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# BESS Deployment Strategy in Jeju Carbon-Free Islands for Reducing Renewable Energy Curtailment

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**Abstract:** Renewable energy curtailment often occurs to accommodate large amounts of renewable energy sources in power systems while maintaining system stability and reliability. Widely known methods, such as new transmission line construction, the introduction of demand-side resources, and the reduction of conventional generator output, can minimize the occurrence of curtailment; however, there are difficulties in introducing them because of social and economic problems. For these problems, the Jeju power system adopted a battery energy storage system (BESS) resource to mitigate the curtailment and secure frequency stability with the high penetration of renewable energy. The small-size Jeju island power system is operated with reliability must-run (RMR) units and high-voltage direct current (HVDC) lines connected to the mainland. Since the number of RMR units contributes to frequency stability by providing inertia, reducing the number of operating units for curtailment mitigation is difficult. Therefore, in this paper, based on the current "Carbon-Free island" policy and operation plan of the Jeju power system, we proposed a BESS for reducing the number of RMR units, observe the effect of reducing curtailment using the BESS, and suggest a practical operation plan to reduce the number of RMR units under conditions that secure frequency stability.

**Keywords:** curtailment; renewable energy; battery energy storage system

## 1. Introduction

Many countries have devoted efforts toward increasing the supply of renewable energy to reduce carbon emissions worldwide. Consequently, accommodating this high penetration of renewable energy into existing power systems while maintaining the reliability of these systems has become challenging [1,2]. The output of renewable energy is typically curtailed to address this issue. Curtailment can be categorized as economic curtailment, self-curtailment, and manual curtailment (or exceptional curtailment) [3]. Without sufficient compensation, manual curtailment, used to ensure system reliability, limits the penetration of renewable energy, thereby acting as an obstacle to policies supporting the expansion of renewable energy. Curtailment is implemented due to various reasons such as network insufficiencies, reduced inertia of the power system, and excess power generation [4]. Developing new transmission and distribution lines is a well-known approach for reducing curtailment [5]. However, developing new transmission and distribution lines is difficult due to social issues, high construction costs, and prolonged construction periods. As alternatives, various methods such as the demand response (DR) have been proposed. Recent curtailment-related studies have also attempted to mitigate curtailment through the use of battery energy storage systems (BESSs) [6–11]. BESSs are commonly used to store excess renewable energy, which helps reduce curtailment. However, in cases where significant curtailment is required, the installation of large-scale batteries is necessary; therefore, using BESSs may not be economically feasible [12]. Since the BESS used to solve curtailment has an economic problem, it is necessary to review more efficient methods for the Jeju system reviewed in this paper. Small-sized power systems such as the Jeju system are highly affected by disturbances; therefore, the minimum number of RMR units to be operated is determined. The determined number of reliability must-run (RMR) units is for the purpose of providing inertia or frequency control and is determined differently according to the load level. Therefore, the use of BESS for storage, which is difficult to handle curtailment in reality, can be improved along with the operation plan of the RMR unit. To propose such an operation plan, this study additionally examined whether the system frequency stability was secured based on the reliability criteria of the Jeju system by reducing the number of RMR units and introducing BESS.

Reducing the number of RMR units will, in turn, reduce the level of renewable energy curtailment by increasing the operating limit of renewable energy generation. For validation, the typical method of employing BESSs and the proposed method are applied to the power system in Jeju to confirm and compare the effects of these methods. Therefore, in this paper, an efficient operation plan for curtailment problems caused by the expansion of renewable energy in accordance with the current Jeju system's "Carbon-Free Island" policy will be presented.

## 2. Jeju Power System

The Jeju power system is nonsynchronized and interconnected with the mainland system via high-voltage direct current (HVDC) lines, as shown in Figure 1. This system is also subject to high penetration of renewable energy from wind farms as well as photovoltaic (PV) energy, as shown in Table 1. The HVDCs are used to supplement the insufficient power supply of this system, helping to maintain system frequency despite the fluctuations in renewable energy and demand, as well as in the case of contingencies.

