Provisional Patent Application

Cadence-Orchestrated Multi-Technology Energy Storage Ensemble

1. Field of Invention

This invention relates to energy storage systems, specifically electric vehicle and stationary architectures employing heterogeneous energy storage technologies (e.g., lithium-based batteries, ultracapacitors, flywheels) managed under a novel cadence-oriented control algorithm.

2. Background

Conventional single-pack EV batteries degrade rapidly (2–3 years to 80% capacity in fleet duty), struggle to capture regenerative energy in cold conditions, experience high thermal stress in hot environments, and require costly mid-life replacements. Prior art on multi-chemistry or hybrid storage systems typically manages devices in parallel for power vs. energy split but lacks dynamic orchestration of cycle cadence to suppress ∆SoC exposure and synchronize module aging across heterogeneous technologies.

3. Summary of the Invention

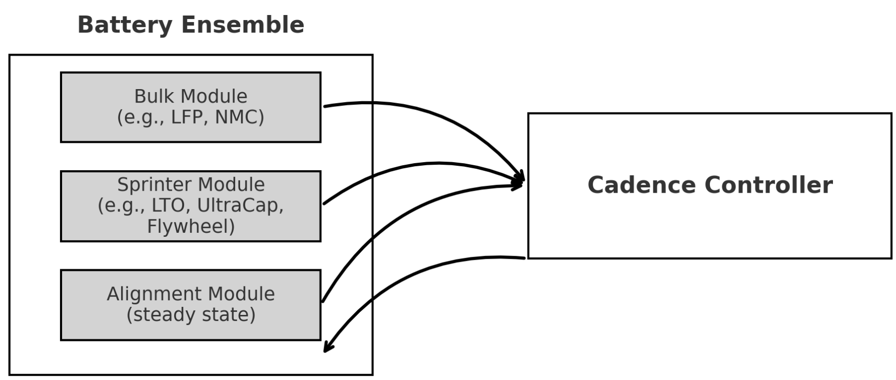
The invention introduces a cadence-based control law that: • Assigns modules distinct roles (bulk, alignment, sprinters). • Cycles modules in a 2–2–3 cadence loop to balance ∆SoC, SoC bands, and thermal stress. • Uses suppression multipliers (e.g., ×40 cold, ×20 warm) to reduce effective ∆SoC on bulk modules by an order of magnitude. • Enables synchronized aging across heterogeneous storage technologies, extending fleet duty from ~2 years to >12 years. • Provides resilience under hot (>40 °C) and cold (<0 °C) duty via sprinter modules absorbing spikes and regen.

4. Detailed Description

General Architecture: The system comprises a plurality of bulk energy modules optimized for capacity per cost (e.g., LFP, NMC, or similar chemistries), and a plurality of high-resilience modules optimized for power and cycle tolerance (e.g., LTO, ultracapacitors, flywheels). Control Flow: • Sprinters handle high C-rate bursts, cold starts, and early regen. • Bulk modules carry steady energy at mid-SoC. • Roles are rotated in 2–2–3 cadence to avoid hotspots and maintain phase alignment. Thermal Clamp: • Active cooling maintains modules ≤35 °C under extreme ambient conditions. Illustrative Embodiment: A 15-module configuration (10× LFP + 5× LTO) was modeled under Northeast fleet duty. Stress-test data demonstrated >6× life extension, safe hot/cold operation, and flat cost-of-ownership over 12 years.

