Real-time Performance Verification of Core Protection and Monitoring System with Integrated Model for SMART Simulator

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1. Introduction

A SMART simulator is being developed in order to evaluate the impacts of design changes on the safety performance of the integral reactor, SMART. Also, the simulator (multi-purpose best-estimate simulator) can improve and optimize the operating procedure of the reactor.

In keeping with these purposes, a real-time model of the digital core protection and monitoring systems for simulator implementation was developed on the basis of SCOPS and SCOMS algorithms[1,2]. In addition, important features of the software models were explained for the application to SMART simulator, and the real-time performance of the models linked with DLL was examined for various simulation scenarios[3,4].

In this paper, performance verification of core protection and monitoring software is performed with integrated simulator model. Typical accident scenarios of SMART are simulated with 3KEYMASTER environmental software and calculated results are compared with those of DLL linked core protection and monitoring software.

2. Methods and Results

2.1 Real-time Model Development

The SCOPS_SSIM and SCOMS_SSIM code were developed as a protection and monitoring program for SMART simulator, respectively. These codes are loaded as DLL (Dynamic Link Library) file in a simulator platform. Each code receives system variables from the simulator, performs core protection or monitoring algorithms and then returns calculated variables to the simulator platform. The codes were developed based on the SCOPS and SCOMS: core simulation code for the analysis of SMART core protection and monitoring systems. The SCOPS calculates the minimum DNBR and maximum LPD and keeps the core condition safe during anticipated occurrences or postulated accidents. The SCOMS calculates the variables of limiting conditions for operation (LCO) and assists the operator in implementing the technical specification requirements for monitoring.

Software design bases and requirements were setup for simulator application as well as software performance requirements. Also, input/output variables, how to execute software and how to connect software with simulator platform were determined. Fig. 1 shows the SCOPS_SSIM software connection way with SMART simulator. The common memory of simulator is used as a data communication buffer. The SCOMS_SSIM obtains system variables and then calculates pre-defined monitoring variables with real-time. A system code, a neutronics code, a thermo-hydraulics code and all other related codes are linked with simulator platform, so does the SCOMS_SSIM. These codes perform their unique algorithm and provide calculated information to common memory of simulator. As shown in Fig. 1, the SCOMS_SSIM calculates LCO and monitoring variables with received system variable and library file. This inter-communication has to meet performance requirements. The SCOPS_SSIM are connected with SMART simulator with similar way, too.

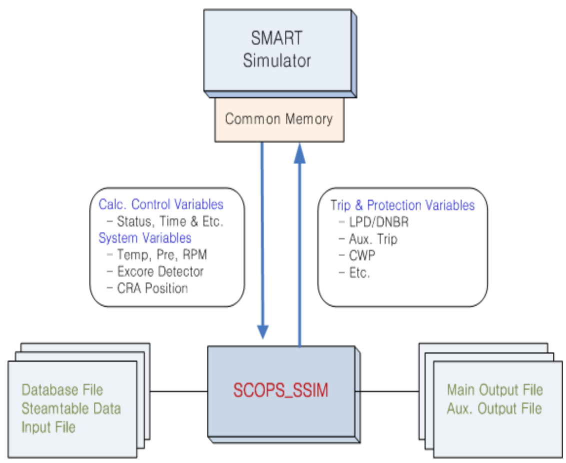


Fig. 1. SCOPS_SSIM code connection with Simulator

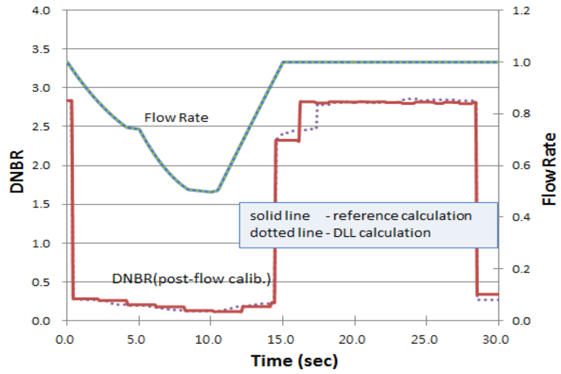
In model development, protection and monitoring algorithms were improved and real-time capability, also, was enhanced in order to satisfy the performance requirement of simulator.