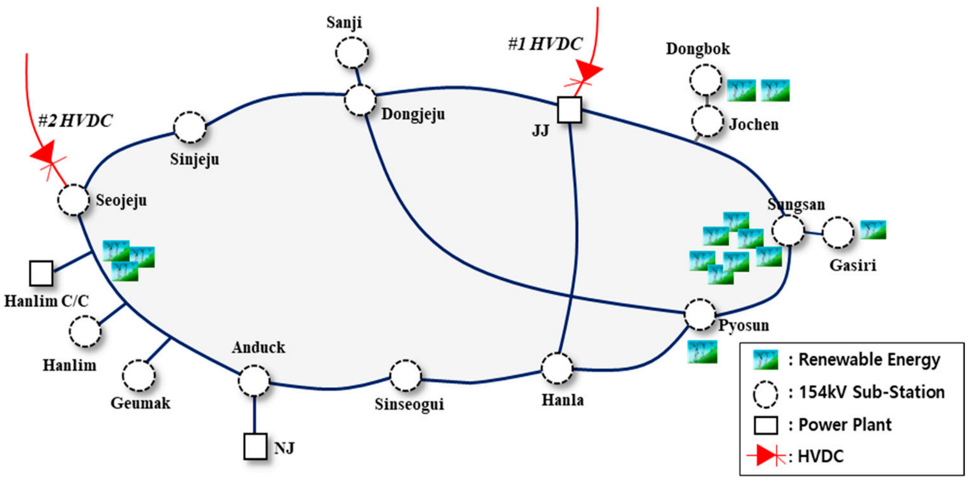


**Figure 1.** Configuration of the Jeju power system.

**Table 1.** Jeju power facilities and renewable energy generation.

| Facility | Capacity (MW) | Generated Energy (MWh) |
|---|---|---|
| HVDCs | 700 (22.4%) | 1808 (31.6%) |
| Conventional Generators | 590 (44.7%) | 3090 (54.0%) |
| Wind | 290 (16.2%) | 252 (4.4%) |
| PV | 290 (16.2%) | 549 (9.6%) |
| Bio, etc. | 9 (0.5%) | 21 (0.4%) |
| Total | 1879 (100%) | 5720 (100%) |

The amount of renewable energy supplied by the Jeju power system can be calculated by subtracting the amount of power generated via conventional generators and the power supplied via HVDCs from the total demand, as shown in Equation (1).

$$RE_{gen} = Demand - (Gen_{Conv} + HVDC_{MW}) \tag{1}$$

where $RE_{gen}$ is the PV and wind energy output (MW), $Demand$ is the total demand in Jeju (MW), $Gen_{Conv}$ is the output of conventional generators (MW), and $HVDC_{MW}$ is the power transmitted via HVDCs from the mainland to Jeju (MW).

To ensure the minimum inertia requirement and maintain a stable frequency during contingencies, four to seven RMR units are required, depending on the demand according to the existing operational planning [13]. These are typically thermal- and gas-based generators. Considering the minimum operation level based on technical specifications and the margin for frequency control, the HVDCs must be operated at 80 MW or higher. In detail, the Jeju power system requires at least four RMR units at the light load period when curtailment often occurs. The total power generation of these units and the HVDCs must amount to 300 MW or more.

Although the peak demand of the Jeju power system is approximately 1000 MW, it decreases to 550 MW during spring and fall. During this period, the maximum amount of renewable energy that can be generated is 250 MW, according to Equation (1). Figure 2 and Table 2 are examples of curtailment that occurred during one day in Jeju islands in March, 2020. Figure 2 depicts a situation where renewable energy curtailment is necessary due to the low demand of the Jeju power system. From Figure 2, renewable energy curtailment begins at 9:00, increases gradually, and lasts until sunset, which begins at 17:00, continuing for approximately 8 h. This curtailment is primarily due to the light load and the increase in PV generation during the day. Table 2 lists the amount of excess renewable energy curtailed at each hour with respect to the power demand.

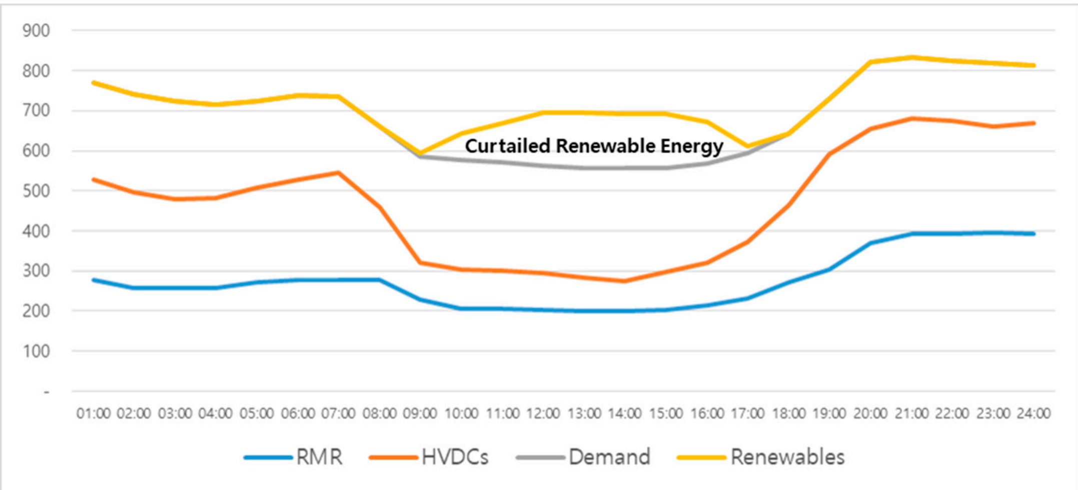


**Figure 2.** Comparison of power from reliability must-run (RMR) units, high-voltage direct currents (HVDCs), renewable sources, and total demand.

