Modeling of CPC/COLSS for YGN#3,4 Simulator

영광#3,4호기 시뮬레이터의 노심보호 및 감시계통 모델링

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요 약 : 본 논문에서는 한국형 원자력발전소의 기준모델인 영광 3,4호기 운전원 훈련용 시뮬레이터의 모델링 절차와 ABB-CE 원전의 독특한 계통인 CPC/COLSS(Core Protection Calculator/Core Operating Limit Supervisory System) 계통에 대한 모델링을 전개하고 있다. CPC/COLSS는 원자로를 포함하는 냉각재계통(NSSS)과 핵연료의 건전성을 보장하기위한 계통으로서 감시 및 보호 과정에서의 계산을 디지털화시킴으로서 정확성과 함께 원자로의 안전성을 향상시킨 특색있는 계통이다. 따라서 영광 3,4호기 시뮬레이터에서는 CPC/COLSS 계통에 대한 정확한 모델링을 하여 시험을 통해 성능 및 기능에 대한 검증을 마침으로서 CPC/COLSS 시뮬레이션 모델 개발이 성공적으로 되었고 영광 3,4호기 운전특성에 맞는 시뮬레이터를 개발하였다.

Keywords : CPC, COLSS, DNBR, LPD, simulation model

I. Introduction

The safety and reliablity of nuclear power plant operations relies heavily on the plant operators ability to respond to various emergency situations. The importance of operator ability to respond to emergency situation was revealed in the accident investigation of the TMI disaster in 1979. The accident report concluded that the operator's mistake during the accident contributed greatly to the disaster. The TMI disaster demonstrated the importance of operator training and the use of simulators for this very purpose. It has become standard industry practice to utilize simulators to improve the safety and reliability of nuclear power plants operations. KEPCO has decided to localize this technology which has been relied soley on foreign vendors until now. The simulators built for Younggwang#3,4("YGN#3,4"), which is the basic model of the Korean nuclear power plant design, has been developed precisely for this purpose. The basic model of the Korean standard nuclear power plant has several features which are conceptually different from those of other nuclear power plants in Korea. One of these features is the CPC/COLSS(Core Protection Calculator/Core Operational Limit Supervisory System).

The CPC, which is a digital computer based protection system, is designed to provide on-line calculations of Departure from Nucleate Boiling Ratio(DNBR) and Local Power Density(LPD) and to initiate reactor trip if the core conditions exceed the DNBR and LPD setpoint. The COLSS is designed to assist the operator in implementing the Limiting Conditions for Operations(LCOs) in Technical Specifications for DNBR/Linear Heat Rate(LHR) margin, azimuthal tilt, and Axial Shape Index(ASI) and to provide alarm when the LCOs are reached. A particular attention was placed on the development of CPC/COLSS safety system which is unique to the YGN#3,4. The analysis of performance and operations showed that the simulation model developed was indeed accurate simulation of the YGN#3,4 power plant[1]-[5].

II. Overview of CPC/COLSS

The CPC(Core Protection Calculator)is composed of 4 computers which continuously calculate DNBR and Local Power Density(LPD) to initiate a reactor trip when needed during certain transients to prevent violation of the DNB and fuel centerline melt fuel design limits[1][4][5]. The minimum DNBR is calculated as follows :

$$DNBR_K = \frac{\ddot{q}_{DNB}^{(K)}}{F_K \cdot \ddot{q}_{LOCAL}^{(K)}} \quad K=2,3...21 \qquad (1)$$

where subscript K stands for the node number of core. The minimum is selected and adjustment terms applied.

$$DNBR_{MIN} = MIN[DNBR_2, DNBR_3, ...DNBR_{21}] \qquad (2)$$

$$DNBR_{ST} = E_{DNB1} \cdot [\ DNBR_{MIN} + E_{DNB2}] \qquad (3)$$

where

$DNBR_K$: Array of DNB ratios in hot-channel

$DNBR_{ST}$: Minimum static DNBR.

E_{DNB1}, E_{DNB2} : DNBR adjustment terms, constant

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$\ddot{q}_{DNB}$ hot channel critical heat flux(BTU/sec-ft^2)

The Local power density is calculated as follows :

$$L_{PD} = B_{LPD} \cdot TR \cdot PKMX \cdot PF_{LPD} \quad (4)$$

where

B_{LPD} : Corrected core average power, % of rated power

$PKMX$: Maximum 3-D peaking factor computed in power distribution program

TR : Azimuthal tilt allowance

PF_{LPD} : CEA deviation penalty factor for LPD

The CEAC(Control Element Assembly Calculator) is composed of 2 computers which continuously measure positions of all CEA's(Control Element Assemblies) to detect deviations and provide power penalties, if needed, for input to the CPC's which provides the 4 independent channels for the DNBR and LPD trip functions[2]. The low DNBR and high LPD trips assure that the Specified Acceptable fuel Design Limits (SAFDL's) on DNB and centerline melt are not exceeded during Anticipated Operational Occurrences (AOO's), and assist the Engineered Safety Features Actuation System(ESFAS) by limiting the consequences of certain postulated accidents, The CPCS software has approximately 6,000 constants[6][7]. The constants used by YGN CPCS have been tuned specifically for the YGN#3,4 power plant. The overall accuracy of the CPCS depends on the accuracy of these constants[1][2].