2.2 DLL Connection Tests and Results

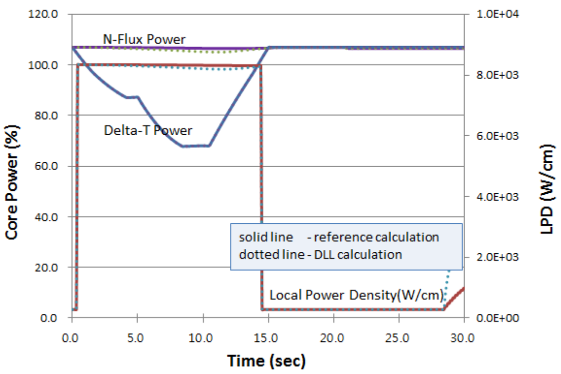
DLL connection tests of SCOPS_SSIM and SCOMS_SSIM software were done for the steady-state and transient conditions with DLL file and simulated system variables. Several test cases were selected with a purpose of verifying the input/output processing performance and justness of real-time protection and monitoring algorithm. Input signals were arbitrary determined for the simulation of steady-state and transient conditions.

Various simulation cases were selected such as: trip and LCO variable generation, DNBR/LPD & POL calculation, power distribution synthesis and so on. For each case, twice calculation were done, i.e., reference and DLL calculation. Reference calculation means the SCOPS and SCOMS standalone calculation that algorithm change is not considered.

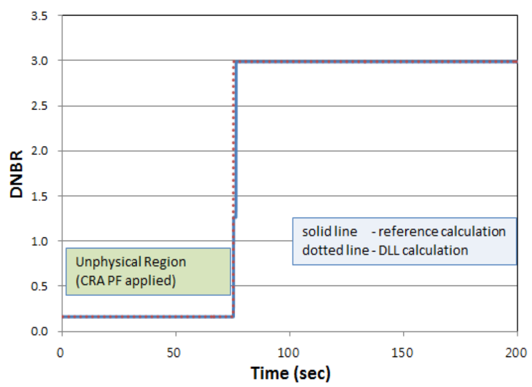
Fig. 2 - Fig.3 shows the several test results. The results of DLL calculation showed good agreements with those of standalone calculation. In addition, as seen, some features caused by model change were properly reflected to the DLL test results. As a typical example, a little difference between two calculations was occurred by the difference of execution period.



