SPV Analysis of CEDMCS in Advanced Power Reactors

Arigi M. Awwal [a], Efenji A. Emmanuel [a], Mohamed M. Faragalla [a], Lee, Yong-kwan [a*],
[a]*Nuclear Power Plant Engineering department, KEPCO International Nuclear Graduate School,1456-1 Shinam-ri, Ulsan, South Korea.*
[*]*Corresponding author: leeyk@kings.edu.kr*

1. Introduction

Nuclear power plants (NPPs) are regarded as one of the safest and most reliable systems yet you can still find some possibilities of failure. Single Point Vulnerability (SPV) is a component whose failure would directly cause an automatic or manual reactor scram or turbine trip [1]. Although some power plants do not consider the cause of any reduction in power as SPV, others consider components that cause a reduction in power of as low as 2% as SPV.

The Control Element Drive Mechanism Control System (CEDMCS) controls and regulates power supplied to drive the control rods with the Control Element Drive Mechanism (CEDM). A 4-coil CEDM is used in the newly built Advanced Power Reactor (APR) 1400 plant, while a new CEDMCS for 3-coil CEDM has been designed to be deployed to another APR1400 plant. This paper shows an approach to evaluate the SPVs that may be available in either of these two systems.

2. Methods and Results

In this section the approach will be shown including the description of the major attributes of both systems. The results will also be presented and discussed.

2.1 Description of Approach

The method employed in this study is summarized as shown in Figure 2. It includes three major stages. In stage 1, System A is thoroughly examined to understand all the workings of the system. This is accomplished using the digital rod control system (DRCS) descriptions, operating manuals, and the Standard Safety Assessment Report (SSAR) of the APR1400. System B is also thoroughly examined in this stage.

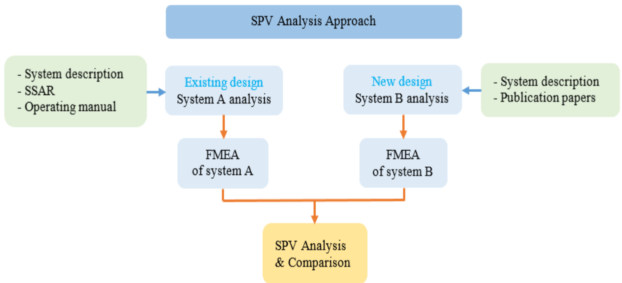

Fig. 2. SPV analysis approach description.

In Stage 2 of the process a Failure Mode Effect and Analyses (FMEA) was developed for both systems A and B. This is based on the understanding of the unique designs of both systems.

In stage 3, a qualitative SPV analysis of both systems was prepared while considering previous FMEA evaluations of the systems.

2.2 System Descriptions (Stage 1)

The CEDMCS/DRCS controls the holding and motive power meant for the CEDM. The DRCS uses either an automatic Control Element Assembly (CEA) motion demand signal from the Reactor Regulatory System (RRS) or manual motion signals from the DRCS soft control. It converts these signals to direct current (DC) pulses that are transmitted to CEDM coils to cause CEA motion. A reactor trip signal removes the motive power from the DRCS which in turn makes the CEAs to be dropped by gravity.

2.2.1. System A Design.

This is the existing Control Rod Control System. The major parts of System A are the Power Cabinets (PC), Logic Cabinet (LC), and Remote I/O cabinets.

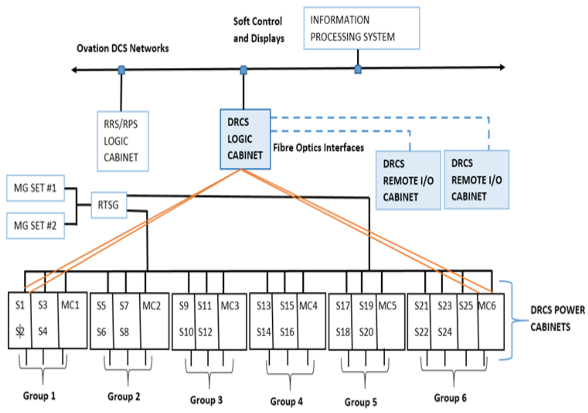

Fig. 4. DRCS configuration of (existing) system A [2].

The control cabinet consists of input modules, power supplies, communication devices and others. It generates the CEDM coil commands to step the rods during startup, shutdown, and power manoeuvring operations. It also coordinates all operations within the DRCS including communication with the Nuclear Application System (NAPS) of Information Processing System (IPS) and providing alarm outputs for detectable failures in some DRCS parts.

The power cabinet consists of 13 selecting cabinets and 6 moving cabinets. The selecting cabinets delivers power to the Upper Gripper (UG) and Lower Gripper (LG) coils while the moving cabinets delivers power to the Upper Lift (UL) and Lower lift (LL) coils (see Fig. 5). The major components of the power cabinet are; power conversion circuit, multiplexing, power regulator, alternative DC hold power, and DC power supplies.

