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Automatic Generation Control System: The Impact of Battery Energy Storage in Multi Area Network

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Abstract: Renewable energy sources (RES) are currently experiencing significant expansion, and the integration of these sources into power systems necessitates more complex auxiliary facilities. Battery energy storage systems (BESS) have been widely recognized in recent literature as an effective means of enhancing control capabilities. This study focuses on the implementation of an Automatic Generation Control (AGC) system with the integration of BESS in a multi-area network. Maintaining system frequency, especially during peak loads, poses challenges for AGC systems. The objective of this study is to investigate the utilization of BESS to enhance AGC for frequency control in power system networks. Additionally, the effectiveness of BESS in improving frequency control in multi-area networks is demonstrated through several case studies. The AGC and BESS simulations were conducted using MATLAB Simulink to evaluate the proposed frequency control method's effectiveness.

Keywords: Automatic Generation Control, BESS, frequency control

1. Introduction

Load demand usage is inherently uncontrollable and uncertain, leading to variations over time. Consequently, during peak load periods, the sudden increase in load demand can disrupt the system's frequency in the power network. To address this issue, the Automatic Generation Control (AGC) system is employed in the power system network. The primary objective of the AGC system is to ensure the balance of active power between the supply and demand, thereby maintaining a frequency of 50Hz [1],[2],[3]. AGC is employed to restore balance between power demand and generation by adjusting the output of generating units [4]. AGC plays a crucial role in maintaining the scheduled system frequency and the tie line, ensuring stability during both normal and abnormal operating conditions [5]. AGC knowingly facing difficulty maintaining the frequency particularly at peak loads for example when sudden increase of demand at high load occurs, generators will spin more to match with the increasing load demand. This becomes more troublesome when involving slower conventional unit commitment i.e., hydro power in AGC environment.

The hydropower plant is much slower compared to the gas turbine combined cycle. During sudden increase of demand, the generators will spin more to match with the load demand however hydropower unable to keep up with the rapid changes in demand unlike Gas turbine combined cycle (GTCC) [1].

The objective of this paper is to investigate the automatic generation control for frequency control in power system network and proposed a control method for battery energy storage system for integrated network.

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This paper is organized as follows: Section 1.1 provides an overview of automatic generation control system. Section 1.2 application of AGC with BESS. Section 1.3 methodology of AGC 30 model and BESS model. Section 2 presents the results of simulation for all cases.

1.1 Automatic Generation Control System

To ensure the reliability and safety of the power grid during real-time operations, AGC plays a crucial role. AGC is responsible for continuously monitoring and adjusting the power output of generators to maintain a balance between electricity supply and demand in real time. One of the key objectives of AGC is to regulate the system frequency and ensure that it remains stable within acceptable limits. As the power output and load demand vary, AGC actively controls the generation resources to ensure that the system frequency is maintained at the desired level. By continuously tracking and adjusting the grid generation, AGC helps to maintain a stable and synchronized power supply, ensuring the smooth operation of the power grid.

In [2], a study on the AGC of a major hydropower project to guarantee the reliability, and protection power grids have been made. The approach is developed to overcome the load distribution and unit commitment (UC) at AGC.

In advance, this approach defines all possible compounds under various water heads and decides permissible operating areas using combinatorial mathematics. AGC has been integrated together with a redesigned cascade controller and renewable sources [6]. A modern hybrid scheme is used for the optimization of controller parameters for better teaching, learning based on optimization-differential evolution (hITLBO-DE). Compared with hITLBO-DE tuned cascaded controllers with complex load shift.

PID controller with automatic generation control and automatic voltage controller loops for two areas of power grid has been discussed [7]. Two field power systems with PSO integrated PID controller were investigated. The analogy with the proposed PSO-based controller indicates the best dynamic solution for a change in the load for the proposed controller. AGC system provides an optimum frequency control scheme for an integrated power grid, in real-life operating conditions, based on the regulator's saturation and generating rate [8].

1.2 AGC with BESS Application

A battery energy storage system (BESS) of an IGBT bidirectional current operated inverse reverser (CCI), a 240 V Ni-Cd battery bank, an LC filter been used, and it was demonstrated that BESS manages to work well under PID controller. Even with the wind power generated below the load, the BESS allows for a temporary WO mode, which improves the WDPS reliability [9].

