Estimation of Common Cause Failure Parameters for Emergency Service Water System Pump of Kori Unit 2

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1. Introduction

The probabilistic safety assessment (PSA) results for Kori Unit 2 showed that the common cause failure (CCF) events of emergency service water system (ESWS) pump failure to run were identified as one of the dominant contributors to its internal event core damage frequency (CDF)[1]. The generic values of the CCF parameters were used in PSA projects for the Kori Unit 2. Thus, we performed the plant specific detailed CCF analysis to estimate the CCF parameters of ESWS pump failure to run for Kori Unit 2 with the CAFE-PSA(common CAuse Failure Event analysis program for PSA) [2], a program to analyze CCF events in the ICDE database.

2. Estimation Procedure of CCF Parameters

2.1 Overall approach

The ESWS of Kori Unit 2 consists of three motor pumps. For a comparison, we estimated the CCF parameters using the conventional method and the decomposition method. We also quantified the system unavailability of ESWS pumps and calculated the CDF of Kori Unit 2. The conventional method is based on the symmetry assumption that the probabilities of CCF events involving similar components are the same [3]. The decomposition method [4] assumes that the total failure events of a component including the CCF events were divided into their symmetrical and asymmetrical parts. In the process of estimating CCF parameters, Base and Detailed Cases were considered. Base Case is the case where the applicability factors of all CCF events are estimated as one. The Base Case assumes that there are no physical, operational, and environmental differences between the ESWS pumps in the ICDE CCF events and those of Kori Unit 2. Detailed Case is the case where the applicability factors of the selected CCF events are estimated at 0.01 and those of the other CCF events are estimated at 1.

2.2 Representations of CCF probability

The probability of a CCF event involving k specific components ($1 \le k \le m$) in a CCCG of size 'm' for a staggered testing scheme, $Q_k^{(m)}$, is calculated by using the following equation [3]:

$$Q_k^{(m)} = (\alpha_k^{(m)} / {}_{m-1}C_{k-1})Q_T = CCF_k^{(m)} Q_T \quad (1)$$

$Q_k^{(m)}$ of Eq.(1) is based on a symmetry assumption that the probabilities of CCF events involving similar components are the same. In Eq.(1), Q_T, $\alpha_k^{(m)}$, and $CCF_k^{(m)}$ are represented as:

$$Q_T = \sum_{k=1}^{m} {}_{m-1}C_{k-1} Q_k^{(m)} \quad (2)$$

$$\alpha_k^{(m)} = n_k / (\sum_{j=1}^{m} n_j) \quad (3)$$

$$CCF_k^{(m)} = (\alpha_k^{(m)} / {}_{m-1}C_{k-1}) \quad (4)$$

Where, n_j is sum of the j-th element of the impact vector.

If the conventional method is used for the representation of the probabilities of CCF events, the failure probability of each ESWS pump can be represented as

$$Q_T(\text{ ESWS pump A,B, or C}) \approx Q_1^{(3)} + 2Q_2^{(3)} + Q_3^{(3)} \quad (5)$$

$$Q_2^{(3)} = (\alpha_2^{(3)}/2)Q_T \quad (6)$$

$$Q_3^{(3)} = \alpha_3^{(3)} Q_T \quad (7)$$

The Kori Unit 2 operator said that, during normal operation, two pumps are operating alternatively. The operation of the third pump is required only where both pumps are unavailable. Therefore, we can classify ESWS pumps into two groups: primary components for ESWS pumps A and B, and secondary components for ESWS pump C. According to reference [4], the failure probabilities of ESWS pump A, B, and C, and their related parameters can be represented as follows:

$$Q_T(\text{ ESWS pump A }) = Q_T(\text{ESWS pump B }) \approx Q_1^{(3)} + Q^c_T + Q^p_T \approx Q_1^{(3)} + 2Q^c{}_2^{(3)} + Q^c{}_3^{(3)} + Q^p{}_2^{(2)} \quad (8)$$

$$Q_T(\text{ ESWS pump C}) \approx Q_1^{(3)} + Q^c_T + Q^s_T \approx Q_1^{(3)} + 2Q^c{}_2^{(3)} + Q^c{}_3^{(3)} \quad (9)$$

$$Q^c{}_2^{(3)} = (n^c{}_2^{(3)} / n_2^{(3)})(\alpha_2^{(3)}/2)Q_T \quad (10)$$

$$Q^c{}_3^{(3)} = (n^c{}_3^{(3)} / n_3^{(3)})\alpha_3^{(3)} Q_T \quad (11)$$

$$Q^p{}_2^{(2)} = (3/2)(n^p{}_2^{(2)} / n_2^{(3)})\alpha_2^{(3)} Q_T \quad (12)$$

3. Estimation results of CCF parameters

From the ICDE database, it was identified that the total number of CCF events for the ESWS pump failure to run was 23 and that of the independent failure events was 188.5 [5]. Based on the characteristics of design, operation, and environments of the ESWS pumps of Kori Unit 2, and references [3, 6], the applicability factors for five CCF events were assessed as 0.01.

For the Base and Detailed Cases by using the conventional method, we estimated Alpha Factors as shown in Table 1. The estimated α_3 for the Detailed Case is about one half of that for US NRC CCF parameters [7].

We quantified the system unavailability for each case as shown in Table 2. In the Detailed Case, the quantified system unavailability by using the decomposition method is about 10% smaller than that of using the conventional method.

In Table 3, 'Change' means that the number of independent failure events for plants whose the applicability factors of CCF events were estimated at 0.01 was changed. In addition, 'No change' means that that was not changed. The calculated CCF factors for 'Change' were increased under 5% compared to those for 'No change'.

With the estimated CCF factors for the change cases where the decomposition method in Table 3 were used, we calculated the CDF of Kori Unit 2. Its CDF was calculated as 16.84% smaller than the originally estimated CDF with generic Alpha Factors. As a result, the contribution of the sum of cutsets including the CCF events of the ESWS pump failure to run to the Kori Unit 2 internal event CDF decreased from about 20% to 3.29%.

4. Concluding Remarks

We estimated the CCF parameters of the ESWS pump failure to run for the Kori Unit 2 with the CAFE-PSA. Reasonable values of CCF parameters were obtained through performing detailed plant specific CCF event analysis. The estimated Alpha Factor with a three out of three failure criterion was about one half of that of recent US NRC CCF parameters. The re-quantification results on the CDF of Kori Unit 2 with the new estimated Alpha Factor showed that the originally estimated CDF with the generic Alpha Factors decreased by 16.84%.

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Table 1. Estimated Alpha Factors by using the conventional method

Alpha Factors (α_k)	ICDE- base	ICDE- detailed	US NRC
α_1	9.6267E-01	9.825E-01	9.874E-1
α_2	1.7108E-02	1.5769E-02	1.01E-2
α_3	2.0222E-02	1.7320E-03	3.36E-3

Table 2. Estimated system unavailability

	Conventional method		Decomposition method	
Cases	Base case	Detailed case	Base case	Detailed case
Unavailability	6.58E-6	2.11E-6	6.51E-6	1.89E-6

Table 3. Estimated CCF Factors for the change of independent failure events

CCF Factors (CF_k)	ESWS Pumps A & B		ESWS Pumps A, B, and C			
	Decomposition method		Conventional method		Decomposition method	
	Change	No change	Change	No change	Change	No change
CF_2	2.0982E-03	2.0038E-3	8.2561E-03	7.8846E-03	6.6868E-03	6.3859E-3
CF_3			1.8136E-03	1.7320E-03	8.8423E-04	8.4444E-4