Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

A Case Study of Harmonic Impact on a Motor-Generator Set System

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1. Introduction

Motor-Generator Sets are usually used to supply power to a Control Element Drive Mechanism Control System (CEDMCS) at nuclear power plants with pressurized water reactors. Two Motor-Generator Sets, which have 100% capacity, are operated in parallel to improve the reliability of the power supply to the CEDMCS. Fig. 1 presents a diagram of a Motor-Generator Set system. The system of a Motor-Generator Set is composed of electrical equipment, such as a motor, a fly-wheel, and a generator, an exciter and protection-control device, such as a protective relay, synchro check relay, and an auto voltage regulator. The electrical equipment and protection-control devices of the Motor-Generator Set can be influenced by the harmonics from CEDMCS's converting power (AC to DC) [1]. In general, the harmonic impact of electrical equipment increases the deterioration of the equipment, the motor, and the generator's lifetime, which can also be caused by vibration and over-heating and mal-operation of the protection-control device [2][3].

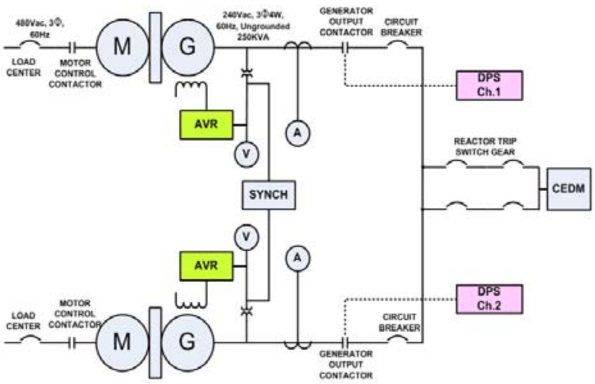

Fig. 1. The M-G set System Diagram

In this paper, we analyzed the non-operation of the synchro check relay and the fault of the under-voltage protective relay on the Motor-Generator Set system caused by increasing the notch and transient voltage from rectifying the load after replacing the CEDMCS.

2. Methods and Results

2.1 Non-operation of synchro check relay because of increasing voltage difference

We performed synchronized closing for parallel operation after maintaining the Motor-Generator Set, but parallel operation was delayed because the synchro check relay did not operate properly. Fig. 2 gives the results of the voltage waveform (L) and the harmonic analysis (R). The upper part of Fig. 2 shows the voltage waveform of unit 1 of the Motor-Generator Set's generator output in no-load conditions, and the lower part is the voltage waveform of the bus connected to unit 2's Motor-Generator Set with load operation conditions. As Fig. 2 shows, the voltage waveform of unit 1 with no-load operation is a perfect sin waveform and fundamental (60Hz) wave. However, the voltage waveform of bus connected unit 2, which supplies power to the CEDMCS, is distorted by harmonics, such as Ringing, Notch and Overshooting, and an included 6N±1 degree harmonic component. A voltage difference appeared between the output voltage of unit 1's generator and the distorted bus voltage even though it matched the angle of both voltages. The level of this voltage difference exceeded the level of synchronized permissive voltage "24V" and was the reason the synchro check relay did not operate. (The voltage difference was 0V between fundamental (60Hz) waves.)

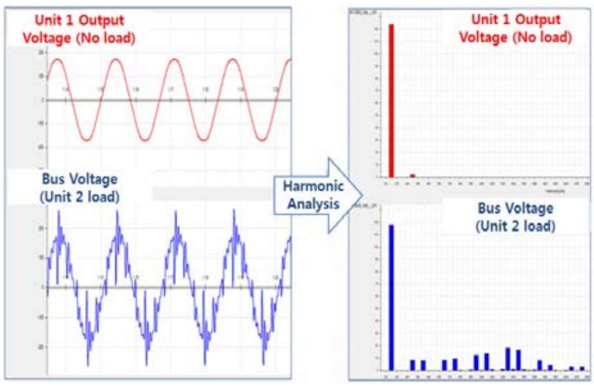

Fig.2. The voltage waveform(L) and harmonic Analysis(R)

We performed a playback waveform test to confirm the voltage amplitude of recognizing through synchro check relay. The playback waveform test was the injecting wave (component, amplitude), which was the same as the voltage waveform achieved at the field of the synchro check relay. The test method was the injecting fundamental and harmonic voltage waveform, which was the same angle and duration (2 cycles) as the synchro check relay's voltage input channels for GEN and BUS as shown in Fig. 3 and Table I. We then controlled the level of synchronized permissive voltage during the injection and the edited waveform until the synchro check relay operated.

