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Optimizing Risk-informed SSCs Classification at the Design Stage by using the Genetic Algorithm

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1. Introduction

Recently, the concept of the risk-informed design (RI-D) is widely accepted in the design process of new nuclear plants, e.g., the EPR, the Gen-IV reactors [1-2].

The roles of the RI-D will be defined differently at each design stage of the plant [2]. However, two basic roles of the RI-D are widely accepted: (1) the derivation/classification of the accidents types, i.e. Anticipated Operational Occurrence, Design Basis Accident, and Beyond DBA, (2) the classification of the structures, systems and components (SSCs) based on the risk information [2].

It is expected that such features of the RI-D will increase the safety and the economy of new plants greatly over the conventional plants.

In this paper, we propose a method to classify the SSCs at the design stage by using the genetic algorithm. The proposed method is tested on a simple PSA (Probabilistic Safety Assessment) model of a PWR (Pressurized Water Reactor).

2. Risk-informed SSCs Classification at the Design Stage by using the Genetic Algorithm

Up to now, the SSCs of nuclear power plant is classified into two groups: (1) the safety related class and (2) the non-safety related one. However, in a risk-informed application of U.S.A called the "Option 2", the SSCs are re-classified into following four groups: (1) safety related & safety significant (SRSS), (2) safety related & non-safety significant, (3) non-safety related & safety significant, and (4) non-safety related & non-safety significant as shown in the Figure 1 [3].

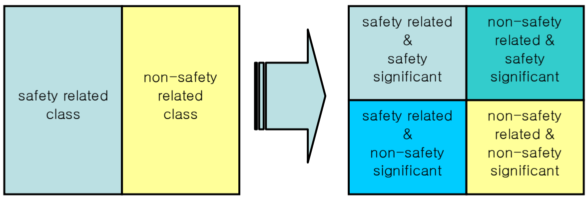

Figure 1. Risk-informed SSCs Classification

This approach enables us to use the commercial grade SSCs except for the ones which belong to SRSS group. It will reduce the operational and/or construction cost of the plant greatly over the existing plant. This approach is already implemented in the EPR which is being built in Finland [1].

In this paper, we propose a method to minimize the number of SSCs which belong to the SRSS group by optimizing the design of the plant.

The PSA provides the important information in classifying the SSCs. Therefore, if we can optimize the reliability of the SSCs, we can minimize the number of the SSCs which belong to the SRSS group. It can be regarded as a kind of the reliability allocation problem, and we use the genetic algorithm to solve this problem.

A genetic algorithm mimics the real physical world. A genetic algorithm generates the initial population of solutions. This population evolves over successive generations based on the survival of fitness. The operations such as reproduction, cross over and mutation are performed on the populations and the fitness of each individual is evaluated. Based on the new fitness of each individual, the population of next generation is produced probabilistically. As time moves on, the individuals with poor fitness will disappear, and the individuals with high fitness will survive. The genetic algorithm is already used in many reliability allocation problems [4].

In general, the cost of SSCs is widely used as the objective function in the traditional reliability allocation problems. However, in this paper, we use the importance measure of the SSCs, i.e. RAW (Risk Achievement Worth) and FV (Fussel-Veselly), as the elements of the objective function instead of the cost functions since the RAW and the FV are the major measures in classifying the SSCs.

3. Development of the Genetic Algorithm Model and the Simulation Results

Reliability allocation is based on a PSA model. So a simplified PSA model is developed for a PWR. We developed simplified event trees for the following four major initiating events:

(1) Loss of Coolant Accident Group;
- ✓ Large & Medium LOCA; the frequency is assumed as 6.60E-6/year.
- ✓ Small LOCA; the frequency is assumed as 2.43E-5/year.

(2) Transient Group;

- ✓ Loss of Main Feedwater; the frequency is assumed as 5.40E-3/year.
- ✓ Loss of Offsite Power; the frequency is assumed as 6.15E-4/year.

The following 11 systems are modeled in the PSA model.

(1) Reactor Trip System (RT),
(2) Bleed System (BD),
(3) Safety Injection Tank (SIT),
(4) High Pressure Safety Injection System (HPSI),
(5) Low Pressure Safety Injection System (LPSI),
(6) Main Feedwater System (MFWS),
(7) Auxiliary Feedwater System (AFWS),
(8) Steam Removal System (SR),
(9) Electric Power Supply System (EPS),
(10) Diesel Generator (DG),
(11) Service Water System (SWS), and
(12) Instrument Air System (IA)

Since the main goal of reliability allocation in this paper is to determine the reliability value at the system level, the developed fault trees are simple ones that consist of the system failures (the hardware failures and the related human errors) and those of the related supporting systems.

We also developed a genetic algorithm model. Based on the sensitivity studies, the main parameters used in the developed genetic algorithm model are selected as shown below:

- ✓ Population Size: 100
- ✓ Length of Chromosome: 32 bits
- ✓ Cross over Rate: 0.9
- ✓ Mutation Rate: 0.01
- ✓ Maximum Generation Number: 300
- ✓ Termination Criteria: Best fitness unchanged after 50 generations.

With the developed models, the optimization is performed to minimize the number of the SSCs which belong to the SRSS group

The simulation results, i.e. the unavailability and FV importance of the modeled safety systems, are shown in the Figure 2 and 3, respectively. As we can see in the Figures, we can reduce the number of the SSCs that belong to the SRSS group, i.e., the number of systems which belong to the SRSS group is changed from 7 to 3.

4. Conclusions

In this paper, we propose a method to classify the SSCs at the design stage by using the genetic algorithm. The proposed method is tested on a simple PSA model of a PWR.

The simulation results show that we can reduce the number of the SSCs which belong to the SRSS group. It will reduce the operational and/or construction cost of the plant greatly.

The present work is a feasibility study. This approach will be applied and validated to the component level in the future work.

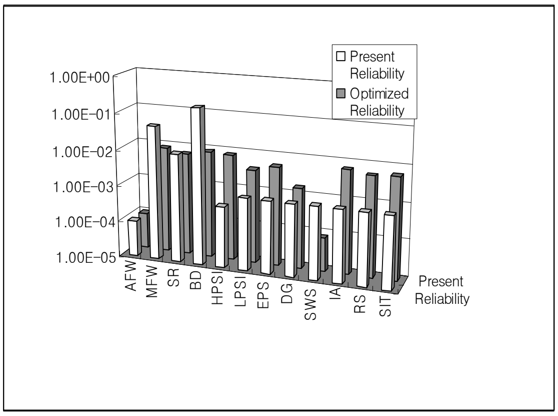

Figure 1 Optimized Reliabilities of Main Systems

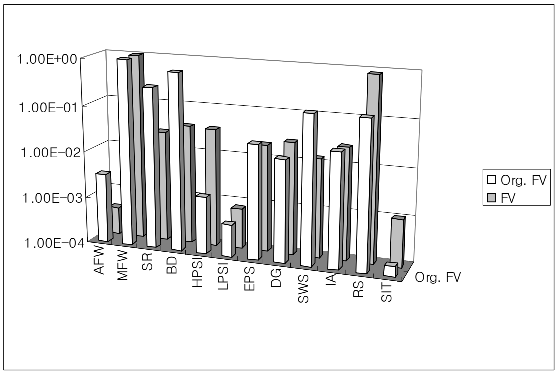

Figure 2 Changes of FV Importance

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