To optimize AGC efficiency of such generators, BESS is used to regulate frequency. At Shingshan Thermal Power Station, Beijing, it uses 2-MW BESS. Usually within 5 minutes the control AGC is reversed. The capacity is set at 15 minutes to satisfy the AGC's energy demand. Few models of case studies have shown that the generator can be shifted to the first spot in the AGC rankings by a power capacity of 2 MW. The BESS is therefore set up to 2MW times with 15 minutes. The 2 MW energy storage has 18 parallel storage units and 8 series battery modules. The inter-cell charging balance is managed by the battery management system (BMS) [10]. Besides, a study in [11] shows that a new self-adapting control strategy that is proposed for multiple BESSs in power system combined with traditional generators able to improve the performance of AGC.

A new BESS management approach for enhancing automated generation controls complex efficiency. This control approach applies to electricity systems that measure AGC output using margins for control reaction precision that usually determine that the power reaction to the regulation signal is the slowest and fastest possible.

The primary objective is to enhance the regulatory service by minimizing the non-compliance rate with the required dynamic performance parameters and specified margins of precision.

A case study of 400 hours of actual AGC activity with different BESS sizes is done to check effectiveness and it shows that a BESS will substantially decrease loss, while retaining low BESS consumption and breakdown. The proposed BESS control strategy is designed to improve electrical power systems' regulatory accuracy that assess regulatory efficiency using power response tolerance margins [12].

The properties and benefits of Lithium-Ion Battery have been studied, including the operating processes, battery architecture and construction and weaknesses [13],[14],[15]. Furthermore, the output in grid storage systems of Lithium-Ion Battery is evaluated with respect to frequency control, maximum adjustments, and the following grid services. Load Frequency Control Mechanism (LFC) in a deregulated power setting for the multiple generation of two areas of connected power systems with energy storage systems was proposed in [16]. In a previous study [17], a new AGC strategy has been introduced, which takes into account the possibility of communication failure. This novel AGC strategy incorporates a LFC strategy that utilizes AGC units with minimal risk of communication failure to effectively manage the unpredictable short-term load fluctuations.

In [18], a strong control structure to include distributed load frequency control (LFC) through BESS aggregators with sparsely communicating networking by applying Model Predictive Control (MPC) and the MPC has been successfully applied to the LFC problem in power systems with wind turbine [19] and also hydro/thermal units [20]. Research in [21] suggested that LFC be suppressed by BESS control system frequency variations and contrasts for the photovoltaic (PV) solution for a power grid. The performance was checked by using Japanese Power System's newer AGC30 model.

1.3 AGC 30 Model and BESS

In the initial stage of the project simulation, all the necessary parameters are initialized, including the values of supply and demand. A total of 30 existing generators are operated based on the load demand forecast, which includes scenarios of both low and high load conditions.

Moving to the second stage, AGC system is designed specifically for frequency control. The AGC system focuses on Load Frequency Control (LFC) and aims to maintain the frequency deviation within the range of ±0.5Hz as shown in Fig. 1. This means that the AGC system actively adjusts the power generation of the generators to balance the load and stabilize the system frequency, ensuring it remains within the acceptable limits.

In the third stage of the project simulation, two parallel conditions will be considered: one with the inclusion of a Battery Energy Storage System (BESS) and the other without it. The BESS is integrated into the system to enhance the performance of the AGC system. The BESS has a rated output of 20MW. Next, the BESS is associated with the supply-demand profile, and the appropriate control method is determined. The control method chosen for this study is the peak shaving method, load shifting method, or load leveling method. These methods are employed to optimize the operation of the BESS and assist in maintaining the system frequency within the desired range. By implementing the selected control methods, it is expected that the frequency deviation can be reduced and controlled effectively, aiming to keep it within the range of ±0.2Hz.

In the next stage, several case studies will be conducted to further investigate the performance of the system. The case studies will be divided into two types: frequency control without BESS and frequency control with BESS. Each type will be further divided into two scenarios: low load and high load. By conducting these case studies, the effectiveness of the AGC system with and without the BESS in maintaining system stability and controlling frequency deviation will be examined. The results of the case studies will provide valuable insights into the performance and potential benefits of integrating a BESS into the frequency control system.