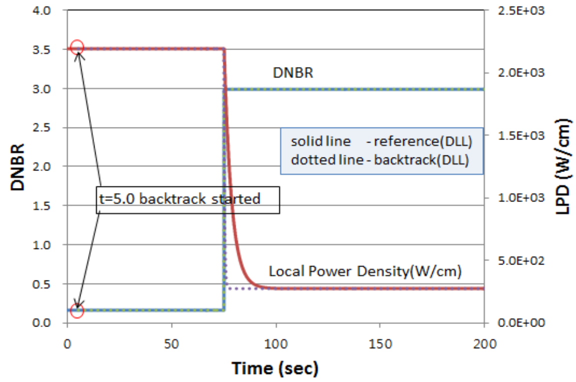
a. SCOPS_SSIM DLL test : DNBR & Flow



b. SCOPS_SSIM DLL test : Flux & Delta-T Power

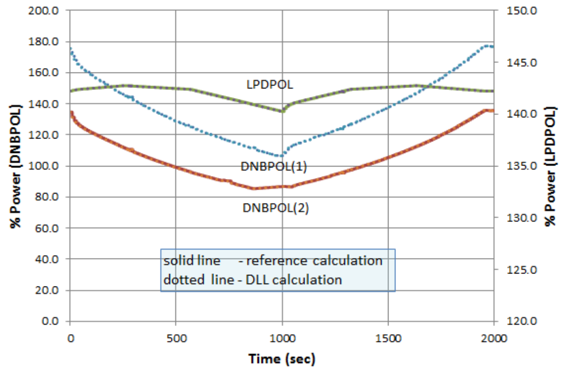


c. SCOPS_SSIM DLL test : DNBR for PF applied

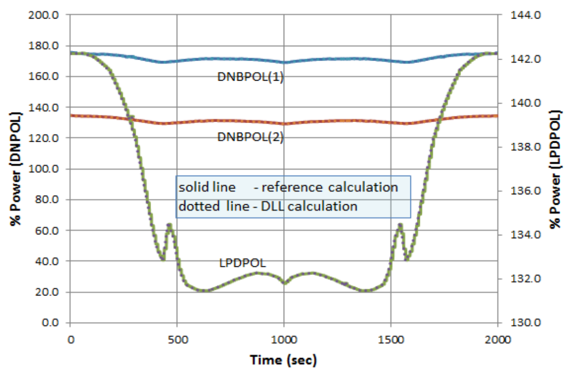


d. SCOPS_SSIM DLL test : Backtrack restart

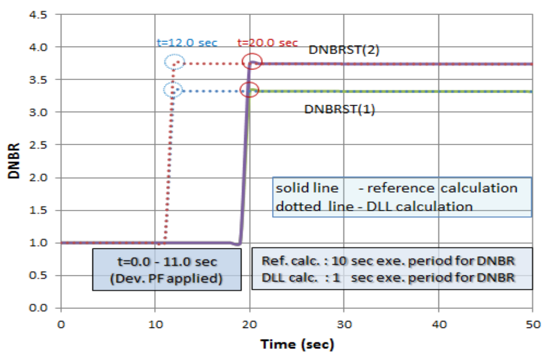
Fig. 2. Test results of SCOPS_SSIM SW DLL connection



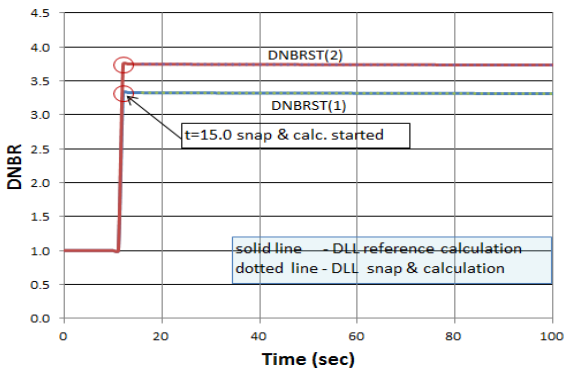
a. SCOMS_SSIM DLL test : LPD & DNB-POL



b. SCOMS_SSIM test result : LPD & DNB-POL



c. SCOMS_SSIM test result : DNBR for PF applied



d. SCOPS_SSIM test result : Backtrack restart

Fig. 3. Test results of SCOMS_SSIM SW DLL connection

2.3 Integrated Tests and Results

The performance verification of SCOPS_SSIM and SCOPS_SSIM was done with integrated simulator model. Fig. 4 shows integrated simulator model with 3KEYMASTER which was developed by WSC as environmental software of simulator. Core analysis softwares (MASTER, MATRA, SCOPS and SCOMS) were integrated with simulator platform as well as system code, BOP and instructor model and so on. Typical accident scenarios of SMART were simulated with 3KEYMASTER. Also, DLL linked independent SCOPS_SSIM and SCOMS_SSIM calculations were performed using the simulated actual variables provided by 3KEYMASTER execution. Then, two calculational results were compared.

Two typical accident scenarios of SMART were selected: turbine trip and manual trip. Each accident was simulated by following scenario:

- *0 to 10 sec. : steady-state calculation*
- *10 to 20 sec. : transient calculation*
- *20 to 300 sec. : control rod(group) inserted and reactor trip initiated*
- *Calc. period : 10 cycle/sec.*

Control rods positions were automatically determined by power-control logic program of SMART. Only single regulating group(R3) was inserted with a constant speed(60cm/sec.) in turbine trip simulation. However, in manual trip, all control rods including shutdown group were inserted to the core bottom with a dropped speed. Fig. 5 - Fig.6 show the test results for integrated simulator model. As seen, simulated results of SCOPS_SSIM and SCOMS_SSIM exactly reproduced those of 3KEYMASTER calculation. This means that SCOPS_SSIM and SCOMS_SSIM were appropriately integrated with simulator platform.

