Rewarding a Group of Customers for Mitigating the Imbalance of Electricity

BY YOSHIHIRO YAMAMOTO

Yoshihiro Yamamoto is with Takasaki City University of Economics, Japan. He may be reached at ysyama@tcue.ac.jp

Customers playing active roles

Customers have traditionally purchased electricity to use appliances, and paid for their consumption. They are considered passive because a public utility is under an obligation to meet their demands.

Recently, some customers have come to play an active role, beyond just consuming electricity for appliances, with devices such as photovoltaic systems, electric vehicles, rechargeable battery systems, and heat pump water heaters. Photovoltaic systems enable them to produce electricity; however, the amount of electricity produced depends on natural conditions. Alternatively, the amount of electricity produced or consumed may be controlled for some devices: not only are electric vehicles and rechargeable battery systems charged but they also discharge electricity and heat pump water heaters transform electricity into hot water to be used later.

Those operations will make the management of the power system more complicated, possibly causing phenomena such as excess supply and reverse power flow, and resulting in frequency or voltage instability, or transmission security degradation (Stoft, 2002). However, if operated to mitigate the imbalance between supply and demand, those devices may contribute to load leveling, decarbonization, affordable energy provision, frequency stability, and so on. For example, an aggregator is performing such a task for a set of commercial, business, or residential buildings equipped to facilitate the aggregation of operations (Zurborg, 2010; DOE, 2015). In contrast, there seem to be still difficulties with some individual homes and small-scale facilities in being aggregated. Thus, it is essential to consider how to deal with such small-scale owners of those devices in an attempt to mitigate the imbalance. This article presents one of such methods, which incentivizes them by a reward for acting appropriately.

Rewarding small-scale owners

The reward should be additional to or compatible with the ongoing billing system since the fact that electricity is sold and purchased does not change. What should be rewarded is a contribution toward mitigating the imbalance between supply and demand. For example, suppose that the imbalance was mitigated as a household consumed electricity, then, the household should be remunerated for its contribution toward the mitigation, while paying for that consumption.

The rewarding system should be designed on a local basis since supply and demand situations vary from area to area. In particular, the photovoltaic electricity supply differs according to the location. Accordingly, we consider is a certain group of customers in the vicinity on the electricity network, which will be determined from an engineering point of view.

The idea of being designed on a local basis is also supported in terms of remunerating customers appropriately. The influence of every individual customer on the outcome of a whole market is too tiny to assess. However, if a group of customers are considered, the actions of each member can influence the outcome by the group. Hence, to assess each contribution, the rewarding system should be targeted at a group of customers, not at a market as a whole.

Thus, the problem is how should we assess the value a group of generation customers and then divide it among the members. In addressing this problem, it might be helpful to separate technological and economic aspects.

The technological aspect concerns how to achieve or maintain the balance between supply and demand within the group. However, the economic aspect is concerned with how to assess the outcome by the group and reward its members accordingly. As this perspective suggests, the economic consideration comes after the technological arrangements. In other words, one possible approach to the problem is to work with the outcome of trade, ignoring the technological arrangements. Note that the reward calculated after trade will work as an incentive since trade is made period after period so that customers would be trying to be better off next time.

How to assess the value generated

Let us address the problem of assessing the value generated, based on the outcome of trade. We present one of potential methods. It considers the discrepancies between production and consumption of electricity within the group for a period in question. The reason is that, regarding mitigating the imbalance, supply is timely if there is more demand and conversely, demand is timely if there is more supply; the discrepancies are finally to be cleared by a system operator using resources outside of the group. In other words, the production should be positively valued if all of it was seemingly consumed within the group or the consumption should be positively valued if all of it was seemingly met within the group, during that period. Note that when the production is positively valued, the consumption is negatively valued or vice versa.

Three points are made. First, the amount of the positive value must be equal to that of the negative value to make the rewarding system a zero-sum game. Second, the positive or negative value should be set at such a level that it would encourage those to whom it is allocated to operate their devices appropriately. Lastly, usual consumption of electricity is negatively valued if the production was smaller than the consumption within the group or vice versa.

How to divide the value among the members

Finally, let us address the problem of dividing the value among every member of the group as a payoff. We present two possible methods, which are based on coalitional game theory (Osborne and Rubinstein, 1994). The first method is to divide the value depending on the contribution of each member. This applies the concept of the Shapley value of a coalitional game. It is considered that the group has been formed by a customer entering an existing group one after another. In this process, every customer makes a positive or negative contribution to the existing group, the amount of which may be calculated in the same way as assessing the value above described. Considering all the possible orderings of a customer entering to form the final group, we can specify the contribution of every member of the group.

