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Performance Test of Coordinated Control of SMES and BESS in Microgrid using the Hardware-in-the-Loop Simulation System

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Abstract

Roles of energy storage systems (ESSs) in microgrid control are very important because a microgrid has uncontrollable energy sources such as the wind turbine and power trade with the utility grid. Especially, the ESSs have different characteristics – power density and energy density. The characteristics show a trade-off. For this reason, the coordinated control among ESSs considering their characteristics is required. In this paper, a coordinated control of SMES and BESS is tested with high reliability using the hardware-in-the-loop simulation (HILS) system in two grid-connected and islanded modes.

Keywords: *Microgrid, Energy storage system, Superconducting magnetic storage (SMES), Battery storage system (BESS), Wind generator, Hardware-in-the-loop simulation system, coordinated control*

1. Introduction

Recently, many research on microgrids control have been performed [1-2]. The microgrid is operated by grid-connected mode connected to the utility grid and by islanded mode without the connection [4-6]. In the grid-connected mode, tile-line power flow should be controlled and output power of wind turbine should be smoothened. In the islanded mode, frequency should be controlled within allowed range. For the control, many energy storage systems (ESSs), such as energy storage system (ESS) such as battery energy storage system (BESS), superconducting magnetic energy storage (SMES), and electric double layer capacitor (EDLC), have been applying [7-12].

ESSs have different characteristics – power density and energy density [13-14]. It means the roles of ESSs in control should be considered by their characteristics. That is, BESS is effective to relatively slow and long-term applications because it has good energy density and SMES is effective to applications requiring fast control because of its good power density. For this reason, the coordinated control considering their characteristics is required [15-16].

On the other hand, there are some limitations on space and costs to test developed devices or systems to check their performance with high reliability. Recently, the hardware-in-the-loop simulation (HILS) system is applied to overcome the problems with a real-time digital simulator (RTDS) in many engineering areas [17-18]. In the HILS system, the developed systems or devices are tested connected the RTDS where plants are modeled with communication links like a real environment.

In this paper, the SMES which has high power density is in charge of smoothing output power of the wind turbine because it can control fast according to the fluctuation and the BESS with high energy density is in charge of controlling power flow between utility grid

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and the microgrid in the grid-connected mode and controlling frequency in the islanded mode. To test the performance of the controllers with high reliability at the laboratory, a HILS system is developed and applied. The HILS system is composed of three digital signal processor boards (DSP B/Ds) for a controller of the BESS and two controllers of the SMES and eMEGAsim as a RTDS for modelling a test microgrid and the rest parts of BESS and SMES.

2. Modeling of Tested Microgrid

As shown in Figure 1, a microgrid shown composed of a wind generator, a diesel generator, a SMES, a BESS and a lumped load is modeled to test the performance of coordinated control of SMES and BESS in the microgrid.

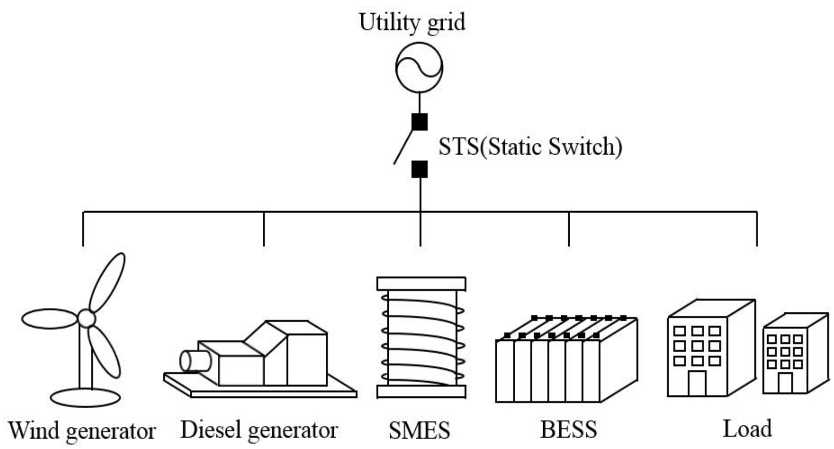


Figure 1. Test Microgrid

2.1. Wind Generator

The wind generator is modeled as an induction generator (IG) type which has a squirrel-cage induction generator as shown in Figure 2.

