Prosumers' Investment Decisions and Social Welfare under Different Pricing Schemes

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1. Introduction

Further investment in distributed energy resources (DERs) and their efficient operation is necessary for decarbonization and sustainable energy systems. In particular, the emergence of prosumers who own renewable DERs has brought about a paradigm shift in the electricity market. The prosumer is an entity that consumes electricity, similar to a conventional consumer, while simultaneously generating electricity as a producer to supply it in the electricity market using its own power generation resources.

On the other hand, the increase in the volume of DERs may cause the fixed cost recovery problem vis-à-vis electric power transmission systems; this is referred to as the death spiral. Owing to the increase in the prosumer self-consumption of electricity from DERs, fewer consumers are to bear the fixed costs of transmission systems. Thus, it is necessary to recover the fixed cost for the expansion and maintenance of networks by increasing DER penetration via appropriate tariffs and pricing schemes that can address the death spiral problem.

The purpose of this study is to analyze the decision-making of each market participant (prosumers, consumers, producers, and ISOs) in the electricity market in equilibrium, focusing on the investment decisions of prosumers, the level of transmission tariffs, and the total social surplus. We formulate complementarity problems for all market participants, considering different pricing schemes, electric power networks, prosumer investments in PVs, and battery operations.

2. Model

In this study, we model the annual decision-making of market participants in a situation where multiple nodes are connected via transmission lines, and each node's electricity demand varies in each period. First, we consider the optimization problems for each market participant and derive the Karush–Kuhn–Tucker (KKT) conditions. Thereafter, we define the market equilibrium problem in the electricity market by overall KKT conditions for all market participants and the condition for the fixed cost recovery of networks.

2.1. Prosumers under net metering

Net metering is a system for prosumers that records the amount of electricity sold from prosumers' DERs to the grid ($z_{it} > 0$) and the amount of electricity purchased from the market via the network ($z_{it} < 0$), offsetting them with a bi-directional meter. The prosumer optimization problem under the net metering scheme in period t at node i can be expressed as follows:

$$\underset{l_{it}, g_{it}, k_i \geq 0, z_{it}}{\text{maximize}} \quad \sum_t (p_{it} + \tau) z_{it} B_t + \sum_t \left(\int_0^{l_{it}} p_{it}^{pro}(m_{it}) dm_{it} \right) B_t - \sum_t C_i^g(g_{it}) B_t - E k_i \tag{1}$$

subject to

$$(z_{it} + l_{it} - CF_t k_i - g_{it}) B_t \leq 0 \qquad (\delta_{it}) \tag{2}$$

$$(g_{it} - G_i) B_t \leq 0 \qquad (\kappa_{it}) \tag{3}$$

Prosumers determine the amount of electricity consumption l_{it}, electricity sales/purchases z_{it}, backup electricity g_{it} at each node and each period, and the capacity of investment in PVs k_i to maximize their objective function, as expressed in Eq. (1). Here, τ is transmission tariff, $C_i^g()$ is cost of backup generation, E is annualized capital cost of solar PV panels, p_{it} is wholesale price, B_t is number of hours in period, CF_t is capacity factor, and G_i is production capacity of prosumer dispatchable unit.

2.2. Prosumers under net billing

Prosumers in the net billing scheme face different prices when selling electricity from their DERs to the grid and buying electricity from the power market through the network. Therefore, net billing requires two meters to record the amount of electricity separately for sales (z_{it}^s) and purchases (z_{it}^b). The prosumer optimization problem in period t at node i under the net billing mechanism can be expressed as follows:

$$\begin{aligned}\underset{l_{it},g_{it},k_i,z_{it}^s,z_{it}^b\geq 0}{\text{maximize}} & \sum_t \left((p_{it}+\tau^s)z_{it}^s-(p_{it}+\tau^b)z_{it}^b\right)B_t \\ & +\sum_t\left(\int_0^{l_{it}} p_{it}^{pro}(m_{it})dm_{it}\right)B_t \\ & -\sum_t C_i^g(g_{it})B_t - Ek_i \qquad (4)\end{aligned}$$

subject to

$$(z_{it}^s - z_{it}^b + l_{it} - CF_t k_i - g_{it})B_t \leq 0(\delta_{it}) \qquad (5)$$

$$(g_{it} - G_i)B_t \leq 0(\kappa_{it}) \qquad (6)$$

Similar to net metering, prosumers in the net billing plan also determine the amount of electricity consumption l_{it}, electricity sales z_{it}^s, electricity purchases z_{it}^b, backup electricity generation g_{it} at each node and each period, and the capacity of PVs k_i. Thereafter, they maximize their objective function comprising the revenue/payment from electricity sales/purchases, benefits from electricity consumption, cost of backup electricity generation, and investment cost for the capacity of PVs. In net billing, when prosumers sell electricity (z_{it}^b=0, z_{it}^s >0), prosumers face the price $p_{it} + \tau_s$.

3. Results

Prosumers in net metering decide to sell their electricity by investing in a larger PV capacity. This prosumer decision-making leads to an increase in the transmission tariff, which affects the surplus of other market participants. On the other hand, prosumers in net billing tend to invest in less PV capacity than that in net metering and cover their electricity consumption with their generation. This results in less sales by prosumers and a smaller impact on transmission tariffs. Comparing the two pricing schemes, the total social surplus in net metering and net billing is approximately the same for a high PV capital cost. However, if the capital cost of PVs is sufficiently reduced, the total social surplus in net billing becomes much larger than that in net metering because the consumer surplus in net metering decreases significantly with a sharp rise in the transmission tariff.

In addition, we show that battery operation increases the capacity of prosumer investment in PV under both pricing schemes. Furthermore, the total social surplus under net billing is larger than that under net metering, with and without battery operation. This suggests that net billing could be a better regulatory scheme in the future, especially when the capital cost of PVs falls sufficiently.

References

[1] B. F. Hobbs, "Linear Complementarity Models of Nash–Cournot Competition in Bilateral and POOLCO Power Markets", *IEEE Transactions on Power Systems*, vol. 16, no. 2, 2001.

[2] S. Ramyar, A. L. Liu, Y. Chen, "A Power Market Model in Presence of Strategic Prosumers", *IEEE Transactions on Power Systems*, vol.35, no.2, pp. 898-908, 2020.