Optimum Design of Battery-Assisted Photo-Voltaic Energy System for a Commercial Application

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Objectives

The optimum design of a battery-assisted photo-voltaic (PV) system by using real world data from commercial users. Specifically:

- The **size** of PV panels: n_b
- The **capacity** of battery energy storage system (BESS): n_s
- The optimum **scheduling** of BESS charging/discharging: q_c, q_d

such that the long-term total cost, including both energy cost and system cost, can be minimized.

Introduction

Photo-voltaic (PV) energy is one of the most popular renewable energy sources. One of the main challenges faced by the designs of PV systems is the intermittent nature of solar energy, which creates an imbalance between power supplies and demands. Such an imbalance can be compensated by integrating the PV system with battery energy storage system (BESS). The BESS can store excessive solar energy during the day time and discharge the stored energy in the evening to achieve reductions in both energy usage and peak demands.

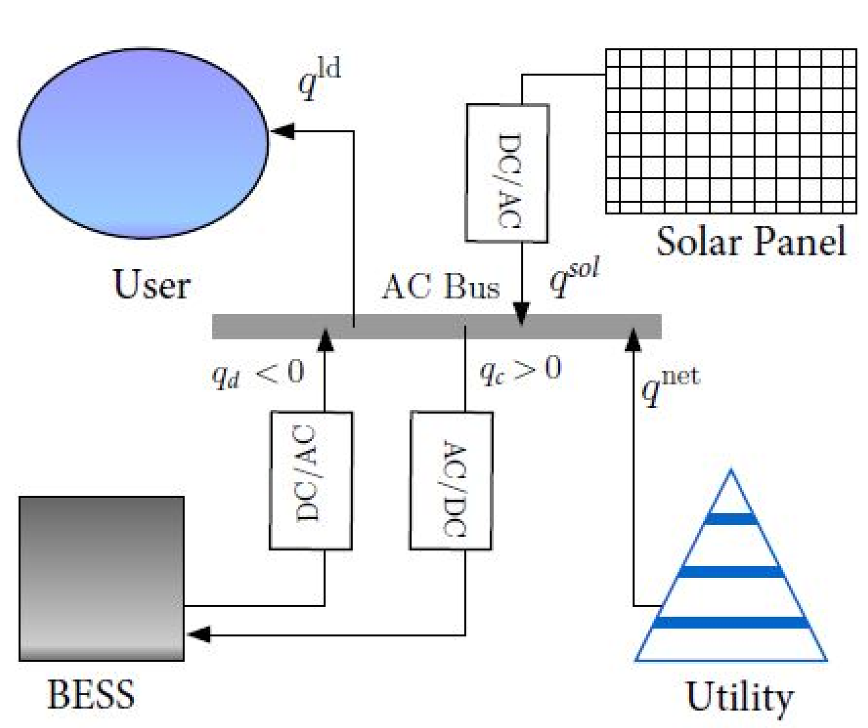

Figure 1:Battery-assisted PV system model

System Model

The time is divided into windows with duration τ each. The **state of charge** (SOC):

$$s(i+1) = s(i) + q_c(i)\gamma_e - \frac{q_d(i)}{\gamma_e} \quad (1)$$

where γ_e denotes the energy efficiency. The physical limits of the battery charging and discharging rate:

$$0 \le q_c(i),\ q_d(i) \le n_b Q\tau, \quad (2)$$

Q is the maximum charging and discharging power of a single battery. Similarly, the limits of the SOC:

$$0 \le s(i) \le n_b S[1-\alpha\cdot(m-1)^{0.75} - \beta\sqrt{m-1}\,] \quad (3)$$

where S is the initial battery capacity. α and β are the calendar aging and cycling aging coefficients of the battery described in months[1]. m is the age of the system in months. The **solar energy**:

$$q^{sol}(i) = n_s q_0(i)\gamma_s^{m-1} \quad (4)$$

where $q_0(i)$ is the PV energy collected by a single panel, γ_s is the efficiency of the solar panel described in months.

Total Cost

The **energy bought** from the utility:

$$q^{net}(i) = q^{ld}(i) - q^{sol}(i) + q_c(i) - q_d(i) \quad (5)$$

The **energy charge**:

$$C_E = \sum_{i\in\mathcal{H}} P(i)\max\left(q^{net}(i), 0\right)(1 + r_{infl}^{y-1}) \quad (6)$$

where P is the unit price, r_{infl} is the inflation rate of electricity cost described in years, and y is the age of the system in years.

The **demand charge**:

$$C_D = \sum_{y=1}^{Y}(1 + r_{\text{infl}}^{y-1}) \sum_{m=1}^{12} \max_{i\in\mathcal{H}_m} \frac{q^{\text{net}}(i)}{\tau} D_{\max}, \quad (7)$$

where $D_{\max}$ is the unit demand charge in the unit of \$ per kW, Y is the total number of years in the time horizon $\mathcal{H}$.

The **system cost**:

$$C_S = P_s n_s + P_b n_b \quad (8)$$

where P_s and P_b are the unit costs of solar panels and batteries.