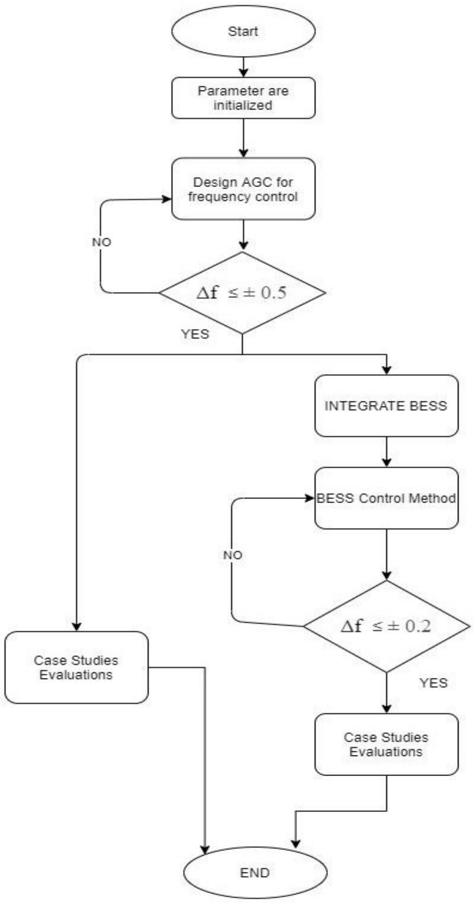

Fig. 1 - Figure flowchart of frequency control in power network system

In this project, the AGC 30 model will be utilized for simulation purposes using Simulink Matlab software. AGC 30 consists of 30 existing generators and is designed for a multiarea interconnected power system. The interconnected areas are specifically related to LFC for frequency control in the power system network. Additionally, the system includes an inertia model to enhance its performance. Fig. 2 provides a visual representation of the AGC 30 model, aiding in better comprehension of its structure and functionality.

This method provides a logical and numerical way to modeling the BESS via MATLAB/Simulink. The modeling methodology offered is based on simple logic and mathematical functions that simulate BESS's functional conduct. The BESS Simulink model has 3 key components, which are supply-demand, energy storage system of the battery and the output of the battery. The supply-demand will be retrieved as the charging of BESS from MATLAB's workspace on an hourly basis.

The BESS charging and discharge controls the charging and discharge of the battery. In the charge settings the power conversion system begins to charge a battery from the grid supply when its load consumption is lower than the kW charging settings.

The conversion system is located among the charging controller, battery, and grid. The load control output determines whether the battery is charged from the grid or discharged to supply power. The input of the electricity conversion system flows via a saturation block which acts as the maximum load and discharge power of the BESS. In the battery component, the input for the battery model is a signed integer representing kW samples on an hourly basis.

The parameter that has been set for BESS to operate is shown in Table 1. Rated power is set at 20MW with nominal battery capacity is at 20MAh and the initial battery state of charge is set at 50%. The battery is located between the supply - demand summing junction and inertia model. The position of the battery will make the peak shaving method easier to apply and helps the inertia to improve its performance.

