A Study on CEDMCS Stabilization in Hanbit Nuclear Power Plant Units 3 and 4

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1. Introduction

In a nuclear power plant (NPP), the control element drive mechanism control system (CEDMCS) provides the control signal and drives electric power to move the control element drive mechanism (CEDM) which withdraws or inserts the control element assemblies (CEAs) in the core. Hanbit NPP units 3 and 4 CEDMCS were operated by regular maintenance and facility improvement since 1995, but its lack of preparation for a single failure caused a number of shutdown in NPP. As a result, the CEDMCS was improved totally with redundant digital control systems in 2012. However, after the total improvement, the CEDMCS during the operation has experienced the symptoms of under-voltage relay (UVR) burnout and failure of the MG-Set synchronization due to the inflow of harmonic derived from the rectifier circuit and the repetitive failure of the power supply.

Therefore, in this study, we analyzed the failure cases. Based on them, we identified the root causes and derived the improvement measures. Finally, we applied the results of the improvement to the NPP.

2. Methods and Results

In this section, the cause of harmonic voltage generation in the CEDMCS of the Hanbit NPP units 3 and 4 is described and the improvements are presented.

2.1 CEDMCS harmonic voltage generation mechanism

The CEDMCS of Hanbit NPP units 3 and 4 was replaced by a digital based redundant control system for enhancing the reliability of the CEDMCS. However, after the improvement, UVR burnout and the failure of MG-Set synchronization occurred due to the inflow of harmonic generated in the newly replaced CEDMCS rectifier circuit. As a cause of harmonic generation, it was assumed that the capacitor of a snubber newly installed in parallel in order to protect SCR causes peak voltage rise by repeating charge/discharge according to change of coil voltage generated in SCR operation.

As shown in Fig. 1, the harmonic voltage generation mechanism generates a harmonic current of 6N±1 in the SCR operation of the CEDMCS power conversion module (PCM) and is charged to the capacitor of the snubber. The harmonic current charged in the capacitor flows divided into a low impedance power system (MG-set), harmonic voltage is generated by the inflow harmonic current and the MG-set generator system impedance, and this harmonic voltage and the fundamental wave voltage induced at the generator terminal are combined to distort the output voltage.

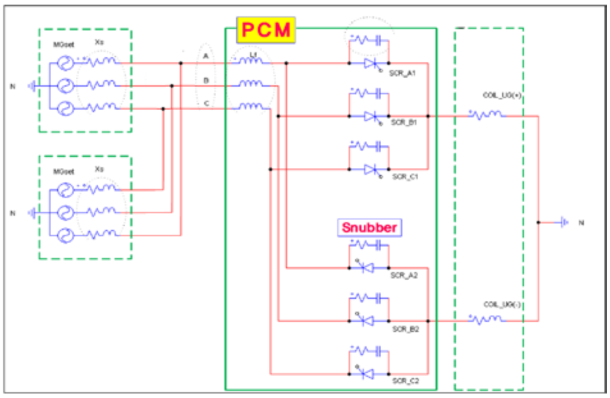

Fig. 1. MG-set and CEDMCS power circuit

2.2 CEDMCS harmonic reduction measures

The harmonic was measured in the MG-Set of Hanbit NPP unit 3. As shown in the measurement result of Table 1, the total harmonic distortion (THD) was 33.8%, the distortion was severe, and the maximum instantaneous voltage was 283V. Thus, it was confirmed that MG-Set synchronization could not be possible and CEDMCS UVR could be damaged.

