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# Using Storage Systems to Provide Frequency Control Reserves Affects Power System Operation

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**Abstract:** *Batteries may offer ancillary services like main frequency response. They, on the other hand, have a limited quantity of stamina. Therefore, temperature set points must be altered, and this energy must come from power plants that are not limited by energy. There are several benefits to power system stability and operational efficiency when energy-constrained units may engage in the ancillary service markets.Ancillary services, frequency control reserves, and battery energy storage systems are all used in this paper (BESS).*

## INTRODUCTION

In every electric power system, the production and consumption of electric energy must constantly be in balance. Control systems that automatically adjust the output of specific power plants to fit current demand are often used to do this. In the event of a plant or line failure, these control mechanisms must be flexible enough to handle the situation. Depending on the quantity of energy produced or consumed, generator speed might increase or decrease due to power imbalances. This in turn affects system frequency f. The inertia of the rotating mass of generators determines the rate of frequency shift when there is a power imbalance. Until rotational inertia is employed to counterbalance the power imbalance, the system frequency will diverge until it becomes unmanageable, resulting in a blackout.To prevent this, the European electrical transmission system has three levels of control. Primary control is a distributed control approach that adjusts the output of the power plant based on the deviation from the normal system frequency and so limits the power plant's frequency change. To maintain a stable state, this secondary control employs a central controller with an included component to restore frequency to its nominal valuers. To relieve secondary control, a tertiary control may be manually initiated to re-dispatch production. There are comparable systems in existence on all of the main electrical networks, but with somewhat different names.Despite the fact that the management method outlined above is adequate to assure the grid's safety and stability in light of the rising quantity of renewable energy in Europe, It is necessary to reevaluate the power plants' ability to offer main control reserves.The primary control power plants now have up to 30 seconds to react to a frequency fluctuation. Since there is already so much inertia in place, it is unlikely that the system's frequency would spike if a major line went down. As a result, renewable energy sources have extremely low or no rotational inertia since they are linked to the grid through converters. An increase in the amount of renewables and a reduction in conventional facilities will lead to a faster drop in frequency after a power loss.

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Systems that offer backup main control reserves may need to have their initial reaction times greatly increased. Reduced frequency deviations are generally attributed to faster ramp rates of major control units. Fast ramp rates might be achieved using batteries and flywheels.Additional options include the use of Demand Response (DR) (DR). In 1980 Schweppe et al. proposed this hypothesis, which was subsequently studied in (Xu et al., 2011) and by other researchers, including Molina-Garc'a et al. (2011) and (Molina-Garc'a et al., 2011). (2011)Now imagine a system with a large proportion of renewable power. As supplementary services, conventional power plants are often used, despite the fact that renewable energy is abundant. This must-run The production of electricity goes against the grain of achieving both cost effectiveness in distribution and a reduction in emissions of carbon dioxide.DR and storage units are becoming more important topics in power system study. There are some challenges ahead. Over an appropriate period of time, auxiliary service signals are not necessarily zero-mean. The battery's charge has run out.As a result, the battery's storage capacity is reduced since it must be charged or drained for a longer period of time. Recharging procedures must be in place to keep track of the auxiliary services signal at all times. Section 2 explains these techniques in further detail. A source of balancing energy, offset energy may be acquired on intra-day markets or retrieved from secondary control reserves.However, the frequency response behaviour has not yet been examined in terms of how it impacts grid-wide issues and the stability of the system. This research aims to fill that gap. We take a look at the effect of different set-point change approaches on overall system stability.The following is a breakdown of the document's organisation: Section 2 explains the recharging process used in this study in great detail. Recharging is described in Section 3 as a system-wide effect. Using faster units for primary control is supported by a simulation in Section 4. Sections 5 and 6 describe and discuss the findings of a historical data-based simulation as well as a contingency analysis.

