Preliminary Modeling and Analyses of Potential Opportunities in Lithium-ion BESS Hybridization

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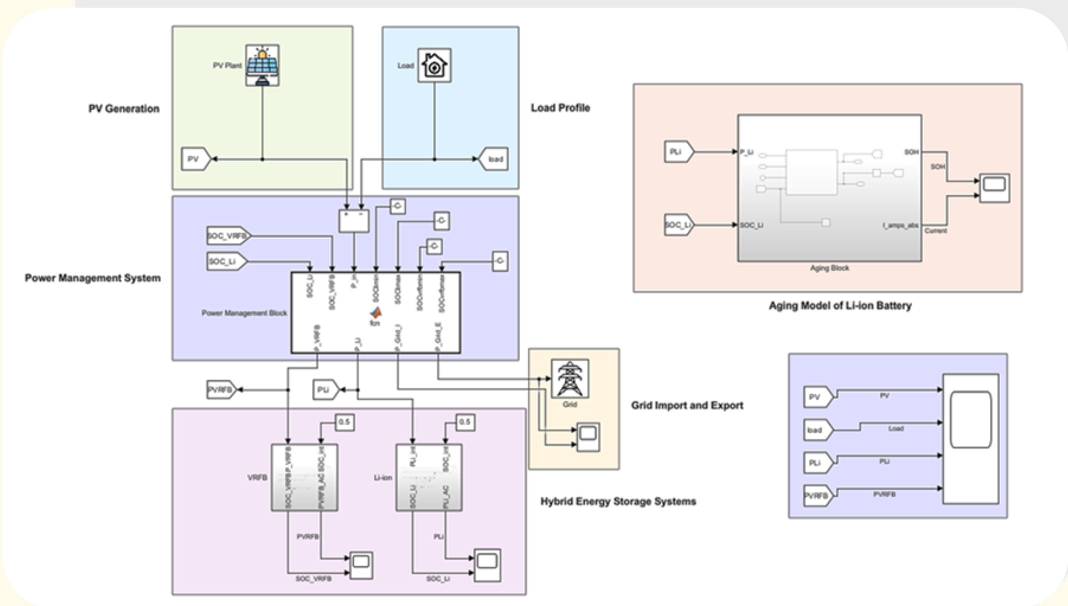
Introduction

The massive deployment of intermittent renewable energy sources (RES) results in variable and unpredictable power generation. Renewable sources cannot provide the natural inertial response historically offered by traditional synchronous generators. Technological solutions are urgently needed to ensure continuity, stability, and flexibility for modern power grids. While Lithium-ion battery-based Energy Storage Systems (ESS) are attractive technical solutions, high transient regulation signals significantly increase charge/discharge micro-cycles, shortening battery lifespan. To mitigate this critical degradation problem, Hybrid Energy Storage Systems (HESS) present a highly promising potential solution. The key objectives are to develop a techno-economic simulation tool to evaluate grid support capability, battery degradation, and lifecycle cost.

Techno-Economic Model

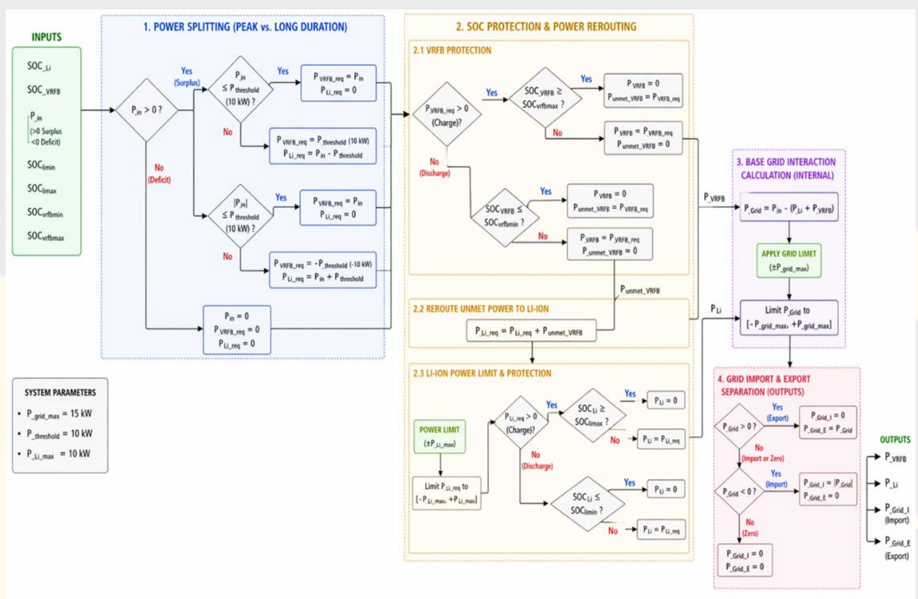
- The model built in MATLAB/Simulink software represents an integrated framework for analyzing and optimizing a hybrid energy storage system (HESS) within a grid-connected photovoltaic (PV) microgrid.
- The central power management system (PMS) acts as the supervisory controller, taking inputs such as the state of charge (SOC) of the storage device, PV generation, and load demand
- The model incorporates a HESS, combining a lithium-ion (Li-ion) battery with another storage technology, such as a vanadium redox flow battery (VRFB) or a supercapacitor. This hybridization allows the model to balance energy density and power density, with one storage handling fast dynamics and the other supporting long-duration energy shifting