The Core Operating Limit Supervisory System (COLSS) which is a part of plant monitoring system consists of process measurements and algorithms used to continuously monitor the following LCO's : LHR margin, DNBR margin, azimuthal tilt and ASI. COLSS also assists the operator in maintaing core power equal to or below the licensed power. To implement the requirements, COLSS is required to perform the following functions :

· Compute the DNBR and LHR power operating limits

· Compute the azimuthal tilt and monitor it with respect to the LCO

· Compute the ASI and Monitor it with respect to the LCO

· Compute the plant power and power distribution.

· Compute the margin to the licensed power, LHR and DNBR power operating limits.

· Initiate appropriate alarm sequences and informative messages when any monitored margin or parameter exceeds its LCO.

LHR power operating limit is calculated as follows :

the temperature dependent KW/FT limit is calculated based on the inlet temperature as

$$KLIM = FLIMO + (FLIMI - FLIMO) * \frac{TCMIN - TLIMO}{TLIMI - TLIMO} \quad (5)$$

IF $TCMIN \leqq TLIM0$
THEN $KLIM = FLIM0$
IF $TCMIN \geqq TLIM1$
THEN $KLIM = FLIM1$

where

$KLIM$: Temperature dependent linear heat rate (KW/FT) limit

$TCMIN$: Minimum compensated coldleg temperature

$TLIM0$: Minimum temperature in the proportional limit region

$TLIM1$: Maximum temperature in the proportional limit region

$FLIM0$: Linear heat rate (KW/FT) limit at $TLIM0$

$FLIM1$: Linear heat rate (KW/FT) limit at $TLIM1$

The following calculations are performed for I = 1 to 40 axial nodes.

$$KWFT(I) = T41 * TDPEAK(I) * (1 + AZTILT) * UNCERT * PP/100.0 \quad (6)$$

$$KWPFPL = (KLIM/KWFT(I)) * PP * T42 \quad (7)$$

Select the minimum value of KWPFPL(I) and set it equal to KWPFPOL

$$KWPFOPL = MIN[KWPFPL(I) \text{ for } I = 1 \text{ to } 40] \quad (8)$$

where

$KWFT(I)$: linear heat rate at node I

$T41$: Core average linear heat rate at rated power, constant

$TDPEAK(I)$: Three-D peaking factor

$AZTILT$: Azimuthal tilt

PP : Plant power, percent

$KLIM$: Temperature dependent linear heat rate limit

$KWPFPL(I)$: Core power operation limit at node I

$T42$: Adjustment factor for linear heat rate limit

$UNCERT$: Adjustment factor for calculation of linear heat rate

$KWPFOPL$: LHR power operating limit

$DNBPOLC$: power operating limit

The main parts of COLSS are power level calculation algorithm, core power distribution algorithm and DNBR & LHR power operating limit calculation algorithm. In core power calculation algorithm, it selects the highest power among the secondary calorimetric power, turbine power and core △T power. In core power distribution algorithm, it determines 1-D and 3-D power distribution, azimuthal tilt and ASI by five level fixed in core detectors and CEA positions. The DNBR & LHR power operating limit algorithms determine the DNBR and LHR margins. COLSS should have always some required power margin to meet fuel design criteria even if any AOO occurs. This margin is called the Required Over Power Margin(ROPM). COLSS checks every second whether the present plant status is within the COLSS LCO's using the ROPM and measured state parameters. If any COLSS LCO is exceeded, COLSS alams and operator action is taken per the Technical Specifications[3].

III. CPC/COLSS model configuration of simulator

The simulator for the YGN#3,4 is a full scope replica type to be used for training plant operators. The CPC/COLSS on the simulator was also designed to provide the same features as those installed in the actual plant. In order to accomplish this, hardware identical to the plant Main Control Room(MCR) was installed. The hardware installed included the same operator module such as the Plasma Display Unit(PDU), CRT and function keyboards. The simulation host computer was a Silicon Graphics Challenge L and Indy Workstations operating under Real-Time UNIX OS. Table 1 shows the configuration of the actual plant and that of the simulator.

Table 1. The configuration of the actual plant and that of the simulator.

