A Sensitivity Analysis of Superheated Steam Generator in SMR using MARS

Sang Jin Kim*, Seul Bin Park, Ung Soo Kim, Seok Jeong Park
Safety Analysis Group, KEPCO-E&C, 111, Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, Rep. of KOREA
**Corresponding author:sangjin@kepco-enc.com*

1. Introduction

In general, most of the PWR commercial reactors employ U-tube steam generators, which produce saturated steam, whereas most of the Integral SMRs adopt superheated steam generators. Although the heat transfer efficiency of steam is significantly lower than that of liquid water, a superheated steam generator is preferred for SMR because an advantage in terms of miniaturization. In the case of saturated steam generator, there are seperators and dryers to maintain a certain level of steam dryness. Considering the compactness of the space for this, SMR with the the superheated steam generator is more advantageous.

In the Feedwater Control System (FWCS) for the saturated steam generators, the water level of steam generators is the basic input, whereas the feedwater level in the tubes of the superheated steam henerators cannot be easily measured. In the case of a saturated steam generator, a large amount of feedwater exists inside the steam generator, so the primary coolant is not greatly affected by a small change in feedwater flow, but the primary coolant with a superheated steam generator is greatly affected by a small change in feedwater flow. For this reason, the FWCS of superheated steam generator differs greatly from that of the saturated steam generator.

In order to develop the FWCS of superheated steam generator in SMR, SMR including the helical tube steam generator was modeled and sensitivity analysis was performed according to the feedwater flow rate and the feedwater temperature using MARS-KS code[1][2].

2. Analysis Methodology

2.1 Plant Modeling and Initial Conditions

In order to simulate the behaviors of superheated steam generators, a SMR model of BANDI-60S[3] which has helical type steam generator was selected for the analysis.

Fig. 1 shows the nodalizations of primary side of BANDI-60S and Figures. 2 and 3 show the steam generator model used in the analysis. In Fig. 2, the red arrows mean the direction of coolant flow at primary side and the blue arrows mean that of secondary side.

The primary part of the steam generator is divided into a riser part where the high-temperature coolant rises inside the pipe and a downcomer part where the coolant comes down while surrounding the outside of the riser part in an annulus form.

The helical tube is located in a space between the riser area and the downcomer area, and as the feedwater flows through the helical tube, heat conduction occurs from the primary coolant in the downcomer area, causing phase change. After the phase change, the steam is continuously heated to become superheated steam and the steam is discharged to the steam line at the top.

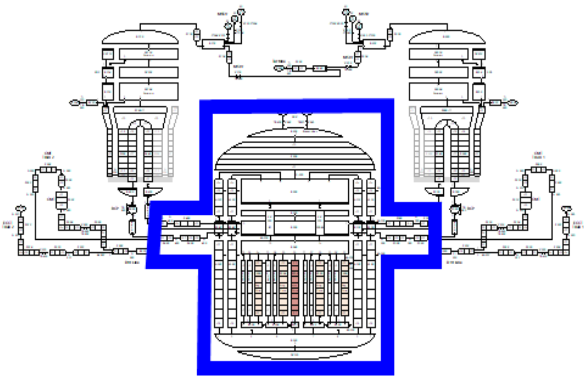

Fig. 1. MARS Nodalization of BANDI-60S
(inside the blue lines)

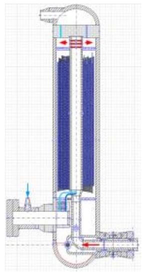

Fig. 2. Types of Helical tube steam generators

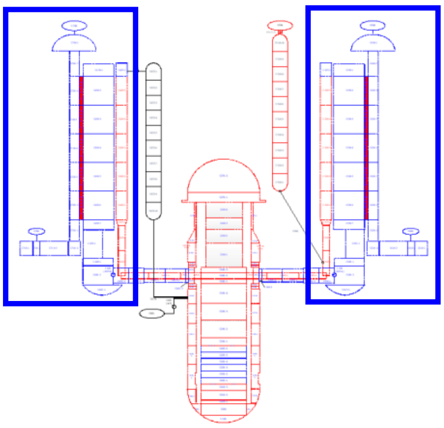

Fig. 3. Nodalization of Helical tube steam generators
(inside the blue line)

The analysis was performed by preparing the MARS-KS input to calculate the steady state. Table 1 shows the basic steady-state calculation results, and Table 2 and 3 show the sensitivity analysis conditions of feedwater flow and feedwater temperature respectively.