**Table 2.** Required curtailment in Jeju power system (MWh).

| **Hours** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amount | - | - | - | - | - | - | - | - | 8 | 66 | 99 | 132 | |
| **Hours** | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 834 |
| Amount | 136 | 136 | 136 | 104 | 17 | - | - | - | - | - | - | - | |

In 2015, for the first time, a curtailment of 150 MWh was necessary for the Jeju power system. Thereafter, there was an increase in the amount of renewable energy, primarily PV energy, in the Jeju power system. Consequently, the total curtailment in 2019 was 9230 MWh, which occurred over 46 events, as shown in Table 3. Table 3 is the result of the number and amount of curtailment occurring annually in the Jeju system, and regardless of whether the amount of curtailment per day is high or less, the number of curtailment occurrences is assumed to be once, and the amount is the sum of the amount generated on each day.

**Table 3.** Renewable energy curtailment in the Jeju power system from 2015 to 2019 (MWh).

| Year | 2015 | 2016 | 2017 | 2018 | 2019 | Total |
|---|---|---|---|---|---|---|
| No. of Event | 3 | 6 | 14 | 15 | 46 | 84 |
| Amount | 150 | 250 | 1300 | 1370 | 9230 | 12300 |

## 3. BESS Deployment Strategy in the Jeju Power System

### *3.1. BESSs for Storing Renewable Energy*

For mitigating renewable energy curtailment, a commonly used method is to store excess renewable energy, which would normally be curtailed, in BESSs. In this method, BESSs undergo charging when the output of renewable energy is high and discharging when the renewable energy output is low; thus, transmission or distribution lines are not overloaded. In such cases, the BESSs are distributed and installed in individual renewable energy power plants. The overall configuration of a BESS is shown in Figure 3 [14].

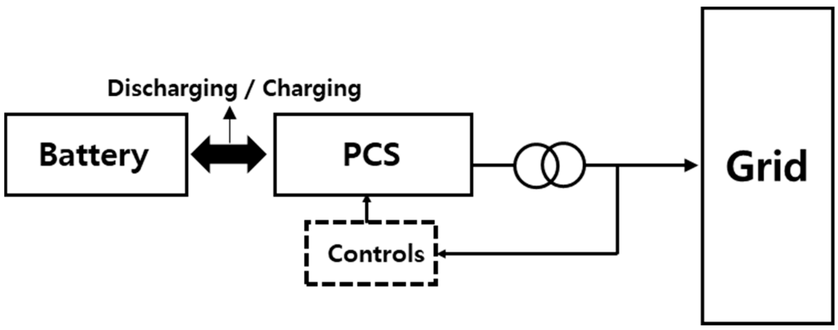


**Figure 3.** Configurations of the battery energy storage system (BESS).

If curtailment is required for balancing the entire system, as discussed herein, BESSs can be installed at the transmission level of substations. For the Jeju power system, the BESS is installed at a 154-kV-level substation. In this paper, BESS was injected into the Geumak substation to perform the simulation, and according to the actual operation plan of the Jeju system, the BESS was planned to be put into the Geumak substation. The capacity of the power conditioning system (PCS), which bidirectionally converts electrical energy between a battery and the power grid, is set to 50 MW, and the battery capacity is 25 MWh. These values are determined based on field installation conditions, such as the area available for the BESS, as shown in Figure 4.

The meaning of the capacity of the battery and PCS in Figure 4 means that it takes 30 min to charge and discharge for 50 MW. Based on the realistic equipment condition of such a BESS, Equation (2) shows the formula for whether the curtailment amount can be handled within the BESS capacity. The expected reduction in renewable energy curtailment through the use of the BESS with a battery capacity of 25 MWh can be determined according to Equation (2).

$$MWh_{ess} = \sum_{n=1}^{m} \min\left(Btry_{cap},\ MWh_{curn}\right) \tag{2}$$

where $MWh_{ess}$ is the reduced generation due to curtailed renewable energy (MWh), $m$ is the total number of the event of curtailment, $Btry_{cap}$ is the battery capacity of the BESS (MWh), and $MWh\_cur$ is the amount of curtailed renewable energy (MWh).