Real Plant CPC/COLSS	Simulator CPC/COLSS
Process(Pipe, Pump, Core, Instrumentation..)	Process Modeling Programs
Main Control Room (Example: CRT, PDU)	Main Control Room (Example : CRT, PDU)
Computer Systems for Calculation, Display (3205/3280MPS)	Simulation Computer Systems (CHALLANGE L, INDY)

IV. Development of CPC/COLSS model of simulator

1. Development process

The first step in the development of the CPC/COLSS simulation model is the generation of the Software Requirement Specifications(SRS). The SRS is generated by compiling performance requirement and specifications from plant operators and plant data. The SRS defines the scope of simulation for the simulator for each specific system. The next process is the development of Detailed Design Specifications(DDS). During the DDS phase, the modeling of algorithm and system interfaces are developed. The design data used for this is the CPC/COLSS functional design requirement which is provided by the vendor. After the completion of the DDS, the developed system model is put through a Stand-alone Test and Non-Integrated Systems Test(NIST). The system model is then integrated with the simulator and put through an Integration Test. Finally, after the Integration Test is completed, the software model is integrated with the H/W and tested by plant operators during the Factory Acceptance Test(FAT) and Site Acceptance Test(SAT). Figure 1 shows the development process[8].

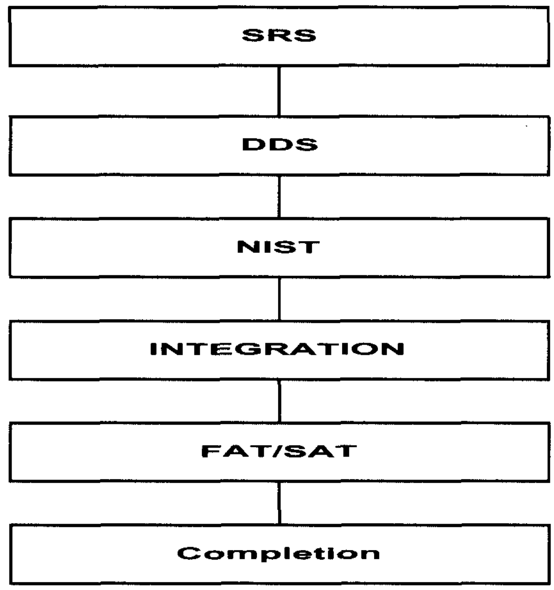

Fig. 1. The development process.

2. CPC/COLSS model program structure and process flow

2.1 CPC/COLSS commonly used software

The computerized systems such as CPC/COLSS developed commonly used software collectively so that changes can be easily made and implemented throughout the simulator. The main task of common S/W development are Data Gathering Task, Communication Manager, Scanning Task, Timer Task.

2.2 CPC/COLSS display task and program module

The display task receives information such as Symbols(pump, valves..), Value(temperature, pressure, level...), text(Point ID, description...) from Current Value Table(CVT) and displays this data on the PDU and CRT in the MCR. The display task also receives operator input and processes the input command.

2.3 CPC program module

The plant CPC is designed to perform rapid and accurate calculations to maintain certain plant safety parameters to within specified safety limits. In order to comply with this design requirement, the calculation algorithm was installed on the simulation host computer. The CPC program module is set in a top-down configuration with segment modules placed in a hierarchial sequence. The structure allows for the independent compiling of the modules. Figure 2 shows the configuration of the CPC model program.

2.3.1 Control module

The control module has the highest place in the program heirarchy. The control module calls submodules(segments, component, subroutines...) for simulation and sets the calculation cycle rate for the various submodules.

2.3.2 Segment module

The segment module is comprised of mathmatical equations which models the CPC based on the FDR(Functional Design Requirenments). The segment module calls on subroutines and component modules for calculating the following functions.

- Coolant Mass Flow Program(FLOW)
- DNBR and Power Density Update Program(UPDATE)
- Power Distribution Program(POWER)
- Static DNBR and Power Density Program(STATIC)
- Trip Sequence Subroutine(TRIPSEQ)
- CEA Penalty Factor Calculation Program(CEAC)

2.3.3 Component

The component modules simulate the control logics of various components in the acutal power plant. The component modules are a type of a subroutine with component level malfunction feature included in them.

2.3.4 Subroutine

The subroutines used for repeated functions. The Subroutines maybe called by control modules, segments, components, and other subroutines.

2.3.5 Functions

The functions maybe called by control modules, segments, components, and other functions. They are used to calculate and return one value.

2.3.6 Block data

The block data is used to store constants which are not actually stroed in the CPC/COLSS program itself. These include constants such as Reload Data Block and Addressable constants.

2.4 COLSS program module

COLSS program being a mounted program is installed separately on a W/S instead of the simulation host computer itself. The COLSS program consists of 5 modules with 20 calculation algorithm written in C programming language.