Conclusion

Results from case study have shown that the proposed system can achieve a **38.5%** reduction in utility bills, and the break-even point is achieved in 62 months. In addition, the integration of BESS is essential for PV system operations, in terms of both **peak shaving** and **energy saving**.

Problem and Method

The optimization problem can be formulated as

$$\min.\quad C_E + C_D + C_S \quad (9)$$
$$\text{s.t.}\quad (1)-(3), \quad (10)$$
$$n_s, n_b \in \mathbb{Z}_+, \quad (11)$$
$$n_s \le N_s, \quad n_b \le N_b, \quad (12)$$

This mixed integer nonlinear programming (MINLP) problem can be transformed into an equivalent mixed integer linear programming (MILP) problem by converting maximum term in C_E and C_D into new constraints, which can be optimally solved by using the branch-and-bound (B&B) algorithm [2].

Results

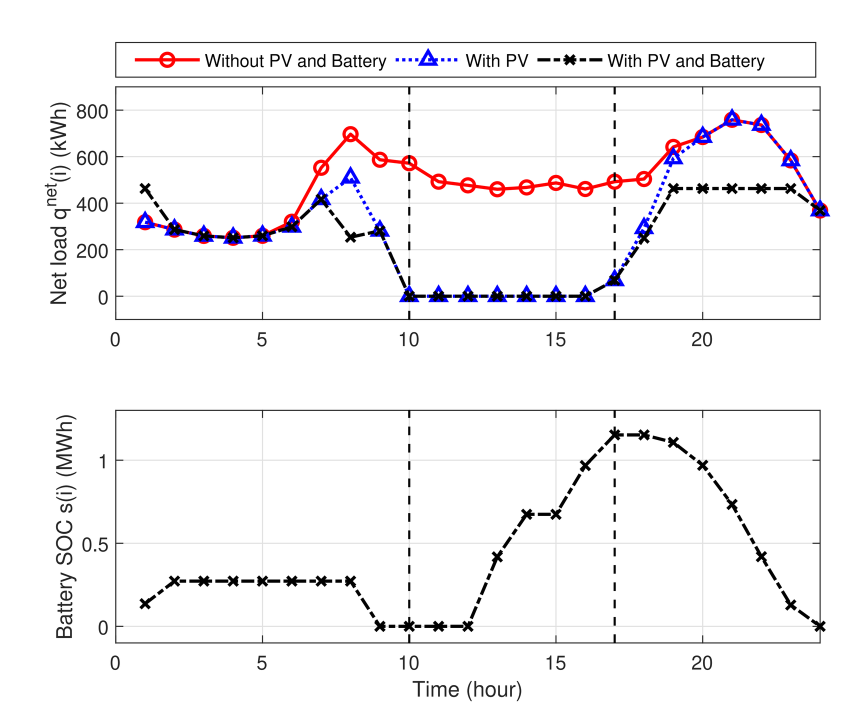

Figure 2:Snap shot of 1-day energy usage on July 1st

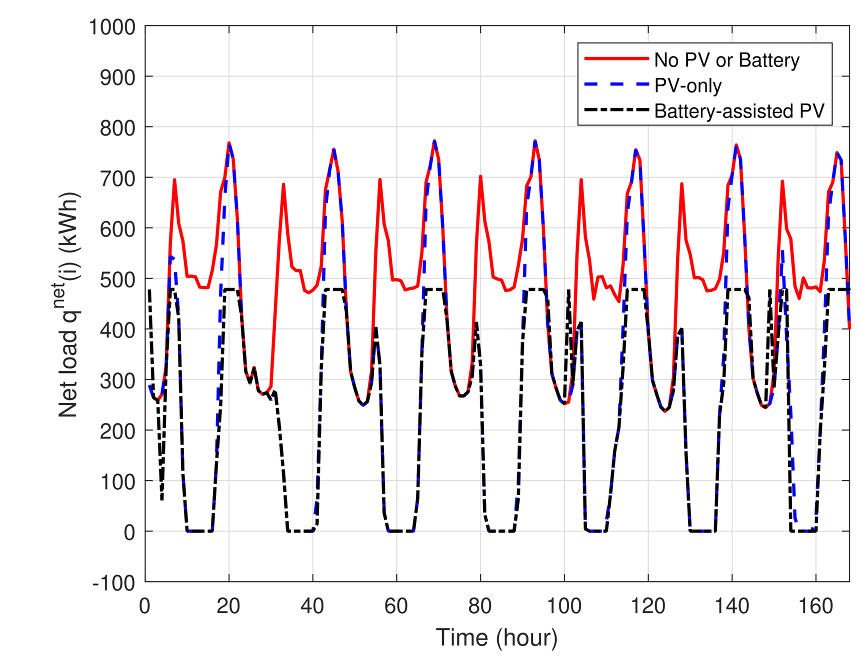

Figure 3:First week of June

System	BESS-PV	PV-only
Utility bill (\$)	4,347,943	5,075,923
Reduction (\$)	2,719,900	1,991,920
System cost (\$)	1,299,000	768,000
Break-even point (month)	62	51

Table 1:Total utility bill under different configurations

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