Design Features of Reactor Protection System for SMART

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1. Introduction

SMART (System-integrated Modular Advanced Reactor) is an integral type pressurized water reactor which has an integral reactor coolant system configuration that eliminates the involvement of large pipes for the connection of the major components. The top-tier requirements for SMART design are the enhancement of safety and the improvement of economics and commercial competitiveness. For the safety enhancement, SMART has the design characteristics of adopting the inherent and passive safety, simplified safety system, and advanced MMIS (Man-Machine Interface System). For the economic enhancement, SMART has the design characteristics of applying the system simplification and the component modularization. Fig. 1 shows an overall architecture of SMART MMIS. According to the top-tier requirements, SMART MMIS should include the followings: 1) to meet all current regulatory and industry requirements; 2) to improve plant safety and availability; 3) to improve the cost effectiveness of nuclear power generation.

2. Reactor Protection System

The Reactor Protection System (RPS) is a vital system which consists of sensors, calculators, logic, and other equipment necessary to monitor selected plant conditions and to effect reliable and rapid reactor shutdown (reactor trip) if monitored conditions approach specified safety system settings. The system's functions are to protect the core fuel design limits and reactor coolant system (RCS) pressure boundary for anticipated operational occurrences (AOOs), and also to provide assistance in mitigating the consequences of accidents. Four measurement channels with electrical and physical separation are provided for each parameter to generate the trip signals.

The RPS performs the reactor trip function and the ESF initiation function. The RPS provides an emergency shutdown of the reactor to protect the core and the reactor coolant system pressure boundary. The ESF-CCS provides those functions required to prevent the release of significant amounts of radioactive material to the environment in the event of pressure boundary rupture.