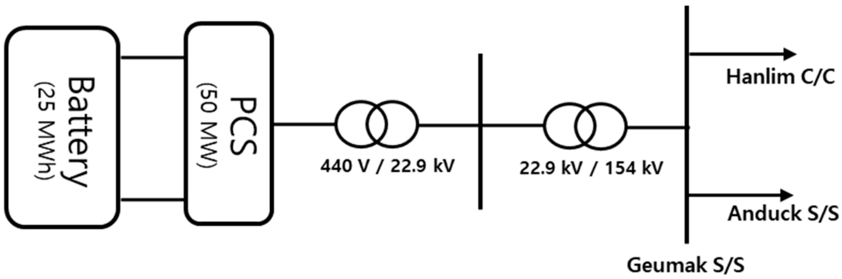


**Figure 4.** BESS installation at the 154-kV Geumak S/S.

In calculating the amount of curtailment based on Equation (2), if the amount of curtailment is larger than the BESS capacity, the number of occurrences of curtailment increases by one, and the amount is calculated as the subtraction from the BESS capacity. On the other hand, if the amount of curtailment is lower than or equal to BESS capacity, the number and amount of curtailment were not reflected in the results. A total of 84 curtailments have occurred since 2015. Among these, 17 events involved a curtailment of less than 25 MWh, and the total curtailed energy during these events was 172 MWh. In the remaining 67 events, daily curtailment exceeded 25 MWh. If a curtailment of 25 MWh or higher occurs, or if curtailments occur at different time periods in the same day, it is assumed that charging/discharging is performed once daily considering conditions such as the charge/discharge life and maintenance of the BESS.

As shown in Equation (2), the total expected mitigation of curtailment for the Jeju power system is 1847 MWh. Therefore, when the BESS with a battery capacity of 25 MWh is applied, the total amount of curtailment in the Jeju power system will be 10,453 MWh, as shown in Table 4.

**Table 4.** Effect of mitigating renewable energy curtailment using a BESS for storage from 2015 to 2019 (MWh).

| BESS | Year | 2015 | 2016 | 2017 | 2018 | 2019 | Total |
|---|---|---|---|---|---|---|---|
| Out of Service (a) | No. of Event | 3 | 6 | 14 | 15 | 46 | 84 |
| | Amount | 150 | 250 | 1300 | 1370 | 9230 | 12,300 |
| In Service (b) | No. of Event | 3 | 4 | 11 | 8 | 41 | 67 |
| | Amount | 75 | 146 | 971 | 1111 | 8150 | 10,453 |
| Effect (a–b) | No. of Event | 0 | 2 | 3 | 7 | 5 | 17 |
| | Amount | 75 | 104 | 329 | 259 | 1080 | 1847 |

### *3.2. Determining the Number of RMR Unit in Jeju Islands*

BESSs can be used to regulate the frequency of the power system. This function can be largely divided into normal frequency regulation, which corresponds to the automatic generation control of a conventional generator, and primary response to serve in the case of contingency such as generator tripping. There has recently been a decrease in the inertia of power systems due to an increase in the penetration of inverter-based renewable energy. Various methods supplementing the insufficient inertia by using wind power generators or synchronous generators have been suggested [15]. BESSs are particularly effective in supplementing the insufficient inertia of power systems owing to their fast response characteristic [16]. The BESS considered in this study has a response time of several hundred milliseconds and maintains its output for 30 min; thus, it can supplement the insufficient inertia of the Jeju power system, increase the frequency nadir, and continue discharging until redispatching is achieved via the HVDCs and the conventional generators as a remedial action. Therefore, it contributes to the frequency stability of the entire power system.

It may appear differently depending on the size of the system and fault, but in most systems, the frequency nadir point appears around 8–10 s after a generator trip occurred. However, in the case of a small-scale system, such as the Jeju power system, it is greatly affected by disturbance, so when one large-capacity generator trip occurs, a frequency nadir point appears within about 2 s. When reaching the frequency nadir point within 2 s, the only resources that can act after fault are the inertia of the synchronous generator and fast-responsive resources such as HVDC or ESS. Generator governor output control is a resource after 4 s and cannot intervene in the formation of the frequency nadir.

Therefore, the number of synchronous generators according to the load level is an important factor in terms of providing inertia until the lowest frequency is formed, and the number of synchronous generators operating in the Jeju power system is reflected in the operation plan.

Compared to the total capacity of the Jeju power system, single-generator units in this system have high capacities. Thus, a three-phase fault at the bus with the largest generator connected is the most critical contingency. Following a contingency, even if the generator is stopped and commutation failure occurs in a nearby HVDCs, some conventional generators are designated and operated in the "must-run" status to prevent a blackout due to under frequency relay (UFR) triggering. As described earlier, four to seven RMR units are required for each demand level. As curtailment occurs during light load, four RMR units are employed. As shown in Table 5, the minimum power generation of the four RMR units is 220 MW.

