

Sensitivity Analysis on Turbine Bypass Valve Capacity for NSSS Response Following a Turbine Trip in APR1400

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1. Introduction

The Steam Bypass Control System (SBCS) discharges excess steam to the condenser through the Turbine Bypass Valve (TBV), mitigating transient such as turbine trip. The criteria of TBV capacity require that the total capacity be at least 55% of the Maximum Steaming Rate (MSR) and each individual capacity not exceeding 11%. Recently, Saeul nuclear power unit 3 was found to have large TBV capacities through the Power Ascension Test (PAT).

The TBV capacity affects steam relief during quick opening and subsequent control after switchover to modulation mode. A large TBV capacity increases initial steam relief causing an excessive steam relief which may cause the undesirable Nuclear Steam Supply System (NSSS) response. Therefore, the effect of TBV capacity should be evaluated considering the influence on the interaction between the quick open and modulation mode of the SBCS.

The purpose of this study is to analyze the effect of TBV capacity on the NSSS response and to identify the TBV capacities range that provides improved for NSSS control. The turbine trip is selected for target event and simulated by the KEPCO E&C Integrated Systems Performance Analysis Code (KISPAC)[1]. The NSSS response following turbine trip was analyzed for the each TBV capacity across five cases: 55, 63, 71, 79, and 87% of the MSR.

2. Modeling and Methods

2.1 SBCS Logic Modeling

In this study, the target plant is based on the APR1400 design. The TBV behavior was evaluated using a computer simulation of the SBCS and the corresponding NSSS response was calculated.

In Figure 1, the SBCS controls the TBVs using two operating modes such as modulation mode and quick open mode.

In modulation mode, the main steam pressure is continuously monitored during relatively small transients. If the main steam pressure increases excessively, the TBVs are opened sequentially to discharge steam to the condenser. The TBVs in modulation mode are controlled in five groups according to their setpoints: TBVs 1, 2, 3/4, 5/6, and 7/8.

Quick open mode is used for relatively large transients and generates demand signals based on pressurizer pressure and main steam flow. The TBVs in quick open mode are fully opened within 1 second and divided into two groups according to their setpoints: Group X (TBV 1–4) and Group Y (TBV 5–8). The quick open signal is generated by the sum of the main steam flow reduction rate and the pressurizer pressure increase rate.

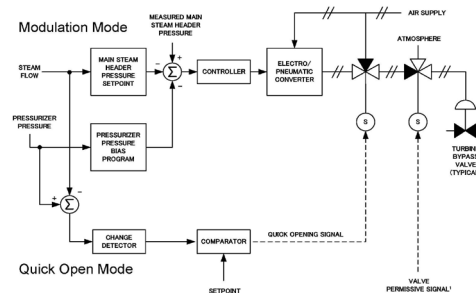


Figure 1. SBCS functional block diagram [2]

2.2 Method of Analysis

The five TBV capacity cases are selected based on the installed eight TBVs. The capacity of each TBV increases by 1%. The total TBV capacity increase by 8% for each case, resulting in capacities of 55%, 63%, 71%, 79%, and 87% of the MSR. Each individual TBV capacity should remain below the 11% limit.

The NSSS temperature and pressure exhibit similar trends. The pressure response is more immediate than the temperature. Three indicators were selected to evaluate the pressure response:

(1) Maximum pressurizer pressure: the maximum NSSS pressure following a turbine trip. A lower maximum pressure indicates more effective removal of primary side thermal energy. Therefore, the lower maximum pressurizer pressure is more favorable for NSSS control.

(2) Stabilization time interval: the time interval required for recovering the pressure into the normal range of ± 25 psi around 2250 psia which is the control region of the pressurizer proportional heater. The pressure undergoes a sudden change and subsequently enters the stabilization region under system control. A shorter stabilization time is favorable for NSSS control.

(3) Modulation demand accumulation time: the time required for modulation demand accumulation after the

quick opening. The degree of secondary side steam relief varies with TBVs capacities. If the relief is excessive, the time required for the main steam header pressure to increase becomes longer. Hence, the accumulation of modulation demand is also delayed. After quick opening, variability of NSSS control increases. A longer modulation demand accumulation time is adverse for NSSS control.

