Under the patronage of **HRH Prince Khalid Al-Faisal**
Advisor to the Custodian of the Two Holy Mosques & Governor Iof Makkah Region

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المؤتمر الدولي الثاني والعشرون لإدارة الأصول والمرافق والصيانة

The 22nd International Asset, Facility & Maintenance Management Conference

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Frequency Regulation Coordinated Framework: Hybrid Battery Energy Storage System and Supercapacitor

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Introduction: Background

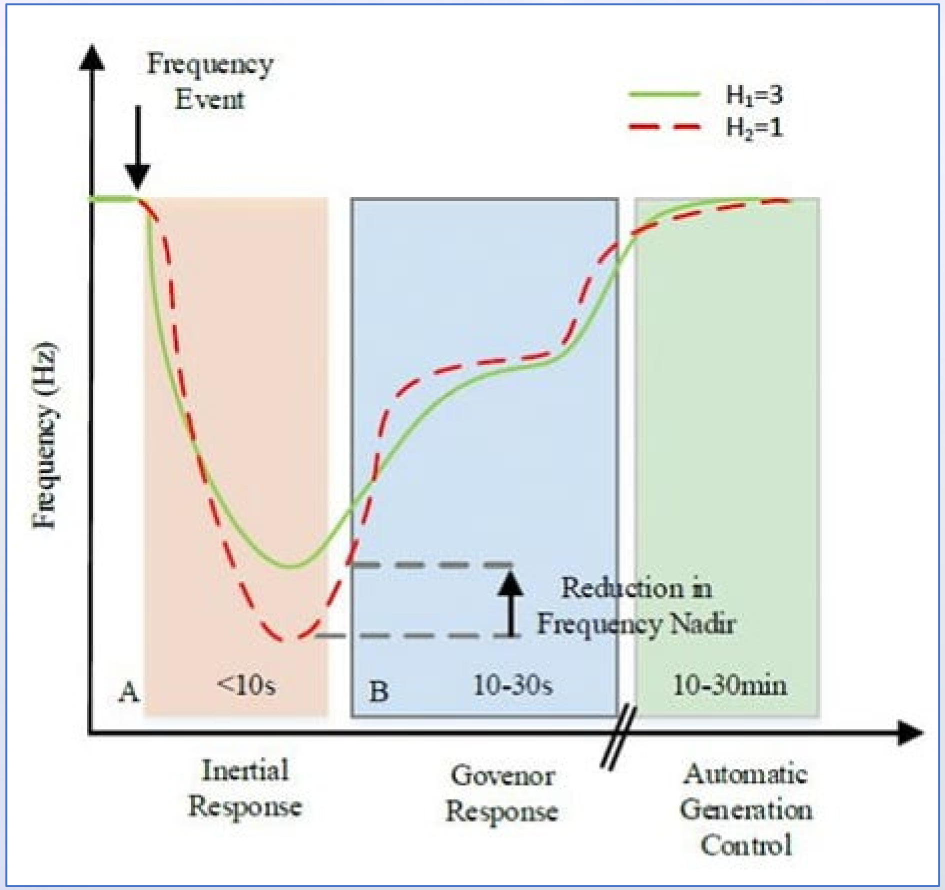
- Renewable resources integration increases steadily due to their economic feasibility, but this comes at a price.
- RE introduces several challenges to the conventional network, one of which is the degraded system inertial response.
- A system inertia response is diminished significantly, for both wind power and solar energy, which in turn, makes the system vulnerable to frequency deviations.

Introduction: Background

- Frequency regulation (FR) works on stabilizing the system frequency by reducing the mismatch between generation and demand

- Frequency control is composed of three hierarchical actions-namely, primary control, secondary control, and manual tertiary control.