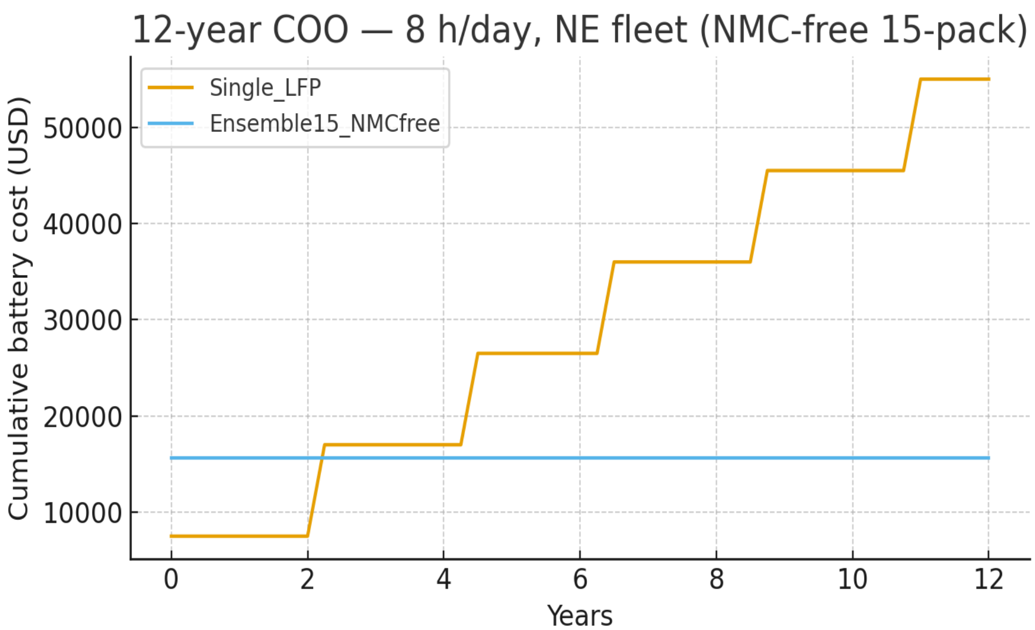
Figure 1: Generalized Cadence-Orchestrated Energy Storage Ensemble

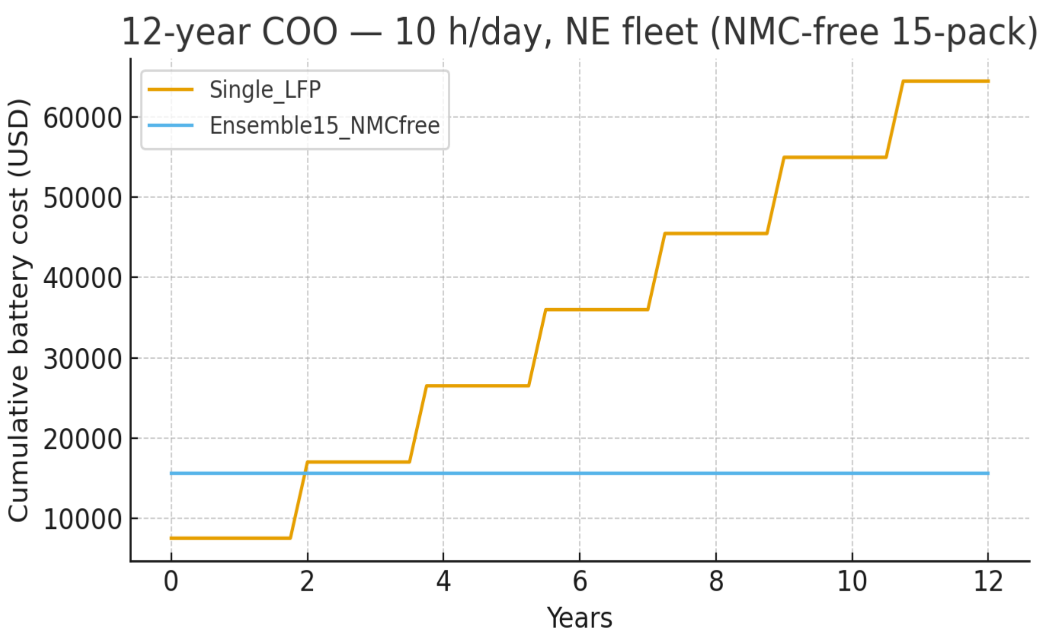
Figure 1: Generalized Cadence-Orchestrated Energy Storage Ensemble
(Arrows indicate bidirectional flow of the cadence-based control law)

