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Optimizing Grid Regulation with Gravity Energy Storage Systems: A Comparative Analysis with Different Motor Inertias

Shubham Sundeep[1], Latha Sethuraman[1], Dayo Akindipe[1], Lee Jay Fingersh[1], Zach Wenrick[2], Aaron Munoz[2]

[1]National Renewable Energy Laboratory, Golden, CO, USA, [2] Renewell Energy, Bakersfield, CA, USA

NATIONAL RENEWABLE ENERGY LABORATORY

1. Motivation

- Unlike traditional power systems, renewable energy sources **lack the system inertia** needed for frequency regulation, leading to prolonged fluctuations in grid frequency and voltage.
- **Quick response time** is required to reduce deviation in the grid frequency and voltage, which otherwise would result in involuntary load shedding.
- **Gravity Energy Storage System (GESS) can be a sustainable solution** for enhancing grid support and ancillary services through optimized control of charging and discharging [1-2].

2. Objective

- **Demonstrate the grid frequency and voltage regulation capabilities** of a GESS through:
  - Optimized control of charging and discharging operations.
  - **Evaluating their response times** during a **frequency drop** event in the **ERCOT grid**, during the Feb. 15, 2021, blackout.
  - **Evaluating the role of electrical machine inertia.**

3. Gravity Energy Storage System

- A **36-kWh** GESS is designed to repurpose an idle oil well for the grid-connected energy storage.
- The performance of two three-phase 100-hp permanent magnet synchronous machines, with **rotor inertias of 0.493 kgm² and 1407.14 kgm²**, is compared under frequency and voltage regulation.

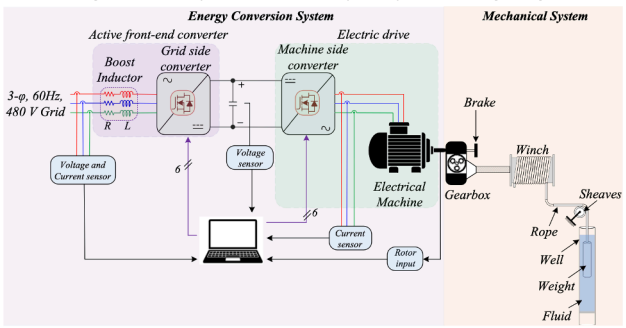


Figure 1. Schematic of the gravity energy storage system under study.

4. Frequency Regulation Control

- **Frequency-watt curve** is used for active power compensation during frequency regulations.

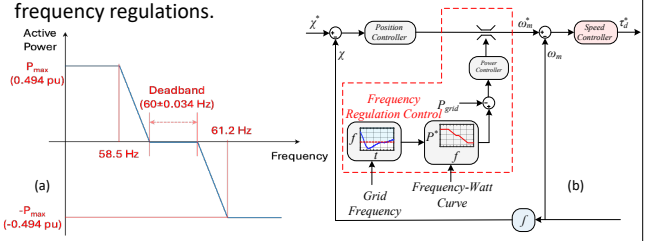


Figure 2. (a) Frequency-Watt curve used for frequency regulation; (b) Schematic diagram illustrating frequency regulation control.

- The GESS responds to frequency drops during both the charging and discharging phases, each with unique characteristics due to their opposing actions.

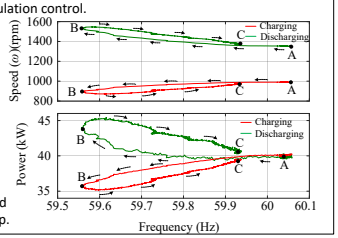


Figure 3. Performance of GESS, illustrating speed and output power of the GESS during grid frequency drop.

5. Voltage Regulation Control

- **Volt-VAR curve** is used for reactive power compensation during voltage regulation.

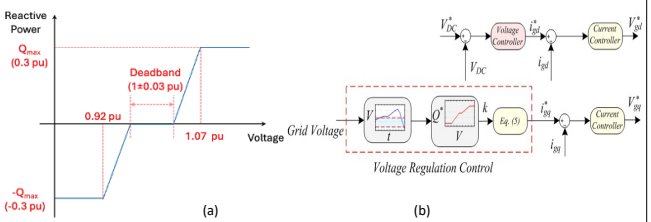
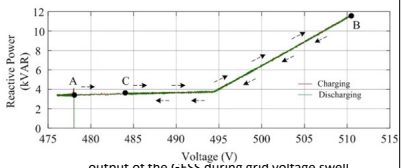


Figure 4. (a) Volt-VAR curve used for voltage regulation; (b) Schematic diagram illustrating voltage regulation control.

- The grid reactive power injection or absorption is controlled using the field-oriented control of the grid-side converter



output of the GESS during grid voltage swell.

6. ERCOT Grid Blackout: February 2021

- **26.2 GW** of forced thermal power plant outage in ERCOT grid in Feb. 2021 leads to frequency drop below **59.4 Hz** for **4 min, 23 s** [3].
- **Grid protocols** allow generators to **automatically trip** if the grid frequency drops to 59.4 Hz or below for more than 9 min [3].

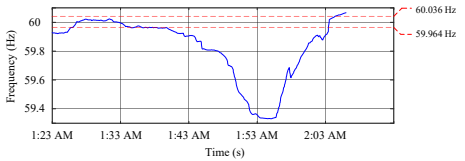


Figure 6. The ERCOT grid frequency during load shedding and generation capacity outage on 15 Feb. 2021.

- Both GESS with different motor inertia respond similarly to frequency drop.

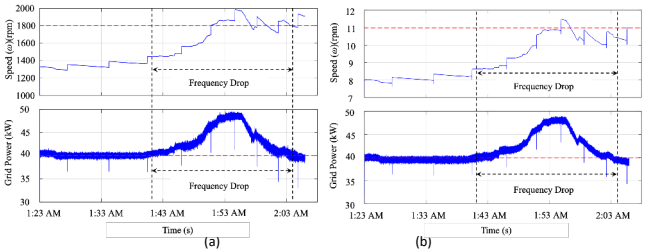


Figure 7. The response of GESS under ERCOT grid frequency drop; (a) low-inertia system; (b) high-inertia system.

7. Conclusion

- Optimized control was demonstrated to achieve full support during a grid contingency.
- The GESS responds within 2 s for frequency and voltage regulation, complying with ERCOT grid code for **primary frequency response**.
- **High-inertia** systems tolerate **more frequency changes** without exceeding rated speed, while **low-inertia** systems face potential lifespan reduction from **extended flux-weakening**.

8. References

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3. Energy institute, The university of Texas, Austin, The timeline and events of the February 2021 Texas electric grid blackouts, [Online] https://energy.utexas.edu/sites/default/files/UTAustin%20%282021%29%20EventsFebruary2021TexasBlackout%2020210714.pdf, Accessed on: 22 June 2024.

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