Dispatch-Routing Optimization of Mobile Energy Storage for Spatiotemporal Arbitrage

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PROJECT PROFILE
Topic: Analytics & Tools | Vertical: Grid Integration and Field Validation
Strategic Pathway: Optimize
Project start and finish: FY25-FY26

BACKGROUND AND MOTIVATION

- Surging electricity demand, limited transmission capacity, and resource constraints are creating regional imbalances and congestion on power systems.
- These challenges underscore the growing need for assets capable of addressing spatial and temporal supply-demand mismatches.
- While stationary energy storage systems have been increasingly adopted for grid support and market applications, their operation is confined to fixed locations, limiting their ability to address regional imbalances.
- Mobile Energy Storage (MES)—battery units mounted on transportable platforms—can move across sites, transferring energy where it is most valuable and supporting applications such as congestion relief, seasonal or event-based load support, and post-disaster restoration.

OBJECTIVE

- Develop a mixed-integer linear programming (MILP) framework that co-optimizes battery dispatch (charge/discharge) and vehicle routing to maximize net revenue from spatiotemporal arbitrage.
- Explicitly model transportation time/costs, battery operational limits, and degradation via cycle throughput constraints.

METHODS AND MODEL

- **Economic objective:** Maximize arbitrage revenue minus transportation costs; routing decisions are coupled with dispatch through binary indicators for in-transit vs. on-site states.

$$\max \quad \Delta t \sum_{i \in \mathcal{L}} \sum_{t \in \mathcal{T}} \pi_{i,t}(P^{\mathrm{d}}_{i,t} - P^{\mathrm{c}}_{i,t}) - \sum_{i,j \in \mathcal{L}} \sum_{t \in \mathcal{T}} c_{\mathrm{trans}} d_{i,j} y_{i,j,t}$$

- **Energy dynamics:** Hourly energy balance with charge/discharge efficiencies, energy bounds, and an energy-neutral end state to avoid end-horizon bias.
- **Battery health:** A daily cycle-throughput cap (1 cycle/day) limits degradation by constraining total charge/discharge energy.
- **Power limits & exclusivity:** Maximum charge/discharge power applies only when assigned to a single active location; MES must either operate at one site or be in transit.
- **Transit logic:** Arrival/departure indicators and multi-period transit constraints ensure continuous in-transit status for the full travel time, including cases extending past the horizon.

CASE STUDY DESIGN

- **Spatial setups:**
  - **Setup 1 (Intra-ISO):** NYISO zones LNIL (Zone K), NYC (Zone J), DNWD (Zone I), MLWD (Zone H).
  - **Setup 2 (Inter-ISO):** Replace MLWD with ISO-NE CNCT (Zone 4004) to test cross-ISO price diversity.
- **Representative geographies:** Zone centroids mapped to major nearby cities (e.g., Hartford for CNCT; Manhattan for NYC), with road-network distances from OSRM and integer-hour travel times derived from average speed.
- **MES parameters:** 0.75 MW/3 MWh, 90% round-trip efficiency, 1 cycle/day, $0.20/mile transport cost, 45 mph average speed, 50% initial SOC.