2.5 CPC/COLSS execution flow

The CPC algorithm is executed by the simulation host computer and the variables calculated are displayed on the operator displays. The communication between the simulation host computer and CPC/COLSS workstations are executed by accessing data from the global memory and sending the information via a Send Server of the communication manager to the receive servers on the workstations. These data are read by the scan task and updated to the shared memory(CVT). Finally the display task scans the data in the CVT and displays it on the operator display. The COLSS algorithm calculates the various variables from the data stored in the

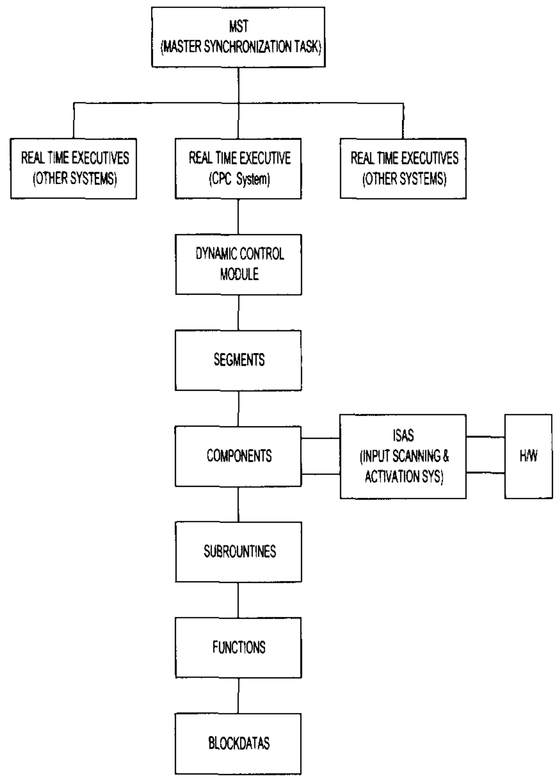

Fig. 2. The configuration of the CPC model program.

workstation CVT. The scan task accesses the CVT and sends the information to the operator display terminal. Figure 3 shows the execution & data flow of the CPC/COLSS model program[8].

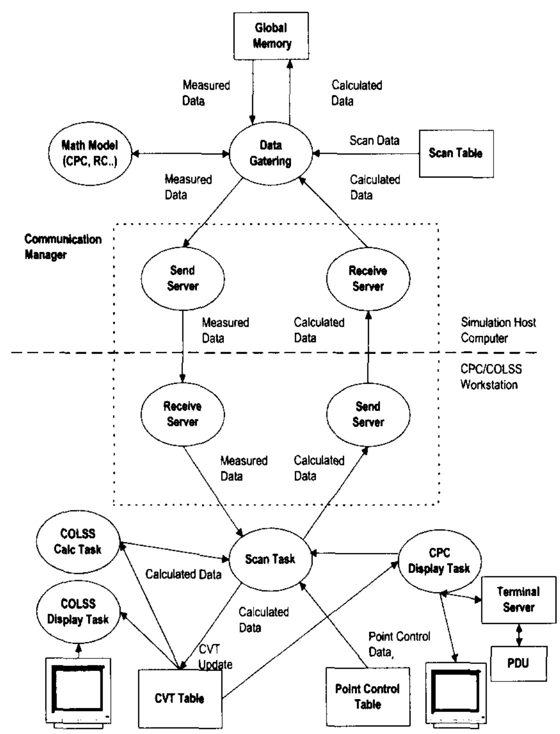

Fig. 3. The execution & data flow of the CPC/COLSS model program.

V. Test, verification and validation(V/V)

Objectives of verification and validation (V/V) of the CPC/COLSS calculation of DNBR and LPD are to verify that the CPC/ COLSS calculated values of DNBR and LPD are consistent with the values calculated by the CPC/COLSS Fortran Code. The V/V of YGN#3,4 simulator CPC/COLSS was performed by comparing the on-line calculated variables(DNBR, LPD...) from the actual plant to those calculated by the simulator model. The data used for V/V was from the data gathered during YGN#3 Start-up Test operation[9][10].

1. CPC simulation model and analysis result

The operation test of the plant is performed at 20%, 50%, 80%, and at 100% full power plant operations. The calculated values for the CPC DNBR, LPD... are compared to those calculated from an identical algorithm off-line called the CEDIPS which is provided by the CPC Vendor for the test of CPC system. CEDIPS accepts the minimum and maximum values of the CPC inputs observed during startup testing as the input. CEDIPS is performed to set up 2^7 static cases, in which the input data are permuted, and one dynamic case, during which the CPC input signals fluctuate with uniform distributions between the maximum and minimum sensor values provided in the input. the minimum and maximum DNBR and LPD values are produced to support the CPC/COLSS Operability Test[11]. The calculated values for these parameters from the simulator were compared in an identical procedure to that of the actual power plant. The requirement is that the plant and simulator CPC output values should be within the maximum and minimum values calculated by CEDIPS[9]. The second requirement is that the simulator CPC output values should be within ±1% of the plant output values[12]. The values of constants used for the two calculations are from the actual plant database. Table 2,3 and Figure 4,5 show the 20%, 50%, 80%, and at 100% full power plant operations. All of the CPC calculated DNBR and LPD values were bounded by the corresponding CEDIPS ranges of values.