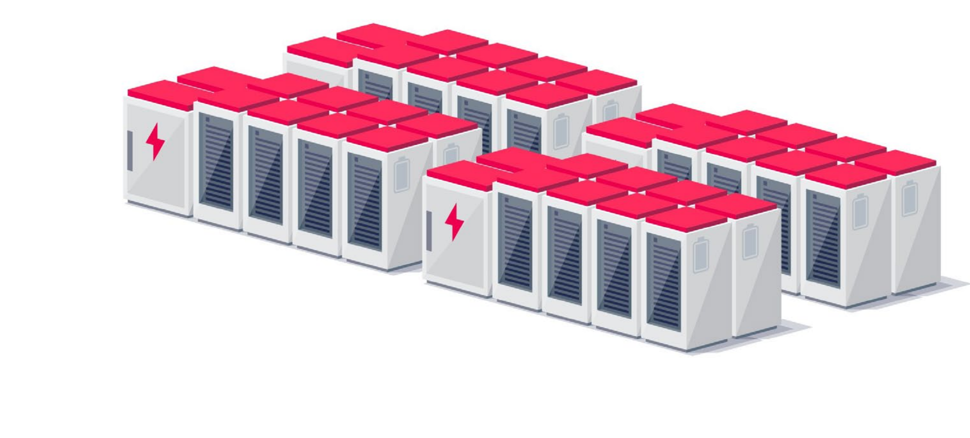
- Power system operation requires a balance between supply and demand to maintain frequency within acceptable limits.



Introduction: Background

- Energy storage systems are good candidates to meet systems need for regulated frequency, like battery energy storage system (BESS) and supercapacitor (SC).

- Ideally, **A STORAGE SYSTEM** must have a high-power density (SC) to keep track of rapid fluctuating frequency signal, and it must possess a high energy density (BESS) to meet the consecutive rather varying frequency signals.



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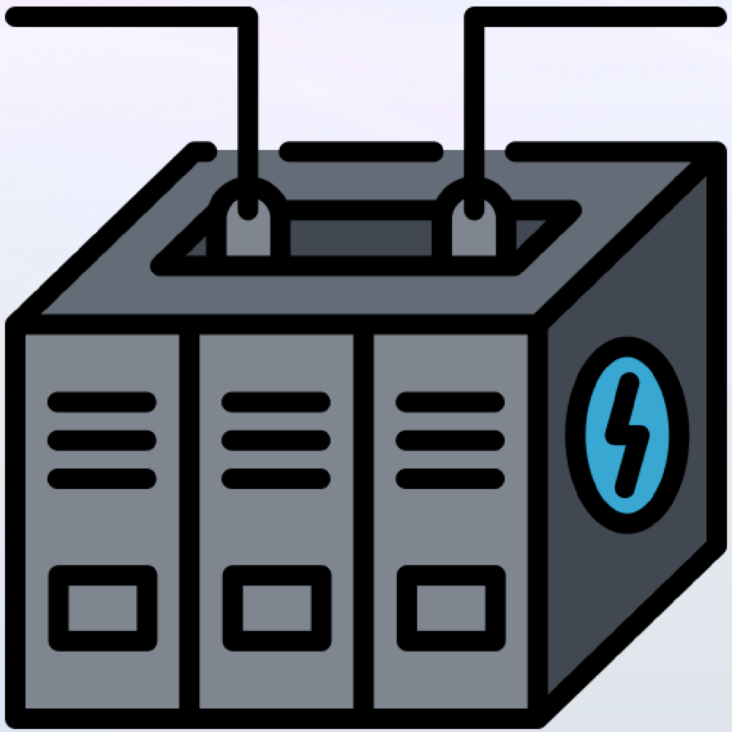
Introduction: Background



- A combined energy storage system is adopted for this purpose as a hybrid energy storage system (HESS), which consists of BESS and SC.
- This HESS provides both high energy and high-power supplies that are suitable for the FR application
- BESS operates within its **bounded state of charge (SOC)** besides its current limits, whilst SC has both voltage and current limits.

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Problem Formulation and Solution Methodology

- This paper opts to utilize the BESS and the SCs to regulate the microgrid frequency measures in the presence of a wind power renewable source
- The objective is to minimize the power deviation in a microgrid to maintain frequency stability.
- The system is composed of **utility supply**, wind power, BESS, and SC. The demand side is satisfied by the utility supply and the wind power; in case of power deficit or power excess, the BESS and the SC take over.

