An Intelligent Adaptive Modular Battery Energy Storage System for the Built Environment

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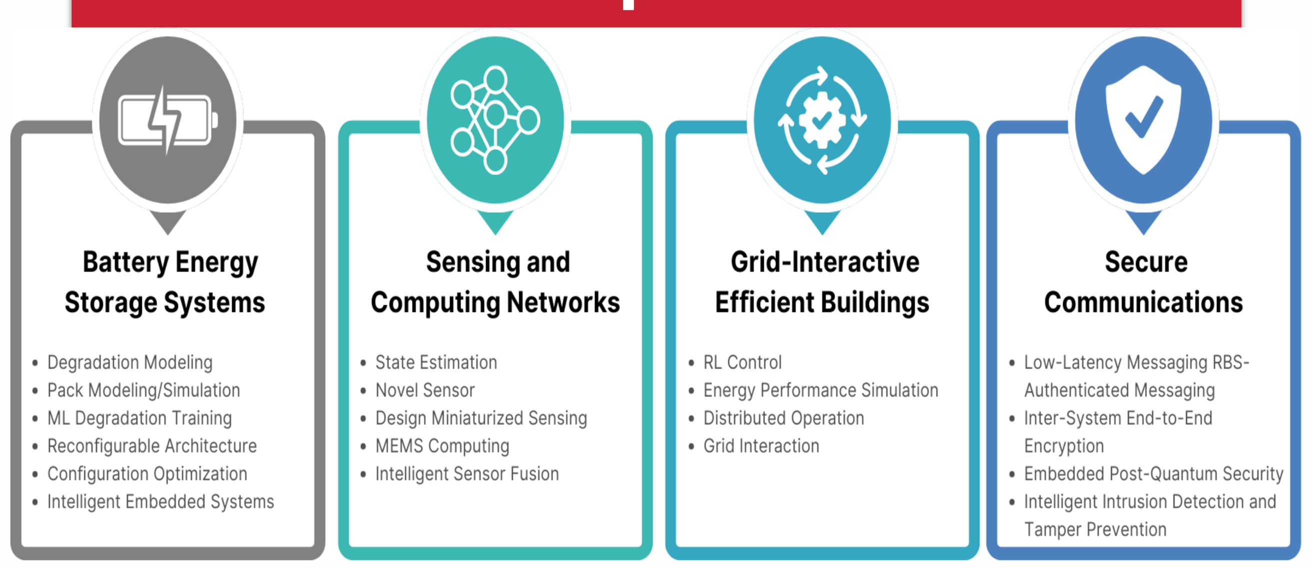
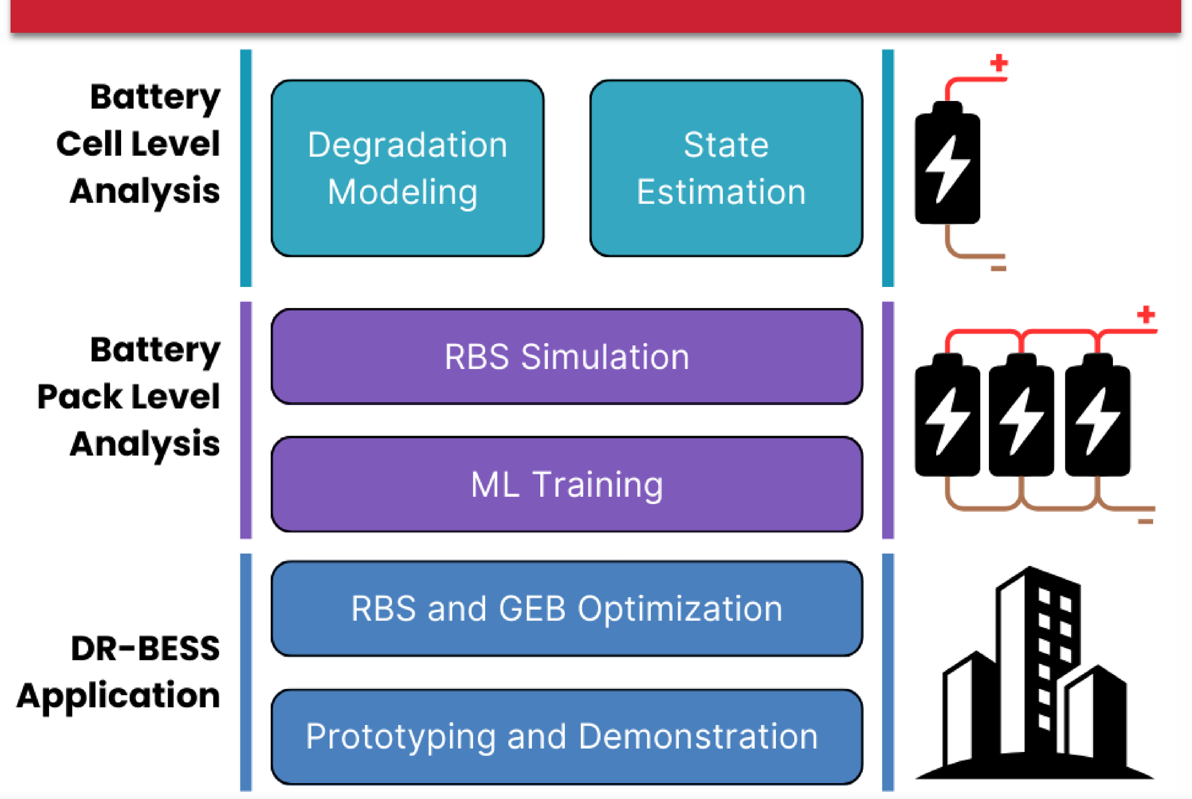
Background/Introduction

