Reviewing the possibility of TLOFW accident scenario using GPWR

Soon Il Chung[a*], Jeong Hun Lee[a], Woo Jae Jeon[a], Yoon Ki Choi[a] , Jin Sik Choi[a]
[a]FNC Technology Co., Ltd.,32 Fl., 13 Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, Korea
**Corresponding author:* soonil@fnctech.com

* ***Keywords :*** Simulator, GPWR, Multiple Failure Accident, TLOFW

1. Introduction

Recently, the high utilization of artificial intelligence(AI) models has been widely proven in autonomous driving research such as automobiles, and the concept of autonomous driving/control is also being studied in the development of a new nuclear reactor. There is a limit to applying the concept of autonomous operation directly in the case of operating nuclear power plants, but it is necessary to improve the safety of operating nuclear power plants by developing a driving support system based on AI that enables optimal response in complex situations.

However, various and vast amounts of power plant operation data are required to develop artificial intelligence algorithms for driving support. In order to compensate for the vulnerability of limited plant operation data, it is necessary to select accidents and develop scenarios for the production of normal/abnormal and accident state operation data of nuclear power plants using simulators.

In this study, the Generic PWR (GPWR) simulator was analyzed for differences from the APR1400 furnace and reviewed for similarity in plant behavior according to the progress of TLOFW. Based on the research results, the possibility of developing scenarios for driving data production was confirmed using GPWR.
.

2. GPWR Model

All domestic simulators of the APR1400 model were developed with WSC's 3KeyMaster tool. The GPWR used in this study is a generic model developed by WSC with the 3KeyMaster tool for PWRs, and the main parameters of the GPWR and APR1400 are shown in Table 1. As shown in Table 1, the main primary parameters such as core power and average temperature are very similar between the APR1400 and GPWR. However, there are some differences that are unique to the APR1400 design, such as the Direct Vessel Injection (DVI) and In-containment Refueling Water Storage Tank (IRWST). Fig.1 shows the nodalization model of GPWR primary side developed with 3KEYRELAP5

3. Scenario and Assumptions

In this study, it was confirmed that damage to the core can be prevented by removing the decay heat of the core through the depressurization of the reactor coolant system and the feed & bleed operation by the emergency core cooling system after Total Loss of Feedwater(TLOFW). TLOFW is a scenario in which the supply of water to the steam generator is completely stopped due to the loss of main feedwater and then the loss of function of the auxiliary feedwater system for reasons such as mechanical failure. It is assumed that the reactor coolant pump is manually stopped by the operator 10 minutes (600 seconds) after the reactor shutdown.

Table 1. GPWR and APR1400 Specifications

RCS	GPWR	APR1400
Configuration	2 loops, 4 Reactor Coolant Pumps, 2 Steam Generators	2 loops, 4 Reactor Coolant Pumps, 2 Steam Generators
Reactor core power	3983 MWt	3983 MWt
Pressurizer pressure	158.2kg/cm2 (2250 psia)	158.2kg/cm2 (2250 psia)
Hot leg temperature	325°C (617°F)	324°C (615°F)
Coolant inlet temperature	292.6°C (558.8°F)	291°C (555°F)
Average temperature rise in vessel	32.4°C (58.2°F)	34°C (62°F)
Average temperature in vessel	309.2°C (588.5°F)	308°C (586°F)

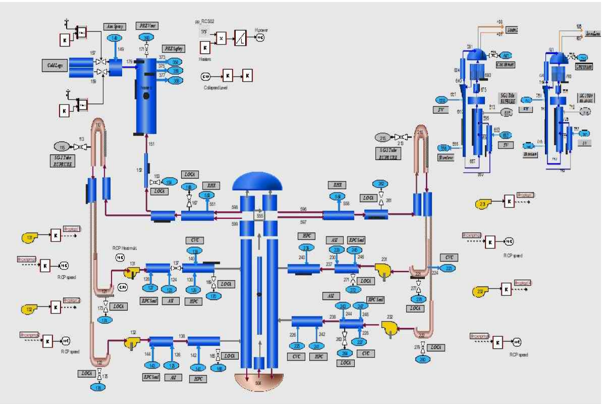

Fig. 1. Nodalization Model of GPWER primary side

4. Calculation Results

The sequence of events is provided in Table 2. After TLOFW, as shown in Figure 1, the steam generator water level decreased rapidly and reaches the reactor shutdown setpoint. At 29 seconds, it causes reactor shutdown and turbine shutdown. At 43 seconds, the steam generator level reaches the auxiliary feedwater injection setpint, but the auxiliary feedwater system does not operate due to failure. All RCPs are shut down by operator action 10 minutes after reactor shutdown. When the inventory of the steam generator is almost exhausted, it becomes impossible to remove the core heat through the steam generator, and the pressure of the reactor coolant system rises rapidly and reaches the PSV opening setting at 1,295 seconds. When the PSV is opened for the first time, operator opened two PSV to perform rapid depressurization, as shown in Fig. 2 and 3. When the primary pressure is reduced below the SIP injection setpoint through rapid depressurization, the SIPs begins to be injected at 1,348 seconds. With feed and bleed operation by PSV and SIPs, the RCS is cooled and reaches the shutdown cooling entry condition. Fig. 1 to Fig. 6 shows the trend of analysis results for major parameters.