The second method is to divide the value to sustain the group. This applies the concept of the core of a coalitional game. Were it to be more profitable for some customers to form a new group than it were to stay in the current group, the rewarding system based on a group of customers would no longer be sustainable. Thus, it is required that any subset of customers not be able to be better off by this kind of deviation.

Concluding remarks

We discussed the rewarding system for mitigating the imbalance between supply and demand of electricity within a group of customers, especially connected with individual homes and small-scale facilities, which are less likely to be included in the aggregation that has been intensively discussed for energy transitions. Thus, our system may serve as a complementary mechanism to it.

The rewarding system may work well by providing relevant information, supporting decision-making of customers. For example, if the information on the current supply and demand situation is provided, they might accordingly increase or decrease either production or consumption under the rewarding system.

Since the rewarding system targets a group of customers, there will be some concern about free riding. A field experiment will be helpful to evaluate the effectiveness of our system as an incentive.

The rewarding system presented here is one of the possibilities aimed at supporting energy transitions. It considers mitigating the imbalance between supply and demand within a group of customers only. Different suggestions may be made if other aspects are considered.

References

DOE, US Department of Energy, 2015. Technology Assessments, Chapter 3: Enabling Modernization of the Electric Power System. Quadrennial Technology Review 2015. Available at: energy.gov/quadrennial-technology-review-2015.

Osborne, M.J., Rubinstein, A., 1994, A Course in Game Theory. The MIT Press.

Stoft, S., 2002. Power System Economics: Designing Markets for Electricity. IEEE Press.

Zurborg, A., 2015. Unlocking Customer Value: The Virtual Power Plant. US Department of Energy. Available at: energy.gov/oe/downloads/

Ansarin (continued from page 28

Division of Energy Resources. 2014. “Minnesota Value of Solar Methodology.” Minnesota Department of Commerce. http://mn.gov/commerce-stat/pdfs/vos-methodology.pdf.

Heald, D. A. 1997. “Public Policy towards Cross Subsidy.” Annals of Public and Cooperative Economics 68 (4): 591–623. https://doi.org/10.1111/1467-8292.00066.

Klass, Alexandra B. 2019. “Regulating the Energy ‘Free Riders.’” SSRN Scholarly Paper ID 3352940. Rochester, NY: Social Science Research Network. https://papers.ssrn.com/abstract=3352940.

Neuteleers, Stijn, Machiel Mulder, and Frank Hindriks. 2017. “Assessing Fairness of Dynamic Grid Tariffs.” Energy Policy 108 (September): 111–20. https://doi.org/10.1016/j.enpol.2017.05.028.

Office of Electricity Delivery and Energy Reliability. 2016. “Advanced Metering Infrastructure and Customer Systems: Results from the Smart Grid Investment Grant Program.” US Department of Energy. https://www.energy.gov/sites/prod/files/2016/12/f34/AMI%20Summary%20Report_09-26-16.pdf.

Rábago, Karl R., Leslie Libby, Tim Harvey, Benjamin Norris, and Thomas Hoff. 2012.”Designing Austin Energ’s Solar Tariff Using a Distributed PV Value Calculator.” In Proceedings of World Renewable Energy Forum. http://www.solarpowerdemocracy.org/wp-content/uploads/2014/03/CPR_Rabago_Designing-VOS-Rate.pdf.

Simshauser, Paul. 2016. “Distribution Network Prices and Solar PV: Resolving Rate Instability and Wealth Transfers through Demand Tariffs.” Energy Economics 54 (February): 108–22. https://doi.org/10.1016/j.eneco.2015.11.011.

Singh, Siddharth Prakash, and Alan Andrew Scheller-Wolf. 2017. “That’s Not Fair: Tariff Structures for Electricity Markets with Rooftop Solar.” SSRN Scholarly Paper ID 2926676. Rochester, NY: Social Science Research Network. https://papers.ssrn.com/abstract=2926676.

Wirth, Dr Harry. 2020. “Recent Facts about Photovoltaics in Germany.” Fraunhofer Institute for Systems and Innovation Research (ISI).

Yakubovich, Valery, Mark Granovetter, and Patrick Mcguire. 2005. “Electric Charges: The Social Construction of Rate Systems.” Theory and Society 34 (5–6): 579–612. https://doi.org/10.1007/s11186-005-4198-y.