3. Results of Analysis

3.1 Pressure Behavior Analysis

Figure 2 shows that the maximum pressure occurs immediately after the turbine trip, followed by a large pressure decrease and a gradual return to the normal control range. The maximum pressure and subsequent pressure response vary with TBV capacity.

In Table 1 for the 55–79% range, the maximum pressurizer pressure tends to increase with increasing the TBV capacity. Exceptionally, the 87% case is observed different behavior. The result of the 87% case is further analyzed in Section 3.4.

After quick open mode, all TBVs are closed. To re-open TBVs, the accumulation of modulation demand needs by increase of steam pressure. During the transition from the quick open mode to modulation mode, pressurizer pressure arises again by the loss of removal of primary-side thermal energy. In Figure 3, the first undershoot occurs due to quick opening and the maximum pressure occurs during the transition time. Therefore, a larger TBV capacity delays the accumulation of modulation demand and the subsequent re-opening of the TBVs.

Table 2 presents the calculated time intervals from the maximum pressure to the stabilization region. The stabilization time decreases as the capacity is reduced. The TBV capacity affects the valve control based on modulation signal. In Table 2, a lower TBV capacity results in a shorter stabilization time. Even if the effect of the increased capacity, the time gap between 63% and 71% shows a significant difference. Furthermore, the equal stabilization times at 71% and 79% are observed. The analysis of this will be explained in Section 3.3 with modulation demand.

Table 1. Maximum pressure values

TBV capacity [%]	55	63	71	79	87
Peak pressure [psia]	2312.6	2316.7	2341.4	2364.6	2318.5

Table 2. Stabilization time interval from pressure peak to normal range region

TBV capacity [%]	55	63	71	79	87
Stabilization time interval [sec]	859	880	1005	1005	1047

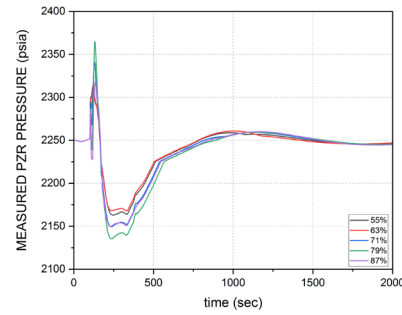


Figure 2. Pressurizer pressure overall behavior

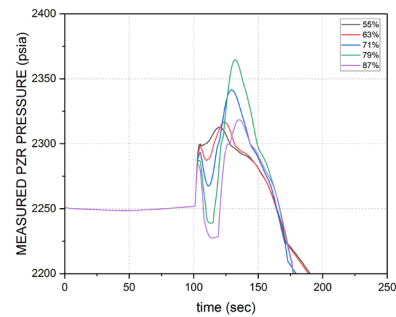


Figure 3. Enlarged maximum pressurizer pressure

3.2 Quick Open Demand Analysis

Figure 4 shows that the first peak of the quick open demand is identical regardless of the TBV capacity, while the second peak varies with TBV capacity. The primary and secondary pressures begin to decrease differently according to the amount of steam discharged following quick opening. When the quick open demand decreases to 39.5% or below according to the quick open demand program, the Y-group closes. When the demand subsequently decreases to 14.5% or below, the X-group closes. As the TBVs close following a decrease of quick open demand, the steam flow decreases more rapidly. The reduction of the steam flow generates the second quick open demand peak. Therefore, a larger the TBV capacity, second peak of quick open demand increases as steam flow decreases. However, in figure 4, the 55–79% cases are not reached at the X-group setpoint of 15% so the TBVs do not re-open.