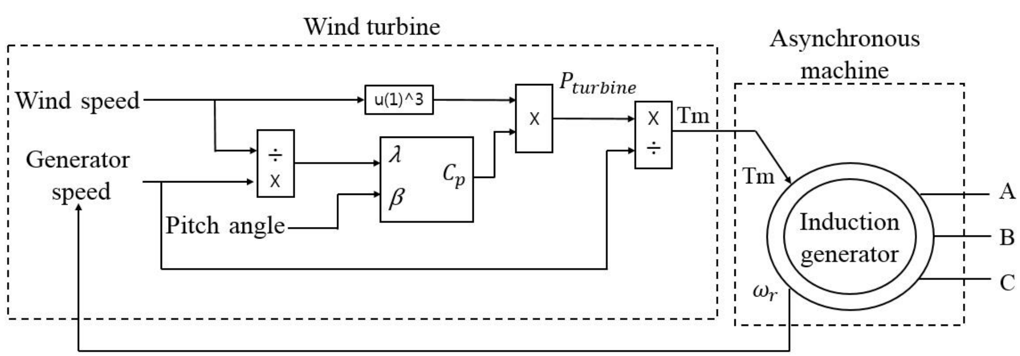


Figure 2. Configuration of Wind Turbine Generator

2.2. Battery Energy Storage System (BESS)

The tested BESS composed of the voltage source converter (VSC) part and the lithium-ion battery part is shown in Figure 3.

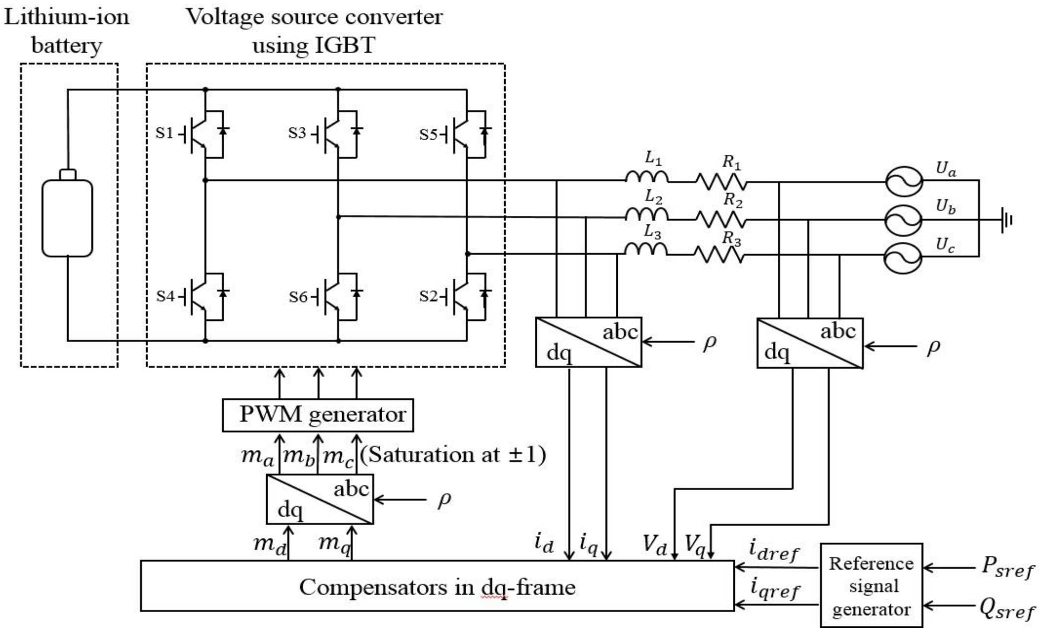


Figure 3. Configuration of BESS

A circuit equation of the VSC shown in Figure 3 can be expressed as equation (1).