Table 1. THD and Vpeak in Hanbit #3

Division	THD(%)		Vpeak
	Sing driving	Parallel driving	
Hanbit #3	33.8	23.9	283.0

*UVR specification (rated voltage): 264.46V

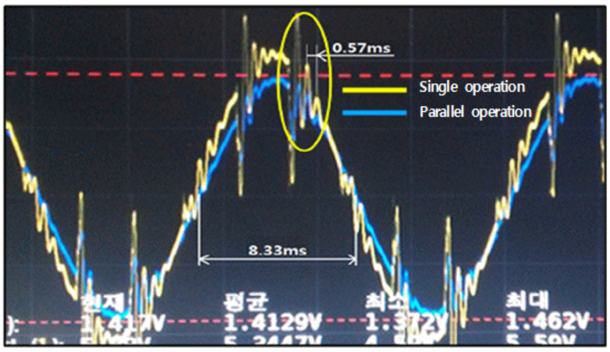

Fig. 2. Parallel and single operation waveforms

The CEDMCS snubber circuit is designed for SCR protection. Therefore, the removal of the capacitor is not possible because it can not protect SCR against dv/dt and also induce new potential risk to a peripheral circuit. Therefore, it is considered that the method of installing the R-C filter in parallel so that the high frequency components can be removed by the resistor is the most appropriate.

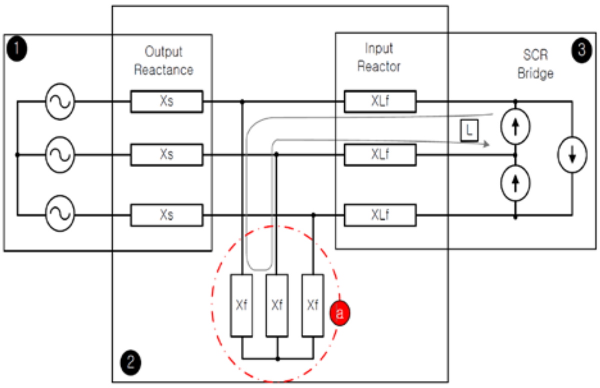

Fig. 3. Power circuit and filter

The filter is indicated as ⓐ of Fig. 3. ① is the MG-Set, ③ is the power circuit inside the power cabinet, ② is the filter area, and harmonic generated in SCR operation is removed through ⓐ. In particular, ⓐ is the structure of a filter that includes a resistor because the spike voltage must be dissipated as joule heat.

2.3 Design verification through simulation implementation

In this simulation, two MG-sets, a full load, a snubber circuit and 4 R-C filters were implemented to design the same situation as the CEDMCS. The inductance of MG-sets in the simulation was applied to 0.112mH considering the 1.75 ㎑(0.57ms) harmonic frequency of the field acquisition data. The line voltage was 240V and the capacitor value of the snubber was simulated as CEDMCS design value of 0.24 ㎌. In the filter design, the capacitors of 12 ㎌ and the resistances of 10Ω were applied considering the power consumption of the resistor and the filter current.

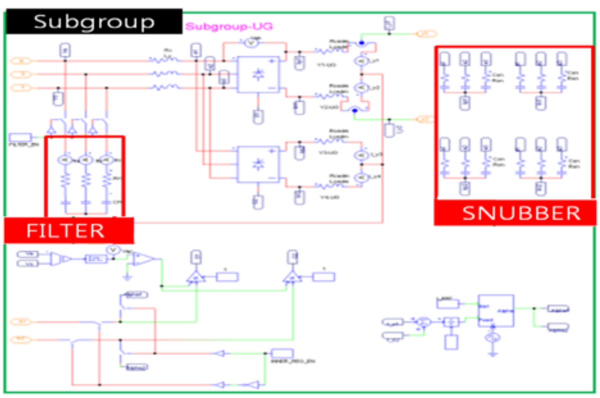

Fig. 4. Modeling with R-C filters and snubbers

The result of simulation tests is shown in Table 2. The THD was improved from 41.3% to 22.9% by installing the proposed R-C filter. The phase voltage Vpeak value was also improved from 295.3V to 215.3V. Therefore, it was evaluated as a solution to fundamentally solve the failure of MG-set synchronization and UVR burnout which are potential risks

