ESS Control Strategy for Primary Frequency Response in Microgrid Considering Ramp Rate

Ho-Jun Jo, Wook-Won Kim, Yong-Sung Kim, Jin-O Kim

Abstract**—**The application of ESS (Energy Storage Systems) in the future grids has been the solution of the microgrid. However, high investment costs necessitate accurate modeling and control strategy of ESS to justify its economic viability and further underutilization. Therefore, the reasonable control strategy for ESS which is subjected to generator and usage helps to curtail the cost of investment and operation costs. The rated frequency in power system is decreased when the load is increasing unexpectedly; hence the thermal power is operated at the capacity of only its 95% for the Governor Free (GF) to adjust the frequency as reserve (5%) in practice. The ESS can be utilized with governor at the same time for the frequency response due to characteristic of its fast response speed and moreover, the cost of ESS is declined rapidly to the reasonable price. This paper presents the ESS control strategy to extend usage of the ESS taken account into governor's ramp rate and reduce the governor's intervention as well. All results in this paper are simulated by MATLAB.

Keywords**—**Micro grid, energy storage systems, ramp rate, control strategy.

I. Introduction

IMPROVED penetration and efficiency of Renewable Energy Source (RES) such as photovoltaic and wind farm, the studies about a microgrid has been receiving more attention recently than ever due to its controllability and effectiveness. The microgrid is normally smaller than 50-100MW usually connected to the distribution system. Due to the small capacity in power system, the microgrid systems provide a lot of advantages that can improve the network quality, reliability and a curtailment in emissions comparison with conventional grid.

A generalized microgrid is consisted of multiple distributed generators, such as conventional generator, RES and Energy Storage Systems (ESS) that provide electric power. The electric power is generated not only by thermal plants but also by renewable sources which enables electric power supply to be more stabilized than normal grids [1]. Recently, renewable sources are utilized in island area for its energy self-supporting. So as to make it to be feasible, the role of ESS is the key to stabilize the microgrid and maximize the usage of RES. The ESS utilizes electric power transmission system to compensate the Transmission Stability Damping, Sub-synchronous Resonance Damping, Voltage Control and Under-frequency Load Shedding Reduction. The implementation of energy storage system for Primary Frequency Response (PFR) provides many advantages both from the generator as well as the network [2]-[4]. However, a large ESS is required to the cost of high investment. In other to reduce cost, control strategy of ESS is crucial in justifying economic viability. Because of the sudden changes in demands in power system, output power from thermal generator should be continuously coordinated accordingly in order to achieve the equilibrium between power supply and demands. Governor is a device that implements Primary Frequency Response (PFR). Governor is the initial source of primary frequency response that generally set in motion within 10 seconds under the criteria of management [5], [6]. The aim of the study is to analyze the control strategy of energy storage system to take account into the ramp rate of generators.

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II. Methodology

The power imbalance between supply and demand makes disturbance of synchronous generator and thus it affects to the system frequency as shown in swing equation (1):

$$\frac{H}{180 f_0}\frac{d^2\delta}{dt^2} = P_m - P_e \tag{1}$$

The departure from steady-state due to a generator speed disturbance results in increasing ($\Delta L < \Delta P$) or decreasing ($\Delta L > \Delta P$) frequencies [7].

$$\Delta\omega = \frac{\pi f_0 \Delta P}{H\omega_n\sqrt{1-\zeta^2}} \cdot e^{-\zeta\omega_n t}\sin\omega_d t \tag{2}$$

The power necessary to compensate the frequency deviation has a linear relationship approximately by (3).

$$\Delta P(t) = \Delta f(t)\cdot k_{grid} \tag{3}$$

where grid constant k_{grid} is the parameter which represents the change of frequency when load changes 1 %.

According to the increasing penetration of ESS due to its lower cost than before and fast response, ESS recently starts to replace the role of governor for frequency regulation.

