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An Advanced Core Protection Calculator System Development

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1. Introduction

The Reactor COre Protection System (RCOPS), an advanced core protection calculator system, is a digital I&C system which provides core protection function based on two reactor core operation parameters, Departure from Nucleate Boiling Ratio (DNBR) and Local Power Density (LPD). It generates a reactor trip signal when the core condition exceeds the DNBR or LPD design limit. The RCOPS configuration, algorithm, and software are presented in this paper. RCOPS software has been implemented on one channel out of four RCOPS channels. Each channel of RCOPS consists of 4 sub-racks and shares the penalty factor with the other 3 channels. Through this configuration change, the number of processors per channel has been reduced from 6 to 4. RCOPS software is implemented adopting an improved DNBR algorithm (CETOP-D) to increase the core thermal margin, improving Control Element Assembly (CEA) signal validation logic to resolve the latching problem of CEA position signal, and generating auxiliary pre-trip alarms, etc. RCOPS Software consists of functional block diagram and C-language for custom block diagram.

2. Reactor COre Protection System (RCOPS)

2.1. System Configuration

RCOPS is a safety-critical system that consists of 4 identical channels whose input signals are independent from each other. Two (2) separated reed switches are installed for one CEA housing in the standard Pressurized Water Reactor. Each COre Protection Processor (COPP) of a channel monitors core average power, reactor coolant pressure, reactor inlet temperature, reactor coolant flow, core power distribution, and CEAC penalty factors. COPP generates planar radial peaking factors which are used to calculate LPD and DNBR. CEA Processor (CEAP) takes all CEA positions of the reactor core through Channel Communication Processor (CCP) and examines the CEA deviation based on subgroup. If this deviation is higher than a specified value, CEAP sends the predefined penalty factor to COPP. Reed Switch Position Transmitter (RSPT) signals representing CEA positions are acquired by CCP analog input cards. There are two separated RSPTs called RSPT1 and RSPT2. RSPT1A ("A" section of RSPT1) signals are measured by channel A CCP. RSPT1B, 1C and 1D signals are acquired by channel B CCP. RSPT2A, 2B and 2C signals are acquired by channel C CCP. RSPT2D ("D" section of RSPT2) signals are acquired by channel D CCP. Channel A CCP and channel B CCP exchange their RSPT1 signals to build whole CEA position information of RSPT1. Channel C CCP and channel D CCP exchange their RSPT2 signals to build whole CEA position information of RSPT2. Two CCPs are installed on each channel for redundancy. COPP takes RSPT signals of the corresponding quadrant of the reactor core called target CEA position through CCP. COPP takes the penalty factors from 4 CEAPs of all channels and selects the largest value for conservativeness and uses it to calculate DNBR and LPD. Figure 1 shows the RCOPS configuration.

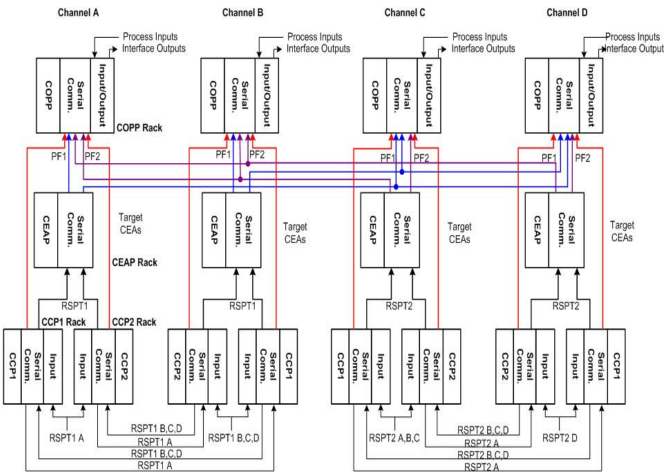

Figure 1. RCOPS Configuration

2.2. Improvements on algorithm

The following algorithms of RCOPS have changed compared with the algorithm of legacy core protection calculator system to achieve more reliable and effective operation.

2.2.1 Improvement of core thermal margin through improved DNBR algorithm

When the DNBR software module of the core protection calculator system performs calculation, it uses an improved algorithm which employs the on-line calculation of enthalpy transport coefficient. The enthalpy transport coefficient is used to relate the radially averaged enthalpies of the boundary sub-channels of lumped sub-channels to the lumped sub-channel counterparts. Its value depends on the core power distribution and the basic operating parameters. The change of on-line DNBR algorithm is considered to improve the DNBR net margin by 2.5%~3.3% [1].

