# A Multiobjective Linear Time-varying Model Predictive Control Strategy for a Battery/Supercapacitor Hybrid Energy Storage System


*Chao Jia, Junwei Cui, Wei Qiao, and Liyan Qu*

*Power and Energy Systems Laboratory, Department of Electrical and Computer Engineering*


## Introduction

**Battery/Supercapacitor (SC) Hybrid Energy Storage System (HESS)**

- Battery/SC HESS has been widely used in electric vehicles, microgrids, and uninterruptible power supplies.
- With a suitable power management strategy (PMS), hybridization of battery and SC take advantage of both energy storage devices to improve the energy efficiency of the HESS while prolonging battery lifetime.

**Research Gap in Prior studies**

- The HESS prediction models in prior literatures do not consider parameters variations with respect to the battery state-of-charge (SOC) and, therefore, cannot guarantee the satisfactory model accuracy over the entire SOC range.

**The Objectives of This Work**

- Proposes a new, linear time-varying (LTV) prediction model for the battery/SC HESS.
- A multi-objective LTV-MPC strategy is proposed to optimally split the current between the battery and SC.
- A scaled-down experimental setup is developed to validate the proposed strategy.

## Model Development and Validation

### A. Powertrain Architecture

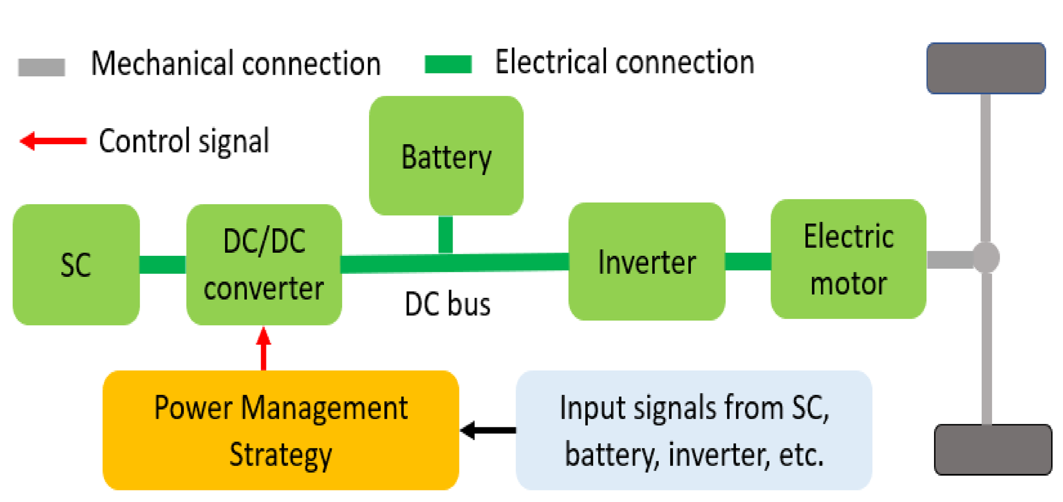


Fig. 1. Block diagram of the EV powertrain configuration studied in this work.

### B. Battery Model

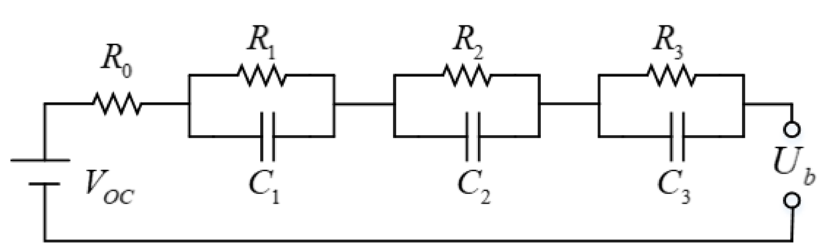


Fig. 2. Battery equivalent circuit model.

### C. SC Model

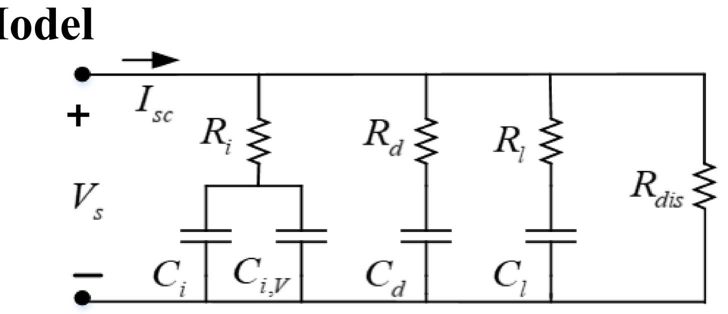


Fig. 3. Supercapacitor equivalent circuit model.

