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# Autonomous active power management in isolated microgrid based on proportional and droop control

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**Abstract**

In an isolated microgrid, coordinated active power control is required for power balance under any circumstances. We propose a proportional control method based on the master-slave concept to achieve power balance even from insufficient power supply. This autonomous control method uses the frequency generated by the grid-forming battery energy storage system (BESS) as a global data signal. Other units are controlled indirectly. The frequency is controlled to be proportional to the AC voltage deviation of the grid-forming BESS for detecting sudden power shortages and for sharing active power. The effectiveness of the proposed method is verified by simulations in MATLAB/Simulink.



*Keywords:* microgrid; energy stroage system; frequency control; active power management; autonomous control; droop control; coordinated control; master-slave control;

## 1. Introduction

With enhanced price competitiveness and sustainability, the penetration of renewable energy sources (RES) into the electricity supply is steadily increasing. A microgrid, which is an integrated platform for supply, storage units and

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demand resources located in a local grid, enables local energy management [1]. Meanwhile, most remote areas such as small oceanic islands have no connection with the main power grid due to cost and/or technical problems.

The electric power supply for these areas in several countries depends primarily on a diesel generator that can be adjusted to meet the power balance of the grid. However, RES such as photovoltaics (PV), wind turbines (WTs) are more difficult to apply as power systems than diesel generators due to their intermittency, which causes even more stability problems in remote power systems. However, the development of microgrid technology and energy storage system (ESS) has rendered RES an attractive option for supplying electricity in remote areas. In an isolated microgrid without any electrical connection with other systems, the battery energy storage system (BESS) unit is typically operated as a grid-forming unit to control the alternating current (AC) bus voltage and the system frequency. This is because the ESS can be controlled immediately and charged and discharged by the smart inverter technology [2]. When the BESS is used for the grid-forming unit, its state of charge (SOC) has to be maintained within the acceptable range for device protection and stable operation [3], [4].

Several control strategies based on the constant-voltage constant-frequency (CVCF) method for the grid-forming ESS unit have been proposed and used in real microgrids across South Korea [5]. This method controls the frequency and voltage to be a constant and primary active power control is met by the BESS which operates as ideal voltage source. However, the SOC level must be considered to protect the battery and guarantee sufficient spinning reserve. In addition, the active power balance depends primarily on the BESS. To share the burden of the grid-forming BESS, frequency-based droop control is proposed [6]-[9]. In [6], active power and frequency droop control is applied to coordinate the distributed energy sources (DER) and ESSs in inverter-based islanded microgrids. To maintain the SOC value, SOC-frequency droop control is proposed in [7]. However, problems arise from the fluctuations in the SOC or from active power in the droop control region. Further, conventional generators such as diesel generators are not considered. Moreover, master-slave-based SOC control method with droop control in diesel generators is presented in [8]. In [9], the active power control algorithm of diesel generators with the SOC of a BESS using low-bandwidth communication is proposed.

This paper proposes an autonomous active power management based on the proportional control of the gird-forming BESS and droop control of diesel generators. With CVCF operation, the BESS controls the frequency when an AC voltage is changed which implies active power imbalance. This method minimizes the low voltage problem and power insufficiency without any communication. A simulation in MATLAB/Simulink is performed to show the effect of the proposed control method.