**Table 5.** Parameters of the RMR generators.

| *Generator* | *Pmax* (MW) | *Pmin* (MW) | *Capacity* (MVA) | *H* (s) |
|---|---|---|---|---|
| JJ | 80 | 50 | 97 | 5.5100 |
| JC | 100 | 80 | 126 | 5.9350 |
| NJ#1 | 100 | 45 | 130 | 5.8360 |
| NJ#2 | 100 | 45 | 130 | 5.8500 |

Even if a contingency occurs in the Jeju power system, the BESS can be used to compensate for the reduced inertia and improve frequency stability, resulting in a reduced number of RMR units. If the number of RMR units in Table 5 can be reduced by one, additional renewable energy can be generated in the Jeju power system. This energy would be equivalent to the generations of the excluded unit among the RMR unit.

PSS/E was used for simulation, and a second-generation BESS model, acquired from the general models provided by PSS/E, was employed in the simulation. This model, comprising three modules, was first developed by WECC (Western Electricity Coordinating Council) and recommended by NERC (North American Electric Reliability Corporation). The modules are REGCAU1(Renewable Energy Generator/Converter Model), REECCU1, and REPCAU1. REGCAU1 is a renewable energy generator/converter module, REECCU1 is a renewable energy electrical control module, and REPCAU1 is a renewable energy plant controller module. For each model parameter, the default values recommended in the PSS/E manual and by NERC were used [17–19].

To compare the effect of mitigating renewable energy curtailment by reducing the number of RMR units, it was assumed that the same capacity with the storing BESS in the previous section was considered. A BESS used for improving frequency stability within several tens of seconds does not necessitate a large battery capacity. However, to maintain a stable frequency of the Jeju power system during redispatching via other conventional generators after the transient period, a BESS of 2 C-rate (Current rate) or lower is recommended.

## 4. Case Study

### 4.1. Effect of Reducing RMR Units Using BESS

#### 4.1.1. Simulation Conditions

To verify the effect of reducing the number of RMR units through the use of the BESS, a simulation was conducted for the cases presented in Table 6. The power demand and HVDC operation conditions were fixed at 550 and 80 MW, respectively, and the simulation was conducted by varying the BESS and RMR unit operation conditions for each case. As the contingency in each case, it was assumed that a three-phase fault occurred at the bus where the generator JC was connected.

**Table 6.** Simulation cases.

| Case | Demand (MW) | Re. Energy Generation (MW) | HVDC (MW) | Number (Capacity) of RMR Units | BESS |
|---|---|---|---|---|---|
| A | 550 | 250 | 80 | 4 (220 MW) | Out of service |
| B | 550 | 300 | 80 | 3 (170 MW) | Out of service |
| C | 550 | 250 | 80 | 4 (220 MW) | In service |
| D | 550 | 300 | 80 | 3 (170 MW) | In service |

In Cases A and B, the BESS is out of service, and in Cases B and D, the number of RMR units was reduced to three. The JJ generator was excluded in operation and renewable energy generation increased by 50 MW. To elucidate the effect of applying the BESS, the frequency of each case was monitored to check whether reliability criteria were met. According to the reliability criteria of the Jeju power system, even if a critical contingency occurs, the frequency must be maintained above 59.4 Hz.

The kinetic energy and inertia constant of each case can be calculated using Equations (3) and (4), respectively [20,21]. The results are summarized in Table 7.

$$E_{k,\ sys} = \sum\nolimits_{i=1}^{N} S_{ri} \cdot H_i \tag{3}$$

$$H_{sys} = \frac{E_{k,\ sys}}{\sum_{i=1}^{N} S_{ri}} \tag{4}$$

where $H_i$ is the inertia constant of the i-th generator, $S_r$ is the rated apparent power, $E_{k,\ sys}$ is the total rotational kinetic energy, and $N$ is the number of generators.

**Table 7.** Kinetic energy and H for the simulation cases.

| Case | $S_{sys}$ (MVA) | $E_{k,\ sys}$(MW·s) | $H_{sys}$(s) |
|---|---|---|---|
| A | 733 | 2801 | 3.8219 |
| B | 686 | 2267 | 3.3047 |
| C | 733 | 2801 | 3.8219 |
| D | 686 | 2267 | 3.3047 |

As the generator operation conditions in Cases A and C were identical, the apparent power, kinetic energy, and inertia constant were 733 (MVA), 2801 (MW·s), and 3.8219 (s), respectively, for both cases. In Cases B and D, where one RMR unit was excluded, $E_{k,\ sys}$ and $H_{sys}$ were reduced to 2.267 (MW·s) and 3.3047 (s), respectively, and the system was supplemented with 50 MW of renewable energy.

