Cost Optimization with Solar and Conventional Energy Production, Energy Storage, and Real Time Pricing

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Objective Function:
\[ \min C = \sum_{i=1}^{t} (G_i \cdot C_i) \]

Equality Constraints:
- \( D_t = G_t + P_t + B_t \)
- \( S_t \cdot PV_{size} = P_t + PC_t + L_t \)
- \( E_t = \sum_{i=1}^{t} (B_{t-1} + PC_i - B_i) \)

Inequality Constraints:
- On the grid:
  \[ G_t \geq 0 \]
- Stored Energy:
  \[ \sum_{i=1}^{t} (PC_i - B_i) + E_0 \geq 0 \]
- Battery Bank Size:
  \[ E_t \leq E_{max} \]
- Battery Discharge:
  \[ B_t \leq E_t \]

I. Introduction/Motivation
Research is presented that investigates the potential for solar power generation with battery energy storage for reducing the effective cost of energy if real time pricing is present. A linear optimization approach is developed based upon a two-step process. This analysis considers an expected lifespan of the solar panel. The capital costs for the solar arrays and batteries are considered. The results illuminate the most cost effective means to provide power to customers.

Observation:
- Demand vs. Wholesale Market Price vs. Solar Irradiance in Dayton, OH (Source: Duck Energy and Nrel)
- System without storage: No control on the flow of the power
- System with storage: With control on the flow of power (Very expensive)

II. System Model
- With storage system and direct connection of PV to loads

III. Formulation

Primary Objective:
Design a Central Energy Manager (CEM) to minimize electricity bill by managing flow of power between solar panels, storage, grid, and loads.

Questions to be answered:
1) At each time what percentage of the solar panels’ output must flow directly to the loads, and what percentage to the batteries?
2) At what time, for how long, and for how much, batteries should be charged and discharged?
3) What is the best size of the solar panels and battery bank? (Capitalized cost)

Secondary Objective:
Considering the capitalized cost of the Solar panels and Battery bank, to find the maximum investment return of the system.

Yearly saving: Initial bill - new bill cost

<table>
<thead>
<tr>
<th>Year</th>
<th>Battery Capitalized cost</th>
<th>Battery Replacement cost each 5 years</th>
<th>Year 25</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>Battery</td>
<td>400 per kWh</td>
<td>1335</td>
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<td>750 per square meter</td>
<td>835</td>
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<td>2</td>
<td>Battery</td>
<td>20 cents per KWh</td>
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IV. Simulation Results:
1) Electricity Bill Minimization:
- For 8 kWh of Battery and 17 square meter of PV and average price of 11 cents per KWh
- Initial electricity bill for a year was $1335, Optimized cost $835

2) Investment Return:
- Storage:$400 per kWh, 13 years life span
- PV:$750 per square meter 25 years life span
- Maximum investment return considering different life span and cost of storage system

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