Problem Formulation and Solution Methodology

The Microgrid net power expressed as in (1)

$$\Delta P = P_G + P_{Wind} - P_{Load} \qquad (1)$$

The resultant frequency deviation value is computed in (2)

$$f_{t+1} = f_t \pm \Delta P \times \kappa \qquad (2)$$

The transformation constant κ is the system frequency response (Hz / MW)

Problem Formulation and Solution Methodology

The following equations show the BESS power and SC power.

$$P_{BESS} = \begin{cases} \eta_{Ch} \Delta P & Charging, \Delta P \leq 0 \\ \frac{1}{\eta_{Dis}} \Delta P & Discharging, \Delta P \geq 0 \end{cases}$$

$$P_{SC} = \begin{cases} \eta_{Ch} \Delta P & Charging, \Delta P \leq 0 \\ \eta_{Dis} \Delta P & Discharging, \Delta P \geq 0 \end{cases}$$

Problem Formulation and Solution Methodology

The objective function (3) aims to minimize the frequency deviation provided that the BESS capacity and the supercapacitor capacity are optimized, and the given constraints are met.

$$
\begin{aligned}
{}_z\varphi = & \sqrt{\sum_{k=1}^{K_T}[\kappa(\pm P_{BESS}(t_k) + \pm P_{SC}(t_k)} \\
& + \Delta P(\mathrm{t}_k))]^2 \\
\text{subject to} : & \; g(z) \leq 0 \\
& h(z) = 0 \qquad (3)
\end{aligned}
$$

Constraints

- $\tau=\{\Delta:0\leq\Delta\leq 900\Delta;\Delta \in W\}$ consists of a time with **4 seconds step in an hour,**
- $H=\{h:0\leq h \leq 24;h\in W\}$ represents the **number of hour a day,**
- $D=\{d:0\leq d \leq 29;d\in W\}$ is for the **number of days in a month,**
- $M=\{m:0\leq m \leq 11;m\in W\}$ denotes the **number of months per a year**,
- $B=\{b:b \geq 0;b\in W\}$ indicates the **BESS number**
- $S=\{s:s \geq 0;s\in W\}$ states the **SC number**.

Solution Methodology

- The BESS and SC set is introduced to the grid with the wind power source to test the frequency deviation impact on the BESS and SC optimal sizing.
- The normal frequency deviation is between 0.08 off the nominal frequency value.
- The BESS is composed of two batteries that operate in a coordinated manner to avoid cyclic charge/discharge that shortens their lifespans.
- A given frequency data were used to evaluate the anticipated using equation (2). Then, the net power result is used as an input to the optimization function (MATLAB nonlinear solver) along with the constraints to find optimal BESS and SC power and energy capacities.

Constraints

- The system was simulated with MATLAB tool to find the resultant net power needed to bring the frequency measures within the tolerable range.
- The optimal size of the hybridstorage system is computed and verified by simulating both the BESS and the SC so that the FR signal is compliant with the required limits.
- Wind power data are collected from literature to simulate MG functionality and represent the RE addition to the grid as shown in Figure 1.

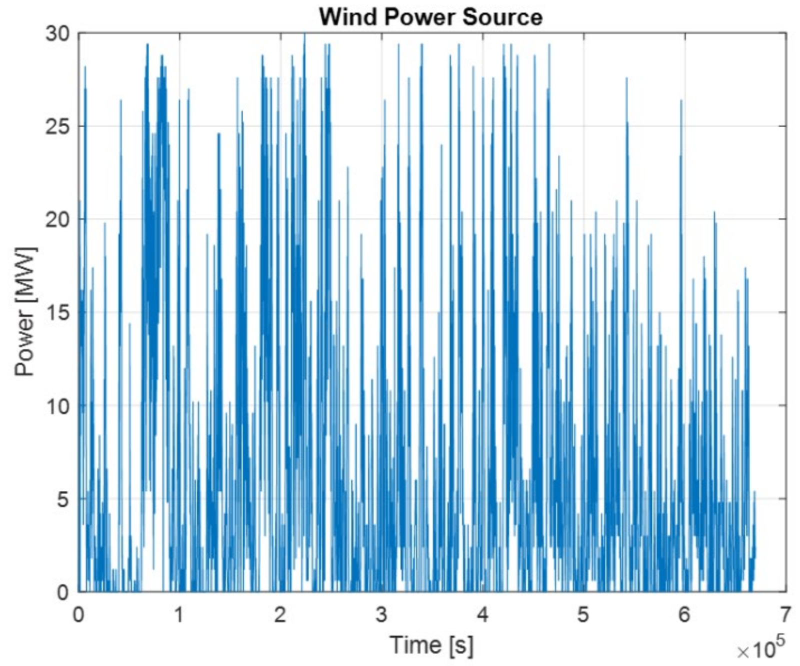

Fig. 1. Wind Power Profile

Simulation

- The network frequency is shown in Fig. 2 depicting the frequency deviations in accordance with the defined deadband.