#### 4.1.2. Simulation Results

Figure 5 shows the simulation results depicting the effect of the number of RMR units. As shown in the simulation results, when the number of RMR units is four and the BESS is out-of-service (i.e., Case A), the lowest frequency after the contingency was 59.49 Hz. When one RMR unit was out-of-service (i.e., Case B), the lowest frequency was 59.35 Hz, indicating that the violation of reliability criteria occurs.

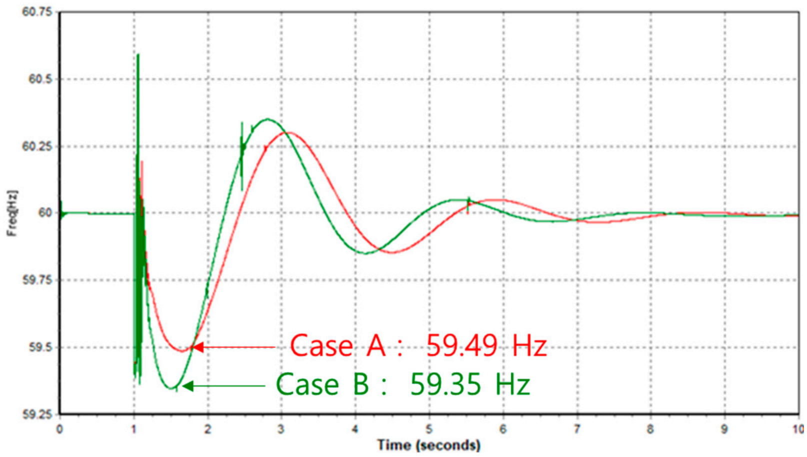


**Figure 5.** Simulation results of Cases A and B; effect of the number of RMR units.

Figure 6 shows the simulation results depicting the effect of the BESS operation. As shown in the simulation results, when the BESS was not operated and four RMR units were operated (i.e., Case A), the lowest frequency after the contingency was 59.49 Hz. When the 50-MW BESS was operated (i.e., Case C), the lowest frequency was 59.60 Hz, indicating an increase of 0.11 Hz.

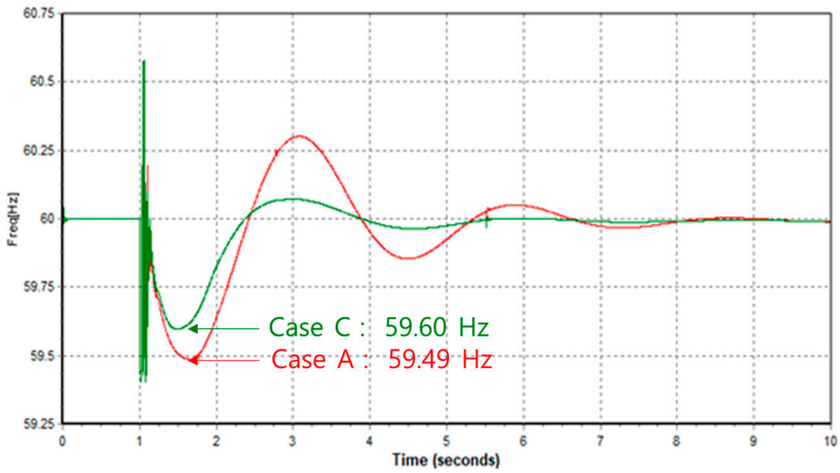


**Figure 6.** Simulation results of Cases A and C; effect of BESS operation.

Furthermore, when operating three RMR units and the BESS, the lowest frequency was 59.47 Hz, indicating a decrease of 0.02 Hz compared with that in Case A. However, it was confirmed that the reliability criteria of 59.4 Hz or higher were still maintained in Case D, as shown in Figure 7.

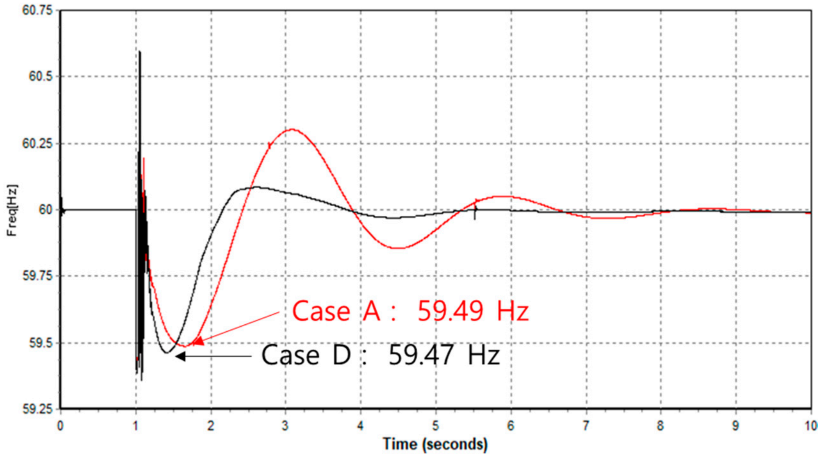


**Figure 7.** Simulation results of Cases A and D; effect of BESS operation.

### 4.2. Effect of Mitigating Renewable Energy Curtailment

When a BESS with a PCS capacity of 50 MW was applied and the system was operated with three RMR units (i.e., Case D), the daily renewable energy curtailment could be calculated using Equation (5).

