Assessment of NPSH Algorithm for Feedwater Booster Pump of Shin-Kori Unit 1

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1. Introduction

On February 18, 2011, with the Shin-Kori Unit 1 (SKN 1) operating in mode 1 at 100% power, the plant transient was caused by the abrupt closure of all the inlet and outlet valves of condensate polishing plant (CPP). During the transient, all of the feedwater booster pumps (FWBPs) stopped due to the signal of net positive suction head (NPSH) low-low, which resulted in the stop of main feedwater pumps and a subsequent reactor trip by steam generator low water level [1].

KINS performed the event investigation and found that the FWBPs had been operated with lower NPSH margin than expected. In comparison with the reference plants, Ulchin Unit 5&6 (UCN 5/6), there was a difference in the calculation method for NPSH. In this study, we investigate the adequacy of FWBP's NPSH algorithm of SKN 1. The difference in NPSH algorithm between SKN 1 and UCN 5/6 is evaluated.

2. Analysis and Results

2.1 NPSH Algorithm of SKN 1

The FWBP's NPSH algorithm of SKN 1 is as follows:

$$\text{NPSHm} = \text{NPSHa} - \text{NPSHr} \qquad (1)$$

where NPSHm denotes NPSH margin [2]. The NPSHm is calculated by the plant control system (PCS). If the NPSHm is maintained less than zero for 30 seconds, the FWBP is designed to trip automatically. The NPSHa, NPSH available, is the absolute pressure of a fluid at the pump inlet minus the saturated pressure of the fluid at a given fluid temperature as given by Eq. (2):

$$\text{NPSHa} = P_s - P_v + C \qquad (2)$$

where P_s is liquid pressure at pump inlet (kg/cm^2 gauge), P_v is saturated vapor pressure at liquid temperature at pump inlet (kg/cm^2 absolute), and C is calibration constant for atmospheric pressure and static head (kg/cm^2). While the P_s is directly measured at pump inlet as shown in Fig. 1, the P_v is deduced from the inlet water temperature. The NPSHr, NPSH required, is the term used to describe the energy losses that occur within a pump and is a function of the pump design at the operating point on the pump performance curve.

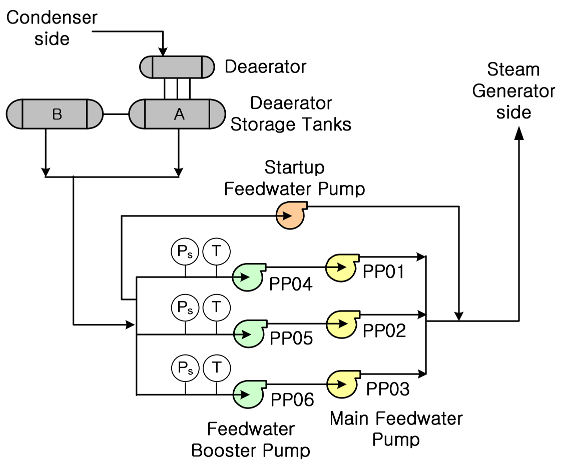

Fig. 1. Schematic diagram of SKN 1 feedwater system.

2.2 NPSHm Calculation Method

The FWBP's NPSH algorithm of SKN 1 is the same as that of UCN 5/6, excluding the calculation method of P_v. To derive P_v, a total of 7 temperature points from 0 to 200℃ are selected, and the linear interpolation is used. Upon investigation, it is found that the SKN 1 PCS supplier had changed the temperature points to approximate P_v without specific reason, as shown in Table 1.

Figure 2 compares the approximate vapor pressure of SKN 1 with the value of UCN 5/6. The real vapor pressures provided by the steam table [3] at intervals of one degree Celsius are also presented. Since linear interpolation is only an approximation, some error can be expected. The SKN 1 algorithm causes relatively high errors at water temperature grater that 120℃ as shown in Fig. 2. While the maximum error of 0.48 kg/cm^2 occurs at 141℃ in the SKN 1 algorithm, the maximum error of 0.22 kg/cm^2 occurs at 101℃ in the

Table 1 Selected temperature points to calculate P_v

Plant	Temperature points (℃)						
UCN 5/6	0	40	80	120	140	160	200
SKN 1	0	40	80	100	120	160	200

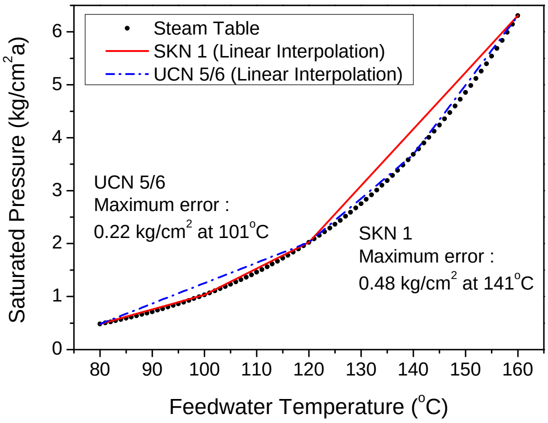

Fig. 2. Comparison of approximate saturated vapor pressures with real values.