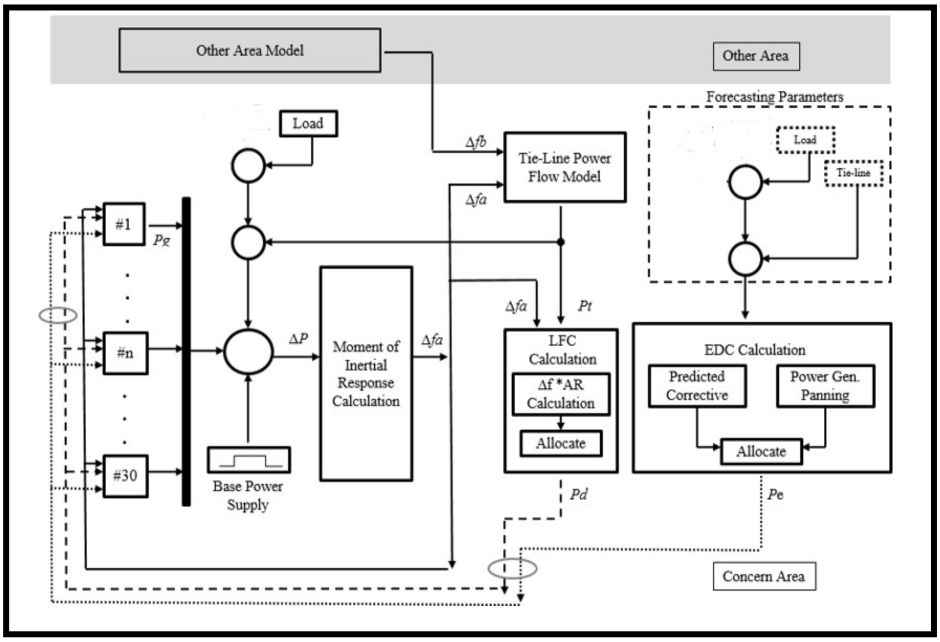

Fig. 2 - AGC 30 model

Table 1 - BESS parameter

Parameter	Value
Rated Power	20 MW
Power conversion system efficiency	95%
Nominal Battery Capacity	20Mah
Initial Battery State of Charge	50%

2. Simulation Results

In this section, the result of simulation AGC30 will be presented which consists of two different case studies and four different scenarios which are: a) High load with and without battery energy storage system and b) Low load with and without battery energy storage system.

2.1 Simulation Comparison of High Load and Low Load without BESS

The result in Fig. 3 shows the frequency deviation of the power system network in high load condition at peak hour. As can be seen in Fig. 3, from 0s to 1000s the frequency was steadily maintained the oscillation at ±0.05Hz. After a while, at 2000s the frequency deviation starting to drop from -0.05Hz to -0.2Hz. This happened when the sudden change of load demand happens. The mismatch between supply and demand in a condition when demand is higher than the load, the frequency deviation will drop to negative value. In the graph showing that at 2000s, the oscillation starting to drop from 0.05Hz to -0.2233Hz.

In the meantime, the AGC system responds and works to maintain the frequency of the system. From the time interval of 4000s to 4700s, the frequency gradually increases from -0.18Hz to 0Hz. After 5000s, the frequency reaches its maximum value of 0.3158Hz. This increase in frequency is a result of the supply of power being higher than the demand.

At 6000s, the frequency begins to decrease, and by 8000s, the frequency deviation stabilizes within the normal range of ±0.05Hz. This indicates that the AGC system has successfully achieved its objective of regulating and stabilizing the system's frequency.

The results in Fig. 4 illustrate the frequency deviation in a low load condition. From the beginning of the simulation (0s) until 4000s, the frequency is consistently maintained within an oscillation range of ±0.1Hz. However, at 5000s, the frequency deviation starts to increase slightly from ±0.1Hz to ±0.119Hz. This occurs due to a sudden change in load demand, causing a mismatch between the supply and demand. When the demand exceeds the load, the frequency deviation tends to decrease into the negative range, while an excess supply leads to a positive deviation. In this case, the changes between supply and demand are relatively small. By 6000s, the frequency is successfully restored and maintained below ±0.1Hz, as indicated in Table 2. The observed oscillation is smooth, indicating that the automatic generation control system is capable of effectively maintaining the system's frequency without encountering any significant issues.

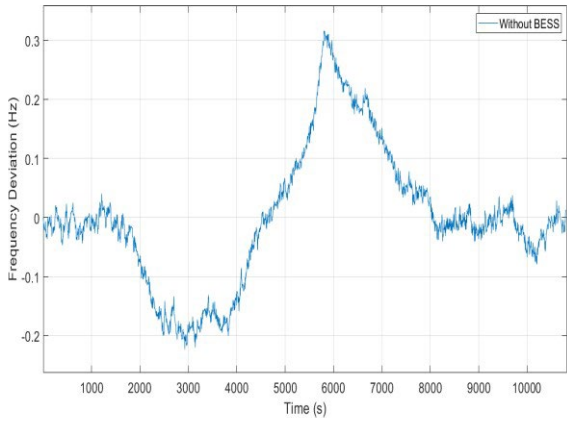

Fig. 3 - High load frequency deviation without BESS

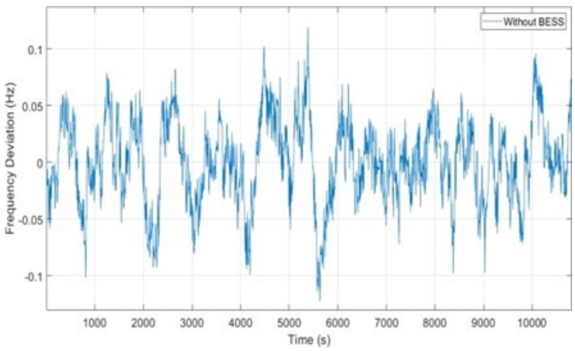

Fig. 4 - Low load frequency deviation without BESS

Table 2 - Data collected from the simulation results

Parameter	High load	Low Load
Maximum Δf (Hz)	0.3158	0.119
Minimum Δf(Hz)	-0.2233	-0.1226

2.2 Simulation Comparison of High Load and Low Load with BESS

The results depicted in Fig. 5 and Table 3 display the frequency deviation during high load conditions with the presence of BESS. Initially, from 0s to 1000s, the frequency is consistently maintained within an oscillation range of ±0.05Hz. However, at 2000s, the frequency deviation starts to decrease, reaching -0.07Hz.