Table 1. Initial Conditions for the sensitivity calculation

Parameter	Bandi-60S + Helical type SG
Total Power (MW)	200.00
Tavg (K)	580.45
Thot (K)	597.97
Tcold (K)	562.93
Flow loop (kg/s)	493.94
PZR Pressure (bar)	155.11
SG Pressure (bar)	59.62
FW Flow (kg/s)	52.00
FW Temperature (K)	505.35

Table 2. Sensitivity analysis conditions according to changes in the flow rate of the main feedwater (51 ~ 59 kg/s)

Index	SG Pressure (bar)	Feedwater Flow (kg/s)	Feedwater Temperature (K)
1	59.61896	51.0	505.3722
2		52.0	
3		53.0	
4		54.0	
5		55.0	
6		56.0	
7		57.0	
8		58.0	
9		59.0	

Table 3. Sensitivity analysis conditions according to changes in the temperature of the main feedwater

Index	SG Pressure (bar)	Feedwater Flow (kg/s)	Feedwater Temperature (K)
1	59.61896	59.0	483.1500
2			488.7056
3			494.2611
4			499.8167
5			505.3722
6			510.9278
7			516.4833
8			522.0389

3. Analysis Results

In Figures. 4 to 6 show the liquid fraction of one SG in the range of feedwater flow. In Fig. 4, most of the inside of the helical tube is maintained in a gaseous state. Since the flow rate is low, most of liquid is vaporized in the lower end of the helical tube and then steam is distributed to the upper end.

In Figures. 5 and 6, liquid remains at the bottom of the helical tube. As the flow rate increases, the cooling capacity increases and the pressurizer decompression speed increases. The maximum overheat was 62.2 K at a flow rate of 52.0 kg/s and 62.0 K at a flow rate of 53.0 kg/s. In Figures. 7, 8 and 9, the pressurizer pressure fails to reach the target pressure in the steady state. It is judged that the cooling capacity is excessive so that the primary side pressure cannot be recovered and is reduced.

As shown in Figures. 10, 11 and 12, the liquid/gas distribution in the helical tube is even, and the pressurizer pressure is gradually recovered as shown Figure 9. However, it is considered non-reasonable to show pressure recovery at these flow rates because the pressure did not recover when the flow rate was 54.0 to 56.0 kg/s.

.

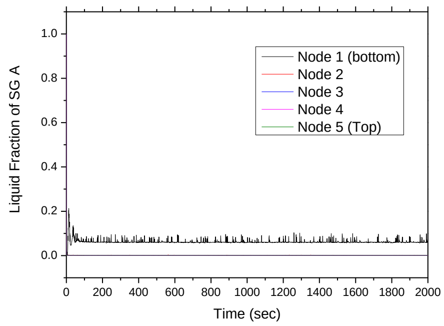

Fig. 4. Liquid fraction of SG A (51 kg/s)

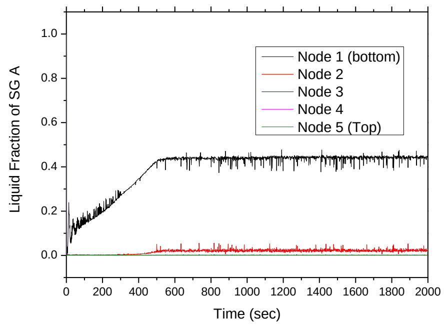

Fig. 5. Liquid fraction of SG A (52 kg/s)

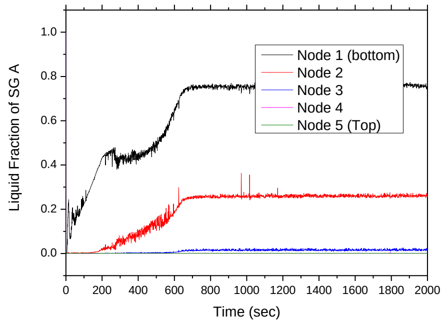

Fig. 6. Liquid fraction of SG A (53 kg/s)

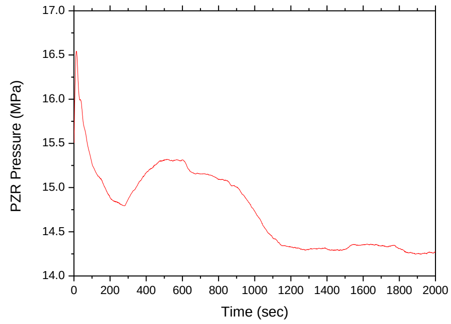

Fig. 7. PZR Pressure (54 kg/s)