## 2. System description

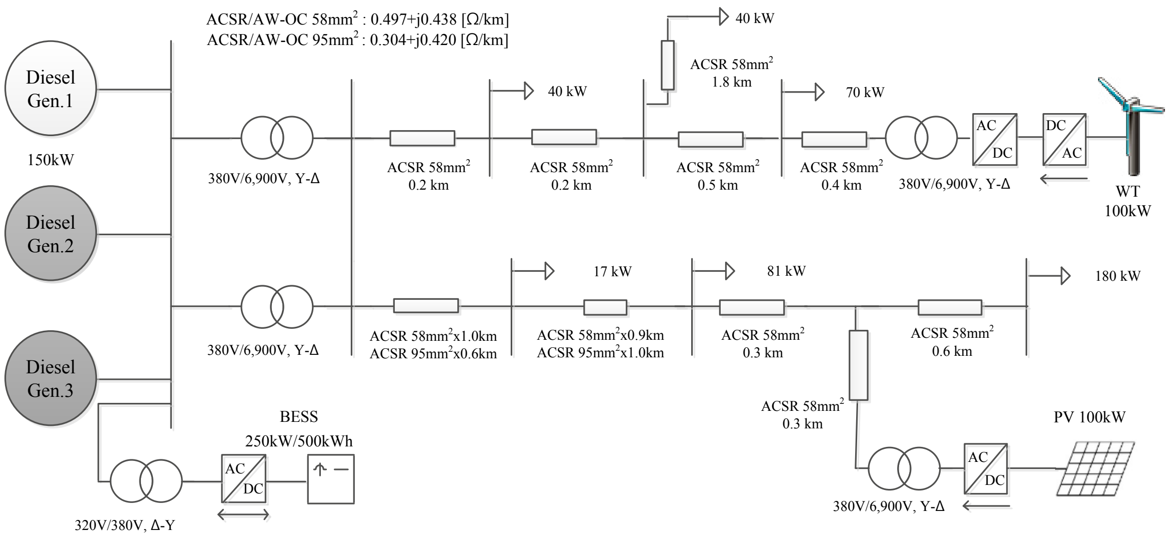



Fig. 1. Geocha Island microgrid system configuration.

Geocha Island, one of the areas of the remote microgrid project driven by Korea Power Electric Corporation (KEPCO), has an isolated microgrid system. Fig. 1 illustrates the configuration of the microgrid system in Geocha Island. The system has no electrical connection with the main grid and includes a 250 kW/500 kWh of BESS, 100 kW of PV, WT, and three 150 kW diesel generators, respectively. The other data are replicated from the real system of Geocha Island. The nominal system voltage and frequency are 6.9 kV and 60 Hz, respectively.

The converters in the system were based on the two-level averaged model. The WT, PV, BESS and diesel generator were modeled based on the MATLAB/Simulink library models. The WT and PV are assumed to be operated by the maximum-power point tracking (MPPT) algorithm to maximize their cost efficiency [10], [11]. The loads were implemented with a three-phase series RLC load model with floating Y and constant Z.

## 3. Proposed control method

### *3.1. Grid-forming BESS unit*

The BESS consists of a battery, LC filter, inverter, and transformer. Fig. 2 shows the configuration of the grid-forming BESS unit, which works as an AC voltage source with a given voltage amplitude and frequency that sets the system frequency and AC voltage of the BESS. The BESS is suitable for grid forming because it can adjust the output quickly and accurately and has bidirectional characteristics. However, if the active power in the microgrid changes suddenly beyond the operating range of the BESS, other resources such as DER and controllable loads must be simultaneously controlled for stable system operation.

The reference signal of the frequency is given by a voltage-frequency proportional controller (VFPC) based on the AC voltage difference of the BESS, as illustrated in Fig. 3. The BESS forms the system frequency with the VFPC considering the AC voltage from the local measurement. $f_{nom}$ is the nominal frequency of the system and $f_{ref}$ is the reference value of the grid forming BESS. $\Delta V_c$ is the value obtained by subtracting the AC voltage from the voltage reference value of the BESS . The coefficient $K_v$ denotes the proportional gain of the VFPC. The limiter plays suppresses the sudden changes in the frequency. The frequency reference signal of the BESS is given by

$$f_{ref} = f_{nom} - K_v \Delta V_c \tag{1}$$

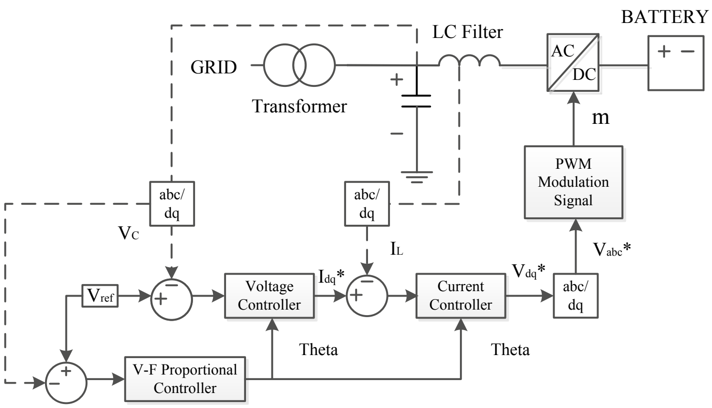



Fig. 2. Grid-forming BESS configuration with control algorithm.