$$U = Ri + L\frac{di}{dt} + v \quad (1)$$

In order to express independent control of active power and reactive power by pulse width modulation (PWM), equation (1) can be divided into two real and imaginary parts as Eq. (2):

$$L\frac{di_d}{dt} = \left(L\frac{d\rho}{dt}\right)i_q - Ri_d + V_{td} - U_d \quad (2)$$
$$L\frac{di_q}{dt} = -\left(L\frac{d\rho}{dt}\right)i_d - Ri_q + V_{tq} - U_q$$

In addition, equation (3) can be obtained from equation (1).

$$I = \frac{1}{R+Ls}(U - V) \quad (3)$$

The control block diagram of current controller shown in Figure 4 can be drawn from equation (3).

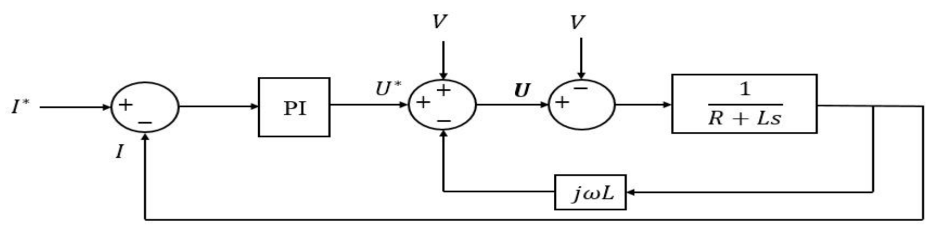


Figure 4. Block Diagram of Current Controller

2.3. Superconducting Magnetic Energy Storage (SMES) System

The tested SMES which is composed of a VSC using IGBT, a two-quadrant DC-DC chopper using IGBT, and a superconducting coil is shown in Figure 5. The VSC and the two-quadrant DC-DC chopper are connected by the dc link capacitor shown in Figure 5.

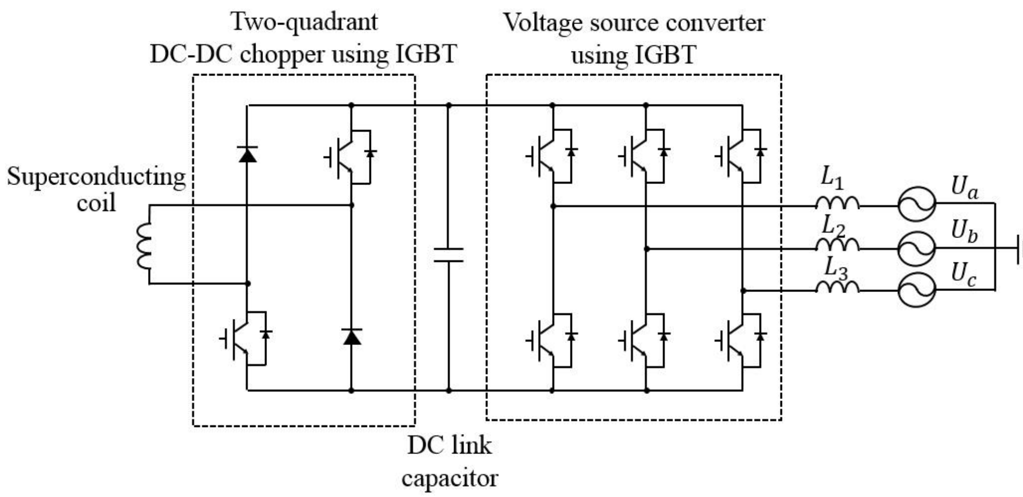
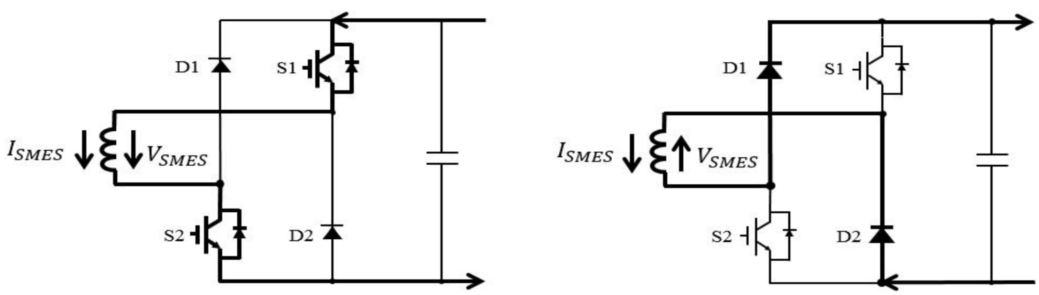