UCN 5/6 algorithm. Considering the deaerator temperature at plant load of 25-100% is in the range of 100 to 140℃, the SKN 1 algorithm causes relatively high error of P_v at power operation.

2.3 Effect of calculation method for P_v on FWBP operability

Figure 3 shows the NPSHm recorded in the PMAS, plant monitoring and annunciator system, during the event of SKN 1. The values of FWBPs' NPSHm were about 1.1-1.2 kg/cm^2 at 100% power, indicating that the error resulted from the linear interpolation caused the about 30% of reduction in FWBP NPSH margin.

As the water inflow into the deaerator stopped by the closure of CPP inlet and outlet valves, the deaerator pressure and the FWBPs NPSHm increased. About 210 seconds later, the CPP bypass valve opened, and the water inflow into the deaerator is recovered. However, the FWBP inlet pressures decreased dramatically, which resulted in the stop of FWBPs by NPSH low-low.

To evaluate the effect of the calculation method for vapor pressure on NPSHm, we calculate the NPSHm at the time of event using the measured properties. The temperature points of SKN 1 are replaced by those of UCN 5/6. Figure 4 shows the calculation results. As can be expected, the values of NPSHm at 100% power are about 1.5-1.6 kg/cm^2. At the time of the FWBP stop, at least 0.26 kg/cm^2 of NPSH margin still exists.

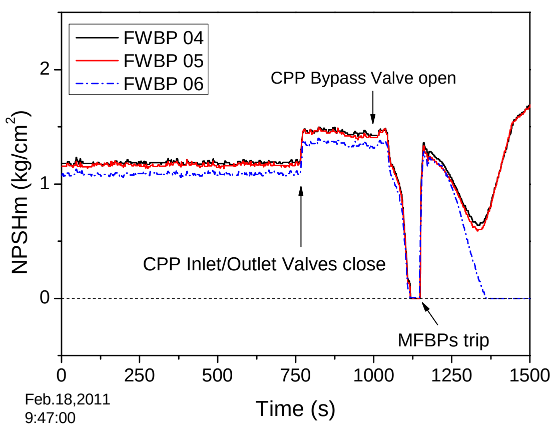

Fig. 3. FWBP NPSHm at SKN 1 event.

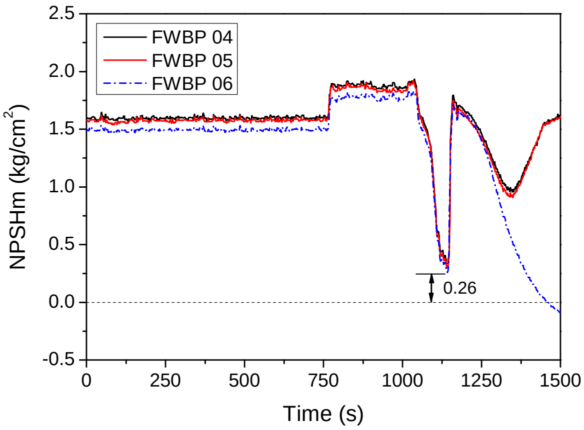

Fig. 4. NPSHm calculated using UCN 5/6 algorithm.

2.4 Discussion

The plant transient was caused by the abrupt closure of CPP inlet and outlet valves. However, if the temperature points had been properly selected to calculate the saturated vapor pressure, it was evaluated that the reactor trip could be avoided. Following the event, the utility has revised the temperature points such that the vapor pressure calculated by linear interpolation is more accurately approximate the real values, which could be considered to improve the operability of FWBPs.

3. Conclusions

The adequacy of FWBP's NPSH algorithm of SKN 1 was investigated. The results showed that the FWBPs of SKN 1 had been operated with about 30% of reduction in NPSH margin. The selection of proper temperature points has considerable effect on the FWBP's NPSH and the pump operability. Following the event, the temperature points of SKN 1 NPSH algorithm were revised to ensure that the reduction of NPSH margin is minimized. To prevent the event from recurring, the operating experience should be fed back to the plants under construction.

REFERENCES

[1] Operational Performance Information System for Nuclear Power Plant (OPIS, http://opis.kins.re.kr)
[2] SKN 1&2 Analog Loop Algorithm (Rev.0), 2006.
[3] Ernst Schmidt, Properties of Water and Steam in SI-Units, Springer-Verlag New York Inc., 1969.