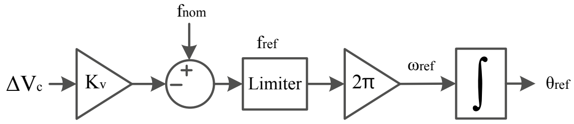



Fig. 3. V-F Proportional controller block diagram.

The frequency formed by the BESS functions as a global data signal that allows the BESS to command other DESs to adjust their output without any communication. If the AC voltage of the grid-forming BESS is changed, it implies that the power balance of the system is broken. This situation means that the active power reserve of the BESS has reached its limit. At this time, the load is reduced due to insufficient power supply, leading to a voltage drop [12]. When the BESS has sufficient power reserve to meet the power balance, they can maintain the AC voltage immediately because the inverter can control the voltage accurately and quickly. Therefore, when voltage fluctuates in the BESS bus, the grid-forming BESS detects it and changes its frequency reference for sharing active power reserve, as shown in (1)). Subsequently, other DESs adjust their output by droop control in response to the frequency that is a global data signal. In this paper, we focus on the coordinated autonomous active power control between the grid forming BESS and the diesel generator. This is because the PV and WT have limits in their output and they are operated with MPPT to maximize economic efficiency.

### *3.2. Diesel generator unit*

Diesel generators are assumed to be operated by the active power droop control method, which mimics the operation of synchronous generators for sharing active power and maintaining power balance in large interconnected power systems [9]. The system frequency is changed when the rotor speed is changed by the effective torque, that is, the difference between the electrical and mechanical torques. This means that power balance is broken and the energy stored in the synchronous generator is used to maintain the power balance of the system. Using this characteristic, active power droop control was proposed such that the generators share the active power for power balance, which can be expressed as

$$\omega_{ref} = \omega_{set} - K_P(P_m - P_{set}) \tag{2}$$

where $\omega_{ref}$ denotes the reference angular frequency of a generator, and the values of $\omega_{set}$ and $P_{set}$ correspond to the nominal value of angular frequency and active power, respectively. $K_p$ represents the droop coefficient. Droop control is widely applied for the reliability and improvement of the system performance and stability. This control is based only on local measurements and allows other generators to operate autonomously.

Fig. 4 shows the control structure of a diesel generator for active power. It includes an active power droop control, PI controller, time delay model of a valve actuator, diesel engine, and a synchronous machine dynamic model. The synchronous machine was modeled by the synchronous machine SI fundamental block in the MATLAB/Simpowersystems. The parameters related to the control block are referred from [8]. The droop controller generates $\omega_{ref\_di}$ and the PI controller is used to track the reference signal by comparing $\omega_{ref\_di}$ and $\omega_{m\_di}$, the latter of which is the measured angular frequency of a diesel generator.

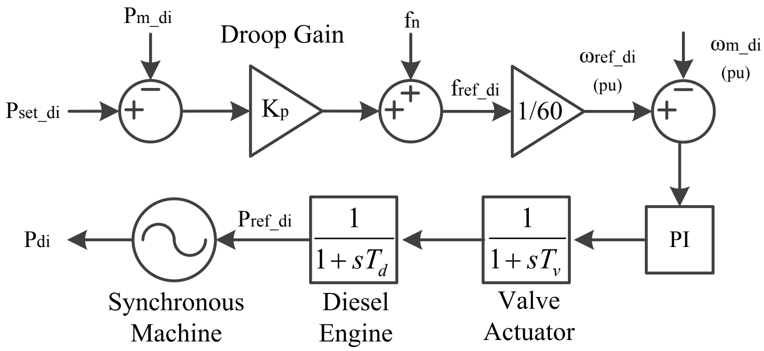



Fig. 4. Control structure for active power of a diesel generator.