Figure 5. Configuration of VSC-based SMES System

The charging mode and the discharging mode are determined by the two-quadrant DC-DC chopper as shown in Figure 6. S2 is ON and S1 can switch ON or OFF during the charging mode. On the other hand, S2 is always OFF and S1 can switch ON or OFF in the discharging mode.



(a) Charging mode (b) Discharging mode

Figure 6. Two Control Modes of SMES

3. Coordinated Control of SMES and BESS

In this paper, the coordinated control of BESS and SMES is designed as follows.

3.1. SMES Control

Fluctuation of output power of the wind turbine makes a disturbance for controlling power flow between utility grid and the microgrid in the grid-connected mode and for controlling frequency in the islanded mode. In this paper, the SMES is in charge of smoothing output power of the wind turbine because it can control fast according to the fluctuation with high power density. For the smoothing of output power of the wind turbine uses a low-pass filter (LPF) which is expressed by equation (4). Figure 7 shows the block diagram of the LPF.

$$H(s) = \frac{\omega_c}{s+\omega_c} = \frac{1}{1+s/\omega_c} \tag{4}$$

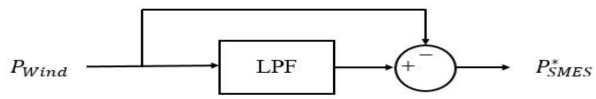


Figure 7. Smoothing Control Block Diagram

3.2. BESS Control

In this paper, the BESS with high energy density is in charge of controlling power flow between utility grid and the microgrid in the grid-connected mode and controlling frequency in the islanded mode.

4. Hardware-In-the-Loop Simulation System

Figure 8 shows the concept of the developed HILS system to test the coordinated control of BESS and SMES. Figure 9 shows the developed HILS system at the laboratory which is composed of three TMS320F28335 DSP B/Ds. Two DSP B/Ds were in charge of controller of two-quadrant DC-DC chopper and controller of VSC of the SMES and a DSP B/D was in charge of VSC of controller of the BESS. The tested microgrid and the rest parts of the SMES and BESS were modeled in eMEGAsim RTDS. The ratings of components of the microgrid are shown in Table 1. The DSP B/Ds and eMEGAsim RTDS are connected with communication links and exchange input signals for controllers and PWM signals as outputs of the controllers. In addition, the static signal (STS) is transferred from the RTDS to DSP modules to inform status of two modes, that is, the grid-connected mode and the islanded mode.

