SIMPLIFIED ANALYSIS OF THE RELATIONSHIP BETWEEN THE PRICES AND OPTIMAL CAPACITIES OF PV SYSTEMS AND BATTERIES

Takuya Hara, Toyota Central R&D Labs., Inc., +81-561-71-7768, thara@mosk.tytlabs.co.jp

Overview

With a simple electricity system model consisting of demand, photovoltaic (PV) power generation, and battery storage, this study investigated the relationships between the following three factors: (1) the prices of PV systems and batteries, (2) the share of PV generated electricity in the total electricity demand, and (3) the optimal installed capacities of the PV systems and batteries. The study was conducted using openly available data regarding Japanese power systems, including those for real demand and PV power generation. This paper presents the results as maps.

Methods

This study considered a simple electricity model consisting of demand, PV power generation, and battery storage. The simplification enabled the obtainment of an optimal charging and discharging schedule using a simple algorithm and without optimization methods such as linear programming.

In this algorithm, with a given hourly demand, D_t, PV power generation, P_t, for time period t, and PV capacity, x_{pv}, the residual demand, r_t is calculated. Let the positive and negative components of r_t be r_t^+ (net residual demand) and r_t^- (surplus generation), respectively. Then,

$$r_t = D_t - x_{pv}P_t \quad (1)$$

The share of PV generated electricity in the total electricity demand, y, is derived as follows, where c_i represents the reduced net residual demand due the electricity discharged from the battery, which charges surplus generation. r_t^+ and c_i are functions of PV capacity, x_{pv}, and battery capacity, x_{bt}. Therefore, y can be represented as a function of x_{pv} and x_{bt}.

$$y(x_{pv}, x_{bt}) = 1 - \frac{\sum_t r_t^+ - \sum_i c_i}{\sum_t D_t} \quad (2)$$

On calculating y by substituting many different values of x_{pv} and x_{bt}, a map is obtained, such as that shown in Figure 1. Using this map, the feasible regions of x_{pv} and x_{bt} that satisfy a given y are obtained. Combining the information regarding the feasible regions with the cost-optimization function consisting of the prices of PV systems and batteries, p_{pv} and p_{bt}, the optimal capacities of the PV systems and batteries, x_{pv}^* and x_{bt}^*, respectively, are determined as the points at which the slopes of the respective tangent lines are equal to the slopes of the respective optimization functions (i.e. the ratio of p_{pv} and p_{bt}. See figure 1). As a result, the optimal capacities of PV systems and batteries can be represented as functions of the prices of PV systems and batteries.

$$(x_{pv}^*, x_{bt}^*) = f(p_{pv}, p_{bt}) \quad (3)$$

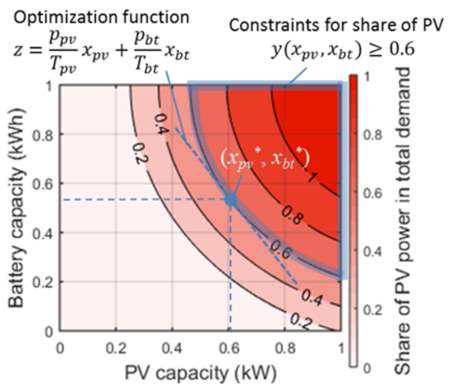

Figure 1 Schematic diagram illustrating the optimization of PV system and battery capacities based on a map representing the relationships between x_{pv}, x_{bt}, and y

Further, the cost of electricity from PV systems, C_{RE}, is calculated for a given value of share of PV generated electricity, y_0, with assumed lifetimes of PV systems and batteries, T_{pv} and T_{bt}. For simplicity, discount rate is not considered; however, the assumptions of lifetimes can incorporate the effect of discounting.

$$C_{RE}(p_{pv}, P_{bt}, T_{pv}, T_{bt}) = \frac{1}{y_0 \sum_t D_t}\left(\frac{p_{pv}x_{pv}^*}{T_{pv}} + \frac{p_{bt}x_{bt}^*}{T_{bt}}\right) \quad (4)$$

The data regarding demand and PV power generation of the Tokyo Electric Power Company in 2016 were used in the model in this study. The data were normalized by setting the maximum demand and PV generation to 1 kW.