2.2.2 Resolution of the latching problem of CEA position signal

CEA calculator program executes the rate-of-change check (Downward rate limit-TFD (10 inches/100msec), Upward rate limit-TFU(5 inches/100msec)) to distinguish the proper CEA position from measured CEA position signal. If a larger noise is applied on the latched signal, latching will occur repeatedly because of the asymmetry of these two values. The position deviation between latched CEA and the three actual CEAs in the same subgroup will increase eventually leading to a reactor trip. To resolve this latching problem, RCOPS program equalizes these two values (TFD and TFU). This will eradicate the source of the latching problem, but the CEA drop judgement algorithm needs to be modified to detect the free dropping of CEA. The basic idea of the CEA drop judgement is that the drop should occur consecutively in at least two consecutive CEA calculation steps if the CEA is actually being dropped.

2.2.3 Addition of the pre-trip alarm generation

When the operating variables other than DNBR and LPD exceed a certain limit, an auxiliary trip is triggered to trip the corresponding channel. In RCOPS, new auxiliary pre-trip alarms are added to the existing auxiliary pre-trips, which will give the operator an early warning to take corrective action before tripping the plant. Added pre-trip alarms are for hot-leg saturation, low pressurizer pressure and low DNBR, cold leg temperature, primary pressure, hot pin ASI, one pin radial peak, asymmetric SG temperature, and variable overpower.

2.3 .Software Implementation

Software has been implemented with the following three phases.

2.3.1 Software Development

To implement custom function block, Promis-e® is used. The symbol definitions and symbols for the custom functional blocks are created in Promis-e® environment. One-step controller compiles and links *.c and *.h and integrates the target codes and custom functional blocks. Flow diagram for software development process is shown in the Figure 2.

2.3.2 Software Module Test using the MS Excel® Tool

Software module test validates the custom functional blocks against the requirements specified for the appropriate module in Software Requirements Specification (SRS) and Software Design Description (SDD). The outputs of compilation of onestep controller are *.LOC and *.DLL files. For software module test, test cases composed of inputs and expected outputs are developed for each custom functional block. Using MS Excel® and *.DLL files, inputs are plugged in, and outputs are recorded and compared with the expected outputs within acceptance criteria.

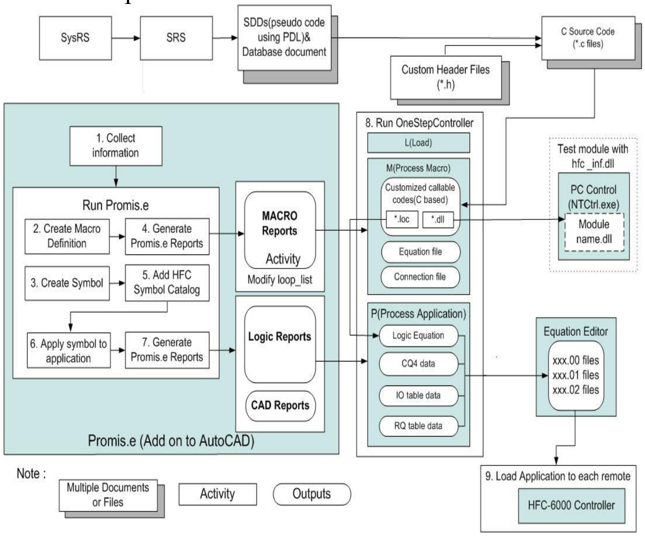

Figure 2. Flow diagram for S/W development process

2.3.3 System Integration Test

The Integration Test verifies that the dynamic response of the RCOPS software and hardware is consistent with that predicted by design analyses, and allows evaluation of the integrated hardware/software system during operational modes approximating plant conditions. There are three cases in System Integration Test. The first case, DNBR value which is produced from CETOP-D algorithm is compared and verified with the expected value from off-line simulation code during the full power operation. The second case, auxiliary pre-trip function (especially ASI) which is newly introduced in this system is verified. The last case, DNBR and LPD trip function is tested to ensure that DNBR and LPD trip functions are implemented correctly during the full power operation.

3. Conclusion

In this paper, RCOPS configuration is newly presented and compared to the configuration of conventional core protection calculator system. The system configuration and hardware platform have been changed and some algorithms have been improved. The changes of DNBR calculation algorithm are expected to improve the DNBR net margin by 2.5%~3.3%. RCOPS software has been implemented on a single channel facility. Design tests, module test, and System Integration Test are successfully performed and V/V activities are to be performed in the next phase of the project.

REFERENCES

[1] Wang Kee In, Dae Hyun Hwang, Young Ho Park and Tae Young Yoon, "Evaluation of DNBR calculation methods for advanced digital core protection system," Korean Nuclear Society Conference, 2003