Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2009

Generation Risk Assessment Using Fault Trees and Turbine Cycle Simulation: Case Studies

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1. Introduction

Since 2007, Korea Atomic Energy Research Institute and Kyung Hee University have collaborated on the development of the framework to quantify human errors broken out during the test & maintenance (T&M) in secondary systems of nuclear power plants (NPPs). The project entitled "Development of Causality Analyzer for Maintenance/Test Tasks in Nuclear Power Plants" for OPR1000 on the basis of the proposed framework is still on-going, and will come to fruition by 2010. The overall concept of GRA-HRE (Generation Risk Assessment for Human Related Events) which is the designation of the framework, and the quantification methods for evaluating risk and electric loss have introduced in other references [1,2]. The originality emerged while implementing GRA-HRE could be evaluated in view of (1) recognizing the relative importance of human errors comparing with other types of mechanical and/or electrical failures, (2) providing the top-down path of the propagation of human errors by designating top events in the fault tree model as trip signals, and (3) analyzing electric loss using turbine cycle simulation.

Recently, we were successfully to illustrate the applicability of GRA-HRE by simulating several abnormalities. Since the detailed methodologies were released enough to follow up, this paper is going to only exemplify the case studies.

2. Methods and Results

This chapter will focus on two aspects: The first is to validate the accuracy of the turbine cycle model for steady-state conditions as well as abnormal conditions. The second is to identify the collaboration of the risk estimator which is the fault tree model and the derate estimator which is the turbine cycle simulation.

2.1 Models and Tools

Basically two tools are working in this paper. The fault tree model taking a role of the risk estimator was developed such that a majority of secondary systems is involved [2] and implemented by AIMS developed by KAERI. In case of OPR1000, there are 14 reactor protection signals, 20 turbine protection signals, and 12 generator protection signals. Since turbine and generator trip signals definitely belong to secondary systems, all of them were selected as the top events. Among reactor trip signals, the signals related to steam generators were decided as top events.

The turbine cycle model was developed by PEPSE [3] as shown in Figure 1. This model includes all of the back-bone components related to electricity generation, and is connected with the support systems contributing the performance and reliability of back-bone components. The validation of the turbine cycle model for steady-state was achieved by comparing the heat balance diagrams at valve-wide-open, 100%, 75% loads produced by the model and provided by the turbine cycle manufacturer. Specifically, electric output, heat rate, and turbine expansion lines are the representative metrics for deciding accuracy and completeness.

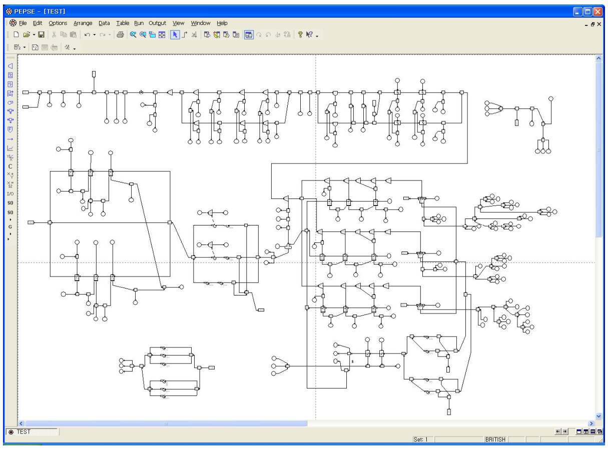

Figure 1. Turbine cycle model developed by PEPSE

Since this model should be able to simulate a heat balance diagram for abnormal configurations, a lot of valves and flow paths such as drain, bypass, or dump paths were additionally attached.

2.2 Case Studies

In order to provide realistic case studies, we referred the cases released in a public domain. The case studies are composed of event overview and the results analyzed by GRA-HRE. Even though the original fault tree and turbine cycle models were developed for OPR1000, some of case studies were accomplished for other types of NPPs. It should be noticed that their results seemed reasonable, which means the products of GRA-HRE as well as the framework itself can be used for extensive applications of secondary systems.