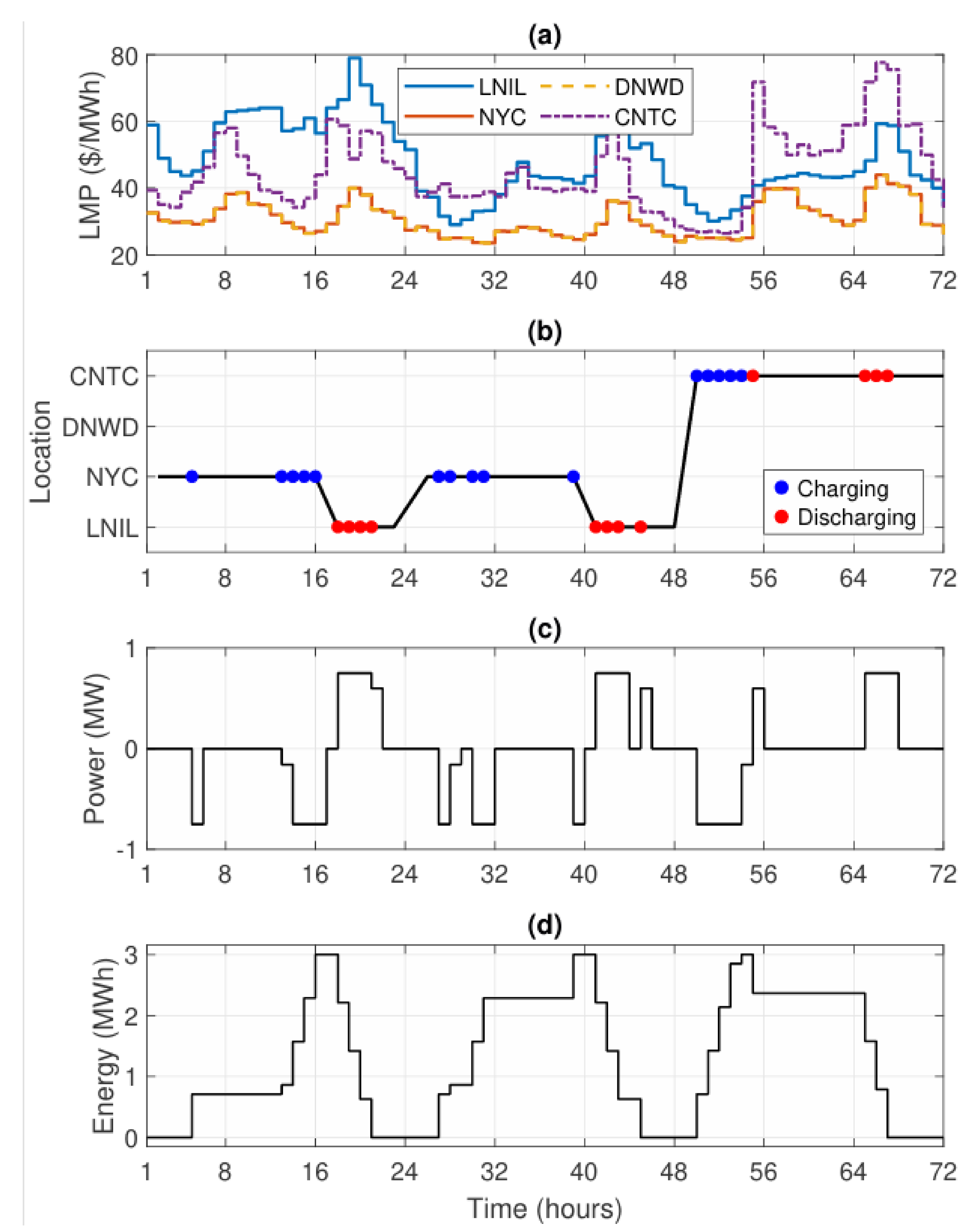
RESULTS AND VALIDATION

- **Illustrative 3-day operation:** MES charges in low-price periods and discharges in peaks; relocations occur when spatial price differentials warrant movement; dispatch resumes promptly post-move; three full cycles over the window confirm health constraint enforcement.
- **Operational continuity:** Mobile runs begin each window at the prior window's final location, preserving realistic logistics while the stationary baseline remains fixed.

Setup	Net Revenue: Stationary	Net Revenue: Mobile	Revenue Increase
1	$20,156	$21,748	7.90%
2	$19,748	$21,653	9.65%

SPATIAL ARBITRAGE INSIGHTS

- **Price spread:** Setup 2 exhibits higher spreads and more frequent high-spread hours, indicating stronger arbitrage potential.
- **Price interdependence:** Lower correlation across zones in Setup 2 enhances spatial diversity.
- **Distance trade-off:**
  - Setup 1: shorter distances → lower travel cost.
  - Setup 2: higher spreads → still produces higher net benefit despite longer travel.
- **Takeaway:** Price diversity can outweigh longer travel distances for MES.



CONCLUSION

- **Validated approach:** Co-optimized dispatch + routing enables MES to consistently capture spatial/temporal price differences.
- **Quantified benefit:** 7.9–9.6% annual uplift demonstrates economic promise, but arbitrage alone may be insufficient for large-scale roll-out—stacking additional services is key.

This material is based upon work supported by the U.S. Department of Energy, Office of Electricity (OE), Energy Storage Division.

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07/14/2026 | PNNL-SA-224998