Buildings are transforming energy grids through behind-the-meter DERs like BESS. This project introduces an intelligent, modular battery energy storage system (RBS) integrated with building environments. Using a sensor network and deep reinforcement learning (RL), the system dynamically monitors and manages battery health (SoC, SoH, SoL), improving resilience and energy efficiency. Simulations show that our approach optimizes grid interaction and building comfort while extending battery life by isolating degraded cells and balancing load across healthy modules.

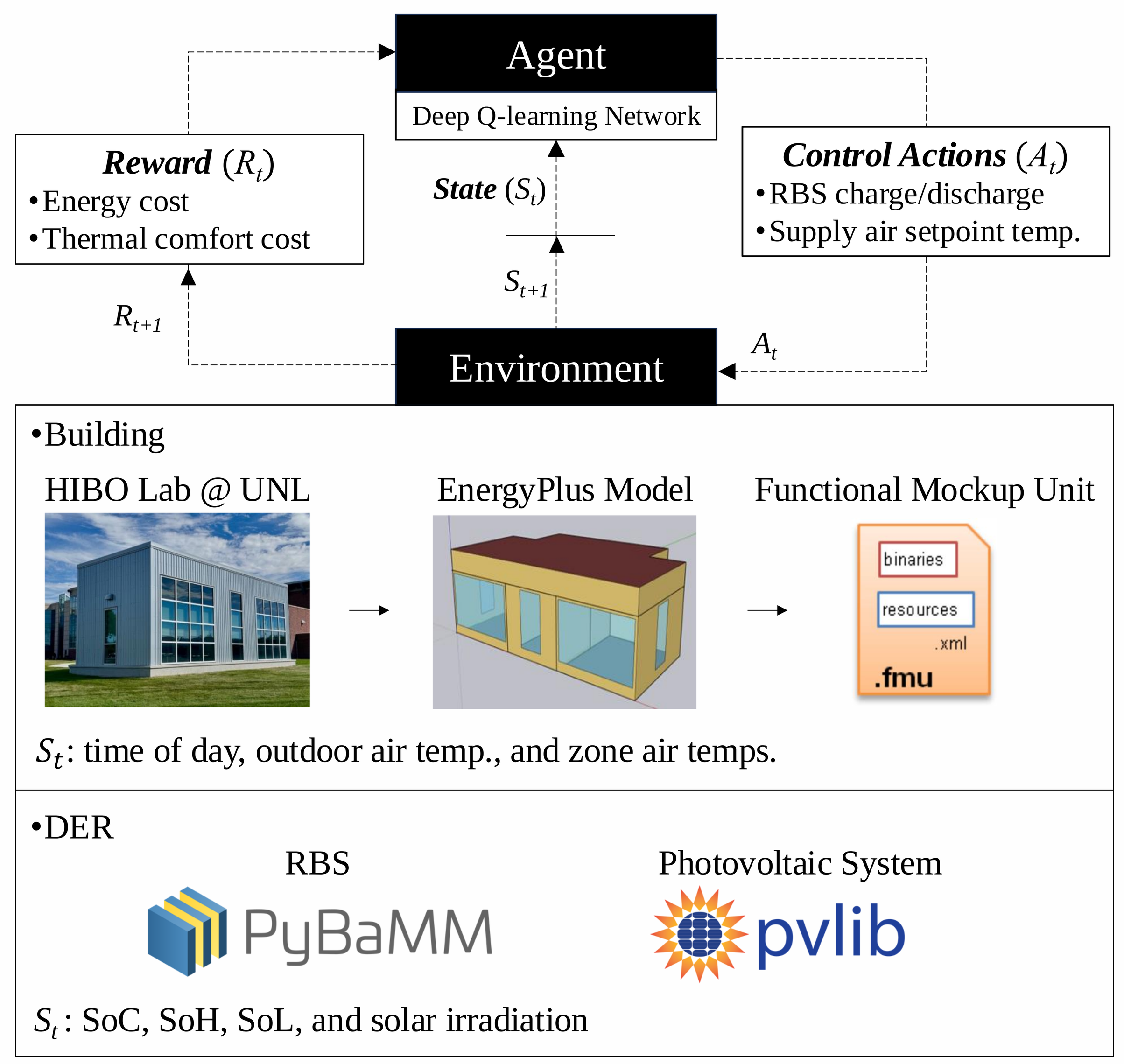
Research Domains and Topics



Proposed Research and Methods



RL Control Framework



The RL agent provides control actions to both the building and the RBS to maximize the reward. To achieve this, the RL strategy aims to charge the RBS during