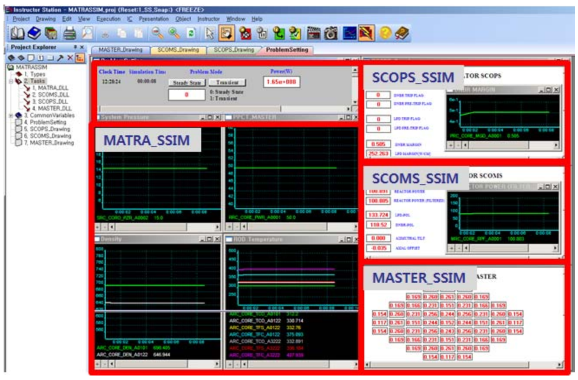
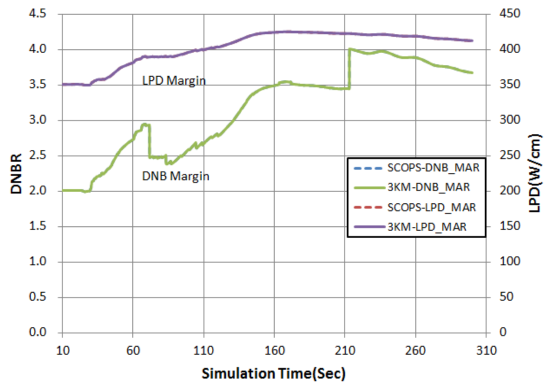
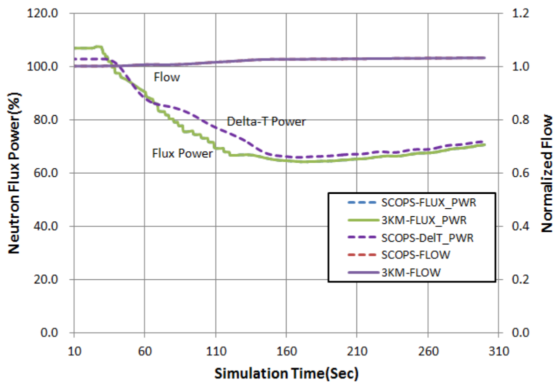


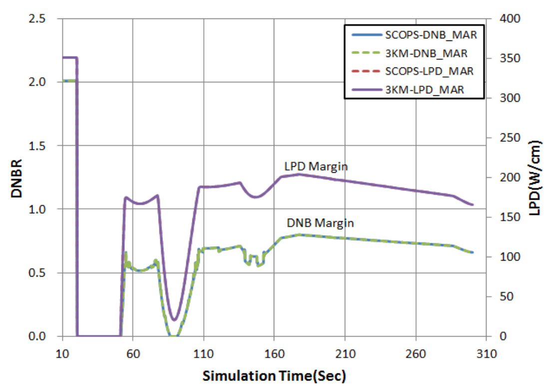
Fig. 4. Example of integrated model under the simulator platform



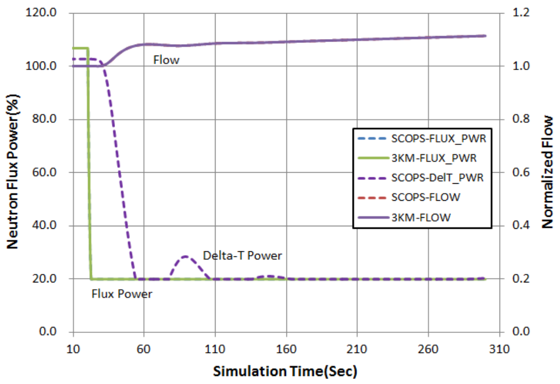
a. SCOPS_SSIM simul. with 3KM : LPD & DNB margin (T/B trip)



b. SCOPS_SSIM simul. with 3KM : Flow & Power (T/B trip)