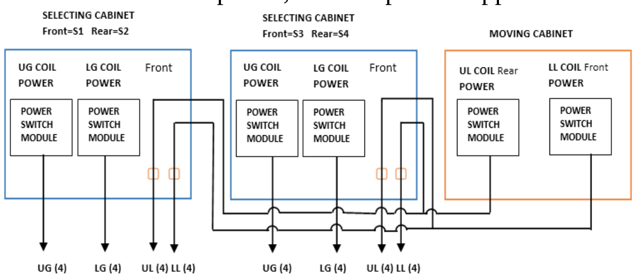

Fig. 5. System A power cabinet configuration [2].

2.2.2. System B Design.

The new digital CRCS consists of two major parts; Control cabinet and Power cabinet. There is only one control cabinet, and a minimum of 3 power cabinets. The number of power cabinets in the APR1400 plant would be eight. The assumption is that at least 93 CEAs are needed in the APR1400 design with 3 CEA groups per Power cabinet (12 CEAs).

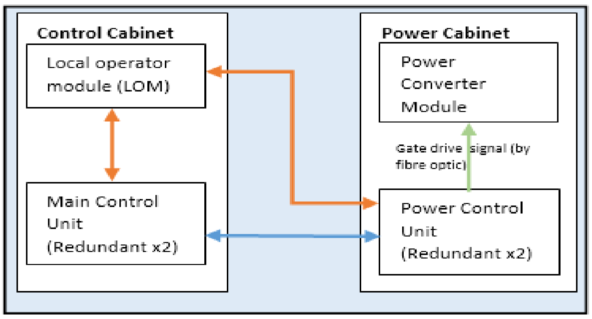

Fig. 6. DRCS configuration of (new) system B [3].

The control cabinet receives command signals form the RRS, MCR or other interfacing systems and sends the signals to the appropriate power cabinet. The Main control unit (MCU) and the Local operator Module (LOM) are the major parts of the Control cabinet. The MCU functions to develop the signals received from external interface systems like the RRS, PPS, Reactor operator or etcetera. The power cabinet has the major parts as; the power control unit (PCU) and the power converter module (PCM). The Power cabinet has 3 sets of hardware to control each CEDM group except for the PCM Lift Coil (LC) which is only one per cabinet as shown in Fig. 7.

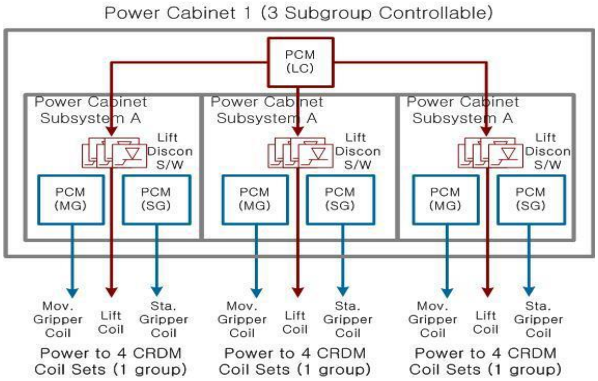

Fig. 7. System B power cabinet configuration [3].

2.3 FMEA (Stage 2)

For failure mode and effect analysis, the system or component function description; system or component logic and power circuit drawings; SSAR and Technical specifications; Industry experience on equipment-related scrams; and Vendor recommendations are utilized. A summary of the FMEA result for both systems are shown in the tables I and II.

2.4 SPV Analysis (Stage 3)

A qualitative SPV analysis is done at this stage based on the results of stage 2 while paying particular attention to components without redundancy and their operational functions. Results are shown on tables III and IV.

The PCM (Power Conversion Module) is a prospective SPV part of the CEDMCS in system B, as they have no redundancy. All its major sections including the Lift Coils Module, Stationary Gripper Coil Module, Movable Gripper Coil Modules, and the Lift Disconnect Switches may individually cause reactor scrams. When the Lift Coil PCM fails to operate, three CEDM groups will be non-functional, and thus cause the LO-DNBR or HI-LPD setpoints to be exceeded. This will make the Reactor Protection System Trigger an automatic reactor trip.

Table I: FMEA for system A

Component Name	**Failure Mode**	**Failure Effect**
PC- PCC-	Spurious actuation	SG or MG latches of one group close. Control rods drop
PC - Digital Out	Malfunction	Causes turbine trip signal which stops the generator