## RECHARGE STRATEGIES

In the past, several methods of recharging have been considered. In the following sections, we'll provide a quick outline.Recharging on a regular basis. Ku nisch et al. (1986) explain the pi-lot battery project for West-then-islanding Berlin's frequency control system. Recharging three times a week during low-load hours, when the battery does not give On the basis of the lessons learnt from the project, it was advised to use a frequency control.There is a recharging of the deadband. Primary frequency control reserves are generally engaged unless there is a dead region around the nominal system frequency. The European grid has a dead band of 10 mHz. No set-point adjustments are done if the system frequency is outside the dead-band (Oudalov et al., 2007) It is necessary to utilise shorter resistors to drain extra energy from a battery whose State of Charge (SoC) is too high. However, there is no guarantee that SoC restrictions will always be satisfied when system frequency deviates from nominal values; the battery provides the essential response. A single month's worth of data might be utilised to show that the SoC is still within the parameters set by (Oudalov et al, 2007).Internet-based recharging. Both Borsche et al. (2013) and M'egel et al. (2013) have recently developed novel strategies based on online set-point adjustments. There must be significantly less dynamic range in the offset correction than the original signal in order for the service to be adequately delivered There are no hard and fast rules when it comes to this, but in general, power plants may alert the Transmission System Operator (TSO) of any modifications to their timetable. You might think of the internet approach as a kind of data filtration. According to (M'egel and colleagues, 2013), batteries with particular SoC levels should have their set-points modified when they reach such numbers. In the set-point changes, a time delay is included to allow for the procurement of the off-set energy from an alternative source. This method has the lowest energy cycle costs when compared to Oudalov's and Borsche's techniques. SoC performance may also be guaranteed to stay within a predetermined range of parameters. Non-linear behaviour around the SoC limits that trigger a recharge is, however, a long cry from linear. from perfect in SoC tests, and this may lead to vastly Batteries of the same kind have various results.Using a moving average, (Borsche et al., 2013) recharges the battery and compensates for battery losses as the battery is charged and discharged. As an example, the P 1 request for the primary control is derived using the f and s system frequency deviations.

$$P^{1} = -\frac{1}{S}\Delta f \quad . \qquad (1)$$

The battery output $P^{bat}$ is then adjusted by an offset $P^{off}$

$$P^{off}(k+d) = \frac{1}{a}\sum_{j=k-a}^{k} P^{loss}(j) - P^{1}(j) \quad , \qquad (2)$$

$$P^{bat} = P^{1} + P^{off} \quad . \qquad (3)$$

The average duration is determined by parameter a, which reduces the ramp rate of the offset and the second-tier service that delivers the recharge energy. Starting a new power plant or delaying the purchase of electricity in intraday markets may be more beneficial than doing so. The battery's losses, known as P loss, are measurable and can be accounted for.Only by keeping an eye on the system frequency can one predict how the battery would respond. In the worst-case scenario, tests on historical time series reveal that lesser storage quantities are sufficient, as shown by (Borsche et al., 2013). To summarise, if you see that P bat is greater than P 1, it signifies that the required battery power exceeds the available reserve power.

Inertia mimicking and control reserve supply using general power system units that are characterised by their particular ramp rate, power, and energy capacity limits, see (Ulbig et al., 2010) techniques based on the MPC (Ulbig et al., 2013). To address inter-temporal constraints on storage systems, such control algorithms may take into consideration common patterns of system frequency, such as hourly and daily cycles. As a result of the inconsistency of the system frequency, predictions, no control method based on such an intricate controller can be said to be predictable.Even though the emphasis of this work is on decentralised main control services, other TSOs have implemented or are planning to implement comparable principles. An example of this is the RegD- signal, which is provided by PJM and used for secondary control.