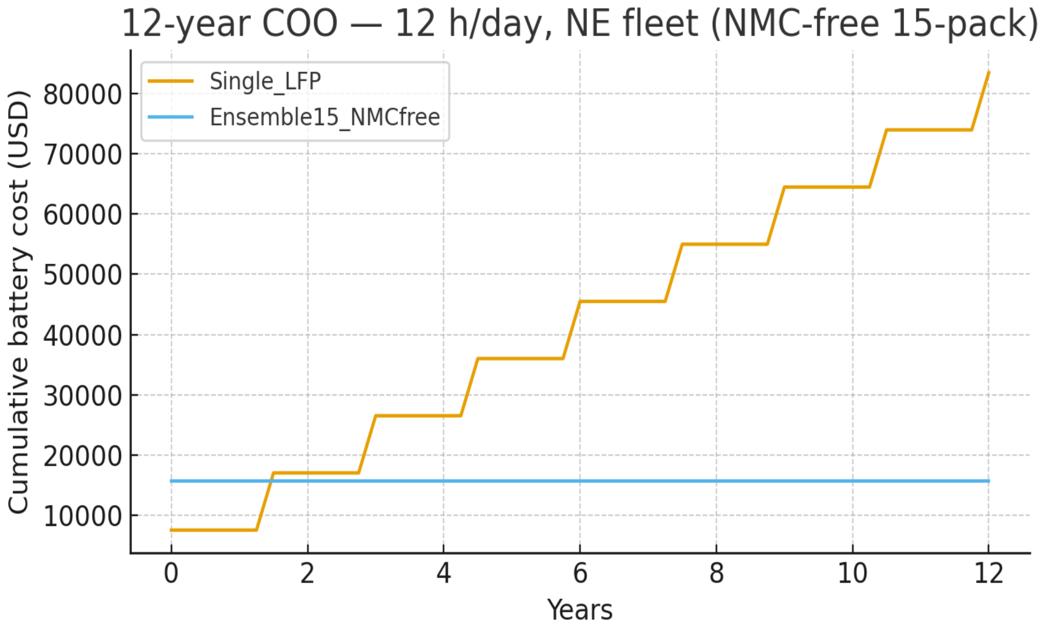


(Arrows indicate bidirectional flow of the cadence-based control law)

Illustrative Cost-of-Ownership Plots (Embodiment: LFP + LTO)







12-year COO — 12 h/day, NE fleet (NMC-free 15-pack)
Single_LFP
Ensemble15_NMCfree
Cumulative battery cost (USD)
80000
70000
60000
50000
40000
30000
20000
10000
0
2
4
6
8
10
12
Years

5. Stress Test Results (Embodiment: LFP + LTO)

A) Mountain Grade, 35 °C, 60 min

• Max T: Bulk 35.2 °C, Sprinter 35.1 °C.
• Regen captured: 6.37 kWh.
• Net energy delivered: 6.43 kWh.
• Outcome: stable thermal profile, no runaway.

B) Urban Heatwave, 42 °C, 45 min

• Max T: Bulk 41.3 °C, Sprinter 41.8 °C.
• Regen captured: 0.67 kWh.
• Net energy delivered: 1.99 kWh.
• Outcome: >40 °C modules, torque derates observed.

C) Urban Heatwave + Active Cooling + 400 V bus

• Max T: Bulk 41.6 °C, Sprinter 41.9 °C.
• Regen captured: 0.87 kWh.
• Net energy delivered: 3.03 kWh.
• Outcome: improved, but >40 °C persists without sub-ambient clamp.

D) Urban Heatwave + Active Cooling Clamp at 35 °C

• Max T: Bulk 35.01 °C, Sprinter 35.02 °C.
• Regen captured: 2.17 kWh.
• Net energy delivered: 6.34 kWh.
• Outcome: temperatures locked to ~35 °C; zero runaway; near-zero derates.
• Confirms sub-ambient chiller effectiveness.

6. Claims

1. A multi-technology energy storage system comprising bulk energy modules and high-resilience modules, wherein a controller assigns each module to a role selected from {bulk, alignment, sprinter}. 2. The system of claim 1, wherein the controller cycles said roles in a cadence pattern such that each module experiences reduced ΔSoC exposure relative to its baseline. 3. The system of claim 1, wherein sprinter modules are selected from the group consisting of lithium titanate batteries, ultracapacitors, flywheels, or other high-power/high-cycle energy storage devices. 4. The system of claim 1, wherein bulk modules are selected from the group consisting of lithium iron phosphate, nickel manganese cobalt, or other high-energy-density batteries. 5. The system of claim 1, wherein the cadence control law synchronizes aging rates across heterogeneous energy storage technologies. 6. The system of claim 1, further comprising active thermal control to clamp module temperatures below 35 °C under ambient conditions exceeding 40 °C.