Simulation of Total Loss of Electric Power Accident in the PWR

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1. Introduction

The station black out (SBO) accident due to a loss of on/off site power and failures of all emergency diesel generators (EDG) is categorized as a common mode failure but it has been regarded as a very low frequency accident until now. Recently, however, the Japanese nuclear power plant accidents caused by Tsunami followed by the earthquake proved the SBO accident could happen simultaneously at any time. Even if the SBO occurs, the emergency battery can provide the essential reactor control system with the electric power to maintain the plant operation. The electric power is required for the actuation of most of the engineering safety features (ESF) such as an emergency core cooling system (ECCS) and motor-driven auxiliary feedwater system (MD-AFWS) during an accident. Therefore, if the emergency battery power is also lost, there is no available decay heat removal system except for the spring-loaded relief valves and the turbine-driven auxiliary feedwater system (TD-AFWS). In order to simulate the total loss of electric power accident in the pressurized water reactors (PWR), Ulchin-1/2 nuclear power plants which are one of the typical PWRs with three loops in Korea are selected as a reference plant and MARS-ViSA[1], which has a interactive control function to simulate various plant operations including manual operator's actions, is used as a simulation tool.

2. Total Loss of Electric Power Accident

The SBO accident can be caused by a loss of all AC power including the EDGs. Failure of all EDGs is out of bound of the assumptions of the design basis accident (DBA) but recent accident in Japan shows that it can happen with small probabilities. Once the total loss of electric power accident which means the SBO with loss of battery occurs, most of the ESF systems which require electric power supply will not work and then we can credit only a few ESFs such as the pressurizer safety valves (PSV) and the main steam safety valves (MSSV) which are spring-loaded system. Even though the TD-AFWS is not one of the ESFs, it is the only passive system to be able to provide the steam generators (SG) with feedwater. Other components such as the ECCS and MD-AFWS which require the electric power to work are unavailable. In addition, if the electric power supply to the main control room (MCR) is also lost due to a loss of battery, the control of plant operation will be almost impossible. Therefore, it should be possible to stabilize the nuclear power plant with automatic operation of the PSV, MSSV and TD-AFWS without operator's intervention during this kind of accident.

Ulchin-1/2 units have several spring-loaded valves to prevent nuclear power plant from over-pressurization and single turbine-driven auxiliary feedwater pump (TD-AFWP) to supply the SGs with water. Three PSVs which are installed at the top of pressurizer and four spring-loaded MSSVs which are installed at the main steam line in each loop prevent over-pressurization of the primary and the secondary side, respectively. The The setpoints of actuation of each valve are listed in Table 1[2].

Table 1. Pressure setpoint of PSV and MSSV

Component	Pressure setpoint (bar.a)
PSV-1/2/3	Open: 166 / 170 / 172, Close: 160 / 164 / 166
MSSV-1,2/3,4	Open: 76.2 / 78.0, Close: 71.1 / 72.8

3. Simulation of the Accident

3.1 Initial Condition

The SBO accident is composed of the loss of off-site power (LOOP) and failure of all EDGs. Therefore, the components which are related with off-site power and EDGs are assumed to be unavailable. Moreover, for conservative analysis, it is assumed that the emergency battery is also unavailable. Table 2 shows the power sources of major reactor components.

Table 2. Power sources of major reactor components

Component	Power source	Availability
Scram rods insertion	Gravity / Electric	O
SI / Charging pump	Electric	X
Reactor coolant pump (RCP)	Electric	X
PZR heater	Electric	X
PZR safety valve (PSV)	Electric / Spring	O
Main feedwater pump	Turbine*	X
MD-AFW pump	Electric	X
TD-AFW pump	Aux. turbine**	O
Condenser/air steam dump***	Compressed air	X
Main steam safety valve	Air / spring-loaded	O

* If the SBO occurs, it is unavailable.
** Operation pressure range of SG is from 7.6 to 83.3 bar
*** Steam dump system is not a safety system so no credit is given

From Table 2, we could establish the initial condition of the total loss of electric power accident and performed the simulation of the accident by using MARS-ViSA. The initial condition of the accident was implemented into the MARS code via an interactive control function of MARS-ViSA.

3.2 Results of Simulation

As soon as the accident happens, due to a loss of off-site power, the reactor is scrammed by gravitational rod insertion and the RCPs stop to run and coast down (Fig. 1). After a while, natural circulation flow in the primary loop is established via steam release though the actuation of MSSVs. The main feedwater pumps are also tripped but TD-AFWP, which discharges the exhausted steam to atmosphere, starts to run and provides three SGs with feedwater (Fig. 1). The MSSVs continue to open and close periodically due to the pressure change of the SGs. The primary pressure decreases at the beginning of the accident but increases again because the heat removal via the SGs decreases due to the decrease of recirculation flow rate. After then, the primary pressure fluctuates according to the periodic steam dump through the MSSVs (Fig. 2). However, the maximum pressure during the accident is lower than 166 bar which is a minimum set-point to open the PSVs. Consequently, the primary coolant inventory can be preserved during the entire period of the accident. If only one SG is supplied with feedwater, the primary cooling power can be reduced, so that the PSVs can be opened. Even this case, the loss of the primary coolant inventory is very small and finally the pressurizer water level maintains above the minimum level (Fig. 3).