System Architecture



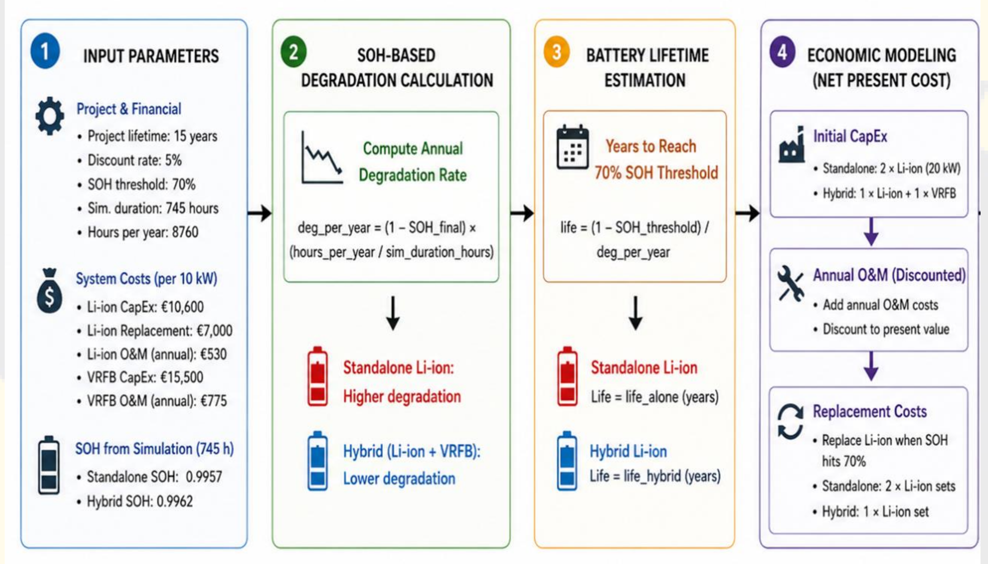
Block Diagram of the HESS & Aging Model

Control Strategy



Cascading Logic of Power management in HESS scenario

Economic analysis



Block Diagram of Economic Analysis in HESS scenario

Case studies

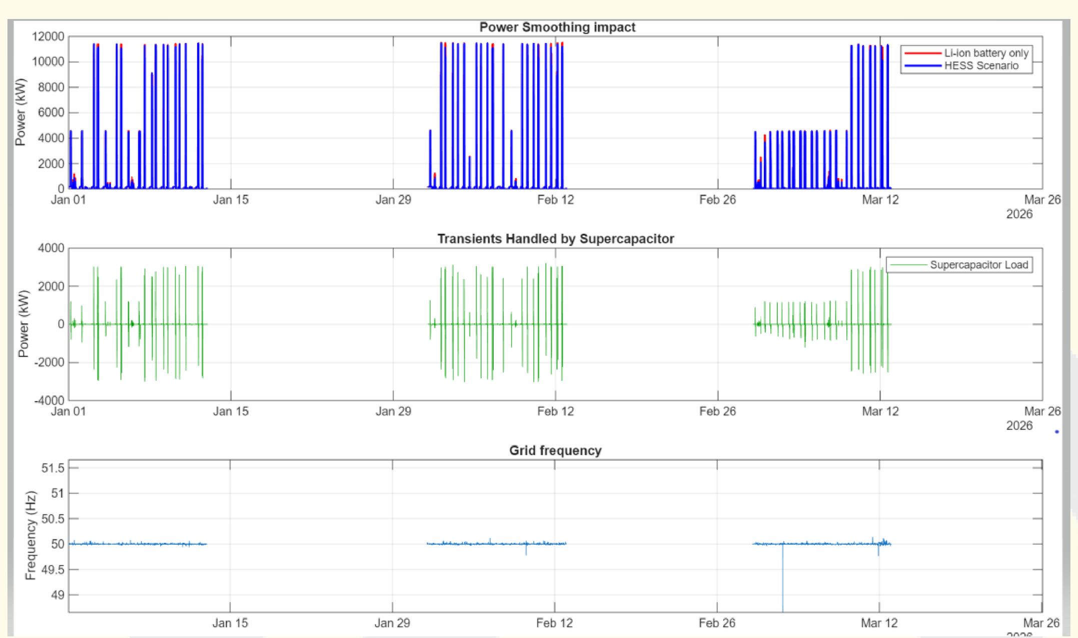
1. Li-ion + Supercapacitor

This case study analyzes whether a HESS could better support grid frequency regulation of the real plant installed in Sardinia.

