In-Core Protection System Software Verification

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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 functions of ICOPS are the same as those 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). 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 [1] was developed by KEPCO NF and the component design was conducted by Doosan. System design, software implementation, and software verification and validation (V&V) were performed by KEPCO E&C.

2. Verification of ICOPS Software

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. System design requirements for ICOPS were set up based on these reviews.

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

2.2 Implementation of ICOPS Software

ICOPS software is comprised of PLC software which implements the functional algorithms and FPD (flat panel display) software. FPD software provides the display information for operators.

PLC software of the legacy CPCS and RCOPS has been manually implemented for all complex algorithms. Case tools are used to implement ICOPS PLC 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. The development process of ICOPS software is shown in Fig.1.

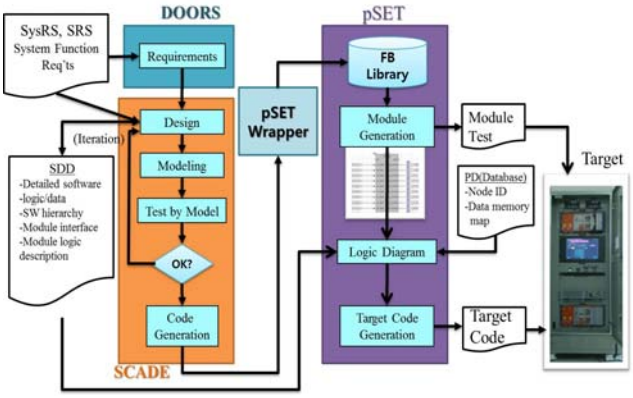

Fig. 1. Development Process of ICOPS Software

ICOPS algorithm is comprised of HEATUP, PSHAPE, ORCA, TRIGGER and CPEN, and these are implemented using user function block referred as module. SCADE was successfully applied to implement these modules except one module. ORCAMD07 was developed using C-code directly due to the performance issue. 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 unit software was implemented using the user function blocks.

The operating system (OS) of FPD is QNX version 6.3.2 and graphic tool is QNX photon application builder (PhAB). FPD software will be installed in operator module (OM) and maintenance test panel (MTP). OM software and MTP software are slightly different each other due to their functions.

2.3 Verification of ICOPS PLC Software

ICOPS PLC software is categorized as safety-critical class software, and V&V processes are the same as those of RCOPS.

For testing of PLC module, test cases were developed based on functional design requirements. The close cooperation between KEPCO NF and KEPCO E&C was needed to develop module test cases because several algorithms are newly developed. Module test consists of two types. One is a coverage test that examines all the branches of each module. The

other is function test according to the requirements. Function test is performed for each module using ICOPS development equipment and I/O simulator.

The modules tested are user function blocks, and 54 user function blocks were selected for module test while the 58 user function blocks were tested in SHN 1&2. The test environment for ICOPS module test is the single channel facility (SCF) and coverage testing platform equipped with LDRA (Liverpool data research associates) testing tool.

The result of coverage test is that 30 modules are not satisfied 100% coverage. The reason to fail to satisfy the 100% coverage is the existence of defensive codes, and the failure is inevitable because case tool has this property generally.

Module test was performed for 54 test cases and the test did not identify any software errors.

Unit test for ICOPS is currently being conducted.

2.4 Verification of ICOPS FPD Software

ICOPS FPD software is categorized as important-to-safety class software. For CPCS and RCOPS, V&V processes of FPD software are simple relative to PLC software. Recently, the regulatory agencies are taking more strict position on the V&V for important-to-safety class software. To satisfy the position, module test for FPD software is added.

For module test of FPD software, code review and coverage test were conducted. The scope of module test includes all test activities to ensure that software functional and non-functional requirements described in the SRS (software requirement specification) and SDD (software design description) for ICOPS can be met on the assembled system before launching actual product. In particular, testing will be executed to ensure the following:

1) All source codes of the modules are implemented correctly according to checklist of test plan.
2) All required functionalities of the modules are in place and working correctly according to the SDD.

The module test was performed for 71 callback functions and 101 display modules. 17 test exceptions were found and resolved.

The unit test for FPD software shall meet the following requirements:

1) Test features shall trace all requirements in SRS.
2) All test features shall be executed and pass this test.
3) Every defects detected within this test is resolved.

As shown in Table 1, there are 18 test cases. The unit test was conducted for OM and MTP using ICOPS development equipment and I/O simulator.

There were 7 test exceptions for MTP software and 8 test exceptions for OM software during unit test. The exceptions are categorized as follows:

1) Navigation Link Error
2) Point ID Mapping Error
3) Indicator Value Display Error
4) Mismatch in SRS and Display

Table 1: Test Cases and Results for Functional Test

ID	Test Feature	Results	
		OM	MTP
01	Display Navigation Test	Fail	Fail
02	OM/MTP Frame Display	Fail	Pass
03	Group Displays	Pass	Pass
04	COPP Trip Buffer Displays	Fail	Fail
05	CEAP Snapshot Displays	Fail	Fail
06	CEAP CEA Position Displays	Fail	Fail
07	Tech. Spec. Channel Check Disp	Pass	Pass
08	ASI Trend Display	Pass	Pass
09	DNBR/LPD Trends Display	Pass	Pass
10	Addressable Constants Displays	Pass	Pass
11	NI Power Calibration Display	Pass	Pass
12	Cumulative Status Words Disp.	Pass	Pass
13	Failed Sensor Stack Display	Pass	Pass
14	Channel Trouble Displays	Fail	Fail
15	COPP / CEAP Failure Display	Pass	Pass
16	Channel Trip Status Display	Fail	Fail
17	Input Comparison Displays	Fail	Fail
18	CRC & System Load Display	Pass	Pass

The exceptions are resolved and the regression test is being conducted.

3. Conclusions

ICOPS has been developed to overcome the algorithm-related obstacles in overseas project. ICOPS software is developed to reflect new functional design requirements document. For PLC software, module test was completed successfully, and unit test is currently being conducted. For FPD software, module test and unit test were completed, and the regression test of unit test is currently being conducted. One channel software testing (OCST) will be performed after the unit test for PLC and FPD software is completed.

REFERENCES

[1] Jae Ho Kim, Tae Young Yoon, Young Ho Park, Young Baek Kim, Functional Design Requirements for an In-Core Protection System for APR+, July, 2018.

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