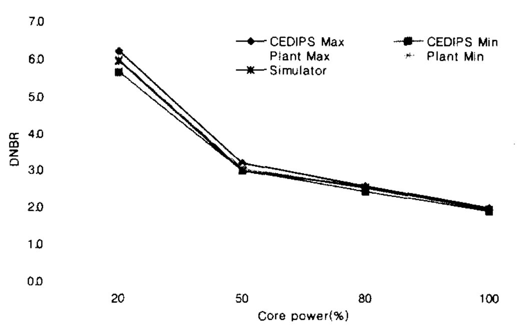

Fig. 4. CEDIPS/plant CPC/simulator CPC comparison of DNBR(for Ch. A).

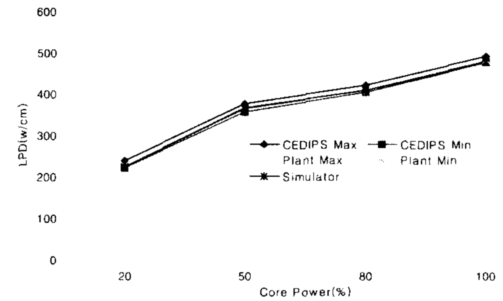

Fig. 5. CEDIPS/plant CPC/simulator CPC comparison of LPD(for Ch. A).

Table 2. CEDIPS/plant CPC/simulator CPC comparison of DNBR(For Channel A).

Power Level	CEDIPS		Plant CPC		Simulator CPC
	Maximum	Mininum	Maximum	Mininum	Output
20%	6.1905	5.6463	6.0325	5.9631	5.93586
50%	3.1937	2.9748	3.0967	3.0552	2.98230
80%	2.5797	2.4219	2.5355	2.5023	2.54811
100%	1.9816	1.8857	1.9632	1.9331	1.95401

Table 3. CEDIPS/plant CPC/simulator CPC comparison of LPD(W/cm)(For Channel A).

Power Level	CEDIPS		Plant CPC		Simulator CPC
	Maximum	Mininum	Maximum	Mininum	Output
20%	239.58	221.78	225.78	225.07	225.82
50%	378.56	358.42	366.55	365.24	367.82
80%	423.47	405.10	410.25	409.42	409.97
100%	491.60	476.80	482.43	480.62	480.97

2. COLSS simulation model and analysis result.

The COLSS operations test is performed by operating the COLSS independently using a test case provided by the vendor. Afterwards the detailed print from the plant is compared to the results from the COLSS verification program called the COLSS FORTRAN simulator. The simulator COLSS was also tested using the identical procedure. Table 4 is the compilation of detailed printout results. Table 5 and 6 are compilation of 40 test case results.

VI. Conclusion

The analysis of the simulator CPC/COLSS output was verified to be within the design performance limit of YGN#3,4 and demonstrates the accuracy of the simulation model developed for the YGN#3,4 simulator.

The success in developing the simulation model of a safety system unique to YGN#3,4 will contribute to the improvement in plant operartion there. Furthermore the author believes that the model developed can be applied to future simulator projects such as the North Korea simulator project.

Table 4. The compilation of detailed printout results.

Parameters	SimulatorCOLSS	Plant COLSS
RCS FLOW RATE	359376.33	359376.40
REL MASS FLOW RATE	1.088643	1.09361
BDELT	98.641586	98.6391
BSCAL	99.868037	99.7502
TBN POWER	98.703	98.703
PLANT POWER	99.700	99.684
ASI	0.01334401	0.012884
INTEGRAL RADIAL INTRAD	1.4643201	1.461660
WEIGHTED AVERAGE TILT	0.00446275	0.00411252
MAX3DPK	1.70240371	1.7107590
DNBRS	112.353228	112.57370
KWFPS	132.626653	132.14280

Table 5. Summary of 40 test case results (for Plant COLSS).

