Study on Diversity Actuation Signal of DAS for ACP100

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INTRODUCTION

Digital Reactor Protection System (RPS) is widely used in new construction nuclear power plant, and Diverse Actuation System (DAS) is adopted to provide Diversity and Defense in Depth (D3) measure to cope with Software Common Cause Failure (SWCCF) of RPS. Once the RPS is malfunction or failure, reactor scram and Engineering Safety Features (ESF) will be actuated by DAS to mitigate the consequence of accident, and the accident risk will be reduced.

ACP100 is a new generation small modular pressurized water reactor developed by NPIC [1], many passive safety systems such as passive residual heat removal system and passive core cooling system was adopted. Also the digital RPS was used for ACP100, and the DAS which with completely independent hardware (including the sensors, actuation device, platform etc) in design, was adopted to provide D3 measure to cope with SWCCF of RPS. The automatic diversity actuation signal for DAS of ACP100 was studied in this paper, and the reasonable and feasible of signal was preparatory validated by D3 coping analysis.

DAS SIGNAL FOR ACP100

The suitable automatic protection signal should be set to realize the function requirement of DAS, and to satisfy the accident acceptance criterion and engineering experience.

Automatic Protection Function of DAS

The essential automatic protection function taken by DAS for PWR include reactor scram, turbine trip, residual heat removal system(emergency feedwater/ residual heat removal system) actuation and maintain the coolant inventory for reactor core(safety injecting system / Core Makeup Tank, CMT). The DAS for ACP100 should satisfy the above function at least. Considering the passive ESFs design for ACP100, the following function requirement should be met

- Reactor scram and turbine trip
- CMT actuation and trip the main pumps
- Passive Residual Heat Removal system(PRHR) actuation and In-containment Refueling Water Store Tank(IRWST) isolation

Acceptance Criterion for DAS Coping Analysis

The Standard Review Plan (SRP) issued by NRC include the acceptance criterion for DAS coping analysis, both for anticipated operation occurrences (AOOs) and postulated accidents (PAs) [2], shown in Table I.

TABLE 1. CCF (common cause failure) Acceptance Criteria in BTP-7-19

	Pressure Boundary	Radiation Release
AOO	Reactor Coolant system Pressure Boundary(RCPB) should not be violated	Should not exceed 10 percent of 10 CFR 100 guideline value
PA	RCPB should not be violated OR Containment Integrity should not be violated	Should not exceed the 10 CFR 100 guideline value

The frequency for concurrent of accident and CCF of RPS is very small and the condition could be classified into beyond the design basic accident, and the integrity of the secondary and the third radioactive barrier should be sustained.

The Anticipated Transient without Scram (ATWS) is one category of events which DAS will be actuated; the acceptance criterion for ATWS presented in SRP 15.8 is in TABLE 2[3].

TABLE 2. ATWS Acceptance Criteria (SRP 15.8)

Pressure Boundary	Coolability
Shall not exceed ASME Service Level C limits (approximately 22 MPa or 3200 psig)	Peak cladding temperature < 2200 ℉ the maximum cladding oxidation < 17% the maximum hydrogen generation <1%

The key criterion for DAS D3 coping analysis and ATWS analysis in SRP are sustaining the integrity of pressure boundary and the coolable geometry for the core, and these criterions was selected for ACP100 D3 analysis. For radiation release, the maximum fraction of fuel with DNB occurred is restricted by ACP100, and the acceptance value for PAs with RPS CCF is more than AOOs condition, which is the same trend as radiation release criterion in TABLE 3.

TABLE 3. Acceptance Criteria in ACP100 analysis

	Pressure Boundary	Coolability
AOO	Same as ATWS	Same as ATWS And the fraction of DNB should be limited
PA	Same as AOO above for RCPB OR Containment Integrity should not be violated	Same as ATWS And the fraction of DNB should be limited

Automatic Protection Signal for DAS

The DAS automatic protection signal preliminary selected by ACP100 is based on the engineering experience of PWR nuclear power plant, the signal is shown in Table. 4.

TABLE 4 DAS automatic actuation signal for ACP100

DAS function		Protection signal
Reactor Trip System(RTS) actuation / Turbine trip		High Power Range Neutron Flux
		High Pressurizer (PRZ) Pressure
		Low PRZ Pressure
ESFs actuation	PRHR	High reactor outlet temperature/ High PRZ pressure
	CMT	Low PRZ pressure
	Trip the main pump	CMT actuation
	Isolation main feedwater/ steam	Turbine trip

The high power range neutron flux signal was selected to limit the DNB consequences for Chapter 15.1 and 15.4 in Safety Analysis Report (SAR), and the low PRZ pressure was adopted for LOCA.

