Development of In-Core Protection System

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1. Introduction

In-core Protection System (ICOPS) is an on-line digital computer system which continuously calculates Departure from Nucleate Boiling Ratio (DNBR) and Local Power Density (LPD) based on plant parameters to make trip decisions based on the computations. The function of the system is the same as that of Core Protection Calculator System (CPCS) and Reactor Core Protection System (RCOPS) which are applied to Optimized Power Reactor 1000 (OPR1000) and Advanced Power Reactor 1400 (APR1400). The ICOPS has been developed to overcome the algorithm related obstacles in overseas project. To achieve this goal, several algorithms were newly developed and hardware and software design was updated. The functional design requirements document was developed by KEPCO-NF and the component design was conducted by Doosan. System design and software implementation were performed by KEPCO-E&C, and software Verification and Validation (V&V) was performed by KEPCO-E&C and Sure Softtech [1].

2. Implementation of ICOPS

In this section, some of the aspects developed in ICOPS are described.

2.1 System and Software Design of ICOPS

To establish the system design requirements for ICOPS, regulatory requirements for Korea, U.S. and EU were reviewed. IEC and IEEE standards were also reviewed. ICOPS system design requirements document was prepared based on these reviews.

The hardware configuration of ICOPS is almost the same as that of RCOPS for Shin-Hanul 1&2. Hence, the software design does not differ from that of RCOPS.

2.2 Implementation of ICOPS Software

Case tools are used to implement ICOPS software. For software implementation, SCADE (Safety Critical Application Development Environment) Suite is used for modelling and generation of C code, pSET II is used to develop POSAFE-Q PLC software, and pSET Wrapper is used for porting of C code generated by SCADE to POSAFE-Q platform. For software V&V, DOORS is used for requirement trace, and Code Inspector and Controller Test are used for testing. The development process of ICOPS software is shown in Fig.1.

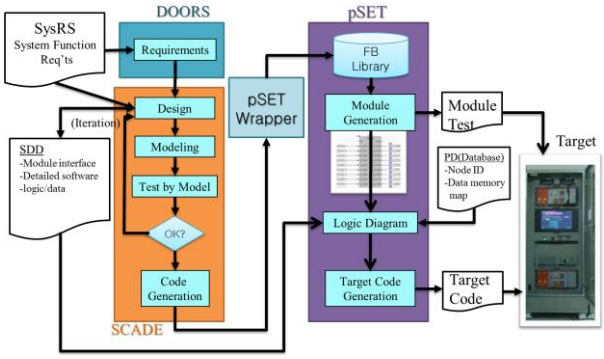

Fig. 1. Development Process of ICOPS Software

Although SCADE is widely used in safety critical system such as airplane, it is difficult to apply it to complex algorithm system. To improve productivity and reliability of the ICOPS, SCADE was used to develop ICOPS software, and Fig.2 shows the example of the modeling.

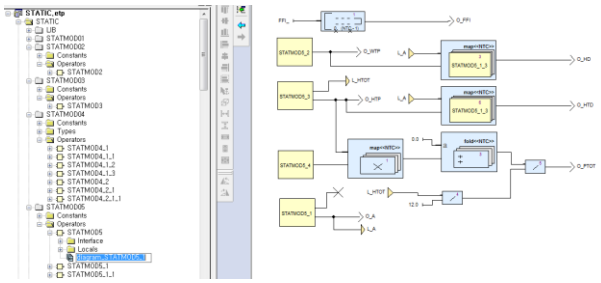

Fig. 2. Example of Modeling by SCADE.

ICOPS software is comprised of CEAC, FLOW, TRIPSEQ, STATIC and UPDATE modules, and SCADE was successfully applied to these modules. The developer tests were performed for the modules using SCADE simulation tool after modeling. The C source codes for the modules were generated by SCADE after the developer tests, and then the C source codes were ported to POSAFE-Q platform by pSET Wrapper tool.

The Software Design Description (SDD) documents were prepared using the function of the SCADE Report. After the completion of modeling and developer test, modeling reports were created, and the SDDs were prepared based on this reports. Although the current documentation system cannot produce the SDDs fully automatic, the productivity of the SDDs was improved.

2.3 V&V of ICOPS Software

For testing of PLC module, test cases were developed based on functional design requirements. Measurement of coverage for several modules of POWER and STATIC were performed using Controller Tester. The code coverage was satisfied with the exceptions such as the protection code for program malfunction. And, the test results for test cases comply with the expected values within 0.1%. After loading the module software on POSAFE-Q PLC, test was performed using I/O simulator and the outputs of modules were within the acceptable errors. Figure 3 shows the Module Test display of I/O simulator.

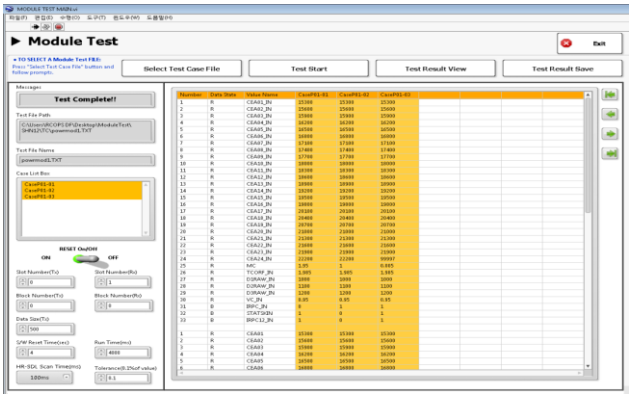

Fig. 3. Module Test Display of I/O Simulator.

For testing of Operator Module (OM) / Maintenance Test Panel (MTP), code review and coverage test were conducted. Using Code Inspector, OM/MTP code was reviewed to confirm whether the rule described in NUREG/CR-6463 is satisfied or not. Coverage test was performed for Standard Display page of OM/MTP. Using COVER tool, the coverage was measured by execution rate of code when each element in Standard Display page is clicked.

2.4 Safety Display System

The display of a nuclear safety system of APR1400 has been categorized as Important to Safety grade (SIL 3: Safety Integrity Level 3). Recently, the regulatory agencies are taking stronger position on requirements for Safety Display System (SDS). To prepare for this position, feasibility study for hardware and operating system which can be applied to SDS was performed [2].

3. Conclusions

The ICOPS has been developed to overcome the algorithm related obstacles in overseas project. The function of I/O simulator was improved even though the hardware platform is the same as that of RCOPS for Shin-Hanul 1&2. SCADE was applied to the implementation of ICOPS software, and the V&V system for ICOPS which satisfies international standards was developed.

Although several further detailed design works remain, the function of ICOPS has been confirmed. The ICOPS will be applied to APR+ project, and the further works will be performed in following project.

REFERENCES

[1] Final Report for Development of the Reactor Core Protection & Monitoring System for Exportation, Ministry of Trade, Industry & Energy, 2016.
[2] J.H. Kim, S.M. Baek, J.H. Cho, C.H. Kim, S.D. Sohn and J.H. Yoon, Development Methodologies for Nuclear Safety Display System, Proceedings of Canadian Nuclear Society Annual Conference, 2016.

ACKNOWLEDGMENTS

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