Case #	CFLOW	TRMFLO	BDELT	BSCAL	BTFSP	PP	ASI	INTRAD	AZTILT	MAX3DPK	DNBPL1	DNBPL2	POLGF(1)	POLGF(2)	DNBRP1	DNBRPLB	KWPFPLB	MARGIN
1	337766	1.0235	BAD	BAD	100	100	9.39E-04	1.603	8.54E-05	2.42402	99.896	101.41	107.333	121.402	99.8955	98.3955	91.4626	-8.5372
2	337766	1.0235	84.699	BAD	BAD	84.699	-0.188433	1.7771	8.54E-05	3.16087	77.798	75.471	84.8084	95.246	75.4711	66.4905	66.0233	18.209
3	337766	1.0235	BAD	BAD	75	75	-0.309605	1.84175	8.54E-05	3.49209	73.409	70.891	80.452	89.8788	70.8907	54.8407	61.8682	-20.159
4	336598	1.01554	BAD	BAD	65	65	0.187874	1.76923	8.54E-05	2.98668	81.524	79.846	88.9136	100.809	79.8457	56.6957	71.9228	8.3043
5	336114	1.01226	BAD	BAD	45	45	0.310977	1.76609	8.54E-05	2.85319	81.023	76.471	88.7957	100.758	76.4713	42.1713	73.3287	-2.8787
6	335872	1.01063	BAD	BAD	85	85	5.57E-04	1.76579	8.54E-05	2.47635	79.31	1000	83.2145	100	79.3099	71.6099	89.4562	13.19
7	335831	1.009	BAD	BAD	88.25	88.25	5.57E-04	1.77064	8.54E-05	2.48281	1000	73.455	100	91.5512	73.4547	67.9047	69.2143	20.345
8	337766	1.0235	102.72	103	100	102.72	-1.32E-06	1.58828	8.54E-05	2.40154	100.5	98.012	107.981	122.158	98.0118	98.0118	93.8517	8.865
9	337766	1.0235	BAD	BAD	25	25	0.310686	2.36813	8.54E-05	3.97491	68.595	68.761	75.176	87.1782	68.5951	32.5951	46.9113	7.59509
10	337766	1.0235	76.942	BAD	BAD	76.942	0.311645	2.04878	8.54E-05	2.97709	76.754	76.825	84.1176	97.4027	76.7539	61.2169	72.619	-15.725
11	337766	1.0235	26.159	BAD	BAD	26.159	8.69E-05	1.58827	8.54E-05	2.40179	100.49	97.612	107.972	121.909	97.6116	67.6116	92.6417	41.453
12	337766	1.0235	29.616	BAD	25	29.616	5.14E-05	2.97899	8.54E-05	4.54528	52.614	51.554	56.7455	64.2554	51.5544	20.0544	46.1442	9.5611
13	337766	1.0235	102.72	BAD	90	102.72	2.16E-03	2.18702	8.54E-05	3.69062	67.601	65.961	72.6339	62.2115	65.9611	64.4611	59.0383	43.678
14	337766	1.0235	61.646	BAD	75	75	2.16E-03	6.56107	8.54E-05	11.0425	BAD	BAD	BAD	BAD	BAD	BAD	16.7861	-58.214
15	337766	1.0235	BAD	28.136	BAD	28.136	1.79E-03	1.15E+07	8.54E-05	2.83E+07	BAD	BAD	BAD	BAD	BAD	BAD	-5.99999	34.136
16	337766	1.0235	BAD	57.81	60.625	60.621	0.309078	21.5744	8.54E-05	47.2205	BAD	BAD	BAD	BAD	BAD	BAD	1.32453	-59.297
17	337766	1.0235	BAD	104.64	79.375	104.64	2.16E-03	6.58107	8.54E-05	11.0425	BAD	BAD	BAD	BAD	BAD	BAD	18.6481	-65.793
18	337766	1.0235	102.72	101.04	BAD	102.71	1.27E-03	19.7539	8.54E-05	33.1672	BAD	BAD	BAD	BAD	BAD	BAD	4.94036	-97.774
19	337766	1.0235	102.72	103.66	98.75	102.72	2.16E-03	8.01445	8.54E-05	12.1135	BAD	BAD	BAD	BAD	BAD	BAD	17.0029	-65.715
20	337766	1.0235	43.674	57.112	50	50.009	2.16E-03	14.9497	8.54E-06	22.8574	BAD	BAD	BAD	BAD	BAD	BAD	5.67149	-44.337
21	337766	1.0235	45.46	56.656	BAD	45.474	1.27E-03	1.47E+07	8.54E-05	2.66E+07	BAD	BAD	BAD	BAD	BAD	BAD	-4.76207	50.236
22	337766	1.0235	26.159	25.055	15	26.157	0.308096	2.00207	8.54E-05	4.01721	66.35	63.988	72.7153	81.1022	63.9883	30.9883	51.3014	4.81106
23	337766	1.0235	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD
24	337766	1.0235	5.6215	BAD	BAD	5.6215	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	94.1785
25	337766	1.0235	BAD	BAD	100	100	1.27E-03	2.0075	8.54E-05	3.32371	76.13	74.309	81.7981	92.6163	74.3093	72.8093	65.7576	-34.242
26	335504	1.00615	BAD	BAD	75	75	1.40E-03	2.08571	0.149319	3.33456	61.711	60.557	66.3048	75.4756	60.5567	44.5067	56.0186	30.493
27	339547	1.03577	BAD	BAD	75	75	7.13E-04	2.10448	7.07E-02	3.13384	67.95	66.977	73.0092	83.477	66.9765	50.9265	64.5592	-24.074
28	337891	1.02504	BAD	BAD	75	75	1.64E-03	2.05577	4.38E-03	3.03714	73.41	72.556	78.8753	90.4315	72.5563	56.5063	71.4187	18.494
29	337541	1.02196	BAD	BAD	75	75	2.99E-03	2.05478	4.17E-03	3.03756	71.124	69.726	76.4193	66.9033	69.7256	53.6756	71.424	-21.324
30	337766	1.0235	BAD	BAD	75	75	-2.16E-03	2.05076	BAD	3.04643	BAD	BAD	BAD	BAD	BAD	BAD	BAD	25
31	337766	1.0235	BAD	BAD	75	75	8.38E-04	2.04971	BAD	3.03146	BAD	BAD	BAD	BAD	BAD	BAD	BAD	25
32	BAD	BAD	BAD	BAD	25	25	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	75
33	BAD	BAD	BAD	BAD	25	25	5.57E-04	1.89653	8.54E-05	2.66791	BAD	BAD	BAD	BAD	BAD	BAD	BAD	75
34	BAD	BAD	BAD	BAD	25	25	5.57E-04	1.89653	8.54E-05	2.66791	BAD	BAD	BAD	BAD	BAD	BAD	77.2817	52.2817
35	BAD	BAD	BAD	BAD	25	25	5.57E-04	1.89653	8.54E-05	2.66791	BAD	BAD	BAD	BAD	BAD	BAD	77.2817	52.2817
36	346728	1.05066	105.44	103	100	105.44	BAD	BAD	8.54E-05	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	5.4367
37	336530	1.01512	101.06	103.38	100	101.06	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	-1.061
38	337564	1.02212	102.78	102.94	100	102.78	5.57E-04	1.73021	8.54E-05	2.43094	92.999	91.324	99.9225	113.823	91.3238	91.3738	82.6964	11.452
39	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD
40	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD