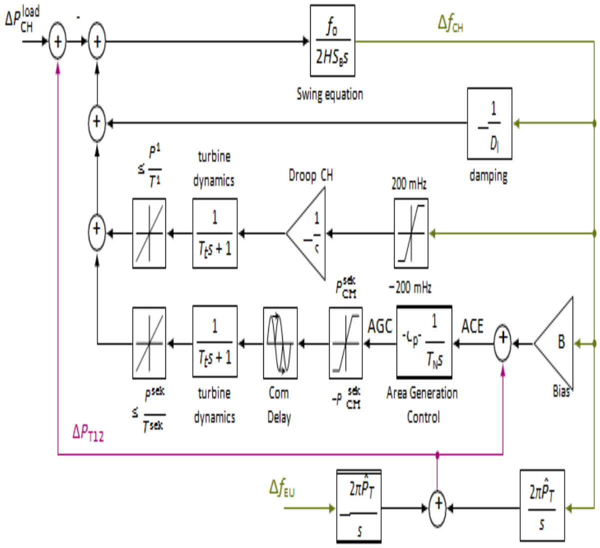


Fig. 1. One-half of the two-area system used for the simulation. Batteries not included.the same auxiliary service (Pilong, 2013, Sec 3.1.2). In order to meet the needs of "dynamic or rapid reaction resources," this signal was created.

## SIMULATION SETUP

Using a simulink model for the synchronous grid of continental Europe, the influence of main control reserves on the frequency evolution is studied. For the sake of this study, the grid is represented as a two-region system, with one area representing the Swiss control zone, and the other area representing the whole European grid.The P load and P load power mismatches serve as inputs to the two-area system. The two-area arrangement shown in Figure 1 is shown in detail. Table 1 lists the parameters utilised in the simulation, which are based on data that was previously published (Weissbach and Welfonder, 2008). The general model has been extensively researched, as shown by, e.g. (Kundur, 1994). The swing equation is the model's nucleus.

$$\frac{\mathrm{d}}{\mathrm{d}t}\Delta f = \frac{f_0}{2HS_B}\,\Delta P - \frac{1}{D_l}\,\Delta f \quad , \tag{4}$$

System inertia (H), nominal power (SB), and damping (Dl) by frequency-dependent loads (H) are all included in this equation. Additionally, the major and secondary control reserves are described in the blocks that follow. A simple low-pass filter is used to reflect the dominating dynamics when modelling the governor and turbine dynamics. For the auxiliary services, ramp rates are also defined that comply with the legislation. This means that in Switzerland all primary and secondary controls are fully activated at the end of 30 seconds, and at the end of 120 seconds elsewhere and at 300 seconds in the other control regions.

The Automatic Generation Control (AGC) activates the secondary control reserves (AGC). The ACE is sent into the AGC as an input. ACE is calculated as follows:

$$\mathrm{ACE}_l = \Delta f\, B + \sum_j \Delta P_{Tij} \quad . \tag{5}$$

Table 1. Parameters used in the simulation of the two-area system.

| parameter | variable | value CH | value EU |
|---|---|---|---|
| inertia | $H$ | 6 s | 6 s |
| base power | $S_B$ | 8 GW | 240 GW |
| Primary control reserves | $P^1$ | 80 MW | 2920 MW |
| Primary Response Time | $T^1$ | 30 s | 30 s |
| droop | $1/S$ | $400\,\frac{\mathrm{MW}}{\mathrm{Hz}}$ | $14600\,\frac{\mathrm{MW}}{\mathrm{Hz}}$ |
| Secondary control reserves | $P^{\mathrm{sek}}$ | 400 MW | 14000 MW |
| Secondary response Time | $T^{\mathrm{sek}}$ | 120 s | 300 s |
| AGC parameters | $C_p$ | 0.17 | 0.17 |
|  | $T_N$ | 120 s | 240 s |
| Load-frequency damping | $D_l$ | $\frac{1}{120}\frac{\mathrm{Hz}}{\mathrm{MW}}$ | $\frac{1}{3750}\frac{\mathrm{Hz}}{\mathrm{MW}}$ |

Unscheduled exports from area I to area j are represented by PTij and B is the bias factor. Additionally, the AGC is often used as an implemented as PI-controller of the form.

$$\mathrm{AGC} = -C_p - \frac{1}{sT_N}\,\mathrm{ACE} \quad . \tag{6}$$

Numerous complexities are eliminated because to the model. Assuming just two control zones, the European grid has a much larger number. Although the AGC systems in different control zones are not specified, the Swiss system is an exception to this rule. Our chosen modelling technique does capture general system behaviour realistically enough, however, and this includes changes over longer time periods, as well as frequency dynamics and the use of control reserves.