This occurrence can be attributed to a sudden change in load demand, triggering the activation of the peak shaving method by the BESS. Referring to Fig. 5, it can be observed that from 2000s to 4000s, the frequency deviation remains consistently oscillating at -0.07Hz. Subsequently, at 5000s, the peak shaving method is implemented within the system. The outcome of this intervention is evident as the frequency oscillation maintains a steady pattern of 0.07Hz from 5000s to 7800s. Eventually, at 8000s, the frequency is successfully regulated and maintained within the range of ±0.05Hz. Next, the result in Fig. 6 shows the frequency deviation in low load condition with battery energy storage system. The main objective of battery energy storage system is to improve the performance of AGC by using the peak shaving method. The result in Fig. 6 shows the frequency deviation steadily oscillates at ±0.07Hz from 0s to 10500s.

2.3 Simulation Comparison with and Without BESS

In Fig. 7, a comprehensive comparison between the frequency deviation with and without the BESS controller under high load conditions is depicted. The primary objective of this analysis is to assess the impact of the BESS in minimizing the frequency deviation, particularly during instances of sudden load changes.

The performance of the frequency deviation in peak load on sudden change of load demand has improved from deviation of maximum 0.32Hz and minimum of -0.2233Hz to ±0.07Hz when BESS is included in the system. As can be seen at 8000s to 10000s, with BESS the performance of the frequency deviation is much better after the mismatch between supply and demand happens.

In Fig. 8, comparison of frequency deviation with and without BESS controller for low load is presented. The performance of the frequency deviation in low load demand has improved from maximum deviation of ±0.12Hz to ±0.07Hz when BESS is included into the system. Unlike the high load scenarios, the AGC system effectively maintains the frequency deviation without encountering significant issues in low load conditions. This is evident from the relatively stable frequency deviation shown in Fig. 8, particularly after a minor discrepancy between supply and demand occurs from 4000s to 6000s. As can be seen in Fig. 8, with battery energy storage system the performance of the frequency deviation is much better compared to without battery energy storage system.

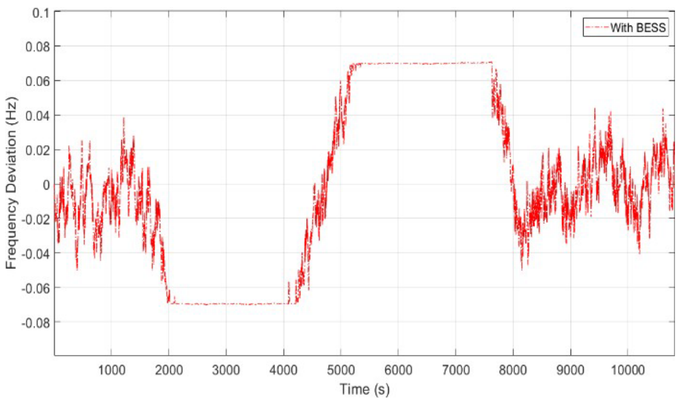

Fig. 5 - High load frequency deviation with BESS

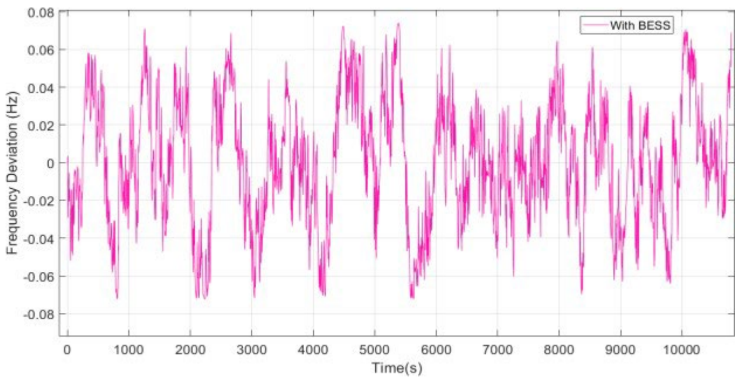

Fig. 6 - Low load frequency deviation with BESS

Table 3 - Data collected from the simulation result with BESS

Parameter	High load	Low Load
Maximum Δf(Hz)	0.07069	0.07408
Minimum Δf(Hz)	-0.07019	-0.07219