$$MWh_{ess} = \sum_{n=1}^{24} max\{(MWh_{curn} - 50MWh),\ 0\} \quad (5)$$

where *MWh_ess* denotes the reduced renewable energy generation due to daily curtailment with the BESS (MWh), and *MWh_cur* represents the amount of curtailed renewable energy without the BESS (MWh).

Table 8 shows the total amount of annual curtailment, calculated using Equation (5), and the actual case renewable energy curtailment occurred in Jeju from 2015 to 2019.

**Table 8.** Effect of mitigating renewable energy curtailment using BESS for improving frequency stability from 2015 to 2019 (MWh).

| BESS | | 2015 | 2016 | 2017 | 2018 | 2019 | Total |
|---|---|---|---|---|---|---|---|
| Out of Service (a) | No. of Event | 3 | 6 | 14 | 15 | 46 | 84 |
| | Amount | 150 | 250 | 1300 | 1370 | 9230 | 12,300 |
| In Service (b) | No. of Event | 0 | 0 | 2 | 3 | 18 | 23 |
| | Amount | 0 | 0 | 63 | 148 | 2285 | 2496 |
| Effect (a–b) | No. of Event | 3 | 6 | 12 | 12 | 28 | 61 |
| | Amount | 150 | 250 | 1237 | 1222 | 6945 | 9804 |

When using the BESS and three RMR units, there was no curtailment of renewable energy in 2015 and 2016, whereas curtailments of 63, 148, and 2285 MWh occurred in 2017, 2018, and 2019, respectively. An annual comparison from 2015 to 2019 indicates that the number of curtailment events decreased by 61, which suggests that the rate was 27.3% of the curtailment during the period when the BESS was not applied. Furthermore, the amount of curtailment decreased by 9804 MWh, which was only 20.3% of the curtailment during the period when the BESS was not applied. The reduction in the number of curtailment events is just as important as the reduction in the amount of curtailment because the number of curtailment events is one of the main concerns for the participants in the renewable energy market. Figures 8 and 9 show the total curtailment before and after the BESS was applied for reducing the number of RMR units.