## FREQUENCY EVOLUTION IN SYSTEMS WITH LOW INERTIA

The system frequency will diverge more rapidly in the case of an emergency, resulting in a lengthier recovery period. Figure 2 shows a 3 GW increase in the amount of power being used. The primary frequency control reserve size is calculated by ENTSO-E using this example as a benchmark. (Weissbach and Welfonder, 2009) state that large swings in output are noticed every hour, resulting to considerable changes in frequency in spite of the rarity of such an event. Frequency deviations may occur if the primary frequency control response time T1 is too lengthy. It is possible to reduce the maximum deviation by lowering the response time. Miniature island grids have a comparable effect since they have a low base load, according to (Mercier et al, 2009). batteries.

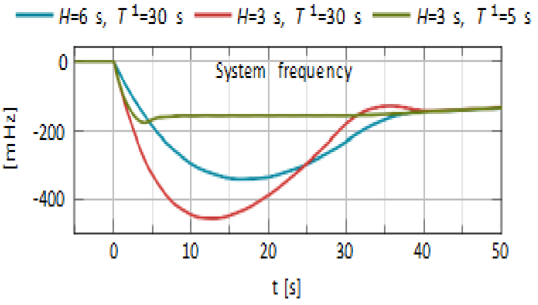


Fig. 2 shows how the frequency changes after a deviation depending on the main control's inertia H and reaction time T 1. In the future, reduced inertia might pose a challenge for grid operations.The frequency development is further influenced by the dead time of the secondary control and the load's frequency dependency. Once again, the total system load is a factor in the second of the two. It is possible that catastrophic situations may emerge when the system's inertia is reduced owing to a substantial share of renewable energy.

## CONTINGENCY ANALYSIS

System and battery behaviour following a crisis are described here. We'd want to learn the following kind of information: Do the frequencies shift when energy-constrained units govern them? Do you think it is necessary for the secondary control system to be explicitly notified about the amount of recharge energy it needs? A system's frequency is affected by a variety of factors, including average time and delay. What's the connection between it and the need for recharging energy?

Figure 3 shows how the batteries fit into the overall control system. (1)and (2) include the equations that determine the offset P off and the bat- tery output P bat (3). The parameter determines how much of the principal control reserves are given by batteries.

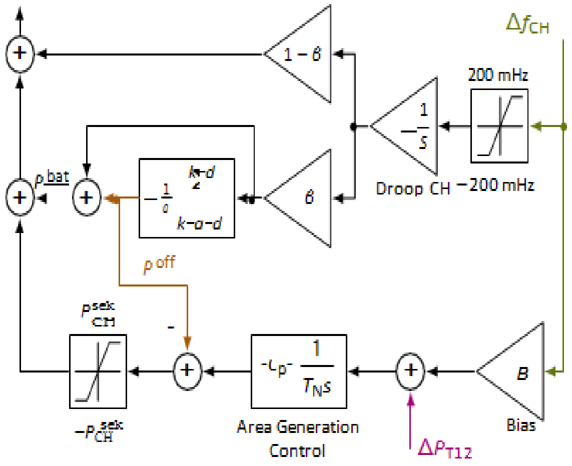
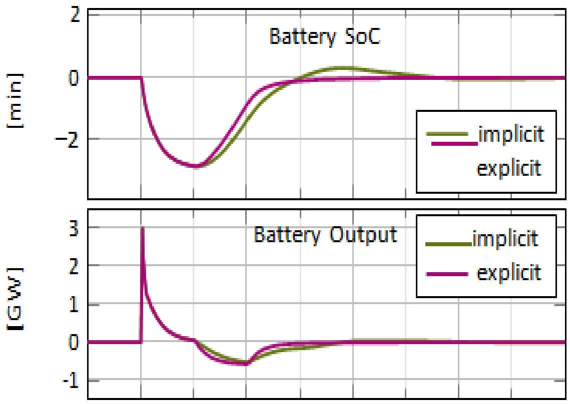


