The Effect of Internal Leakages on Thermal Performance in NPPs

Gyunyoung Heo, Doo Won Kim, Seok Bo Jang
Department of Nuclear Engineering, Kyung Hee University
Seocheon-dong, Giheung-gu, Yongin-si, Gyeonggi-do, 446-701, Korea, gheo@khu.ac.kr

1. Introduction

Since the Balance Of Plant (BOP, limited to a turbine cycle in this study) does not contain radioactive material, regulatory authorities did not need to have concerns on it. As the interests on safety and performance is getting more serious and extensive, controlling the level of safety and performance of a BOP have just begun or is about to begin. The performance standards or ageing management programs of the major equipment in a BOP is being developed. The regulatory requirements for tests and/or maintenance are being actively built up. [1] There is also a probabilistic approach quantifying performance of a BOP. The study on quantifying the rate of unanticipated shutdowns caused by careless maintenance and/or tests conducted in a BOP is going on. [2] In this study, the modeling of the entire BOP and the methodologies of thermal performance analysis should be one of the must-have items as well.

This study was achieved to ensure fundamental skills related to 1) the detailed steady-state modeling of a BOP and 2) thermal performance analysis under various conditions. Particularly, the paper will focus on the effect of internal leakages inside the valves and FeedWater Heaters (FWHs). The internal leakage is regarded as the flow movement through the isolated path but remaining inside the system boundary of a BOP. [3] For instance, the leakage from one side of a valve seat to the other side, or the leakage through the cracked tubes or tube-sheets in a heat exchanger correspond to internal leakages. We made a BOP model of OPR1000 and investigated thermal performance under the internal leakage in Turbine Bypass Condenser Dump Valves (TBCDV) and FWHs.

2. Methods and Results

In the literature, we are easily able to find the qualitative results on the subject while it is not easy to get quantitative ones. [3~9] This means the general tendency of the effect of internal leakages might be known, but we should have a plant-specific model for the detailed diagnosis of internal leakages.

When an internal leakage happens, it costs a utility's money. Internal leakages impact plant efficiency and affect the ability to operate at full capacity. There are also direct costs associated with the appropriate repairs. It is usually critical to get the parts fixed and back in a timely manner. Even though there are numerous factors to consider for making an optimal maintenance schedule, it should be important to identify the position and quantify leak-rate.

2.1 BOP Modeling

We used PEPSE (Performance Evaluation of Power System Efficiencies) for modeling the BOP of OPR1000. PEPSE was developed by Scientech, USA and is a generic-purpose simulation toolbox for steam or gas turbine cycles. User groups actively working and sharing their know-how are another advantage that PEPSE has. Figure 1 shows the BOP model being developed by PEPSE. We call this model a 'base model.'

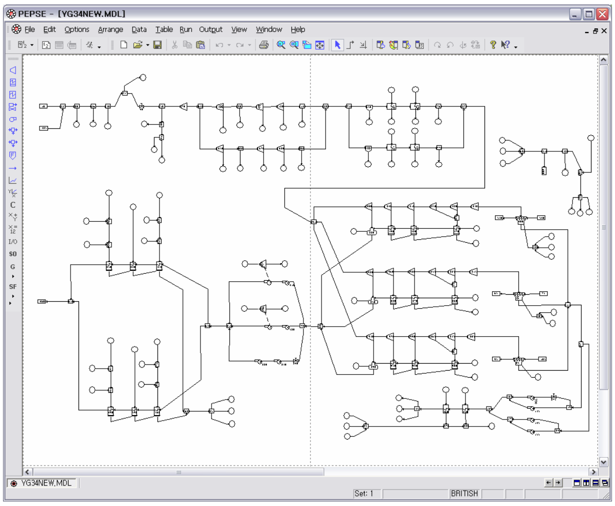

Figure 1. BOP model of OPT1000 created by PEPSE

The base model starts at the outlet of a SG and ends at the inlet of the SG. It contains the entire piping network including a main steam system, a condensation system, and a main feedwater system, which are the essential systems for analyzing the effect of internal leakages. The base model was established on the basis of the heat balance diagram at a Valve Wide Open (VWO) condition and the specification sheets of a generator, turbines, heat exchangers, and pumps. Originally the capability of PEPSE is limited to the steady-state modeling. In order to increase the ideality of the model, condenser vacuum control and FWH level control are approximately implemented even though we can only observe the final steady-state. The accuracy of the model was validated by comparing the results produced by the base model with VWO, 100%, and 75% design heat balance diagrams.

