A Study on Using Large-Scale Energy Storage Systems in Automatic Generation Control Operations of the Energy Management Systems

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Abstract

KEPCO has completed the installation and demonstration of a 52 MW battery energy storage system (BESS) for frequency regulation. Especially, 24 MW BESS is for Automatic Generation Control (AGC) in Shin-Yongin substation. Recently, KEPCO Research Institute has operated it connected to EMS of KPX. This paper discussed the operation strategy of EMS through a study on using 24 MW BESS in AGC operation and propose the improvement of AGC target. It is expected that this paper helps a safe and reliable operation and control of ESS for AGC through its continuous update.

Keywords: Battery Energy Storage System, frequency regulation, automatic generation control,

I. INTRODUCTION

As an energy storage technology is developed, an application of the energy storage system (ESS) has been regarded as a core technology in power systems. Especially, battery energy storage system (BESS) using a large-scale battery is under the demonstrating stage over the developing stage. Among the many applications of BESS, one of the important functions is the frequency regulation service (FR) [1]. The technical and economic benefits of using energy storage for FR are already being proven in the US, particularly in the PJM Interconnection in the United States, where regulatory policies and markets for energy storage are already in place [2]-[4]. In Korea, BESS has been determined to provide better frequency regulation services to the power grid. KEPCO has demonstrated for commercial operation using 52 MW FR-ESS and has been installing additional 200 MW FR-ESS [5].

Maintaining the frequency of a power system within an acceptable range and responding to sudden frequency drops are traditionally done by deploying thermal power plants to correct frequency deviations. In Korea, frequency regulation is performed by “governor-free” (GF) control, wherein turbine governors are to respond within 10 seconds and provide power for 30 seconds; and through automatic generation control (AGC), wherein a power plant must respond within 30 seconds and provide power for 30 minutes. These methods, however, are inefficient in that they require power plants to operate below their rated capacity to remain on standby until they are needed [6].

The GF algorithm for BESS has been developed and modified in many times. And GF algorithm of BESS proves its excellence in power systems. But, the AGC operation for BESS has not been considered yet [5][7][8].

In this paper presents the development and trial run results of the AGC operation for BESS with energy management system (EMS) reference of Korea Power Exchange (KPX). AGC operation performance with BESS is better than that of conventional power plants in terms of fast response. But AGC operation with BESS has the concern about duration time for AGC operation. So, this paper shows the trial results of the AGC operation with variable conditions and analyzes the results in terms of SOC with AGC reference of KPX.

The rest of the paper is organized as follows. Section 2 explains the system configuration of BESS controller which is operating now for FR services. Section 3 accounts for the results of AGC operation. In Section 4, we evaluate the results of the test and propose some improvement points of AGC target generation. Finally, we present the conclusions in Section 5.

II. SYSTEM CONFIGURATION OF BESS CONTROLLER FOR FREQUENCY REGULATION SERVICES

Following the successful demonstrations of performed at the 4 MW/8 MWh lithium-ion BESS facility of the Jocheon substation located in Jeju island, 52 MW lithium-ion BESS facility for only frequency regulation service has been installed in February 2015. Table 1 is the facility description of the installed BESS in Seo-Anseong and Shin-Yoinin. The 28 MW Seo-Anseong FR-ESS facility performs governor response operations to regulate the system frequency. The 24 MW Shin-Yongin FR-ESS facility performs AGC operations by providing power depending on the AGC control signal it receives. Both facilities perform frequency regulation services under normal conditions to maintain the system frequency at 60 Hz.

The FR-ESS facilities are each connected to a 22.9 kV bus at each substation as shown in Fig. 1. The 22.9 kV bus is connected to the 440 V PCS via a step-down transformer. The PCS is also connected to the battery system (battery management system and lithium ion batteries) both electrically and via a communication line. Fig. 2 shows the block diagram of the installed 52 MW BESS controller for frequency regulation services. The PCS communicates also with the frequency regulation controller (FRC), which determines the output of the battery system needed to maintain the required frequency level of 60 Hz. The FRC can be set to “manual mode” or “auto mode” via

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the human-machine interface (HMI), which also displays critical information such as the system frequency, individual battery state-of-charge (SOC) and temperature. Fig. 3 shows the block diagram for AGC operation tests connected with the EMS of KPX. When the AGC reference reaches FRCM, FRCM devides the power references refer to state of charge (SOC) of each FRC. So, FRCM has to know the SOC information of every FRCs.

### III. AUTOMATIC GENERATION CONTROL

#### A. AGC operation of conventional power plants

In conventional power plants, the turbine operates with not only AGC reference but also speed reference. The system has the inevitable delay due to the turbine inertia, friction, throttle valves, and so on. Fig. 4 shows the frequency control of conventional power plants with AGC reference. The time point ‘A’ is when the frequency is changed and the point ‘B’ is when the output of power plants is changed by control. As previously mentioned, the output of the power plants do not correspond with the AGC reference exactly. In the waveform, there is an output error about 5 MW with the power ripple and the time delay of the output from AGC reference more than 100 seconds.

It is hard to understand the accurate delay time to FR operation with only output waveform, because there are too many control variables. There, however, is one thing for sure, which is a delay time to follow AGC reference for conventional power plants.