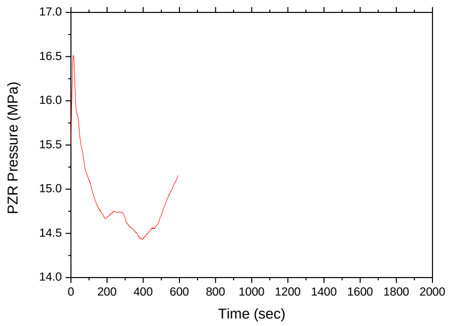

Fig. 8. PZR Pressure (55 kg/s)

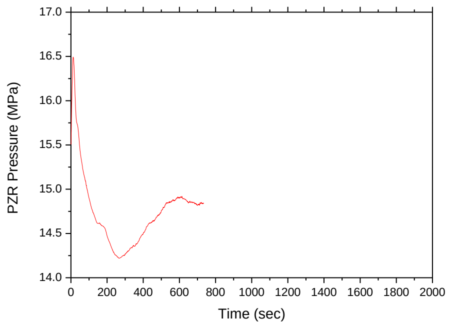

Fig. 9. PZR Pressure (56 kg/s)

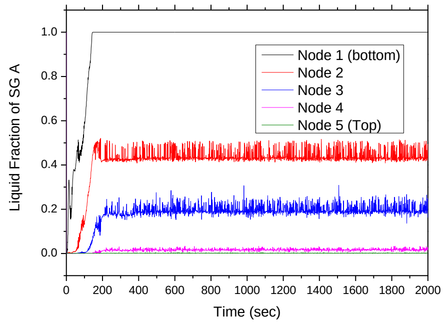

Fig. 10. Liquid fraction of SG A (57 kg/s)

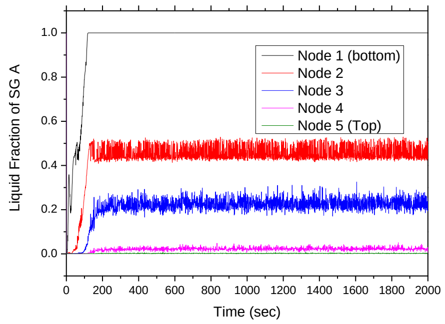

Fig. 11. Liquid fraction of SG A (58 kg/s)

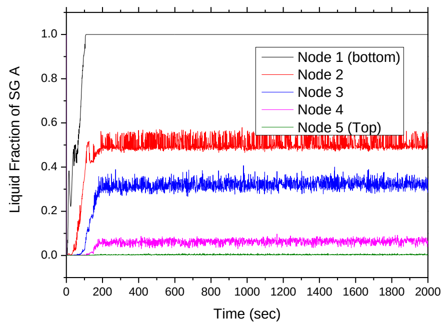

Fig. 12. Liquid fraction of SG A (59 kg/s)

Figures. 13 through 20 show the results of the sensitivity analyses according to the main feedwater temperature of 483.15 to 527.5944 K. In Figures. 13 through 15, the pressurizer pressure fails to recover to the steady-state pressure after the initial fluctuation. It is judged that the cooling capacity of the steam generator is excessive due to the low feedwater temperature.

In Figures. 16 through 18, the pressurizer pressure is gradually increased, and liquid/gas in the helical tube are also appropriately distributed. The maximum degree of superheat was 61.7 K at 449.8167 K, 62.2 K at 505.3722 K, and 61.8 K at 510.9278 K, respectively.

In Figures. 19 through 20, the pressurizer pressure rises rapidly, and most of the helical tube is formed of gas. If the feedwater temperature is higher, the calculation failed because of the relatively low cooling capacity. The maximum degree of superheat was 71.0 K at 516.4833 K, 78.6 K at 522.0389 K, respectively.

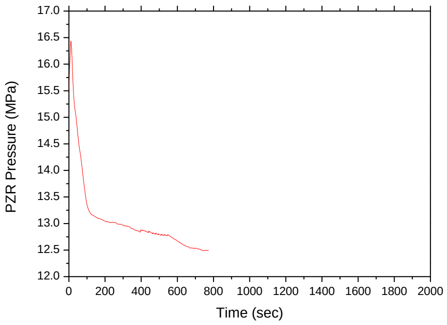

Fig 13. PZR Pressure (483.15 K)

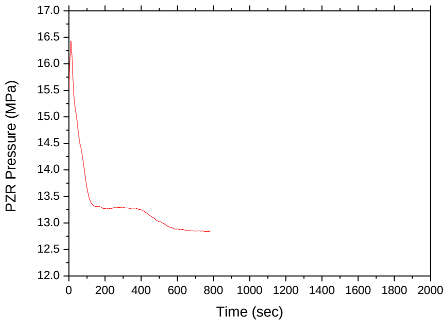

Fig 14. PZR Pressure (488.7056 K)