### D. Battery and SC Test and Model Validation

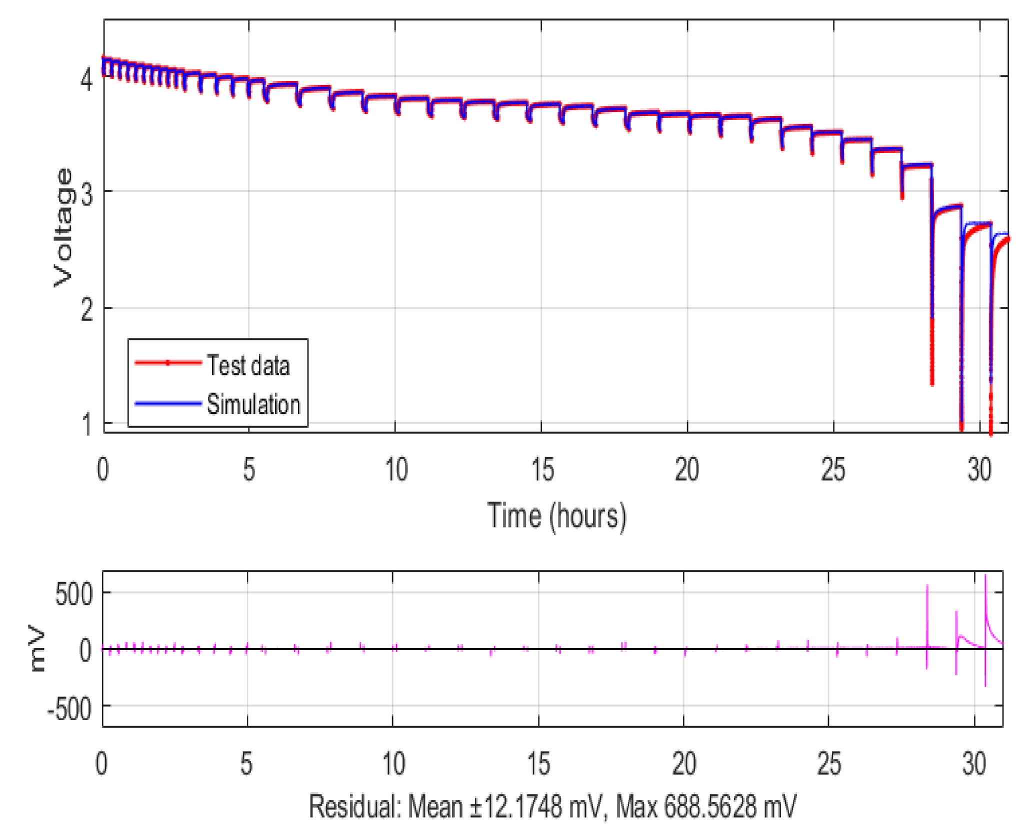


Fig. 4. Battery voltage curves of the test and simulation results.

## Proposed LTV-MPC Strategy

### A. LTV Prediction Model

The proposed discrete-time state-space model of the HESS can be derived as follows

$$x(k+1) = A(k)x(k) + B(k)u(k) + D(k)d(k)$$

$$y(k) = Cx(k)$$

where $x = [V_1, V_2, V_3, SOC_b, SOC_{sc}]^T$ is the state vector, $u = I_{sc}$ is the control variable, $d = I_{dem}$ is the measured disturbance, $y$ is the output vector, and $A$, $B$, $C$ and $D$ are matrices of the state-space model.

### B. Multiobjective Function

Three cost functions $J_1$, $J_2$, and $J_3$ are considered in the MPC strategy of the HESS.

- Power losses of HESS

$$J_1(k) = P_{Bat,Loss}(k) + P_{SC,Loss}(k)$$

- Battery current variation

$$J_2(k) = \left(I_{Bat}(k) - I_{Bat}(k-1)\right)^2$$

- Penalty term on the state of charge of the SC

$$J_3(k) = (SOC_{sc}(k) - 0.75)^2$$

The following combined objective function $J$ is used to evaluate the overall performance.

$$J(k) = J_1(k) + \omega_1 J_2(k) + \omega_2 J_3(k)$$

where $\omega_1$ and $\omega_2$ are weighting factors. By minimizing the combined objective function $J$, the energy efficiency of the HESS can be improved to offer a longer driving range (via $J_1$) and the battery lifetime can be prolonged (via $J_2$).

### C. Rolling Horizon Optimization

According to the LTV prediction model, the control action at time $k$ is obtained by minimizing the following multiobjective function over a prediction horizon $N_p$ steps:

$$\min_{U(k)} J = \sum_{i=1}^{N_p} \left(J_1(k+i|k) + \omega_1 J_2(k+i|k) + \omega_2 J_3(k+i|k)\right)$$

$$u_{min} \le u(k + r_1|k) \le u_{max},\ r_1 = 0, 1, \ldots, N_c - 1$$

$$x_{min} \le x(k + r_2|k) \le x_{max},\ r_2 = 1, \ldots, N_p$$

where $N_c$ is the control horizon, $(k+i|k)$ means $i$-step ahead of the time index $k$, and $U(k) = [u(k|k), \ldots, u(k+N_c-1|k)]^T$ is the sequence of the SC current (i.e., control variable) to be optimized. At the time step $k$, the MPC receives the new measurements or estimations of the current states and then solves the constrained optimization problem to obtain the optimal value of $U(k)$. Then, the controller only applies the first optimal control action $u^*(k|k)$ to the plant.