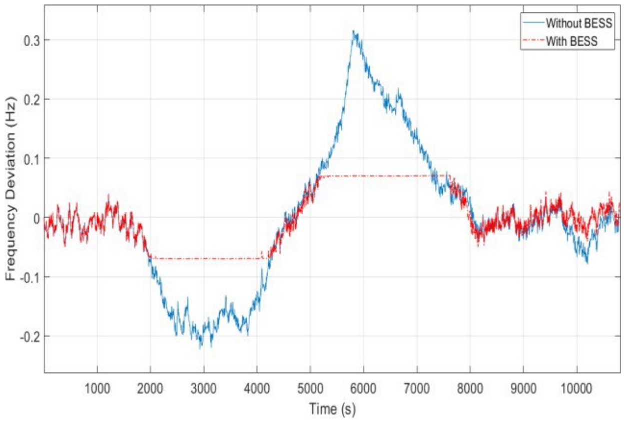

Fig. 7 - High load frequency deviation with and without BESS

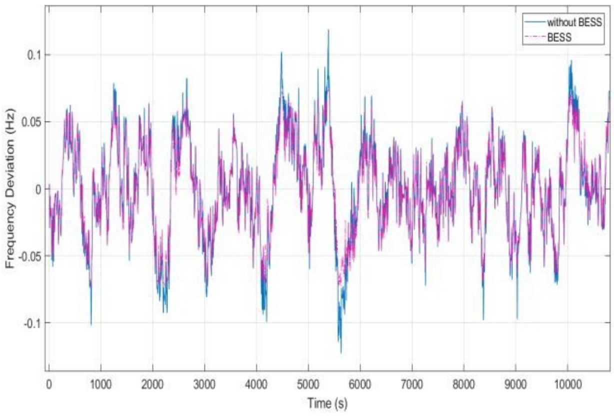

Fig. 8 - Low load frequency deviation with and without BES

2.3 Comparison of Minimization of Frequency Deviation

Another observation has been presented in Table 4, which compares the minimization of frequency deviation. For high load at maximum Δf, the percentage of frequency deviation reduction is 77.4%, and for the minimum frequency deviation reduction, it is 68.2%. For the low load, at maximum and minimum Δf, the percentage of frequency deviation reduction is 41.6%. Tables 4 and 5 show that BESS has a significant impact on minimizing the frequency deviation at high load compared to the low load.

Table 4 - High load frequency deviation reduction

Scenarios	without BESS	with BESS	Reduction, %
Maximum Δf	0.32Hz	0.07 Hz	77.4%
Minimum Δf	-0.22Hz	-0.07 Hz	68.2%

Table 5 - Low load frequency deviation reduction

Scenarios	without BESS	with BESS	Reduction, %
Maximum Δf	0.12 Hz	0.07 Hz	41.67%
Minimum Δf	-0.12 Hz	-0.07 Hz	41.67%

3. Conclusion

This study aims to investigate the automatic generation control (AGC) system for load frequency control (LFC). The literature review provides a comprehensive description and explanation of AGC. The project simulation flowchart illustrates the detailed flow designed to achieve the desired load frequency control. The simulation model, AGC 30, is employed in a multi-area interconnected power system using Simulink in MATLAB software. AGC 30 consists of 30 existing generators and two interconnected areas that relate to LFC for frequency control in the power system network. The system also includes an inertia model. A 20MW output battery energy storage system (BESS) is designed, positioned between the supply-demand summing junction and the inertia model. The purpose is to enable the BESS to determine the appropriate control technique. In this study, the BESS utilizes the peak shaving method to enhance and minimize the frequency deviation of the system. The AGC 30 system for load frequency control produces results for four different scenarios: high load with and without BESS, and low load with and without BESS. Each result is analyzed, and the impact of the BESS is highlighted in the simulation analysis of each scenario.

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