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Evaluation of Component Failure Data of the Operating Nuclear Power Plants in Korea Based on NUREG/CR-6928

Ho-Jun Jeon*, Jang-Hwan Na, Tae-Young Shin
KHNP Central Research Institute. 25-1 Jang-Dong, Yuseong-Gu, Daejeon, Korea, 305-343
jhj@khnp.co.kr

1. Introduction

Probabilistic Safety Assessment (PSA) has been widely used as a method for evaluating risk of a nuclear power plant. There have been, however, controversial issues on the quality of PSA because of its uncertainties in modeling and data sources [1]. This paper focuses on ensuring the quality of component failure data. When performing data analysis in PSA, we have customized the component failure data based on Bayesian analysis [2] using plant specific experiences and the generic data of Advanced Light Water Reactor Utility Requirements Document (ALWR URD) [3]. However, ALWR URD was established by collecting US nuclear power plant (NPP) practices from mid 1980s to early 1990s. In order to improve technical adequacy of component failure data in the PSA models of the operating Nuclear Power Plants (NPP) in Korea, we decided to change the generic data to reflect the latest operating experiences of NPPs. And, we analyzed the component failure data using the raw data of component failures in Pressurized Water Reactor (PWR) plants by 2012. This paper presents the results from analyzing the component failure data based on the new generic data and the latest specific failure data. We also compare the new component failure data to the existing data of PSA models, and evaluate the risk impacts by applying the new data to the PSA models of reference NPPs in this paper.

2. Method and Results

2.1 Review of NUREG/CR-6928 and ALWR URD

Although we have reflected the plant specific component failure data on performing data analysis in PSA, the quality of the component failure data still need improving because of the outdated sources of ALWR URD. So we reviewed the latest generic component failure data and decided to change. In 2007, US Nuclear Regulatory Commission (NRC) published NUREG/CR-6928 [4], which reflected industry performance between 1998 and 2002. US NRC also updates the results of the industry performance periodically. Therefore, we decided to apply NUREG/CR-6928 to the component failure data in PSA models.

At first, we reviewed the differences between the two generic data. While lognormal distribution, on the perspective of statistical analysis, is proposed as a probabilistic prediction model of failure rates and probabilities in ALWR URD, NUREG/CR-6928 postulates different probability distributions in demanding and running failures with beta and gamma distributions, respectively. Another fundamental improvement of NUREG/CR-6928 is the distinction between standby and running component failure data and the breakdown of fail to run into fail to run for the first hour and fail to run beyond the first hour for Diesel Generators (DG), cooling units, and pumps [4].

Since the fault trees of the PSA models and the plant specific data analysis program of KHNP were developed based on the failure modes of ALWR URD, we should customize the failure data of fail to run for the first hour of NUREG/CR-6928 into the failure data of fail to start in order to apply NUREG/CR-6928 to the PSA models. Table 1 shows the comparison of the component failure data of NUREG/CR-6928 and ALWR URD.

Table 1. Comparison of component failure data between NUREG/CR-6928 and ALWR URD

Component	Failure Mode	NUREG/CR-6928	ALWR URD	Increasing Rate
Diesel Generator (Standby)	Fail to Start	7.43E-03	1.40E-02	-46.9%
	Fail to Run	8.48E-04	2.40E-03	-64.7%
Chiller Unit (Running)	Fail to Start	9.83E-03	6.00E-03	63.8%
	Fail to Run	9.42E-05	1.00E-05	*842.0%*
Fan (Running)	Fail to Start	1.79E-03	6.00E-04	*198.3%*
	Fail to Run	1.08E-05	1.00E-05	8.0%
Check Valve	Fail to Open	1.30E-05	2.00E-04	-93.5%
	Fail to Close	1.04E-04	1.00E-03	-89.6%
Motor Operated Valve	Fail to Open/Close	1.07E-03	4.00E-03	-73.3%
Motor Driven Pump (Running)	Fail to Start	2.23E-03	1.30E-03*	*71.5%*
	Fail to Run	4.54E-06	5.00E-06*	-9.2%
Motor Driven Pump (Standby)	Fail to Start	1.85E-03	3.00E-03**	-38.3%
	Fail to Run	5.80E-06	1.50E-04**	-96.1%
Turbine Driven Pump (Standby)	Fail to Start	9.52E-03	1.50E-02	-36.5%
	Fail to Run	7.35E-05	3.00E-04	-75.5%

*: The data for component cooling water pump
**: The data for auxiliary feed water pump

As a result of comparing the component failure data of the two generic data sources, the failure data of most components show a decreasing trend except for some components such as a chiller unit, a fan, and the specific failure mode of a pump. It is considered that the recent maintenance system like Maintenance Rule (MR) in US is well-managed and effective.