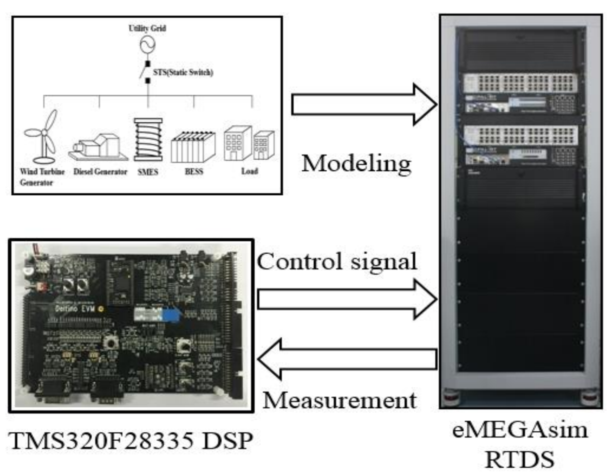


Figure 8. Concept of Developed HILS System

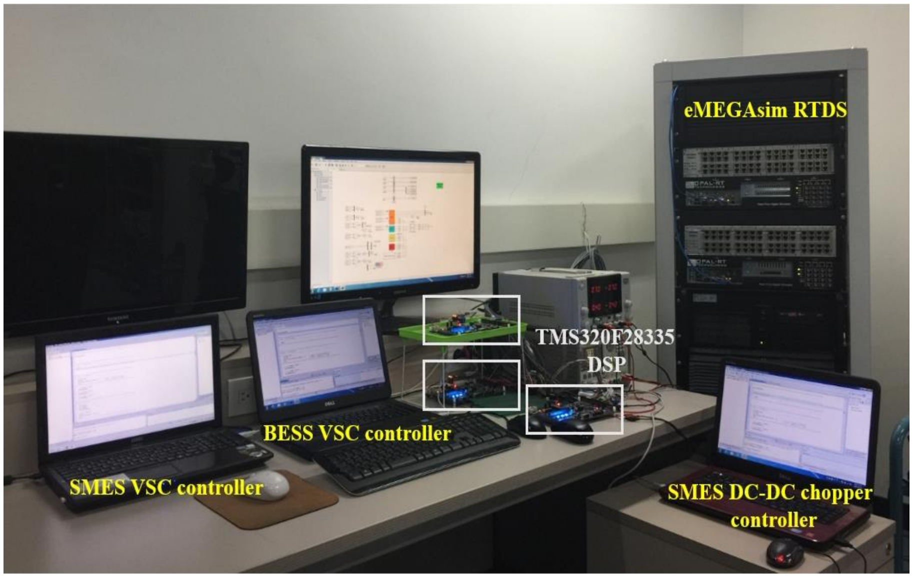


Figure 9. HILS System Developed at the Laboratory

Table 1. Component Ratings

Components	Ratings
Diesel	150 kW
Load	180 kW
Li-BESS	100 kW
SMES	200 kJ

5. Test Results

For the performance of the controllers, the following scenario is applied;

- The initial operation mode of microgrid is grid-connected mode.
- The operation mode of the microgrid is changed to islanded mode at 60 seconds by opening the STS.

Figure 10 shows the result of smoothing frequency by the SMES. The result shows the frequency was smoothened effectively by the SMES. It can be checked by comparing the frequency without the SMES. Figure 11 shows the output of the SMES for the smoothing the frequency. From the figure, frequent charging and discharging can be checked by the controllers of the SMES.

Figure 12 shows the result of power flow between the utility and the microgrid in the gird-connected mode until 60 seconds. From the result shows constant power exchange can be possible between them. In addition, during the islanded mode, there is no power flow between them because the connection is not available from 60 seconds.