Table 2. Simulation results with varying R-C filter

	상 전압 THD [%]		선간 전압 THD [%]		상 전압 0-p [V]		선간 전압 0-p [V]		상 전압 r.m.s [V]		선간 전압 r.m.s [V]		상 전류 [A]		역률 [%]		필터전류 r.m.s [A]		필터저항 소비전력 [W]	
MG-Set	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
No Filter	41.3	23.5	41.3	23.5	295.3	276.7	572.4	507.8	135.7	136.0	235.0	235.6	165.7	81.9	28.8	28.6	-	-	-	-
4 Filters	22.9	14.7	22.9	14.7	215.3	226.2	394.4	408.8	128.8	133.9	223.0	232.0	156.1	77.6	33.4	31.5	3.19	2.63	101.8	69.2

2.4 R-C filters installation and improvement results in CEDMCS

After installing 4 R-C filters in the CEDMCS of Hanbit unit 3, MG-set output waveforms were re-measured to verify the improvement of THD and Vpeak values. The result was improved like Table 3. Also, it is confirmed that MG-set synchronization is possible.

Table 3. THD and Vpeak with 4 filters installed

No.	Test Requirements	Vpeak	THD(%)
1	MG-Set #1	220	28.1
2	MG-Set #2	219	27.6
3	MG-Set #1 and MG-Set #2	217	17

2.5 Problem of the CEDMCS power supply failure

The CEDMCS has experienced a number of secondary power supply failures (11 times) that affect safe operation of the Hanbit NPP units 3 and 4. The power supplies of the CEDMCS are redundant and maintained under a hot & standby mode. So, the secondary power supplies are in no load condition during normal operation.

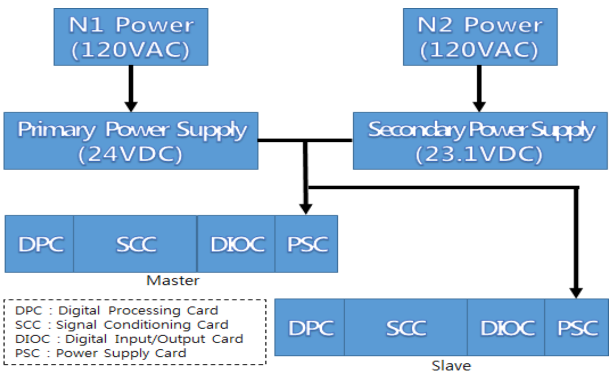

Fig. 5. Power circuit and filter

2.6 Power supply check and analysis

After the disassembly of the power supply, visual inspection was conducted to check for breakage, deterioration, and leakage.

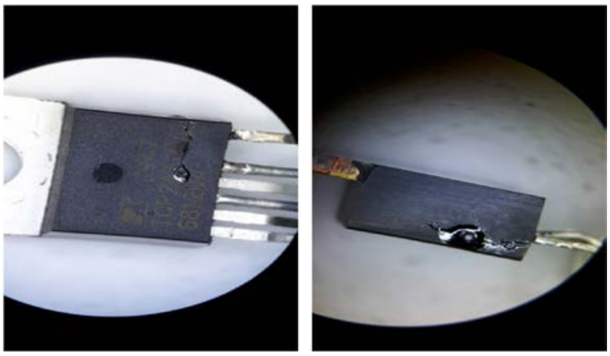

Fig. 6. The crack TOP244YN(Auxiliary power switching element)

Table 4 shows the result of checking the circuit element connected to the crack element found in the visual inspection.

Table 4. Circuit analysis result

Division	Uses and Functions	Check electrical characteristics	Check results
TOP244YN	Switching controller for auxiliary power generation	Open mode failure	Loss of auxiliary power
Transformer	Circuit element for auxiliary power generation	Impedance loss	Loss of auxiliary power
TC1413NEOA713	Main power output PFC controller	Loss of function	PFC circuit failure

※ check the normal operation after replacement of fault elements

The block diagram of the power supply circuit and the circuit diagram for the main fault section are shown in Fig. 7.

