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The Combined Application of Fault Trees and Turbine Cycle Simulation in Generation Risk Assessment

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1. Introduction

The paper describes a few ideas developed for the framework to quantify human errors taking place during the test & maintenance (T&M) in a secondary system of nuclear power plants, which was presented in the previous meeting. [1]

GRA-HRE (Generation Risk Assessment for Human Related Events) in Figure 1 is composed of four essential components, 1) the human error interpreter, 2) the frequency estimator, 3) the risk estimator, and 4) the derate estimator. The proposed GRA gave emphasis on 1) explicitly considering human errors, 2) performing fault tree analysis including the entire balance-of-plant side, and 3) quantifying electric loss under abnormal plant configurations.

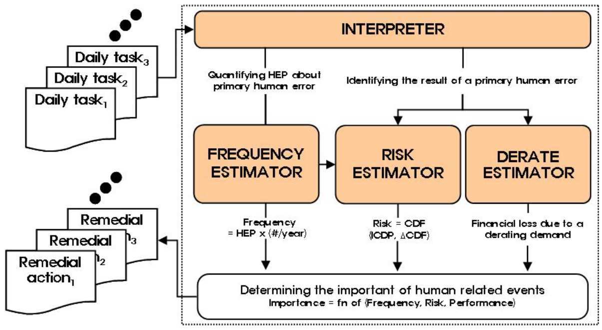

Figure 1. Framework for quantifying human errors of T&M tasks, GRA-HRE

In terms of the consideration of human errors, it was hard to distinguish the effects of human errors from other failure modes in the conventional GRA because the human errors were implicitly involved in mechanical failure mode. Since the risk estimator in GRA-HRE separately deals with the basic events representing human error modes such as control failure, wrong object, omission, wrong action, etc., we can recognize their relative importance comparing with other types of mechanical failures.

Other specialties in GRA-HRE came from the combined application of fault tree analysis and turbine cycle simulation. The previous study suggested that we would use the fault tree analysis with the top events designated by system's malfunction such as 'feedwater system failure' to develop the risk estimator. However, this approach could not clearly provide the path of propagation of human errors, and it was difficult to present the failure logics in some cases. In order to overcome these bottlenecks, the paper is going to propose the modified idea to setup top events and to explain how to make use of turbine cycle simulation to complete the fault trees in a cooperative manner.

2. Methods and Results

2.1 Risk Estimator Using Fault Trees

The risk estimator primarily provides the probabilistic variation of the unexpected trips or shutdowns which may be changed by the additional human errors during the T&M tasks on the basis of the fault tree analysis. The fault tree analysis facilitates feeding the updated initiating events or failure probability of trip events to a conventional probabilistic safety assessment (PSA) results. One of the best methods to back-track the root cause of the trips should be to start from the trip signals because the trip signals must be the clearest evidence showing the serious anomalies of power plants. It is expected that the approach based on top-down decomposition from the trip signals for protecting a reactor, a turbine, and a generator to the basic events related to human errors can provide more intuitive information on the path of human errors' propagation up to plant shutdown. 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 a candidate for the top event. In case of manual trip, we investigated the abnormal operation procedures (AOP) and made some of them involved in the fault trees whether the transient scenario of an AOP can possibly trigger plant shutdown in manual manner.

A simplified fault tree for developing the risk estimator is shown in Figure 2. Figure 2 shows a few depth of the fault tree designated 'Condenser Vacuum Low Trip' as the top event, which is one of the turbine protection signals. The system malfunctions are again decomposed into the sub-systems as tracking the root causes. The basic events are typically 1) mechanical random failures such as 'fail to open' of a valve or 'fail to run' of a pump, 2) common cause failures, and 3) failures caused by human errors which come from T&M procedures. Establishing the fault trees, we can generate the minimal cutset, calculate importance measures, and determine the variation of trip probability for specific T&M tasks.