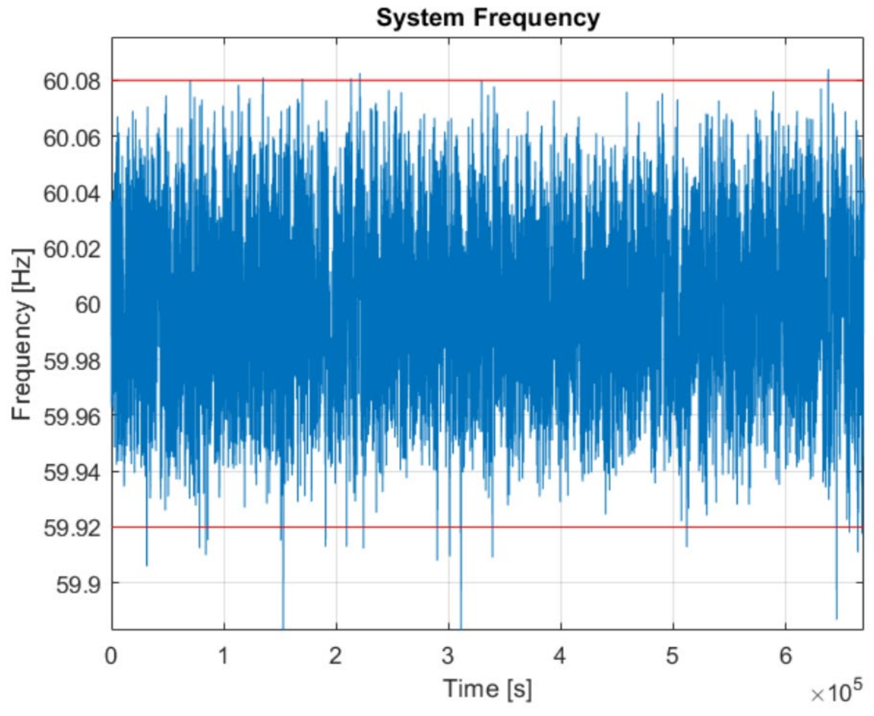

Fig. 2. System Frequency.

Simulation

- The frequency deviations, the deadband, and the initial BESS and SC SOCs are significant in determining the BESS and SC sizes.

- (Initial SOC of 1) The reason for this is that the overfrequency conditions are only a few and occur later, so the first battery tackled it without exceeding the SOC maximum limit, on the other hand, the underfrequency conditions are many and span the entire interval, so having high initial SOCs, help avoid going below the minimum SOC limit