Table 2. Event Sequences for TLOFW

Time(s)	Event	Note
0.0	LOFW occurs	
19.0	Reactor trip(SG low level) Turbine trip	
43.0	AFAS	Assuming loss of AFW
619.0	RCP Shutdown	Assuming 10 minutes after reactor shutdown
1,295.0	Pressurizer safety valve open	
1,295.0	manual opening Pressurizer safety valves	2 PSVs
1,348.0	Start SIP Injection	2 SIPs
4,101.0	Shutdown cooling entry condition reached	

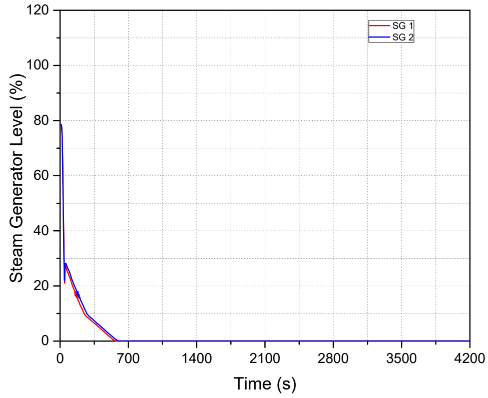

Fig. 1 SG Level

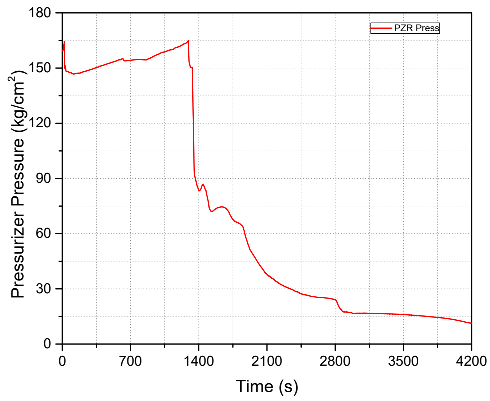

Fig. 2 Pressurizer Pressure

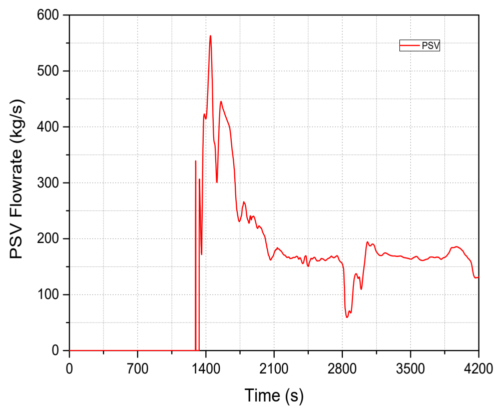

Fig. 3 PSV Flow

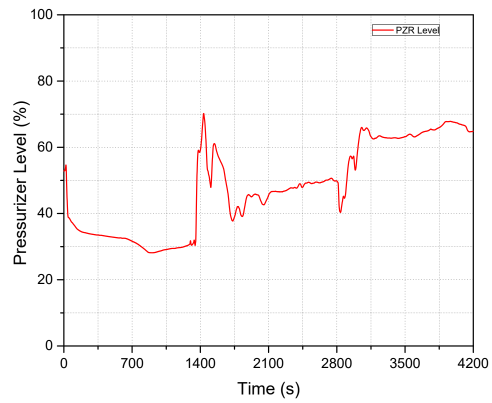

Fig. 4 Pressurizer Level

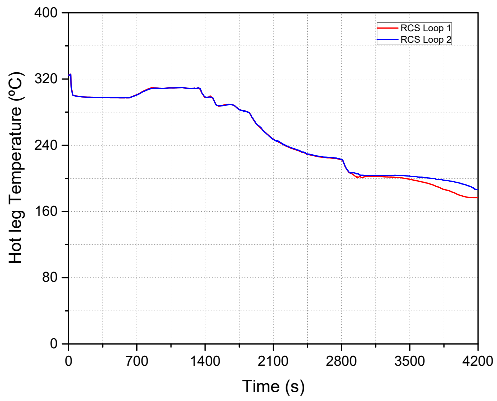

Fig. 5 RCS Hot Leg Temperature

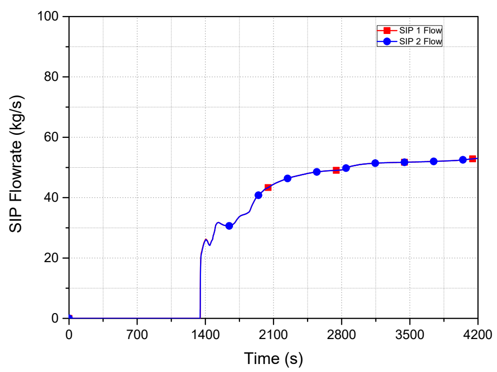

Fig. 6 SIP Flow

3. Conclusions

For the TLOFW scenario, the analysis was performed assuming the same operator actions as the APR1400. As a result of the analysis, it was confirmed that the entry conditions of the shutdown cooling system were reached through the feed and bleed operation by PSV and SIPs.

The evaluation of the accident confirmed the following

- Performance of decompression through depressurization system of reactor coolant system
- Evaluation of Core Cooling Capacity by Injection Discharge Operation through Accident Analysis

GPWR has differences according to its own design in terms of systems compared to APR1400, but it has been confirmed that the overall plant behavior is similar. In addition, it was confirmed that the accident mitigation strategy of the APR1400 was also effective in GPWR. Accordingly, in terms of the application of the 4th industrial revolution technology, GPWR is expected to be used in various ways, such as scenario development and confirmation of the validity of operator actions.

REFERENCES

[1] KINS/RG-N16.01, Rev.0, Regulatory Guideline 16.1, “Assessment of accidents due to multiple failures,” 2016.
[2] KINS/RG-N16.04, Rev.0, Regulatory Guideline 16.4, “Accident Consequence Assessment,” 2016.
[3] Korea Hydro and Nuclear Power, The final safety analysis report of Shin-Hanul Units 1&2
[4] Korea Hydro and Nuclear Power, The accident management plan of Shin-Hanul Units 1&2
[5] ANSI/ANS-3.5, Nuclear power plant simulators for use in operator training and examination, 2009