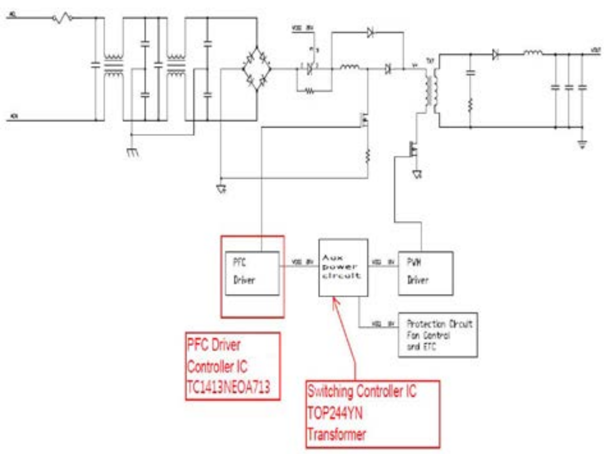

Fig. 7. Block diagram of power supply

The auxiliary power circuit diagram is shown in Fig. 8. The parts marked with a red box in Fig. 8 are elements that cause failures or are circuit blocks containing the elements.

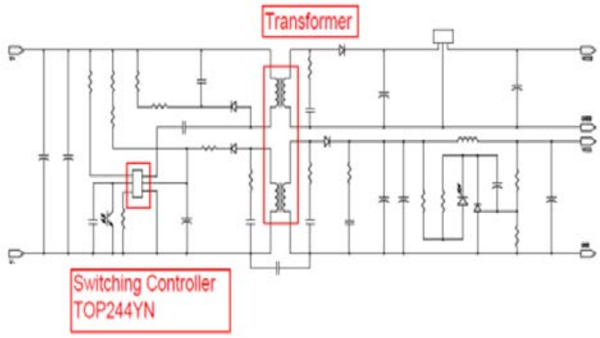

Fig. 8. Aux power circuit diagram

2.7 Switching controller function check

Fig. 9 shows the result of checking auxiliary power switching controller (TOP244YN).

☐ Failure condition: Output signal is not measured.

☐ No-load condition (normal): The output waveform of the element measures noise in the switch section.

☐ Load condition (normal): Clean waveform with noise removed in the switch section

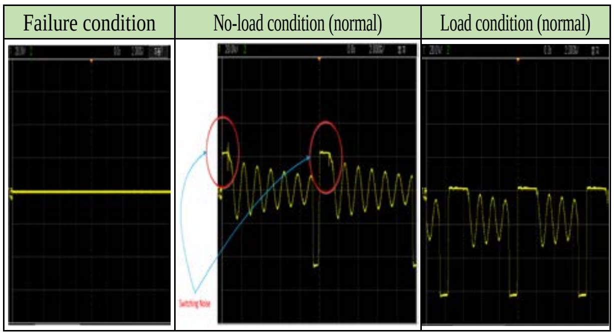

Fig. 9. Waveform of TOP244 YN

2.8. Aux power switching controller malfunction mechanism

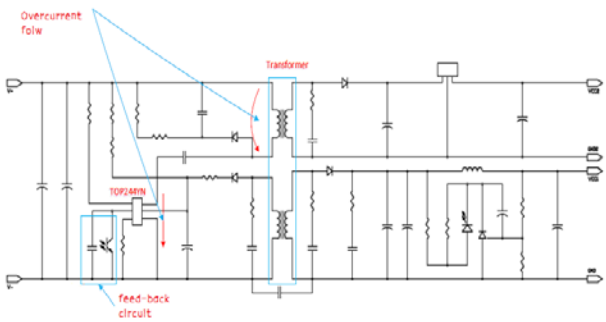

Fig. 10. Aux power circuit description

① Abnormal feedback signal input to TOP244YN element due to noise or signal distortion

② TOP244YN switch element malfunctions in short mode due to abnormal feedback signal

③ Transformer connected to TOP244YN element deteriorates

④ Due to the reduced impedance of transformer, overcurrent flows to TOP244YN switch and breakage

2.9 PFC controller function check

Fig. 11 shows the result of checking main power PFC controller (TC1413NEOA713).

