Sandia National Laboratories

Model Predictive Control of Energy Storage Systems for Combined Energy Arbitrage and Power Quality Applications

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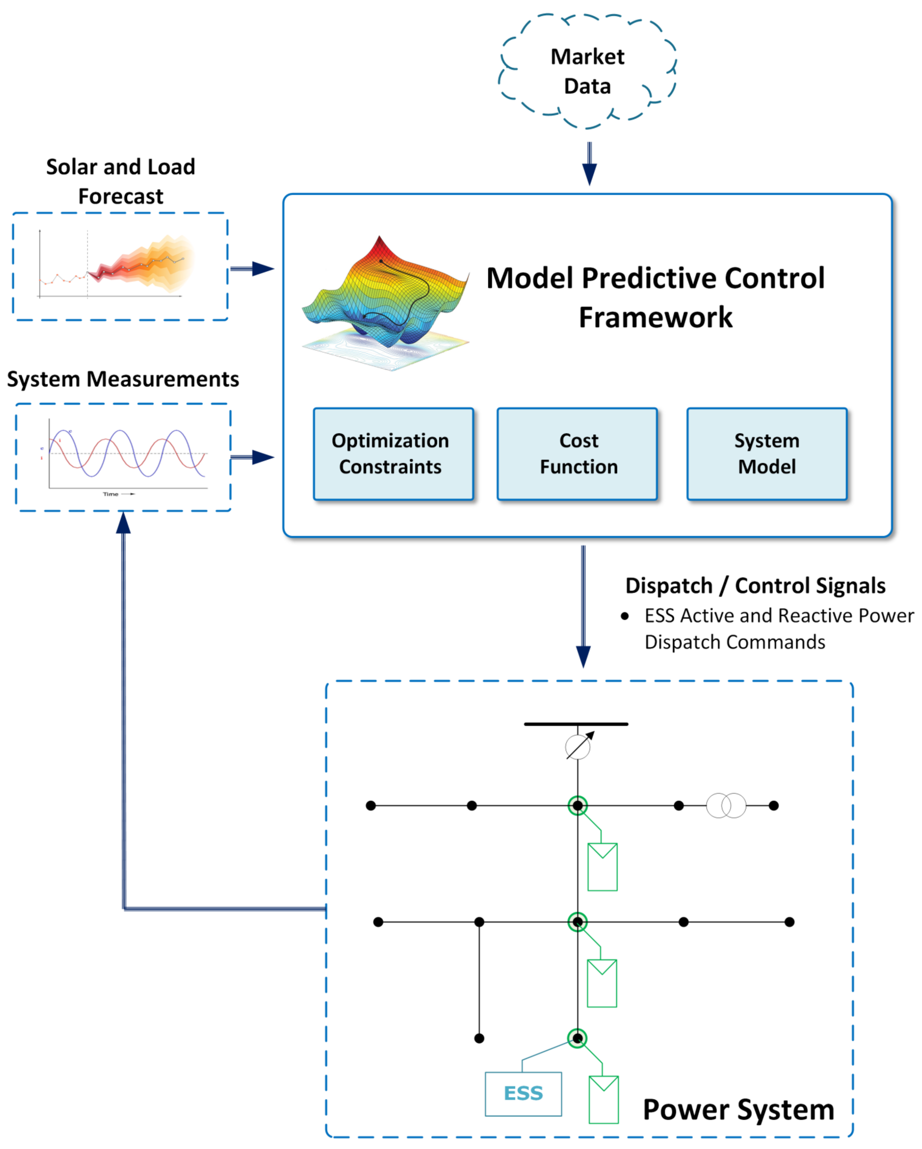
Abstract

In this work, we present a framework for real-time dispatch of energy storage systems (ESSs) to simultaneously provide energy arbitrage and power quality. A case study demonstrating combined usage of energy storage for energy arbitrage and voltage regulation is demonstrated. The real-time applicability of the framework is demonstrated though controller-hardware-in-loop tests.