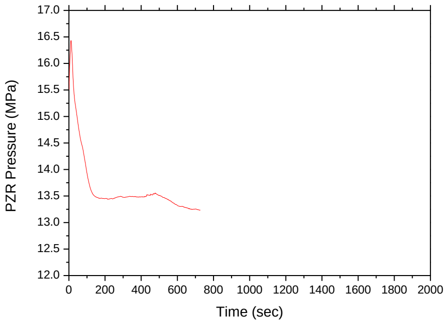

Fig 15. PZR Pressure (494.2611 K)

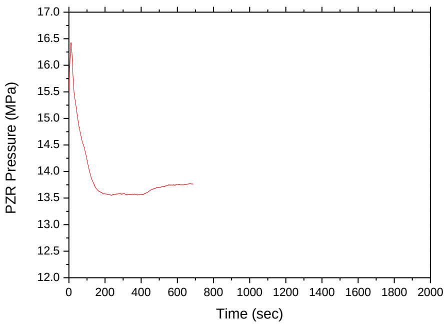

Fig 16. PZR Pressure (499.8167 K)

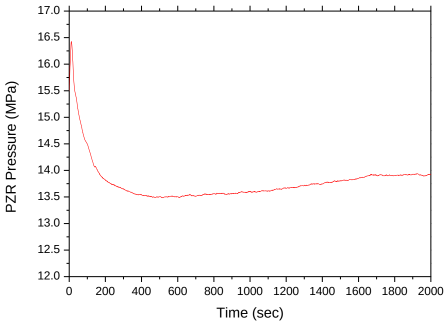

Fig 17. PZR Pressure (505.3722 K)

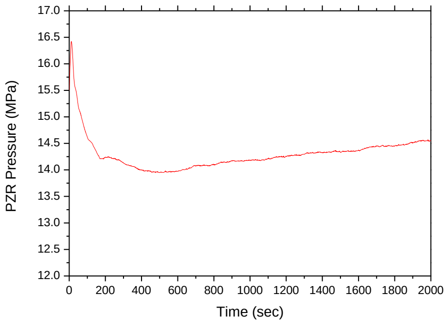

Fig 18. PZR Pressure (510.9278 K)

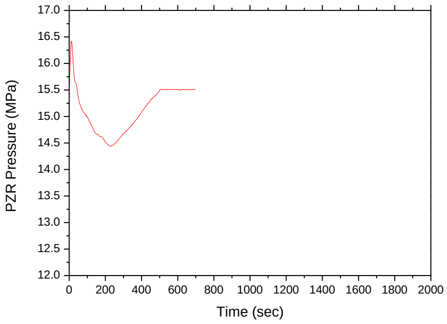

Fig 19. PZR Pressure (516.4833 K)

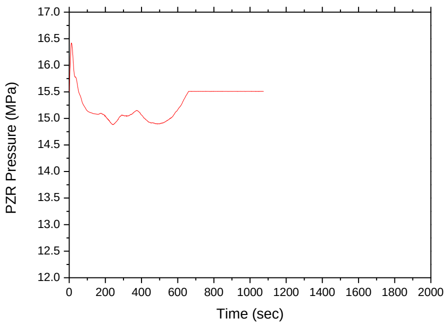

Fig 20. PZR Pressure (522.0389 K)

4. Conclusions

SMR mostly uses steam generators that produce superheated steam. In terms of FWCS, the feedwater control of superheated steam generator is significantly different from that of saturated steam generator. Furthermore, the inventory of the steam generator is very small, and the FWCS has a very large effect on the reactor behavior. For the development of the control logic for the superheated steam generator, the superheated steam generator of the BANDI-60S was modelled by using MARS-KS code, and the characteristics of the superheated steam generator were reviewed.

In order to investigate the characteristics of the superheated steam generator, the sensitivity analysis according to condition changes was performed. The feedwater flow rate and the feedwater temperature of the steam generator. Reasonable analysis results were derived at the flow rate of 52.0 to 53.0 kg/s and feedwater temperature of 499.8167 to 510.9278 K.

REFERENCES

[1] Korea Atomic Energy Research Institute, "MARS code manual, Volume 1, Code Structure, System Models, and Solution Methods," 2010.
[2] Korea Atomic Energy Research Institute, "MARS code manual, Volume 2, Input Requirements," 2010.
[3] Il Hwan Kim et al., "Development of BANDI-60S for a Floating Nuclear Power Plant," KNS Autumn Meeting, 2019.