



## Design architecture of simplified core protection calculator system algorithm

Donghwi Jeon, Jaechon Jung\*

Department of Nuclear Engineering, KEPCO International Nuclear Graduate School, 658-91 Haemaji-ro, Seosang-myeon, Ulju-gun, Ulsan 45014 South Korea



### ARTICLE INFO

#### Keywords:

Core Protection Calculator System (CPCS)  
System complexity  
Common cause failure  
High local power density calculation algorithm

### ABSTRACT

The methodology which simplified the Core Protection Calculator System (CPCS) architecture was developed in this work. The current CPCS implemented on Programmable Logic Controller (PLC) has been reported a lot of disadvantages such as unintended reactor trip initiation, safety channel communication disruption, and the possibility of the Common Cause Failure (CCF). This work aimed to minimize the complexity of the current system by introducing system engineering methodology to the current CPCS calculation algorithm. To verify the feasibility of CPCS calculation algorithms on FPGA that does not feature calculations, the simplified LPD calculation algorithm has been implemented in this work. The simplified LPD calculation algorithm that replaced current algorithm has been developed by adjusting the input parameters. In addition, the new approach to minimize the possibility of CCF using FPGA based architecture was also discussed in this work. Based on the functional design, the enhanced functional flow block diagram was designed and the timing simulation was performed to demonstrate the reduction of system complexity. To solve the CCF problem of CPCS, the proposed CPCS LPD calculation algorithm was converted into VHDL code, and the simplified LPD calculation algorithm was implemented in the FPGA board. The verification test was performed using LPD calculation algorithm which was a crucial part of development. The performance of the implemented system showed consistent output to the expected results.

### 1. Introduction

Advanced Power Reactor 1400 (APR 1400) equips with a core protection system for the concept of defense in depth, among which the Core Protection Calculator System (CPCS) is one of the most important systems. The CPCS calculates the Departure from Nucleate Boiling Ratio (DNBR) and the Local Power Density (LPD) to protect the core of the reactor as well as continuously monitor relevant core conditions. The CPCS consists of the FLOW, CEAC, POWER, STATIC, UPDATE and TRIPSEQ program modules for the implementation of the calculation algorithm (KEPCO & KHNP, 2015). Because of this CPCS calculation algorithm and communication structure, unintentional core trips have occurred in the past.

Also, the current CPCS is based on Programmable Logic Controller (PLC) and is equipped with a microprocessor. The Operating System (OS) is necessary for system operation. Due to this system architecture, the current PLC-based CPCS has intrinsic unreliability. There are several types of research work on the Instrument and Control (I&C) systems of the Nuclear Power Plant and research reactors, in particular on the reactor protections and how to improve the reliability and design of

I&C system architectures (Ur et al., 2014; Naser et al., 2009).

The purpose of this study is as follows. First, to develop the simplification methodology for complex calculation algorithms of the current CPCS. To improve the complicated calculation algorithm of the current CPCS, a method has been developed to minimize the complexity of the system by adjusting input parameters.

The input parameters to be changed are the RCP speed pulse signal for the mass flow rate calculation and the CEA groups position signal for calculation of the radial peaking factor. The algorithm complexity of the two systems is compared by converting the current CPCS calculation algorithm and the simplified CPCS calculation algorithm to the Enhanced Functional Flow Block Diagram (EFFBD) (Jung, 2016).

Second, to devise a method to minimize the possibility of Common Cause Failure (CCF) in the current system. The PLC-based CPCS requires the OS and application for system operation, and the CCF is likely to occur (KEPCO & KHNP, 2014a,b; Choi and Kim, 2016). To solve the hardware problem of the current CPCS, the FPGA technology is actively introduced to the nuclear power plant (Ranta, 2012). To reduce the possibility of CCF by converting the simplified algorithm developed in the previous step to VHDL code and implementing the

\* Corresponding author.

E-mail address: [jjung@kings.ac.kr](mailto:jjung@kings.ac.kr) (J. Jung).

