sensor Fail-Low	Steam Flow Sensor Fail-High	Steam Generator Level Sensor Fail-Low	Steam Generator Level Sensor Fail-High	Feedwater Flow Sensor Fail-Low	Feedwater Flow Sensor Fail-High	Steam Line Pressure Sensor Fail-Low	Steam Line Pressure Sensor Fail-High	Turbine 2nd Stage Pressure Sensor Fail-Low (Over Turine Power 18%)	Turbine 2nd Stage Pressure Sensor Fail-High (Over Turine Power 18%)	Turbine 2nd Stage Pressure Sensor Fail-Low (Under Turine Power 18%)	Turbine 2nd Stage Pressure Sensor Fail-High (Under Turine Power	Steam Header Pressure Sensor Fail-Low (If only "Pr Mode" available)	Steam Header Pressure Sensor Fail-High (If only "Pr Mode" available)		
Available set of tests	t_1	SG1 STM FLOW WTR FLOW LO	●	X	●	X	X	●	●	●							1	0.490400248
	t_2	SG2 STM FLOW WTR FLOW LO	●	X	●	X	X	●	●	●							1	0.490400248
	t_3	SG3 STM FLOW WTR FLOW LO	●	X	●	X	X	●	●	●							1	0.490400248
	t_4	SG1 LVL SET PT - 5%	●	●	●	●	●	●	●	●	●	X	●	●			1	0.287312628
	t_5	SG2 LVL SET PT - 5%	●	●	●	●	●	●	●	●	●	X	●	●			1	0.287312628
	t_6	SG3 LVL SET PT - 5%	●	●	●	●	●	●	●	●	●	X	●	●			1	0.287312628
	t_7	SG LOW LEVEL OR LOW FEEDWATER FLOW	●	●	●	X	●	X	●	●							1	0.554320319
	t_8	STEAM LINE FLOW OR PRES	X	●					●	X	●	X					1	0.675179165
	t_9	SG LO LO LEVEL			●	X											1	0.668669157
	t_{10}	SG HI HI LEVEL			X	●											1	0.668669157
	t_{11}	STEAM LINE LO LO PRES							●	X							1	0.168324723
	t_{12}	STEAM LINE DIF PRESSURE							●	●							1	0.287356725
	t_{13}	DEV TEMP AVG MAX/TREF									●	●					1	0.289238409
	t_{14}	LOW TRAVEL LIMIT									●	X					1	0.169479352
	t_{15}	BANKS LO - LO TRAVEL LIMIT									●	X					1	0.169479352
	t_{16}	ROD WITHDRAW BLOCK BY C11									X	●					1	0.169479352
	t_{17}	S/G Level Increase											X	●			1	0.169479352
	t_{18}	S/G Level Decrease											●	X			1	0.169479352
	t_{19}	Maintain Steam dump valves to condensor abnormal open													X	●	1	0.169479352
	t_{20}	Steam dump valves to condensor abnormal open and close													●	X	1	0.169479352
Frequency			2.6070E-06 (PSA)	2.6070E-06 (PSA)	3.2350E-06 (PSA)	3.2350E-06 (PSA)	4.6300E-08 (Industry)	4.6300E-08 (Industry)	3.7072E-07 (PSA)	3.7072E-07 (PSA)	3.7400E-07 (Industry)	3.7400E-07 (Industry)	3.7400E-07 (Industry)	3.7400E-07 (Industry)	3.7400E-07 (Industry)	3.7400E-07 (Industry)		
Prior probability			1.7660E-01	1.7660E-01	2.1914E-01	2.1914E-01	3.1364E-03	3.1364E-03	2.5113E-02	2.5113E-02	2.5335E-02	2.5335E-02	2.5335E-02	2.5335E-02	2.5335E-02	2.5335E-02		

Fig. 3. The first test determination matrix

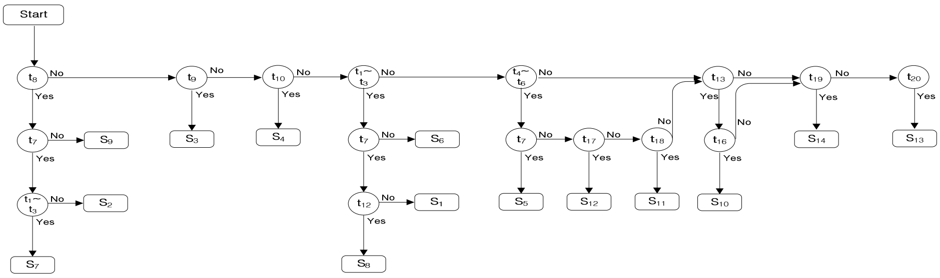

Fig. 4. The optimal diagnostic process on the AOP