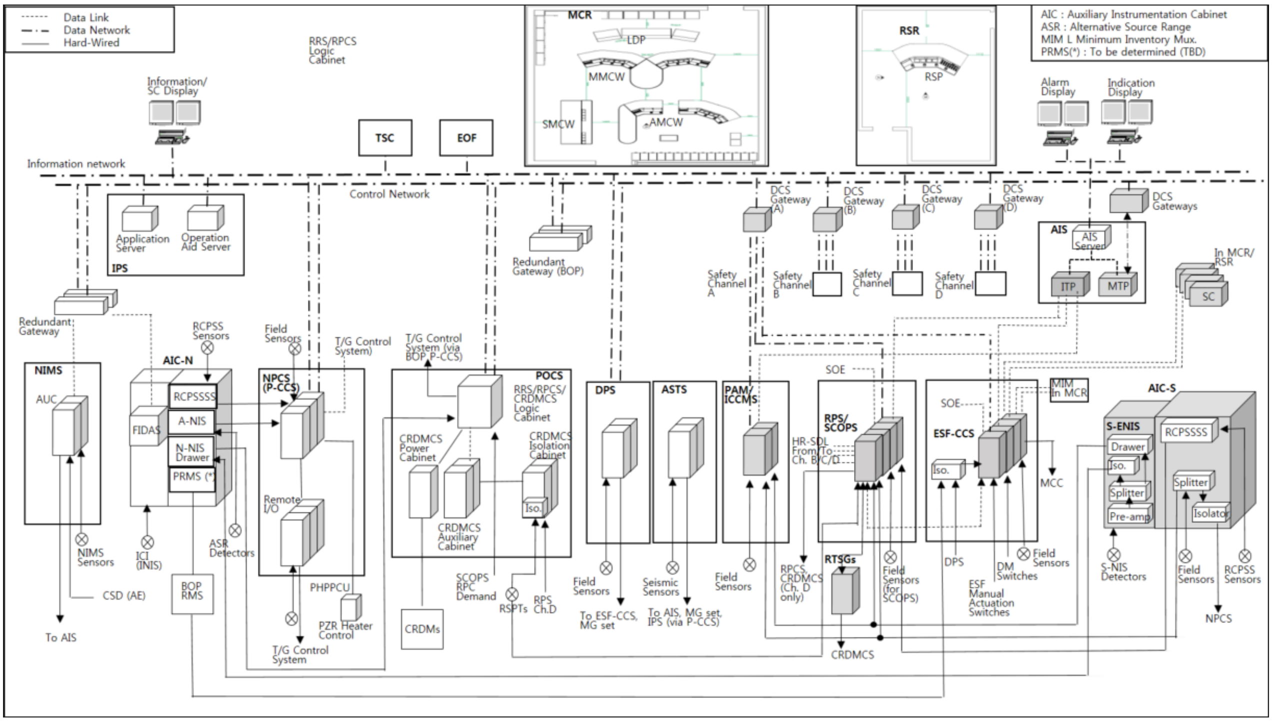

Fig. 1. Overall Architecture of SMART MMIS

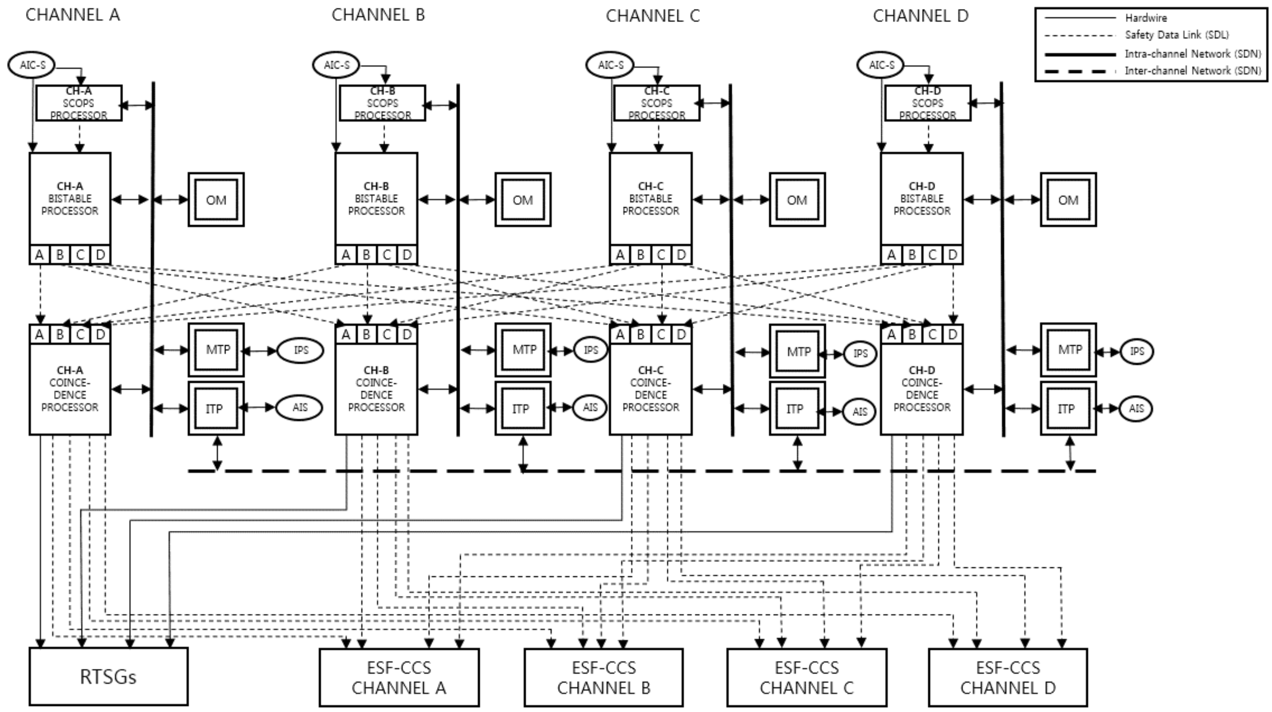

Fig. 2. Block Diagram of RPS

2. Design of RPS for SMART

In this section, major design characteristics of RPS for SMART are described. This research introduces an optimized and simplified design features of the RPS for SMART.

2.1 Design Features

For the safety and economic enhancement, RPS adopts the proven technologies from the conventional nuclear power plant and the simplified design including SCOPS (SMART COre Protection System) as a processor module in the RPS. RPS performs the reactor trip function and the ESF (Engineered Safety Features) initiation function. RPS provides an emergency shutdown of the reactor to protect the core and reactor coolant system pressure boundary. SCOPS, located in the RPS cabinet, generates DNBR and LPD trip and pre-trip signals, as well as CWP (CRA withdrawal prohibit) output signals to the RPS. The RPS will use these and other inputs to automatically actuate a reactor trip whenever the safety parameters exceed a predefined value in at least two of the four redundant RPS channels.

The RPS (as shown in Fig. 2) includes the SCOPS processor, bistable processor, coincidence processor, initiation and actuation logic and other devices necessary to monitor the selected safety-related plant parameters and initiate reactor trip and/or actuation of engineered safety features upon detection of non-permissible plant conditions. Initiation of a reactor trip is achieved through the RPS and actuation of engineered safety features is achieved through the ESF-CCS.

The RPS and SCOPS for SMART are designed with the proven safety grade platform based on PLC (Programmable Logic Controller) of the conventional nuclear power plant. RPS includes bistable processor, coincidence processor, interface and test processor, maintenance and test panel, and SCOPS processor. For the simplified design, we changed the number of processors for bistable and coincidence from two or three processors to one processor, respectively. In the conventional plant, core protection system is an independent system which consists of four processors, but SCOPS is composed of one processor and included in the RPS cabinet as a sub component.

