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Risk- and Cost-Based Optimization of NPP SSCs Multihazard Capacity in Post-Disaster Stage

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1. Introduction

As a part of an IRONS (Integrated Research on Nuclear Safety) project, authors at Korea Atomic Energy Research Institute (KAERI) are investigating the optimal accident prevention and management technology of nuclear power plants under extreme/combined natural hazards. In this project, we developed the multihazard risk quantification methods [1], software [2], multihazard capacity optimization frameworks using multi-objective genetic algorithms [3], and indirect and direct cost models for the NPP SSCs [3-4]. However, while pre-disaster NPP SSCs capacity optimization based on both multihazard risk- and cost is discussed in the previous work, capacity optimization in the post-disaster risk management stage has not been extensively studied yet. Therefore, in this study, post-disaster multihazard capacity optimization of NPP SSCs is investigated.

2. Methods

In this section, models used for multi-objective optimization, multihazard risk quantification, and cost evaluation are summarized.

2.1 Multi-objective Genetic Algorithm Model

To identify the optimal multihazard capacity settings of the NPP system, which not only reduces the multihazard risk but also costs compared to the as-is setting, non-dominated sorting genetic algorithm II (NSGA-II) is used. The flowchart of the NSGA-II is illustrated in Figure 1. To identify the optimal post-disaster multihazard capacity setting of NPP SSCs, two objective functions multihazard risk and cost are evaluated.

2.2 Multihazard Risk Quantification Model

One of the objectives of the optimization is to minimize the multihazard risk. Therefore, the multihazard risk of NPP SSCs capacity settings generated during the NSGA-II algorithm should be evaluated repeatedly. Since both the multi-objective genetic algorithm and multihazard risk quantification are sampling-based algorithms, a computationally effective algorithm is required for the multihazard risk quantification. Therefore, the authors use Two-stage direct quantification of the fault tree using the Monte Carlo simulation (Two-stage DQFM) method [1].

2.3 Cost Model

Minimizing the cost of the SSCs is also a key goal of the optimization. To date, there are a few models available for the NPP SSCs cost model. In this work, direct cost models are used for cost evaluation [4,5]. While modeling the cost of generic nuclear facilities (GNF), step function is used for the motor control center (MCC), Battery, and coolant pump; linear function is used for the air handler, reactor vessel, steam generator, core rod drive mechanism, and tsunami wall; square root function is used duct and piping, and lastly, quadratic function is used for the structure.

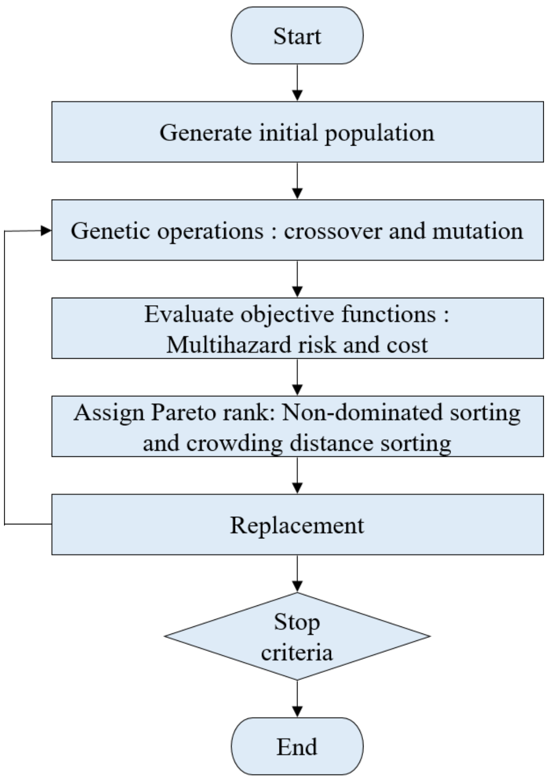

Fig. 1. Flowchart of NSGA-II

3. Numerical Example

To illustrate the post-disaster SSCs capacity optimization, the GNF model is used [5]. Among the various GNF SSCs, it is assumed that components in the electrical system (i.e., MCC and battery) and tsunami wall are damaged in the post-disaster stage, while others are not damaged. Using, the multi-objective optimization approach summarized in section 2, various optimal settings, which outperform in both multihazard risk and cost aspects of the as-is setting, are identified (Figure 3). An optimal seismic capacity of MCC and battery and tsunami wall is also plotted in Figures 4 and 5.

