Gravity Energy Storage Using Linear Electric Machine Technology

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Outline

Introduction

- As renewable energy sources grid integration increases, the need to ensure grid flexibility and reliability also increases.
- One solution for this requirement is energy storage.
- The most commonly used storage method is pumped hydroelectricity.
- There are numerous ways of classifying storage methods, e.g. the service they provide or according to various technical characteristics.

Overview of Existing Gravitational Energy Storage Methods

Water-based Gravitational Energy Storage Methods

- Pumped Hydroelectricity Storage (PHES)
- Underground PHES
- Piston-based PHES
  - Gravity Power Module (GPM)
  - Hydraulic Hydro Storage (HHS)
  - Ground-breaking Energy Storage (GBES)
- Underwater Ocean Storage Systems (UOSS)

Dry Gravitational Energy Storage Methods

- Advanced Rail Energy Storage (ARES)
- Gravitricity

Overview of Existing Gravitational Energy Storage Methods

Table 1: Summary of GES technologies.

Storage Technology	Power Rating	Energy Rating	Discharge Time	Efficiency
PHES	1–5000 MW	1 MWh–20 GWh	1–24h +	65–87 %
GPM	40–1600 MW	1.6GWh–6.4 GWh	1–4 h	75–80 %
HHS	20–2750 MW	1 GWh–10 GWh	1–24h +	80 %
GBES	100 MW to multi-GW	Up to 20 GWh	24 h +	80 %
UOSS	Up to a few GW	Up to a few GW	1–10 h	65–90 %
ARES	100–3000 MW	Up to 6 GWh +	2–24 h	78–80 %
Gravitricity	Up to 40 MW	Up to a few MWh	min–2 h	80–90 %

Simplified System

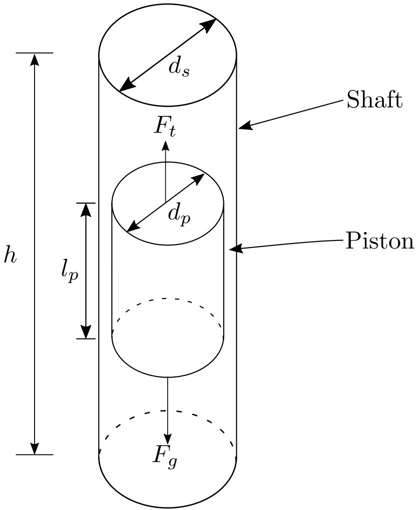

Figure 1: A simplified illustration of the GES system.

Energy Storage Capacity

Energy stored in Joule

$$E = mgh,$$
$$= \rho\pi(\frac{d_p}{2})^2 l_p g h$$

Energy stored in kWh

$$S_D = 2.78 \times 10^{-7} \rho\pi(\frac{d_p}{2})^2 l_p g h$$

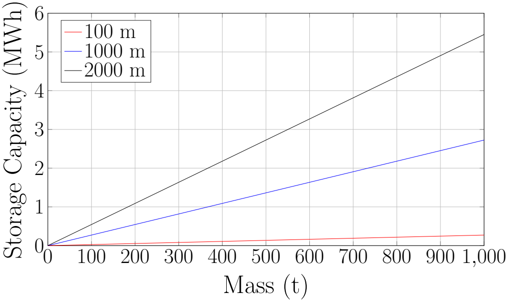

Figure 2: Storage capacity in terms of three relative system heights and mass.

Energy and Power Density

Energy density in kWh/m^3

$$S_D = \frac{2.78 \times 10^{-7} \rho \pi (\frac{d_p}{2})^2 l_p g h}{\pi (\frac{d_s}{2})^2 h} = 2.78 \times 10^{-7} \rho g l_p$$

Power density in kW/m^3

$$P_D = \frac{\rho l_p g}{3.6 \times 10^6 t_{dis}}$$

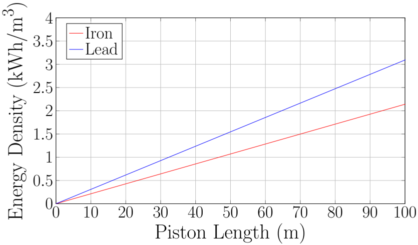

Figure 3: Energy density of the GES system.

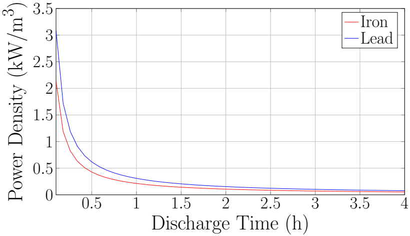

Figure 4: Power density of the GES system with $l_p = 10$ m.

Proposed Linear Electric Machine Hoist System

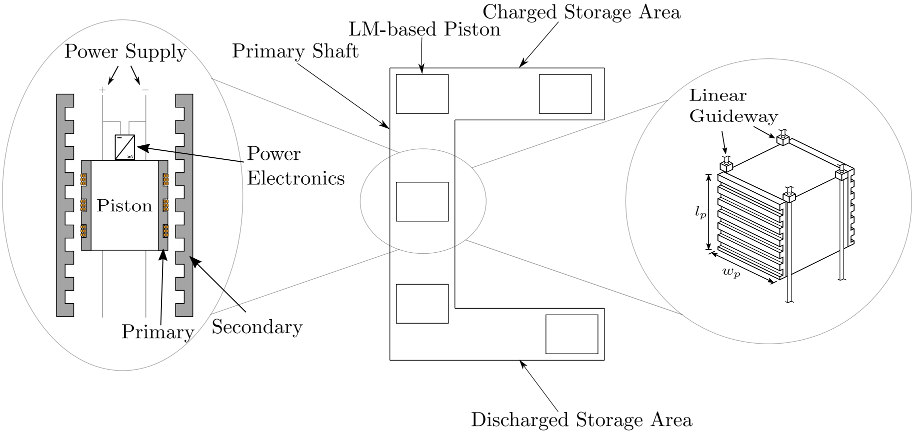

Figure 5: The proposed gravity energy storage system using linear electric machine technology.

Sizing a linear machine

$$\sigma = F/A = \frac{ma + mg}{4 w_p l_p} \approx \frac{1}{4} \rho w_p g$$

Table 2: Minimum width requirements

	30 kN/m^2	100 kN/m^2
Material	w_p	w_p
Iron	1.5 m	5.19 m
Lead	1.07 m	3.59 m

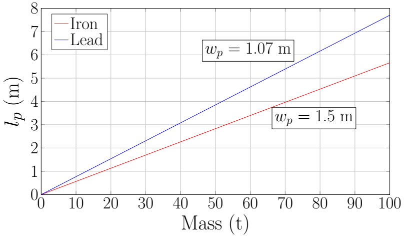

Figure 6: Mass versus piston length for a shear stress of 30 kN/m^2.

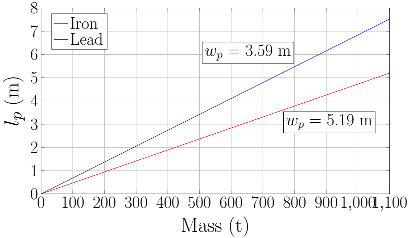

Figure 7: Mass versus piston length for a shear stress of 100 kN/m^2.

Conclusions

- The proposed GES system is a waterless, electromechanical form of energy storage.
- A multi-piston approach allows for more efficient use of the storage shaft.
- The next step would be to design a linear electric machine and perform a detailed levelised cost of storage.

Thank you.

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