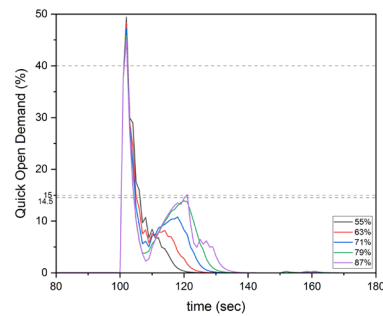


Figure 4. Overall quick open demand

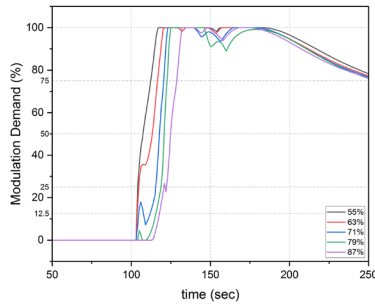


Figure 5. Overall modulation demand

3.3 Modulation Demand Analysis

In Figure 5, when the main steam header pressure starts to rise, modulation demand also begins to accumulate. The valves are opened according to the valve position demand program for each modulation group. The TBV groups are opened sequentially as the modulation demand reaches 12.5%, 25%, 50%, 75%, and 100%. In Figure 5 for cases of 71% and 79%, there is a section in which the demand decreases once before rising. This is the reason why the large time gap and the equal time of stabilization occurs. After the quick opening, the primary side thermal energy is transferred to secondary side. However, the pressurizer pressure reduction responds more slowly than the main steam header pressure reduction. The modulation demand momentarily decreases by remained effect of the pressurizer pressure reduction and then increases again. TBV groups 1-5 are opened sequentially following accumulation of modulation demand. Table 3 shows that as TBV capacity increases, the time required to reach each setpoint is delayed.

Table 3 Time at which modulation demand accumulation starts and reaches 50, 100%

TBVs Capacity [%]	Starting time [sec]	Passing time [sec]	
		Setpoint 50%	Setpoint 100%
55	103	108	117
63	103	114	121
71	103	118	123
79	104	121	125
87	113	125	132

3.4 Additional Analysis of TBV Capacity 87%

The reason why the differed behavior at 87% is that, all TBVs closure causes the rate of steam flow reduction increases. In Figure 6, the quick open demand is generated once more reaching the X-group setpoint of 15%. The modulation demand is already accumulated upon reaching the Group 2 setpoint of 25%. The TBVs 1-4 of X-group are actuated by quick open demand. This additional steam relief causes a temporary decrease in the modulation demand near the 25% setpoint. Control returns to modulation mode. The setpoint of 25% is reached again so TBV Group 2 is opened once more. Figure 7 shows that the repeated TBV opening causes

fluctuations of the steam flow for the 87% case. Consequently, the additional quick open results in a reduction of the maximum pressurizer pressure. However, the repeated occurrence of TBVs opening is not part of intentional control. This behavior indicates an unintended interaction between the quick open and modulation modes.

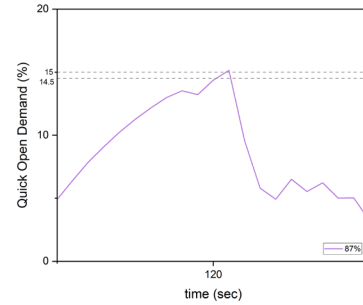


Figure 6. Second quick open demand peak for the 87% case

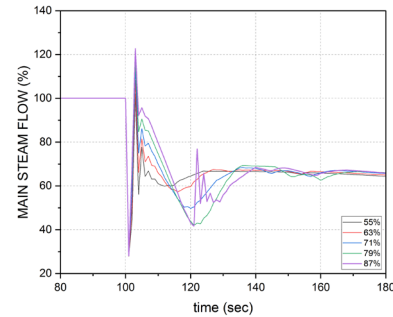


Figure 7. Main steam flow depending on TBV capacities

4. Conclusions

The analysis of a turbine trip at 100% reactor power results in that a lower TBV capacity within the 55–79% range is more favorable for NSSS pressure control. However, to determine the optimized TBV capacity, the interaction between the quick open and modulation modes should be confirmed in other transient of other partial reactor power plateaus including turbine trip.

An increase in TBV capacity enhances steam relief. However, at excessively large TBV capacities, the interaction between the quick open and modulation modes may degrade NSSS control performance. These results provide a basis for identifying a favorable TBV capacity range for NSSS control.

Further analyses should be conducted for other partial power plateaus. Therefore, future study will be evaluated turbine trips at 50% and 80% reactor power plateaus.

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