☐ Failure condition: Output signal is not measured

☐ No-load condition (normal): The waveform is measured like a periodic chattering phenomenon without continuous operation of the FET.

☐ Load condition (normal): The waveform is measured with a period of operation of the FET.

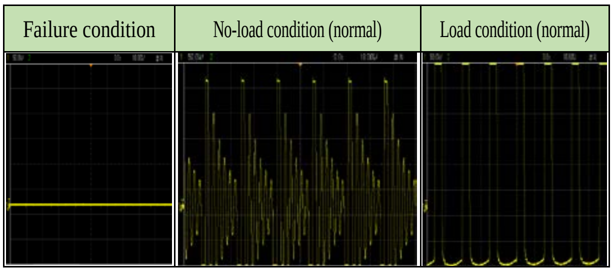

Fig. 11. Waveform of TC1413NEOA713

2.10 PFC controller malfunction mechanism

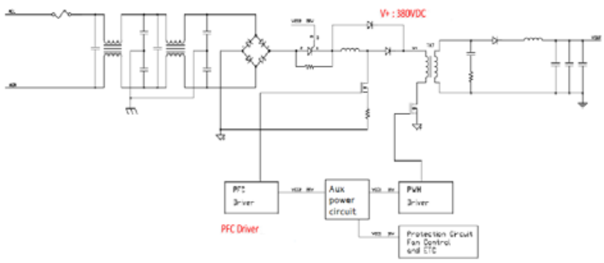

Fig. 12. PFC controller circuit description

① Operating voltage rise of the PFC controller (TC1413NEOA173) during the TOP244YN element fails

② Failure due to voltage exceeding rated voltage to the element of TC1413NEOA173

2.11. Comprehensive analysis

Table 5 is the analysis result of 6 out of 11 power supplies failure.

Table 5. The result of power supplies

No	Serial No	Failed element	Visual inspection result	Check electrical characteristics	Check results
1	K10470102	TOP244YN Transformer TC1413NEOA713	Damage Coil internal deterioration No specific	Open mode fail Impedance 0.6uH Loss of function	Loss of auxiliary power, PFC
2	K10470101	TOP244YN Transformer TC1413NEOA713	Damage Coil internal deterioration No specific	Open mode fail Impedance 0.2uH Loss of function	Loss of auxiliary power, PFC
3	K10470002	TOP244YN Transformer TC1413NEOA713	Damage Coil internal deterioration No specific	Open mode fail Impedance 0.2uH Loss of function	Loss of auxiliary power, PFC
4	K10470019	TOP244YN Transformer TC1413NEOA713	Damage Coil internal deterioration No specific	Open mode fail Impedance 0.5uH Loss of function	Loss of auxiliary power, PFC
5	K10470036	TOP244YN Transformer TC1413NEOA713	Damage Coil internal deterioration No specific	Open mode fail Impedance 0.4uH Loss of function	Loss of auxiliary power, PFC
6	K10470049	TOP244YN Transformer TC1413NEOA713	Damage No specific No specific	Open mode fail Impedance 70uH Loss of function	Loss of auxiliary power, PFC

An unstable signal is applied to the switching element feedback circuit due to noise or signal distortion in a no-load power supply, which causes deterioration of the transformer, which causes the switching element to be burned out and the auxiliary power circuit function to be lost. Therefore, it is considered that the operation of the load condition is relatively better than the no-load condition in the power supply, so it is necessary to change the redundant power supply mode to a current sharing type in which the load is divided in a hot & standby mode and applied to the CEDMCS in NPP units 3 and 4.

3. Conclusions

This study was conducted to solve the harmonic generation and the power supply failure in CEDMCS. A lot of troubles like these problems in NPPs have been issued after commercial operation. But, since most troubles are solved simply without root cause analysis, similar problems occur repeatedly. This study was proposed to solve the problem through root cause analysis. It has improved the system performance and reliability for the CEDMCS. Accordingly, it will enhance NPP safety and reliability.

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