2.2 Internal Leakage of Valves

This study conducted the analysis of the TBCDVs which are knows as one of the most serious leaking points. TBCDVs can directly release maximum 40% of main steam when turbines are shutdown. Total 6 TBCDVs are isolated during a normal operation. Since the pressure of discharging-side is less than 1 atm while that of main stream-side is over 70 atm, so it is very likely to take place of internal leakages through the valve seats. We reviewed the valve type, the design parameters, and the operational conditions of the TBCDVs in the handbooks of OPR1000. From the data, we determined the rated flowrate of the valves and investigated thermal performance on the BOP in leakage conditions. The correlations between the internal leakage rate per a single TBCDV and electric output or heat rate are in Equation (1) and (2):

$$\Delta kW\ (kW) = 0.194559\dot{m}(kg/hr) \qquad (1)$$

$$\Delta HR\ (BTU/kWh) = 0.00181\dot{m}(kg/hr) \qquad (2)$$

2.3 Internal Leakage of Feedwater Heaters

The regenerative cycle of OPR1000 consists of 6 closed-type FWHs and 1 open-type FWH which is called deaerator. The close-type FWHs are tube-shell type, horizontal or vertical heat exchangers. In order to increase the flexibility of modeling the leaking spots and flowrate, we split the default FWH model provided by PEPSE into two sub-models; straight condensing FWH and external drain cooler. We corrected some internal parameters of the split FWH so it can produce the same design performance indices, for example, Terminal Temperature Difference (TTD), Drain Cooling Approach (DCA), and pressure drop in tube- and shell-side. We then simulated three internal leakage cases in the 7th FWH as shown in Figure 2. At each case, the leakage rate was decided to 1.0 ~ 5.0%. Table 2 shows the results.

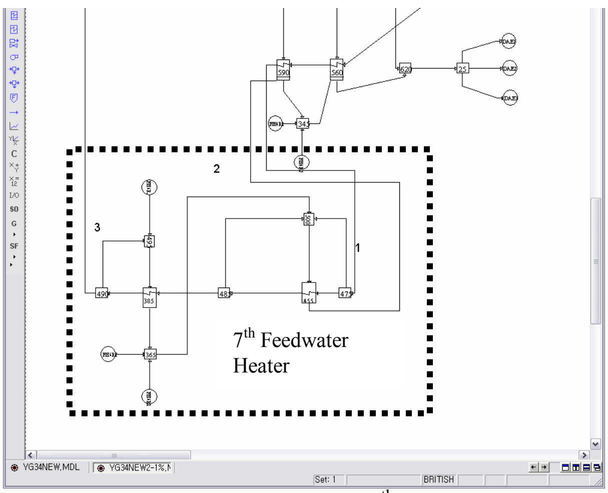

Figure 2. Leaking positions at the 7th FWH

Table 1. Effect of the internal leakage of the 7th FHW

Leakage(%)		Output	Heat rate	TTD	DCA
No leakage		0	0	0	0
I	1.0	-0.004	+0.012	-0.50	+20.93
	5.0	-0.024	+0.058	-2.85	+68.60
	10.0	-0.052	+0.116	-6.47	+86.05
II	1.0	-0.004	+0.012	-0.50	+20.93
	5.0	-0.024	+0.058	-2.81	+70.93
	10.0	-0.051	+0.116	-6.27	+90.70
III	1.0	-0.001	+0.012	-0.95	+26.74
	3.0	-0.003	+0.035	+2.94	+72.09
	5.0	-0.005	+0.058	+5.05	+109.30

* All values are percent gain or loss.
** Case I: Inlet tube-sheet leakage, Case II: U-region leakage, Case III: Outlet tube-sheet leakage

We could observe a strong linear correlation between output (heat rate) and leak-rate and some characteristics of each case. These facts will be helpful to identify or diagnose the internal leakage in NPPs.

3. Conclusion

We attempted to support academic as well as industrial needs, particularly, related to the ageing management or optimal maintenance planning. More extensive simulation and the leakage detection (or diagnosis) algorithm will proceed as a next step.

REFERENCES

[1] S.J. Cho, Regulatory Issues on Secondary System in NPPs, Nuclear Safety Information Conference, April 5~6, 2007, Daejeon, Korea.
[2] G. Heo, Development of Causality Analyzer for Maintenance/Test Tasks in Nuclear Power Plants, Research Proposal, 2007.
[3] Korea Electric Power Research Institute, Thermal Power Plant Turbine Performance Analysis Guide, TM.SO2.Z96.80, 1996.
[4] E. Hansen, R. Godwin, D. Wood, L Turner, Early Detection of Feedwater Heater Leaks, Transaction of the ASME, Vol. 118, pp. 198, January 1996.
[5] K.A. Loparo, M.R. Buchner, K.S. Vasudeva, Leak Detection in an Experimental Heat Exchanger Process: A Multiple Model Approach, IEEE Transactions on Automatic Control, Vol. 36, No. 2, pp. 167, February 1991.
[6] J.L. Tsou, Y. Mussalli, Condenser On-line Leak Detector and Method, US Patent 5,070,723, December 1991.
[7] M.A. Shapiro, System for Detecting Tubing Rupture in Feedwater Heaters of Steam Power Plant, US Patent 4,583,369, April 1986.
[8] J.K. Hayes, Quantifying Isolation Valve Leakage, US Patent 5,067,094, November 1991.
[9] R.J. Reardon, T.J. Muldoon, Guidelines for Feedwater Heater Testing, Inspection and Condition Assessment, Proceedings of American Power Conference, April 14-16, 1998, Chicago, IL..