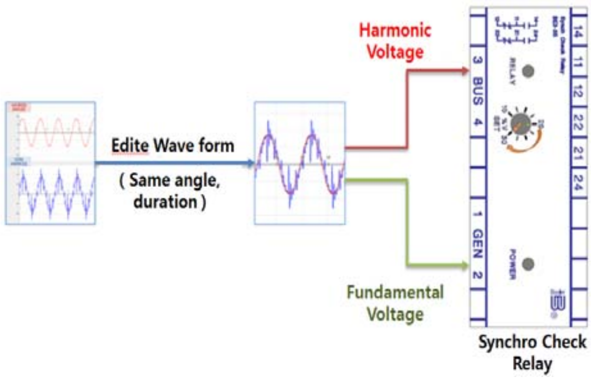

Fig.3.The Diagram of Playback Test

Table I: Test Procedure

Editing achieved waveform ; same angle and duration
⇩
Injecting voltage to BUS channel: harmonic 120V∠0°
⇩
Injecting voltage to GEN channel: fundamental 120V∠0°
⇩
Adjust synchro check relay's setting : 0% to maximum
⇩
Check the setting value at operating the relay

The table of the test results shows that the voltage difference of recognizing the synchro check relay was 27.6V more than the synchronized permissive voltage of 24V. However, it injected the same angle and amplitude voltages. This is why the synchro check relay did not operate. We also determined that the voltage difference level depended on how distorted the voltage waveform was.

Table II: Test Results

Test Condition	Value of operation	setting
BUS : harmonic 120V∠0° GEN : fundamental 120V∠0°	23% over (27.6V)	20% (24V)

2.2 The fault of under voltage protective relay

After replacing the CEDMCS, the under voltage protective relay was faulted during the test operation with one Motor-Generator Set. Fig. 4 gives the voltage waveform of the Motor-Generator Set's output at the moment the protective relay faulted. As Fig. 4 reveals, the notch from the momentary short circuit phase to the transition of switching SCR and voltage recovery was repeated. Overshooting voltage was periodically generated when the system voltage recovery from voltage dropped by a notch. The level of overshooting voltage was 283V peaks, which exceeded the limit input level 264V peak of under voltage protective relay. As high overshooting voltage was repeatedly applied to the under voltage protective relay, the relay was faulted.

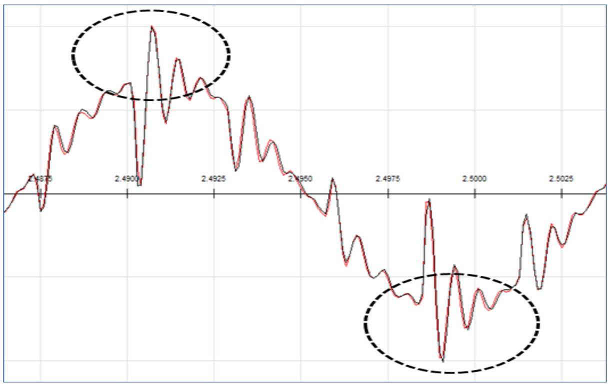

Fig.4. The Voltage waveform inputted under voltage relay

The main reason for both the non-operation of synchro check relay and the fault of under voltage protective relay was the increase of the maximum instantaneous voltage as the harmonic current flows increased into the Motor-Generator Set system. An RC filter was installed at the input circuit of the CEDMCS to minimize the harmonic impact. Fig. 5 shows the effect of the RC filter. The black line is the RC filter uninstalled, the blue line is the 4RC filter installed, and the red line is 8RC filters installed. The Notch's depth and area decreased, and the maximum instantaneous voltage was also generated below the 217V peak as the RC filter installation increased. The effect of the RC filter can be a solution to solve the problems of non-operation of the synchro check relay and the fault of the under voltage protective relay in the Motor-Generator Set system.

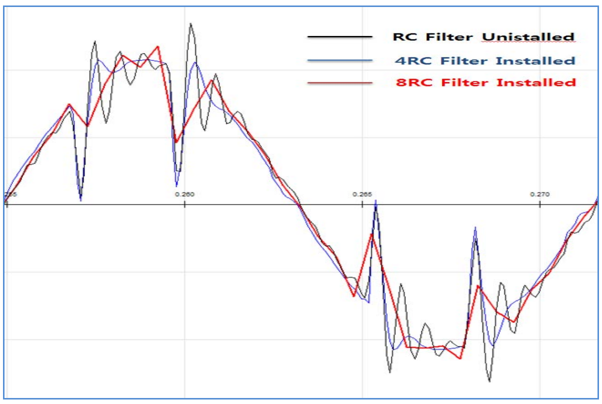

Fig.5. The voltage waveform with RC Filter

3. Conclusions

In this paper, we came to understand the harmonic impact on the Motor-Generator Set system through a study of delaying parallel operation by non-operation of the synchro check relay and the fault of under voltage protective relay. Thus, KHNP has established and applied the measures of harmonic reduction by the CEDMCS, such as limiting the voltage harmonic distortion to less than 10%, which is described in IEEE Std 519.

REFERENCES

1. EPRI Technical Report "Impact of Nonlinear Loads on Motor Generator Set (2001.11)"
2. IEEE Std 519-1992 "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems
3. IEEE Paper (1991) “Effect of Waveform Distortion on Protective Relays