Overview

- ESSs have the potential to provide multiple unique services
  - Provides avenues for higher revenue streams
- ESSs can provide reactive power to grid on top of active power services
- A control framework is required to dispatch ESSs in real-time while maximizing benefits
  - Model predictive controls (MPCs) ideal for such applications

Methodology



Objective Function

Maximize arbitrage revenue

$$\max_{p_k^d, p_k^c, q_k^d, q_k^c} J_{EA} := \sum_{k=1}^{T} \left(c_k p_k^d \tau - c_k p_k^c \tau\right)$$

Constraints

Voltage Constraints

$$x_k = A x_{k-1} + K_p p_k^{net} + K_q q_k^{net}$$
$$x^{min} \leq x_k \leq x^{max}$$

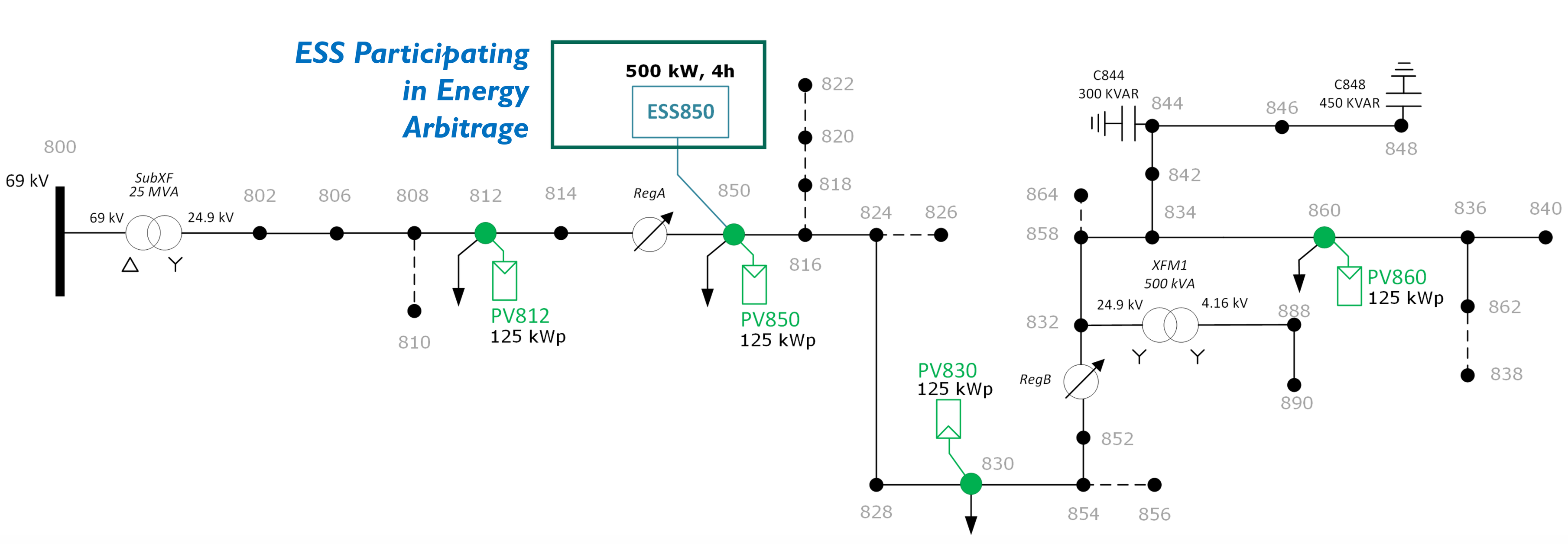
ESS SOC Constraints

$$S_k = \gamma_s S_{k-1} + \gamma_c p_k^c \tau - p_k^d \tau$$
$$S^{min} \leq S_k \leq S^{max}$$

