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A Comparison of ESF Actuation Signals in Passive System Design

K.I. Jeong*, C.H. Kim
Nuclear ICT Research Division, Korea Atomic Energy Research Institute
**Corresponding author: hisunny@kaeri.re.kr*

1. Introduction

Since the mid-1980s it has been recognized that the application of passive safety systems (i.e. those whose operation takes advantage of natural forces such as heat convection, pressure differences and gravity), can contribute to simplification and potentially improve economics of new nuclear power plant designs [1]. SMART (System-integrated Modular Advanced Reactor) is the integral reactor that eliminates the involvement of large pipes for the connection of the major components. Therefore the possibility of a large pipe break of LOCA is inherently eliminated. During SMART during SMART pre-project engineering (PPE), SMART passive safety systems are being developed to improve safety and simplicity of their operation. The passive safety systems of SMART are designed to function automatically on demand and use no active pump and diesel generator. Using passive safety systems, SMART can maintain the plant in a safe shutdown condition following design basis accidents (DBAs) such as LOCA and non-LOCA without safety grade AC power, active component actuations and operator actions within 72 hours.

In this paper, we describe the NSSS safety systems and perform a comparison of the ESF actuation signals of ESF-CCS and monitoring parameters to actuate those systems reflecting the passive system design.

2. NSSS Safety Systems in SMART PPE

The NSSS safety systems of SMART consist of passive residual heat removal system (PRHRS), passive safety injection system (PSIS), automatic depressurization system (ADS) and chemical and volume control system (CVCS). In this section, we describe these systems and actuation signals to actuate these systems.

2.1 Passive Residual Heat Removal System

The PRHRS removes the core residual heat and sensible heat in the reactor coolant system (RCS) when the secondary system is not capable of normal cooling of the RCS by any reason after the reactor trip. The PRHRS brings the RCS to the safe shutdown condition within 36 hours after reactor trip and maintains the safe shutdown condition for at least another 36 hours without any operator actions or the aid of external AC power. The PRHRS consists of four independent trains each with a 33% capacity.

The ESF-CCS generates the passive residual heat removal actuation signal (PRHRAS) to actuate the PRHRS and isolate the main steam and feedwater in order to decrease the RCS temperature below the safe shutdown temperature.

2.2 Passive Safety Injection System

The PSIS injects cooling water into the RCS by using the gravitational head naturally caused by the height difference of the fluid. When PSIS actuates, it can provides emergency core cooling for at least 72 hours following postulated DBAs without any operator actions or the aid of external AC power. The PSIS consists of four mechanically independent trains each with a 33% capacity. Each train has a core makeup tank (CMT), safety injection tank (SIT), related valves, instruments and so on.

The ESF-CCS generates the core makeup tank actuation signal (CMTAS) which is initiated by a high primary containment area pressure signal or a low pressurizer pressure signal, low-low Steam Generator (SG) inlet temperature or PRHRAS. Then the isolation valve in the safety injection line on the CMT open to inject the borated water from the CMT into the RCS. Also the ESF-CCS generates the safety injection tank actuation signal (SITAS) which is initiated by a low-low pressurizer pressure signal and low-low steam generator (SG) inlet temperature following a LOCA and the isolation valves on the pressure balance line open. The cooling water in the SIT is injected into the reactor by the gravity when steam from the RCS is injected into the SIT through the pressure balance line, and the internal pressure of the RCS and SIT reaches the equilibrium state.

In the case of a LOCA and the loss of onsite and offsite AC power, emergency cooling water is supplied without operator action to maintain the reactor coolant level above core top for at least 72 hours.

2.3 Automatic Depressurization System

The ADS lowers the RCS pressure to facilitate the injection of emergency cooling water into the RCS and the early connection of the non-safety auxiliary to refill the SIT after 72 hours following the LOCA. The ADS consists of two trains. Each train of the ADS is connected to the inside of the in-containment refueling water storage tank (IRWST) through the sparger.

The ADS is in standby during normal operation of the reactor. The ESF-CCS generates the automatic depressurization actuation signal (ADAS) when the water level of CMTs reaches the setpoint level and then each train of ADS is operated automatically and make the RCS pressure lower to facilitate the cooling water injection.

2.4 Chemical and Volume Control System

The CVCS performs the following two major functions among various functions: 1) maintain the water chemistry condition and purity of the reactor coolant during normal operation and during shutdowns, 2) maintain the required volume of water in the RCS, compensating for reactor coolant contraction or expansion resulting from changes in reactor coolant temperature and for other coolant losses or additions among various functions

The CVCSIAS isolates the valves penetrating the containment to mitigate the consequences during a pressure level control system (PLCS) malfunction, or letdown line break outside containment.

