COMPETITIVE EQUILIBRIUM IN POWER MARKETS WITH STRATEGIC PROSUMERS

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Background

In the energy system, the recent construction of a smart grid which adjusts electricity supply and consumer demand, and adding value to the whole system, is promoted. This new era has begun because customers now have power generation facilities, such as renewable energy. There would be “prosumers” in the future when wind power and storage facilities are fully introduced. A *prosumer* is a coined word formed by combining the terms producer and consumer. The prosumer is responsible for the supply and demand of electricity in his/her target area. The advent of the prosumer has the merit of increasing the resilience of the entire energy system. For instance, in the event of a disaster, power generations could be recovered in the target area of the prosumer. To minimize costs, the prosumer manages power generations of each household or enterprise in a region, power generation with auxiliary power to support uncertainty of renewable energy generation, and the quantity of transactions by bilateral contracts with the producers. In terms of those contracts, the prosumer can be both a seller and a purchaser. The prosumers might have some impact on the power market but few studies deal with the prosumer. Chen and Ramyar (2018) propose a model to evaluate the effect of prosumers on the power price.

Our study generalizes the model in Chen and Ramyar (2018) and extends it to one that adds bilateral contracts, considers linear or quadratic cost functions, and considers that a power producer is dominant and behaves in Cournot fashion, i.e., it is able to influence the power price. We show the impact of the prosumer on the power price and social surplus. In particular, we focus on the power price and the profit of the prosumer as an indicator of the effect of the prosumer.

The Model

We consider a prosumer, a power producer and consumer in a target area. The prosumer has a bilateral contract with the power producer. Figure 1 shows the conceptual diagram of model. The prosumer determines power generation outputs with backup resource and sells power volume z in the bilateral contract to the power producer, in order to maximize its profits inclusive of revenues in the bilateral contract, electricity revenues collected from residents or companies under the prosumer’s jurisdiction, and generation costs related to the backup generation. The power producer determines power generation outputs and sells power volume s to the power market, to maximize its profits inclusive of revenues within that market, purchasing costs within the bilateral contract, and generation costs.

We formulate the above problems as the maximization problems. These equations are transformed to Karush-Kuhn-Tucker conditions because they are convex functions. We derive optimal power outputs with the backup generation, selling power volume under the bilateral contract, power generation outputs, selling power volume to the power market, and power price, by means of transformed equations.

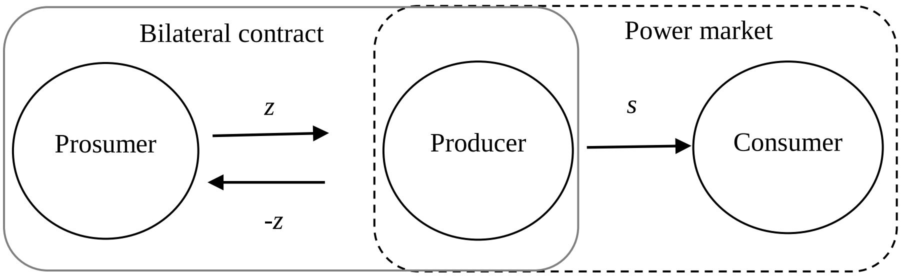

Figure 1. Conceptual diagram of model

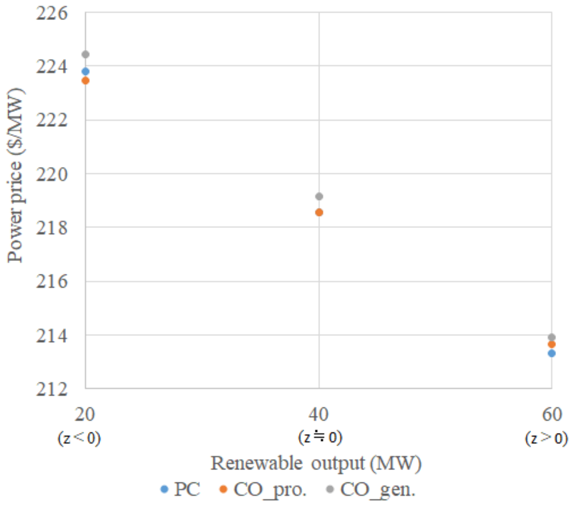

Figure 2. Power price for each scenario

Table 1. Social surplus for each scenario

	Renewable outputs (MW)		
	20 (z＜0)	40 (z≒0)	60 (z＞0)
PC	$12,889	$17,195	$21,305
CO_pro.	$12,883	$17,195	$21,319
CO_gen.	$12,868	$17,173	$21,284

Results and Discussions

We follow the assumption by Chen and Ramyar (2018) for the parameter values. Figure 2 and Table 1 show the main outcomes. Figure 2 plots the resulting power price against the renewable energy generation for three scenarios. In the figures, the prosumer and power producer are price takers, the prosumer is dominant and behaves as expected under Cournot conditions, i.e., it is able to inuence the power price, whereas the power producer remains a price taker. The power producer is dominant and behaves as expected under Cournot conditions, i.e., it is able to influence the power price, whereas the prosumer remains a price taker. These elements are denoted by PC, CO_pro., and CO_gen., respectively. The power price under CO_pro. is lower than that of PC when $z < 0$, i.e., the prosumer purchases the power in the bilateral contracts. By contrast, the power price under CO_ pro. is higher than that of PC when $z > 0$, i.e., the prosumer sells power under the bilateral contracts. The power price under CO_gen is the highest of all the scenarios.

We show the social surplus against the renewable energy generation for three scenarios in Table 1. Social surplus under CO_pro. is lower than that of PC when $z < 0$. By contrast, social surplus under CO_ pro is higher than that of PC when $z > 0$. This is because the profit of the power producer fluctuates as the prosumer influences the bilateral contract price. Social surplus under CO_gen is the lowest of the scenarios because consumer surplus under CO_gen declines as power prices rise.

We assume that the power producer covers the demand in the target area of the prosumer. We compare results with and without a prosumer. Consequently, the appearance of a prosumer reduces social surplus, e.g., without prosumers the surplus is $24,986; with a prosumer it is $12,787 for $z < 0$ and $21,509 for $z > 0$, because resilience costs within the electrical power system is high.

Concluding Remarks

This work explores the effect of the prosumer on the power price and social surplus. We find that a strategic prosumer generates more auxiliary power when it has purchasing power withing the bilateral contract. In other words, a strategic prosumer reduces the power and contract prices by reducing the purchase amount with the bilateral contract. By contract, a strategic prosumer generates little auxiliary power when selling it under a bilateral contract. This means that strategic prosumers raise the power or contract prices by reducing the amount sold under the bilateral contract. The appearance of the prosumer reduces social surplus. Thus, the prosumer affects on the power price and social surplus. In future work, we will extend the model to evaluate the influence on the power price and social surplus when a prosumer utilizes storage facilities.

Acknowledgements

This work is partially supported by the Grant-in-Aids for Scientific Research (B) (grant No. 15H02975) from Japan Society for the Promotion of Science.

References

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