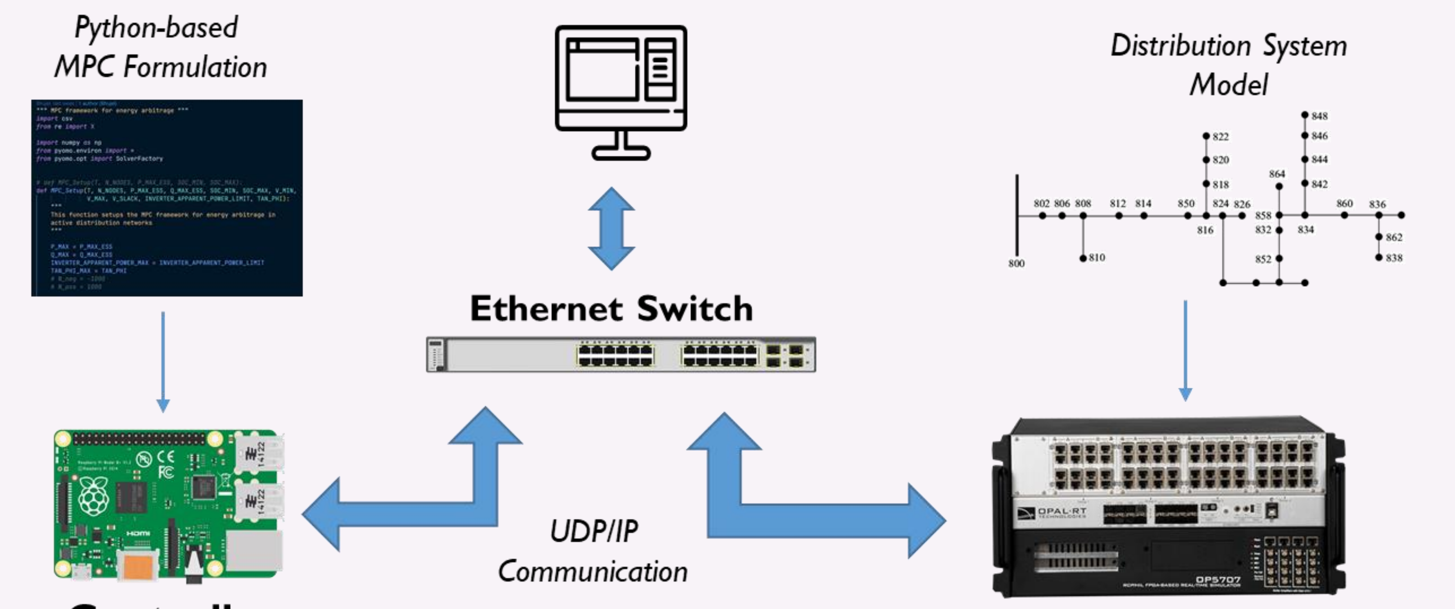
Inverter Capability and Power Factor Limits

$$-tan\left(\bar{\phi}\right) p_k^c \leq q_k^c \leq tan\left(\bar{\phi}\right) p_k^c$$
$$-tan\left(\bar{\phi}\right) p_k^d \leq q_k^d \leq tan\left(\bar{\phi}\right) p_k^d$$
$$\left(p_k^d\right)^2 + \left(q_k^d\right)^2 \leq \left(\bar{P}\right)^2$$
$$\left(p_k^c\right)^2 + \left(q_k^c\right)^2 \leq \left(\bar{P}\right)^2$$

