Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2012

Strategy of Risk-Informed Inspection for Secondary Systems in NPPs

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1. Introduction

Recently, unexpected accidents such as large-scale blackout have been occurred due to increasing demand of electricity. The unplanned trips have great influence over the economics although they rarely affect the safety of system. Because the cost for inspection and maintenance is limited, it is beneficial not only economically to take follow-up action in a timely manner to prevent plant trip but also in safety by protecting against the risk which is occurred from trip.

In nuclear power plants (NPPs), the importance about risk-informed service such as inspection, maintenance and replacement is becoming on the rise. Risk-informed techniques such as in-service test, in-service inspection, design guide change and etc. are already used in nuclear field but these techniques are applied focusing on primary system for safety-related regulatory issues. It is needed to consider the optimization of inspection informed risk for entire plant including secondary system which is not applied enough.

The study about risk-based inspection for boilers in thermal power field is in progress actively, but not for turbine cycle, which is similar with nuclear industry. Today, the most of inspections or tests for turbine cycle are time-based maintenance, being performed on time. It is required to perform condition-based maintenance by evaluating risk analyzing both of probability and consequence simultaneously about damage mechanisms that can be predicted by equipments or devices configuring the secondary system.

Probability of failure (POF) is analyzed in terms of materials' ageing mechanisms, but consequence of failure (COF) should be evaluated in terms of thermo-hydraulic condition then it is needed to check power loss and period of maintenance.

This paper is going to propose the idea to quantify the consequence of failure using the fault tree and simulation for secondary system, and propose quantitative risk-informed inspection by these approaches.

2. Methods and Results

2.1. Risk Assessment

Risk is the combination of the probability of some event occurring during a tie period of interest and the consequences associated with that event.

Mathematically, risk should be defined as multiplication of probability (or likelihood, frequency) and consequence. Understanding the two-dimensional aspect of risk allows new insight into the use of risk analysis for inspection prioritization and planning.

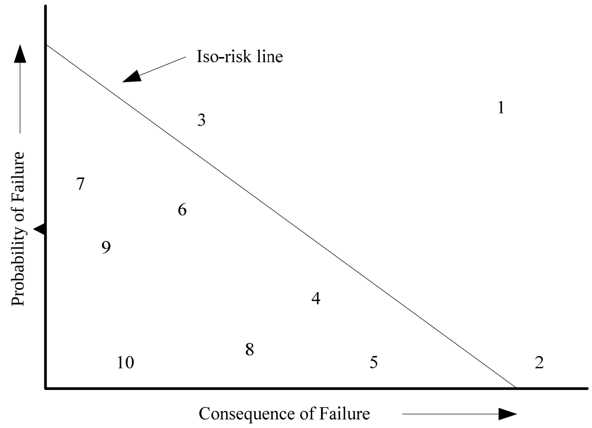

Fig.1. Risk profile

Figure 1 describes the risk associated with the operation of a number of equipment items. This figure shows the points representing the risk associated with each equipment item and an iso-risk line representing a constant risk level. In this way, the acceptable risk line would separate the unacceptable from the acceptable risk items. Also, Risk levels or values may be assigned to each equipment item. This may be done graphically by drawing a series of iso-risk lines and identifying the equipment items that fall into each band or it may be done numerically. Either way, a list that is ordered by risk is a risk-informed ranking of the equipment items [1].

2.2. POF Analysis

Quantitative probability analysis of plant components provides the measure of the POF between 0 and 1.0. POF is not constant and must be represented by more elaborate mathematical models. Such a model to estimate the POF, Weibull distribution, is often used in the field of reliability [2]. Using this distribution, POF can be estimated depending on the type of the provided data. Average of POF can be estimated from generic data and distribution of POF can be derived using history of failure. And there is a method to update the POF using result of inspection such as remaining lifetime. By these methods, it is estimated to change the POF over time as well as distribution of POF.

2.3. COF Analysis

COF should be evaluated quantitatively by power loss in terms of thermo-hydraulic condition for plants. In this section, it is described how to determine the consequence applying the combine approach of fault trees and turbine cycle simulation proposed in previous study. [3]

In a fault tree, the path flows from the top event back to the initiating event result in a top event. Using this approach, the consequences can be considered. Fault tree is qualitatively model which is the relationships among fault events and system states. Through the fault tree for interesting components, if the failure of the components results in trip as top event, the cost considering power loss and repair can be estimated and applied to COF. If the failure of component causes power defect, not complete loss from trip, turbine cycle simulation provides the cost for power defect then applies to COF. Therefore it can be applied to COF to estimate the cost for power by combining both approaches regardless of whether a trip happens or not.