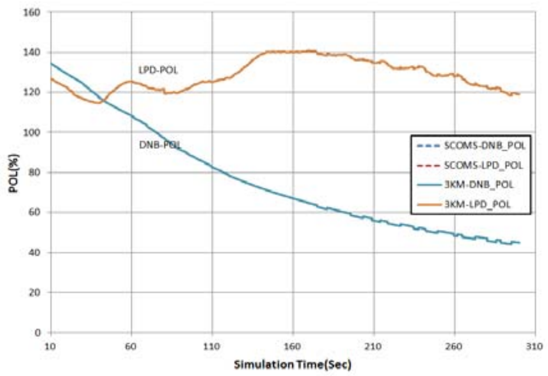


c. SCOPS_SSIM simul. with 3KM : LPD/DNB margin (Manual trip)

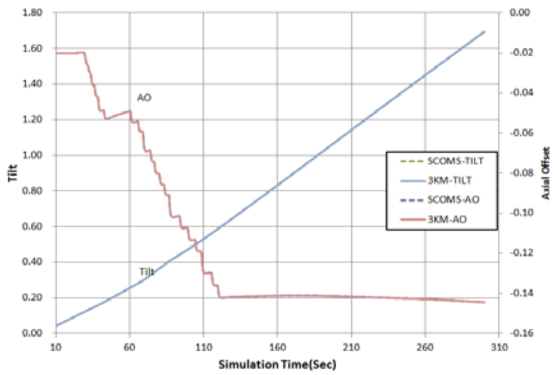


d. SCOPS_SSIM simul. With 3KM : Flow & Power (Manual trip)

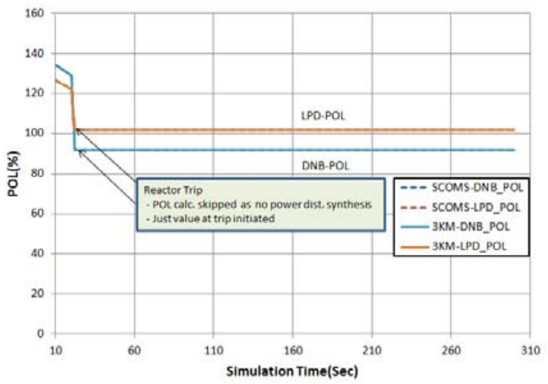
Fig. 5. Test results of SCOPS_SSIM SW integrated model



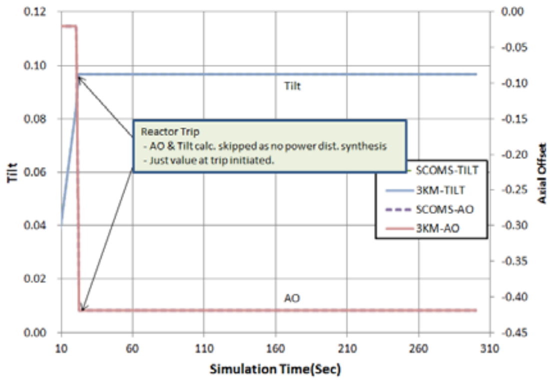
a. SCOMS_SSIM simul. with 3KM: LPD & DNB-POL (T/B trip)



b. SCOMS_SSIM simul. with 3KM: AO & Tilt (T/B trip)



c. SCOMS_SSIM simul. with 3KM: LPD & DNB-POL (Manual trip)



d. SCOMS_SSIM simul. with 3KM: AO & Tilt (Manual trip)

Fig. 6. Test results of SCOMS_SSIM SW integrated model

3. Conclusions

A real-time performance verification of core protection and monitoring software for SMART simulator was performed with integrated simulator model. Various DLL connection tests were done for software algorithm change. In addition, typical accident scenarios of SMART were simulated with 3KEYMASTER and simulated results were compared with those of DLL linked core protection and monitoring software. Each calculational result showed good agreements. Therefore, it demonstrated that the algorithms and calculational capabilities of SCOPS_SSIM and SCOMS_SSIM were proper for core protection and monitoring program and appropriately integrated with simulator platform.

Acknowledgements

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REFERENCES

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[4] B.S. Koo, et al., “Performance Evaluation of SMART Core Protection and Monitoring System for Simulator Coupling,” Transactions of ANS Winter Meeting, Washington DC Nov. 10-14, 2013.