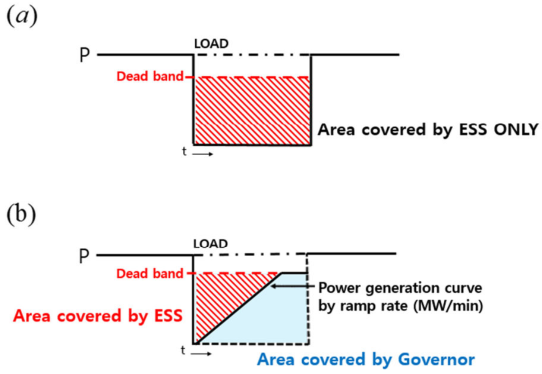

Fig. 1 (a) The conventional model for ESS PFR service, (b) The model for ESS PFR service with ramp rate

Fig. 1 (a) shows that ESS only replaces the role of the conventional governor and Fig. 1 (b) shows the case where ESS and the conventional governor with ramp-up rate are used at the same time to compensate the imbalance. Typical generator with a governor has a ramp-up and down rates defined as the rate of change in MW per minute from output power. The rectangular area in Fig. 1 (a) is caused by the power imbalance which is a difference between supply and load. To solve the imbalance, power should be supplied to the amount corresponding to the whole rectangle but is allowed up to the dead band only which is considered as secure. The necessary amount of power from ESS only is calculated from Δf to ΔP expressed by (3). The power of ESS can be evaluated by (4) using the definition of grid constant k_{grid} as appeared in (3), and ESS energy necessary to the frequency regulation can be expressed by (5) which corresponds to slashed rectangle in Fig. 1 (a), where f^{db} is the dead band of frequency and interval from ramp-up time.

$$P_{ESS}(t) = 0.01 \times \frac{f^{db} - f(t)}{k_{grid}} \times L(t) \tag{4}$$

$$E_{ESS}(t) = \int_{ramp-up}^{t} P_{ESS}(t) \tag{5}$$

For Fig. 1 (b), ESS should supply the energy represented only by the slashed triangle in Fig. 1 (b) since the remained area can be covered by governor, where slope of triangle is depended on the ramp-up rate of the generator. The power and energy of ESS in this case can be calculated by (6) similar to the case of ESS only.

$$P_{ESS}^{'}(t) = 0.01 \times \frac{f^{db} - f(t)}{k_{grid}} \times L(t) - P_{ramp}(t) \tag{6}$$

where the power by ramp-up rate are expressed approximately by (7).

$$P_{ramp}(t) = \varepsilon \times (t - t_{ramp-up}) \times \frac{1}{60} P_G^{\max} \text{ MW/sec} \tag{7}$$

where ε , t_s and $P_G^{\max}$ are a ramp-up rate, the time that governor starts to increase the generation by ramp rate and the maximum output power from generator, respectively.

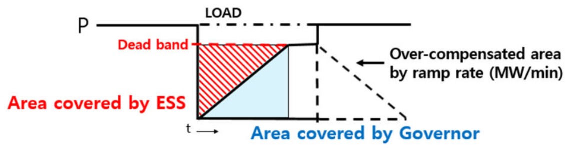

Fig. 2 The proposed model for ESS PFR service

As same as Fig. 1 (b), the governor and ESS are operated for PFR service and the frequency is reached in its permissible frequency limits (dead-band) in Fig. 2. However, when the governor is ramp-down, it would over-compensate due to its ramp-down rate as much as the amount of dotted triangle, and the over-compensated energy is wasted. The wasted energy can be also obtained approximately by multiplying the time with ramp-down rate and this wasted energy can be recycled by charging the ESS additionally for the next frequency fluctuation as shown in (8):

$$E_{ESS}^{add}(\mathrm{t}) = \int_{ramp-down}^{t} P_{ramp}(t) \tag{8}$$

If the SOC level of ESS charged by energy saving is enough to conduct a PFR service, governor will not be activated for a small disturbance frequently. The SOC level improved by recycling is given in (9):

$$SOC(t+1) = SOC(t) + \frac{E_{ESS}^{add}(t)}{E_{ESS}^{\max}} \tag{9}$$

where $E_{ESS}^{\max}$ is the maximum capacity of ESS.

Fig. 3 shows the control strategy, where ESS provides the PFR at all times requested. The ESS is activated if the grid frequency is reached or exceed frequency limits, and governor and the ESS are in motion at the same time to operate the cooperative power control for primary frequency response. After that, the ESS will be in charging mode with the recycled energy. As a result, the ESS will be able to cover the small disturbances that not reached in frequency limits instead of governor. This new control strategy can decrease the stepping out of generator and improve the system stability as well as the application of ESS in microgrid.

III. Case Study

The installed capacity of the sample system for the case study is 62-MW including a 60-MW thermal power plant and one 2-MW ESS. The total load of this simulation is assumed as 70-MW as shown in Fig. 4.

In the simulation, it is assumed that the total power output of thermal power unit is 60-MW at rating 70-MW with 5% ramp rate (3.5-MW per min). ESS is 2-MW capacity and 1-Mwh at initial SOC 50% and the simulations are ran in 10,000 seconds.