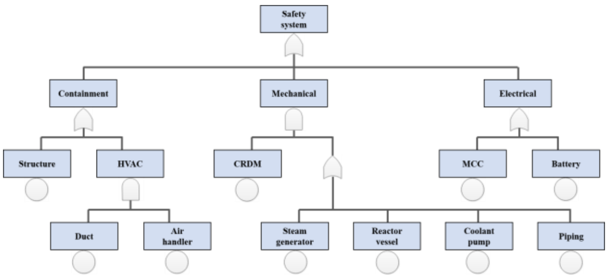

Fig. 2. Fault tree model of GNF (adopted from [4])

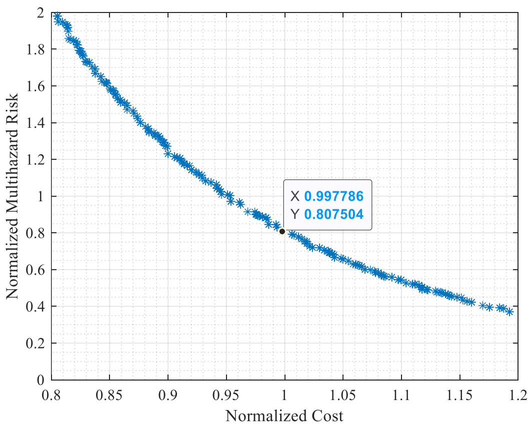

Fig. 3. Pareto surface of optimal GNF system in post-disaster scenarios in normalized cost and multihazard risk space

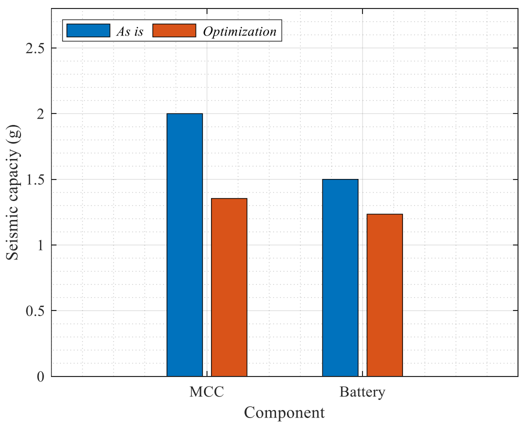

Fig. 4. Example of optimal seismic capacity setting

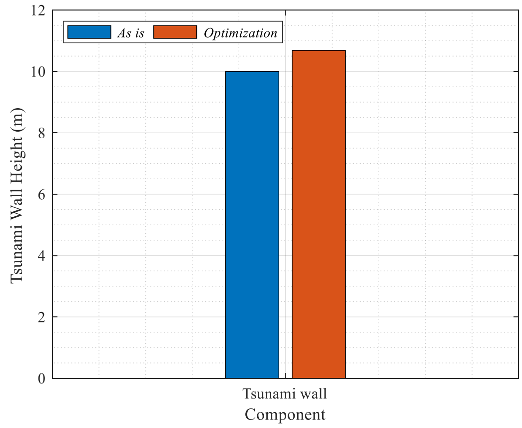

Fig. 5. Example of optimal Tsunami wall capacity setting

4. Conclusions

In this paper, an optimal capacity setting of post-disaster SSCs is identified based on both the multihazard risk and the cost. Using the GNF system example, the optimal SSCs multihazard capacity is investigated under the assumption that only the tsunami wall and the electrical components (MCC and battery) are damaged in the post-disaster stage. The authors believe this multi-objective optimization approach can support decision-makers in the post-disaster mitigation stage.

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