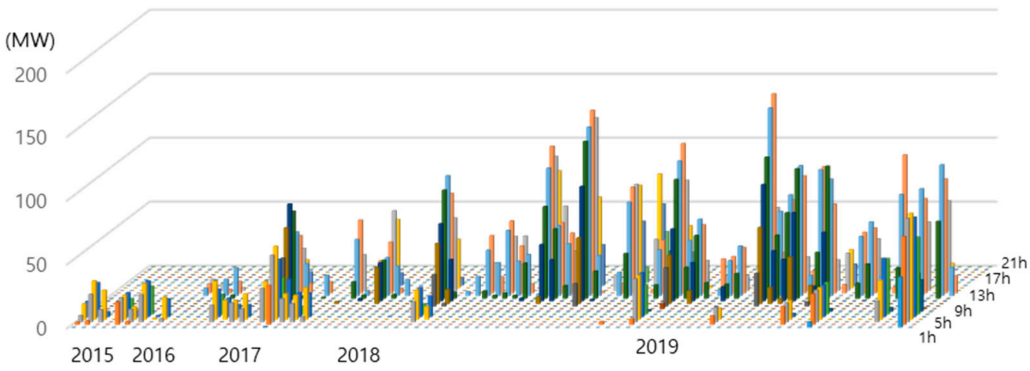


**Figure 8.** Renewable energy curtailment without an ESS.

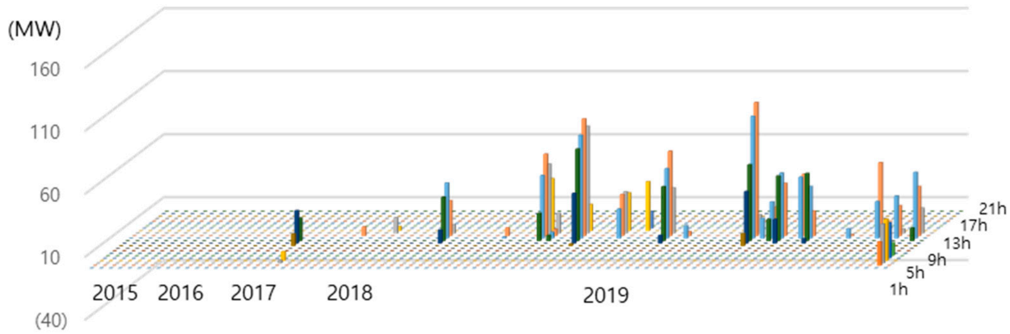


**Figure 9.** Renewable energy curtailment with an ESS.

## 5. Comparison of Results on Applying BESS

As discussed in Section 3.1, when a BESS with a PCS capacity of 50 MW and a battery capacity of 25 MWh was applied for storing renewable energy in the Jeju power system from 2015 to 2019, a total of 1847 MWh of additional renewable energy could be generated. Furthermore, on reducing the number of RMR units and using a BESS with the same capacity to improve frequency stability, an additional 9804 MWh of renewable energy could be generated; thus, this approach was approximately 5.3 times more effective than using the BESS for storing renewable energy, as shown in Table 9.

**Table 9.** Comparison of the effect of applying BESSs for storage and improving frequency stability (MWh).

| BESS | | 2015 | 2016 | 2017 | 2018 | 2019 | Total |
|---|---|---|---|---|---|---|---|
| Storing (a) | Frequency | 3 | 4 | 11 | 8 | 41 | 67 |
| | Amount | 75 | 146 | 971 | 1111 | 8150 | 10,453 |
| Stability (b) | Frequency | 0 | 0 | 2 | 3 | 18 | 23 |
| | Amount | 0 | 0 | 63 | 148 | 2285 | 2496 |
| Difference (a–b) | Frequency | 3 | 4 | 9 | 5 | 23 | 44 |
| | Amount | 75 | 146 | 908 | 963 | 5865 | 7957 |

The difference between the two methods is that when the total daily curtailment exceeds the battery capacity of the BESS, further curtailment mitigation is not possible; hence, effective curtailment mitigation is limited by the battery capacity of the storing BESS. If the number of RMR units is reduced using the BESS for improving frequency stability, an additional renewable energy generation equivalent to the generation output of the excluded RMR unit is persistently achieved.

Considering the abovementioned results, a similar trend is expected for systems with significant and prolonged curtailments. However, in systems with lower daily curtailments less than the battery capacity of the BESS, results may differ.

Considering the recent increase in the penetration of renewable energy and the difficulty in further developing power grids, renewable energy curtailment is expected to increase gradually. Therefore, mitigating such curtailments by improving frequency stability using BESSs is deemed a more effective alternative.

## 6. Conclusions

To reduce carbon emissions, several countries have adopted the expansion of renewable energy as the primary goal for power and energy industries. Through the "Carbon-Free Island Project" in Jeju Island, renewable energy generation is expected to reach approximately 4 GW by 2030, for which wind and PV energy will be the main contributors. However, the peak demand in Jeju is approximately 1 GW. If 4 GW of renewable energy is penetrated in Jeju, a significant amount of its renewable energy will need to be transmitted to the mainland, which is not feasible when considering reliability constraints. Thus, renewable energy curtailment will be necessary as this amount of energy cannot be transmitted via HVDCs owing to operational limits. These HVDCs are used to ensure power reliability in Jeju and interconnect the mainland and Jeju power systems. Several researchers have focused on alternatives such as P2G and P2H to accommodate the additional penetration of renewable energy. Employing BESSs is one of these currently discussed alternatives.

In this study, two methods that employ BESS to increase renewable energy generation were applied to the Jeju power system. The resulting effects of these methods were analyzed and compared. The first method is a widely known method whereby excess renewable energy, which would normally be curtailed, is stored in the BESS. In the second method, the number of RMR units is reduced by improving frequency stability with BESS. When the amount of curtailment was considerably greater than the capacity of the BESS, such as in the Jeju power system, it was confirmed that the second method offers more prominent mitigation of renewable energy curtailment, as compared to the first method.

A comparison between these methods based on actual curtailment events in the Jeju power system from 2015 to 2019 indicated that using BESS to reduce the number of RMR units is more effective than using it to store excess renewable energy. As noted in this analysis, the performance of the method may vary depending on the PCS and battery capacity of the BESS and the amount of renewable energy curtailment. However, it was also concluded that reducing the number of RMR units is more beneficial given the current trend of rapidly increasing renewable energy penetration.

In this study, although the BESS was used to improve frequency stability, it can also be used in power systems requiring RMR units to improve reliability. In such cases, the method is expected to be more effective than simply using BESS for storing excess energy. To validate the effectiveness of each method more precisely, the curtailment mitigation afforded by each method needs to be compared and analyzed based on changes in the PCS and the battery capacity of the BESS. These analyses will be performed in future studies.

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