## Simulation and Experimental Results

Proposed LTV-MPC-based current split strategy is compared with a rule-based strategy and a frequency-decoupling strategy for the HESS in EV applications.

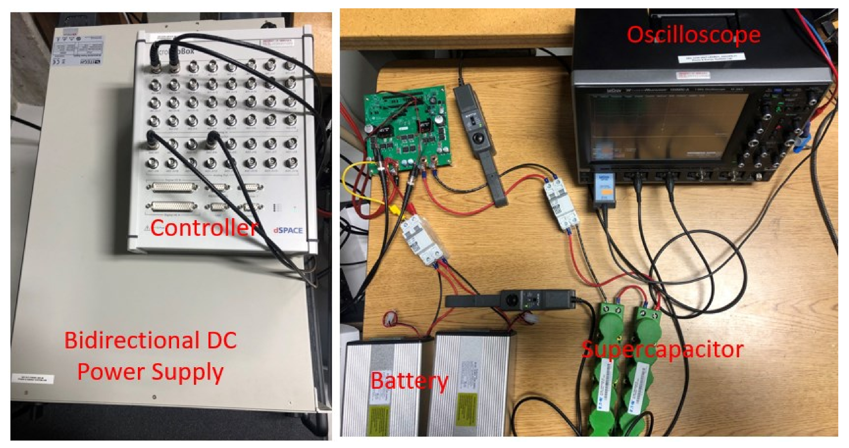


Fig. 5. Experimental setup for the HESS

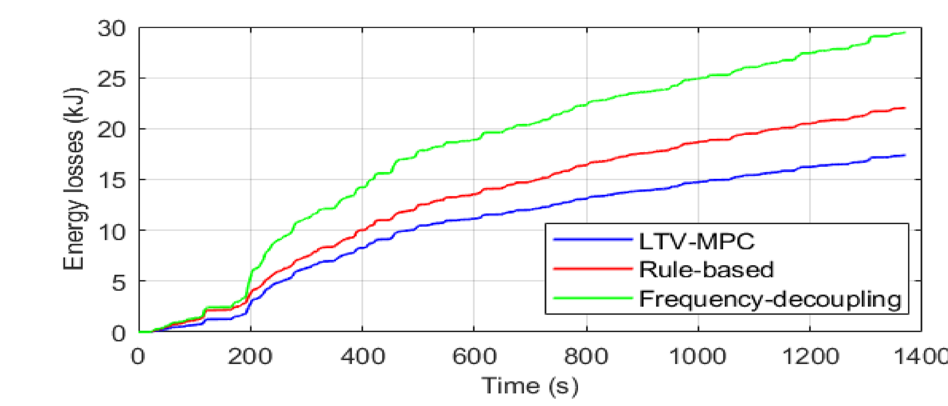


Fig. 6. Accumulated energy losses of three strategies.

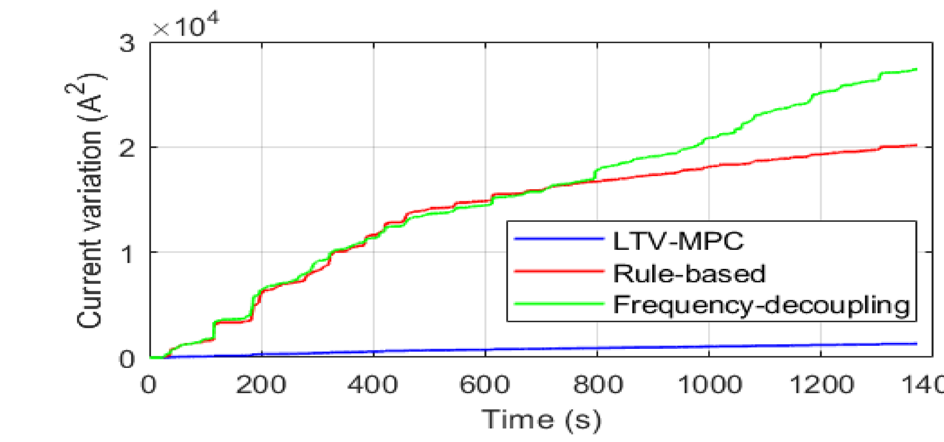


Fig. 7. Accumulated current variations of three strategies.

## Conclusions

- A multiobjective LTV-MPC strategy was proposed to properly distribute the load current between battery and SC.
- Simulation and experimental results validated the superiority of the proposed LTV-MPC strategy over a rule-based strategy and a frequency-decoupling strategy.


University of Nebraska Lincoln — Nebraska Center for Energy Sciences Research

Nebraska Public Power District — Always there when you need us