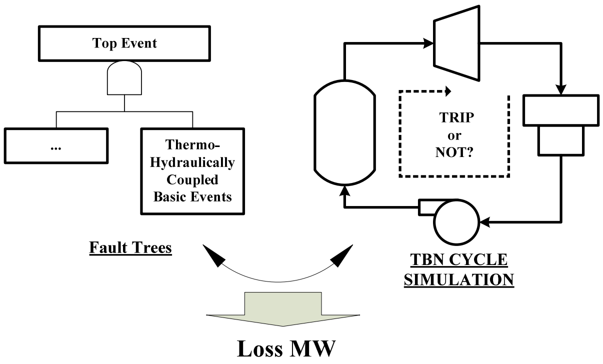

Fig.2. Cooperation of fault trees and simulation

2.4. Prototype Implementation

As an example, NPPs usually perform inspection for whole of plants every overhaul. The period and method are determined by guideline of plant inspection and manufacturer recommendation. However, the current inspection being performed is time-based maintenance to take the time of fuel replacement. The cost for power loss and inspection become increase as longer overhaul time due to its period is short than that of recommendation.

By combining contents described in the previous section, we can determine the risk and the priority for high-risk component through risk analysis. When conducting inspection of the turbine, a time-based NDT is generally performed for blade ring & gland, rotor, other cylinder base & cover. We can find that the minimal cutsets related to gland or seal are not generated in the turbine fault trees in Figure 3 obtained in the previous studies.

It is also available to estimate the impact on leakage caused by failure of gland and seal using turbine cycle simulation. Figure 4 shows the simulation display using PEPSE. [4]

Considering probability of leak occurrence during operation, it is possible to compare the cost for leakage occurrence resulted from failure of components with the benefit by reducing the associated maintenance.

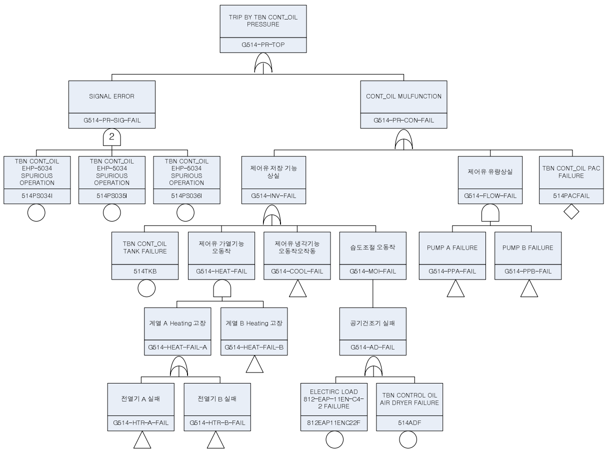

Fig.3. Fault tree model of a turbine (part)

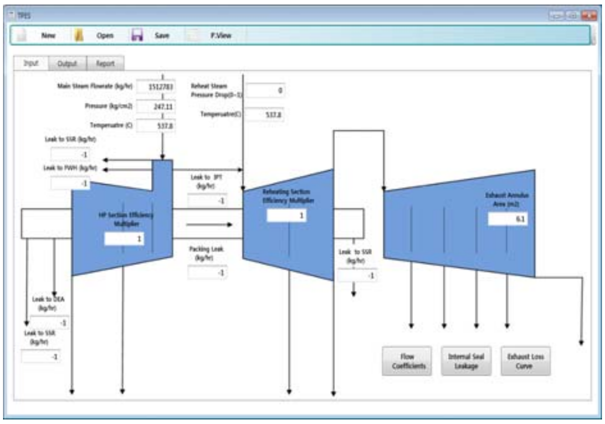

Fig.4. Display of turbine cycle simulation for performance test allowing calculation power defect

3. Conclusions

In this study, it is proposed to apply risk-informed analysis to the secondary system of NPPs utilizing quantitative POF by existing methods and quantified COF using combination of fault trees and simulation.

Extending such a methodology and applying to important test & maintenance task, the components having higher risk will require more attention in an inspection plan informed a risk analysis and the associated increased inspection costs may be offset by reducing or eliminating inspection of components that pose minimal risk. It is expected to promote economically by reducing cost from unexpected trip or power defect..

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