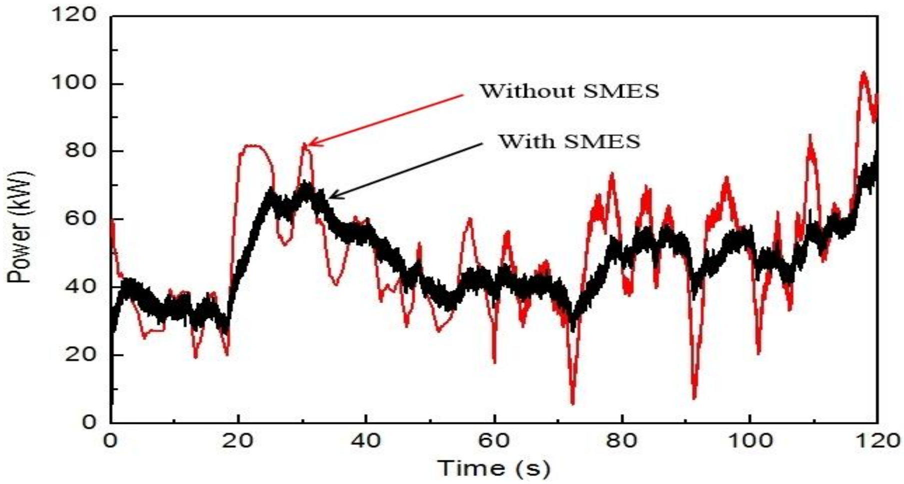


Figure 11. Smoothing Output Power Fluctuation of the Wind Generator

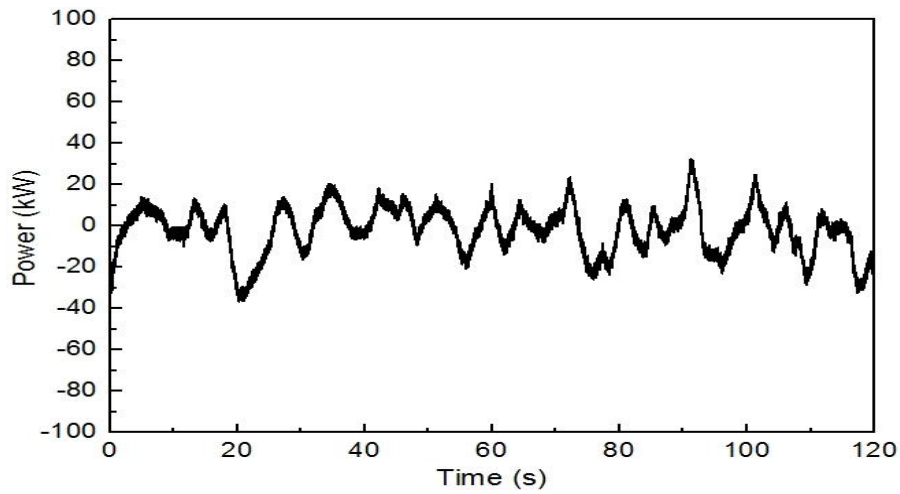


Figure 10. Output Power of the SMES

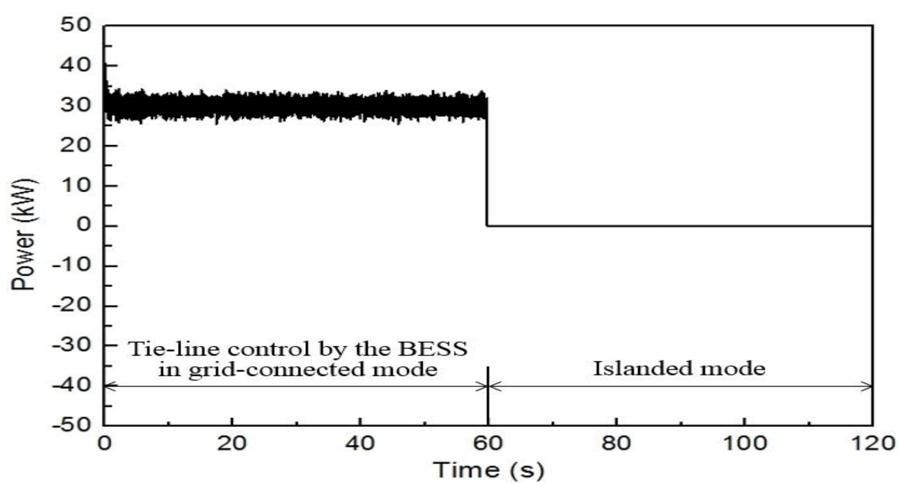


Figure 12. Power Flow between Utility Grid and the Microgrid

Figure 13 shows frequency of the microgrid during the islanded mode. After changing to islanded mode, the frequency was controlled well in the allowed ranges by the control of the BESS.