low-cost hours and discharge during high-cost hours. It also monitors the battery's SoC, SoH, SoL to determine the optimal cell configuration in real time, ensuring overall RBS performance and longevity.

Reward Function

Reward (R_t): Ensure thermal comfort at minimal energy cost through efficient PV use and strategic battery control.

$$R_t = -C_{violation}(A_t, S_t) - E_{cost}(A_t, S_t)$$

Thermal comfort violation ($C_{violation}$): zone temperature outside 21–24°C during occupied hours (08:00–18:00).

$$C_{violation} = \frac{1}{3}\sum_{i=1}^{3}[1_{T_i<21}(21-T_i)^2 + 1_{T_i>24}(T_i-24)^2]$$

T_i: the indoor air temperatures for each zone [°C]

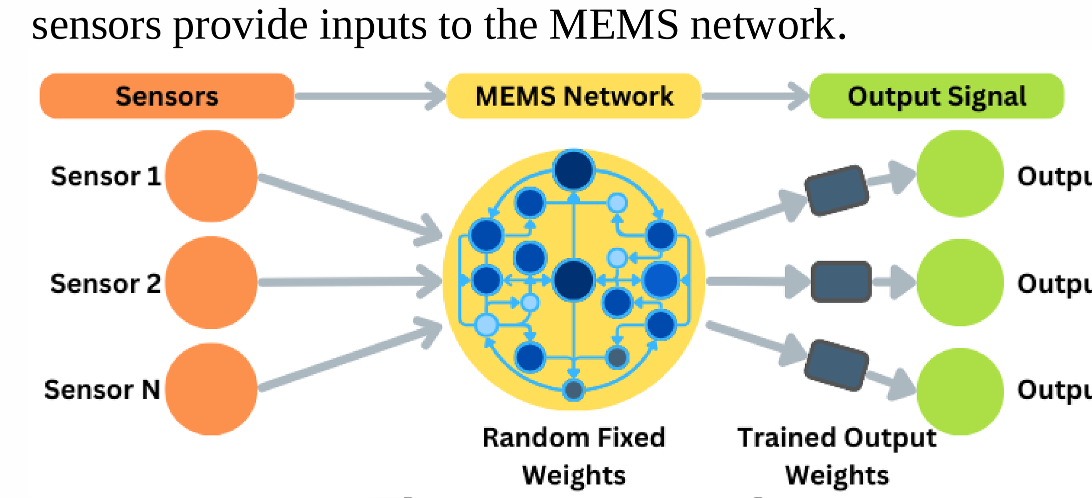
Electricity cost (E_{cost}):

$$E_{cost} = \rho_t \cdot W$$

ρ_t: time-varying electricity price [$/kWh]
W: the energy consumed by the total facility [kWh]