Fig. 3. Batteries as part of the control reserve framework, with recharging algorithm and explicit communication of the offset. Turbine dynamics and rate limits omitted.Messages conveying the ability to recharge. Section 2's recharge techniques presume that other services will provide the energy needed. Secondary control reserves must be used if the energy is not purchased openly on an energy market. Either the offset may be added to the AGC signal to express the needed quantity of energy, or secondary control can be activated implicitly through the system frequency to communicate the requirement.



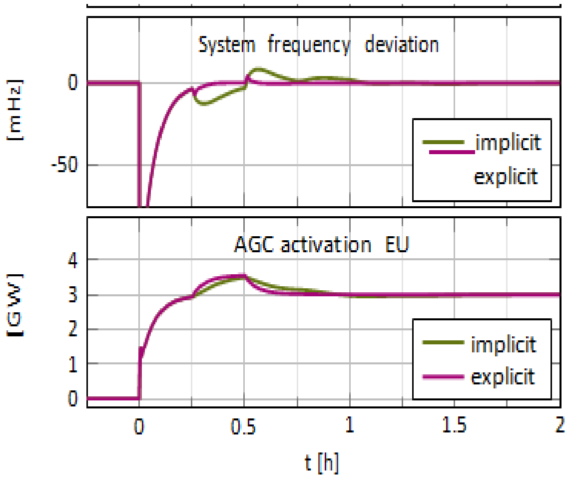


Fig. 4. Effect of communication of the battery offset to

the secondary control. Communicating the offset both implicitly via the system frequency and explicitly lead to a rather smooth response.

For a 3 GW loss in production and 100% primary control supply by energy limited units, i.e., = 1, the results are shown in Figure 4. a and d are both set to 15 minutes. If the offset is not transmitted, the results are shown in green; if the offset is provided, the results are shown in purple. System frequency is not affected, and battery SoC does not overrun in the latter technique. A little amount differs whether the offset is included or not. There is some evidence that conveying the offset is beneficial, although it is not required. It's good to know that these channels are only nice-to-haves and aren't absolutely necessary in the event that anything goes wrong.

Averaging period and delay sensitivity. The recharging approach includes both a delay d and an average period a. Reducing a and d has a positive impact on a battery's storage capacity needs, hence doing so is beneficial to the battery's owner. Choosing values that are too tiny, on the other hand, may be counterproductive to the requirements of the system. The offset was not given clearly for the following runs.

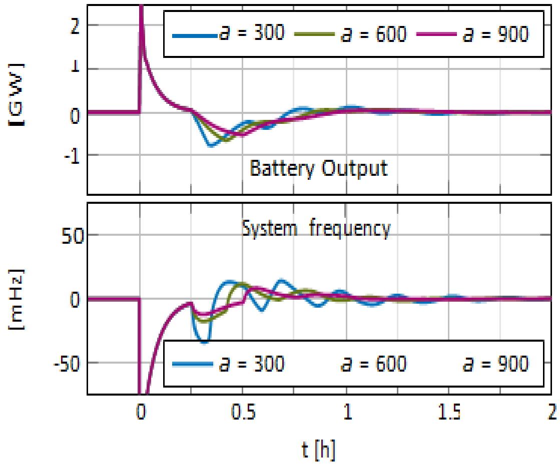


Fig. 5. Effect of averaging period a on system response, if offset is not communicated. Decreasing the averaging period leads to more pronounced oscillations.