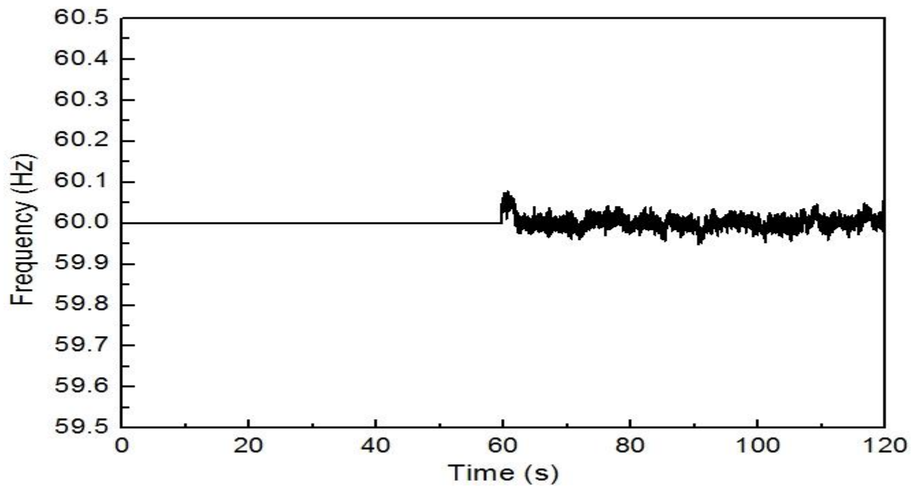


Figure 13. Frequency in the Microgrid

Figure 14 shows output power of the BESS for controlling power flow during the grid-connected and islanded modes, respectively.

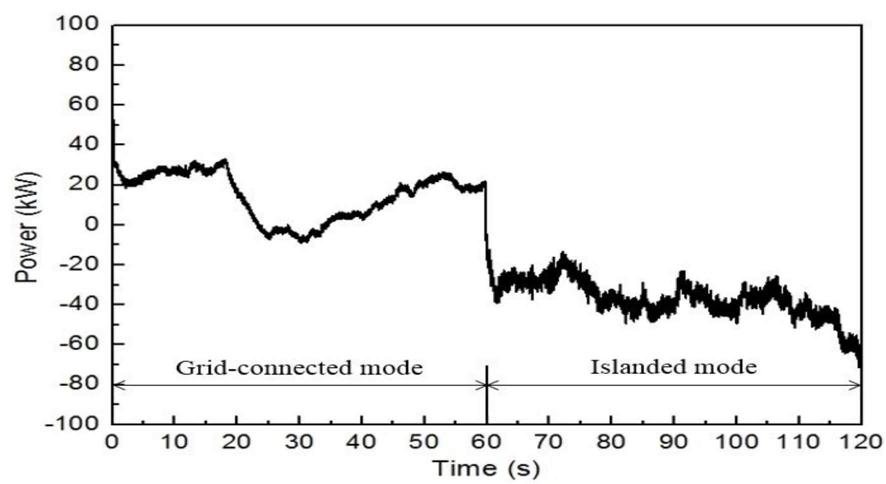


Figure 13. Output Power of the BESS

6. Conclusion

In this paper, a HILS system was applied to test the performance of coordinated control of SMES and BESS under conditions similar to the real environment in the microgrid. The SMES and BESS were in charge of smoothing frequency and of controlling tie-line power flow between the utility grid and the microgrid in the grid-connected mode and frequency in the islanded mode, respectively, considering their characteristics – power density and energy density. The test results showed good performance according to design purposes.

Acknowledgements

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