Table 6. Summary of 40 test case results (for slmulator COLSS).

Case #	CFLOW	TRMFLO	BDELT	BSCAL	BTFSP	PP	ASI	INTRAD	AZTILT	MAX3DPK	DNBPL1	DNBPL2	POLGF(1)	POLGF(2)	DNBRP1	DNBRPLB	KWPFPLB	MARGIN
1	337766	1.0235	BAD	BAD	100	100	9.39E-04	1.603	8.54E-05	2.42402	[illegible]	101.4815	107.436	121.4783	[illegible]	[illegible]	91.40901	-8.53719
2	337766	1.0235	84.699	BAD	BAD	84.699	-0.1848	1.7771	8.54E-05	3.16097	77.8500	75.42	84.8620	95.1816	75.42	[illegible]	[illegible]	[illegible]
3	337766	1.0235	BAD	BAD	75	75	0.3096	1.84175	8.54E-05	3.49209	73.2707	70.7479	80.3902	[illegible]	70.7479	54.8[illegible]	61.69913	20.30212
4	336598	1.01554	BAD	BAD	65	65	0.18767	1.76923	8.54E-05	2.98668	81.7071	80.0291	89.1137	101.041	80.0291	[illegible]	71.92281	-0.12[illegible]
5	336114	1.01226	BAD	BAD	45	45	0.31049	1.76609	8.54E-05	2.85319	81.4679	76.8008	89.2863	101.1758	76.80081	42.45061	73.32614	2.54[illegible]
6	335872	1.01063	BAD	BAD	85	85	5.57E-04	1.76579	8.54E-05	2.47635	79.4091	1000	83.3968	100	79.40911	71.8081	89.45621	13.03080
7	335831	1.009	BAD	BAD	88.25	88.25	5.57E-04	1.77064	8.54E-05	2.48281	1000	73.8079	100	92.0279	73.80725	68.28725	69.21437	19.98775
8	337766	1.0236	102.7163	103.000	100	102.7167	-1.38E-06	1.58828	8.54E-05	2.40154	100.502	98.1277	108.0811	122.3027	98.12774	98.12714	93.95188	8.86480
9	337766	1.0236	BAD	BAD	25	25	0.31068	2.36813	8.54E-05	3.97491	68.5903	68.6967	74.9859	88.0883	68.39082	32.33082	46.91126	7.53892
10	337766	1.0236	76.9417	BAD	BAD	76.9417	0.31164	2.04878	8.54E-05	2.97709	76.4782	76.5689	84.0166	97.0884	76.47823	60.84114	72.61952	-16.0088
11	337766	1.0236	26.1586	BAD	BAD	26.1586	8.69E-05	1.58827	8.54E-05	2.40179	100.4837	98.117	109.0721	122.2882	98.11690	67.61688	92.64127	41.7584
12	337766	1.0235	29.6158	BAD	25	29.6156	5.14E-05	2.97899	8.54E-05	4.54528	52.5838	51.3298	58.4773	63.9757	51.32981	19.82981	46.14421	-8.70984
13	337766	1.0236	102.7168	BAD	90	102.7163	2.16E-03	2.18702	8.54E-05	3.69062	67.3106	[illegible]	72.8218	61.8441	65.86692	64.16692	59.00836	-49.67886
14	337766	1.0236	61.6489	BAD	75	75	2.16E-03	6.56107	8.54E-05	11.04246	BAD	BAD	BAD	BAD	BAD	BAD	16.78692	58.21881
15	337766	1.0236	BAD	28.136	BAD	28.1360	1.79E-03	[illegible]	8.54E-05	28544270	BAD	BAD	BAD	BAD	BAD	BAD	-5.99999	-34.13681
16	337766	1.0236	BAD	57.809	60.625	60.6212	-0.30908	21.5744	8.54E-05	47.2205	BAD	BAD	BAD	BAD	BAD	BAD	1.32453	-59.2957
17	337766	1.0236	BAD	104.639	79.375	104.6392	2.16E-03	6.58108	8.54E-05	11.04246	BAD	BAD	BAD	BAD	BAD	BAD	18.84809	-65.79388
18	337766	1.0236	102.7169	101.04	BAD	102.7142	1.27E-03	19.75394	8.54E-05	33.16719	BAD	BAD	BAD	BAD	BAD	BAD	4.94035	97.77386