2.5 Other ESF Actuation Systems

Also we designed the new ESF actuation signals. The boron dilution stop signal (BDSS) is applied in order to cope with an inadvertent boron dilution events.

The containment isolation actuation signal (CIAS) is the same as the function of the commercial nuclear power plant and isolates the process lines penetrating the containment to mitigate the consequences of a release of radioactive material during a LOCA, feedwater line break, or main steam line break.

3. Comparisons

In this section, we describe and compare the ESF actuation signals of SMART SDA (standard design approval) which is granted in 2012, APR 1400, AP1000 and SMART PPE. We include the APR1400 and SMART SDA for the comparison of the number of ESF actuation signals and monitoring parameters.

The SMART SDA, which has active systems and components requiring ac power sources, generates four NSSS ESF actuation signals as following:

- CIAS
- Safety injection actuation signal (SIAS)
- PRHRAS
- Containment spray actuation signal (CSAS)

The APR1400, which also has active systems and components, generates six NSSS ESF actuation signals as followings:

- CIAS
- SIAS
- CSAS
- Main steam isolation signal (MSIS)
- Auxiliary feedwater actuation signal (AFAS)-1
- Auxiliary feedwater actuation signal (AFAS)-2

The AP1000, which uses passive safety systems that rely on natural forces, has many ESF actuation signals So we listed 8 signals only among 26 ESF actuation signals as followings[2]:

- CIAS
- In-Containment Refueling Water Storage Tank Injection Alignment Signal
- Core Makeup Tank Injection Alignment Signal
- Automatic Depressurization System Actuation Signal
- Passive Residual Heat Removal Heat Exchanger Alignment Signal
- Containment Recirculation Alignment Signal
- Steam Generator Blowdown System Isolation
- Startup Feedwater Isolation Actuation Signal

The SMART PPE, which also uses passive safety systems, has 7 ESF actuation signals as described in previous section.

Table I shows the major NSSS parameters requiring ESF actuation in those plants. We can see that the number of ESF actuation signals as well as monitoring parameters increases as the system changes from active system to passive system. Especially, in the case of AP1000, the number of ESF actuation signals and monitoring parameters increased sharply, but in SMART PPE, we can see that it is slightly increased due to inherent characteristics of the integral reactor.

4. Conclusions

We describe the design changes of ESF-CCS reflecting the passive safety systems which are applied in SMART during SMART pre-project engineering (PPE). As SMART design changes from the active system to the passive system, it tends to use more monitoring parameters and more automatic logics to mitigate the consequences of the DBEs in terms of instrumentation and control systems (I&C). But the characteristics of passive safety systems ensure the safety enhancement of SMART.

Acknowledgement

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REFERENCES

[1] IAEA-TECDOC-1624, Passive Safety Systems and Natural Circulation in Water Cooled Nuclear Power Plants, 2009.

[2] AP1000 Design Control Document Rev.19, Chapter. 7, Instrumentation and Control, 2011.

Table I: The major NSSS parameters requiring ESF actuation

SMART SDA	APR1400	SMART PPE	AP1000	
1. Low pressurizer pressure 2. Low main steam pressure 3. High main steam pressure 4. High containment pressure 5. Low feedwater flow 6. High-High containment pressure	1. Low pressurizer pressure 2. High containment pressure 3. High- High containment pressure 4. Low SG pressure 5. High SG level 6. Low SG level	1. Low-Low SG inlet temperature 2. High primary containment area pressure 3. Low-Low pressurizer pressure 4. Core makeup tank level 5. Safety injection tank level 6. Low pressurizer pressure 7. Low main steam pressure 8. High pressurizer Level 9. High pressurizer pressure 10. Low SG inlet temperature 11. Low Pressurizer level	1. Low Pressurizer Pressure 2. Low lead-lag compensated steam line pressure 3. Low cold leg temperature 4. High-2 containment pressure 5.Core makeup tank level 6.Extended undervoltage to Class 1E battery chargers 7. Low reactor coolant system pressure 8.High-2 steam generator narrow range level 9.Low reactor coolant temperature 10.Low-2 pressurizer level 11.Low wide range steam generator water level 12.High hot leg temperature 13.High reactor coolant pump bearing water temperature	14. High steam line negative pressure rate 15. Low startup feedwater flow 16. High-3 pressurizer level 17. Flux doubling calculation 18. High-2 pressurizer water level 19. High-1 pressurizer water level 20. Low-1 pressurizer level 21. High-2 containment radioactivity 22. Low spent fuel pool level 23. Low IRWST level 24. Low-1 hot leg level 25. High reactor coolant pump bearing water temperature 26. Low-2 containment pressure