2.2 Detail Functions

The RPS includes the following functions: bistable trip, coincidence, reactor trip initiation and testing of RPS logic. The bistable processors generate trip signals if the measurement channel process value exceeds a setpoint. The bistable processor provides their trip signals to the coincidence processor located in the four redundant channels. The coincidence processors determine the coincidence logic trip based on the state of the four like bistable trip signals and their respective bypasses. The coincidence trip signals are used in the generation of the RTSS or ESF-CCS initiation. A coincidence of two-out-of-four trip signals is required to generate a reactor trip signal. The one channel of four channels can be bypassed as a spare channel for testing or maintenance while converting to a two-out-of-three coincidence logic. The reactor trip signal deenergizes the control rod drive mechanism (CRDM) coils, allowing all control rod assemblies (CRAs) to drop into the core.

The SCOPS consists of 4 independent channels, each of which is mounted in the same channel of the RPS. Calculation of the DNBR and LPD is performed in the SCOPS, utilizing the input signals described below. The DNBR and LPD calculated are compared with trip setpoints for initiation of the low DNBR trip and the high LPD trip. In addition to the DNBR and LPD trips, auxiliary trip is generated in the SCOPS if core operating parameters except the DNBR and LPD violate the predefined operating range or if the setpoint is violated. Trip signals from each channel of the SCOPS are sent to the bistable processor in each RPS channel. The SCOPS also provides pre-trip output signals to prevent unnecessary reactor trip.

The ITP monitors the RPS status and is used to initiate manual and/or automatic surveillance testing based on operator input via the MTP. It has interfaces with the bistable processor, coincidence processor, and MTP. It interfaces to the RTSS and ESF-CCS for status indication and surveillance testing feedback. The MTP is provided to serve as data communication gateways to send selected RPS channel status and test results to the IPS. The bistable processor, coincidence processor, operator modules, MTP and ITP exchange information within a channel over an intra-channel network.

2.3 Hardware Configuration

The RPS consists of eight redundant cabinets (two cabinets per channel) as shown in Fig. 3. The cabinets of each channel are located in a separate I&C equipment room. The cabinets contain the input and output module, SCOPS processor, bistable processor, coincidence processor, and other hardware for the interface with other RPS channels. Each channel is designed based on microprocessor based computer. All protective channel process inputs, protective channel trip functions, and the two-out-of-four coincidence logic functions are processed within the processors in that channel.

The maintenance and test panel (MTP) and interface and test processor (ITP) are located in a separate cabinet and located in a separate I&C equipment room for each channel. The MTP and ITP are shared by the SCOPS. The MTP also provides trip channel bypasses, operating bypasses, and variable setpoint resets. It is the man-machine interface (MMI) for the maintenance testing, including manual testing of bistable trip functions. Four redundant OM (one per channel) shared by ESF-CCS and SCOPS are located in the MCR. Each OM of the RPS provides the displays and controls needed to support the operation of the RPS, ESF-CCS, and SCOPS. The MCR SMCW and RSR provide means to manually initiate reactor shutdown.

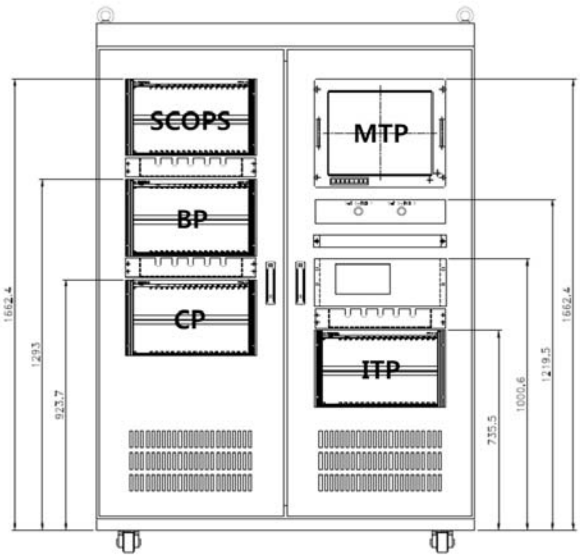

Fig. 3. Configuration of RPS Cabinet

3. Conclusions

An optimized and simplified design of RPS for SMART was accomplished by integrating SCOPS in the RPS cabinet and simplification of BP and CP. Through our design of the RPS for SMART, the number of cabinets can be reduced about 60% than the conventional design and we are expecting that the response time between RPS and SCOPS could be decreased by our integrated design through safety data link. In this research, the design validation is conducting to check the possibility of implementation and the performance requirements such as response time. Consequently, we hope that our design could contribute to the safety and economic enhancement of SMART MMIS design.

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