- ✓ 23 MWLFP Li-ion
- ✓ 14.8 MW BESS Power
- ✓ 8.8 MWh Energy Capacity
- ✓ 16 MW PCS
- ✓ 1152V Average Voltage
- ✓ 2 MW Supercapacitor (Optimized Value)
- ✓ Low-Pass Filter based Control Strategy

The three-month simulation period from January to March 26 for HESS are summarized in the table below:

Parameter	Li-ion Only	Hybridization
Energy throughput (MWh)	2053	1665
Equivalent Full Cycles	147	119
Li-ion battery Stress	Higher ✗	Reduced by 18,8% ✓



Power profile of Li-ion only in blue, and HESS in red.
Power of the supercapacitor supports a high spike in green.
Grid frequency or frequency regulation in the last portion.

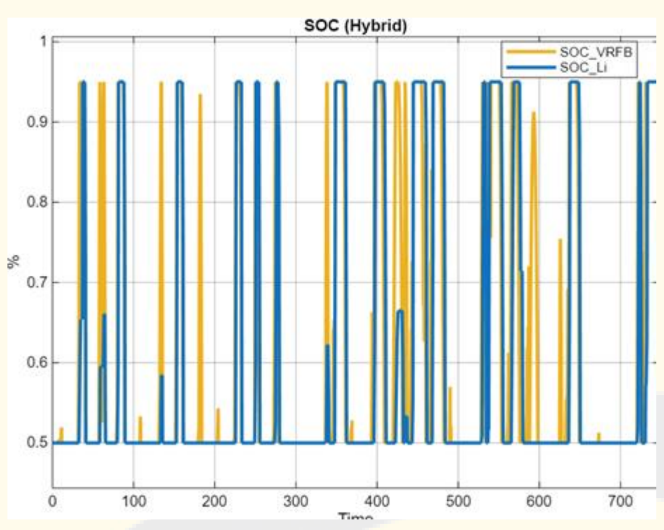
2. Li-ion + VFB

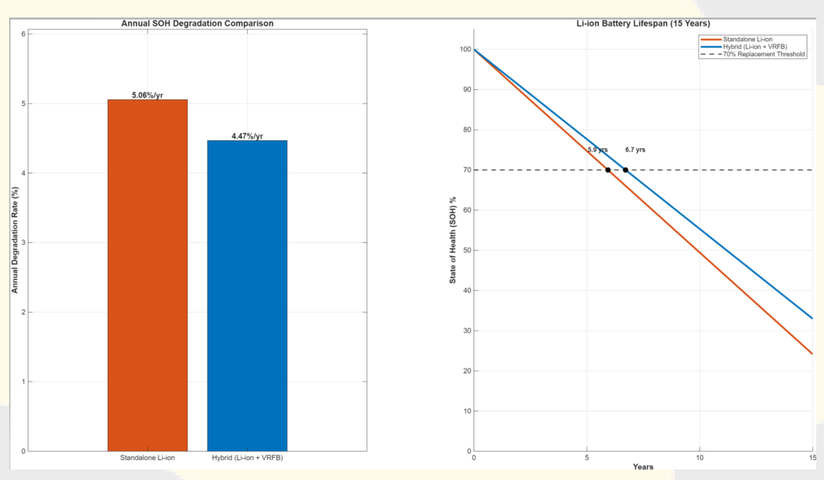
In this case study, a PV power profile corresponding to the North-Western Italy region is considered.

Plant Configuration

- ✓ 13 kW PV System
- ✓ 11.5 kW Peak Load Demand
- ✓ 20 kW / 21 kWh Li-ion BESS
- ✓ 15 kW Grid Connection
- ✓ Hybrid ESS: Li-ion + VRFB
- ✓ Equal Storage Sharing (10 kW / 10 kWh each)

The SoC in the HESS configuration and annual degradation of lithium battery are presented below





- ✓ HESS Configuration reduces the Li-ion degradation rate to 4.47% and extends its lifespan to 6.71 years.
- ✓ Net Present Cost of HESS is €48,766.82 compared to €51,766.59 for the standalone system, due to the replacement cost resulting in lifetime savings of 2,999.77.

Conclusion

Preliminary analyses indicate that HESS provides significant technical and economic advantages by reducing Li-ion battery degradation (case study 1: from 5.06% to 4.47% annually) and extending Li-ion battery lifetime (case study 2: from 5.93 to 6.71 years). Although the hybrid configuration requires higher initial CAPEX, the system achieved a lower Net Present Cost (€48,766.82) compared to the standalone Li-ion system (€51,766.59), resulting in lifetime savings of approximately €2,999.77. The results confirm that integrating secondary storage technologies, such as VRFBs or supercapacitors, effectively mitigates harmful high-frequency cycling and enhances long-term grid support performance.
To improve the reliability of our model further studies will implement the aging model of lithium-ion batteries

References

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[2] S. K. M. E. a. D. U. S. J. Schmalstieg, "A Holistic Aging Model for Li(NiMnCo)O2 Based 18650 Lithium-ion Batteries," Journal of Power Sources, 2014.