Sensing and Switching

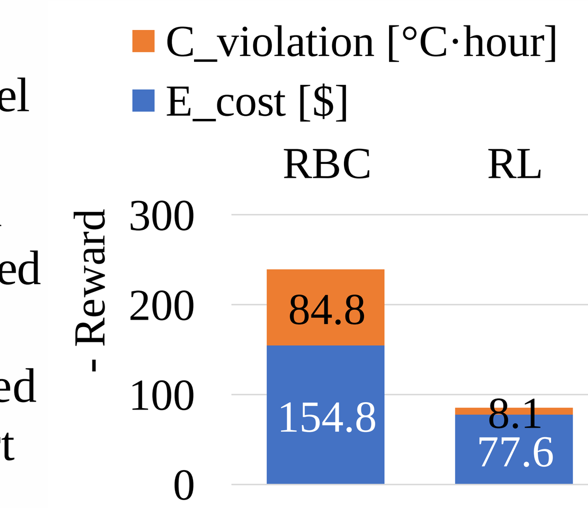
Proposed sensor network: configuration where multiple sensors provide inputs to the MEMS network.

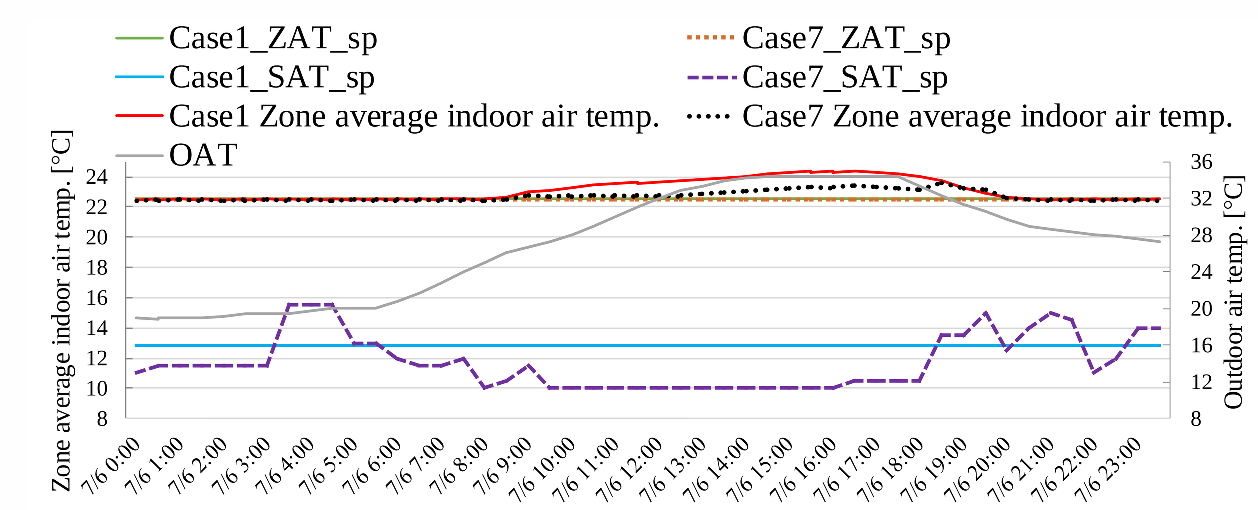


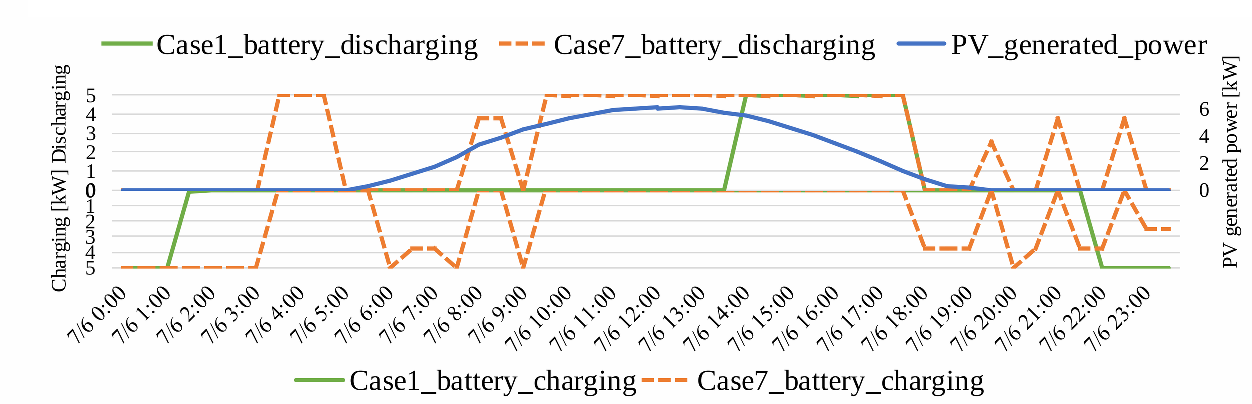
The sensor network

Intermediate RL Result