Results

Figure 2 shows a map representing the relationships between PV capacity, battery capacity, and share of PV power in the total demand. In the cases of smaller PV capacities (less than 1 kW), the contour lines are almost parallel to the y-axis. This is because the surplus generation is almost zero and the battery does not contribute to reducing the net residual demand when PV capacity is less. Greater PV and battery capacities led to increases in the shares of PV power, though increasing only either one of them resulted in gradual decreases in PV power.

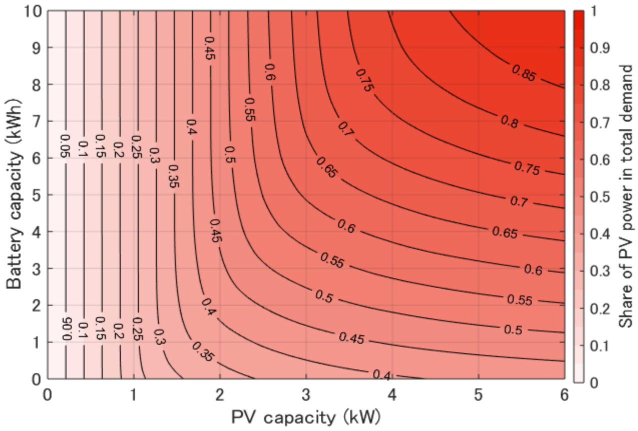

Figure 2 A map representing the relationships between PV capacity, battery capacity, and share of PV power in the total demand

Figure 3 shows maps representing the relationships between PV price, battery price, share of PV power, and cost of renewable electricity, calculated based on the optimal PV and battery capacities using the above map. Larger share of PV power led to a higher cost of renewable electricity under the same conditions of price for PV systems and batteries.

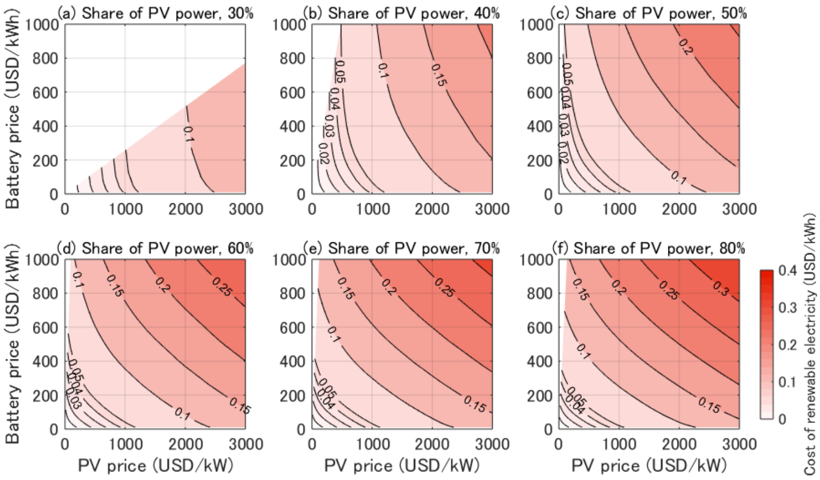

Figure 3 Maps representing the relationships between PV price, battery price, and cost of renewable electricity with different shares of PV power

Conclusions

This study developed a framework for analyzing the relationships between the prices and optimal installed capacities of PV systems and batteries. It also determined the renewable electricity costs for a given share of PV power. The obtained maps could be beneficial for evaluating the effect of technological development (e.g. the pricedown of PV systems or batteries) on the total cost of electricity.

The maps are entirely based on input data (i.e. demand, D_t, and PV power generation, P_t). This study also evaluated how the results varied with variation in input data, but this is not discussed here in the abstract due to limited space.