#### B. Control performance of BESS for AGC operation

For comparison with the conventional power plants about the control performance; the time response, the step function response of BESS is demonstrated. Fig. 5 shows the results of a step response from a FRCM reference change. It takes about 130 ms from the FRCM target generation to power output of BESS. BESS can be a very fast facility enough to operate AGC operation that BESS is able to provide power to grid within 30 seconds from AGC standards.
C. AGC operation of BESS

Fig. 6 shows the results of BESS for 7 hours AGC operation. BESS repeats the AGC following operation and the state of charge (SOC) recovery operation. In the AGC operation period, the sum of power output of each FRC is same to AGC reference. If the SOC of FRC decreases under 50%, FRC implements the SOC recovery operation. So, there are 3 cycles which are composed of 3 AGC operation period and 3 SOC recovery period. Under the SOC recovery operation, FRC charges own batteries at the rate of 0.1 [pu] until reaches 63% SOC. This condition is specified in Table 2.

In cycle 1 sector, it is not satisfied that BESS has to provide during 30 minutes for AGC operation; only 23 minutes. But, In cycle 2 sector and cycle 3 sector, it meets output duration for AGC operation. Meanwhile, the SOC recovery period of each cycle is constant, 73 minutes.

IV. THE ANALYSIS OF AGC OPERATION WITH BESS

From the long term operation, more than hours, there are AGC operation period and SOC recovery operation period. Fig. 9 reports the analysis of experimental result of Table 4 conditions. In the view of an error of AGC target and power output of FRC,
the rate between charging target and discharging target is similar. The mandatory duration. The SOC has only small change, because BESS is low (50%), AGC operation time is enough to keeping Honam thermal plant with its own EMS. Though the SOC of time under 30 minutes. Fig. 10 shows the BESS response data in contrast to the average frequency level. High discharging target from FRCM by 5 times. The average rate of discharge time is 80% enabling 30 minutes operation. Table 5 shows the measured data in points.

Table 5. Relation with the measured frequency and AGC target of EMS

| Division | Frequency | Test #1 | Test #2 | Test #3 | Test #4 | Test #5 | Average |
|----------|-----------|---------|---------|---------|---------|---------|---------|
| AGC Target | > 60 Hz | 69% | 61% | 62% | 62% | 66% | 64% |
|           | < 60 Hz | 31% | 39% | 38% | 38% | 34% | 36% |
| Charge    |           | 13% | 35% | 15% | 16% | 13% | 18% |
| Discharge |           | 86% | 58% | 84% | 84% | 87% | 89% |
| Standby   |           | 1%  | 7%  | 1%  | 0%  | 0%  | 2%  |

Table 4. Conditions of the AGC operation tests under the SOC unbalance among the PCS

| Available SOC range | Target SOC for recovery | Initial SOC of FRC #3 | Initial SOC of FRC #6 |
|---------------------|-------------------------|-----------------------|-----------------------|
| 50% ~ 80%           | 63%                     | #3-1 52%              | #6-1 56%              |
|                     | #3-2 60%                | #6-2 61%              |
|                     | #3-3 65%                | #6-3 72%              |
|                     | #3-4 70%                | #6-4 74%              |

there are quite lower percentage of normal operation. The normal operation means that the error between AGC reference and power output of BESS is within 5%. It is one of the cause of reliability deterioration for assuring 30 minutes AGC operation. In worst case, in order that BESS guarantee 30 minutes AGC operation, BESS must have 1 C-rate capacity considering 50% available SOC.

Under the limited conditions, there are some improvement points.

First, AGC target has to be set by condition of BESS for enabling 30 minutes operation. Table 5 shows the measured data from FRCM by 5 times. The average rate of discharge time is 80% in contrast to the average frequency level. High discharging target of EMS let the SOC of BESS provide the insufficient operation in contrast to the average frequency level. High discharging target from FRCM by 5 times. The average rate of discharge time is 80% enabling 30 minutes operation. Table 5 shows the measured data in points.

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| Discharge |           | 86% | 58% | 84% | 84% | 87% | 89% |
| Standby   |           | 1%  | 7%  | 1%  | 0%  | 0%  | 2%  |

Second, it is a additional function not for AGC operation time. Generally, the rate between charging target and discharging target is not same. Thus, BESS for AGC operation has to need the SOC recovery operation time. In order to reduce the SOC recovery operation time, increasing the rated charging power may be used. If it involves a SOC error of BMS, the variable speed operation of charging can be considered.

V. CONCLUSION

KEPCO has demonstrated for commercial operation using 52 MW FR-ESS and has been installing additional 200 MW FR-ESS, govenor free and automatic generation control. This paper describes the results of the AGC operation test using 8 MW FR-ESS for advancing AGC technology of BESS. From the long term operation, there are AGC operation period and SOC recovery operation period. Currently, in the view of an error of AGC target and power output of FRC, there are quite lower percentage of normal operation.

In contrast to AGC operation of the conventional plants, BESS has good strenths, because that of BESS has no delay and precision of power reference following. But, it is hard to use long term operation, because AGC operation must need continous and random power target.

For improving AGC operation performance of BESS, Some solutions are suggested. First, the rate between charging target and discharging target of EMS must be in the similar level. So, EMS must consider the condition of FRC. Other method to meet the time for required AGC operation duration is to increase the available SOC range. Finally, BESS for AGC operation has to need to shorten the SOC recovery operation.

KEPCO has the plan to improve the AGC algorithm using BESS for stabilizing the power system. In future, it will be demonstrated additional experiments based on this study. It is expected that helps to make an friendly AGC reference for BESS.

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