2.2.1 Close of feedwater heater (FWH) drain valve

- Overview: Due to the failure of a FWH level controller, a drain valve was closed and 2.2% outputs were lost.
- Simulation: Setting an 'out-of-service' option to the same heater, which is the extreme case of a level control failure, an output decreased by 3.1%.

2.2.2 Dump of moisture separator (MS) drain tank

- Overview: Due to the abnormal open of a MS drain tank dump valve, 0.13% outputs decreased.
- Simulation: Due to the uncertainty of a dump valve size, 1. Assuming 10% dump of drain flow to a condenser, 0.06% decreased; 2. Assuming 50% dump, 0.31% outputs were lost.

2.2.3 Open of FWH bypass valve

- Overview: Due to the abnormal open of a FWH bypass valve, 1.6% electricity was down.
- Simulation: Due to the uncertainty of a bypass valve size, 1. Setting 25% bypass which is a positively extreme case, 0.8% was lost; 2. Considering pressure drop and the length of flow path, setting 62.5% bypass, 1.6% decreased.

2.2.4 Failure of MS level control

- Overview: Due to the abnormal close of a normal drain valve and the failure of an emergency drain valve, a MS drain tank level was high enough to generate a turbine trip signal.
- Simulation: This case belongs to the minimal cutsets which has the top event designated by 'MSR DRN TK LVL HI' so the risk estimator runs. The risk estimator provides a relevant minimal cutset representing this case is one of single point vulnerabilities.

2.3.5 Failure of condenser vacuum control

- Overview: There are six seawater circulating pumps, and one or two of them are standby in normal conditions. The failure of standby pumps could be a minimal cutset or not depending on thermo-hydraulic conditions such as condenser heat load, seawater temperature, hotwell level, or tube fouling.
- Simulation: Setting 35°C seawater temperature, 75% clean factor, 10% plugging, and four operating pumps, condenser pressure increased to 99.5mmHgA, which belongs to a minimal cutset unless the standby pumps and vacuum pumps are out of order at the same time. If a single standby pump is successfully running, then the pressure decreased to 85.0mmHgA which does not belong to a minimal cutset. 4.3% electric outputs would be decreased without a turbine trip.

In the last case, all of the plant conditions are preliminarily evaluated in the derate estimator to see whether trip setpoints are violated or not. If there is any violation, it means the combination of failures should belong to minimal cutset. Figure 2 explains the cooperation of both estimators.

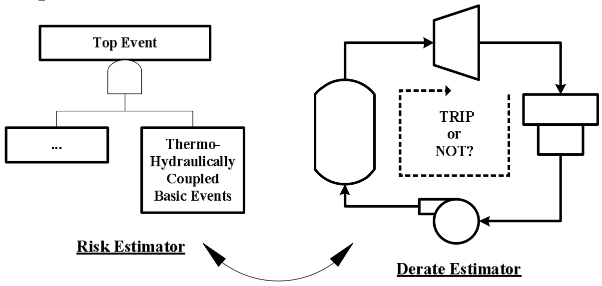

Figure 2. Cooperation of the risk estimator and the derate estimator

3. Conclusion

This paper was focused on two aspects: The first is to validate the accuracy of the turbine cycle model, particularly for abnormal conditions. The second is to identify whether the collaboration of the risk estimator and the derate estimator works in a comprehensive manner. Checking up the case studies, we concluded the framework of GRA-HRE would be available in quantifying the consequence of failures in a secondary system. Even though the models were developed for OPR1000, the abnormal situations taking place in other types of plants could be approximately but quite accurately characterized. The next step of this study will be to integrate these products with the failure modes of human errors using a user interface.

ACKNOWLEDGEMENT

This work was supported by Nuclear Research & Development Program of the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korean government (MEST). (Grant code: M20702030004-08M0203-00410)

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