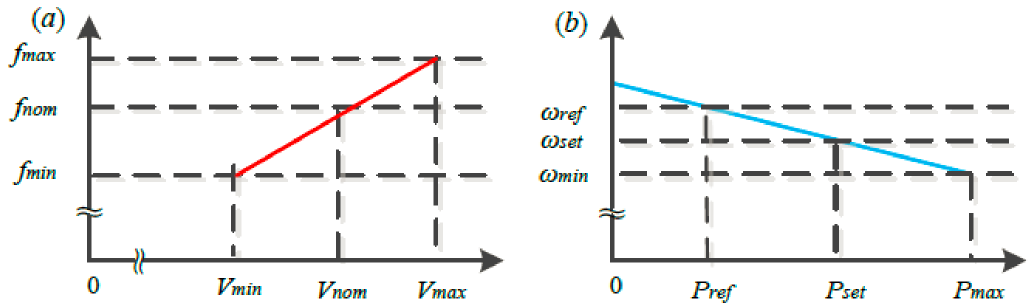



Fig. 5. (a) VFPC scheme in the BESS; (b) conventional droop characteristic.

### *3.3. Proposed autonomous active power management*

The conventional primary control method by grid-forming converters based on CVCF and SOC does not respond well with the large change in active power beyond the active power reserve of the BESS because it only depends on the BESS to maintain the power balance of the system. By using the VFPC of the BESS and the active power droop control of the diesel generator as shown in Fig. 5, the autonomous active power management can be achieved for solving the active power shortage due to the active power limit of the BESS, without any communication equipment. This is because the frequency generated by the grid forming BESS plays the role of a global data signal based on master-slave control. The BESS notices insufficient active power condition in the system by measuring the AC bus voltage of the BESS. Subsequently, they controls frequency proportional to the voltage deviation from the nominal voltage to control the diesel generator with active power droop control.

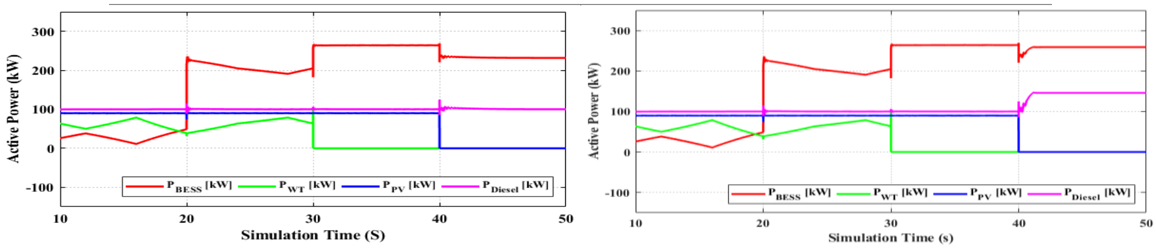
This method enables the utilization of other resources in the system when the active power is rapidly changed. Further, the advantage of the proposed control method includes compatibility with the conventional control structures.

## 4. Simulation results and discussion

To verify the effect of the proposed control method, a simulation is carried out based on the MATLAB/Simulink model of Geocha Island. In this paper, we focus on the low voltage condition, which is more important and more common than the high voltage condition due to the limited active power reserve in the system. The simulation was performed for three successive events in low voltage condition: (i) the load (Dongyuk, 180 kW) is connected at t = 20 s; (ii) WT is tripped at t = 30 s; and (iii) PV is tripped at t = 40 s. We assumed that the wind speed changes from 11 m/s to 14 m/s. At t = 0 s, the total load demand, PV, and diesel generators are set to 248 kW, 90 kW, and 100 kW, respectively. The simulation results are shown in Fig. 6 to Fig. 8. Other parameters related to the simulation are shown in Table 1.

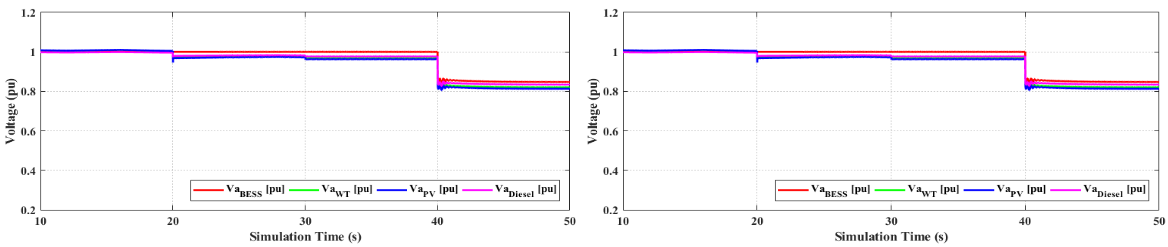
Table 1. System parameters

| Parameter name | Symbol | Value | Units |
|---|---|---|---|
| Time constant of diesel engine | $T_d$ | 0.5 | s |
| Time constant of valve actuator | $T_v$ | 0.05 | s |
| Droop coefficients of the diesel generator | $K_p$ | 0.6/150e3 | - |
| System nominal frequency | $f_{nom}$ | 60 | Hz |
| Low frequency of the BESS | - | 59.4 | Hz |
| Rate limit of the BESS frequency | - | 0.3 | Per sec |
| Rated voltage | $V_{ref}$ | 1 | pu |
| V/f proportional gain | $K_v$ | 6 | - |