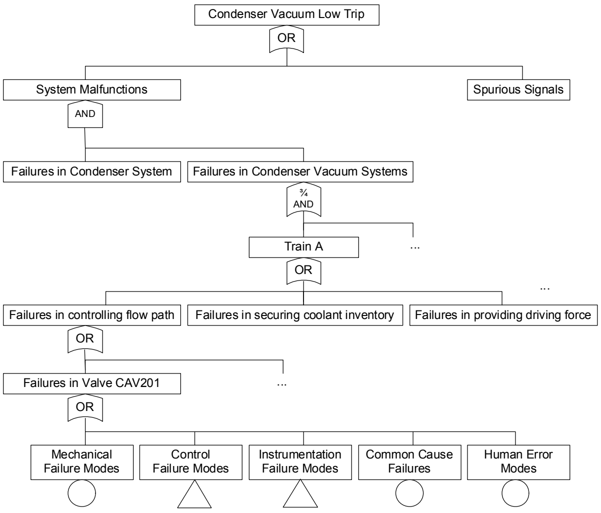

Figure 2. Example of the simplified fault tree for developing the risk estimator

2.2 Derate Estimator Using Turbine Cycle Simulation

In order to deal with the basic events not to contribute plant shutdown or not to belong to the minimal cutset of the risk estimator, the turbine cycle simulation in the derate estimator computes the electric loss and/or the total cost by the moment that the basic events get back to normal condition. Each component in the turbine cycle model can have different configurations depending on its failure mode related to human errors. The turbine cycle simulation is performed by PEPSE. [1, 2] This model includes all of the bare-bone systems related with electricity generation, and is connected with the support systems contributing the performance of electric generation.

In order to estimate total electric power loss, the electric loss (Unit: kW) computed by the derate estimator is multiplied by the period (Unit: hour) that is necessary for the anomaly caused by a human error to get back to a normal condition and a unit cost for electricity generation. Ultimately the effect of the human error is converted to a cost metric so that the cost metric can be used when deciding whether the T&M procedure needs to be corrected or revised by remedial actions.

2.3 Combined Applications

The turbine cycle simulation is also used when the availability of minimal cutsets should be evaluated in terms of thermo-hydraulic conditions for determining whether a trip happens or not.

There may be the cases that the basic events are neither independent nor a common cause failure in the fault trees of the risk estimator because they are correlated in terms of thermo-hydraulic conditions, which is quite strange situation distinguishing a PSA. For example, condenser vacuum could be low or high depending on the temperature of sea water even though the circulating pumps are fully running. Valve arrangement of branch paths could be another instance because the flowrate of those branch paths is not so large. This case cannot be managed by only fault trees. The idea is to merge the capability of the derate estimator for this purpose. Figure 3 shows the cooperation of the derate estimator with the risk estimator. Turbine cycle simulation facilitates determining whether a trip happens or not given correlated basic events. Since the derate estimator is based on the turbine cycle simulation, it can take a role of providing the feasibility of the minimal cutsets containing thermo-hydraulically correlated basic events.

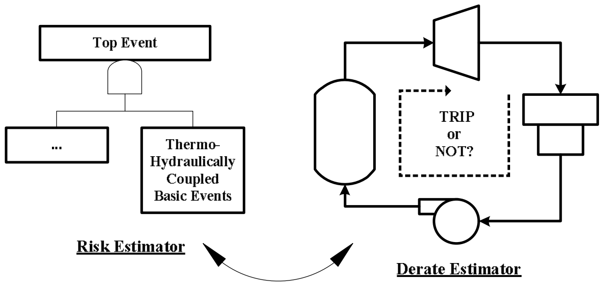

Figure 3. Cooperation of the risk estimator and the derate estimator

3. Conclusion

This study was motivated by the need of quantifying human errors during the T&M, particularly, in a secondary system. 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 at KAERI and Kyung Hee University, and will be finalized by 2010. The GRA is a massive theme and the human error itself is also an enormous discipline. Even though their combination must be, therefore, an extremely huge topic, we expect that some of key ideas proposed in this study should contribute on the development of a tool reducing the various losses resulted from human errors in NPPs.

ACKNOWLEDGEMENT

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REFERENCES

[1] G. Heo, J. K. Park, Framework for Quantification of Human Errors in Testing and Maintenance, Transactions of the KNS, PyeongChang, Korea, October 30-31, 2008.

[2] Minner G.L., et al., PEPSE and PEPSE-GT Volume 1 Manual, User Input Description, Scientech, Inc., Idaho Falls, USA, 2002.