2.2 Analysis of the plant specific component failure data of PWR plants

We have collected the raw data of component failure from NPPs using Enterprise Resource Planning (ERP) system since 2003, and have used web-based

Plant Reliability Data Information System (PRinS) which was connected to the ERP system to analyze component failure data for PSA models. The component failure data of 16 PWR plants by the end of 2012 were collected and analyzed in this paper. Over 1,100 raw data were analyzed as a complete failure and over 500 raw data as a degraded failure. As for the raw data analyzed as a degraded failure, 20% of weighting factor was considered when counting the number of failures. To analyze the failure data, we also estimated the number of demands and the running time of each component, and reviewed the DGs, cooling units and pumps to classify the operating status into standby or running components. Also, we reviewed the statistic characteristics of beta distribution and gamma distribution used in NUREG/CR-6928. Beta distribution assumed as demand failure probabilities uses two parameters. One is the alpha parameter, which means the number of failures; the other is the beta parameter, which means the total number of successes on demand. For gamma distribution postulated as running failure rates, the alpha parameter means the number of failures, and the beta parameter means component operation time.

2.3 Bayesian update of the component failure data based on NUREG/CR-6928

To perform Bayesian update, we reviewed and compared the component failure modes of NUREG/CR-6928 and those of PSA models. We should combine two failure modes of 'fail to start' and 'fail to load and run' of NUREG/CR-6928 because of the inconsistency with the PSA models. For the failure mode of 'fail to run' of standby components, we could not gather the raw data because we do not perform a test over an hour. Therefore, we cannot but using only the generic data for the failure mode. Also, we could not perform Bayesian update for the failure data of safety relief valves, batteries because we analyzed the raw data generated from only full power operations. Table 2 shows the comparison of the component failure data of NUREG/CR-6928 and the Bayesian updated data.

Table 2. Comparison of component failure data between NUREG/CR-6928 and Bayesian updated data

Component	Failure Mode	NUREG/CR-6928	Bayesian Updated data	Increasing Rate
Diesel Generator (Standby)	Fail to Start	7.43E-03	9.73E-03	*31.0%*
	Fail to Run	8.48E-04	-	-
Chiller Unit (Running)	Fail to Start	9.83E-03	1.78E-02	*81.0%*
	Fail to Run	9.42E-05	8.99E-05	-4.5%
Fan (Running)	Fail to Start	1.79E-03	1.57E-03	-12.3%
	Fail to Run	1.08E-05	2.70E-06	-75.0%
Check Valve	Fail to Open	1.30E-05	7.02E-05	*441.2%*
	Fail to Close	1.04E-04	1.19E-04	*14.9%*
Motor Operated Valve	Fail to Open/Close	1.07E-03	1.40E-03	*31.1%*
Motor Driven Pump (Running)	Fail to Start	2.23E-03	2.55E-03	*14.6%*
	Fail to Run	4.54E-06	2.32E-06	-48.9%
Motor Driven Pump (Standby)	Fail to Start	1.85E-03	1.83E-03	-1.2%
	Fail to Run	5.80E-06	-	-
Turbine Driven Pump (Standby)	Fail to Start	9.52E-03	2.54E-03	-73.4%
	Fail to Run	7.35E-05	-	-

In general, the Bayesian updated data are a little higher than the generic data, but a little lower than the previous generic data. For check valves, the updated data increase a lot, but are lower than the data of ALWR URD.

2.4 Risk assessment using the new Bayesian updated data of component failures

To compare the component failure to the existing PSA models and the risk impact, we selected a reference NPP and reviewed the PSA models. Applying the new Bayesian updated data of component failures to the reference PSA models, the Core Damage Frequency (CDF) were evaluated. As reviewing the existing CDF and the importance measures of the PSA models, the component failure data of high pressure injection pumps, containment spray pumps, motor operated valves, auxiliary feed water motor driven/turbine driven pumps were identified important to CDF. The demand failure data of these important components are compared in Fig. 1. As a result of decreasing in failure data of major components, the CDF of the reference NPP also decreased over 30% by applying the new Bayesian updated component failure data.

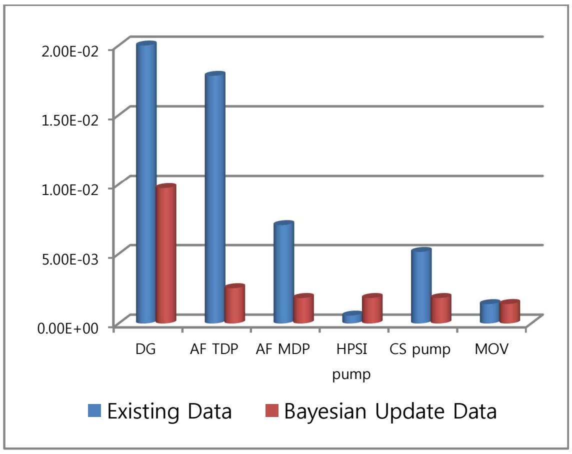

Fig. 1. Comparison of the demand failure data for the major components in CDF

3. Conclusions

To apply the new generic data source to PSA models, we reviewed and compared NUREG/CR-6928 and the existing generic data source, ALWR URD. In addition, we analyzed the component failure data generated from 16 PWR plants by the end of 2012, and performed the Bayesian update with these raw data based on the new generic data source of NUREG/CR-6928. Also, we reviewed the PSA models of the reference NPP, and identified some important components to CDF. The failure data of the major components decreased in general by applying the new generic data and the latest plant specific data. As a result, the CDF of the reference NPP decreased over 30% compared to the value of the existing CDF.

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