Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2017

A Review of Risk Impact on Operating Nuclear Power Plants due to an Outage of an Adjacent NPP in a Reference Site

Ho-Jun Jeon*, Kye-Min Oh
KHNP Central Research Institute, Daejeon, 34101, Republic of Korea
**Corresponding author:jeonhojun@khnp.co.kr*

1. Introduction

71% of the nuclear sites in the world have two or more reactor units, and some countries, such as Canada, France, Japan, China, etc. have nuclear sites containing over six units. Korea also has the nuclear sites with six or more reactor units. Moreover, most people in the world watched the extreme tsunami caused significant damage to multi units at Fukushima Dai-ichi in 2011. Based on these, the multi-unit issues have arisen as one of the most important challenges in nuclear industries, and Korea Hydro & Nuclear Power (KHNP) has launched the project for multi-unit Probabilistic Safety Assessment (PSA) to cope with the issues.

There is, however, no mature technical background in the world, so we have derived technical challenges and tried to solve easier one first. In this paper, we reviewed risk impact on operating NPPs resulting from an outage of an adjacent NPP in a reference site with focusing on design characteristics. The ideas from this paper and the concept from the previous paper introduced at KNS spring meeting in 2017[1] shall be used to develop multi-unit PSA models in the reference site.

2. Methods and Results

We limited the scope in this paper with focusing on Level 1 Loss of Off-site Power (LOOP) PSA for all modes. This paper mainly reviewed the single unit PSA models and the design characteristics of units in the reference site based on Core Damage Frequencies (CDF).

2.1 Review of the Single Unit PSA Models

Single unit PSA models have been separately developed based on the operating modes. KHNP has developed and maintained one for full power operation, and about seven model sets for Low Power and ShutDown (LPSD) operation based on Plant Operating Status (POS). However, we suggested developing PSA models with considering all operating modes of all the units at the same time in the previous paper [1], in which introduced Site Operating Status (SOS), and proposed to select K2, K4 or K5 as the representative unit of OverHaul (O/H) on the basis of CDF. So, we reviewed single unit PSA models for LOOP and Station BlackOut (SBO) events not only for full power operation but also for LPSD operation. Table I shows the relative portion, based on K2, of Conditional Core Damage Probabilities (CCDPs) of LOOP including SBO for the units in the reference site, and the summed values. Actually, aggregation of risk measures, such as CDF is one of the most controversial issues on multi-unit PSA, so we do not handle with the issue in this paper. Therefore, we used the simply summed mean values. Instead of CDFs, we used CCDPs in Table I because the frequencies of initiation events on full power operation are different from those on LPSD operation.

Table I: CCDPs Comparison of LOOP for the reference site

<table>
<tr><th></th><th>K2</th><th>K3</th><th>K4</th><th>K5</th><th>K6</th><th>K7,8</th><th>K9,10</th><th>Tot.</th></tr>
<tr><td>C1*</td><td>1.0</td><td rowspan="4">0.334</td><td>0.334</td><td>0.307</td><td rowspan="4">0.307</td><td rowspan="4">0.1</td><td rowspan="4">0.1 **</td><td>2.48</td></tr>
<tr><td>C2</td><td>93.5</td><td>0.334</td><td>0.307</td><td>95.0</td></tr>
<tr><td>C3</td><td>1.0</td><td>3.20</td><td>0.307</td><td>5.35</td></tr>
<tr><td>C4</td><td>1.0</td><td>0.334</td><td>2.67</td><td>4.84</td></tr>
</table>

*Case 1: All the nine units are on full power operation
*Case 2: K2 is in outage, the others on full power operation
*Case 3: K4 is in outage, the others on full power operation
*Case 4: K5 is in outage, the others on full power operation
** CCDP of K9,10: Assumed the same as K7,8

2.2 Review of Design Characteristics Affecting CDFs

There are various reactor types of units in the reference site. Accordingly, the design characteristics affecting CDFs are different from each other. The basic design concept of Korean NPPs is based on the Korean regulatory requirement of 'Sharing of safety systems between multiple units of a nuclear power plant', which is almost the same as IAEA Specific Safety Requirements, No. SSR-2/1, Requirement 33 [2], and 10CFR Appendix A to Part 50 GDC Criterion 5 'Structures, systems, and components important to safety shall not be shared among units unless it can be shown that such sharing will not significantly impair their ability to perform their safety functions, ~' [3]. In PSA modeling, however, we consider and reflect non-safety related systems as well as safety related systems.

Therefore, we reviewed the systems, which are reflected in single unit PSA models but used in multi units. We also reviewed the equipment, which needs being tested and maintained during an outage of a unit, affecting the CDFs of other units on full power operation.