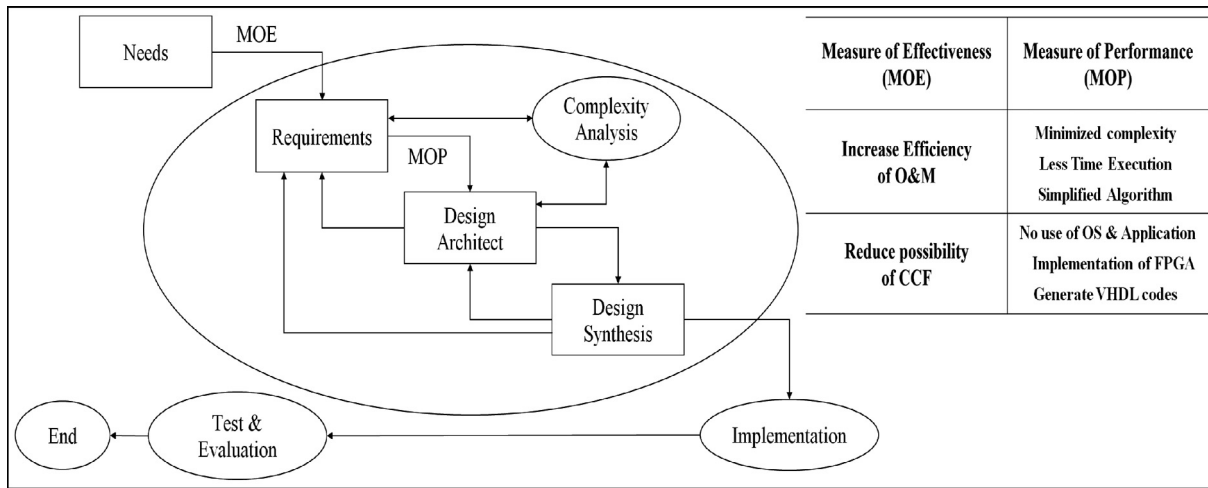


Fig. 1. System Engineering based Development Process.

code on the FPGA board (EPRI, 2011).

To achieve the two goals, all stages of development must be systematically linked by applying the System Engineering (SE) (Jung and Ahmed, 2016). Each stage is applied to various methodologies for development of new CPCS design architect. The SE approach applied to this work is illustrated in Fig. 1.

## 2. Boundary and constraints of design architecture

### 2.1. Boundary of the study

To improve the efficiency of research, the following research boundary is specified. First, to verify the feasibility of CPCS calculation algorithms on FPGA that does not feature calculations in this work, the simplified LPD calculation algorithm has been implemented. Second, individual CEA mismatches within the CEA subgroup are not considered. The reason for definition of this research boundary was that the functions of the current CPCS were so complex that it was difficult to research all parts of the CPCS at the same time. For another reason, this study was related to the I&C research for improving the calculation and communication structure of the current CPCS. Therefore, the minimum research boundary had to be set.

### 2.2. Input parameter constraints

The input parameters of CPCS are Reactor Coolant Pump (RCP) speed pulse signal, Ex-core neutron flux detector, CEA groups position, pressurizer pressure, and temperature of the hot and cold leg. When the Design Basis Accident (DBA) occurs in the nuclear power plant (NPP), the CPCS calculates low DNBR and high LPD (Lee and Chang, 2003). In this study, the calculation algorithm is simplified by optimization of the input parameters. The input parameters of the current CPCS are depicted in Table 1. The input parameters applied to this study are

Table 1  
As-Is [CPCS Input parameters].

Signal	Input per CPC	Representative Range	Signal Type
RCP Speed Pulse	4	10–100% of rated speed	Digital
Cold Leg Temperature	2	446°F–626°F	Analog
Hot Leg Temperature	2	482°F–662°F	Analog
Pressure	1	1500–2500 psia	Analog
Ex-core Neutron Flux	3	0–200% Power	Analog
Deviation Penalty Factor	2	0–8.0	Digital
CEA Position	23	0–100% withdrawal	Analog

Table 2  
To-Be [CPCS Input parameters].

Signal	Input per CPC	Representative Range	Signal Type
Differential Pressure of SG	4	1500–2500 psia	Analog
Cold Leg Temperature	2	446°F–626°F	Analog
Hot Leg Temperature	2	482°F–662°F	Analog
Pressure	1	1500–2500 psia	Analog
Ex-core Neutron Flux	3	0–200% Power	Analog
Deviation Penalty Factor	2	0–8.0	Digital
Look Up Table CEA Position	–	0–100% withdrawal	Numeric

depicted in Table 2. Adjusting the input parameters is the most important work in simplification of the calculation algorithm.

### 2.3. Calculation timing constraints

The diagram of current CPCS program modules is illustrated in Fig. 2. The program modules are divided into the STATIC and UPDATE to meet 50 msec calculation timing requirement. In detail, when the STATIC transmits the calculated value to the UPDATE every 2 s, the UPDATE module satisfies the system performance requirement by transmitting the calculated value updated every 50 msec considering the core condition to TRIPSEQ. Therefore, based on the calculation timing of the current system, the newly developed system should satisfy the calculation timing within 50 msec (KHNP, 2012).

## 3. Basic concept of the new LPD calculation algorithm

### 3.1. Thermal power calculation

The calculation of the primary side thermal power is necessary for LPD calculation. The mass flow rate calculation is required to calculate the primary thermal power. The current CPCS uses the RCP speed pulse signal to calculate the reactor coolant mass flow rate. However, in this study, instead of the RCP speed pulse signal, the mass flow rate is calculated using the differential pressure between the inlet and the outlet of the primary side of the Steam Generator. The differential pressure meter of the SG is depicted in Fig. 3. With this method, it is not necessary to reprocess the RCP pulse signal, and the mass flow rate can be calculated by Eq. (1) by utilization of the differential pressure. The primary thermal power can be calculated using Eq. (2) by utilization of the calculated mass flow rate. By applying this method, the mass flow rate and primal thermal power calculations can be processed by

Download English Version:

<https://daneshyari.com/en/article/6759010>

Download Persian Version:

<https://daneshyari.com/article/6759010>

[Daneshyari.com](https://daneshyari.com)