A contingency is shown in Figure 5 in terms of battery output and system frequency. At 15 minutes, both f and P bats are quite stable. This may cause oscillations in the battery charging process, which can then lead to fluctuations in the system frequency. Shorter averaging durations seem to cause an undesirable interaction between the battery and the secondary control.. When the delay is changed, the system's behaviour does not change dramatically. Even a zero-delay time constant provides smooth frequency transitions. Secondary control reserves may be activated more quickly with no delay, using less offset energy at the same time, since the battery is freed sooner.

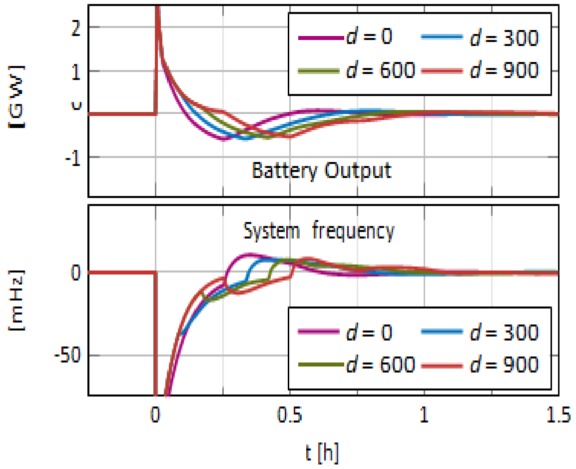


Fig. 6. Effect of delay d on system response, if offset is not communicated. Reducing the delay

has no major effect on system frequency or battery output.

## LONG-TERM SIMULATION

Next the contingency analysis in the previous part, the following sections evaluate the normal operation of the power system. Findings that are at least partly trustworthy need simulating a year's worth of data. The simulation takes as inputs the frequency of the system and the activation of secondary controls in the Swiss control zone. Both datasets are given with a 10 mHz frequency discretization. The dynamics of the swing equation limit the data presented.

Table 2. Sensitivity of battery and AGC usage on design parameters. Results of one-year simulation. Colourings highlight correlation between parameters and outcome.

| Parameters | | | | AGC,CH | | Battery response | | |
|---|---|---|---|---|---|---|---|---|
| $\beta$ [s] | offset | $a$ [s] | $d$ [s] | $E^{pos}_{CH}$ [GW h] | $E^{neg}_{CH}$ [GW h] | $\Delta$ SoC [min] | $\lVert P^{off} \rVert_\infty$ [p.u.] | $\lVert P^{bat} \rVert_\infty$ [p.u.] |
| 0 | - | - | - | 317.1 | -506.2 | – | – | – |
| 0.5 | yes | 900 | 900 | 317.7 | -509.9 | 22.91 | 0.61 | 0.91 |
| 1 | yes | 900 | 900 | 318.5 | -513.9 | 22.91 | 0.61 | 0.91 |
| 1 | no | 900 | 900 | 318.2 | -513.7 | 22.94 | 0.61 | 0.91 |
| 1 | yes | 600 | 900 | 319.0 | −514.3 | 20.81 | 0.64 | 0.93 |
| 1 | yes | 300 | 900 | 319.9 | −515.1 | 18.87 | 0.66 | 0.91 |
| 1 | yes | 900 | 600 | 319.5 | −515.0 | 18.49 | 0.61 | 0.92 |
| 1 | yes | 900 | 300 | 320.8 | −516.6 | 14.03 | 0.61 | 0.92 |
| 1 | yes | 900 | 0 | 321.3 | −517.7 | 8.85 | 0.61 | 0.84 |

are seconds and mHz apart. The frequency data may be used to calculate primary and secondary control activation and damping by frequency-dependent loads, while the AGC signal, along with frequency, also provides information regarding tie-line power. The P load may be calculated using this information. Power mismatches in the remaining European grid, known as P load, are addressed in the same way. For primary control, we'll look at how energy-constrained units impact system frequency and AGC activation, as well as how much store space is required. When the inertia of the system is lowered, we examine how the frequency of the system changes.