IEEE34 Bus Test Case



CHIL Validation – Energy Arbitrage with Voltage Regulation

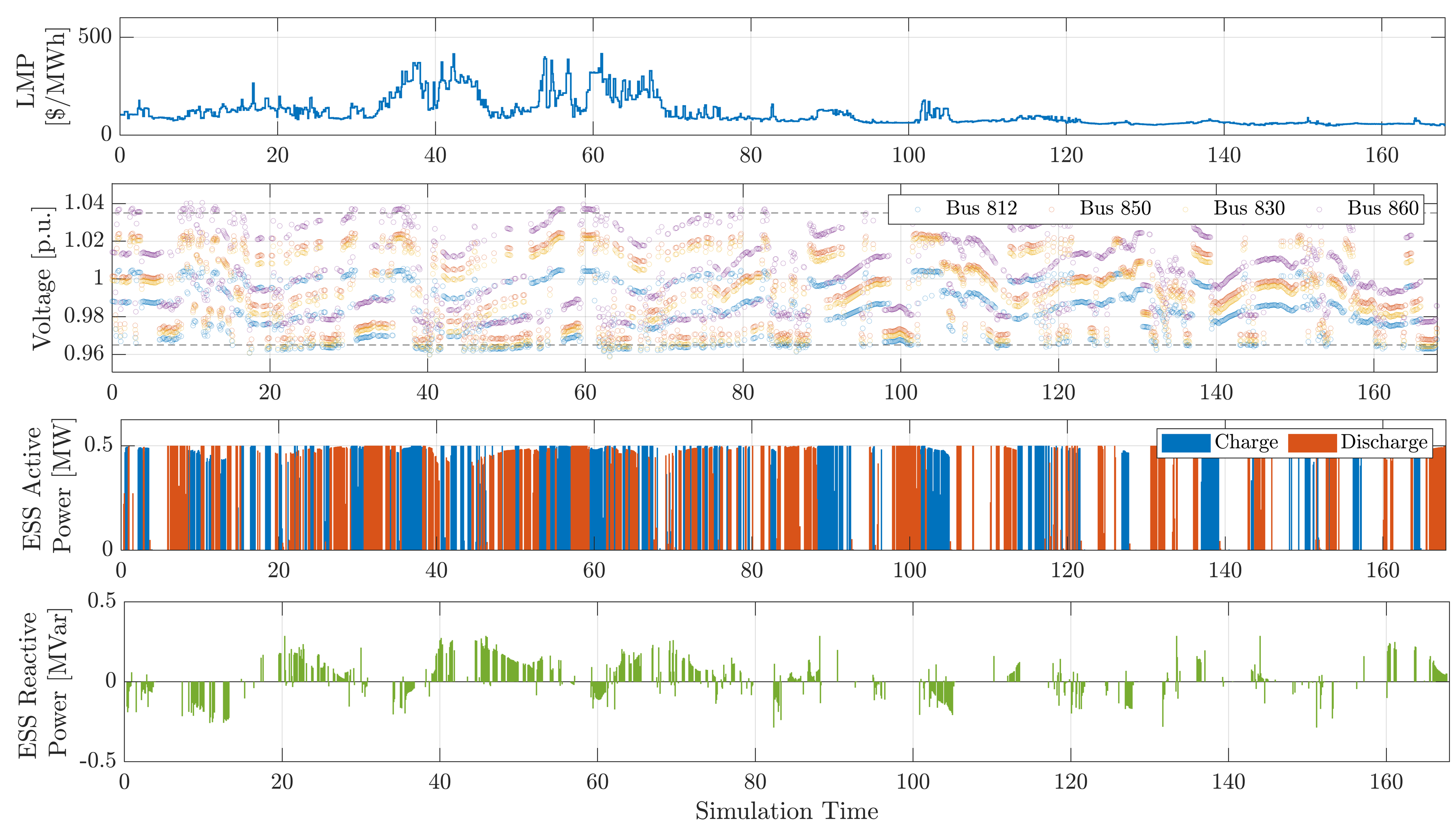


- Controller Hardware in the Loop (CHIL) study performed to highlight real-time applicability
  - IEEE 34 bus simulated in OPAL-RT with models of PVs and ESS
  - Measurements are passed to a Raspberry-Pi where the proposed controller is implemented

Results and Analysis

Simulation Settings:

- Dispatch Interval = 5 min | Prediction Horizon = 4 hours | Voltage limit = ±3.5%
- Simulation repeated with and without Q-support



Q-support allows more charge/discharge opportunities without violating voltage limits

Revenue = $1162 (*No Q-support*)

Revenue = $1320 (*Q-support*)

Key Takeaway

Technical and economic benefits from ESSs can be maximized by combining energy arbitrage and power quality applications in a single dispatch framework.

Future Work

- Verify proposed framework with more detailed/realistic energy storage models and power HIL tests
- Distributed MPC for larger feeders with several ESS units

This work was supported by the U.S. Department of Energy Office of Electricity Energy Storage program under the guidance of **Dr. Imre Gyuk**.

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