As shown in Figure 3, the SG water level continues to increase after the TD-AFWP actuation and reaches to full level after one and half hour. If turbine blades are damaged by incoming of large amount of moisture as the SG separator is filled with water, the TD-AFWP will not be able to work and finally, decay heat removal is unavailable. Therefore, the minimum electric power and compressed air for the SG level measurement and TD-AFWP control to prevent the SG full water level should be maintained during entire accident period.

4. Conclusions

The simulation of the total loss of electric power accident in Ulchin-1/2 units has been performed by using MARS-ViSA. From the results, it is found out that decay heat removal via the MSSVs and TD-AFWS could be performed successfully even if only one SG was supplied with auxiliary feedwater. However, in order to prevent the damage of the turbine blades, incoming of large amount of moisture from the SGs should be blocked. For this purpose, the SG level gauge and controlling feedwater flow rate from the TD-AFWP should be available.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Kyung Doo Kim, *et al*., "Development of a Visual System Analyzer based on reactor system analysis codes", Progress in Nuclear Energy, vol.49, p.452~462, 2007.
[2] MARS code input deck for Ulchin1/2 unit

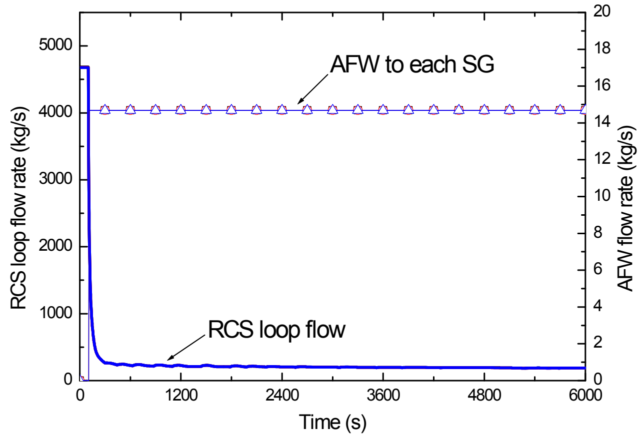

Figure 1. RCS and SG feedwater flow rate

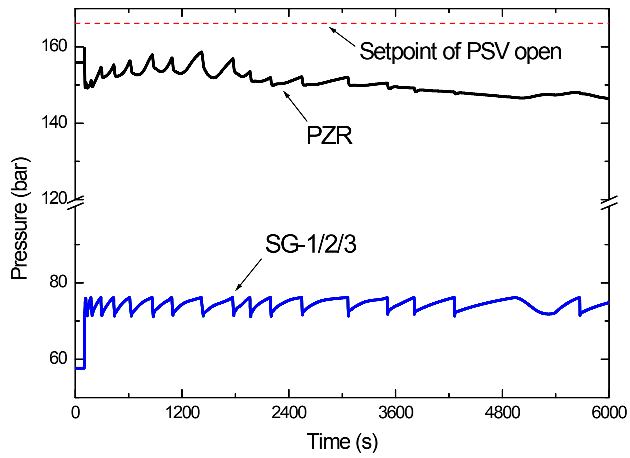

Figure 2. Primary and secondary pressure

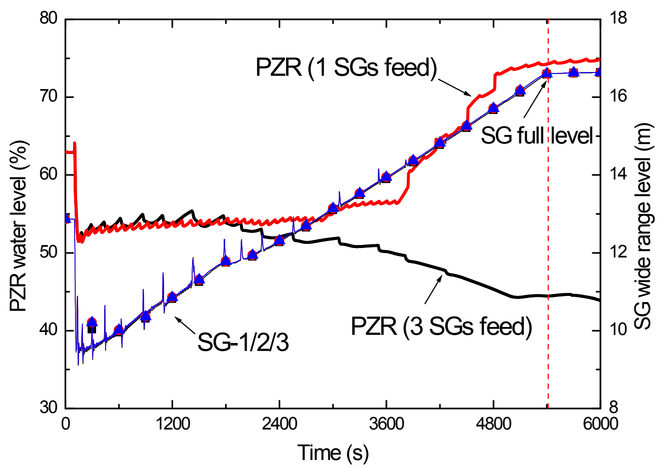

Figure 3. PZR and SG water level