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Fig. 5 is the case that the governor activates according to the power imbalance.

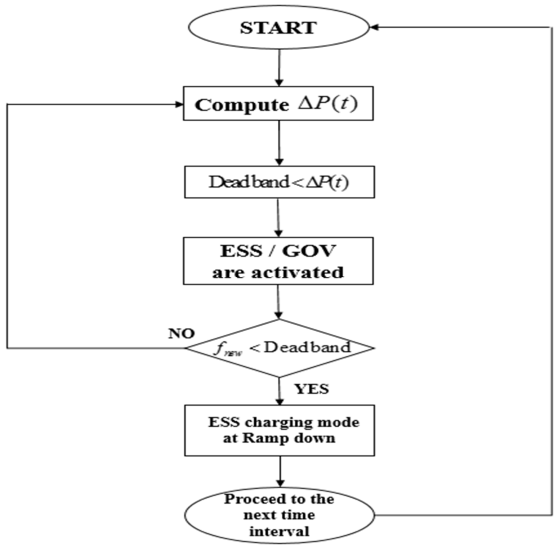


Fig. 3 The schematic of Proposed Control Strategy; $\Delta P(t)$ Power difference between supply and demands, f_{new} Adjusted frequency by Governor and ESS, P_{ramp} Power generation by governor

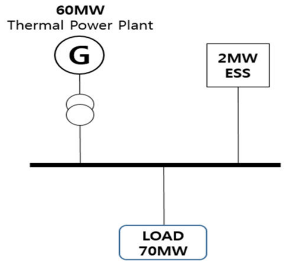


Fig. 4 The sample system

Fig. 6 (a) shows that frequency changes due to the power imbalance is improved by governor activation. Fig. 6 (b) shows that ESS and governor compensate energy imbalance together as explained previously at Fig. 1 (b). In Fig. 6 (b), it can be seen that the frequencies exist within dead-band, but over-compensated. On the other hand, it is observed in Fig. 6 (c) that the frequencies exist in the dead-band exactly without over-compensated, and instead, the surplus energy of ramp-down governor is used to charge ESS after rated frequency is achieved.

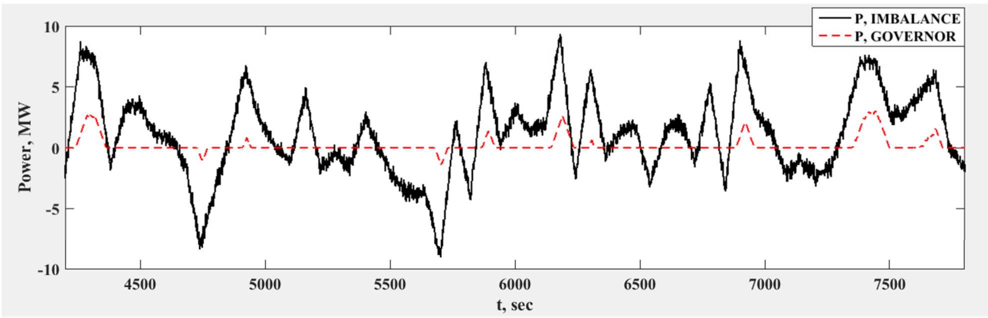
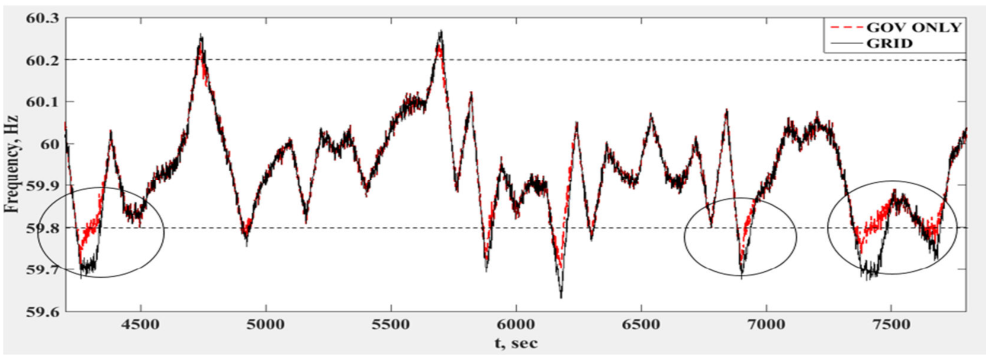
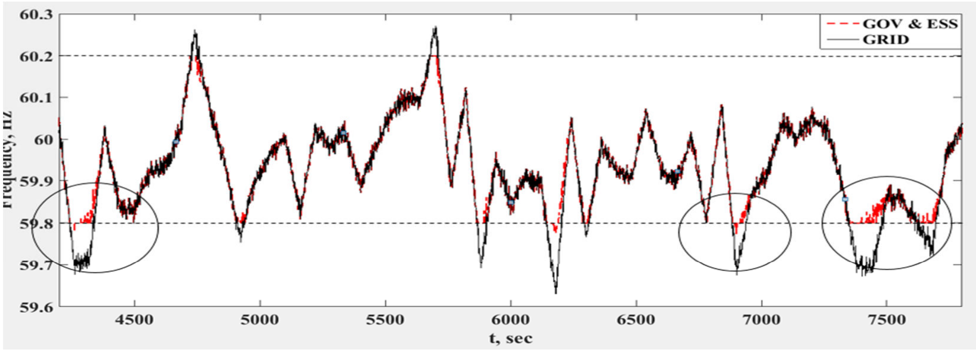


