Optimal Control for Battery Storage Using Nonlinear Models

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Outline

1. Introduction
2. Optimal charging control using linear and nonlinear models
3. Case study
4. Conclusion and future work

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Background

Grid applications:

- Energy arbitrage
- Balancing service
- Capacity value
- Distribution system upgrade deferral
- Outage mitigation

Customer-side applications:

- Energy charge reduction
- Demand charge reduction

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Motivation

- Optimal control is desired in order to best utilize the limited power and energy capacity of BSS
- Look-ahead optimization is required to capture interdependent operation over time
- Fixed power rating and constant round-trip or one-way efficiencies are used in existing optimal scheduling methods
  - inaccurate economic assessment results
  - infeasible operating schedule

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Optimal scheduling with linear battery model

$$\mathbf{P}_1: \max_{p_k, p_k^{\text{batt}}, s_k, \Delta s_k} \sum_{k=1}^{K} \lambda_k p_k$$

subject to:

Charging/discharging limit: $-p_{\text{max}}^- \leq p_k \leq p_{\text{max}}^+, \quad \forall k = 1, \cdots, K$

Rate change of energy in batt.: $p_k^{\text{batt}} = \begin{cases} p_k/\eta^+ & \text{if } p_k \geq 0 \\ p_k \eta^- & \text{if } p_k < 0 \end{cases}, \quad \forall k = 1, \cdots, K$

SOC change: $\Delta s_k = p_k^{\text{batt}} \Delta T / E_{\text{max}}, \quad \forall k = 1, \cdots, K$

Dynamics of SOC: $s_k = s_{k-1} - \Delta s_k, \quad \forall k = 1, \cdots, K$

SOC limits: $\underline{S}_k \leq s_k \leq \overline{S}_k, \quad \forall k = 1, \cdots, K$

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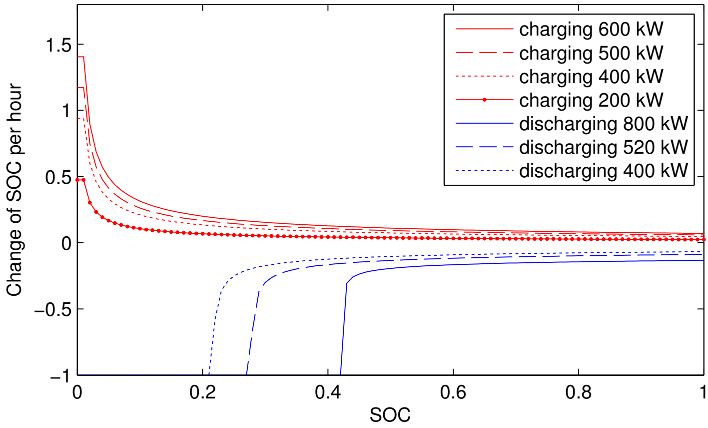
Limitations with existing linear battery model

- $[-p_{\mathsf{min}}, p_{\mathsf{max}}]$: incapable to model varying charging/discharging range
- E_{max}: inaccurate to represent energy capacity
- η^{+}, η^{+}: difficult to estimate overall efficiency and inaccurate to capture actual losses

Varying power capability and SOC change rate



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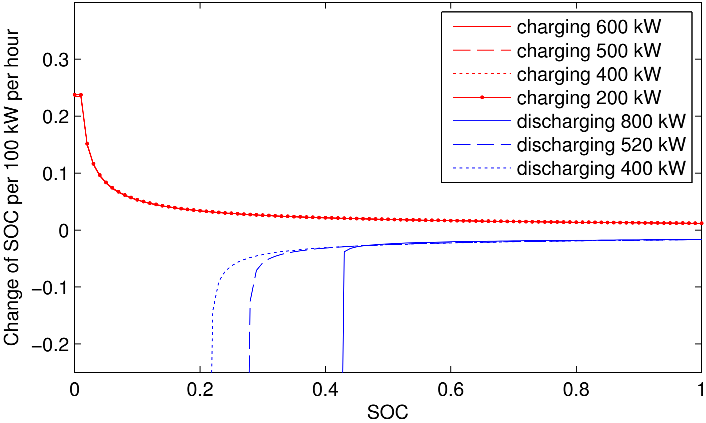
1 MW/3.2 MWh vanadium redox BSS

Varying power capability and SOC change rate (cont.)



