Synergies between Building-Sited Batteries and Thermal Energy Storage

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Seminar 30 - The Solar Panel: Enabling Renewables' Grid Integration with Thermal Energy Storage Systems
Learning Objectives

1. Explain how water heaters can provide demand side management to the grid.
2. Identify effects of load shifting on end-user electricity bills and the use of solar-self consumption.
3. Describe how a phase-change-material-based cool thermal energy storage system can be used to enable renewables on the electric grid.
4. **Describe the pros and cons of behind-the-meter battery and thermal energy storage, and how to select the appropriate combination depending on the building load profile.**
Pros/Cons of Energy Storage Systems

• Batteries
  ▪ (+) More flexible—directly meets total electric load
  ▪ (-) More costly—capital expense is typically higher
  ▪ (-) More sensitive to cycling

• Thermal energy storage
  ▪ (-) Less flexible—can only meet thermal loads
  ▪ (+) Less costly
  ▪ (+) Less sensitive to cycling
Outline

• Simulations
  – Methods
  – Results – optimal sizing of thermal and battery storage

• Experiments
  – Hardware-in-the-loop setup
  – Results – supervisory control and additional efficiency benefits
Simulation
Analyzed case

A big-box retail building in Phoenix, AZ with a 600-kW PV array, and six 150-kW EV chargers with assumed load profiles from EVI-EnSite\(^1,2\)

- **Independent variables:**
  - Thermal energy storage size
  - Battery energy storage size
- **Dependent variables:**
  - Utility cost savings
  - Battery cycles per year
  - Annualized cost savings

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Model parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low</th>
<th>Nominal</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>BES Capital Cost ($/kWh&lt;sub&gt;e&lt;/sub&gt;)</td>
<td>300</td>
<td>600</td>
<td>900</td>
</tr>
<tr>
<td>BES Lifetime (yr)</td>
<td>10</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Demand Charge ($/kW)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.5</td>
<td>15</td>
<td>22.5</td>
</tr>
<tr>
<td>Discount Rate (%)</td>
<td>4</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Energy Rate ($/kWh)</td>
<td>0.08</td>
<td>0.12</td>
<td>0.16</td>
</tr>
<tr>
<td>TES Capital Cost ($/kWh&lt;sub&gt;e&lt;/sub&gt;)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>50</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>TES Lifetime (yr)</td>
<td>10</td>
<td>15</td>
<td>20</td>
</tr>
</tbody>
</table>

<sup>a</sup> We consider cases where the demand charge is assessed all year or only in summer months

<sup>b</sup> We also consider a case where the TES capital cost equals the BES capital cost ($600/kWh<sub>e</sub>)
Annual and daily load profiles

(a) Electric Demand Power (kW)

Time in Year (h)

(b) Time in Day (h)

Curve Legend:
- B
- B+PV
- B+EV
- B+PV+EV
Example day load leveling

Electric power demand (kW)

Time of day (hr)

Total (no storage)
Total (with BES+TES)
Chiller (no storage)
Chiller (with TES)
Battery discharge (chiller off)
Annual simulation results

- Building-only scenario
- Demand charges in summer only
- Battery and TES both $600/kWh_e capital cost

Annual simulation results

- Building-only scenario
- Demand charges in summer only
- **Battery $600/kWh_e capital cost; thermal storage $100/kWh_e**
Annual simulation results

- Building-only scenario
- **Demand charges year round**
- Battery $600/kWh_e$ capital cost; thermal storage $100/kWh_e$
Annual simulation results

- Building + PV generation + EV charging
- Demand charges year round
- Battery $600/kWh_e capital cost; thermal storage $100/kWh_e
Annual simulation results

- Building + PV generation + EV charging
- Demand charges year round
- **Battery and TES same $/kWh_e capital cost**
Experiments
Laboratory hardware and controller
Chiller plant + thermal storage

Chiller is controlled to modulate down with ice tank making up the difference.
Chiller plant + thermal storage

- Chiller, 30 ton (105 kW)
- Ice tank, 162 tonh (570 kWh)
- Fluid conditioning module
Battery emulator with inverter

Electric Power Measurements at Panel:

- CB1: EPWRBattery
- CB2: EPWRchiller
- CB3: EPWRchilled glycol Pump
- CB4: EPWRcondenser Pump

Battery charge/discharge is controlled with 30-kW CE+T inverter/rectifier, through MODBUS signal.
Supervisory controls

Simulated Parameters:
- EPWR: Non-HVAC Building
- Building EPWR Limit

Chiller Plant Operational Mode:
Chiller, TES, Hybrid-Cool, or Hybrid-Charge

Panel EPWR Meter:
Total Chiller Plant Power

Panel EPWR Meter:
Chiller Power

Chiller CW Temperature Setpoint

Simulated Parameters:
- Building Thermal Load

Fluid Conditioning Module

Imposed Loads:
Building Load and Heat Sink

Chilled Water Plant
Real-Time Control

Setpoint: Chiller Power

Error

Realtime Controller

Chiller CW Temperature Setpoint

cw Plant: Chiller + Ice Storage

Panel EPWR Meter:
Chiller Power

Battery Energy Storage System

Setpoint: AC Discharge Power

Error

Controller

Panel EPWR Meter:
Battery AC Discharge Power

Battery Real-Time Control
- Modulation of chiller increases efficiency by ~45%

- Compressor modulation limited to 60-100%, based on an internal Trane software limit.
Example experiment: Electric load leveling

- Chiller modulation reduces electric load from 5-6:30pm. Battery provides additional load reduction from 6:30-7:30pm.

- Chiller efficiency improves by ~40% at part load.

- 35.3 kWh of shaved energy
  - 71% from TES
  - 29% from BES
Conclusions

Simulations:
• Adding batteries to a TES system can increase the total system’s load shaving potential (and increase TES utilization for peak demand reduction)
• Adding TES to a battery system can improve economics since TES often has a lower capital cost, and because it can significantly lower battery cycling, extending the battery life
• In the climate analyzed in this study, which has a large cooling load, the pseudo-optimal hybrid design is often some combination of thermal and battery storage, and rarely only a battery-only or TES-only system

Experiments:
• Supervisory controllers can communicate with both thermal and battery energy storage systems to optimize controls
• Improved chiller efficiency at part load can increase the load shifting capability for TES (not yet included in above simulations)
• Limitations on chiller turndown ratio and response time can limit what is possible compared to simulations above. This should be considered when selecting a chiller for a thermal storage application
Questions

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Supplemental slides
Modeling approach

**Model Inputs**

2.1 Variable utility rate structures
2.2 Energy storage system models
2.3 Electric demand from building thermal and nonthermal loads

**Processing**

2.4.1 Binary search approach
2.4.2 Idealized dispatch algorithm
2.5 Post-processing
2.6 Sensitivity analysis

**Results & Discussion**

3.1 Load profiles and load duration curves
3.2 Annual performance and cost savings of hybrid storage systems
3.3 Sensitivity to model inputs
Idealized dispatch strategy

Binary search finds peak load reduction by successively guessing the final shaved load shape.

Sensitivity analysis