Functioning normally. Table 2 shows how the sensitivity of each parameter to the others is affected by the values of the various parameters. Amounts of positive and negative control energy are given for each simulation run. The maximum offset power P off and the total battery power P batstoragecapacity .'s are also shown, as is the SoC storage capacity, which is the difference between the highest and lowest SoC achieved. It is necessary for batteries to be able to store a specific quantity of energy. A maximum activation of 0.78 p.u. occurred over the simulated period.Despite the fact that batteries are taking the role of traditional main control reserves, just 1% of the total energy cycled is being used for secondary control reserves. There is no difference in conveying recharge energy implicitly or explicitly. Battery capacity requirements may be reduced greatly by shortening the average ageing period and minimising the delay. Although the influence on the storage system's minimum power capacity is minimal and seems to be dependent on the specific features of the time series, reducing the delay does have an effect. Because of this, in combination with Section 5, you may change the time interval between the two events.The amount of inertia is reduced. Secondary control activation is shown in Table 3 in addition to the system's lowest frequency (F min), the average frequency (F mean), and the highest frequency (F max) (F max). This strategy makes it easy to see.

Table 3. Frequency deviations and secondary control activation over one year, depending on use of batteries and inertia.

| Set-up | | | | AGC,CH | | System frequency | | | |
|---|---|---|---|---|---|---|---|---|---|
| $\beta$ [] | $H$ [s] | $T^1$ [s] | offset | $E^{pos}$ [GWh] | $E^{neg}$ [GWh] | $f^{min}$ [mHz] | $\mu^f$ [mHz] | $\sigma^f$ [mHz] | $f^{max}$ [mHz] |
| 0 | 6 | 30 | – | 317.1 | −506.2 | −155.96 | 2.88 | 22.11 | 142.88 |
| 1 | 6 | 30 | yes | 318.5 | −513.9 | −156.17 | 2.88 | 22.13 | 143.00 |
| 0 | 3 | 30 | – | 317.1 | −506.2 | −156.63 | 2.88 | 22.25 | 142.48 |
| 0 | 1 | 30 | – | 317.1 | −506.2 | −157.51 | 2.88 | 22.39 | 144.66 |

When it comes to frequency evolution, energy-constrained devices and the When the recharge occurs, it has just a little effect, causing only small alterations. It was hypothesised that an increase in system frequency deviations would be caused by a reduction in inertia. However, our simulations did not indicate this at all. ' There are two explanations as to why this is occurring. Main control reserves are able to maintain pace with frequency shifts as long as the load mismatch is somewhat modest. Instead of inertia and primary activation rate, damping and primary control reserves limit maximum frequency deviations. The data utilised in the simulation has a time resolution of 10 seconds. The load imbalance is dealt with using an interpolation rather than a step-by-step technique. If this assumption is correct, then the absence of association between inertia and frequency fluctuation may be attributable to this. Based on the facts provided, it is impossible to determine whether option 1) or option 2) is right. If a contingency occurs, a contingency analysis, as illustrated in Section 4, may be used to examine how a system responds.

## CONCLUSION

Primary frequency control supply by energy restricted components, such as batteries or DR, was studied to see how it affected system function. So that the batteries may recharge and preserve their SoC limits, the secondary control must offer some extra energy. This does not have a significant impact on the system's frequency. The secondary control may be explicitly informed of the amount of recharging energy required, or the system frequency can be used to relay this information. In power systems with low inertia, a contingency analysis indicated the benefits of quicker primary control reserves. Batteries were found to be sufficient in all of the scenarios studied.Primary control based on energy restricted units is as dependable as conventional primary control since it does not need new communication links or higher secondary control reserves. In terms of operational benefits, quick battery ramp rates and the decoupling of control and energy output are equally important to a battery-powered system.

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