1 MW/3.2 MWh vanadium redox BSS

Optimal scheduling with nonlinear battery model

$$\mathbf{P}_2: \quad \max_{p_k, s_k, \Delta s_k} \quad \sum_{k=1}^{K} \lambda_k p_k$$

subject to:

$$\begin{aligned}
\text{Charging/discharging limit:} \quad & p_k \in \mathcal{P}_{s_k}, && \forall k = 1, \cdots, K \\
\text{SOC change:} \quad & \Delta s_k = f(p_k, s_k), && \forall k = 1, \cdots, K \\
\text{Dynamics of SOC:} \quad & s_k = s_{k-1} - \Delta s_k, && \forall k = 1, \cdots, K \\
\text{SOC limits:} \quad & \underline{S}_k \leq s_k \leq \overline{S}_k, && \forall k = 1, \cdots, K
\end{aligned}$$

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Assumptions and inputs

- BSS: 1 MW/3.2 MWh vanadium redox BSS at Turner substation in Pullman in Washington State.
- Applications: energy arbitrage and energy imbalance reduction
- Price: The Mid-Columbia prices from 2011 to 2015

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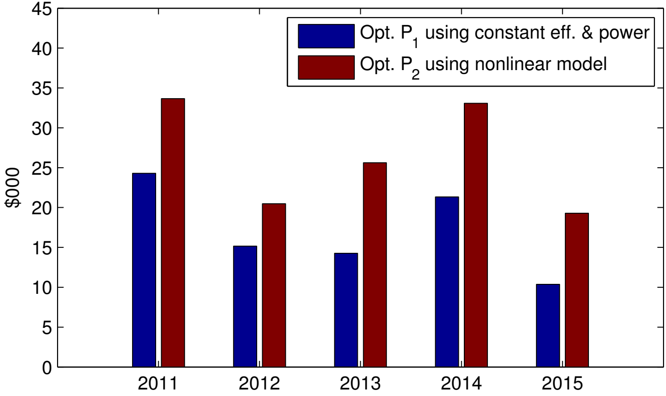
Economic performance comparison results



2 MW/6.4 MWh

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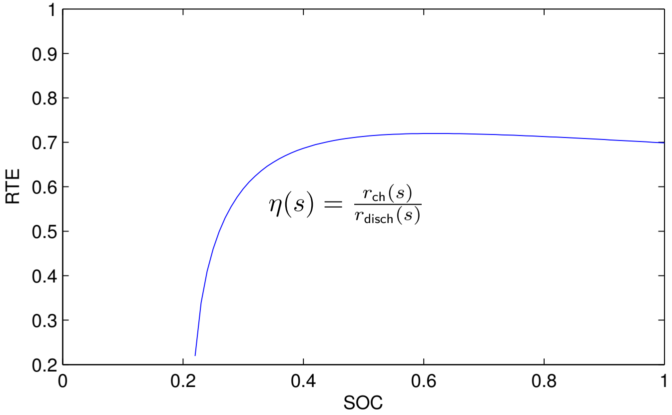
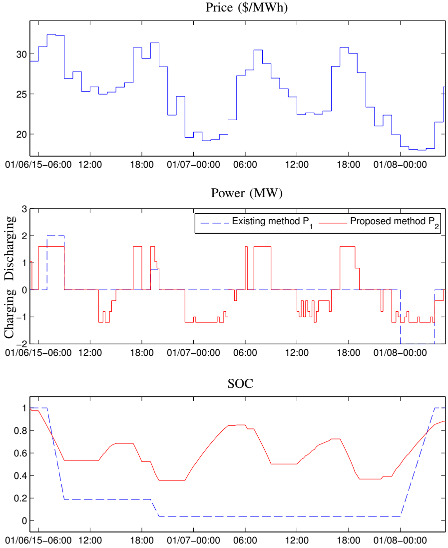
Varying round-trip efficiency



BSS power and SOC



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Conclusion and future work

Conclusion:

- Nonlinear BSS model better captures varying charging/discharging power capability and efficiencies.
- Optimal scheduling without accurate nonlinear BSS model could result in significant errors in benefits assessment, and even infeasible operation.

Future work:

- Apply the proposed method with nonlinear model for other grid and/or customer-side applications.

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Thank you! Questions?

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