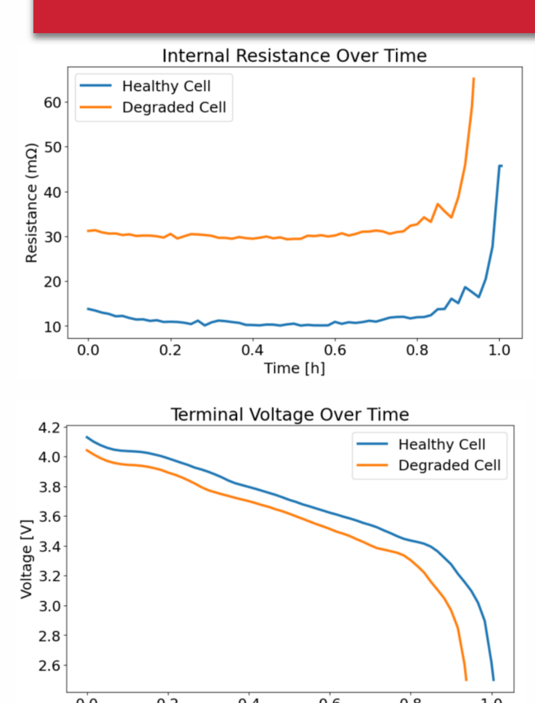
As an intermediate result, we used a simplified battery model (211.5 Ah, 5 kW) and PV system (8.1 kW) embedded in EnergyPlus. RL control reduced $C_{violation}$ by 91% and E_{cost} by 50% compared to rule-based control (RBC) based on expert practices.