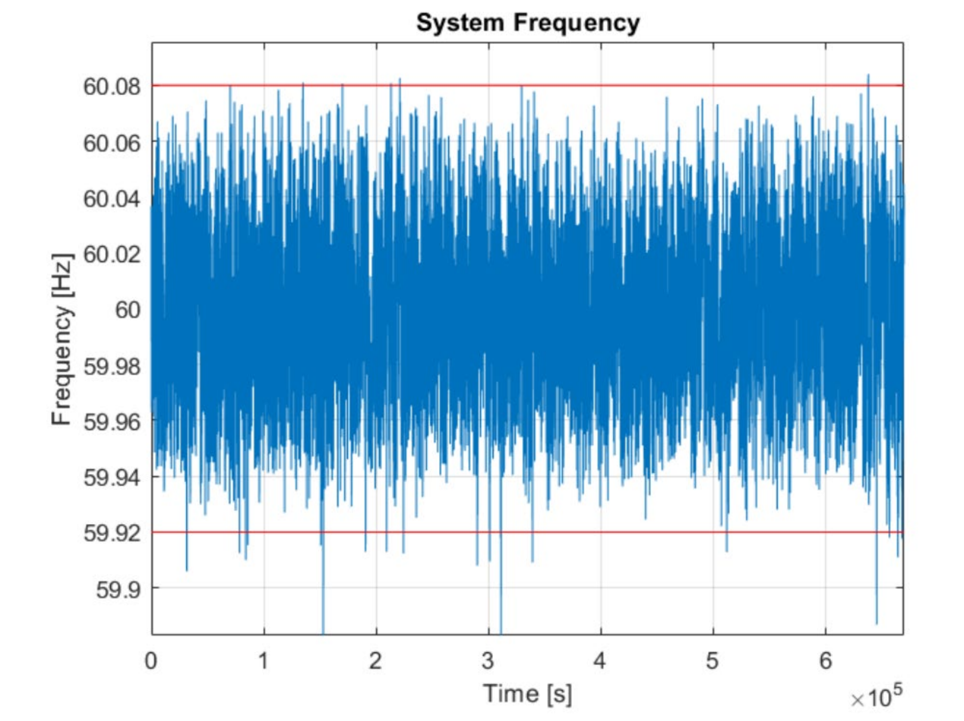

Fig. 2. System Frequency.

Simulation

- The rectification of the hybrid system process is observed in Fig. 3 that depicts the system frequency is brought back into tolerable range.
- SC takes rapid frequency-changing signals that would otherwise put the BESS under a stressed charge/discharge process.
- The filtration system explained earlier works to isolate the steady signals from the fluctuating ones for the same purpose.

Table 3 BESS Total Capacity.

BESS(MWh)	BESS(MW)	SC(MWh)	SC(MW)
448.7895	43.0104	16.6970	419.7674

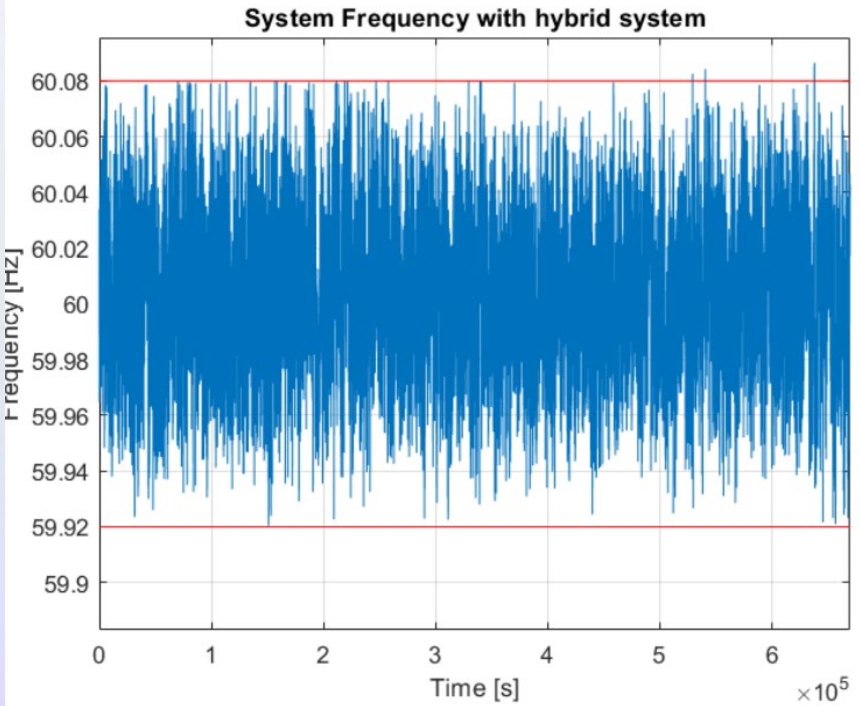

Fig. 3. System Frequency with hybrid system.

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Simulation

- SC power size is substantially larger than the BESS power size.
- Conversely, the BESS energy capacity is much higher than that of the SC. This complies with the two hybrid system components essences.
- The SC charges so fast that its SOC is filled almost instantly, but it cannot fulfill consecutive FR needs. The BESS is quite the opposite, as it functions badly at high power requirements, but it does well for consecutive low FR requirements.

Table 3 BESS Total Capacity.

BESS(MWh)	BESS(MW)	SC(MWh)	SC(MW)
448.7895	43.0104	16.6970	419.7674

Conclusion

- A coordinated model of BESS and SC was proposed in this paper for FR for the selected network in the presence of the wind power source.
- The sizing model uses the nonlinear programming tool to set the optimal BESS and SC capacity provided that the frequency limits are maintained
- Although SC reduces the expected BESS size, its capacity is still considered practically large. However, conventional-generating units help reducing the hybrid system size in several setups.
- This will be the future research work to explore different combinations of the hybrid system along with conventional units.
- The proposed methodology is straightforward and general, so it can be extended to incorporate the conventional-generation units.

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