As a result, we identified the sharing systems between a pair of units or among more units, which are reflected in single unit PSA models. Table II shows the examples of sharing systems reflected in the single unit PSA models in the reference site. In addition, we identified the important equipment to the CDFs of the units on full power operation, which is not in service due to the maintenance during an outage of a specific unit. For example, an Alternative AC Diesel Generator (AAC DG) is tested and maintained during an outage of K4, which makes the CDFs of K2&3 higher. During an outage of K5, another AAC DG is maintained and discharge concrete conduit of Essential Service Water (ESW) system is inspected, which were identified as the main characteristics affecting the CDFs of K6.

Table II: Examples of sharing systems in the reference site

	Shared system or equipment	Units
1	Instrument Air System	K1&2 / K3&4
2	AAC DG	K1,2,3&4 / K5&6 / K7&8
3	Discharge Concrete Conduit	K1&2 / K3&4 / K5&6 / K7&8 / K9&10

2.3 Results of reevaluating CCDPs with Reflecting the Design Characteristics

Considering multi units, the sharing systems can only be used in a unit under multi-unit LOOP. Accordingly, the single unit PSA models should be modified based on the design characteristics. Sharing systems can be modeled for all the related units according to the functional availability of a unit. For reflecting this, however, we need to handle with complex models. So, we plan to reflect sharing systems on the models of a designated unit based on CCDPs. For example, AAC DG can be used among the units of K2, 3 and 4, however, we considered AAC DG only for the K2 models, because the CCDPs of K2 is much higher than those of K3 and K4.

As for the instrument air system, supplying air from the other unit was conservatively assumed not possible to use for LOOP event in the single unit PSA models. So, we do not need to consider this shared system for developing multi-unit PSA models for multi-unit LOOP events. Table III shows the reevaluated CCDPs with considering the design characteristics, which were reviewed and identified in section 2.2.

Table III: CCDPs Comparison with reflecting design characteristics

<table>
<tr><th></th><th>K2</th><th>K3</th><th>K4</th><th>K5</th><th>K6</th><th>K7,8</th><th>K9,10</th><th>Tot.</th></tr>
<tr><td>C1*</td><td>1.0</td><td rowspan="4">1.79</td><td>1.79</td><td>0.307</td><td rowspan="4">2.14</td><td rowspan="4">0.1</td><td rowspan="4">0.1 **</td><td>7.23</td></tr>
<tr><td>C2</td><td>93.5</td><td>1.79</td><td>0.307</td><td>99.7</td></tr>
<tr><td>C3</td><td>2.9</td><td>3.20</td><td>0.307</td><td>10.6</td></tr>
<tr><td>C4</td><td>1.0</td><td>1.79</td><td>2.67</td><td>9.59</td></tr>
</table>

*Case 1: All the nine units are on full power operation
*Case 2: K2 is in outage, the others on full power operation
*Case 3: K4 is in outage, the others on full power operation
*Case 4: K5 is in outage, the others on full power operation
** CCDP of K9,10: Assumed the same as K7,8

3. Conclusions

This paper is related to the project, which KHNP has just launched of multi-unit PSA for the reference site. And, this is a sequential study to the previous paper [1]. We reviewed the single unit PSA models for LOOP including SBO of all units in the reference site, and the design characteristics, which can affect multi-unit PSA modeling, such as sharing systems and the maintenance during an outage of a specific unit. In addition, we modified the PSA models by reflecting the design characteristics and reevaluated the CCDPs to confirm our ideas to select the representative units of O/H. As a result of reevaluation in section 2.3, we identified Case 2 is the most conservative configuration in the reference site, and the levels of CCDPs of Case 2 is about ten times higher than those of Case 3 and 4. And, the reviews and the results of this paper shall be used to develop multi-unit PSA models for multi-unit LOOP in the next stage of the project.

REFERENCES

[1] H.J. Jeon, et al., “Evaluation Plan for Multi-unit PSA Considering Operating Modes in a Reference Site”, Transactions of the Korean Nuclear Society Spring Meeting, May 17-19, 2017
[2] K.M. Oh, et al., “Study on Quantification Method Based on Monte Carlo Sampling for Multiunit Probabilistic Safety Assessment Models”, Nuclear Engineering & Technology, 2017
[3] D.S. Kim, et al., “Estimation of Site Core Damage Frequency due to Multi-Unit LOOP: A Case Study on OPR1000 Plants”, Transactions of the Korean Nuclear Society Spring Meeting, May 17-19, 2017