Field Validated Utility-Scale Battery Storage Control Models for Quasi-static Analyses

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Introduction

Project partners

- National Renewable Energy Laboratory
- Sumitomo Electric (SEI)

Project background

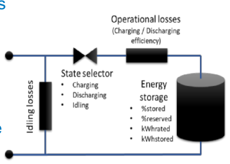
- San Diego Gas and Electric (SDG&E) and Sumitomo Electric (SEI) initiated a 2MW / 8MWh vanadium red-ox flow battery (VRFB) storage pilot project in California.

Objectives

- Identify value streams through the application of utility-scale VRFB for local grid support use cases, including:
  - Base loading and peak shaving (BLPS)
  - Capacity firming
  - Voltage support
  - Energy arbitrage
- Optimally dispatching a utility-scale vanadium redox flow battery (VRFB) energy storage system

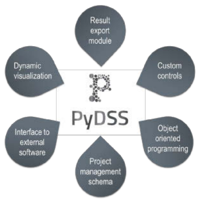
Modeling and simulating the system

- The test distribution feeder has been modeled in OpenDSS
- Storage model available in OpenDSS simplistic
- Control modes available to the VRFB not available for the OpenDSS storage model



The OpenDSS battery model

Development of PyDSS



- An open source high-level Python interface for OpenDSS
  - Expands upon its organizational, analytical, and visualization capabilities.
  - Simplifies co-simulation framework integration
  - Allows the user to develop custom control algorithms and embed them into the simulation environment.
- Is available at: https://github.com/NREL/pydss

Development of control algorithms

Base loading & Peak shaving

- BLPS is a method used to flatten the load profile
  - Storage discharges into the grid if demand is greater than a predefined peak shaving threshold
  - Storage charges from the grid if demand is less than a predefined base loading threshold

Algorithm 1: Pseudo code for base loading / peak shaving algorithm

Input: $Err_{tol}, I, P_{batt}^{rated}, P_{ps}, P_{bl}, \eta, T$
Output: $P_{batt}[t]$

while $t \leq T$ **do**
  while $Err \geq Err_{tol}$ **do**
    if $P_{ref}[t] > P_{ps}$ **then**
      $\Delta P[t] = P_{ref}[t] - P_{ps}$;
      $P_{batt}[t] \mathrel{+}= \Delta P[t] \times \eta$;
    else if $P_{ref}[t] < P_{bl}$ **then**
      $\Delta P[t] = P_{ref}[t] + P_{bl}$;
      $P_{batt}[t] \mathrel{+}= \Delta P[t] \times \eta$;
    else
      $P_{batt}[t] = 0$;
    if $P_{batt}[t] \geq 0$ **then**
      $p_{dchg}[t] = P_{batt}[t]/P_{batt}^{rated} \times 100$;
      $Battery.state = Charging$;
      $Battery.\%Discharge = p_{dchg}[t]$;
    else
      $p_{chg}[t] = -P_{batt}[t]/P_{batt}^{rated} \times 100$;
      $Battery.state = Discharging$;
      $Battery.\%Charge = p_{chg}[t]$;
    $Err = |P_{batt}[t] - P_{batt}^{old}[t]|$;
    $P_{batt}^{old}[t] = P_{batt}[t]$;
    if $i >= I$ **then**
      break;
    $i \mathrel{+}= 1$
  $t \mathrel{+}= 1$

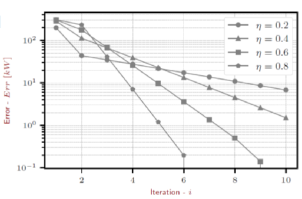
Capacity Firming

- Capacity firming is a method used for improving power quality by limiting rate of change in active power at the control node within a distribution system

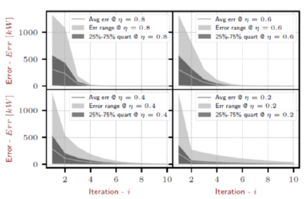
Both algorithm are implemented using the OpenDSS storage model and iteratively converge to a steady state solution

Analyzing algorithm convergence

- Slope of a semi log graph has been used to calculate convergence rate of the algorithms
- A damping factor is introduced to control the speed of convergence
  - Small damping factor slow down the rate at which the algorithm converges
  - For highly intermittent days large values of might cause the algorithm to diverge
- Both algorithms successfully converged to steady state solutions at every time iteration during the simulation runs



Impact of varying damping factor on peak shaving algorithm's convergence (Error averaged over time iterations)

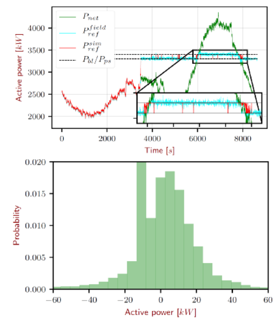


Impact of varying damping factor on peak shaving algorithm's convergence

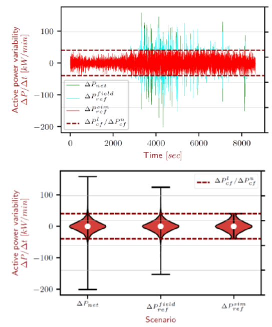
Field validation of the developed algorithms

Base loading & Peak shaving

- VRBF operated in BLPS mode on September 13th, 2017 starting
  - Base loading limit: 3300 kW
  - Peak shaving limit: 3400 kW
- The control algorithm, does well to mimic the actual hardware
  - Residual mean: -3.37 kW
  - Residual std: 21.197 kW
  - R^2 score: 99.83%



Field validation results for the BLPS algorithm



Field validation results for the CF algorithm

Capacity Firming

- VRFB operated in capacity firming mode on 5th September 2017
  - Upper limit: +40 kW/min
  - Lower limit: -40 kW/min
- Field measurements show VRFB unable to limit active power variability due to:
  - Error pertaining to sensing in the measurement device.
  - the battery controller always lags behind the actual state of the system,

Conclusions

- Paper presents implementations of two control algorithms for a utility scale Vanadium redox floe battery
  - Base load and peak shaving
  - Capacity firming
- The control algorithms have been implemented in PyDSS; a Python based high-level interface for OpenDSS.
  - The tool is now open source and publicly available
- The algorithms have been validated using the 2 MW / 8 MWh red-ox flow battery installed in San Diego, California
  - The results presented in this paper show that the implemented algorithms mimic the behavior of the actual battery storage system very closely

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