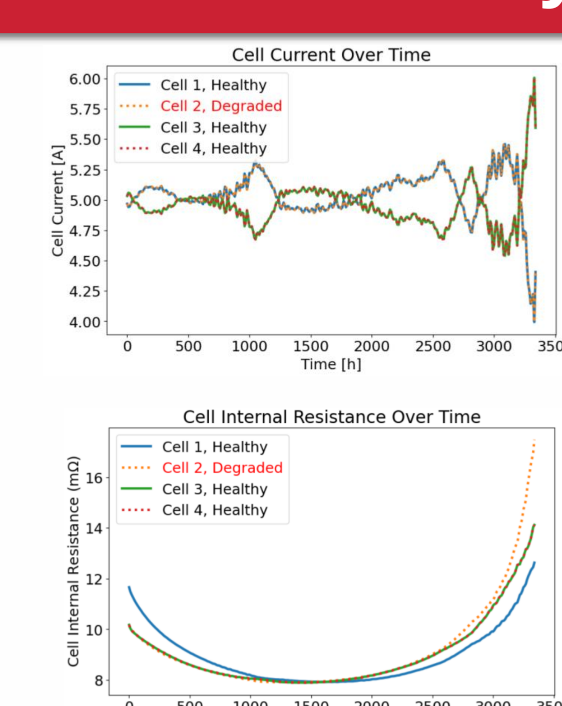




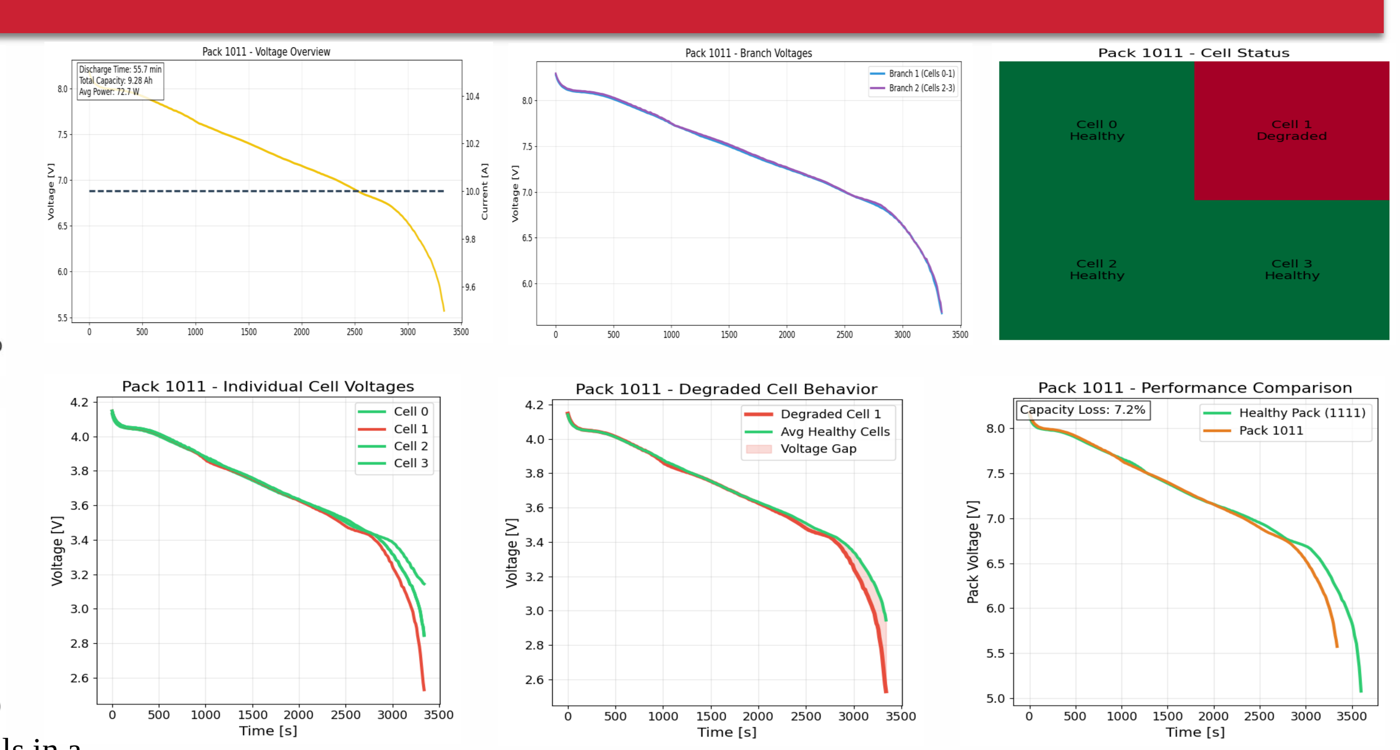
Battery simulations



Discharge performance of a healthy cell vs degraded cell, modeled in PyBaMM



Current and internal resistance for cells in a 2-series, 2-parallel pack, over a full discharge.



Battery pack performance for cells in a 2-series, 2-parallel pack, over a full discharge.

Conclusions

Our RBS system revolutionizes building-integrated storage through real-time monitoring, adaptive configuration, and RL-based control. By isolating faults, cutting energy costs, and preserving battery health, it outperforms traditional systems and offers a scalable, AI-driven solution for future smart grids and sustainable buildings.

Acknowledgment

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