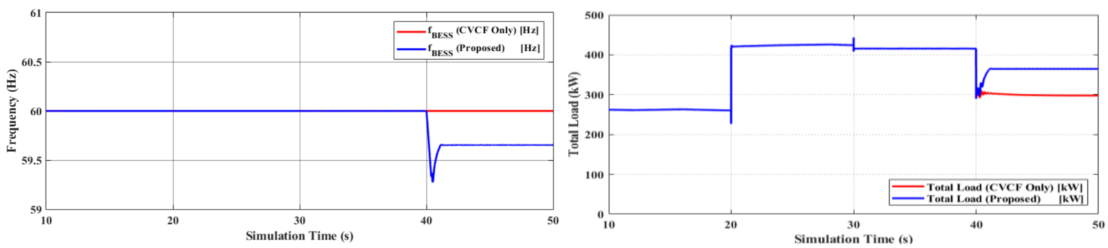

(a) (b)

Fig. 6. Active power profile in Geocha microgrid: (a) CVCF only; (b) Proposed.




(a) (b)

Fig. 7. Local voltage profile in Geocha microgrid: (a) CVCF only; (b) Proposed.




(a) (b)

Fig. 8. Comparison of system profile in Geocha microgrid: (a) System frequency; (b) Total load.

### *4.1. Low voltage condition*

When the Dongyuk load is connected to the microgrid at t = 20 s, the total load is increased from 248 kW to 428 kW. Consequently, the grid-forming BESS adjust its active power to meet the load demand. The total load profile, which is shown in Fig. 8(b), is the sum of the total load demand and the total loss of the system. The real load demand is smaller than the load rating because the load is modelled by a constant Z model that is proportional to the square of the bus voltage. The voltage drop is greater near the Dongyuk load due to the increase in line flow toward this load. At t = 30 s, when WT is tripped, the active power of the BESS is increased and a further voltage drop in the other generators occurred. The total load demand is decreased due to the additional voltage drop by power shortage. Meanwhile, the other resources retain their active power because the BESS is responsible for maintaining the active power balance.

When the PV is tripped at t = 40, the active power reserve of the BESS cannot afford the power balance. An additional voltage drop occurs to reduce the load demand. In the CVCF-only case, the active power of the BESS is lower than its rating power because of the current limit and voltage drop as shown in Fig 6(a). The total load is greatly reduced with the large voltage drop (0.8 pu) as shown in Fig 7(a) and Fig 8(b). However, when the proposed VFPC is applied with CVCF, the frequency is reduced from the voltage dip in the rated voltage, as shown in Fig 8(a). At this time, the diesel generator increases the active power output by the droop control. Therefore, as shown in Fig. 7 and Fig. 8, the voltage drop (0.9 pu) and load reduction (364.5 MW) are mitigated by adding the VFPC.

### *4.2. Discussion*

Because the grid-forming BESS is solely responsible for the spinning reserve of the system, a method to supply the reserve using other resources is required when the limit is reached. The proposed VFPC operates when the active power is insufficient, as measured from the AC voltage of the BESS. This control method adjusts the frequency that is proportional to the voltage difference to control the diesel generator with active power droop control. Therefore, this method does not require any communication and can be easily applied with other conventional control methods such as CVCF.

## 5. Conclusion

The VFPC is proposed in this paper for the isolated microgrid to operate as an additional control to the conventional CVCF controllers to solve the low voltage problem due to the limited reserve of the grid-forming BESS. This method uses the system frequency as a global data signal, which is the method to control the other DES indirectly without any communication. The simulation results show that the proposed VFPC method could mitigate active power shortage using the frequency based operation of the DER in the system.

## Acknowledgements

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