Component Name	Failure Mode	Failure Effect
PC- Current Regulation Card	Fail to operate	No drive signals generated for PCC. Reactor trips due to RPS signal (LO-DNBR/HI-LPD)
PC - Digital Signal buffer Card	Malfunction	No drive signals generated for PCC. Reactor trips due to RPS signal.
PC - Gate firing driver Card	Malfunction	Reactor trips due to control rods drop.
PC -Multiplexing Error Detector	Fail to operate	Related CEA groups are inoperable
PC - Backplane Card	Malfunction	No control signal transmission to PCC. Reactor trips due to control rod drop.
PC - Power supply Card	Fail to operate	Reactor shutdown due to RPS signal
PC - Power Regulator	Malfunction	Reactor shutdown due to RPS signal
PC - Phase control	Malfunction	Coils are energized out of sequence. Reactor trips due to control rods drop.
PC -Fuse	Fuse cut	Causes Reactor shutdown due to RPS signal
PC -Circuit Breaker	Breaker open	Causes Reactor shutdown due to RPS signal
LC -communication card	Failure to transmit or receive data	No manual control of CEAs. The RPS initiates reactor trip
LC -sequence logic of bank and group	Malfunction	Causes Reactor shutdown due to RPS signal
LC -sequence order generator	Malfunction	Causes Reactor shutdown due to RPS signal
LC -data store& diagnostic	Malfunction	No drive signals failure detection.
LC - I/O manager	Malfunction	No drive signals. Rector shutdown due to RPS signal
Master Cycler	Malfunction	Related CEA groups are inoperable
Slave Cycler	Malfunction	Related CEA groups are inoperable

Table II: FMEA for system B

Component Name	Failure Mode	Failure Effect
PCM-MGC	Spurious actuation	MG latches of one group close. Control rods drop
	Fail to operate	MG latches of one group are inoperable
PCM-SGC	Spurious actuation	SG latches of one group close. Control rods drop.
	Fail to operate	SG latches of one group are inoperable
PCM-LD switch	Fail to ON/OFF	Related group or individual rods are inoperable. Eventual RPS signal is initiated.
PCM-Lift Coil circuit	Spurious actuation	Improper voltage to CEDM coils. Related CEA groups are inoperable
	Fail to operate	Related CEA groups are inoperable
Power Control Unit (PCU)	Fail to operate	No drive signals generated for PCM. Reactor trips due to control rods drop.
Backplane board	Malfunction	No control signal transmission to PCM. Reactor trips due to control rod drop.
LOM communication card	Malfunction	No manual control of CEAs. The RPS initiates reactor trip
MCU-speed pulser	Malfunction	The RPS initiates reactor trip
MCU-sequence logic of bank and group	Malfunction	The RPS initiates reactor trip
MCU- sequence order generator	Malfunction	The RPS initiates reactor trip
MCU-data and diagnostic.	Malfunction	The RPS initiates reactor trip

Component Name	**Failure Mode**	**Failure Effect**
MCU- I/O manager	Malfunction	No sequence logic signals generated. The reactor condition remains same. Eventual Reactor trip

Table III: SPV components for system A

Device Name	**No.**	**Failure Mode**	**Failure Effect**
Digital Out (Under-Voltage Relay)	26	Malfunction	Causes turbine trip signal which stops the generator
Current Regulation Control card	13	Malfunction	No drive signals generated for PCC. Reactor trips due to control rods drop.
DRCS Digital Signal buffer Card	13	Malfunction	Reactor shutdown due to RPS signal
Gate firing driver Card	13	Malfunction	Reactor trips due to control rods drop
Backplane Card	13	Malfunction	Reactor shutdown due to RPS signal
Power supply Card	13	Fails to operate	Reactor shutdown due to RPS signal
Power Cabinet Fuse	13	Fuse cut	Reactor shutdown due to RPS signal
Power Cabinet Circuit Breaker	13	Breaker open	Reactor shutdown due to RPS signal

Table IV: SPV components for system B

Device Name	**No.**	**Failure Mode**	**Failure Effect**
PCM-MGC	24	Spurious actuation Fail to operate	MG latches of one group close/ inoperable. Control rods drop.
PCM-SGC	24	Spurious actuation Fail to operate	SG latches of one group close/inoperable. Control rods drop.
PCM-LD switch	24	Fail to ON/OFF	Related group or individual rods are inoperable. RPS signal initiated.
PCM-Lift Coil circuit	8	Spurious actuation Fail to operate	Improper voltage to CEDM coils. Related CEA groups are inoperable.

3. Conclusions

System A design has employed a fail-safe concept to its design with less redundancies while System B design provides redundancy and design change although this comes at a high price for the Utility. The System B design has improved reliability but not necessarily eliminating the SPV items. Naturally, the cost of a new redundant system will be more. However, future work will examine the economic effect of the new system considering the operating experiences of power plants on the CEDMCS (i.e. SCRAM rates and power outage cost).

Further work on this subject will also attempt to produce a ranking of the SPVs in terms of their Risk level. This will help utilities in determining the kind of maintenance strategy that should be applied to individual SPVs.

REFERENCES

[1] Single Point Vulnerability (SPV) Process Guide. EPRI, Palo Alto, CA: 2015.3002005419.
[2] NPP Systems Textbook – Control and Protection Systems, Rev.2, KHNP-HRDI, BNP-FU-COM-SYS-TB-DRCS.
[3] C. H. Nam *et-al*, Design and Implementation of Advanced Digital CRCS for Pressurised Water Reactors, (European Nuclear Conference) ENC 11-14 Dec, 2005.