19	337766	1.0236	102.7163	103.659	98.75	102.7175	2.16E-03	8.01445	8.54E-05	12.11366	BAD	BAD	BAD	BAD	BAD	BAD	17.00286	65.71482
20	337766	1.0236	43.6744	57.112	50	50.0089	2.16E-03	14.94973	8.54E-05	22.85743	BAD	BAD	BAD	BAD	BAD	BAD	5.67149	-44.3374
21	337766	1.0236	45.4568	56.659	BAD	45.4739	1.27E-03	14701863	8.54E-05	26687222	BAD	BAD	BAD	BAD	BAD	BAD	4.76208	50.23801
22	337766	1.0236	26.1586	25.054	15	26.1572	0.3081	2.00208	8.54E-05	4.01727	66.2487	63.6864	72.5968	80.7195	63.68842	30.68842	51.30143	4.50924
23	337766	1.0236	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD
24	337766	1.0236	5.6215	BAD	BAD	5.6215	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	94.17867
25	337766	1.0236	BAD	BAD	100	100	1.27E-03	2.0075	8.54E-05	3.32371	75.808	74.0665	81.4892	92.2869	74.06548	72.56548	65.75754	-34.24246
26	335504	1.00615	BAD	BAD	75	75	1.40E-03	2.08571	0.14932	3.33467	61.4268	60.3091	66.0098	75.1888	60.30907	44.25907	56.0186	30.74090
27	339547	1.03577	BAD	BAD	75	75	7.13E-04	2.10448	0.0707	3.13384	67.6778	66.6883	72.8827	83.1178	66.6883	50.63881	64.55917	24.9517
28	337891	1.02504	BAD	BAD	75	75	1.64E-03	2.05577	0.00438	3.03714	73.0889	72.2823	78.5411	90.09	72.28234	56.23234	71.41862	18.76758
29	337541	1.02196	BAD	BAD	75	75	7.09E-03	2.05478	0.00417	3.03756	70.8759	69.5878	76.1526	88.7004	69.58275	53.51775	71.42380	21.48725
30	337766	1.0236	BAD	BAD	75	75	-2.16E-03	2.05076	BAD	3.04643	BAD	BAD	BAD	BAD	BAD	BAD	BAD	25
31	337766	1.0236	BAD	BAD	75	75	8.38E-04	2.04972	BAD	3.03146	BAD	BAD	BAD	BAD	BAD	BAD	BAD	25
32	BAD	BAD	BAD	BAD	25	25	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	75
33	BAD	BAD	BAD	BAD	25	25	5.57E-04	1.89653	8.54E-05	2.66791	BAD	BAD	BAD	BAD	BAD	BAD	BAD	75
34	BAD	BAD	BAD	BAD	25	25	5.57E-04	1.89653	8.54E-05	2.66791	BAD	BAD	BAD	BAD	BAD	BAD	77.28177	52.28177
35	BAD	BAD	BAD	BAD	25	25	5.57E-04	1.89653	8.54E-05	2.66791	BAD	BAD	BAD	BAD	BAD	BAD	77.28177	52.28177
36	346728	1.05080	105.4417	103.002	100	105.4367	BAD	BAD	8.54E-05	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	5.4367
37	336530	1.01512	101.0584	103.378	100	101.081	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	1.08087
38	337564	1.02212	102.7767	102.936	100	102.7758	5.57E-04	1.73021	8.54E-05	2.43094	93.1158	91.4143	100.0481	113.9354	91.41434	91.41434	82.69637	11.28159
39	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD
40	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD

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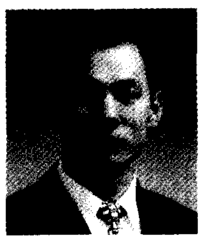

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