Beside the RTS/ESF actuation function, the RCS main pump trip function is also considered in DAS, as the operation of passive safety injection system will be affected by forced coolant flow. As the water inventory in secondary side of OTSG is small and this is no auxiliary feedwater system as PWR ,the residual heat will be transferred by PRHR connected to reactor coolant system. Considering the main feed water of steam pipe break accident and the potential overpressure risk to containment, the main feedwater/main steam automatic isolation function were also included in DAS.

ACP100 D3 COPING ANALYSIS

Method

The main function for DAS is to mitigate the multi-failure situation or beyond design basic accident, refer to the ATWS analysis method ,best estimate method was adopted and the RELAP5/ MOD3.2 was selected to study the transient response

Events to be analyzed

Based on BTP 7-19, all of the events in SAR Chapter 15 are considered as events to be analyzed in the D3 coping analysis. Where possible, events are grouped into categories and detailed analyses are performed only for either representative or bounding cases in order to simplify or reduce the event-specific analyses.

Each event in the SAR chapter 15 safety analysis assuming CCF can be assigned to the following five categories for the above criteria.

1. Event has a very low probability of occurrence
2. RTS and /or ESF not actuated and no adverse impact
3. Event mitigated by DAS and no adverse impact
4. Event similar to other event and no adverse impact
5. Analysis required and results show acceptance criterion is met

As the result of above screening process, considering the DAS signal and system design for ACP100, the following cases should be analyzed for D3 coping analysis for ACP100：

TABLE 5 the events identified for quantitative analysis for ACP100

Event	Purpose for analysis
Steam Piping Failures	feasibility analysis of high power range neutron flux scram signal, containment response
Loss Of Off-site Power(LOOP)	feasibility analysis of high pressure scram , study the burnout fraction of reactor fuel
Loss Of Normal FeedWater Flow(LOFW)	feasibility analysis of PRHR actuation signal
Uncontrolled Control Rod Assembly Withdrawal at full Power	feasibility analysis of scram signal , study the burnout fraction of reactor fuel
Loss of coolant accident	feasibility analysis of low pressure scram signal and CMT actuation signal

The Result

The result for LOOP and LOFW events with CCF was given in this report; the result of preparatory analysis is shown in Table6.

TABLE 6 Sum up of result for DAS coping analysis

event	RCS peak pressure,MPa	Fuel burnout
LOOP	18.39	No DNB
LOFW	18.15	No DNB

The change trend for the pressure of RCS and DNB for fuel rod is shown by Fig 1 and Fig 2.

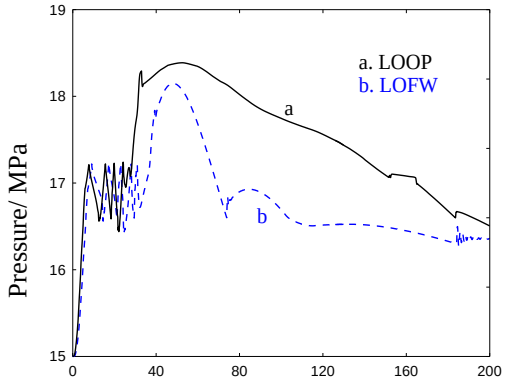

Fig. 1 Change of pressure of RCS

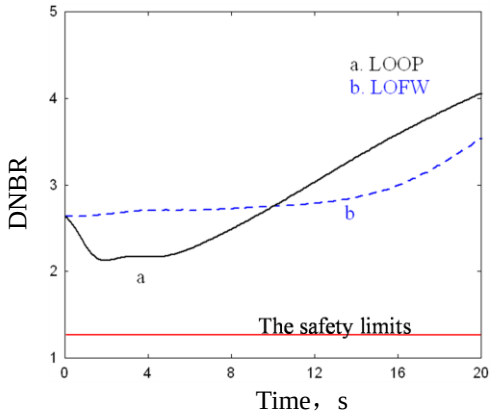

Fig. 2. The minimum DNB of fuel

The maximum pressure of RCS is lower than 22MPa, the operation of PRHR will cooling the system and the pressure will drop gradually, the RCPB criterion could be satisfied .No burnout was occurred for reactor fuel ,the DNB and radiation release criterion was met also.

The result of analysis is consistent with expectancy, the DAS signal and the set point is reasonable and feasible for ACP100.

CONCLUSION

The DAS automatic protection signal and trip set point is studied based on the nuclear power plant engineering experience and rule of law, the reactor scram/ turbine trip, ESFs actuation (PRHR, CMT), main pump trip, isolation of feed water/main steam were selected as automatic protection signal for DAS.

The reasonable and feasible of DAS signal was validated by preparatory coping analysis.

REFERENCES

1. IAEA, “Advances in small modular reactor technology developments”, IAEA (2016)
2. NUREG-0800, SRP BTP 7-19, “Guidance for evaluation of diversity and defense-in-depth in digital computer- based instrumentation and control systems,” USNRC (2007)
3. NUREG-0800, SRP 15.8, “Anticipated transients without scram,” USNRC (2007)