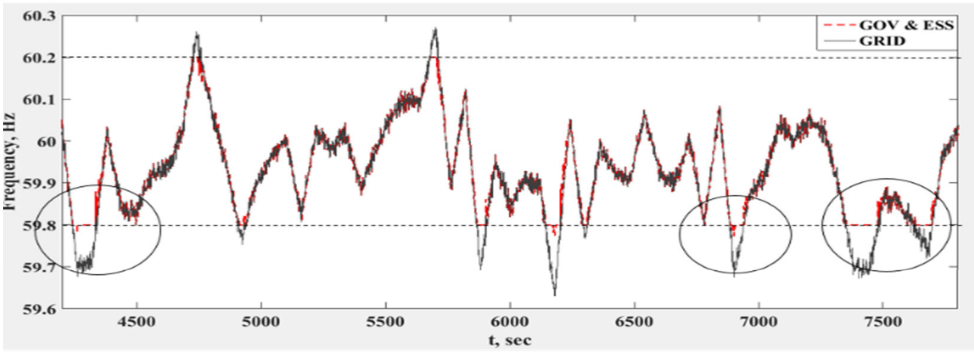
Fig. 5 Power generation by Governor



(a) Frequency regulation by Governor



(b) Frequency regulation by ESS and Governor



(c) Frequency regulation by ESS and Governor considering ramp-down rate

Fig. 6 The PFR service by ESS and Governor

The effect of ramp-down energy can be confirmed by the State of Charge (SOC) of ESS. In Fig. 7, ESS1 which is the solid line and ESS2 which is the dotted line represent the SOC level of the cases of Figs. 6 (b) and (c), respectively. It can be observed that charging the ESS at ramp down rate maintains SOC level, while it keeps in decline without compensating. Life-span of ESS depends upon closely, especially for the frequent low level of SOC, and it should be avoid considering its high cost.

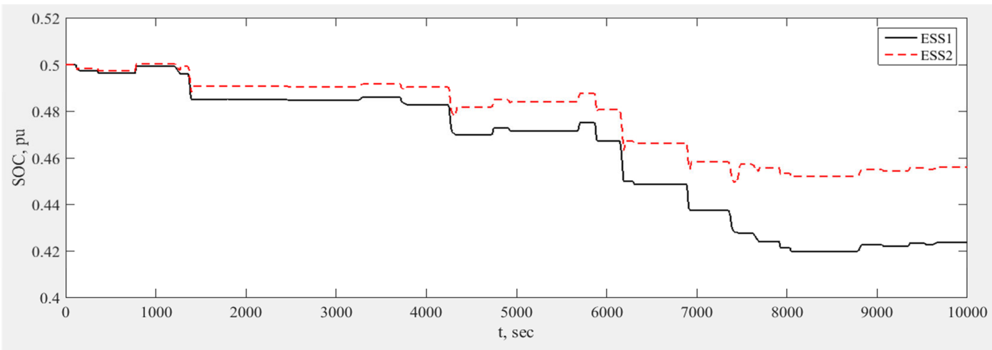


Fig. 7 Comparison of SOC for the cases of Figs. 6 (b) and (c)

IV. Conclusion

The control strategy taken into governor ramp rate has determined its effectiveness for primary frequency response in microgrid. Consequentially, the motion frequency of governor is decreased since the SOC is stable to fulfill the power imbalance between non-acceptance area and dead band. The SOC level of ESS has improved by the ramp down rate.

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